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P. W. D. HANDBOOK

BOMBAY

CONTAINING

Specifications, Rates, Tables, Plates

AND

Notes on Work

ORIGINALLY COMPILED FOR THE USE OF THE P. W. DEPARTMENT
IN THE BOMBAY PRESIDENCY

BY

CAPTAIN E. L. MARRYAT
Royal Engineers

VOL. II

(Sections IV—VIII)

REVISED AND BROUGHT UP TO DATE UNDER THE ORDERS OF
THE GOVERNMENT OF BOMBAY

NINTH EDITION

NAGPUR
GOVERNMENT PRESS
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PREFACE TO THE NINTH EDITION

First Edition (1876).—The first edition of Captain Marryat's Specifications was published under Government Circular No. 178-E, dated 25th March 1876, with the principal object of laying down a good standard set of specifications for use in the Public Works Department in the Bombay Presidency for all ordinary works, and a series of rates for such specifications. In addition to this, sketches of masonry, brick-work, carpentry, etc., were added for the use of maistries and others by whom the Roorkee Treatise and other larger and practical books are unobtainable, and some practical notes on various subjects were compiled so as to form a handy note-book.

The following were the principal sources from which the specifications were framed and notes compiled:—Standard specifications, Oudh, by Captain Peile, R.E.; for Rajputana, by Lieutenant-Colonel Forlong; for Bombay, by Colonel Fuller, R.E.; Specifications of G. I. P. and B. B. & C. I. Railways; The Roorkee Treatise; The Chatam Course; Professional Papers on Indian Engineering; Engineer's Pocket Book; The Manufacture of Portland Cement, by H. Reid, C.S.

Second Edition (1877).—The second edition was issued in September 1877, with the following principal additions:—

1. Index.
2. Table of contents.
3. Tables on roofing by Major Seton, R.E.
4. Tables of scantlings for doors and windows by W. Howard, Esq., C.E.
5. Tables of timber topped culverts.

Third Edition.—The second edition of this compilation, which was published in 1877, was revised under the orders contained in Government Resolution No. 33-E-185, dated 6th February 1882.

The matter contained in this edition, both new and old, was arranged somewhat differently to that of former editions. The specifications and rates followed each other instead of being separately massed together as in previous editions. The number of specifications and rates was largely increased, the most important addition being a set of standard specifications for use in the Irrigation Department furnished by the Chief Engineer for Irrigation.

Fourth Edition.—The third edition of this compilation issued in 1883, was revised under the orders contained in Government Resolution No. 237-A.-1533, dated 16th September 1886. Some specifications which were somewhat incomplete were replaced by others taken from the "Standard Specifications in the Madras Presidency". A new sub-head "Drains, Culverts and Bridges" was added. The average plans and tables of quantities of which it consists were published with the permission of J. H. E. Hart, Esq., M. Inst.C.E., Chief Engineer for Irrigation. This section was a reprint, slightly amended, of two very useful pamphlets "intended to facilitate the preparation of road projects in Executive Engineers' offices", published by that officer in 1868.

Fifth Edition.—The fourth edition of this compilation, which was issued in 1887, was revised under the orders contained in Government Circular Memo. No. 52-E., dated 25th January 1896. Under the resolution, Mr. C. I. Burke, M.I.C.E., was put on special duty for the purpose of Revision. This edition was entirely re-arranged so as to bring all information pertaining to each particular kind of work together in one place. A chapter on Irrigation Works including specifications for Earthen and Masonry dams was included and the information on Water-works was extended. A section on Fireproof floors was added. All rates were omitted, the materials and labour required for a given quantity of work only being shown, so that Executive Engineers might fill in for themselves the rates prevailing in their respective districts.

Sixth Edition.—This edition was revised in the Secretariat under the immediate supervision of Mr. R. W. Murphy. Some useful notes, recipes for preparing materials were added. On the suggestion of many officers, the rates for work (which were not given in the previous edtioin) were entered in this edition. The rate abstracts of works specified in each chapter were placed at the end of their respective chapters and numbered according to the specifications to which they related.

This edition was reprinted in the year 1916, with the addition of "Rules for blasting with dynamite and other high explosives" and "General rules to be observed in Government Magazines for Explosives".

Seventh Edition.—This edition was thoroughly revised and brought up-to-date under the orders contained in Government Resolution No. 3225, dated 29th November 1922. Mr. N. N. Ayyangar, B.A., L.C.E., M.I.E. (Ind.), Executive Engineer, was appointed as Officer on Special Duty for the purpose. New chapters were added on Reinforced Concrete, Arboriculture, Hydraulic formulae and data, Retaining walls, Sanitary Engineering including drainage and sanitation, and notes on Mechanical and Electrical Engineering. In the chapter on Road work full notes were added on road construction and repairs, care of steam-rollers and tarring of roads. In the section on drains, culverts and bridges, additional matter was introduced on high level causeways, temporary crossings and landing stages on tidal creeks. The chapters on Irrigation works and Water-supply, as well as Chapters I, II and III, were revised and additional notes included. A large number of new tables, specifications, rate abstracts and plates were added. Some obsolete portions and plates were omitted.

The following books were consulted :—

1. Indian Woods and their Uses, by R. S. Troup, F.C.H.
2. A Handbook for Cement Works Chemist, by F. B. Gatehouse, F.C.S.
3. Reinforced Concrete, by Harrington Hudson.
4. Reinforced Concrete, by J. C. Gammon, B.Sc. (Lond.), A.C.G.I., O.B.E.
5. Reinforced Concrete, by V. M. Kothasthane, B.A., B.Sc., L.C.E.
6. Detail Design in Reinforced Concrete, by E. S. Andrews, B.Sc.
7. Reinforced Concrete, by Captain A. F. Day, R.E.
8. Reinforced Concrete Manual, by Marsh and Dunn.
9. London County Council Regulations.
10. Rivington's Series of Notes on Building Construction.
11. Manual of Arboriculture.
12. Hydraulics, by Lieutenant-Colonel H. D. Love, R.E.

13. Treatise on Hydraulics, by Prof. Unwin.
14. Irrigation Pocket Book—Buckley.
15. Irrigation, Roads and Buildings—W. L. Strange.
16. Water Supply of Towns, by Prof. Burton.
17. Water Supply, by R. E. Middleton, M.I.C.E.
18. Surface Drainage, by H. A. Gubbay, A.M.I.C.E.
19. Sanitary Engineering, by Colonel E. C. S. Moore, R.E.
20. Drainage Problems of the East, by C. C. James.
21. Sanitary Engineering in India, by J. Wallace, C.E.
22. Manual of Vital Statistics and Public Health, by Dr. J. D. Munsiff.
23. Military Works Handbook.
24. Pocket Companion—Messrs. Dorman Long & Co.
25. Civil Engineer's Pocket Book—Merriman.
26. Pocket Book of Engineering—Molesworth and Hurst.
27. Kemp's Engineer's Year Book for 1922.
28. Engineer's Pocket Book—Trautwine.
29. Proceedings of the Bombay Engineering Congress.
30. Proceedings of the Institute of Engineers (India).
31. Publications of the Governments of India, Bombay and Madras.

Almost all the suggestions made by the P. W. D. Officers were given effect to and contributions were specially obtained from many Officers including several not in the P. W. D. It would be invidious to mention individual names among so many and grateful thanks are due to all of them for the ready and valuable help received.

The rates were revised and brought up-to-date. This edition was published in two volumes.

Eighth Edition.—This edition has been revised in the Secretariat. A number of additions in the form of notes, new specifications, additional tables and plates have been made in this edition. Exhaustive tables have been added in the chapter on Reinforced Concrete with a view to facilitate the work of designing and to ensure as far as possible uniformity of practice in the same. Most of the useful suggestions made by the Public Works Department Officers have been given effect to; besides a number of additions and alterations have been made on the subject of cement concrete and the allied specifications to bring this section up-to-date and as accurate as possible and grateful thanks are due to the Concrete Association of India for suggestions and assistance in this matter.

In most cases the rates prevailing in the Poona District have been adopted and, in others, figures such as might be assumed as fair average have been entered. As the rates are so very fluctuating from place to place and from time to time, the figures are meant only as a guide and each item has to be worked out for each special occasion and purpose.

This edition too, as the previous one, is published in two volumes.

Ninth Edition (1949).—The eighth edition of the P. W. D. Hand-Book which was published in 1931 was thoroughly revised in the P.W.D. Secretariat

under the direct supervision of Mr. H. K. Thakore, L.C.E., J.P., B.S.E. (Retired Executive Engineer), who was specially deputed on this work. The two main characteristic departures over the previous edition of the Hand-Book, introduced in the present edition, are—

(a) Non-embodiment of the rates in the rate abstracts.

(b) Distribution of the entire Hand-Book, which previously was in 14 Chapters in 8 sections each section dealing extensively with the main subject as under :—

Section I	..	Materials.
Section II	..	Buildings.
Section III	..	Reinforced Concrete.
Section IV	..	Roads.
Section V	..	Hydraulic formulae and data, drains, culverts, etc., etc.
Section VI	..	Irrigation works and storage for Hydro-Electric Projects.
Section VII	..	Water-supply and Sanitary Engineering.
Section VIII	..	Valuation tables, Mechanical and Electrical notes and tables and miscellaneous information.

Rates in the rate abstracts are not given in view of the fact that those entered in the Hand-Book (previous edition) are nowhere near the current rates or rates which are likely to be obtained for some years to come. While compiling this edition no effort was spared to bring the existing matter up-to-date as is warranted by the present times. Besides many new items have been introduced such as Asbestos Cement Sheets, Pile foundations, Lintels with their design with necessary tables, curves and superelevations, etc., in connection with Roads. Also new specifications for many items, such as, cement mortar, lime-cement mortar, cement concrete, cement rendering and guniting, Shahbad stone flooring, granolithic and Terrazo toppings, Sand clay roads, gravel roads and other improved types of surfaces, etc., etc., have been introduced in this publication.

Great care has been devoted in the compilation of this publication, which includes the latest available experience, so as to make it an extensive and the best guide for all concerned as far as possible.

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P. W. D. HANDBOOK

BOMBAY

Volume II

SECTION IV

ROADS

1949

CHAPTER V—ROAD WORK

Notes on the preparation of a Road Project in accordance with the rules of the Public Works Department

SURVEY AND FIELD WORK

1. Examine the adjustment of the instruments, and test the length of the chain before commencing the survey.

2. Choose the best line for the road according to the usual rules, paying special attention to the bridging sites of large rivers, of which the best crossings, within reasonable limits of deviation, are to be selected.

The line should cross rivers at right angles and with easy curves.

3. In chaining, make a fresh start at every mile, not at every station.

4. Permanent and easily recognized bench marks, such as large headers, should be firmly fixed in the ground on the centre line, dressed on the top and numbered ; these, as well as notches cut on large trees, rocks, etc., are to be recorded.

How the staff is held should be clearly described and sketched in the Field Book.

One permanent bench mark at least in each mile shall be made, and its position shall be clearly shown on the plan, and the levels should, when possible, be connected with the zero of the Trigonometrical Survey.

Bench marks of the previous day's work should be checked before commencing the day's levelling.

5. The chief objects along the line, such as towns, rivers, tanks, temples, isolated trees, to be included in the survey.

In the case of hills, their several peaks, spurs, and terminations of ranges should be fixed by bearings or angles.

6. The position of buildings and "metal" stone quarries to be fixed, if within half a mile of the line, also the distance and direction of lime, *kankar* and *muram* quarries to be given.

When further off than half a mile, their distance is to be ascerained and written on the plan, mile by mile.

7. The description of soil, and, if possible, the sub-soil chained over, and the points of change of one sort of soil for another, to be noted.

8. When a stream is crossed, sights in detail are to be taken, the staff being held at least at the top and bottom of its banks, and at the lowest point in the bed the stream.

9. The nature of the banks and the strata composing the bed to be noted ; and the depths at which solid foundation may be obtained, all across, to be ascertained, if necessary by sinking trial pits, or by borings.

The pits or borings should be sunk to rock, or to a depth of 10 feet for large and 5 feet for small works, below the level of the sole of the foundation pits, sections should be plotted showing accurately the depth and nature of the several strata pierced.

The level of highest floods to be recorded after careful enquiry from villagers and investigation of the country. The courses of all streams for 100 feet at least to be included in the survey ; but if the stream be such as would be likely to require a small bridge, it is to be surveyed for half a mile on either side of the line.

To show the course of the river in the proximity of a bridge site, it is necessary to make a contour survey of a 1,000 feet length upstream and downstream. For this purpose cross-sections at every 100′, should be taken. The contour plan should then be prepared to a scale of 50 feet to one inch, with contours at 2 feet vertical intervals. On this contour plan the bridge or causeway should be marked as nearly at right angles as possible to the river course.

It is necessary to state whether the river at the proposed site is affected by tides or by the floods of another river backing up.

For rivers or streams having a lineal waterway exceeding 100 feet, the monsoon daily flood charts for as many years as possible should be sent up with the project.

Any records of the summer flow which may be available should also be sent with the project.

For small streams, a longitudinal section of the nala bed 100 feet upstream and 100 feet downstream should be given, to enable the floor level of the work being fixed correctly.

If there are tanks or bandharas in the catchment area of a cross-drainage work, this fact should be particularly brought out. In such cases normal discharge passing through the cross-drainage work will be that due to the catchment *below* the tank or bandhara. It is a possibility to be reckoned with however, that extraordinary cloud bursts may breach tanks or bandharas, sending down a violent rushing torrent which may sweep away ordinary drains or bridges. In such cases it would be advisable to design the cross-drainage work as a causeway with sufficient openings to pass the normal discharge, and permitting the extraordinary breach discharges to pass over it.

10. The probable size of the bridge required may be ascertained as follows :— the course of the stream should be examined above and below the crossing for a well defined section, and from a sketch of this section, taped roughly, an estimate of the water way can be formed, the H.F. L. being approximately ascertained by enquiry.

11. If the bridge is likely to be of 15 feet span or over, a *longitudinal section* of its bed, or of the water in its bed, for half a mile on either side of the crossing, and a *cross-section* at each end, that is, at half a mile upstream, and half a mile downstream, to be taken.

These sections should give the highest as well as the ordinary flood levels, the sections being carried out beyond the reach of the floods ; and from them will be obtained the area of flood section, the wetted border and the fall per mile, in detail.

When a river branches, or divides within the half mile, a section across all its branches must be given ; and in such case, other sections at some intermediate points, showing the river undivided, should be taken.

12. The sizes of drains and bridges, if any, on the same stream, either above or below the line, should be given.

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13. Every estimate for a bridge of greater importance should, if possible, be accompanied by a plan and longitudinal section of the river bed and banks extending *two* miles above and below the intended site, and by a sufficient number of cross-sections of the stream showing the maximum flood levels.

The area of the flood section in each case, with the hydraulic mean depth, shall be noted on the plan, as also the velocity of the stream, as determined (preferably) by experiment in floods, or by calculation, or botn, and the water-way proposed to be allowed through the bridge with the increase of velocity and probable rise in flood level due thereto. The formulae (it is advisable in all cases to use Kutter's formulae for calculating river discharges) used in such calculations should in variably be stated, and, when practicable, a map showing the entire drainage area of the river, and a statement of the known maximum rainfall in 24 hours, or other short periods of time, should be supplied.

14. Should any bridges have been previously erected over the same stream near the site of that proposed, the water way and the effect of the current should be noted and entered in the report.

15. For arches of large span, detailed drawings must be given of the proposed centres, showing the arrangement of striking them.

Centres for large bridges should form a separate item in the estimate.

16. A special memorandum should be drawn up, pointing out any difficulties or facilities of construction, with the distances at which good stone, lime, sand, wood, etc., can be procured.

17. Cross-sections of the country to be taken with greater or less frequency according as the original surface of the ground is more or less transversely sloping at right angles to the line, and extending to between 150 to 300 feet, according to circumstances, but always beyond the water line of the flooded land on either side of the line.

The middle sight of these sections must be one of the staff points of the section of the main line.

The section should show the general side slope of the country, and the level of any floods on land by the side of the line. The staff points on these section need seldom be closer than 100 feet apart.

18. But when the side slope ot the country is steeper than 4° about 1 in 15—these cross-sections should be taken at about 100 feet apart, and they should, when plotted to a large scale, be used to calculate the earth-work.

19. The several sections should show, without any unnecessary detail, all changes of surface, the heights of floods on the lands, etc. It will facilitate the calculations of the earth-work, if the distances and sights are taken, as far as possible, at even hundreds ; and it is usually possible to take them so without sacrificing accuracy to any appreciable extent. This does not refer to sections of *nalas*, where the details snould, of course, be greater.

PLANS AND OFFICE WORK

1. Projects for the construction of new roads must be accompanied by the following plans, described in detail in the ensuing paragraphs :—

1st.—An Index Map.

2nd.—A detailed Survey and Longitudinal Section.

3rd.—Sheets of Transverse Sections.

4th.—Drawings of all the masonry, iron or timber works in the order in which they occur in the line.

2. For the Index Maps, those of the Trigonometrical Survey with the project entered upon them should be used. The Index Map should show all towns within 3 miles of the road, and the direction of the chief towns beyond this distance, say, up to 15 miles. It should also show catchment areas consecutively numbered, and with areas of catchments written.

All plans shall be consecutively numbered, the number being placed in the top right-hand corner of each sheet, the upper number indicating the serial number of the sheet, and the lower the total number of sheets.

The covering sheet should give the name of the project, and below it the year of preparation.

3. The detailed survey will follow, in separate consecutive sheets, the survey or plan above, and the corresponding longitudinal section, on the same horizontal scale, below, with transverse sections, in place, above or below the longitudinal section. When the latter arrangement is adopted, separate sheets as per 3rd head, paragraph 1, will not be needed excepting sections for the drainage works passed on the line, which i may be convenient to show separately.

4. It will generally be found most convenient to plot the plan of the road on the Revenue Survey village maps, scale generally 8 inches to the mile or 660 feet to an inch, and to copy or plot a strip of sufficient width to form the plan of the locality through which the road passes.

On this detailed plan should be marked the proposed sites of all drains and bridges, which should have numbers affixed to them in regular order, also the miles from one end of the road (or sub-division of the road) to the other, the centre line of the road and the width of land proposed to be acquired for the roads and where the road passes through inhabited localities, abutting buildings with offsets from the centre line. All curves should be marked giving radii, lengths of tangents, and the length of curve, and also the angle between the extreme radii. Distances should be marked at all tangent points of curves, which should be serially numbered.

5. The Longitudinal Section must show the heights of the natural surface of the ground along the centre line of the proposed road, the proposed surface or formation level in red, heights of embankment and depths of cutting, the greatest height of inundations, as also the heights of any existing lines of communication at the points crossed by the proposed road. The gradient of every portion must be shown, and the position of any bench marks of which levels may have been taken also the proposed sites of all drains, bridges, miles, etc., so as to correspond with the plan. These levels should, where possible, be connected with the zero of the Trigonometrical Survey, and permanent bench marks should be left for subsequent reference.

The tangent points of curves, the number of each curve and its radius, and the included angle between tangent points should also be shown on the longitudinal section.

6. The datum is to be selected a sufficient number of feet below the station, or other permanent and defined bench mark.

7. The office copy, or rough plot, to be as far as possible on continuous paper ; the plan above the section.

The cross-sections of the country, above the point of section on the same sheet or on separate sheets as may be most convenient.

The fair copies to be on paper, or tracing cloth, in sheets of the size of imperial paper ($30\frac{1}{2}'' \times 22''$), and containing in each sheet 1 or 2 miles according to the scale selected.

The last furlong of the previous sheet to be repeated, at the commencement of each sheet, in outline.

The survey line to be in red; other lines to be in black or other appropriate colour.

8. The scales for general survey plan, longitudinal section and cross-sections of the country to be 660 feet to the inch for the horizontal and 40 feet for the vertical.

In special cases, as in intricate ground, or where more details are required the scales may be 300 feet and 20 feet (horizontal and vertical respectively) to the inch.

The cross-sections of streams, mentioned in the item of survey and field work, paragraph 11, to be 40 feet to the inch, both vertical and horizontal; but the longitudinal section of the bed may be 660 feet horizontal and 40 feet vertical.

9. The primary datum should, as far as practicable, be used as the datum line drawn on the section; but when necessary, for economy of space, or for convenience, secondary datum lines may be ruled at a given number of feet, above the assumed primary datum. This change should be noted on each sheet of the section; but *the heights written on the verticals must always be the true heights over the primary datum* usually those of the "reduced level" column of the field book.

10. Vertical (thick) lines are to be ruled at every change of inclination of the surface; and on them is to be written, in the following order upwards :—

1st.—The height of natural surface of ground over datum.
2nd.—The height of formation over datum.
3rd.—The height of filling, or depth of cutting.

The last two are usually filled in after the Executive Engineer has settled and ruled the formation line.

When the verticals are very close together, as is usually the case at the *nalas* the drawing becomes crowded, and the heights cannot easily be entered on the verticals; it is, however, seldom necessary on the fair copy to give more lines than one showing the lowest point of the bed, one for the flood lines, and one where each abutment or the drain will come, and of course one at each side at the top of the *nala* banks.

11. The horizontal distances to be written continuously in miles and feet, from the commencement of the section, each mile being marked distinctly in Roman figures. Corresponding distances should be shown on plan also for easy identification.

12. The various classes of soil should be shown by conventional sectional edging in colours, such as—

Muram or red soil	Burnt sienna.
Black soil	Indian ink.
Rock	Indigo.

Boulders in any of these soils may be shown by hatching, or conventional etching of stones.

13. The formation line (the surface of road under the metalling or muraming) to be shown by a red line.

At each change of gradient heavy black vertical lines should be ruled between which should be writen the rate of inclination, or grades, as, 1 in 100, etc.

14. Embankments may be coloured yellow, green, or brown ; and cuttings, red.

Although not necessary as a rule, yet it will assist the estimator to give the distances between the verticals used to estimate the contents of banks and cuttings. These intermediate distances may be written over the 3rd horizontal column of the section.

15. The water-courses and rivers are to be numbered consecutively on both plan and section ; and on the latter is to be written the size of the structure required, the height of formation being given on the central vertical.

16. On each sheet of the plan—
the north point is to be drawn ;
the names of villages, rivers, tanks, etc., given ;
the direction of flow of streams shown by arrows ;
tracks, or other roads leading to towns not shown in the plan, to have their destination indicated by To—, From—.

17. Detailed cross-sections of the country, when required for the calculation of the quantities of cutting and embankment, paragraphs 17 to 19 (Survey and Field Work), are to be plotted at a natural scale of 40 feet to the inch, and on them are to be drawn the cross-sections of the road, giving the outline of the formation, catch-waters, etc.

18. Enlarged cross-sections of the rivers at the bridging sites are to be plotted separately, if necessary on separate sheets, to a scale of 20 or 10 feet to the inch according to the scale selected for the elevation of bridges ; and on these sections are to be drawn, in outline, the elevations, plans and transverse sections of the bridges, with design of centres, etc. On these sections should be shown the ordinary as well as the highest flood lines with the date of the latter, if possible the hot weather flood lines, the nature of the banks, and the strata forming the bed of the river, the borings, or trial pits being regularly plotted on the section for this purpose. On the same sheets should also be shown—
the mean of the three hydraulic mean depths ;
the velocity of the river in feet per second, the fall and the afflux calculated for the obstruction of the gridge.
Scales should also be given on each sheet.

Fuller details, to scales of from 10 to 5 feet to an inch, may be given if necessary ; and may be on the same or another sheet, as found convenient.

On the cross-sections of cross-drainage works the following reduced levels should be shown :—

Actual ground, bottom of foundation, top of foundation, sill of openings, springing of arches or bottom of beams or slabs, intrados and extrados of arches, or top of slab, centre and edges of road way, top of parapet.

19. The elevations and plans of drains may also be drawn to a scale of 10 feet to an inch ; but if "average or standard" plans be used, special drawings are unnecessary.

20. Estimates for new lines of road must include the cost of all dwelling and inspection houses intended to be built along it for the accommodation of officers, subordinates and others.

21. The title page should give the designation of the road ; a memorandum of the letter and estimate accompanying it ; the several scales ; and a "reference" showing what the various colours and lines represent in the body of the plans.

22. A sheet of general cross-sections, showing in detail the method of forming the road, on level, in banks, in cuttings, on sidelong ground, and in *ghats*, should accompany. The scale of these sections to be at least 10 feet to an inch. These type sections shall also show bottoming or soling if any, the thickness of metel, the nature of material and its depth in sidewiths, the blanketting of slopes if any, the positions of the three avenue and the side gutters.

23. The width of land required for Local Board roads to be 66 feet in valuable land, and 82½ feet in cheap land. The adoption of these units simplifies survey works and calculations when acquiring land, for 1 Gunter's chain=66 feet, and 1¼ Gunter's chain=82½ feet.

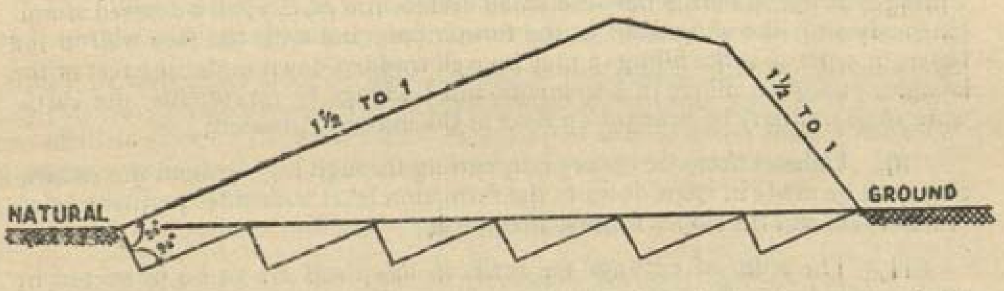
EARTHWORK FOR ROADS

Specification No. 162

1. The embankment will generally be formed of earth obtained from pits excavated along the side of the road. The inner edge ot these pits will correspond witn the inner edge of the road gutter, whose place will be taken by these borrow pits.

2. The ground to be occupied will be cleared of all large bushes or trees, but, generally speaking, it is not necessary to grub up roots or grass or to remove, the surface soil.

3. The surface of sloping ground on which an embankment is to be erected shall in variably be preapared to receive the earth work, by having cut in the slope a sufficient number of footings or benches forming a right angle with the slope of the embankment as per sketch below :—



4. Before commencing any embankment, the foot of the slopes on each side will be marked by pegs firmly driven into the ground at intervals of 20 feet ; then, care being taken to place them at right angles to the centre line, profiles made of bamboo or other convenient material and string, or, if desired, earth sections may be set up for the guidance of the workmen, at such intervals along the embankment as the Executive Engineer deems necessary. The profiles will show the total height including allowance for settlement.

5. No mud, slush or watery stuff from wells or springs, and no decayed vegetable matter or rotten stuff of any kind, shall be allowed to be put into embankments. All such material taken out of excavations shall be placed on one side, or used to fill up excavations no longer required.

6. All embankments are to be raised in regular layers. The layers will be of the thickness fixed by the Executive Engineer, and will be rammed and consolidated, being moistened with water if so directed by him. They will be carried out to the full width of the slopes in all instances, so that no additions may be required to the slopes after the bank is made up to the formation level.

All lumps and clods of earth are to be broken up, so as to allow of a regular subsidence of the earth-work throughout.

7. In carrying up embankments, the full allowance for shrinkage shall be made at first, as may be laid down for the specific class of soil by the Executive Engineer, so that no addition of earth will be required after settlement to bring the bank up to its full dimensions.

Unless otherwise directed, the following allowances shall be made for shrinkage of earth-work :—

In firm compact earth	1 to 1½ inches per foot.
In ordinary loose earth	1½ to 2 inches per foot.
In black cotton soil	2 to 3 inches per foot.

These allowances will, however, depend upon the nature of the consolidation, etc., adopted ; when the earth is moist, laid in thin layers and well rolled, smaller allowances will suffice.

8. The tops of all embankments are to be brought up to the levels set out by the Executive Engineer (including the allowances for shrinkage), and be nearly levelled off. The slopes are to be dressed to the required inclination and neatly trimmed.

9. In carrying embankments over a bridge or culvert intended to be covered in, the earth-work shall be brought up evenly on both sides of the structure, so that the pressures may be equalised. In filling in the approaches of a bridge, or the spandrils between small arches, the earth shall be raised simultaneously with the wing walls in the former case and with the face wall in the latter, in order that the filling in may be well trodden down under the feet of the labourers ; and in filling in basements and backings to revetments, the earth-work shall similarly be brought up level as the masonry proceeds.

10. Unless otherwise ordered, in cutting through high ground the excavation shall be made in steps down to the formation level with sides perpendicular, or nearly so, and the slopes formed afterwards.

11. The sides of cuttings for roads in loose soil are to be protected by catch-water drains above the cuttings, or by surface drains running diagonally at such inclination down the slope as may be ordered by the Executive Engineer. At the foot of the slope will be a small berm, and between this and the edge of the formation level, a catch-water drain of dimensions to be fixed in each case by the Executive Engineer.

12. Unless intended to be used as side or catch-drains, the side cuttings shall not be continuous, but regular rectangular bars, 10 feet wide, shall be left at intervals of 100 feet.

When intended to be used as side or catch-drains, the side cuttings shall be carefully trimmed and formed to the proper dimensions, and with the inclination of bed fixed upon by the Executive Engineer.

13. In making cuttings care shall be taken not to injure or interfere with irrigation channels, tank embankments, roads, etc. Temporary arrangements must always be made for carrying irrigation or drainage water across cuttings until the permanent arrangements are completed.

14. Earth from cuttings, when not required to be led into embankments, shall be taken to spoil within limits fixed upon by the Executive Engineer, and shall be the property of Government.

The spoil is not to be thrown up in irregular, shapeless heaps, but formed into a regular bank, of uniform height, so far as possible, with a level surface and with slopes of 1½ to 1, or as may be ordered by the Executive Engineer. In the case of channel or river spoil banks, their top surfaces must be sloped away from the channel so as to prevent drainage from flowing over and forming gullies down the slopes and berms.

15. All "dead men" shall be removed from cuttings when no longer required for measurement purposes. All temporary pathways, ramps, etc., are to be dressed off neatly and the whole work properly finished. These works are to be carried out by the contractor within the over-all rates.

16. The measurements of earth-work will be taken from the pits furnishing the earth which shall be numbered, the numbers being marked on pegs driven into the corner of each pit to facilitate check measurement. Pits, moreover, should, if possible, be of a uniform size and the "dead men" should not be removed till the final measurements have been made and passed.

In filling an excavation or hollow, the horizontal lead only to be allowed, and the lead will be measured from the centre of gravity of the cutting or mass of earth moved to the centre of the hollow.

In valuing the work, one foot of vertical lift shall be taken as equal to 12½ feet of horizontal lead.

17. When earth has to be carted, the excavation will be paid for without lead, and the carriage separately paid for according to the schedule rates.

18. Contractors shall be held personally responsible for all damage they may cause to private property (such as buildings, wells, trees, etc.), in the execution of their work. They must also, excepting in special cases, make their own arrangements with the owners of land for "getting" or stacking earth, gravel, etc., as may be required.

Note.—The question of earth-work is more fully treated of in Chapter X, Irrigation Works.

19. When land is taken up, the Executive Engineer should see that the necessary corrections are made in the village maps and records.

COLLECTION OF METAL

General

1. The collection of metal for the surfacing of roads is generally one of the most important duties of a Road Engineer. As metal frequently remains exposed to the weather for some considerable time before being used, and as some kinds of stone and many kinds of *muram* are subject to disintegration when alternately wet and dry, the greatest care is necessary in the selection of any

kind of metal. The following notes will be of assistance as a guide to the methods to be adopted and the specifications to be enforced.

2. The quarries from which road material of whatever kind is obtained must be approved by the Executive Engineer or his authorized representative.

N. B.—It will generally be necessary to use such road metal as may be available in the district, such as broken stone, *muram*, lime, *kankar*, etc.

Specification No. 163

1. The broken stone metal shall be of a close, tough, durable and hard texture, and be broken so as to pass in every direction through a 2-inch ring for the under layers and through a 1½ inch ring for the surface. Each piece should be square and sharp ; no round or oblong pebbles, no angular chips or flakes, and no stones larger than what is above specified shall on any account be used.

2. Laterite for road metal should be hard, compact, heavy and of a dark colour. The lighter coloured sandy laterities, as well as those containing much ochreous clay, should be rejected. Laterite which approaches hæmatite in quality is the best material to be used. Laterite may be broken into sizes varying from 1½ to 3 inches.

3. *Muram* to be sound and hard, of a quality not affected by the weather : to be screened at the quarry, and freed from all impurities, the pure *muram* only being received on the work. The large lumps must all be broken at the quarry, and the *muram* so delivered must pass in every directions through a 2½ inch ring.

4. *Kankar* shall be as tough as can be procured in the locality.

A brown, almost opalescent fracture, will generally indicate a good specimen of *kankar*, and, when broken, each piece must pass in every direction through a ring 2 inches in diameter.

5. Gravel should be composed of large, coarse, silicious grains, sharp and gritty to the touch, and thoroughly free from dirt and impurities. The pebbles composing laterite gravel should be separated by screening from the excess of clay which usually accompanies them before being used as gravel. Sand used for blinding road surfaces should be sharp, gritty and clean, and the quantity used shall not exceed half an inch in depth.

6. No road material shall be stacked until it has been thoroughly screened and freed from all earth, etc., and, when ready, must be stacked entirely clear of the roadway, either upon the berms and platforms provided for the purpose, or at the foot of the side slope.

7. Experience shows that comparatively large heaps of metal are more economical than small ones ; and it is recommended that the height should generally not be less than 2 feet, and no heap of a less height than one foot should be measured.

The length and breadth of the heap must depend on the quantity required and the shape of the site.

It is essential for many and obvious reasons that sites for the stacking of metal should be specially levelled and maintained ; they should be selected at, as nearly as practicable, equal distances of about ½ furlong apart, that is 16 to the

mile, on each side of the road ; when ground is available, the sites might measure 40×20 feet, and when space is cramped, proportionately less.

N. B.—On some roads in England, the Engineers have arranged walls round the stacking places which saves cost of periodical measurement, keeps metal clean, prevents trafic over it, etc.

8. When metal for two layers has to be stacked, as in the case of a new road, the material for the two layers, unless otherwise ordered, shall be stacked on the opposite sides of the road.

9. In stacking material, the deposition should commence at one end of the mile and be carried continuously towards the other end, unless the Executive Engineer shall direct otherwise ; and, as a rule, measurements will not be taken until sufficient for a furlong, half mile, or mile has been fully collected ; any fractions of those distances will not be measured up.

10. Metal, etc., collected for petty repairs, shall be stacked on the opposite side to that where the material for renewals is stored, and the form and dimensions of the heaps shall be such as to distinguish them at once from the metal collected for new work.

11. All road material shall be examined and measured before it is spread, and immediately on being paid shall be marked by whitewash or otherwise as may be directed by the Executive Engineer, to prevent the possibility of being paid for over again. As a rule, collecting and spreading must not be carried on at the same time in one and the same mile, or in two adjoining miles.

12. The Executive Engineer shall supply the contractor with a statement mile by mile, of the quantities of metal that will be required and with written instructions concerning the particular localities in which the metal is to be stacked, as well as those in which the collections are to be first made.

13. The contractor shall be bound to make progress in the collection of metal at a certain minimum speed, proportional to the quantity to be collected to be at the time agreed upon between him and the Executive Engineer, as also to remove all materials that may be rejected to such distance as may be ordered, within 48 hours after receiving written instructions to do so from the Executive Engineer.

14. No excavation for earth, ***muram***, gravel, etc., to be used in the construction or repair of a road, shall be made nearer than 20 feet clear distance from the outside boundary of the sidewidths.

SPREADING AND CONSOLIDATION

Specification No. 164

Thickness of metal on new roads

1. The thickness of metal to be laid on new roads depends upon the nature and extent of the traffic, but on important roads with heavy traffic should not generally be less than 9 inches in thickness, and no less important road should not be less than 6 inches.

The metal should be laid in layers of about 3 to 4 inches in thickness, the lower layer being nearly consolidated, not completely so, before the next layer is put on with bullock drawn rollers, this thickness should not exceed 3″ loose maximum.

Soling

2. *Soling.*—Soling is now generally specified for all important roads except in sections passing through rock or good hard *muram.*

Thickness.—If rubble is used—for sections in good soil 6″ of rubble is specified, to be increased to 9″ if the sub-grade is of poor soil such as black soil. If hard *muram* is used the depths are increased to 9″ and 12″, respectively. In the alluvial north Gujrat where stone is dear, brick-on-edge soling is generally provided.

Width of soling.—This is usually kept 1 foot wider than the width of metalling and in high banks and on metalled dips it should extend over the whole width of road. In the case of hard *muram* the whole formation width is usually blanketted.

Before metal is laid, the soling requires rolling over. The interstices are filled with metal, good gravel, *kankar*, or *muram*, and the surface is then rolled. The *kankar* or *muram* should be only a little above the soling after rolling is complete.

No stone is to be less than 4 inches thick and not to exceed in length and breadth twice its thickness. Stones to be hand-packed as close as possible and voids to be filled in with chips.

A gang with hammers will then go over the soling and knock off all projecting corners above the general level. A 3-inch layer of metal should then be spread over this and rolled true to section, but not thoroughly consolidated.

The 6-inch layer of metal may now be spread and rolled, care being taken to get the edges of full thickness by using a 6 inch board between the edge of metal and the edge of the side width.

The primary function of soling is to distribute the load over a soft subgrade in such a way, that there will be no sinking of the road crust into the subgrade. It is necessary, therefore, that where rubble is used for soling, the flat side which rests on the subgrade should have an area sufficient to achieve this purpose. Soling should not be laid in two layers, as the top of the bottom layer has generally an uneven surface, and the upper layer is likely to rock under traffic. In cases where the full depth of soling specified cannot be obtained by a single rubble layer, a layer of large size metal of the necessary thickness should be laid over the rubble to fill the interstices in it, and to give the total depth of soling necessary.

Where brick-soling is used as in Gujerat and Sind, it should be laid flat, breaking joint in successive layers if necessary, for the same reason as is given for rubble soling. In places however, where the soil is loamy, the soling may be brick-on-edge as this subgrade affords good support to the bricks.

The soling should be spread at least 6″ more on either side, than the proposed width of metalling.

Convexity or Barrelling

3. Before the metal is added, the "formation" of the earth-work should be thoroughly drained, barrelled and well rolled, so that when wet weather occurs, the consolidation which ensues should not exceed, in the road centre, the amount of convexity that has been given to it.

The banks should, if possible, be exposed to the whole of a wet season before the metalling is added.

The convexity or barrelling is usually expressed by a ratio viz., $\frac{\text{the height of the centre of the road above the edge}}{\text{the half width}}$ if there is one continuous slope from centre of road to edge. This ratio is laid down as 1 in 24 to 1/30 for murum kankar, and gravel roads, 1/30 to 1/48 for metalled roads, 1/48 to 1/60 for asphalt treated surfaces and 1/60 to 1/90 for cement concrete surfaces.

The trend is towards making this ratio as small and the surface as flat as possible so that the traffic may have no inducement to hug the crown or central portion of the road. Generally the more wear-resisting a surface, the flatter the slope.

Remetalling existing Roads

4. Before spreading the metal on existing roads, the surface of the road shall be picked up $1\frac{1}{2}$ inches deep, and the loosened material should be removed to the sides and used to form up the side bands outside the central metalled formation.

The new metal will then be carefully spread between the side bands, the larger pieces being placed at the bottom and the smaller at the top. The thickness of the metal layer will vary from $1\frac{1}{2}$ to 3 inches in thickness according to the traffic and importance of the road.

N. B.—In the Poona cantonments and suburbs where the foundations are now very hard owing to repeated renewals, the layer of metal employed for renewals varies from 2 to 3 inches in thickness consolidated by 15-ton steam rollers. This layer lasts about three years.

In the Poona district $1\frac{1}{2}$ inches is found to answer well with renewals every 3 years.

To ensure correctness, wooden templates, of the exact size and shape of the new layer, should be applied to the old surface at regular distances apart, and the metal should be laid to these templates.

5. Care must be taken that the incline or level parts in each length of the road are truly maintained; and where the new metal terminate no sudden steps should be left, but the junction of the two surfaces must be made quite perfect. Similarly, in fixing iron road boxes, etc., to water and drainage valves, etc., there should be no rise or unevenness of surface in joining up the road metal.

Note.—The remarks above apply, though in a less degree, to muruming roads. In such roads the *murum* is generally laid of the full width at once. The "barrelling" of the road is equally important.

Consolidation

6. The new metal will be consolidated by rolling, being thoroughly saturated with water if the rainfall proves insufficient, and will be continued until the surface is thoroughly hard and smooth, no more "blinding" of sand and *murum* being used than is absolutely necessary to ensure the metal binding. The weight of the rollers should be at least $\frac{3}{4}$ ton per foot of length. Over this, as a finishing coat, a thin layer of sand should be applied.

N. B.—Ramming is of little use unless performed with a large force of about 16 men working in unison in four consecutive rows, using abundance of water. The work of each portion cannot be considered finished till the water has been completely expelled under the rammers and the surface left smooth and hard.

Traffic not to be interfered with

7. Care shall be taken to interfere as little as possible with the traffic and the workmen shall be instructed to facilitate its passage by helping carts and carriages over the portions rendered partially impassable by their operations. No heaps of loose material, road rollers, tools, etc., shall in any case be left at night on the road.

8. The contractor shall use all due precautions for the safety of passengers and shall place barriers across each end of the length of road which is being worked upon. Watchmen should be employed and bright red lights placed and maintained in such places as the officer in charge may direct.

Curves

Curves on roads are required at a change in direction of the road, and also where one road meets another road at an angle. For curves of very large radius, say with radii over 1,000 feet in length and curves of very small deviation angle a simple circular curve of constant radius or a compound curve with flank curves of flat radius, and a central comparatively sharper curve, can be employed without inconvenience to traffic. These curves can be set out either by the offset method or the angle method, the former being usually employed.

For curves of short radius and curves with large deviation angles however, such as occur at changes of direction in hilly sections, and at junctions of roads, a simple circular curve or even a compound circular curve is not very satisfactory, because—

(1) the transition from the straight portion to the curve is abrupt, and.

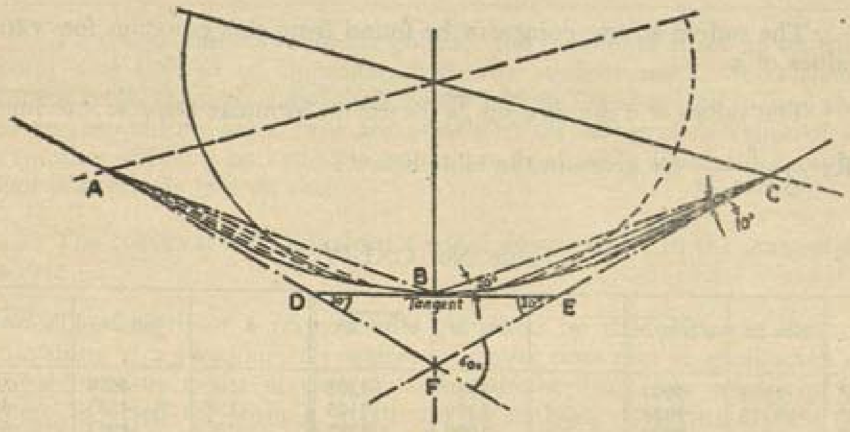
(2) the cross-fall from centre to the edges cannot be worked into the continuous cross fall from the outer-edge of the curve to the inner.

In such cases a curve which changes its radius of curvature progressively, starting with a very flat curve of large radius at the initial point, and culminating into a curve of small radius at the apex is generally used. Such a curve has under-noted advantages :—

(1) Since the curvature from the straight length gradually and progressively increases, the driver of a vehicle on horizontal curves has not to slow his vehicle round suddently, but can do so gently, and at vertical curves he is able to roll over the curve without a bump.

(2) For curves due to change in direction of the road the superelevation can be gradually increased since the curvature also gradually increases, and the maximum superelevation is required only near the apex. The transition from the double cross fall from centre to edges, to the single cross fall from edge to edge, is more easily introduced.

Bernouilli's Lemniscate.—Of the two or three curves which change curvature progressively, this curve is one and is preferred because the laying out is easy, and the calculations simple. It can also be made either entirely transitional or have a central circular arc, as convenient. It is eminently suited to the natural curve of a car negotiating a bend. It is also a symmetrical curve with a fixed and definite relation between the vectorial angle, that is the angle which a radius vector or polar ray makes with the straight alignment at the starting point, and the angle between the radius vector to a point, and the tangent at the point. The Vectorial angle is always half of the latter angle. The relationship is explained by diagram No. 4A.



4A

Here AF and CF are the prolongations of the roads intersecting at F, the angle O or AFC being 120°. Point B, the apex of the curve is fixed since the angles FCB and FAB are known being equal to 1/6 (180° −0)=10° (This follows from the relationship of the curve angles because ∠BFE is an angle of 60°, and as the angle FBE is a right angle, the angle BEF is 30° and from the relation of the curve that the Vectorial angle is always hlaf the angle between the radius vector and the tangent at any point on the curve, the angle ECB = $\frac{1}{2}$ the angle EBC ; but ∠ECB+ EBC=outside angle BEF=30° ∴ ECB=10° and BC=20°).

If r is the polar ray or radius vector, and a the polar angle, and R the radius of the Curve at any point the equations of the curve are :

(1) $r^2=3C \text{ Sin } 2a$ where C is a constant. The value of the polar ray for any point and the vectorial angle at that point unable us to obtain C. In this case at the point B the centre point of curve, we know the angle $a=10°$ and scale off the length of the tangent BE ; then

$$\frac{BC}{BE}=\frac{\text{Sin BEC}}{\text{Sin BCE}}=\frac{\text{Sin}(180°-3a)}{\text{Sin } a}=\frac{\text{Sin } 3a}{\text{Sin } a}=\frac{\text{Sin } 30°}{\text{Sin } 10°} \text{ and } BC=BE\times\frac{\cdot 5}{\cdot 1736}$$

from which BC or polar ray at centre point of curve is known and since $C=\frac{r^2}{3 \text{ Sin } 2a}=\frac{BE^2}{3 \text{ Sin } 20°}$ C also is found.

Having found it we can then proceed to find the other vectors or rays ; from the equation $r^2=3 \text{ C Sin } 2a$ or $r=\sqrt{3c}\ \sqrt{\text{Sin } 2a}$ assuming different values of a. (2) $r=3R \text{ Sin } 2a \therefore R=\frac{r}{3 \text{ Sin } 2a}$.

The radius at any point can be found from this equation for various values of a.

The values of a Sin $2a$ $\sqrt{\text{sin } 2a}$ for use in formulae $r=\sqrt{3c}\times\sqrt{\text{Sin}-2a}$ and $R=\frac{r}{3 \text{ Sin } 2a}$ are given in the table below :

Table No. CXLIV

a	Sin $2a$	$\sqrt{\text{Sin } 2a}$	a	Sin $2a$	$\sqrt{\text{Sin } 2a}$	a	Sin $2a$	$\sqrt{\text{Sin } 2a}$
44°	·9993	·9997	29°	·8480	·9208	14°	·4694	·6851
43°	·9975	·9988	28°	·8290	·9105	13°	·4383	·6621
42°	·8945	·9972	27°	·8090	·8995	12°	·4067	·6377
41°	·9902	·9952	26°	·7880	·8878	11°	·3746	·6120
40°	·9848	·9924	25°	·7660	·8752	10°	·3420	·5848
39°	·9781	·9891	24°	·7431	·8621	9°	·3090	·5559
38°	·9702	·9851	23°	·7193	·8481	8°	·2756	·5250
37°	·9612	·9804	22°	·6946	·8334	7°	·2419	·4919
36°	·9510	·9752	21°	·6691	·8180	6°	·2079	·4560
35°	·9396	·9694	20°	·6427	·8017	5°	·1736	·4166
34°	·9271	·9629	19°	·6156	·7846	4°	·1391	·3730
33°	·9135	·9559	18°	·5877	·7666	3°	·1045	·3233
32°	·8987	·9479	17°	·5591	·7477	2°	·0697	·2640
31°	·8829	·9397	16°	·5299	·7279	1°	·0348	·1866
30°	·8660	·9307	15°	·5000	·7071			

Example.—Taking an actual curve on the Bhor Ghat which has been set off as a lemniscate :—

Angle of deflection was 114°, and therefore angle at intersection of tangents was $180°-114°=66°$; angle made by polar ray to centre of curve with the straight road line L (max for curve)$=\frac{180°-66°}{6}=19°$ therefore $2a=38°$

In this case the polar ray from the starting point to the centre of curve as

measured actually was 58 feet (when $\alpha=19°$). For other values of α the respective polar rays are tabled as shown below, together with the radius of curvature at each point; the constant $C=\frac{58}{\sqrt{\text{Sin } 38°}}=\frac{58}{\cdot 7846}=73\cdot 92$ say 74 feet.

Table No. CXLV

α In degrees	Sin 2α	$\sqrt{\sin 2\alpha}$	$r=C\sqrt{\sin 2\alpha}$ feet	$R=\frac{r}{3 \sin 2\alpha}$ feet
2	·0697	·2640	19·5	93
4	·1391	·3730	27·6	66
6	·2079	·4560	33·7	54
8	·2756	·5250	38·8	47
10	·3420	·5848	43·3	42
12	·4067	·6377	47·2	39
14	·4694	·6831	50·6	36
16	·5299	·7279	53·9	34
18	·5877	·7666	56·7	32·2
19	·6156	·7846	58	31·4

To set out the curve on the ground, the theodolite is set up on the starting point and sighted in alignment with the straight road. It is then turned successively, through the various values of α in the above table, and the lengths of corresponding polar rays are measured off along each value of α. Thus a number of points on half of the curve are fixed, after which the complementary half is similarly laid down.

The curves at road junctions are laid down exactly in the manner described above.

The length of a transition is governed by the principle that a vehicle travelling at a given speed requires a definite time rate of application of centrifugal force up to the maximum, and a similar time rate when the contifugal force is eased off from a maximum to nothing. Maximum rate change of radial acceleration usually adopted for a comfortable rate of turning is 1 foot per sec. per sec., in a second, which gives the length of transition $h=3\cdot 155V^2/R$ where V is the speed in miles per hour and R the radius of the curve in feet. Where the curves are close together, this length can be reduced to 1/3rd as up to a rate of acceleration or deceleration of 3′ per sec. per sec. in a second, discomfort is not obvious.

It will be noticed from the last column of the above table that the radius gradually changes from 93 feet at the starting point to 31·4 feet at the centre point of the curve. The superelevation in feet per foot width, which is given by the formula $\frac{V^2}{15R}$ (nearly), where V is the authorised maximum speed of the vehicle on the curve in miles per hour, and R the radius of the curve in feet, is also thus introduced gradually. If we take a maximum permissible speed of 10 miles per hour (which is that at present laid down on all curves in the Bhor Ghat except hairpin bends), the superelevation at the first point in the curve where the radius is 93 feet $=\frac{V^2}{15\times 93}=\frac{10\times 10}{15\times 93}=\frac{10}{139\cdot 5}=0\cdot 07$ feet, i.e., nearly 0·84″ per foot or 1″ in 14 approximately whereas the

superelevation at the central point of the curve where the radius is 31·4 feet $\frac{10\times10}{15\times31\cdot4}$ = nearly 2·54″ per foot, or about 1 in 5. Since the maximum permissible superelevation is 1 in 12, it will be clear that the speed must be 6 miles per hour near the centre of the curve, increasing to 11 miles per hour at the first point on the curve ; and after the peak of the curve, it can be safely increased from 6 miles gradually to 11 miles, co-efficient of friction between wheels and road surface not being considered.

In the above discussion on superelevation the effect of friction between the wheels and the road surface has not been taken into account. If the road surface is cement concrete, this co-efficient of friction can usually be taken at 0·25, and the formula will be $E = \frac{V^2}{15R} - f = \frac{V^2}{15R} - 0\cdot25$. Taking this co-efficient of friction the following table gives the safe speeds in miles per hour for various radii of curvature in feet, with banking or super-elevation of 1 in 12 where V is in miles per hour.

Speeds with 1 in 12 banking for various radii.

Radius of curvature in feet	25	50	75	100	125	150	175	200
V or speed in miles per hour	11·6	16·3	19·6	22·8	25·8	27·9	32·4	36·1

Widening at curves.—For the curve we have considered above, the widening can be calculated for all points by the formula—

Widening $= 2\,(R - \sqrt{R^2 - l^2}) + \frac{V}{\sqrt{R}}$ and will be gradually increasing from the starting point to the peak of the curve. At the first point on the curve the widening will be $= 2\,(93 - \sqrt{93^2 - 16^2}) + \frac{11}{\sqrt{93}}$ (l = wheel base assumed 16 feet and 2 is the number of lanes) $= 2\,(93 - 91\cdot6) + \frac{11}{9\cdot64} = 2\cdot8 + 1\cdot15 =$ 3·95 say 4 feet. At peak of curve. Widening $= 2\,(R - \sqrt{R^2 - l^2}) + \frac{V}{\sqrt{R}} -$

$$2\,(31\cdot4 - \sqrt{31\cdot4^2 - 16^2}) + \frac{V}{\sqrt{31\cdot4}} = 2\,(31\cdot4 - 27) + \frac{6}{5\cdot6} = 8\cdot8 + 1\cdot1 = 9\cdot9 \text{ feet.}$$

The widening should be on the inner side of a curve generally, as shown in figure 2.

If the transition curve is used throughout, and if the inner edge curve and the outer edge curve are laid down independently, it will be found that there is an automatic and progressive widening of the road width from the starting point to the peak of the curve, though this is not sufficient.

To use this curve for transition of a main curve of say 300 feet radius,

since $R = \frac{r}{3 \sin 2a}$ and $\sin 2a = \frac{r}{3R}$. If the length of the transition is 60 feet, at maximum superelevation $\sin 2a = \frac{60}{3\times300} = \frac{60}{3\times300} = \frac{1}{15} =$ ·0667 and $2a + 3°\cdot50'$ and $a = 1\cdot55'$ which is the polar angle for r = 60 at the point of commencement of main curve.

The method of setting out curves above described is the polar ray method, which has the disadvantage that when the rays are several chains in length there may be inconvenience in setting out. Prof. Royal-Dawson in his book 'Elements of Curve design for road, railway and racing track' gives another method, the Equal-chord method, and gives a table giving deflections for obtaining each chord point, the unit of measurement being a polar ray whose deflection is 16 minutes. By this method the curve can be set out by taking the deflection and setting the chord from the last point to cut line of deflection.

Vertical curves.—Vertical curves used at the intersections of two rising grades, i.e., at summit intersections, are usually circular arcs, or what is approximately similar a parabolic curve with offsets varying as the square of the distance from the crown of the curve. The shape of the curve is governed by the 'visibility' required. For valley curves visibility is generally good, and they can be laid down in the same way as summit curves. Where a level gradient of sufficient length intervenes between two rising grades as in a causeway and its approaches, the rounding at each intersection of approach and level bit, can either be made by a half parabola with the apex of the parabola on the straight length some distance away from the intersection, or by a vertical lemniscate, using the equal-chord method which fixes points on the curve at equal-chord lengths.

' Sight distance ' or limit of vision.

Vertical curves.—In the case of summit vertical curves, the 1932 Road Board Specifications lay down a minimum length of vision of 500 feet, except when speeds are specifically restricted.

Horizontal curves.—In the case of horizontal curves round a spur or obstructing vegetation, the same minimum length of vision of 500 feet should generally apply, the portions of the spur or vegetation above 3 feet in height being cut down to give this visibility at 3 feet above road level.

Note.—In the Ghats where this standard cannot be maintained, speed limits are usually enforced. In the Bhor Ghat the maximum length of vision is often only 100 feet, but the speed limit in such a case is cut down to 15 miles per hour, giving a length of travel in one second of 22 feet, and for cars proceeding in opposite direction 44 feet, leaving 56 feet for braking to a stop if necessary.

The technical sub-committee of the Indian Road Congress lay down the following *ruling gradients* :—

For plain roads ..	.. 1 in 30
For hill roads ..	.. 1 in 20
Maximum gradients	1 in 15 in stretches not exceeding 300 feet.

The gradient at curves should not exceed 1 in 30 and should be as flat as possible for 100 feet above hair-pin bends, even if it is necessary to increase the gradient for a short distance beyond this length of 100 feet.

Radii of curves.

Minimum on roads in plains	1,000 feet.
Minimum on hill roads	50 feet.

NOTES ON ROAD CONSTRUCTION AND MAINTENANCE

(PLATES LXIX TO LXXIII)

I. Alignment

On the watershed.—Align roads on or near the watershed, so reducing the number and dimensions of drainage works. This applies principally in country with flat ruling slopes, or gently rolling.

Round hills.—Go round rather than over hills. The effort of climbing a hill is not recovered in descending the reverse slope, especially with animal traction.

A considerable detour is justifiable in order to avoid a gradient amounting probably to 12½ feet additional length of level road for every foot of rise avoided.

Not alongcart-track.—Avoid the line of the old sunk cart-tracks found in Guzerat and Sind.

Straight.—Other things being equal, the straightest road is the shortest cheapest and, therefore, the best.

Near villages and across rivers.—Roads should be aligned to pass close beside, rather than through villages, and should cross the principal drainage lines as nearly at right angles as possible.

Final line.—The final line must be a compromise between these considerations.

On ghaut roads.—Eliminate all small zigzags and get the alignment a straight as possible, as in Fig. 1.

II. Corners and curves

Hair-pin corners.—A simple form of hair-pin corner is as shown in Fig. 3. In this case the maximum turning circle obtainable is about 17′, which is suitable for light traffic only.

Form of hair-pin corner designed by the French authorities, as the minimum suitable for heavy traffic, is as shown in Fig. 4. Radii should, therefore, be increased, if possible.

Superelevation.—All curves with a radius of less than 1,000′ should be superelevated, the superelevation being continued throughout the curve, the road surface being given a continuous cross-fall from the highest point to the gutter. The transition from this cross-fall to the regular barrelling on straight reaches should be gradually worked off.

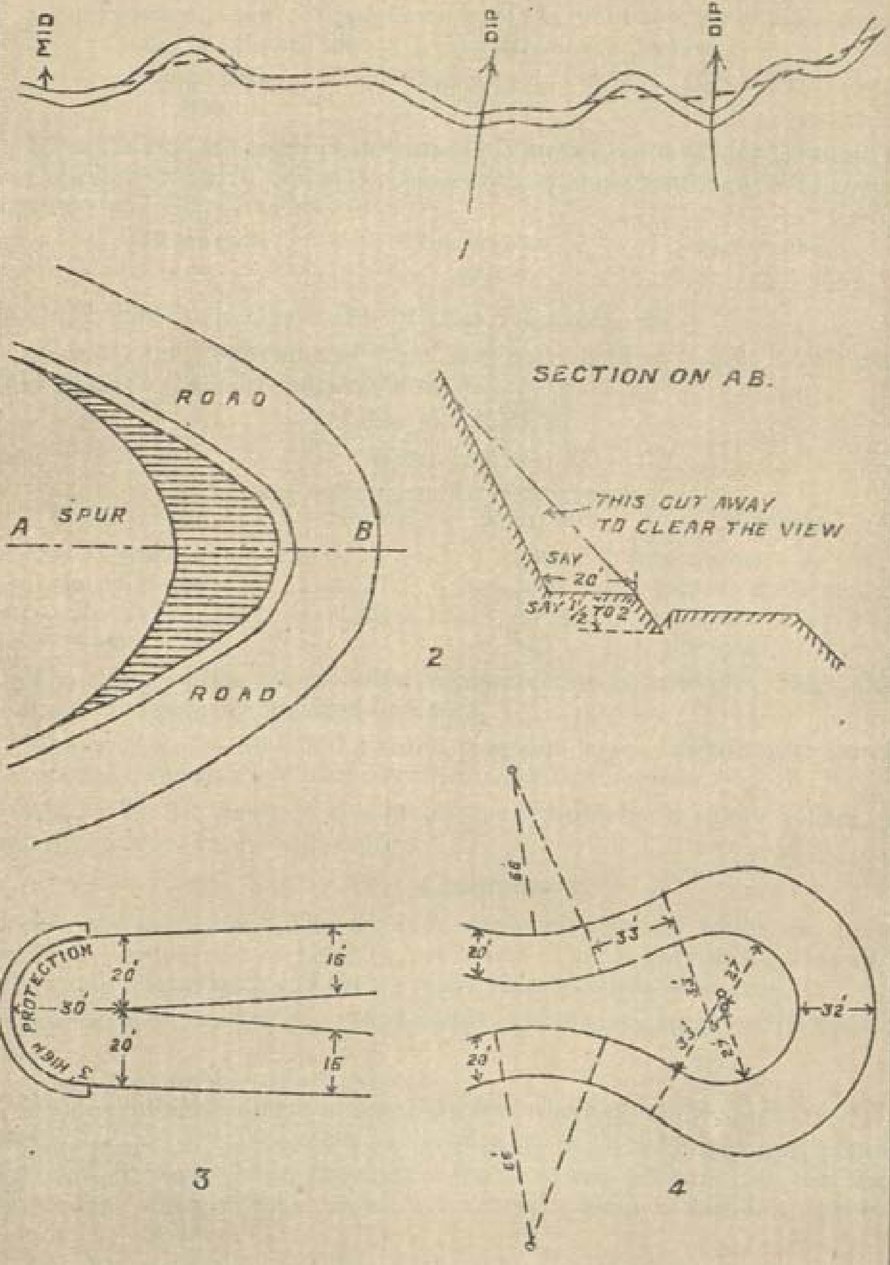
The maximum cross-fall on account of superelevation is limited to 1 in 10 or 1 in 12 to prevent transverse sliding of a vehicle at low speed on a smooth road. Present Government orders limit it to 1 in 12 in this province.

In calculating superelevation frictional resistance of the road surface should be taken into account.

The tendency of cart traffic being always to keep to the inner side of the curve, shift the metal to the inner side, instead of keeping to the centre, as shown in Fig. 5.

Plate LXIX

DETAILS OF ROAD CONSTRUCTION



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III. Land widths

Land widths.—The width of land to be acquired for a road varies according to the class of road, and according to the width of running surface for traffic. The Road Board Specifications in 1932 laid down the following :—

Class I roads or roads of importance from the point of view of more than one province or state, or of more than one Commissioner's division :—

Heavy traffic	Medium traffic	Light traffic
110′	99′	88′

Class II roads are roads of importance from the point of view of more than one Collector's district, and also road serving as important feeders to railways, waterways and Class I roads :—

Heavy traffic	Medium traffic	Light traffic
99′	88′	66′

Other extra municipal roads or class III roads—66′.

Recently the Conference of Chief Engineers held at Nagpur in December 1943 laid down the following standards :—

Table No. CXLVI

Land widths	Width in feet. Normal	Minimum	Remarks
National Highways ..	250	150	Approaches to or by-passes at large towns require special treatment.
Provincial Highways ..	250	100	
District Roads	100	66	
Village Roads	..	25	

The above widths are exclusive of construction borrow-pits, which should be on land temporarily acquired or leased.

Registration of.—All land for roads, compounds, etc., should be demarcated by stones, and the area and plan recorded in the land register.

All P. W. D. quarries should be demarcated by masonry pillars, and similarly recorded in the land register.

IV. Gradients

Absolute maximum.—The absolute maximum gradient which can be used by animal traction is 1 in 12 or 8½ per cent. This is only to be used in hill roads where unavoidable and for not more than ¼ mile at a stretch.

Maximum on main roads.—Main roads in ordinary country, 1 in 20=5 per cent.

Country roads, 1 in 17=6 per cent.

Reduce ruling gradients to 1 in 25 or less where practiable.

Long gradients.—Some authorities advocate the breaking of long gradients (over two miles long), with stretches of flat or of less gradient, but this should only be done where it does not involve a steeper gradient beyond, than could otherwise be obtained.

Maxima dependent on surface.—The following maxima, dependent on the surfacing material, should also be observed :—

Asphalt or smooth tar macadam—3 per cent or 1 in 33.
Wood paving—4 per cent or 1 in 25.
Brick or stone set paving—5 per cent or 1 in 20.

Gradients of bridge approaches.—On bridge approaches in cities, where heavy traffic is likely and, therefore, greater expense is justifiable to offset the reduced cost of haulage, the gradient should be limited to 1 in 33.

Long lengths of gradients.—Long lengths of similar gradients are unnecessary on a road, a rolling profile with moderate gradients following the general line of country being unobjectionable.

Gradients at sharp curves.—Gradients at hair-pin or other sharp curves, with inside curve of 27′ to 50′ should never exceed 1 in 20. Reduce to 1 in 25, if possible ; or something less than the ruling gradient on other parts of the same hill.*

V. Borrow pits

Position.—These are not to be dug closer than 15′ to the toe of a bank. They are not to be dug in the berms, and, if practicable, only on the high side of the road.

Borrow pits should be of regular shape, and, if possible, of equal sizes and not more than 2′ deep. They should not be continuous, but broken into 20′ lengths or thereabouts. Except in plain black soil country no borrow pits should be dug without the written permission of the Sub-Divisional Officer specifying the chains in which they are allowed. None should be dug until all cutting has been finished and the spoil used up in bank, and other sources of material have also been exhausted. They should not be dug in road limits, but land should be temporarily acquired or leased for the purpose when a new road is being constructed. As far as possible borrow pits should not be dug within six furlongs of villages or towns.

Table No. CXLVII

Formation widths

The Conference of Chief Engineers lay down as follows :—

Type of road	Width in feet		
	In plains		In hard rock cutting
	Desirable	Minimum	
National Highway	40	32	26
Provincial Highway	..	32	26
District Road, Major	30	24	22
District Road, Other	..	24	22
Village Road	16	12	8

**Note.*—While it is well to keep within 1 in 20, some fine roads would probably not have been put, if this limit had been regarded as unalterable. The Bhor ghat (Bombay and Poona) and Paserni ghat (Wai to Panchgani) are both steeper. Arbail ghat (Dharwar to Karwar) is 1 in 20.

VI. Bank

Setting out.—Set out new banks 1′ each side wider than the formation width, and dress off. Set out, and construct 1″ per foot of height, higher than the formation to allow for shrinkage. If the work is paid for by bank section measurement, this additional height should be deducted in every bill, and not left to the last.

Top.—Top of bank should be finished and rolled or otherwise consolidated to the final barrel of road. Slopes of banks to be 2 to 1 for black soil uncovered, and 1½ to 1 for other soils and *muram*, and 1 to 1 for hard *muram* and boulders.

Time for settlement.—If practicable, allow a monsoon to pass over a road bank before metalling.

Spoil.—Materials for banks should be obtained, (1) from cutting, (2) by enlarging cutting in soft material, especially on the inside of a curve, to obtain a clearer view, (3) by widening and sectioning an adjacent nalla or waterway, (4) by excavating a cut to lead drainage water away from a boundary or catch water gutter and (5) from waste land outside road boundaries. Only when these sources are exhausted should borrow pits be permitted within the road limits.

Cost of lead of materials for banks.—Lead of the first 100′ is usually included in excavation rates. Beyond that lead may be paid for. Thus if the average cost of a cooly is 7 annas,—

Lead.	*Cost by cooly labour*	*Cost by carts*
0—100′	2·8 per brass	..
100—200′	5·6 per brass	..
300—400′	10·3 per brass	9·0 annas.
400—500′	11·2 per brass	10·6 annas.
1,000′	..	22·2 annas.

It will, therefore, pay to lead soft material from cutting 3 to 4 chains, and harder stuff by carts 1,000′ or more, where hard stuff is required.

The Nagpur Conference of Chief Engineers propose a side slope for banks, up to 2 feet height at 1 in 4.

The height of formation should be at least 1′-6″ above the level of ponded water touching the road bank. If rice fields bound the road, the height should similarly be kept at least 1′-6″ higher than the surface of the water in the rice fields.

Muram casing.—Where the road bank is made up of black soil it is advisable to blanket the formation top and the side slopes with good *muram* if obtainable within reasonable leads. The thickness of blanketting is usually 6″ for the top and 3″ for the slopes. This prevents bed guttering of slopes in the rains and fissuring in the hot season.

Roads in high bank are dangerous to traffic, as frightened bullocks trying to run down slopes, overturn carts, and a motorcar skid would probably mean a bad accident. High banks are also costly in maintenance, as they are of course costly in intial construction.

VII. Cutting

In black soil localities, the road should as far as possible never be in cutting. In *muram* and firm soil however provided gutters can be given a fair slope a road in cutting is not to be avoided, if the grading or regrading requires it. The crests of saddles should also generally be cut through. A road in small bank raised well above the drainage water surface, is however to be preferred on account of its easy drainage facilities.

Width.—Make all cuttings the full width of formation, plus drainage gutters.

Gutters.—Gutters should be at least 3″ deep and 9″ wide, and be provided with curbing.

In rock and deep cutting where additional width can only be obtained at great expense, gutters may be made as in Fig. 6.

Otherwise it is better to make sloping gutters, so that cart wheels will not get stuck in them. Fig. 7.

Side slopes.—Side slopes 1½ to 1 for soft material, ½ to 1 for hard *muram* and ¼ to 1 for rock. A small slope of this kind facilitates quarrying and insures the absence of an overhang.

On a gradient.—All cuttings should be on a gradient of at least 1 in 80 to facilitate drainage.

Cutting for spoil.—If extra cutting is made to provide spoil, it should be in the convex curve to improve visibility. In this additional portion, grade formation to 1 in 16 in cross-section.

Mile stones in cutting.—Mile stones in cutting should be set back in specially cut niches 6′ long, and be set 5′ from the metal edge.

VIII. Berms

Condition.—Berms should be kept clean and tidy, free from scrub and jungle and may be gradually dressed back at a slope of 1 : 24, and side gutters set back.

Dressing of.—*Muram* for blindage and side widths, and stone for metal can often be obtained in this way.

Excavation in.—No excavation should be permitted in the berms.

IX. Gutters or Side Drains

Length.—Avoid long lengths of gutter parallel to the road. Pass the gutter either under or away from the road at intervals. Except in cutting, gutters should be shallow, and there should be no sudden drop into these.

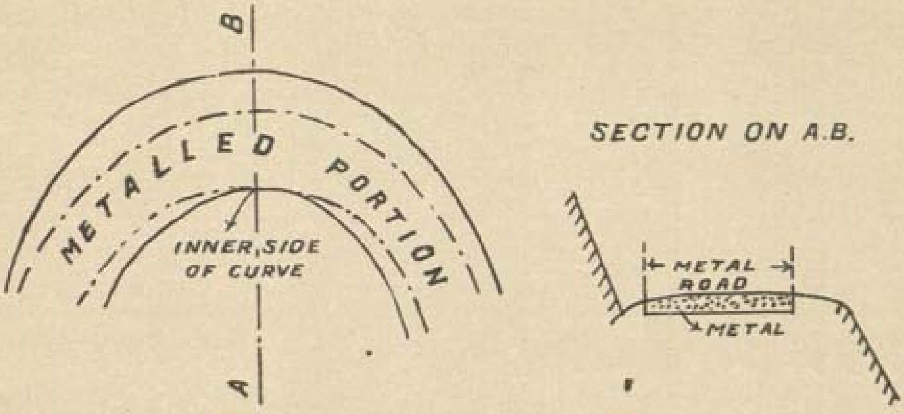
Depth.—Cut the gutter back at a slope of 1 in 16 to form the gutter, as in Fig. 8.

All gutters to be cleared in May and October.

All side drains along portions of roads in bank less than 3 feet high, should be located at the extreme road boundaries, and should be of such section, and graded to such slopes, as to discharge the drainage quickly. On side-long ground the upstream side drain should have its bed at least 3 feet lower than the road centre. The surface of water when the drain is running full, should in no case be higher than a level 18″ below the road surface.

Note.—In flat or low-level areas where the whole surrounding area gets flooded and remains flooded during the monsoon, the road level should be so fixed that it is at least 18 inches above this level.

DETAILS OF ROAD CONSTRUCTION



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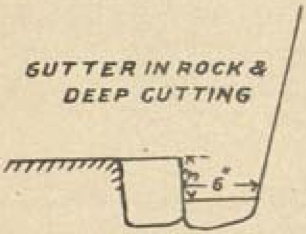

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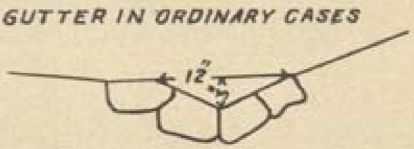

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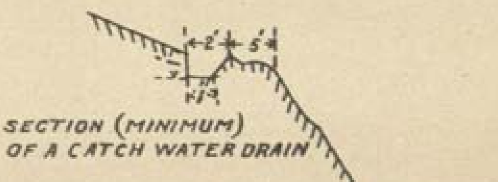

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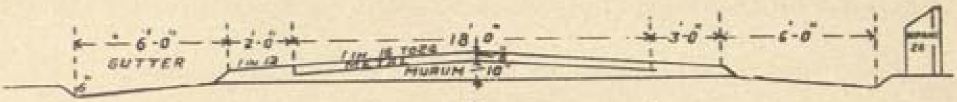
Plate LXXI

TYPE CROSS SECTIONS



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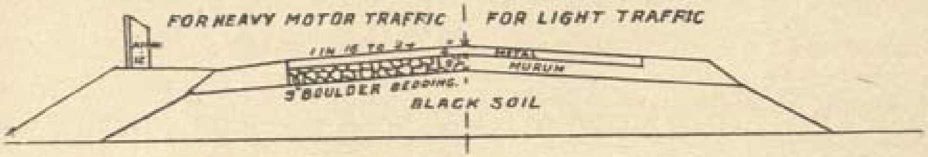
CROSS SECTION ON MURUM GROUND



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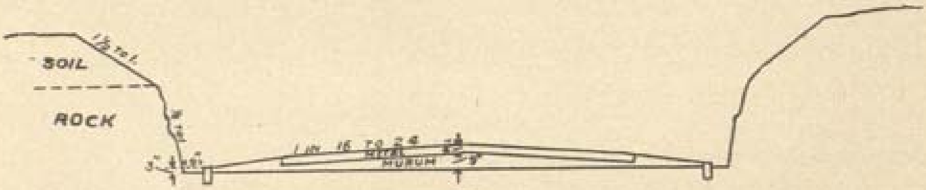
CROSS SECTION ON BLACK SOIL BANK



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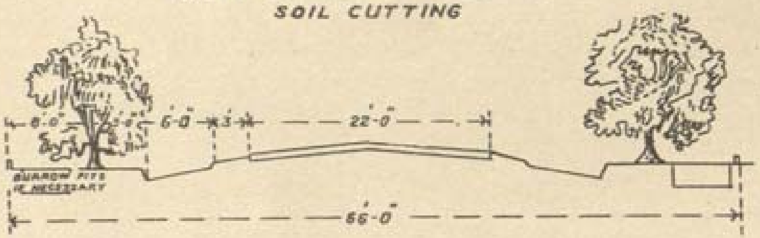
CROSS SECTION IN ROCK AND
SOIL CUTTING



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GENERAL CROSS SECTION

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X. Catch water drains

Purpose.—These are to be excavated, where land drainage is to be provided for, and where slips have been found to occur or are likely to occur.

Position.—They should be constructed at about 15′ from the slipping edge and outside the line of trees, and not too close to the road, and given a fall of 1 in 40.

Maintenance.—All such drains are to be carefully cleared before the monsoon.

Section.—Should be as shown in figure 9 and should be gradually widened out from the ridge point towards the outfall to take the increasing discharge and properly graded.

XI. Cross-sections

Traffic " Lanes "

See plate LXXI.

A traffic "lane" is the width of roadway which a single line of vehicles can use with comfort. The "lane" width will differ with the nature of the vehicle; for bullock-carts a lane of 7′ to 8′ is usually taken, while for motor-vehicles a minimum lane of 9′ was laid down as a minimum by the Provincial Road Board in 1932. As roads are improved the tendency of motor traffic to increased speeds, necessitates a wider lane and the Chief Engineers' Conference assumed a lane of 10 feet for concrete surfaces, and 12 feet for other surfaces. The addition of one or more lane would depend on the development of traffic. In the Bombay Presidency, most of the main roads with heavy traffic have a hard travelling surface of not less than 18 feet width, which is increased to greater widths near towns like Poona and Bombay.

Widths of surfacing (as specified by the Road Board 1932) :—

Heavy traffic, any class ..	.. not less than 18′.
Medium traffic, any class ..	.. not less than 15′.
Light traffic, any class ..	.. not less than 9′.

The Nagpur Conference of Chief Engineers lay down—

Medium traffic up to 1,000 tons for 24 hours—Concrete 10′, others 12′.

Heavy traffic 1,001 to 1,500 tons for 24 hours—as above with 3′ gravelled side widths or berms.

Very heavy traffic over 1,500 tons per 24 hours—18′ with gravelled berms; otherwise 20′.

The Road Board specifications are more liberal as in addition to surfaced widths, 3 to 4½ feet wide side widths are provided, though gravelling is not specified for them.

The width of water-bound macadam should be more than the width of the improved surface, by at least 1 foot on each side, so as to form supporting shoulders.

Type of surface.—The Nagpur Conference of Chief Engineers propose that National and Provincial Highways and Major District roads should be mostly provided with a durable hard crust economical to maintain, and that

other District roads, village roads and National trails should generally have a properly engineered earth surface, but improvements such as gravelling, soil stabilization, providing a water-bound macadam surface, or trackways, should be undertaken where necessary.

Surfacing shall be provided over the full width between wheel guards on bridges and to the full width on culverts and dangerous high banks minimum 20 feet. The wider surfacing on bridges, culverts and high banks shall be gradually eased to the normal width of surfacing in a length of 200 feet on each side.

Profile.—The Nagpur Conference of Chief Engineers recommend for concrete or other improved road surface types, a cross-fall of 1 in 72 to 1 in 36; for water-bound macadam and gravel—1 in 48 to 1 in 24, the side widths being continued at the same cross-fall. On curves, there will be no cross-fall from centre to sides, but superelevation and a continuous cross-fall from the elevated edge to the other edge.

XII. Kerbing

When required.—Kerbing is required over wing walls to give guard stones a secure hold, and at the edge of gutters in cutting, but is not required and is undesirable elsewhere. It is also required in streets of populated places and on bridges where there are raised footpaths, and is generally used as an edging to asphalt surfaces.

XIII. Ghauts

Maintenance.—Threatening land slips and precarious boulders must be removed before they fall. If falls occur on to the road, the debris must be removed as soon as practicable. Until it is done, protection by fencing and lamps at night must be provided. Side cutting in ghauts should be done, if possible, to the natural angle on the hill, and begun at the top.

Rivetments (dry stone).—The courses should be built at right angles to the face batter right down to the foundations. Insert frequent headers. Backing to be of dry materials. Thickness at the top 2′-6″. Back, vertical. Face batter 4 to 1. Fig. 14.

Where such wall threatens to fall by bulging, fence the portion of the road 3′ or 4′ back from the inside. Carefully inspect before or during monsoon for signs of failure in this way.

Boulder parapets.—Boulders roughly dressed on two faces are best, but expensive. Rubble parapet should be 2′ high by 1½′ thick. Fig. 15. Where the hill side is not steep, banks 2′ high by 2′ wide with hedges may be provided.

Reduced level stones.—Stones similar to furlong stones and showing reduced levels of the centre of the road deduced from G. T. S. bench marks, should be fixed on the ghat portion of a road at each furlong.

The reduced level of the road centre to the nearest foot similarly connected with G. T. S. bench marks should be shown on the flat portion of the top of milestones.

XIV. Cross-drainage works

Inspection.—Inspect all such twice a year, once before the monsoon to see that there is no obstruction, and once after to see whether any damage has occurred.

Inspection step.—Should be provided at each bridge or causeway having inear waterway of 30 feet or above. These steps should be at the ends of the

left side wing in each direction, for bridges and culverts with a linear waterway between 30 feet and 100 feet, and at the end of all the four wings for a linear waterway of 100 feet and over. The steps should be of masonry and 3 feet in width.

For drains and culverts with a linear waterway of less than 30 feet, the slopes of the road should be cleared of all vegetation in a 3-feet wide strip, at the ends of the left side wings in each direction.

Sill level

The sill of a cross-drainage work should never be above the nalla bed levels, as this results in a pool forming upstream, and leads to mosquito-breeding. If the openings are paved there should not only be a slight longitudinal slope from upstream to downstream, but there should be a very slight cross-slope from the sides of the opening to the centre, so that all water drains easily away.

Location.—Locate a cross-drainage work, as far as possible, where the nalla is straight.

Sizes.—Should be designed as per notes in Chapter VIII.

Live Loads on Cross-drainage Works.—The live loads on cross-drainage works are now prescribed for the whole of India by the Indian Road Congress.

The I. R. C. specifications lay down two types of loading both applicable to a carriageway width of 10 feet, viz.,

(1) I. R. C. standard loading and (2) I. R. C. heavy loading.

For all National highways and trails and for all Provincial highways and Major District roads I. R. C. heavy loading has been prescribed.

TABLE No. CXLVIII

Loading type	Bending moments		Shear
	Distributed load per lineal foot of traffic in Tons	Knife edge load, Tons	Traffic edge load, Tons
I. R. C. Standard	0·34	6	3
I. R. C. Heavy	0·58	7	10

Proviso.—In the case of the standard loading in computing bending moments, for loaded lengths of 20 feet and under, the distributed load shall never be less than 6·8 tons per lane of traffic, and in the case heavy loading less than 11·6 tons per lane of traffic.

For all portions of the bridge accessible to pedestrians and animals only, the loading shall be 84 lbs. per square foot.

Impact factor.—The I. R. C. specifications lay down that the increment of stress in the members of any span, due to speed, is to be taken as the appropriate standard live-load at the position giving the greatest stress in the member multiplied by the factor $I=\frac{1}{2}\times\dfrac{65}{45+\dfrac{L(n+1)}{2}}$ with maximum value of 0·50.

Here L is the loaded length of the span giving maximum stress in the member considered, and n is the number of traffic lanes.

Note.—Up to 14 feet width take 1 lane of traffic;

above 14 feet up to 23 feet width take 2 lanes of traffic;
above 23 feet up to 33 feet width take 3 lanes of traffic;
above 33 feet up to 43 feet width take 4 lanes of traffic and so on.

Horizontal Loads due to Water Currents.—Any part of a cross-drainage work which may be submerged in running water shall be designed to sustain safely the horizontal pressure P due to the current calculated by the formula.

$P=kAV^2$ where P=Total pressure in lbs.: A=area in square feet of vertical projection of the exposed part, V=velocity of current in feet per second, and k is a constant with values as under :—

	k
For square ended piers and for superstructure	1·24
For circular piers	0·62
For piers 5 to 6 times as long as broad .. .. .. With cut-waters the faces of which make an angle of 30°	0·46

Width of roadway.—The width of the carriageway on a bridge is the net distance from kerb to kerb or wheel-guard to wheel-guard, and the minimum allowable carriageway is laid down by the I. R. C. specification as 10′ clear between these. It is also specified that no bridge on a main or arterial road should have a carriageway of less than 20 clear feet, between kerbs or wheel-guards.

Headway.—The I. R. C. specifications lay down a minimum clear vertical headway of 16 feet, for ordinary cases. For bridges in towns, local ordinances may require a greater headways and where bridges carry electric tram lines, the headway should be preferably 20 feet.

If knee bracing is used it shall not encroach on the specified beadway more than 4 feet vertically or 5 feet laterally. For single lane bridges, these will be limited to 2 feet and 2 feet 6 inches respectively.

XV. Nalla diversions

Diversion.—Except for very small nallas, close together and with contiguous hardly defined catchments, diversion is inadvisable on many grounds.

Sectioning.—The diversion channel should not approach a road embankment nearer than 50′. Resection the combined nalla from the junction to the culvert and for a short distance below, to take the combined discharge.

Drop.—If a drop in the nalla is required, put it *above* the culvert.

XVI. Masonry works

Levelling.—Rock foundations. Level off sufficiently to provide an even bed. If the stratum is sloping, the foundations should be stepped.

Offsets.—Where the rock is hard and sound a concrete bed and offsets are not required.

Foundations.—On softer strata, concrete filling, stone faced if liable to exposure, should be laid, the thickness depending on the nature of the strata. In the case, culverts and causeways on black soil, a complete raft of concrete, 3′ to 6′ thick, should be liad below the neat work. Provide a curtain wall also at the downstream edge of the wing walls.

Where the foundations have to be unwatered, the concrete should be stone-faced so as to prevent the lime being washed out by the water flowing towards the pumps.

Superstructure.—In wing walls over 10′ high, insert weep holes occasionally and fill in behind with 3′ of muram, gravel or chips.

Covering of arches and slabs.—All such drains and culverts should have at least 6″ cover over the slab or arch; 12″ to 24″ would be better in these days of fast and heavy motor traffic. Neglect of this precaution will result in cracked arches and slabs.

Pointing.—When pointing of masonry work is resorted to, the joints should be scraped out ¾″ to 1½″ deep, while the mortar is still sufficiently soft to do this, and fine lime mortar or cement mortar, 1 of cement to 1 of fine sand inserted, neatly finished and kept wet for 10 days. Unless the pointing work keeps pace with the masonry work, the raking out of joints is invariably scamped.

Rubbed joints.—Pointing is, however, usually unnecessary and rubbing the joints while green, *i.e.*, 24 hours old, with a curved tool, known as "nayla", is better practice. For this purpose the face stones must be set full in mortar, and the joint be about ½″ thick. "Tuck" pointing and lined joints are objectionable.

Inspection.—Inspect all masonry works twice a year in May and October.

Vegetation in masonry works.—No vegetation or tree growth should be permitted on or near masonry works. If any occurs, it should be pulled out and the roots killed by pouring into the interstices in the masonry a saturated solution of common salt.

Whitewash.—Whitewash the ends of parapets of culverts and bridges to increase the visibility at night.

Numbering.—Number all culverts and bridges on the left hand parapet at both ends. Engrave a bench mark on all important bridge parapets, preferably at a point over a pier.

XVII. Bridges

Inspection of iron and wood.—Test wood and iron bridges by hammering to detect rotten wood and rusted iron work.

Waterways.—Bridge waterways should be sufficient to provide for the full discharge calculated with an approved formula or obtained from approved curves.

Date stone.—Every important bridge should have date of construction engraved on it, and a bench mark fixed near it, the latter in a situation secure from accidental disturbance.

Vents.—Drainage vents are required on short or long bridges and the drainage should be led to a spout over the arch centre to prevent staining of the masonry in arched bridges.

Parapet camber.—The parapet of long bridges should have a slight camber equal to a slope of about 1 in 200. Otherwise it will appear to sag when seen in elevation.

Standard Clearance for Bridges over Roads.

The Indian Road Congress Sub-Committee recommend as follows :—

(*a*) Under railway bridges over metalled roads or roads likely to be used by mechanical transport, for the full horizontal formation width of the road a minimum height of 14 feet.

(*b*) For tunnels the minimum width should be 20 feet and minimum height 14 feet.

XVIII. Causeways

A marked change in the design of causeways in recent years, is the provision of sufficient waterway to discharge ordinary floods. The Nagpur Conference of Chief Engineers propose that all National highways, Provincial highways, and Major district roads should be adequately bridged, and the permissible likely interruption to traffic should generally not be for a greater period than 12 hours at a time on six days in a year, and there should not be frequent stoppages for shorter periods. In the case of other district roads and village roads, the interruptions to traffic may be up to 3 days at a time and up to 6 times a year.

Width.—Minimum 20 feet between wheel-guards.

Openings.—It is now possible to provide Hume pipes up to 4 feet diam. in a causeway to discharge floods; for bigger nallas openings slabbed over by R. C. C. slabs are very convenient and economical. The openings should usually extend the full nalla or river bed to minimize afflux.

Where a reinforced concrete slab spans the openings it is usual to provide a 3″ cement concrete wearing surface.

Bridge loadings.—The Nagpur Conference of Chief Engineers propose that I. R. C. Heavy Loading should be adopted for all bridges on National and Provincial highways and on Major district roads, and other district roads and village road bridges and culverts should be designed for a lighter loadings up to a gross load of 6 tons.

Pavement.—Pavement to be carried a foot or two above H. F. L. or into sufficient depth of cutting to protect the side walls, and should be laid diagonally on 6″ concrete. Stones should not be larger than 8″×12″. The smaller the stone the smoother the paving. Paving is laid level, while the road beyond is barrelled the transition should be introduced gradually from the one to the other section. The junction of the paved approach with the level paving should be a vertical curve.

Cross-bands.—Avoid bands of paving normal to the side walls. They are unnecessary and lead to irregular wear.

Size of stones.—Paving should be of selected stones, without bushing; alternatively, the whole surface, or the central 10′ width, if money will not run to the whole, may be of "tanki" dressed stones. Some authorities advocate coating the causeway with ¼″ of sand or muram to protect the pavement and increase the foothold of animals. This is useful only in the dry season, and if the pavement is even to begin with, is not absolutely necessary.

Clay foundations.—On such strata build the superstructure on a raft of reinforced cement concrete, 3′ to 4′ thick.

Downstream protection.—When foundations are erodible, the bed downstream must be protected by a concrete pavement 15′ wide, with a masonry toe wall in the nala bed portion. Beyond that rubble pitching of large heavy stones should be provided.

Cart stands.—It is especially necessary that along each approach of a causeway and as near as possible to the river bank, sufficient land should be acquired to form a halting place for carts. Causeways usually remain closed

for certain periods in the monsoon, and unless a properly prepared space is reserved for carts, they will be kept standing on the road and block it to traffic for some time after the flood has gone down.

XIX. Approaches

Alignment of.—For causeways across deep river beds never align the approach roads facing upstream below H. F. L. They should be square or facing downstream. Some difference of opinion exists as to the relative merits of these alternatives. but in the case of high causeways where there is little danger of silting, square approaches are preferable. Oblique approaches facing downstream are supposed to reduce silting, but whether they do or not is doubtful. In any ease there is a longer length of road for silt to deposit on.

Radii of.—Where oblique approaches are necessary, *e.g.*, to save cutting, the curve on to the causeway should be of at least 50′ and preferably 150′ radius, and well protected. The river side of oblique approaches should not be in bank but in cutting and well protected from erosion.

Protection of.—Diversion for bridge approaches should not take off the original road line too abruptly. Make the minimum radius 150′. This should also be the ordinary minimum radius on bridge approaches. In the latter case the outside edge should be well protected with railings, large guard stones or hedges, particularly when the bank is more than 5′ high.

XX. Dams (road)

A single wall on the downstream side of the road. These should only be constructed in small shallow nallas. No opening need be provided, but a 6″ pipe is useful in some situations. The central portion should be horizontal and the wall carried well in to inerodible cutting or a foot or two above H. F. L. Gravel, silt, or debris should be cleared off after every flood, and any erosion of the surface made good. Special care must be taken that any narrow channel cut by a flood is filled up immediately.

Dips

Metalled dip.—A well metalled dip is better than a badly paved one.

Keep a supply of metal at hand during the rains and dump it into fill ruts and hallows when the ground is soft. Constant repetition of this process will eventually insure a good bed of metal. Boulder and small round stones must not be used for this purpose.

Approaches to.—The surface of a road is frequently cut back during the monsoon near the toe of the approach slope. Such places must be properly regarded after each monsoon. This work can be done in October and November and if dips are properly metalled and rolled during the late rains, they will stand a moderate flood. Metal should be laid to a fair vertical curve.

Record H.F.L.—If the construction of masonry work is likely, take steps to record the highest flood level occurring in the nalla.

XXI. Irrigation Channels

Position of.—Should not be taken parallel to the road within road limits.

Troughing of.—Such channels should be troughed where they cross road gutters, *i.e.*, where the gutter runs away from the road and cross an irrigation channel running parallel to it.

XXII. Road materials, collection and stacking

A. Metal

Qualities required and testing.—In order to resist successfully weathering, abrasion and fracture due to stresses brought on by traffic, a road metal should be durable, hard and tough. In addition it should possess good cementation powers so that it may retain a well-locked surface under the repeated shocks of traffic. The last quality is very important for water-bound macadam roads, and it is this quality which makes good, Kankar limestone and laterite roads so much smoother and pleasanter to travel on, provided that the traffic is not too great. The harder metal like quartzite, granite, diorite, basalt should be broken smaller that is from 1″ to 1½″ size, so as to allow the clay or murum binder to hold it better. The smaller size will also make the metal less nobbly.

Whatever may be the case for water-bound macadam, it is very important that the metal used in the wearing coats or top dressings of the improved types of surfaces (such as cement macadam, cement concrete, or asphalt and tar surfaces) should be of the hardest, toughest and soundest type available. In these cases the binder has very strong holding properties, and in the case of cement a very good resistance to abrasion. A softer stone would crush and diminish the holding power of asphalt, and would wear and pit the surface of a cement concrete surface.

Aggregate is tested for its various properties of hardness, toughness, etc., when it is to be used for improved surfaces.

Hardness or the ability to resist direct abrasion is tested by grinding a cylinder of the stone 25 centimetres in diameter, on a cast iron disk with a fixed pressure of 25 grammes per square centimetre, the disk being rotated at 30 revolutions per minute using crushed quartz as an abrasive. The loss in grammes per 100 revolutions is measured, and the coefficient of hardness $h = 20 - W$ where w is the loss in grammes. A good limestone has a value of h=12 to 15, and granite and trap of 15 to 19.

Toughness or the ability to resist impact is measured by the height in centimetres through which a 2 kilogramme hammer has to fall, to splinter the specimen. The impact is administered through a steel block with a spherical bearing, to a cylinder 25 millimetres in length and diameter, and the fall of the hammer starting from one centimetre is increased one centimetre for each successive blow.

The French Coefficient of wear.—In this test a washed and dried sample weighing 5,000 grammes for 50 fragments, is put into a cast iron cylinder set at an angle of 30° and rotated at 30 revolutions per minute for 1,000 revolutions. The dust is removed and the fragments washed, dried and weighed. The percentage loss of weight is found and the French coefficient $= \frac{40}{\text{percentage loss of weight}}$.

Cementation test.—Cementing value is of special importance for water-bound macadiam metal. The stone is ground in a ball mill with distilled water, and the paste is moulded into cylinders 25 millimetres length and diameter. After they dry, the specimens are subjected to the impact of a 1 Kilogramme hammer falling 1 centimetre. The number of blows required to fracture is the criterion, limestome gives values between 25 and 100, trap between 100 and 800, sandstone has little cementation value. A minimum of 25 is usually required.

For cement concrete and cement macadam pavements trap and granite where available should have a French coefficient of 8, for limestones, sandstones the minimum French coefficient can be reduced to 7. Anything below a French coefficient of 7 is risky for this type of work.

For bituminous surface treatments since the life of a paint coat depends largely on the rate of crushing of the chips or coarse sand, the latter should possess very good resistance to crushing, and should, therefore, be the toughest material procurable. They should also give good adhesion to the bitumen, resisting separation of the film on wetting. In this respect basalt and limestone are good.

For bitumen, asphalt, tar, or pitch grouted macadam the French coefficient of hardness of the stone should preferably be 8, with a minimum of 7. Under light traffic and where hard rock is very expensive, a coefficient as low as 5 has been used, but in such a case the size of the aggregate should be 2½″ to 3½″ and the seal coat should be with chippings of hard metal.

Kinds.—The following kinds are in ordinary use.

Boulder trap.—Hard, dustless, rather nobbly and does not bind well Break to pass one way through a 1½″ ring.

Quarry trap.—Good for all traffic. The softer the metal the smoother the surface ; a hard quality metal gives greater wear. Break to pass a 2″ ring.

Laterite.—Makes an excellent running surface particularly in dry weather. Use as far as possible, the purple variety and reject laterite containing much oshrey material (lightish yellow colour). Break to 2½″ to 3″ gauge, and allow to harden for a season before use.

Laterite can be successfully laid just before the break of the monsoon or in the late rains.

Granite.—When sound, makes a good road ; when decomposed is too friable for use.

Quartz.—This is sometimes objected to as causing punctures to cycles and motors. If the metal is broken small and well consolidated in the rains, it forms an excellent smooth surface, and lasts long.

Quartzite, or chert.—Too brittle for a good road, and the stones tend to become rounded and nobbly, but in some places fissured quartzite giving small angular metal is used successfully.

Sandstone.—Sand particles cemented with lime or iron makes a good, smooth road.

Cherty ironstone found round about Dharwar, though brittle, gives a good enough surface if of good heavy quality.

Limestone.—A fairly good stone. Rather inclined to work up into a greasy mud in wet weather. Break to 2″ gauge.

Kankar.—A good light traffic road. Is a glaring white. Break to 2½″. Used mostly in Northern india and Guzerat.

Field or jungle metal.—Useful for third grade roads and side widths ; break to 2.*″

**Note.*—Many provinces, notably Punjab, U. P., Central Provinces and Orissa are now using metal graded into different sizes, instead of the uniform size used in Bombay. The gradings are however not uniform. The idea is that mechanical interlocking should be obtained by wedging the metal with small size stone, instead of soft blinding. It is claimed that the results are superior to those obtained with ungraded metal.

Completion.—All metal collection should be completed by May 31st for the ensuing rains.

Size of pharas or heaps.—Metal, muram and sand shall normally be stacked on the road-side in standard pharas 5′×5′×12″ in size. In the case of rubble and laterite metal the dimensions may be increased to 10′×5′×1′.6″ to 2′. All pharas shall be stacked at clear levelled places on the berms as pointed out, or on specially prepared platforms.

A deduction for voids shall be specified in the case of each material, and the payment shall be made on the quantities arrived at after this deduction is made

Measuring.—Before measuring each heap should be opened with a "phawra' to see that it is of uniform quality, and after measuring, it should be marked with a white cross.

In the measurement book record the furlong in which the heaps are situated, as well as the mile, and, as a rule enter each heap separately.

XXIII. B. Hard Muram

Quality.—The nearer it approaches to metal, the better the quality. Muram cannot be judged by appearance and feel when newly quarried. Nothing but experience of the particular muram in question will decide its value and durability.

Breaking and measuring.—Break to 3″ cubes and stack in 18″ or 2′ heaps.

Hard muram is used as soling under water-bound macadam, and as the wearing surface on side-widths. Most varieties of trap hard muram, though simulating the hardness of metal on first quarrying, crumble and disintegrate on exposure to atmospheric influences. Soft muram is used for blinding metalled road surfaces, and for casing the side slopes of banks made up with black soil. On account of the property of disintegrating on exposure, trap hard muram should not be quarried much in advance of the time of use on the road. "Katak", found in the Southern districts is a hard indurated shaly substance, and is used in the same way as hard muram.

C. Soft Muram, Kankar, Sand, etc.

There are other varieties of soft muram which are used for blindage, one variety being the well-known red muram found in most districts of the Southern Circel, consisting of red ferruginous pea-gravel mixed with red earth. The greater the proportion of pea-gravel the better the muram. Other rocks like granite and gneiss also disintegrate into a muram, made up of China clay and siliceous particles. In this case the higher the proportion of siliceous particles and the coarser their texture, the better the muram.

Other materials besides muram are used for blindage, of which sand is the most general. In Gujerat, small Kankar obtained from river beds used in the Kaira District, is a very good material, as even when ground up it has good cementing properties. Yellow chalky kankar-mixed earths and loam are also used, but yellow clay is to be avoided as it is sticky, and metal is lifted out by traffic in wet weather and the surface is apt to be greasy and skiddy.

XXIV. Rollers, Rolling and Resurfacing

Kind of rollers.—Rolling is done with steam rollers, iron bullock rollers or motor rollers.

Rollers vary in weight from 2 ton for bullock rollers to 15 ton for steam rollers.

For ordinary district work 6 to 8 ton steam rollers are probably the best, and 10 tons near or in towns, and for improved surfaces except when brick is tne aggregate in which case 6 ton rollers should be used.

Economical thickness of metal.—For maximum economy use a steam roller and at least 3" of metal. A steam roller should be able to consolidate about 800 to 1,000 cubic feet of metal in a day, of hard metal well rolled to full compaction.

For softer metal hard rolling is inadvisable, and in such a case 2,250 to 3,250 cubic feet may be consolidated, if water is easily available.

Length to be rolled simultaneously.—In bullock rolling, long lengths of rolling are necessary to prevent waste of time in turning round. For steam rolling short lengths are no objection and are less impediment to traffic ; ½ to 1 furlong should be the limit.

Half width rolling.—Half widths of tne road snould be picked, spread and rolled at one time, so as to provide for traffic, unless traffic can be diverted to another road without inconvenience, when it is better to roll full widtn. Spread metal and muram for side widths to template. With trap metal, hand packing is not quite necessary, if the stones are properly broken and rolled before blindage is spread. Laterite should be hand packed under careful supervision.

Roolling.—Should be commenced from the edges and carried on towards th centre of the road.

The metal should be rolled dry twice and after that it should be freely flooded with water during consolidation. This rolling is to go on until the surface is so hard and compact that a loaded bullock cart going over it makes no impression on it. Till this is done, no blinding or surfacing material is to be used.

Note.—While rolling the surface in two halves, a strip of 9 inches along the centre of the road should be left unrolled while consolidating the first half. This should be properly joined while the metal is being spread on the second half and consolidated with it. This obviates the occurrence of a continuous longitudinal furrow along the ridge of the road.

Side width rolling.—The shoulders of a surfaced road or side widths as they are called in Bombay, should be finished to the specified cross-slop with definite edges properly consolidated, so that they can be used by all traffic without inconvenience or danger.

Rolling in sections.—Wherever possible, all repair operations, picking spreading and rolling, should proceed simultaneously, thus :—Roll section 1. (see Fig. 16) Meanwhile pick up section 2. Traffic proceeds along 3 and 4. When 1 is rolled, 2 should be ready for rolling. Pick up section 3. Traffic proceeds along 1 and 4 and so on.

Size of gang.—For continuous, simultaneous working, and assuming 9,000 square yards are to be rolled each day, the following gang is required. Thickness of metal 2" :—

Picking ... ... 33 (more, if the road is dry and hard).
Metal ... Filling, 8 men.
Carrying metai 8 women.
Sectioning .. 6 men.

Spreading blindage	.. 3 men. 3 women	400 cft.
Brushing	.. 6 men	
Total	.. 56 men, 11 women.	

Blindage.—For blindage use nalla sand or laterite sand, if possible: muram crushes to mud, and if damp, pulls the metal out, but has generally, in spite of this,to be used. It is, therefore, most important to brush in the muram dry before it is rolled, and while still in the gravelly state. The cost or brushing is offset by the much quicker consolidation achieved. Spreading and brushing of blindage should proceed simultaneously, so that local excesses or deficiencies of meteril can be corrected at once.

Never use clay or black soil as blindage.

Rolling new roads.—On new roads, if there ara two layers of metal 3" to 4" each, roll the first layer without gravel or blindage till the stones interlock; then lay the second layar and complete as above.

Maintenance.—After consolidation is complete and the road opened, the section should be well-watered for one week, and care should be taken that portions beginning to raval are immediately attended to. If the temperatures are high, this preiod may well be extended.

Note.—In areas where the monsoon rains are heavy and fairly continuous, resurfacing should be postponed, to late in the monsoon. The new surface is not then likely to be damaged by traffic as would be the case if it were laid early and subjected to traffic during heavy rains. On the other hand in areas of limited rainfall it is of great advantage to start resurfacing after the first good fall of rain, so that the surface can have the advantage of maturing under favourable moisture conditions during the rest of the monsoon.

Junctions.—The junctions between the old and new metalling mast be made with a long ramp or slope which must not be terminated with a feather edge but buried in the old metal.

Equipment.—Provide at least 2 water carts with each steam roller ; also the following equipment.

TABLE CXLIX

For a 10 ton compound roller, working 10 hours a day

Cylinder oil, ¼ gallon per day
Engine Oil, ⅓ gallon per day
} These to be of good quality mineral oil.

Six hurrican lamps to mark the engine and unrolled road at night (at least two of these should be red).

Four to six bottles kerosene oil per week for lighting and cleaning.

Two or three pieces of bar soap.

Cotton waste, 1/3 lb. pei day.

Full set of tools.

White lead, 2 or 3 lbs. per year.

Red lead, 1 lb. per year.

Fine copper wire for oilers, 2 or 3 oz. per year.

Jointing material.

Asbestos mill board, one large sheet 4 feet square and 1/16" thick.

Asbestos twine, about 1 lb. of assorted sizes.

Coal 7 maunds (Bengal) per day of 10 hours (if good quality).

Wood for lighting 1 to 2 maunds (Bengal) per week.

Wood fuel in place of coal 14 to 21 maunds per day.

Use heavy engine oil for gears and bearings.

Milometers.—If possible fit roller with a milometer and pay the drivers a small premium for distances over 8 miles travelled per day.

Pay of drivers.—Employ good drivers and pay them good wages, particularly to men who care for their engines.

Raoties.—Supply them with "raoties", when working away from head quarters so that they can remain close to and be early on their work.

Position of rollers when standing idle.—Do not leave rollers of any kind in the middle of the road or on high banks or bridges or in cuttings or close to a blind corrner when out of use.

Lighting.—If a roller cannot be moved off the road, while on a job, light well at night with red lamps.

Overhaul and inspection.—Overhaul and arrange for the inspection of steam rollers between December and May. Clean out boilers every 10 days.

XXV. Blindage

Use.—Blindage is used either for filling the interstices of metal, or for forming a smooth running surface.

Quality.—For surface dressing a metalled surface, there is nothing to equal coarse sand or small gravel, as it is not easily blown away as are other types. Red gravelly muram and kankar, are also good as surface dressers, and they have the additional advantage of holding the metal if they penetrate in the voids between metal pieces. Soft muram from trap areas varies in quality, and clayey murams grind to dust easily and are soon blown away. Black soil should never be use d as it blows away very easily, and is a nuisance in wet weather.

Quantity.—On metal roads $\frac{1}{4}''$ to $\frac{1}{2}''$ blindage is required. Or $\frac{1}{4}$ of the depth of the metal $+\frac{1}{8}''$ to $\frac{1}{4}''$ for running surface will probably do.

On muram roads.—Blindage is not usually required on muram roads, which however, may be finished off with a top dressing of sand.

Blinding matetial should not be spread in thick layers, especially if the clay content is high as in some types of red muram. It should be used sparingly in several thin layers, each layer being brushed in, watered, and rolled, before another is put on. A thick layer of sticky material lifts up metal under rolling. A final topping of sand while the surface is still damp after the muram blindage, will give satisfactory results, if muram has been laid in thin layers so that only a film remains on the surface.

XXVI. Side widths

Definition.—Side widths are the strips of second class material on either side of the metal.

Width.—They are usually 3 or 4 feet wide and constructed of muram.

Stacking platforms.—At frequent intervals, especially when the road is in very high bank, stacking platforms as an extension of sidewidths should be provided for stacking repair materials. Where the road is in heavy bank these materials are generally stacked on side slopes, and there is a very great loss from sinking, or sliding down and being washed away. Stacking platforms would prevent this loss, and would also permit material to be measured with ease and used when necessary with less labour. It would pay in the long run to bring the necessary fill even from a distance, to form these platforms. In cuttings, unless the material at sides is too hard to be removed without undue cost, niches should be formed for stacking platforms.

XXVII. Surfaces and sub-surfaces

Construction.—For a country road in muram country, 3″ to 6″ metal on a properly shaped, rolled and drained formation is sufficient.

For a country road on banks of soil, other than black soil, lay 3″ to 4″ muram and roll to proper, section, before laying metal. On black soil increase muram to 6″ or 9″.

On a suburban and heavy traffic road lay 6″ to 9″ Telford bottoming (rubble with largest surface downwards) and 6″ metal in two layers; roll each layer separately.

In wet situations, 3″ to 4″ engine cinders make the best foundation for macadam or Telford construction.

XXVIII. Miles and furlong stones

Number of.—All roads should have a milestone and furlong stones in each mile.

Half furlong stones.—Half furlong stones are not necessary except occasionally in difficult ghaut sections.

Correct position—All distance stones to be set on the left hand side of the road in the direction of the mileage.

Distance from road edge.—Mile and furlong stones to be set 5′ to 8′ from the edge of the side width. In country with heavy vegetation, it may be desirable to set them at the road edge.

Position.—In cuttings they should be set in nitches, the sides of the niche being cut back on a slant to permit the milestone being seen from distance; on banks on specially built platforms.

Incised lettering.—All letters and figures should be cut into the stone with a V shaped incision which greatly facilitates neat repainting and prevents errors.

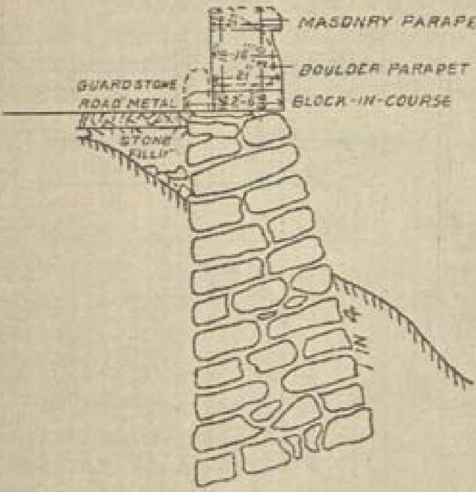
Painting.—Paint mile and furlong stones white with black letters as in Fig. 18.

Size of letters.—Letters and figures to be $2\frac{1}{2}'' \times \frac{1}{2}''$.

Supply of brushes.—When painting mile and furlong stones see that the painter has separate brushes for white and black paint, or the white will turn into a dirty grey.

Plate LXXII

DETAILS OF ROAD CONSTRUCTION



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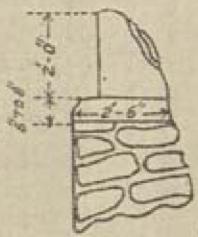

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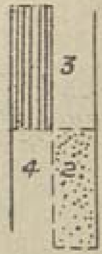

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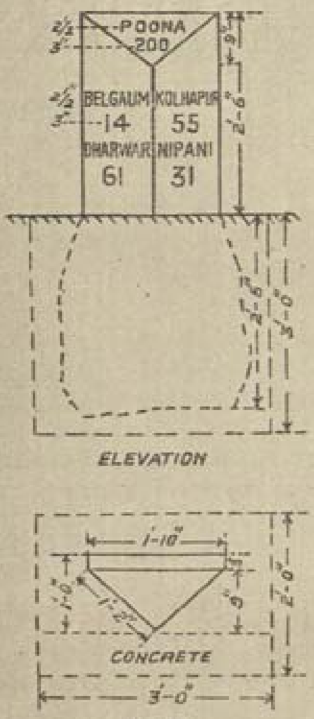

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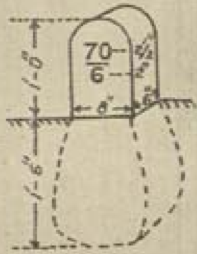

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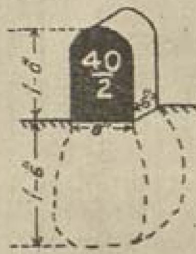

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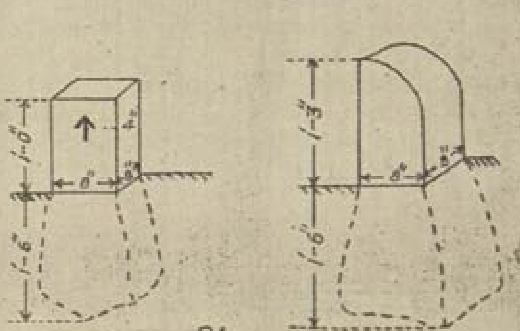

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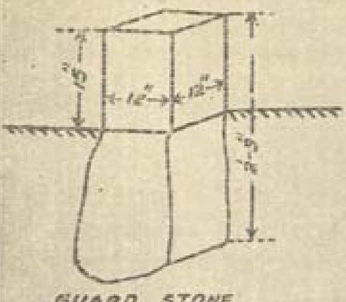
DETAILS OF ROAD CONSTRUCTION.



GUARD STONE.

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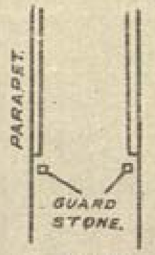

PLAN.

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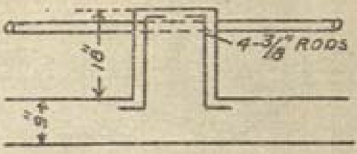

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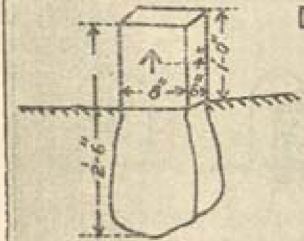

BOUNDARY STONE.

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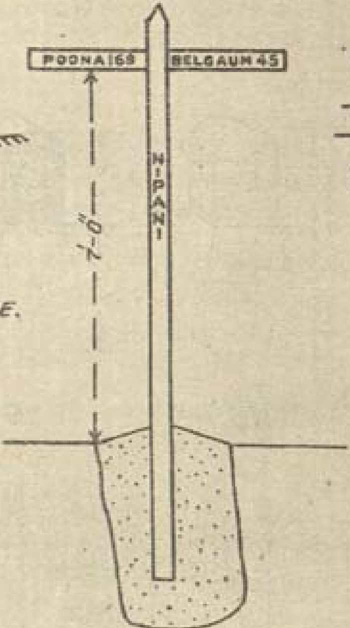

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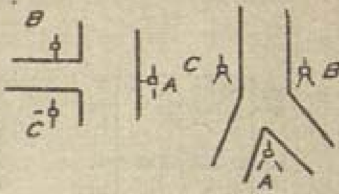

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Information.—On milestones show, (1) mileage to next large town, and (2) on the top chamfer, the mileage to point of origin in the case of trunk roads, like the Poona-Bangalore road.

On furlong stones show the mileage in the form of a fraction as in Fig. 18.

All furlong-stones should have the appropriate figures neatly carved on both faces, and should be fixed on the left side of the road facing the direction of rising mileage.

They should be fixed at right angles to the road, i.e. facing the traffic square, and midway between the road-ege and the road boundary.

XXIX. Guard stones

Pattern.—To be square or quadrant topped. The curved top looks, perhaps, better, but the square topped pattern is equally useful and slightly cheaper. Size not less than 2¼′ long. Projection above ground 12″ to 15″ as in Figs. 21, 22.

Where to put guard stones.—Guard stones are necessary on the outside edges of curves, on the easing curves when a road joins another, on the straight portion of the latter road opposite the joining road, on the downstream side of long dips especially if raised more than 2 feet above the downstream ground level, on causeways, of low height, on both sides, leaving 1 foot clear space beyond outer edge of guard stones, and on high banks, inside bridge parapets, and at ends of culvert and bridge parapets.

Note.—Guard stones should be spaced 3′ to 8′ apart according to circumstances.

On causeways.—Guard stones should project 18″ above paving. Either fix them 1 foot deep in masonry, or make them of concrete reinforced properly and cast integral with the coping. Further protection can be provided by connecting with gas piping, as in Fig. 24.

Railings.—Railings should be provided on each approach of a bridge wherever the formation is more than 8′ above the ground level, and similarly where the road is banked more than 8′ especially if the banking is on a curve.

Limit stones.

Limit stone should be fixed at Taluka and District boundaries, and at the points where an Indian State or Municipal Road Section starts on a provincial road. These stone or R. C. C. slabs should be about 4 inches thick, and 4 feet above ground level, the lower 2 feet being buried. The width should be sufficient to accommodate the necessary lettering. They should be fixed at right angles to the road, i.e. facing traffic, midway on berms, and should show what taluka or District, Indian State or Municipal road, *begins on passing* the limit stone point.

XXX. Boundaries and boundary marks

Frequency.—Road boundaries should be marked at every change of direction. Where straight boundaries are long, intermediate stones at every 330 feet should be put in. In villages and where encroachments are likely, stones should be put more frequently. Revenue boundary stones, on the road edge, must be treated as road boundary stones and whitewashed annually. Fig. 25.

XXXI. Sign posts and notice boards

Road junctions.

When one road meets another at an angle, the corners the former road makes with the latter, require to be suitably rounded. This rounding is done as follows :—

Bisect the angle of intersection of the two edges AB, AC and draw a line EF at right angles to this bisector, so that its length between the two edges AB AC is 20 feet. From points E and F measure 10 feet away from the intersection to obtain the tangent points G and H respectively. Draw a curve touching G,H and the intersection of EF and the bisector. (See Fig. 21).

Pattern.—To be of the pattern given in the figure 26 (see plate LXXIII).

All direction boards should be so sited that the boards face the motorists squarely. Where three roads meet, it may be necessary to erect three direction boards sited as in fig. 27A, or where sufficient space is available at the intersection, as in Fig. 27B. The letters should be 6″ high, painted black on lemon-yellow ground.

Information.—On a sign post give the terminus of the road only, except in towns and suburbs where particular places such as, cantonments, city, travellers' bungalow, should be marked. On very long roads, *e.g.*, the Poona- Bangalore road, give the next big town, Satara, Belgaum, and Dharwara rather than the terminus.

Mileage should be indicated by whole miles, or at the most, to the nearest half mile. The addition of the name of place, written vertically down the post at the outskirts of towns and villages having inspection bungalows, is useful.

XXXII. Road Signs

Road signs.—Road signs are now standardised by the Government of India. These signs are sub-divided into three categories as under :—

(1) Warning signs,
(2) Prohibitory signs, and
(3) General information signs.

Warning signs are characterised by a red triangle, and the device showing the kind of danger against which the warning is given, is in black on a separate plate 18″×15″ with a 1¼″ red border. Under this category are included signs indicating, rough road, road under repairs, Irish bridge, bends, cross-roads, level crossings with and without gates, schools, steep hills, ferry or temporary bridge, narrow bridge nallah crossings, etc. The technical Sub-Committee (of the Indian Road Congress) has laid down that these signs should be fixed 400 feet from the point of danger.

Prohibitory signs are characterised by a red circular disc and intimate speed limits, load limits, etc.

Information signs are on a rectangular blue plate and convey information as regards "parking", etc.

Care should be taken not to put danger signs where no real danger exists as it leads to the disregard of other properly placed boards.

Hills of the ghaut type should be marked with their names and any special traffic regulations, very clearly and briefly at the top and foot.

For bridges.—Notice boards indicating speed and weight limits for bridges should be put on the left hand side of the road, 400′ before reaching the bridge.

XXXIII. Tracks (field) and carts

Junctions.—Where tracks join the road, approaches should, if necessary, be banked to a grade of 1 in 15, commencing 5′ beyond the edge of the road.

Ramp repairs.—Such ramps should be made up annually to prevent damage to embankments and top-dressed with muram as for side-widths.

XXXIV. Trees

Kinds of.—In road projects provision should be made for planting young trees along both sides of the road, and for maintaining them for a period of four years. Do not plant trees of incongruous habits together, *e.g.*, banyan and babul or cork tree. Plant generally trees that flourish locally and generally in lengths of a couple of furlongs to half a mile of similar trees.

Trimming.—Trees should be cut back (to give the road surfaces sufficient ventilation), but indiscriminate lopping must not be resorted to. Such work must be done under the personal orders of the Executive Engineer or the Sub-Divisional Officer. Putting a ring of whitewash round the branches to be cut is a good plan.

The cutting back of trees is bad for their appearance at first, but after a few years, a higher avenue vista is produced which adds greatly to the effect. Heavy horizontal branches of banyan trees are dangerous, as they sometimes crash of their own weight, especially in old trees, and should be cut back before they have the chance of doing damage.

Do not plant trees within 200′ of a wing wall or masonry work particularly trees with spreading roots, like banyan. A limit of 20′ is suitable for non-spreading kinds.

XXXV. Ruts and hollows

Telegraph and Telephone or Electric-lighting poles should be fixed normally at least 5′ outside the existing road edge, and if possible at the road boundaries, so as not to interfere with tree growth by loppings.

Economical patching.—The expenditure of small repair grants can often be more economically performed by greater attention to ruts and hollows than by resurfacing in long continuous lengths, but this economy is entirely dependent on the amount and quality of the supervison. If the latter is indifferent it is very easy to waste a lot of money on patching a road which should be relayed.

Patching.—Patching and filling ruts and pot holes require, if anything, even more care than resurfacing on a large scale. The worn place should be cut out to the full depth of the metal, the hole so cut being rectangular in the centre line of the road and with the edges kept vertical. Road metal as specified above is then to be laid in the holes (in the case of small holes it should be hand-packed), its surface being brought up to slightly above the road. It is then to be consolidated with water and heavy iron rammers to the same degree of hardness as a new coat of metal, after which a top-dressing of fine stuff is to be put on and rammed in, until the finished surface of the new patch lies perfectly even with the surface of the road.

The best time to do patching is at the beginning of the monsoon as the water will stand in the holes and render them apparent, also water will be more easily available then for consolidation. Large holes must be patched, however, at whatever time of the year they appear. A stitch-in-time policy is the best in this connection.

Rut prevention.—Two lines of continuous ruts are often found on district roads. These can be avoided and corrected by filling, as soon as they show signs of forming with gravelly muram or gravel about ¼″ size.

Bullocks will not walk on this and traffic is diverted to the unused portion of the road. This filling must be done separately from ordinary blindage work. It must not be done in patches, but in continuous lengths of a furlong or more at a time. It has been found very successful in the Nasik district and elsewhere.

Note.—Picking the whole surface to be reinstalled should not be permitted when there is a thin crust of less than 2″ of metal on the road. In such a case the surface should be scored in diagonal lines (not parallel lines at right angles to the road length) 1½″ deep and 9″ to 12″ apart to provide the necessary keying. Alternatively the old surface should not be touched except to the extent of removing ridges and filling ruts and hollows, and then after removing loose dust, covered by ½″ of good muram to form a bed for new metal. When the road is well-watered and rolling started, this muram works up from below, and holds the metal.

XXXVI. Metalling

Frequency.—District roads should be remetalled once in five years on the average. Town roads once in two or three years. The amount of money available is, however, the governing factor and no hard and fast rule can be laid down.

Section of miles.—The miles to be remetalled should be first selected during the previous monsoon and checked during the subsequent cold weather, as the worst miles in the wet weather, are not always the worst in the dry season, and *vice versa.*

Per cent. of C. R. grant.—65 per cent. of the current repairs grant should be available for resurfacing.

Thickness of coat.—The minimum thickness of resurfacing is 1½″ for trap or granite, and 2½″ for laterite. These should only be used when there is already an ample thickness of metal. Otherwise on new roads, thickness up to 6″ trap and 8″ laterite should be used.

Anything above 3″ trap and 4″ laterite should be laid in 2 coats, and each coat rolled separately.

Chamber profiles.—When remetalling, always provide a profile of suitable shape and size and a spirit level to see that the top is horizontal, when testing the camber. Fig. 28.

Half widths.—Do not take up half widths of the road unless the other half can be resurfaced during the same season.

XXXVII. Picking road surface

Depth.—Should be done to a depth not exceeding 1½″. Picking may be done all over, as is usual in this Presidency, or by picking parallel lines across the road 12″ apart for thin coats and 15″ apart for thicker coats of metal.

Reuse the fine material on the side-widths, and the remaining metal on the road.

XXXVIII. Water-tables

Small oblique cross-bands are placed during the monsoon on ghauts and hills to divert water into the gutter. Make 3″ to 4″ high and 25′ apart on a 1 in 20 grade further apart on flatter grades. Only on roads impassable during the monsoon should water-tables be put all across the road. There are comparatively few such roads.

On other roads they should project 5′ only from the gutter. The road camber, if properly maintained, should do the rest.

Water-tables should be put in after 15th May and removed before the 31st of October, except in places where the "return monsoon" gives heavy rain early in November where they should be removed immediatly the rains cease.

XXXIX. High flood marks

Recording.—Record abnormal flood by a white or engraved mark on all bridges thus,—H.F.L———July 1894, top of mark being the flood height.

Also it is useful to record the H. F. L. downstream. If the afflux is appreciable, the discharge can be calculated with fair accuracy.

XL. Corrugation of surfaces

The speed of modern mechanically propelled vehicles has introduced a new trouble in road surfaces, viz., "corrugations". In extreme cases, at certain speeds, the riding is extremely uncomfortable.

It has been observed that corrugations form more on banked portions of the road than in cuttings, suggesting that the sub-grade may be a contributory cause. It has also been observed that if traffic is not allowed on a newly rolled water-bound macadam road for some days, the formation of corrugations is delayed. This suggests that it is inadvisable to allow fast-moving mechanically propelled traffic on road crusts which are still plastic due to a large amount of moisture. Muram ridges should be avoided as they initiate corrugations. In fact muram should always be thinly spread and swept into the crevices. Where there is a good soling below the road crust, corrugations are at a minimum.

The Technical Sub-Committee of the Road Congress has expressed the view that the following were contributory causes:—

(1) Wheel spin throwing up loose surface blindage;

(2) defective rolling of thick coats of metal which produce the effect of the metal creaping in front of the roller, and then forming a hard ridge over which the roller rides to commence another depression.

XLI. Traffic statistics.

Traffic statistics are necessary in deciding the nature of the wearing surface, which will carry without requiring frequent and costly repairs, the volume and the type of traffic which a road has to carry. There are really two classes of traffic, which are of importance in wearing out road surfaces, viz., motor vehicles and bullock-carts; the other classes like light-tongas, ekkas, or cycles having hardly an appreciable effect. On ordinary rural roads where the metalled carriage way varies from 9′ to 16′, the total numbers and weight of vehicles is all

that is necessary, as on such roads there cannot be segregation of different classes of traffic. For widths of metalled carriageway exceeding 20′, there will usually be segregation of different classes of vehicles, and in this case separate statistics may be necessary for each lane. For example, if loaded carts from a quarry or brick field hug one side of road, as in the case of the Bund Garden Road from Jalkagate to Mangaldas Road, a separate traffic census for this lane is absolutely necessary; as in such cases the lane carrying such traffic fails badly, while the other lane carrying unloaded carts may remain in good order.

The Technical Committee of the Indian Road Congress suggests taking a traffic census under the following heads and sub-heads :—

(1) Motor transport—
 (*a*) buses and lorries,
 (*b*) cars.

(2) Bullock Carts—
 (*a*) Four-wheeled :—(*i*) loaded, (*ii*) empty,
 (*b*) Two wheeled :—(*i*) loaded, (*ii*) empty.

(making further sub-divisions into rubber-tyred, wooden-tyred and iron-tyred, where necessary).

The total load under—(1) motor transport, and (2) bullock carts is arrived at by multiplying each type with its average unit weight as actually occurring on each road.

NOTES ON THE WORKING OF STEAM ROAD-ROLLERS

Labour.—Two men only are required to work a steam roller. The driver should be a man qualified to take charge of a steam boiler. The steersman or fireman may be any intelligent coolie. Extra labour is required to supply roller with fuel and water. Wages of a good driver varies from Rs. 45 to Rs.75 a month; that of a fireman from Rs. 15 to Rs. 30. It should be the duty of the driver to attend to the fire whenever the roller is actually at work.

Repairs.—Small repairs, such as packing glands, making joints, tightening up of bolts or nuts (which should all be looked to about once a month) and even the adjustment of water in brasses should all be done by a competent driver, and the services of a mechanic should be very seldom required, apart from the annual overhaul.

Fuel.—If coal is used, a good quality of ordinary Indian coal serves well. If wood is used, the box and firebars should be specially adapted, when the roller is ordered. The fire should be banked up at night, when the roller is in work. This is done by damping down the fire with small coal and half-burnt ashes, closing the damper, and placing a cover of some sort over the chimney top. The fire will then smoulder during the night keeping the water in the boiler hot and saving fuel in raising steam in the morning. This is not generally done as it involves a certain amount of trouble after the day's work is over, but it is a practice which has many advantages. It is a common thing for the men to come to work late in the morning and then force steam quickly with a lot of wood fuel. Excessive expenditure of wood for lighting up purposes is the indication of this practice, which is bad for the boiler and leads to leaky tubes.

Water.—This should be as free from mud or salts in solution as possible. The presence of the latter is always readily noticeable by slight incrustations appearing at the glands, cocks or joints. Both muddy and salty water cause priming which does damage to valves and cylinders. The daily consumption of water by a 10-ton compund steam roller, for 10 hours' work, is 300 gallons and for a single cylinder one-third more.

Boiler.—This is the most important part of a roller, and officers-in-charge should see that proper care is taken of it. Every seven or fourteen days, according to the cleanliness of the feed water used, the boiler has to be washed out, and half a day should be allowed for this work, including filling the boiler again, packing glands, etc., and raising steam. The plugs or mud-hole doors at the bottom of the fire-box must all be removed, and all mud and deposit thoroughly washed out from the four sides. If this mud is allowed to accumulate above the level of the fire-bars, the fire-box place will become overheated, and will bulge or crack and the stays will leak or be broken, involving expensive and difficult repairs. The manhole door in the boiler barrel should be removed at least once a year, and oftener if the feed water is bad, and as much cleaning and scaling done as possible. If incrustation of tubes and other surfaces is very noticeable, expert advice as to some remedy should be obtained. The fusible plug, which is provided in the fire-box crown plate of every boiler, should be taken out, and, if encrusted, carefully cleaned, at least once a year, oftener if the feed water is saline. An encrusted feasible plug has been the cause of many boiler explosions, as, if badly choked, it will not melt out, should the boiler be short of water. If there is the slightest doubt about the condition of the fusible plug, a new one should be fitted and the old one sent to be refilled.

The boiler tubes should be kept clean inside by being swept once, twice or even three times daily with a tube brush. If kept clean they will not crust up with a scale which requires special tube cleansers to scrape out, and which interferes with the steaming capacity of the boiler, if allowed to remain. If the tubes leak at their junction with the tube plates as a result of bad feed water or from working for long periods on a steep gradient, and not keeping sufficient water in the boiler to cover the ends, they should be expanded with a tube expander, but repeated use of this should not be resorted to. Leaky tubes invariably indicate defective working in some direction.

Raising steam.—According to fuel, whether the boiler is quite cold or not, etc., this will take from half an hour to an hour. It is a mistake to hurry it by using the "blower", a cock which sends a jet of steam up the funnel to increase the draught. This is only intended for occasional use to brighten the fire, when it has become dull from standing.

Steam pressure.—Most compound rollers work at 180 lbs. per square inch and most single cylinders at 140 lbs. It is a common superstition among drivers in that the lower the steam pressure at which the engine will work, the less the labour required to keep steam and the greater the economy. As the exact converse is the case, the driver should be made to work the boiler at, or nearly at its full working pressure continuously. At the same time there is no excuse for repeated blowing off from the safety valves, which is wasteful and noisy.

Reversing under steam.—Nearly all drivers have a habit of reversing the engine without first shutting off the steam, and a device to prevent this is sometimes asked for. Any such device might be extremely dangerous in an emergency. There is no harm done in reversing a roller, when under steam, provided it is travelling quite slowly, but it causes slight wear and tear, and may possibly be responsible for a breakage, if done at high speeds.

The use of frost spikes.—In the rims of the hind wheels, there are cast a number of holes, normally plugged up with hard wood pegs. With the outfit there are a corresponding number of spikes to fit the holes in the rims. When the roller is required to travel over any surface, which its smooth wheels cannot grip well, the hard wood pegs in the rims can be driven out and the frost spikes put in their places. In country districts, on soft or slippery grounds, when travelling through nallas, or up steep banks, the use of frost spikes is often most useful.

Unmetalled Roads

About three-quarters of the mileage maintained by public authorities in the whole of India is unmetalled. In the Bombay Presidency (British area) this proportion is about 43 per cent. of the total road length. Unmetalled also are all village roads, and side-widths on each side of the central metalled or improved surface. The worst conditions occur in black cotton soil areas, where vehicular traffic must come practically to a standstill during the monsoon. Conditions are also bad in the alluvial plains where a flat country and agricultural prosperity would otherwise encourage heavy loads. If a way could be found by which the bearing power of the road, under all the variations of weather conditions, could be maintained at a fairly high level, it would be a very great boon to traffic.

In the Bombay Presidency generally we are fortunate to possess muram of good quality in extensive areas, the main types being (1) that obtained from the de-composition of trap rock, (2) the ferruginous or red variety so common in the districts of the Southern Circle and (3) muram obtained from the disintegration of granite which is less common than the other two varieties. Of these the ferruginous type, especially if it contains a sufficient amount of ferruginous gravel as it very often does, is the most satisfactory for an all-weather surface. It can be easily improved if there is a preponderance of clay by topping with sand. In places a properly proportioned gravel is obtainable, which gives a surface which for moderate traffic is far superior to a metalled surface, being much smoother to travel over. A good quality muram of this type is not dusty under moderate traffic.

Trap muram is variable from what is called hard muram which shades into metal, to soft muram which is easily crushed to dust under traffic and is used for blindage. Hard muram though hard when quarried disintegrates fast when exposed to the atmospheric influences and should therefore be used as soon as possible after quarrying. Heavy cart traffic however grinds the surface into dust in a short time. This type is therefore useful only for moderate bullock-cart traffic.

Granite muram is obtainable in small scattered areas. The best type contains little kaolin and a preponderating amount of quartz. As the percentage of kaolin or china-clay increases, the muram grows more plastic, and unable to bear traffic loads.

Though this Presidency is much better off than other provinces as regards metal resources, even taking kankar laterite brick surfaces as "metalled", it has been shown that 43 per cent. of the total mileage maintained by public authorities is "unmetalled" Deducting mileage surfaced with muram gravel, etc., the balance are "earth" roads, which constitute about 16·6 per cent. of the mileage. To this must be added the side-widths of metalled roads, which are generally "earth". The metalled road mileage in 1939 was 9,565 miles, and if we assume 3 feet side-widths, this is equivalent to $9{,}565 \times \frac{3 \times 2}{16}$ 3,577 miles of roads 16 feet wide. Even in Bombay with its comparative wealth of surfacing materials, there is still a considerable road surface which would benefit by some sort of cheap improvement or soil stabilization.

Soil stabilization.—The cheapest method of soil-stablization is that of introducting the missing component or components necessary for stabilization in a soil. For this purpose, it is necessary to understand the properties of each element in a soil. All soils have a coarse meterial, a filler, and a binder, in varying proportions, and its properties depend on the relative proportions of these materials.

Mechanical Analysis of a Soil

Sand.—The material which passes through No. 10 Sieve but is retained on No. 200 Sieve (American Standard Nos.).

Silt has particles of a size between 0·05 and 0·005 millimetre in diameter.

Clay has particles finer in size than 0·005 millimetre in diameter (colloidal clay particles below 0·002 millimetre).

The sand proportion is determined by Sieving, the remainder being clay and silt, the fixing of the proportions of these involving laboratory methods.

Qualities of ingredients.—Sands possess a high degree of internal friction, and the sharper the sand grain the greater is this internal friction. Dry sands have however no cohesion.

Silts have varying degrees of internal friction, practically no cohesion, and have a high capillary index.

Clays and colloids furnish cohesion but possess internal friction to a negligible extent.

Pure clay is very retentive of moisture, and usually becomes plastic and unstable when wet, and as it abrades easily, produces considerable dust in the dry season. The extent to which these objections occur depends on whether the clay is of the "slaking" or "non-slaking variety". The former variety is undesirable, as it is more muddy in wet weather, and more dusty in dry.

Dry sand offers great resistance to traffic as the wheels sink in the cohesionless sand. Sand roads are at their best when moist and addition of silt with its high capillary index aids in keeping the sand moist, but clay also must be added to give cohesion and hold the road in the dry weather.

It will be noticed that mere mechanical analysis is no guide to quality in the case of "clay" as its qualities are influenced by other ingredients making it "slaking" or "non-slaking" and on the proportion of colloidal clay. Better guides to quality are the "Liquid Limit", the "Plastic Limit" and the "Plasticity Index".

What is required is an indication of the cohesive properties of the soil. This is obtained by the plasticity index, which is determined as shown on page 594, and which is a measure of the range of moisture content within which the soil remains plastic. For unmetalled roads it is said that a plasticity index between 7 and 11 is good, the low index being used in wet places and tne higner index in dry places. If the traffic later so increases that it is proposed to give a waterproof surfacing, it is desirable to scarify the stabilized top course and add sufficient filer to bring down the plasticity index to somewhere near or not mucn above six. Thorough compaction by a sheep's foot roller at optimum moisture content, is necessary before the waterproof surfacing is laid on.

Note.—For finding the plasticity index two observations are necessary, viz. (1) The liquid limit, and (2) the plastic limit.

The liquid Limit.—Thirty grammes of the pulverised dry soil passing through a No. 40 sieve (American standard), is placed in a porcelain dish in a uniform $\frac{3}{8}''$ layer. Water is gradually added, and the soil mixed with a spatula, the quantity of water being gradually increased till the soil is pasty. It is then smoothed level, and a groove made with a standard tool. The dish is held horizontal with the groove along the line of sight, and lightly tapped against the other palm ten times. If the lower edges of the two sections just flow together the experiment is over. Otherwise more water is gradually added and the experiment repeated, till the lower edges just flow in and touch with ten tappings as above. The soil is then weighed and the Liquid Limit=

$$\frac{\text{Weight wet soil—weight dry soil}}{\text{weight dry soil}} \times 100.$$

The Plastic limit.—15 grammes of pulverised soil sieved as above, is mixed with gradually added water, till it could be easily balled. This was then placed on $\frac{1}{8}''$ sheet glass and gently rolled with the palm, till a $\frac{1}{8}''$ diam. thread was obtained. If the soil crumbles long before being thus rolled, slightly more water is added and the experiment repeated, till the rolled thread just breaks up at about $\frac{1}{8}''$ diam. The pieces are then collected and weighed, then oven-dried at 110° C. and again weighed.

$$\text{The Plastic Limit :—}\frac{\text{Weight of wet soil—weight of dried soil}}{\text{Weight dried soil.}} \times 100$$

The plasticity Index=The liquid limit—The Plastic Limit.

General conclusions arrived at tentatively by Dr. Puri, Physical Chemist in charge of Road Research, Lahore, are as under :—

(1) If the clay content is less than 10 per cent the road will be bad whatever the value of "M" (mean diameter of particles). (2) If the clay content is above 10 per cent. but less than 16 per cent. the road is more likely to be good if the value of *M* is below 0·1 Millimetre than above.

(3) When the clay content is above 16 per cent, then the value of *M* in the generality of alluvial deposits is likely to be less than 0·1 mm. and such a condition will usually give a good hard road. Where heavy bullock-cart traffic is to be catered for, the top crust should have, embedded in it, abrasion-resisting material such as gravel, brick ballast or kankar.

In America it has been found that the mechanical analysis of a soil for a good road base is—

Clay 9 to 18 per cent.
Silt 5 to 15 per cent.
Sand 65 to 80 per cent. of which that retained on a No. 60 sieve should be from 45 to 60 per cent.

Other materials besides sand silt and clay have been added and the effect studied. It is clear that the more uniformly the clay ingredient is distributed in the mixutre, the better would be its condition. The addition of sodium carbonate 1/5th of a per cent. almost doubles soil cohesion, as the sodium brings about the dispersion of clay when water is added. Experiments further showed that 3 per cent. molasses and 4 per cent. lime, when mixed with soil, gave it the greatest resistance to water, and the mixture thus prepared has great recuperative powers, as addition of water and rerolling gives a cut-up surface a fresh start.

Black soil.—The treatment of heavy black soil is a special case of soil stabilization. Such soils contain practically no sand, and would require heavy doses of sand and if possible silt. The mixing of sand and clay should be done in the dry, with the clay pulverised to a powder, in the proper proportion, just before the monsoon and after the first good rain the surface should be rolled and covered with gravel if available in a thick layer, so that the thickness of sand clay and gravel is at least 6 inches.

In America in dealing with gumbo (similar to black cotton soil) it was found that if the soil is treated with about 3 per cent. by weight of a light low-grade oil and 0·3 per cent. of soap solution, the surface is more waterproof and more stable. If gravel is obtainable and is mixed in, the surface is able to resist abrasion,. In Burma a surface made with a gravel containing 30 to 40 per cent. of earth, mixed with 10 per cent. of water, 5 per cent. of oil and 0·5 per cent. of soap solution (all by weight) gave very stable surface.

GRAVEL ROADS

(1) *Introductory.*—Gravel occurs naturally as rounded particles of many varieties of stone, sufficiently large to be retained on a ¼ inch mesh screen. A soil containing 40 to 50 per cent. of gravel with sufficient cementing material to hold the gravel particles is easily drained and stable.

(2) *Ingredients and conditions.*—In building a gravel road the first consideration is good drainage. The next most important consideration is the quality of the gravel, as it is the gravel that has to resist abrasion ; and finally the quality of the binder. The most common binder is of course clay, but certain gravels occur in nature in which the pebbles are held together by either lime or iron oxides. Generally gravels which have pebbles cemented together in the quarry will not only recement on the road but give a more closely-knit surface.

(3) *Pebbles.*—The most durable pebbles come from quartz and chert, but pebbles from hard limestone, good trap, and iron-stone, are also good material. These latter materials though more easily abraded, have high cementing values and a certain proportion mixed with quartz or chert pebbles, aids in holding the surface firmly bonded. The least durable pebbles are those from sandstones, shales, or soft slates.

(4) *Binder.*—No matter how durable the pebbles they cannot by themselves make a road surface, till held together by some cementing material such as carbonate of lime, iron oxide, or clay, the last being the most generally available binder. The suitability of clay as a binder depends on exactly the quality of plasticity which made it useful for a sand clay road. The quality of the other binders, iron oxides, and carbonate of lime, is judged by observing the sides of the gravel quarry. If the sides stand practically vartical the binder quality is satisfactory.

(5) *Grading.*—To obtain a satisfactory gravel surface, the pebbles should be graded in size, so as to form a good compact mixture, with the addition of a small amount of binder. In general American experience suggests the following limits of grading :—

(*a*) Material retained on a ¼″ sieve : 55 to 75 per cent.,

(*b*) material retained on a ¾″ sieve : not less than 15 per cent.,

(*c*) material passing a 200 mesh sieve.

(*i*) for surface course 8 to 15 per cent.,

(*ii*) for foundation course 10 to 15 per cent.

In general all pebbles above $1\frac{1}{2}$ inches—2 inches should be excluded, the sand content should be at least twice the clay content, and the sand-clay mortar should fill the voids in the gravel.

(6) *Thickness of surface.*—The compacted thickness should be about 8″ at the centre and 6″ at the edges, for a 4′ wide half-width, that is the cross slopes should be about 1 in 24 for level grades, being made steeper as the longitudinal slope increases, till it is 1 in 12 for a grade of 1 in 20. When the thickness of surface is more than 3″ or 4″ it cannot be properly consolidated. It is therefore necessary to obtain the above consolidated thickness of 8″, by laying the gravel mixture in two layers, each of 4″ to 5″ loose.

(7) *Spreading material.*—The material for each coat should be spread evenly by rakes after proper mixing in such a thickness loose, as will give the required consolidated thickness. Usually the loose thickness diminishes by 1/3rd to 1/4th.

(8) *Sprinkling of water.*—After spreading each mixed coat the surface must be sprinkled with water to wet the aggregates and moisten the clay binder but the sprinkling must be done through a fine rose, and only in just the necessary quantity to assist binding.

(9) *Consolidation* is to be done with a 8 to 10 ton roller where the sub-grade has been previously well consolidated. The completed surface should be firm and unyielding.

(10) *Sanding.*—Before opening to traffic, the surface must be lightly sanded so as to obtain a cover of $\frac{1}{4}$″ to $\frac{1}{2}$″ over the whole surface.

(11) *Maintenance.*—The newly made surface should be watched carefully for several months, and defects developed under traffic corrected immediately.

Modern improved road surfaces

It is common knowledge in India and elsewhere that a water-bound macadam road, which has to carry iron-tyred animal drawn carts and also high speed motor vehicles, is most difficult, almost impossible, to maintain in good condition. The reason is that both types of traffic are very destructive to water-bound macadam when occuring together ; the iron-tyred carts by crushing and grinding the metal projections, and the fast rubber-tyred vehicles, by removing fine material by suction from the road, thus loosening metal. Thus roads which were satisfactory before the advent of motor traffic, now require to be modernised i.e., made suitable for present conditions, by adopting various more or less effective expedients. These expedients fall into two main classes, —viz., holding and protecting the metal by a viscous asphalt or tar envelope, or bedding it in cement. The types range from comparatively cheap surface dressings to high grade asphaltic concrete and cement concrete—different types being suitable for different types and weights of traffic.

Classification of modern road surfaces

Since it has been proved that water-bound macadam is not a form of road surface which can stand economically the present day motor transport, especially if motor transport is mixed with animal-drawn transport, endeavours have been made to find other suitable surfaces. These are of two main types :—

(1) Surfaces in which the binder for the stone is either tar or bitumen, the so-called black-top surfaces ; and

(2) Surfaces in which cement is a binder. The asphalt-bound surfaces are sub-divided into various types according to the manner in which the binder is applied and the type of the aggregate, the main types used on district roads being :—

(1) surface dressing with tar or bitumen, one or two coat ;

(2) tar or bitumen carpets ;

(3) tar on bitumen macadam sub-divided into :

(*a*) tar or bitumen full grout macadam ;

(*b*) tar or bitumen semi-grout macadam ;

(*c*) tar or bitumen premix macadam ;

(4) tar or bitumen concrete ; of two types—coarse-grained and fine-grained.

(5) sheet asphalt ; with tar or bitumen.

Cement-bound surfaces are of two types only :—

(1) Cement macadam, and (2) Cement concrete.

Road-tar

The coal-tar generally available for use on roads in India, is the Shalimar Road Tar. Coal-tar is one of the bye-products of the distillation of coal in gas works, and coke ovens and crude coal tars contain some water and light oils. In the manufacture of Shalimar Road Tars the light oils are removed and the tar de-hydrated. Shilimar tars are available in various grades, starting with the lowest viscosity tar No. 1 and proceeding to tar No. 2 and tar No. 3, with increasing viscosities, and finally ending with High Viscosity Tar. A low viscosity (tar No. 1) is used for priming, as it easily flows into the metal surface, to a good depth, coating the metal with a thin coat. This tar is also used for mixing with pitch for grouting work. Tars with higher viscocity such as Tar No. 2 are used for surface-painting, while High Viscosity Tar is used for grouting work.

Pitch is the residue left after benzols, volatile oils, etc., contained in coal-tar, have been distilled off. In India Shalimar Road Pitch is used after mixing Tar No. 1 with it, for grouting. On the Nasik Station Road, the proportions for the mix were 2 of pitch to 1 of tar by weight.

Bitumen

Bitumen forms a constituent of natural asphalt, occurring mixed with other substances as rock asphalt. In this form it is widely distributed, the best known sources being Venezuela, Cuba, Trinidad and Mexico.

It is also obtained from the industrial distillation of petroleum, in various places where petroleum is found, and is then called "residual" bitumen. Bitumen used for roads is usually a highly refined product, containing from 90 to 99 per cent. of bitumen in carbon disulphide.

Bitumen is marketted in various grades, suitable for various purposes, and the different grades vary in "penetration". This is a quality which like the "viscosity" of tar, measures the suitability of a bitumen for various uses. The higher the penetration the softer the bitumen. To hold the base course stones together in a strong bond, low penetration (30/40) bitumen is either poured in the voids, or the stones are precoated with the bitumen. For surface dressing or seal coat, a bitumen with a higher penetration (80/100) is used, as it is softer and the chips can work into the interstices of the base course.

Standard nomenclature for bituminous materials and types of construction

A. Materials

(1) *Bitumen.*—A mixture of hydrocarbons completely soluble in carbon sulphide which is characteristically solid or semi-solid, black, and sticky, and which melts or softens on the application of heat.

(2) *Asphalt.*—A mixture of bitumen and mineral matter which may occur in natural deposits, or be produced by artifial means.

Note.—Scientifically, tar and tar-mineral mixtures would fall within the above definitions of bitumen and asphalt but are expressly excluded.

(3) *Road Tar.*—A bituminous product, viscous or liquid, resulting initially from the destructive distillation of coal and so refined as to be suitable for road work.

(4) *Cut-back.*—A solution of bitumen in a volatile or partly volatile solvent.

(5) *Road Emulsion.*—A liquid in which a substantial amount of bitumen or tar is suspended in water in a finely divided and stable state.

(6) *Filler.*—Mineral matter of which not less than 75 per cent. by weight passes a sieve of 200 meshes per lineal inch.

B. Methods of Construction

(1) *Surface dressing.*—Spraying or painting a road sufrace with some binding material in a liquid state including the subsequent application of sand or fine stone.

(2) *Grouting.*—Pouring a binding material in a liquid state on to a vertically consolidated surface or road metal, so that the binder penetrates the interestice, the consolidation being then completed with the addition of sand or fine stone.

Note.—It does not appear to be necessary to define "Seal", "Seal coat" or "Premixed seal".

(3) *Premix.*—The process of mixing mineral aggregates with bitumen or tar off the road, and then placing and consolidating the mixture on the road.

(4) *Sheet asphalt.*—A premix of bitumen (with or without filler), and sand.

Note.—Sheet asphalt may contain not more than 30 per cent. of fine stone.

(5) *Asphaltic concrete.*—A premix of bitumen (with or without filler), sand, and not less than 30 per cent. by weight, of mineral aggregate of a size larger than sand.

Note.—Sand is defined (vide page 593) as material passing a ten mesh sieve.

(6) *Asphaltic macadam.*—A mixture of bitumen (with or without filler), and a mineral aggregate of a size larger than sand. It can be made by the grouting or premix methods.

(7) *Tar concrete.*—As asphaltic concrete substituting "Tar" for "Bitumen".

(8) *Tar macadam.*—As asphaltic macadam substituting "Tar" for "Bitumen".

Certain other terms used generally in dealing with tar or asphalt road surfaces, though not yet standardized are defined below to facilitate the understanding of the specifications.

Asphalt emulsion.—A combination of asphalt with a small amount of a soap-forming compound and water.

Carpet (asphalt or tar).—A term applied to the wearing surface or top course of a bituminous or tar surface laid in two or more coats.

Cut-backs—or cut-back products—are products obtained by mixing heavy or hard petroleum residue with lighter distillates.

Crude oil.—Unrefined petroleum, i.e., petroleum from which none of its constituents have been taken out.

Flux or Flux oil.—A high flash paint oil used for thinning down or softening asphalts which are too hard for use.

Penetration.—The consistency of an asphalt measured by the depth to which a standard needle will penetrate the substance in 5 seconds under a load of 100 grammes at a temperature of 25° C. or 77° F.

Road Oil.—A term applied to various types of liquid or cut-back asphalts, heavy oils, etc., which are applied to road surfaces to lay dust.

Seal Coat.—A dressing of tar or asphalt blinded with grit, etc. applied to open texture asphalt surfaces to render them impervious to moisture.

Note.—A "premix seal" is a term used to indicate, that this dressing is in the form of chips already coated with asphalt or tar, and a "liquid seal" is a term used to indicate, that the material used for dressing is in a liquid form and does not require to be heated.

Units

The Sub-Committee of the Indian Roads Congress has recommended—

(1) that surface treatments and grouts be specified and invariably described in terms of pounds per 100 square feet ;

(2) that the asphaltic or tar binder in a premix be specified in terms of pounds and decimals per cubic foot of aggregate ;

(3) that the cost of any road surfacing, grouting, premix, or cement concrete surface should be stated in rupees and annas per 100 square feet.

Primers

"A primer may be a road oil, a cut-back asphalt, or a low viscosity road tar". Its main function is to penetrate into the road, and to coat the blindage thoroughly upto a depth—usually ½" to 1"—and it must therefore contain some volatile oil plus bitumen.

The viscosity of the primer and the percentage of bitumen in it, varies with the nature of the aggregate, the nature of the blindage material, and traffic conditions. If the blindage is sandy clay or if the aggregate is broken brick, the porous nature of these would permit the use of a more viscous primer with advantage, and the quantity of bitumen may also be high, even as much as 70 per cent. Conversely, for stone metal aggregate and sticky clayey blindage, or for close textured kankar or laterite roads, a thin primer must

be used for good penetration. For the latter type, a medium curing cut-back asphalt or a low viscosity tar is recommended, in view of their low viscosity. A cut-back with heavy oil, or road oil, or high viscosity tar, cannot penetrate such surfaces.

By varying the percentage of asphalt or tar dissolved in the solvent, primers of different viscosities are obtained.

It is possible to use the primer (a medium curing cut-back), on a murum surface, which it will penetrate to a depth of over ½″, with an application of 30 lbs. per 100 square feet. If this primed surface is then seal-coated with a heavier cut-back asphalt, and blinded with pea-gravel and sand a good surface can be obtained.

Note.—"Road oil" strictly speaking is a residual oil obtained from the distillation of crude petroleum, after the lighter fractions such as naphtha, petrol, kerosene, lubricating oils, etc. are removed, and is a combination of "heavy oil" and asphalt.

Further distillation removes "heavy oil' leaving pure bitumen.

"Cut-back asphalts" are obtained by combining bitumen with different oils, i.e., oils with differing viscosities and volatility in different proportions, for different grades of "cut-back."

The grades are slow curing, medium curing and rapid curing, sub-divided according to viscosities.

Primers are not necessary for water-bound Macadam surfaces with good hard metal and suitable blindage, but are necessary when :—

(1) the road metal is porous or soft and crushes during consolidation. Such metals are soft sandstones and limestones, kankar, laterite ; and also brick aggregate. A priming coat dispenses with the need of cleaning the road to receive a bitumen surface ;

(2) the blindage is sandy soil or loam. In such cases the water-bound Macadam must be stabilized with a primer ;

(3) the road is gravelled ; gravel has hardly any mechanical inter-lock : priming makes it more stable ;

(4) the asphalt wearing coat has to be deferred for some reason, a priming coat with sand blindage will preserve the water-bound macadam;

(5) low cost roads are to be maintained for a large volume of motore traffic. It is cheaper to give liquid seals every 2 or 3 years, then to maintain them as water-bound Macadam surfaces ;

(6) skilled labour is not available. A hot bitumen seal over a coat of cold primer coat is a fool-proof job ;

(7) the road has a highly capillary sub-grade. In this case the application of a suitable primer is said to be effective in checking the rise of sub-soil water. A thin and slow curing primer applied to the sub-grade before laying the stone metal gives the best results ;

Rate of application.—22 lbs. per 100 square feet normally and up to 30 lbs. for rough or loose surfaces ;

Treatment of laterite or kankar surface roads

These surfaces are usually dusty and require a priming coat of some sort before any bituminous treatment is applied. Experiments were carried out in Burma, December 1933 to February 1934, with various priming materials,

followed by a bituminous surface dressing. The results showed Burma Oil Company's road oil as the best primer. It has a bitumen content of 35 to 40 per cent. and was applied hot at the rate of about 28 lbs. per 100 square feet. It penetrated the aterite surface to a depth varying from ¼" to ⅜". Forty-eight hours after the application of the priming coat, asphalt 80—100 penetration was applied at the rate of about 29·5 lbs. per 100 square feet, and while still warm was covered with gravel at 2 ⅝ cubic feet per 100 square feet and rolled. The cost was Rs. 4—6 per 100 square feet, and the surface after 18 months was excellent. Kankar surfaces similarly treated also proved satisfactory, for light traffic which will not crush the base metal.

Alternatively for somewhat heavier traffic, either 1" to 1½" carpet or a 1½" armour coat after priming are satisfactory. No priming is necessary for carpets.

For heavy traffic, chiefly loaded bullock carts, nothing less than a 3" hard metal surface before treating with bitumen or a cement concrete surface will suffice.

Blindage of clean sharp sand should only be applied after the primer has penetrated to the required depth. The time this will take varies with the primer. A thick primer on porous surface requires from 6 to 24 hours, and a thin primer on close-taxtured surfaces from 4 to 12 hours.

Qualities required for aggregates for improved surfaces

A water-bound Macadam surface made with locally available materials is a fairly low-cost surface, and usually no effort is made to obtain superior material from a distance. Where however materials have in any case to be brought from a distance and are therefore costly, and in cases where a modern improved surface is justified, it is desirable to have the best stone metal and chippings, grit and sand, available within a reasonable distance. In the case of modern improved surfaces, the cost of stone forms a comparatively small part of the cost of the completed surface. For the cheapest improved surface, surface-dressing, the chippings used are about 4,500 cubic feet per mile for two coats work, 10 feet wide, and even at a rate of Rs. 35 per 100 cubic feet, the cost would be Rs. 1,575 while the total cost of the surface would be about Rs. 6,000. The proportionate cost of stone, with higher-coat surfaces would be still less, and it would generally be false economy to ruin a costly surface. by using soft or easily deteriorating metarial in the wearing coat especially if the traffic consists to an appreciable extent of heavy iron-tyred bullock-carts. It is necessary therefore that the stone used for these costly surfaces should be tested, and only the best available material at reasonable cost used.

For bituminous surface treatments two qualities are essential in the chippings :—

(1) The capacity of retaining the film of bituminous material applied to the stone, in all weather conditions, and especially in wet conditions.

(2) The capacity to carry the loads without crushing.

The first quality varies with different varieties of stone, but basalt, dolerite and limestone are good in this respect, while granite and quartzite are comparatively bad. The second quality is determined by crushing tests as for cement concrete blocks or cylinders. Basalt and dolerite are generally good in this test also ; limestones vary.

Grouted surfaces.—The stone for this type must be hard and tough. Under heavy traffic a stone with a minimum French co-efficient of wear of 8 is required. It will be seen from the table which follows that Basalt, Dolerite and Cherty quartzite, or manganiferous quartzite, occurring in this Province, have all a co-efficient of wear higher than 8. Laterite has a much lower co-efficient and is unsuitable for this type of work.

Cement concrete or Cement Macadam.—The minimum co-efficient of wear for heavy traffic here also is 8, though in exceptional cases softer material has been used.

How the co-efficient of wear is found is explained in section 1, but is here repeated briefly. About 11 lbs. of the stone or material to be tested is placed in standard size cast iron cylinders, with their axis of rotation at 30° to the horizontal. The stone should be in 40 to 60 pieces of sizes varying from 2″ to 2½″. The cylinders are rotated 10,000 revolutions, at a uniform rate of 30 revolutions per minute. During the revolutions aggregate pieces rub against each other, and are also thrown against the sides of the cast iron cylinder. After completing the revolutions, the percentage of wear is found by sieving through a standard 16 mesh to the inch sieve. The percentage of material passing through is the wear. The French co-efficient of wear is $= \frac{40}{\text{percentage passing through}}$; since the stones grind against each other, and knock against the cast iron cylinder sides, this test gives a measure of hardness as well as toughness.

TABLE No. CL

French Co-efficient of wear of certain Bombay stones

Rock type	Name of quarry and situation	Specified paints	Percentage ; n Deval	oss of weight trition test	French co efficient of wear	
			Wet	Dry	Wet	Dry
Basalt	Gilbert Hill quarry, Andheri, Thana District	2·90	1·4	2·3	28·6	17·4
Basalt (amygdeloidal)	Quarry near Kalyan, G.I.P. Railway	2·60	3·7	11·5	10·8	3·5
Basalt	Malad quarry, Thana District	2·90	2·6	5·4	15·4	7·4
Do.	Second specimen Gilbert Hill quarry	2·91	1·7	2·1	23·5	19·0
Do.	Goregaon quarry, Thana District	2·81	2·4	4·0	16·7	10·0
Do.	Poisar quarry, Thana District	2·80	2·4	5·1	16·7	7·8
Dolerite	Harubidi Hongal quarry, Dharwar District	2·98	1·8	4·1	22·2	9·8
Laterite	Mahableshwar, Poona Division, average values	2·61	12·4	19·6	3·25	2·1
Do.	Deola quarry, Ratnagiri District, average values	2·30	28·3	32·5	1·4	1·3
Do.	Amba quarry, Kolhapur State, average values	2·70	10·9	20·7	3·66	1·97
Do.	Quarry near Ratnagiri, average values	2·73	14·5	23·1	2·77	2·73
Limestone	Quarry near Rohri, Sind	2·57	4·8	30·7	8·3	1·3
Quartzite (Black Manganiferous).	Shivrajpur, Panch Mahals District	2·67	1·7	1·7	23·5	23·5
Quartzite Cherty	Yettingud, Dharwar District	3·20	3·5	3·8	11·4	10·5
Do.	Navalur, Dharwar District	2·64	2·4	2·2	16·7	18·2

*Indian Roads, April 1936.

I. TRACKWAYS OR WHEELERS

There is a very large mileage of earth, murum, or kankar roads in every province in India, and it has been shown by experience in the Punjab and other parts of India where the monsoon is not heavy, and the soil good, that such roads can serve motor traffic, if relieved from the wear and rutting caused by heavy bullock-cart traffic. This relief can be afforded by trackways, or "creteways" as they are called, if made of cement concrete.

Where fairly long flags of hard stone are available, these if available in 6" thickness, can be used for trackways, but generally the most suitable material for trackways is cement concrete in the usual 1 : 2 : 4 proportions. A leaner mix than this— 1 : 3 : 6 was used in Sind, but was found to wear out very quickly. As usually laid these trackways are cement concrete slabs, 2 feet wide and 4½ feet centre to centre, i.e., 6½ feet from outer edge to outer edge of slabs. It has been found that cartmen and bullocks prefer this hard level surface, and do not try to hug the centre of the road where trackways are provided. In this province trackways or "creteways" have been laid in the Ahmednagar District.

Thinner slabs than 6" of cement concrete are being tried, and other expedient are, to provide a bedding for the cement concrete slab by laying 6" or 9" of good lime concrete, in which case the cement concrete slab may be made only 3" thick. Is the Punjab on the Jaranvala Sayadwala road, lime concrete is used in depths of 9" and 4½", and the cement concrete is 3" to 4½" thick, with an inlay of 1" premix in it in one case, leaving only a 2" thickness. This inlay was rapidly worn away. These trackways were laid in 1934-35 and 1935-36, and were in sound condition after 6 years, and as the loaded bullock-carts were going over the trackways, the earth road had remained in good order for the use of other traffic.

II. SURFACE DRESSING OR SURFACE PAINTING

It has been the general experience that a good water-bound macadam surface, though slowly ground down by cart wheels, does not disintegrate under cart traffic. The fast moving motor traffic, however, rocks the metal pieces, sucks out the fine blindage, and thus loosens up the surface. It was in an attempt to prevent this disintegration and to do away with the dust nuisance, that surface dressing with asphalt or tar as a binder was introduced. As its name implies, surface dressing merely provides a fairly thin tar or asphalt bound weather proof coat, adhering strongly to the surface of the road, and holding the fine aggregate spread as top-dressing, firmly together. The thin mat acts also as a cushion between the traffic and the road metal, diminishing shock and preventing abrasion of the metal as long as it lasts.

From its very nature surface dressing is not a cure for a defective water-bound macadam surface. If the water-bound macadam surface is uneven and rough, before surface dressing, it will remain uneven and rough after being dressed. If the water-bound surface is not consolidated properly, it will ravel and rut, even after being surface-dressed, though the ravalling may be retarded, and if the metal in the road surface is soft, it will crush under the bullock-cart traffic in spite of the thin cushion of surface dressing. But where a water-bound macadam surface with hard *tough* metal is thoroughly consolidated, so as to have a good mechanical bound, and a firm level surface, it has been proved that surface-dressing renewed as required by traffic, so as not to leave the metal hare, is good enough to stand even fairly heavy bullock-cart traffic.

Tar surface dressings in the Punjab and the North-West Frontier Province have been eminently successful. Where the stone is not of very great hardness and toughness provided the foundations and the water-bound macadam base are satisfactory, surface-dressing can carry fairly heavy motor traffic satisfactorily.

Surface-dressing may be done with tar or bitumen, may be one-coat or two-coats, according to the traffic conditions, hot or cold, and may be laid on a fresh rolled (unblinded) water-bound macadam surface, or on blinded water-bound macadam (after priming or using emulsions in the case of bitumen) and on stabilized gravel or sand-clay roads in a similar way. It is used on bituminous surfaces with an open taxure as a seal coat. The specifications differ according to the type and the sub-grade below the surface dressing.

A. *Surface-dressing with hot asphatt, single coat, on fresh consolidated water-bound macadam surface, hot process*—1. *Drying.*—The water-bound macadam should be allowed to dry till the surface is thoroughly devoid of moisture.

2. *Cleaning.*—All loose stuff, droppings, dust, etc., are scraped, brushed off or blown off, till the surface is perfectly clean.

3. *Marking out.*—The clean dry surface is then marked off into proper areas to be covered by a 2½ gallons (25 lbs.) can, at the rate of ⅓ gallon per square yard, or about 37 lbs. per 100 square feet.

4. *Applying asphalt.*—Asphalt of 80—100 penetration is heated in a boiler to about 375° (never exceeding 400°F.), and is either sprayed or poured on the marked off surface in a uniform layer, as far as possible avoiding fat spots or uncovered metal.

5. *Gritting.*—While the surface asphalted is still hot, chippings ⅜" to ⅝" size are broadcast evenly (brooming where necessary) at the rate of about 4 to 5 cubic feet per 100 square feet.

6. *Rolling.*—Immediately after chips are spread, rolling follows with a roller of such weight that the metal in the base or the gritting, is not crushed. The rolling is continued till the surface presents a firm uniform apperance throughout.

B. *Surface-dressing with hot asphalt, two coats, on water-bound macadam.*—Single coat surface-dressing is the cheapest type of asphalt construction, and is generally used in cases where the traffic is mostly rubber-tyred, with only very little iron-tyred traffic. It is especially suitable for station roads and streets, and in allaying the dust nuisance on roads passing through villages. A stronger type of surface dressing is to apply the binder (asphalt) in two coats.

The specifications for this type, follow the specifications for one coat surface-dressing as given above with the following additions :—

(1) *Cleaning.*—The surface is brushed over and all loose material, dust, droppings, etc. are completely removed.

(2) *Applying asphatt.*—Asphalt of 80 to 100 penetration is applied at the rate of ¼ gallon per square yard or about 28 lbs. per 100 square feet, as evenly as possible.

(3) *Gritting.*—¼" to ⅜" grit is broadcast evenly over the hot asphalted surface, at the rate of 2 to 3 cubic feet per 100 square feet, the surface being broomed if necessary.

(4) *Rolling.*—The surface is then rolled with a suitable roller till it presents an even fine-grained appearance throughout.

Note.—When surface dressing is to be done on a water-bound macadam surface which has been blinded by earth or muram, hot-asphalt will not adhere to the metal, on account of the fine particles of dust on it. In such cases a priming coat is necessary before the hot asphalt is applied. This coat covers the dust and generally penetrates the metal crust to a small depth.

C. *Surface Treatment of Metalled Roads, with Colas emulsion, two Coat work.*—Surfacing can be done in one or two coats according to requirements. In single coat work $\frac{3}{8}''$ to $\frac{1}{8}''$ chips are used. In two coat work the first coat is covered with $\frac{5}{8}''$ to $\frac{3}{8}''$ chips, followed very soon afterwards by the second coat, which is covered by $\frac{3}{8}''$ to $\frac{1}{8}''$ chips.

Single coating a metalled road is not a great success.

Cold emulsions have gained a great deal in favour from the quickness with which the work can be done, and from the added fact that it can proceed without interrupting traffic. The emulsions that are most in favour at the present time are Colas and Colfix and Bitumuls.

Colas breaks and sets quicker than Colfix and the cost is less.

Selection of road for surfacing

A newly-metalled road is not ready for surfacing in the ordinary way. If it has been well-shaped and rolled smooth, it is advisable to allow the traffic on it for a year before surfacing. During that period the crust will have become firm and consolidated, and the soft material on the top will have disappeared to a great extent.

The application of a cold emulsion surface, consists essentially in coating a clean road with the emulsion, placing $\frac{5}{8}''$ to $\frac{3}{8}''$ chippings on the top, and rolling at once. The second coat is put on after 24 hours, using $\frac{1}{8}''$ to $\frac{3}{8}''$ chippings which are rolled after six hours.

Cleaning the road surface

To get the road properly clean three operations are required :—

(*a*) Sweeping the surface with Bass Brooms to take off the dust and expose the stone.

(*b*) Brushing the road so cleaned, with wire brushes until the stones show up well.

(*c*) Fanning the Cleaned surface with gunny bags, to remove all loose dust.

Cleaning the surface is of the utmost importance.

The bitumen will not stick to dust or to animal droppings. With dust it simply balls up and comes away, and with animal droppings the ammonia and other things cause the emulsion to break down. If it becomes impossible to remove anything caked on the road, a little water applied shortly before brushing may help. It is not a good thing to use water if it can be avoided, as the emulsion will not hold to metal until the water has dried out, and during the process of drying which will take several hours, it may be picked up by traffic or by the wheels of the roller.

Preparing road surface after cleaning

Where the pot-holes are large, it will be best and cheapest to clean them out, and fill with fresh metal and chips, and consolidating with hand rammers and water.

For the smaller holes small metal can be rammed in, until an even surface is obtained. Where, however, the hollows are slight, the best and quickest method is to brush the spot clean, fan it with a gunny bag to remove the dust, any apply a small quantity of the emulsion, brushing it evenly over the area, and then covering it with $\frac{3}{8}$″ chips.

Applying Emulsion, First Coat

The emulsion should be applied at the rate of about 44 lbs. per 100 square feet, with watering cans of 2 to $2\frac{1}{2}$ gallons capacity fitted with baffles. It is first poured along the edges parallel to the road, and then transversely from side to side. It should be seen that the operator walks quickly with the can, and does not endeavour to do the work without having to move.

As the emulsion is poured, two men one on each side of the road and each with a Bass Broom, should draw any surplus over those places where the application is thin or where bare spots are found. To keep it from running through the side strips and off the road, it is advisable to place some chippings on the side stiips in the first instance. If the road is very dry and the dust is coming out from between the stones, it will be found advantageous to sprinkle the road surface with water before pouring. The sprinkling must be very light, and must under no circumstances wet the road in such a way as to leave a wet patch.

Applying Chippings, First Coat

Application of $\frac{3}{8}$″ to $\frac{5}{8}$″ chippings should be started from the sides, to keep the emulsion from running to waste at the sides. A few minutes after emulsion has been applied it will be found to change from its brown colour to blue-black. It will also be found to lose its watery appearance, and to have become tacky or sticky. This change is known as "Breaking". Immediately this is noticed, the chippings should be put on, so that the whole area is well and evenly covered. An even thickness of one stone thick should be aimed at, and the chippings not allowed to lie one over the other. The quantity depends entirely on the state of the metal surface being coated, but is usually 5 to 6 cubic feet per 100 square feet. It is far better to put on too little in the first coat, than too much.

The best course is to put on chippings evenly until the emulsion is still just visible. Rolling will then cause them to knit into the metal beneath, and to interlock between themselves.

Rolling Chippings, First Coat

The roller should pass at least three times up and down. It can begin work immediately the chippings begin to hold. When the metal below is close, considerable rolling will be required. Much less rolling is needed where the metal is more open. Only sufficient rolling is necessary to make the surface smooth and to form the chippings and bitumen into a fairly close carpet. Absolute smoothness in a first coat must not be aimed at.

Second Coat

The second or seal coat should be applied 24 hours after the first coat, that is, it should be laid on the day following the laying of the first coat.

Cleaning, Second Coat

All leaves, foreign matter and animal droppings should be scraped and brushed off. No dirt of any kind should be permitted to remain.

Preliminary Rolling, Second Coat

When the surface has been thoroughly cleaned and not until then should the roller be brought on to the work. The first coat should be rolled lightly. Usually not more than twice up and down. Just sufficient rolling to roll back any chippings that might have become loose and to bring the whole to a clean even finish is all that is required.

Applying Emulsion, Second Coat

The Colas should be put on at the rate of about 33 lbs. per 100 square feet, beginning at the sides as in the case of the first coat, first longitudinally and then transversely. ⅜″ chippings being applied immediately on the longitudinal strips to prevent wastage.

Two men with Bass Brooms should work with the "Pourers" to ensure that the emulsion is spread evenly over the surface. The brushing must be lightly done to avoid disturbing the ⅜ inch chippings. The application is to be such that the whole area will receive a covering. The more open the chippings and the greater the depth the greater the quantity of emulsion required.

Applying Chippings, Second Coat

The ⅛″—⅜″ chippings about 3 to 3½ cubic feet per 100 square feet, are put on in two coats 50 per cent. in laying the second coat and 50 per cent. after preliminary rolling. They are applied along the sides on the longitudinal strips and as the emulsion breaks they are scattered by hand over the surface evenly and lightly, a small quantity at a time. Care must be taken that surplus chippings are not put on.

Rolling, Second Coat

The rolling of the second coat is done twice once in the evening of the day the coat is laid and again on the next day. The first rolling should not be done for some hours after the chippings have been put on—usually about six hours.

The first rolling of the second coat should be done very lightly and fairly quickly. It should seldom be necessary to roll more than twice up and down. The edges for a width of 18 inches should not be rolled at all unless they have hardened sufficiently. Usually it is advisable to leave them unrolled for 24 hours as they are generally too soft to be touched. As the rolling proceeds several men with chippings should fill up those places where the coat appears thin, taking great care to see that an even thickness is maintained.

The second rolling should be done on the following morning. The edges which were omitted the previous evening should be rolled first. Wherever necessary ⅜″ chippings should be applied so that no part is left uncoated and no part overcoated. All the hollow places should be made up by the addition of chippings applied a little at a time.

In places where traffic is light more rolling will be required than where it is heavy. The roller will have to do additional work to make up for its absence.*

D. *Surface-dressing with Shalimar Road Tar.*—Tar surface-dressing can be carried out on a new surface soon after it has been consolidated and has dried out fully, or on an old surface in good condition.

Specification (Punjab).—

(1) *Preparation of water-bound macadam base.*—All pot-holes over ¾″—1″ depth should be cut out square to a depth of about 2″, the bottoms of the holes should be loosened and watered, and then the pot-holes should be filled with 1½″ gauge precoated metal and rammed thoroughly. The surface of the patch should be covered with precoated ⅜″—⅛″ gravel or chips, and again rammed flush with the surrounding surface.

Deep ruts should be scarified to a depth of 1½″—2½″ and after adding new metal, they should be consolidated like ordinary water-bound macadam, small ruts ½″ to ¾″ deep, should be painted with Tar No. 1 at a rate of 16 to 27 lbs. per 100 square feet, and covered with gravel ⅛″ to ⅜″ size, and well rolled or rammed.

(2) *Cleaning and round surface.*—For at least two weeks before tarring is started, the road should not be blinded with earth or muram. The operations begin with cleaning the road surface and for this purpose the following steps are necessary :—

(*a*) removing the surface dust by ordinary brooms or soft brushes with long handles,

(*b*) removing the caked mud from the surface by small miniature picks,

(*c*) loosening the mud and fine blindage from the interstices of the road surface with wire brushes,

(*d*) cleaning the road with soft brushes again, to remove the material loosened above,

(*e*) and finally removing fine dust by flapping with gunny bags.

(3) *Heating and pouring tar.*—(*a*) Tar No. 2 for surface dressing is heated as far as possible in tar boilers, the temperature being maintained between 240° and 250° F. A full drum should always be suspended over the boiler, so that its contents should be maintained at at least quarter-full, as otherwise the temperature rises rapidly.

(*b*) Tar can either be sprayed on the cleaned surface or hand-poured —

(*i*) In spraying with a sprayer, great care is necessary to obtain a uniform coating along the length of the road, and overlapping should be guarded against and reduced to a minimum by brushing, if necessary.

(*ii*) In pouring by hand an area of 90 square feet is marked out, to take the contents of two one-gallon pots. Pouring should be immediately followed by brushing to obtain even distribution.

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*Abstracted from " Note on the Surface Treatment of Metalled Roads" by A. A. Barnard, O.B.E., B.E.I.S.E.

Pouring should be done if possible in the noon when the temperature is not less than 100° F. as it is then possible to spread the tar more evenly.

(4) *Spreading stone chips or gravel.*—Screened stone chips or hard river bed shingle ⅛″ to ¾″ size, is broadcast evenly over the tarred surface immediately after the pouring and spreading of tar is done, the quantity being about 3 cubic feet per 100 square feet. The surface is drag-broomed or swept over to obtain an even spread.

(5) *Rolling.*—As soon as possible after the spreading of chips or gravel the surface is rolled over by a 8 to 10 ton roller, until the small aggregate has adhered to the metal. Six to 8 trips of the roller are usually sufficient.

(6) *Opening to traffic.*—The surface should be barred to traffic for 24 hours after the rolling. After that interval traffic should be permitted over the road.

(1) *Surface-dressing with Shalimar Tar, second-coat. Cleaning the surface.*—Manure, dropping, caked mud, etc., are scraped off from the surface by a suitable tool, the surface is cleaned with wire-brushes loosening, adhering, clay, etc., the material loosened as above is removed by soft brushes, and finally the fine dust is removed by flapping with gunny bags.

(2) *Heating and pouring tar.*—This is done as in the first coat except that the quantity of tar No. 2 is reduced to about 13 to 14 lbs. per 100 square feet (10 square yards per gallon of tar).

(3) *Spreading stone chips or gravel.*—As for the first coat, but the size of chips or gravel is ⅛″ to ⅜″, and the quantity broadcast should be at the rate of about 1¼ cubic foot per 100 square feet.

(4) *Rolling.*—As for first coat.

(5) *Opening road to traffic.*—As for first coat.

Note.—In the Bombay Presidency the initial use of tar in the early twenties was not successful, but later specifications are said to have given good results. In the Punjab tarring is stated to be successful but a renewal paint coat is given every year, 1/10 gallon per square yard or about 13 lbs. per 100 square feet being applied. In the North-West Frontier Province, in the Peshawar District, the renewal coat is given every 2 to 3 years, and the traffic carried is stated as heavy being 350 tons per yard width, and a large proportion of it bullock cart traffic. However, in this case, the first application of tar is at 44 lbs. per 100 square feet, and the second at 28 lbs. per 100 square feet.

Later specifications for heavy traffic roads, lay down the application of tar at 44 lbs. per 100 square feet for the first coat, and 33 lbs. per 100 square feet for the second coat.

Experiences.—Mention must be made, of surface painting in the North-West Frontier Province and the Punjab, where surface-painting with tar, etc., takes successfully, even fairly heavy bullock-cart traffic. This result is obtained by using a very hard and tough metal, which is consolidated thoroughly without blindage, the rolling being done by 10 to 12 ton rollers and continued so far, that a day's work consolidates only about 600 to 800 cubic feet of metal against the 2,250 to 3,375 cubic feet minimum mentioned for Bombay in the P. W. D. Handbook, Volume II, 1931 Edition. With such rolling, the following results have been obtained :—

Roads to the South of Kohat, surface-dressed with Colas single coat, traffic argely lorries with a small percentage of carts, require painting only once in 3 years.

The Attock-Peshawar road tar-painted carries successfully heavy bullock-cart traffic, and is only repainted once in a triennium. The general conclusion is, that 'given good stone and first class consolidation, surface painting with tar can withstand successfully loads which require premix carpets' elsewhere.

In the Bombay Presidency our experience varies. Two coat tar surface dressing on Bombay-Ahmedabad road miles 387/3 to 387/5 using Shalimar tar No. 1 at 44 lbs. per 100 square feet for the first coat and Shalimar Tar No. 2 at 28 lbs. per 100 square feet for the second coat, the coats being followed by chippings $\frac{3}{4}''$ to $1''$ at $3\frac{1}{2}$ cubic feet per 100 square feet and $\frac{1}{8}''$ to $\frac{1}{4}''$ at $3\frac{1}{2}$ cubic feet per 100 square feet. Over the second tar coat, laid in April 1937 was given a seal coat again in 1941-42.

Traffic.—Iron-tyred bullock-carts 19^{T} and rubber-tyred 55^{T} per yard with per day; cost Rs. 10-8-0 per 100 square feet.

Nasik Station Road.—Trinidad paint coat at 37 to 44 lbs. per 100 square feet, followed by a coat of hot trinidad refined asphalt and flue oil at 56 to 61 lbs. per 100 square feet, gritted and consolidated as usual, laid in 1930, traffic per yard per day 165 tons tongas and carts, 544 tons motor vehicles; badly deteriorated by 1935; cost high Rs. 17 per 100 square feet.

Poona-Bangalore Road (near Belgaum).—Surface dressing 2 coats with Spramex laid in April 1934 had worn out considerably and pot-holes had formed by the end of 1938.

A similar surface laid with Socony 105 E laid adjoining the above in May 1934 had pot-holes at places and top-coat had worn out by the end of 1938. Traffic in both cases mostly tongas and motors: 92 tons per yard.

Link Road.—Treated with Socofix 1 coat at 40 lbs. per 100 square feet, laid in January 1936; had completely worn off by the end of 1938. Traffic 127 tons per yard, tongas and motors.

Poona-Bangalore Road (Poona Division).—Colas painted single coat at about 58 lbs. per 100 square feet wore out in 14 months. Traffic per yard per day 33 tons motors, 75 tons tongas and carts.

On the same road trinidad paint coat (single coat) at about 79 lbs. per 100 square feet wore out in 10 months.

III. BITUMEN-CHIPPED MACADAM (BIJAPUR DISTRICT)

This is a cold-mix carpet introduced about 1940. It aims at producing a surface in which the premixed chips not only adhere to the base, but are wedged into it. In laying this surface the procedure was as follows:—

(1) After removing the muram from the surface, and from the joints of old water-bound macadam with stiff wire brushes, or picking the old surface lightly, and rolling dry, a new coat of metal $1\frac{1}{2}''$ to $2''$ size, $3''$ loose, was spread. The grading was about 40 per cent. passing through a $1\frac{1}{4}''$ ring, and the whole passing through a $2''$ ring. The surface was then rolled over dry, till movement of metal was as little as possible, taking care not to crush metal.

(2) Over this surface, a tack coat of Shelspra was applied at the rate of 25 lbs. per 100 square feet.

(3) ¾″ to ½″ chips (50 per cent. of each), at about 8 cubic feet per 100 square feet, were mixed with Shelspra in an improvised drum mixer, Shelspra being used at the rate of about 3¾ lbs. per cubic foot of aggregate.

(4) The coated chippings were spread evenly by rakes over the surface to be consolidated, the edges on the sides being restrained by khandkies laid before laying the new coat of metal.

(5) The surface was then, rolled over till all movement had ceased; a day's work being about 170′ × 20′ or 3,400 square feet.

The carpet is about ¾″ thick and costs Rs. 5-4-0 per 100 square feet. Traffic light; about 10 tons motor traffic and 37T cart traffic per yard width per day.

This is a light surface and will not stand heavy bullock-cart traffic. I has also a fairly open surface and would probably not last in heavy-rain tracts.

This type of carpet was laid on Sholapur-Hubli Road near Bijapur in 1940 and is being given a seal coat now. A similar carpet on Belgaum-Hungund Road near Bagalkot failed very soon. This latter road carries heavy bullock-cart traffic.

IV. TAR MACADAM SURFACE ¾″ THICK

A ¾″ surface coat of tar madadam has been tried in Bombay, but its use is not recommended in a hot climate. It has been tried but became brittle and broke up in a short time, apparently owing to rapid evaporation of the volatile oils. Tar and pitch mixtures, however, have, it is understood, given good results in Calcutta and appear to hold out considerable prospects of success. In this connection, it may, however, be noted that tar-grouting done in Poona on part of the main road near the Sassoon Hospital which carries constant and heavy traffic has been extremely successful. The tar used was British Standard Road Tar No. 2 and the surface is still after some 3½ years in good condition and has needed very little in the way of repairs.

V. ARMOUR COATS

"Armour Coat" is essentially a macadam type of construction, but by this process, it is possible to build up a rather more dense macadam, than is usually obtained by the "premix" method. In this type the largest size aggregate is first spread and an emulsion applied, the voids in the large size metal are then filled in as far as possible by broadcasting intermediate aggregate, and emulsion again applied, small size aggregate is then broadcast to fill voids in the intermediate aggregate, emulsion again sprayed and so on. Thus layers of aggregate, each of a size smaller than the previous one are successfully spread and emulsion sprayed, until the final blinding with sand or fine grit.

In laying Armour coats, the water-bound macadam surface is usually primed before spreading the first or base layer of aggregate, usually of 1″ to ¾″ size metal at the rate of about 12 cubic feet loose per 100 square feet. The metal is then lightly rolled, water is sprinkled over it, and a quick-setting emulsion (bitumen content about 55 per cent.) is applied at the rate of about 44 lbs. per 100 square feet. This application is left for 12 hours, and then the surface is lightly rolled, and key intermediate aggregate ⅜″ to ⅛″ size is spread, at the rate of 2 to 3 cubic feet per 100 square feet and broomed thoroughly into the

interstices of the base. A second application of emulsion at the rate of about 66 lbs. per 100 square feet then follows, which is left to break for 12 hours, and then the surface is lightly rolled; and as a final blindage, grit (¼" to 10 mesh) is used, at the rate of 1 to 1½ cubic feet per 100 square feet. The grit is brushed or broomed into the interstices, and after about 24 hours the road is thoroughly rolled to compaction.

Armour coats with emulsions have not been much used in this Province but the results obtained in other places may be of interest. Armour coast using "Colas" emulsion and "Bitumuls" emulsion were laid in September and October 1934 on the Grand Trunk Road to Karnal in miles 3 and 4. The traffic is stated to be 832 tons total consisting especially of village carts and tongas. It is stated that the Armour coat with bitumuls stood better than other types. The costs were Rs. 12 per 100 square feet with Colas and Rs. 14 per 100 square feet with bitumuls, and the general conclusion was: "On the whole emulsion have not been found particularly successful either for painting or for built-up carpets or for premix carpets, but the surface treated with bitumuls in October 1934, was renewed with a 1½" bitumuls armour coat only in June 1940 which gives a fair life".

VI. CARPETS

Where motor traffic is of medium intensity but bullock-cart traffic is fairly heavy, light surface-dressings wear out rapidly, and have to be renewed practically every year. In such cases it is advisable to have some sort of carpet. A carpet is a sort of asphaltic concrete, in which since the thickness is usually small, a smaller gauge stone is used, and the grading proceeds from the highest gauge down to filler stone dust. In true asphaltic concrete no filler dust is used, the ingredients being metal, stone chips and sand. For a 1" carpet in Delhi Province the proportions were:—,

	Per cent
1" to ¾" size	35
¾" to ½" size	30
½" to ⅛" size	30
Filler stone dust	5

For a 2½" and 1½" carpets, the proportions were:—

1½" to 1" size	30
1" to ½" size	35
½" to ⅛" size	30
Filler stone dust	5

But carpets thicker than 1½" are usually only laid in City streets. The cost of a 1" carpet is only slightly if at all above that of a 2-coat surface-dressing, and the surface is more stable, as excess of asphalt which results in bleeding and corrugation in a 2-coat surface-dressing, is avoided. Where a thin carpet is to be laid, great care is necessary to ensure that the water-bound macadam base is properly consolidated and very even, as the thin carpet follows any unevennesses that may exist in the base, and unevennesses result in squeezing and ultimately destroying the carpet.

Carpets can be either a "cut back" tar or asphalt emulsion as a binder, but difficulties arise with emulsions, when sand or other fines are used in conjunction with the stone, as in a carpet.

Specification No. 165

One and a half inch thick premixed Shalimar tar carpet

General.—The stone metal should be of the best quality obtainable and tough. It must be clean and free of all foreign matter before coating.

Method of Construction

(*i*) *Preparing the Road Surface.*—The road surface on which the carpet will be laid should be properly cleaned of all clay, dust, dung, and other matter, with hard and soft brushes, scrapers, small picks, etc. Immediately before laying the premix, the surface will be fanned with gunny bags to remove dust and dirt.

(ii) *Base Coat.*—Stone metal as specified and thoroughly mixed in the dry state, should be placed in improvised mixing drums made from empty road tar drums, in measured quantities, and with High Viscosity Road Tar at the rate of 4 pounds per cubic foot of aggregate heated to 260 degrees to 270 degrees Fahrenheit should be poured in, and the aggregate and tar thoroughly mixed by revolving the drum until all the particles are coated. It is of vital importance that the exact measured quantity of tar should be used for each batch. (If on account of cold, difficulty is experienced in mixing properly, the apparatus can be mounted on an iron-lined platform on which a brazier can be placed under the drum. This is unlikely to be necessary in Bombay.)

The premixed metal is then removed from the drum and at once spread evenly to specified thickness and camber on the road surface, with trowels, forked kodalies, rakes, etc. The premixed metal should then be rolled lightly (2 or 3 turns of the roller), and any depression or humps appearing should be rectified by adding or removing the premixed material.

(iii) *Top Coat.*—The chips of the top-coat are premixed in exactly the same way as described for the stone metal of the base coat. They should then be spread evenly at the rate of 4½ cubic feet per 100 square feet.

The whole carpet should then be rolled to compaction, *i.e.*, till all movement ceases.

After rolling is complete (rolling of any section must be done in one day and not commenced on one day and completed the next day), it is possible to use the road 24 hours later, but it is preferable, if possible, to close the section to traffic, roll for 3 or 4 days and then open to traffic.

(iv) *Seal or Wearing Coat.*—It is a matter of visual observation to decide when to apply the seal coat. The correct time is, when the carpet has been rendered thoroughly compact by the action of the traffic and does not present at all an open surface (if the surface is still partially open, too much tar runs into the body of the carpet, and there is a danger of the chips of the seal coat not adhering sufficiently). This is dependent on the type and volume of the traffic. The minimum period is one month after compaction of the carpet, and it may be necessary to prolong this up to two or three months. (*a*) The surface should be cleaned thoroughly as for painting. Where tar No. 3 is to be used, it should be treated to a temperature of 260 to 270 decrees Fahrenheit.

The hot tar is to be poured evenly over the surface at the rate of 33 pounds per 100 square feet; and the chips at 4 cubic feet per 100 square feet evenly spread once, and rolling of the chips done without delay to final compaction. (Rates of rolling that can be done is 16,000 square feet per diem.)

QUANTITY OF MATERIAL REQUIRED FOR PREMIXED TAR CARPET FOR AN AREA 2′ × 660′ × 18′.

1. Base Coat—

About 1½ inch loose, layer of metal, size 1½ inch to ¼ inch.	2,750 c.ft.
Of this 70 per cent. is 1½ inch to 1 inch ...	2,050 c.ft.
and 30 per cent. is ¾ inch to ¼ inch	700 c.ft.
High Viscosity Road Tar at 4 lbs. per c.ft. 11,000 lbs.	5·0 tons

2. Top Coat—

½ inch to ⅛ inch chips at 4½ c.ft. per 100 s.ft. ...	1,070 c.ft.
High Viscosity Road Tar at 4 lbs. per c.ft. ...	1.91 tons

3. Seal Coat—

¼ inch to inch chips at 4 c.ft. per 100 s.ft. ...	951 c.ft.
High Viscosity Road Tar at 33 lbs. per 100 s.ft.	3·5 tons.

Thicker asphaltic surfaces are necessary if the water-bound macadam base is uneven or if tne traffic is too heavy for 1″=1½″ carpets. These may be either—

(1) premix asphalt macadam;
(2) semi-grout asphalt macadam;
(3) asphaltic concrete;
(4) full-grout asphalt macadam; or
(5) carpets 2½″-3″ tnickness.

These surfaces having a greater thickness, and being generally made with a larger size base course aggregate, there is better interlocking with the water-bound macadam aggregate, and less tendency to follow the unevenness. Each type has its own qualities and defects which will be mentioned under each type.

The choice between premix macadam and full-grout.—Premix macadam requires much less bituminous material and the aggregate can be uniformly coated. It is cheaper than grout but it is found that it cannot carry heavy bullock-cart traffic. For motor vehicles the surface is satisfactory.

Full grout is more costly than premixed macadam, but is superior in the following points :—

(1) The relatively thicker film between the metal and chips, makes the pavement more resilient and durable.

(2) The action of water does not strip the bitumen from silicious stones.

(3) Carrying capacity is greater, especially where iron-tyred bullock carts are to be catered for.

Note.—The first full-grout macadam surface laid down by the P. W. D. on the heavy traffic Bandra-Ghodbunder road in 1925—28 is still giving service. Repairs have been necessary in about 4 furlongs in 5 miles.

A brick aggregate full-grout asphalt macadam laid on the Eastern approach of the Ellis Bridge at Ahmedabad in 1931-32 carrying heavy motor traffic and appreciable iron-wheeled traffic is still in service.

On the Poona-Bangalore road, miles 3/2 to 6/0, 2½″ premixed asphalt macadam laid in 1937-38, could not stand the bullock-cart traffic. The surface in 1939 was badly rutted, especially where loaded carts have come on it. The experience in the United Provinces has been similar where on the Grand Trunk Road a 2½″ premix macadam surface laid in November 1934, required patch repairs in 1937, had become wavy, and had developed corrugations, under the action of bullock-cart traffic.

VII. PREMIX ASPHALT MACADAM

General.—A consolidated thickness of 2″ or 2½″ is generally specified on main roads. The main advantage of this type is, that it uses much less asphalt than is necessary with grouting, and the danger of rutting or waving under traffic due to excess of binder, is avoided. Premix asphalt macadam 2½″ consolidated thickness requires only about 114 lbs. of bitumen for coating both the base and the mixed seal aggregates, while for a similar thickness of grouting (full grout), the quality is at least 140 lbs. For semi-grout, the quantity is about the same as for premix with mixed seal coat.

It has been the general experience, however, that this type ruts under heavy bullock-cart traffic. It was laid on the Poona-Bangalore road, mile 2/2 to mile 6 in 1937-38, but could not stand the bullock cart-traffic, and the surface got badly rutted especially on the side used by loaded bullock carts. Trial stretches were laid in Bombay City adjoining a semi-grout surface, and it was found on examination after a year and a half, that "semi-grouted surface appeared rich and in perfect condition", while the "premix surface appeared dry as if there was no binder, and the seal coat had worn out in some places and required renewal". The resaon for this failure lies in the specification which lays down the use of stone and chips which being precoated, and having no extra asphalt, give a more open texture than in grouted surfaces. This open texture renders the surface less water-proof, and more liable to rut under heavy bullock cart traffic. A hot seal coat remedies the former defect.

2½″ PREMIXED ASPHALT MACADAM

I. *Reconditioning sub-grade*—(1) *Cleaning.*—The existing water-bound macadam surface is cleaned thoroughly removing all dust, particles and loose metal.

(2) *Tack Coat.*—Over this cleaned surface a tack coat of hot pramex at the rate of 20 lbs. per 100 square feet is spread, uniformity in spreading being obtained by using bass brooms.

(3) *Filling pot-holes and correcting cross-fall.*—Premixed metal is then used for filling the pot-holes, removing inequalities and correcting the cross-falls to 1 in 80 using about 16 cubic feet of metal per 100 square feet.

(4) *Consolidation.*—The metal thus spread is then consolidated by a roller weighing not less than 10 tons, any inequalities shown up during rolling being corrected by picking up, raking-level, and adding new metal if necessary.

II. *Premix Asphalt Macadam—Base Coat.*—The base coat shall consist of approved quality black trap metal ½" and 1" in size, graded in the proportion of 1 part of ½" metal to 4 parts 1" metal, and coated with bitumen heated to 300° F. at the rate of 3½ to 4 lbs. of bitumen per cubic foot of metal.

The metal is coated by being turned over with the hot bitumen in a machine mixer, and is spread immediately after mixing to a loose depth of 3 inches. About 30 cubic feet of graded metal is usually sufficient for the base. The base coat is rolled lightly two or three times and inequalities made good.

III. *Top Coats.*—For this coat metal ⅜" and ½" size is used, in the proportion of 1 part of the former to 4 parts of the latter, coated with bitumen in a machine mixer, using 4 to 4½ lbs. of bitumen per cubic foot of metal. The premixed metal is spread immediately after mixing to a uniform 1-inch layer, the quantity of metal necessary being usually 10 to 12 cubic feet.

IV. *Compaction.*—After laying of the top coat, the surface is thoroughly compacted by a roller weighing not less than 10 tons, to the proper grade, cross-falls, and super-elevations, correcting inequalities, etc., wherever they show up during rolling.

V. *Seal Coat.*—Traffic is allowed to pass over the compacted surface for about a month, before the surface is brushed clean of dust and loose matter, for receiving the seal coat of spramex or other bitumen with similar penetration. The bitumen is heated to 350° F. and sprayed evenly at the rate of about 25 lbs. per 100 square feet. Metal grit of approved quality of ¼" to ¾" size is spread evenly at the rate of about 4 cubic feet for 100 square feet, and the surface rolled thoroughly with an 8-ton roller.

VIII. ASPHALT MACADAM (SEMI-GROUT)

Hot Bitumen

This type of surface was evolved from asphalt macadam (full grout) in an effort to cut down the amount of asphalt cement in the latter. Various methods were adopted to attain this object, *viz.* :—

(1) hard-rolling the metal, thus decreasing the interstices between pieces of metal ;

(2) using graded aggregate, and thus diminishing voids ;

(3) scarifying the old water-bound macadam, laying the top layer, and watering heavily, so that on rolling the " hoggin " comes up about half way up the new metal ;

(4) the Ahmednagar method of rolling moderately, and brushing sand and small gravel into the interstices to fill them about half way up.

Method (1).—The Bombay Municipality about 1930 adopted the first method. " In this method, the metal layer is well consolidated—as in water-bound macadam. Comparatively greater, consolidation . . . . reduces the voids in the surface and thereby requires less asphalt ". The cost of semi-grouting was about Rs. 12-8-0 per 100 square feet.

As stated under " premix " asphalt macadam, an examination of contiguous premix and semi-grout surfaces 18 months after laying, showed the former to be " dry " and with the premix seal coat gone, while the latter was standing up very well.

Method (2)—*The Nasik Specification* (vide *Technical paper No.* 29, *pages* 17 *and* 18).—The old water-bound surface was picked and loosened before spreading the new graded metal to provide a bond between the old surface and the new surface.

The metal was then rolled to give a consolidated thickness of 2½".

In a length of 2 furlongs, 345 feet, over this consolidated surface ¾" chippings were sparingly broadcast and lightly rolled. in the rest 1 furlong and 315 feet chippings were not used.

The former length was then grouted using asphalt at the rate of 111 lbs. per 100 square feet, while the latter length was treated at a rate of 117 lbs. per 100 square feet.

After grouting the surfaces were covered with ½" chippings and rolled tight.

Seal coat.—For the latter surface a seal coat was provided. The surface was brushed clean of all loose chippings, and asphalt at 55 lbs. per 100 square feet was poured and covered by ¼" chippings, and the surface thoroughly rolled.

The unsealed portion started to disintegrate and was repaired and sealed after 8 months.

Method (3) is not generally used as it involves the closing of the road over a long period till the surface is picked, new metal laid and rolled, surface made bone-dry and then asphalt applied.

Method (4).—This was used on the Ahmednagar Station Road. The surface was laid in September 1929. It was eminently successful in carrying the bullock-cart and tonga traffic, 261 tons per yard width, and it was not till 1936-37 that a seal coat ½" thick was found necessary.

Other semi-grout surfaces were laid in Poona and must be considered successful. These are enumerated below :—

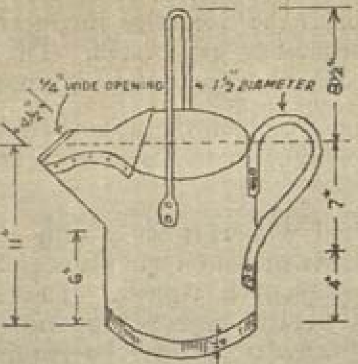
Specification No. 166

Two-inch Semi-Grout Asphalt Macadam, including reconditioning of base

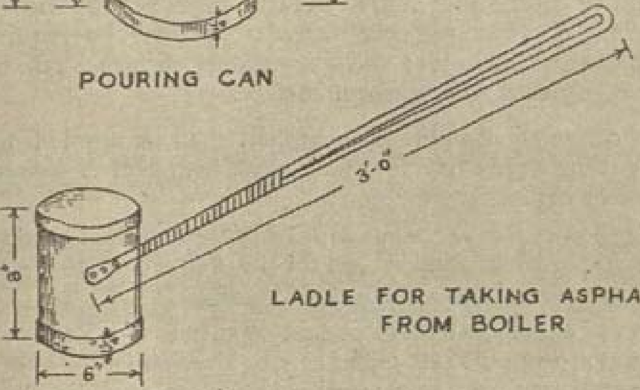
1. *Preparing base.*—The existing road surface shall be picked up and barrelled to the cross-falls of 1 to 40 or to such cross-falls as may be approved by the Executive Engineer, and to the required grade and super-elevation.

On the surface so barrelled, a layer of fresh blasted hard black-trap metal of approved quality and grade (1½ inches to 2 inches in size) shall be spread in a uniform layer of 4 inches (about 32 cubic feet of metal would be required per 100 square feet allowing for local hollows and depressions).

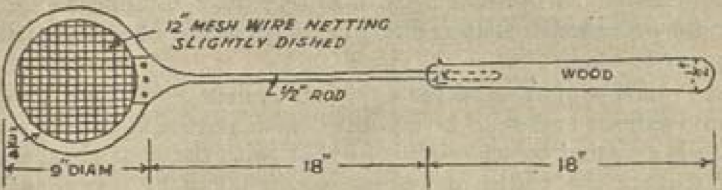
This shall be consolidated thoroughly with a 10 to 12-ton Steam Road Roller with profuse artificial watering as required till the hoggin rises to about ½ inch below the top of metal surface. Any inequalities in the cross-fall or grade or super-elevation shall be made by the addition or removal of metal as required before the final consolidation is over. The rate includes cost of metal and murum and labour in spreading them. In places where the thickness of surface to be spread is more than 4 inches, the consolidation shall be done in 2 layers to the satisfaction of the Executive Engineer or his Assistant.



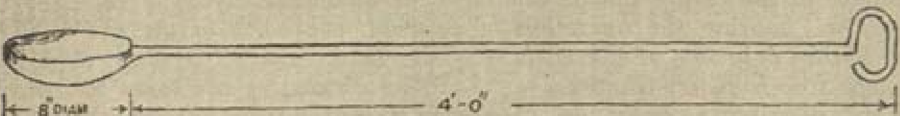
POURING CAN



LADLE FOR TAKING ASPHALTE FROM BOILER



SIEVE FOR REMOVING DIRT FROM ASPHALTE



LADLE FOR REMOVING DIRT FROM ASPHALTE & FOR TOUCHING UP UNTREATED SPOTS ON ROAD SURFACE

During pouring the can should be kept within 4" to 6" of the surface being treated. The width of application will be about 8+ and the length for each charge of the can shall be marked off so that the spreading shall be uniformly made.

To face Page 619

The reconditioned water-bound macadam surface must then be left over for a period of not less than 24 hours, or as the Executive Engineer desires, till the moisture in the sub-grade is absolutely evaporated. The surface during this period shall be properly maintained without any extra cost.

2. *Brushing.*—Prior to the spreading of asphalt, the water-bound surface shall be swept very clean to remove all blinding materials so as to expose the metal surface.

The compacted course aggregate shall possess a fairly firm and even surface, true to the grades and cross-sections shown on the plans and present a texture which will allow a uniform penetration of the asphalt. If any irregularities appear during or after rolling, they shall be remedied by loosening the surface and removing or adding coarse aggregate as may be required after which the area disturbed including the surrounding surface shall be rolled until satisfactorily compacted to a uniform surface.

3. *First application of Asphalt.*—(*a*) Asphalt shall be applied only when coarse aggregate is thoroughly dry for its entire depth and is passed by the Executive Engineer or his Assistant.

(*b*) Upon the rolled coarse aggregate asphalt of the required grade (Socony 101E Asphaltum) and quality shall be uniformly applied at the rate of 11 gallons per 100 square feet as directed by the Engineer.

(*c*) Application of the asphalt shall be laid by means of a Pressure Distributor or with hand pouring pots but preferably by the former.

(*d*) The asphalt shall be treated in kettles or boilers to secure uniform heating of the entire contents and shall be brought to a temperature of 300 degrees Fahrenheit as directed by the Executive Engineer. A thermometer must be provided to determine the temperature of the asphalt during heating or prior to application.

(*e*) Hand pouring pots used for applying asphalt shall have a capacity of not less than 3 gallons and shall be equipped with slotted spouts so placed that when the can is emptied by carrying it forward with the end of the spout close to the road surface the width of application shall not be less than 8 inches. Each pot shall be measured off and the pouring operation conducted so that the rate of application will be uniform as the pot is emptied. The direction of successive pourings shall be revised. Application shall be made at such an engle to the centre line of the road or longitudinally as directed by the Engineer. During the operation of pouring, the holes of the pot shall be kept within 6 inches of the surface of the road. In distributing, slots shall be kept free from obstructions and shall be cleaned as necessary to insure a uniform distributing aperture. A narrow spout pouring pot may be used to apply asphalt. It is necessary to touch up all spots unavoidably missed during the original application.

4. *Filling surface voids with intermediate aggregate.*—After the first application of asphalt, and if practicable while still warm, a thin layer of dry intermediate aggretate consisting of $\frac{3}{8}$ inch to $\frac{1}{4}$ inch metal shall be broadcast over the treated surface in such quantity as to fill the surface voids and just cover the treatment. About 6 to 8 cubic feet of metal per 100 suqare feet is required. It shall then be broomed if necessary to break up all clumps and produce a uniform covering after which the pavement shall be steam-rolled until thoroughly compacted and interlocked.

Suitable precautions shall be taken to prevent the distribution of the intermediate aggregate over portion of the coarse aggregate which has not received the application of asphalt and in no case shall it be dumped directly upon either the treated or untreated coarse aggregate. The surface shall then be left over for a period of nearly 24 hours and then allowed to be used by traffic.

5. *Seal Coat.*—After the surface has been compacted well under traffic, it shall be swept clean of all loose material and treated with a second application of heated asphalt under the same condition and in the same manner as previously specified except that the rate of application shall be 4 gallons per 100 square feet.

If hand-pouring pots are used, the lines of distribution shall cross those of the first application at an angle of approximately 90 degrees.

6. *Fine aggregate cover.*—After the second application of asphalt, and if practicable while it is still warm, dry fine aggregate consisting of grit shall be broadcast over the surface and rolled until thoroughly bonded to the road (quantity of grit per 100 square feet is 4 cubic feet). As required, additional fine aggregate shall be spread and broomed over the surface during rolling in sufficient quantity to take up all excess of asphalt.

Upon completion, however, only a very light uniform covering of loose aggregate shall be allowed to remain on the road. The finished surface shall be uniform, free from ruts or irregularities in camber and true to the required grade.

Specification No. 167

ASPHALTING THE AHMEDNAGAR STATION ROAD

2″ Semi-grout Asphalt Macadam on a Newly Consolidated 2″ Metal Coat

The metalled asphalted width is to be 30 feet on the average. As there is no alternative road to use while this work is in progress, only one-half width can be done at a time. A post and rope barrier shall, therefore, be provided along the whole length of the road being repaired, so as to keep traffic off it until it is ready. Having settled on the portion to be undertaken first, it shall be roped off and work commenced. The new metal layer which is to be asphalted shall be consolidated in the usual way with 2″ gauge metal, and the side widths shall be completed at the same time. Before picking is commenced, however, the old surface shall be thoroughly swept clean and free from dust, and the dust shall be carted away at once from the site. The opposite half width which is in use, shall also be swept clear of dust in the same way, and kept, watered while the work on the first half width is in progress, so that dust is not carried over to the new work. In making up the new surface, great care shall be taken in having its section to proper template, and there must be no unevenness in its final surface after rolling. When the metalled surface is thoroughly consolidated and presents a uniform appearance, free from dust or ash spots, the voids left in between the surface stones shall be filled in with carefully graded ⅛″ to ¾″ gravel, worked into them by hand, so as to reduce the voids to the minimum. Loose gravel left on the surface shall be brushed away lightly and removed without disturbing the particles of gravel in the exposed voids, so as to leave the top of the metalling free from gravel, with gravel filling the voids up only up to the surface of the metalling. Great care

must be taken to see that the grade of the gravel is correct, as any finer material will not allow sufficient penetration of the asphalt due to the asphalt cooling and thickening sooner due to contact with the finer material, with the result that much remains on the surface which would otherwise penetrate. The consolidated metalled surface shall be allowed to thoroughly dry out, before any asphalting is commenced. The time will vary with conditions, and shall be settled locally at the time. In continuous dry weather 48 hours will generally be quite sufficient.

2. The asphalt to be used shall be that supplied by the Standard Oil Company of New York, whose grade known as " No. E. Socony " has been found the most suitable of their grades, in work carried out on certain portions of roads near the Sassoon Hospital. This asphalt shall be heated in tar boilers to a temperature ranging between 400° F. to 425° F., the latter temperature being adhered to as far as possible as the asphalt is then much more fluid and penetrates better. Great care shall be taken to see that it is not heated to a higher temperature than 425° F., as its good properties are affected at higher temperatures. The temperature shall not be allowed to exceed 375° F., until the road surface is ready to receive the asphalt, when it should be raised to 425° F., and used immediately. Prolonged heating at temperatures over 400° F., tends to destroy the physical characteristics of asphalt, although it may be safely heated to 425° F, without harm, if immediately applied to the road and not allowed to remain any great length of time at that temperature. A suitable glass or other thermometer reading up to about 600° F., shall be constantly used to check temperatures. The area to be treated shall be marked off into suitable sized rectangles, to receive a fixed amount of asphalt on each, so as to ensure the correct quantities being used. The heated asphalt shall be quickly drawn off into buckets with spouts as hereafter described and poured slowly, but without any loss of time on to the prepared road surface. The pouring shall be done parallel to the length of the road, and shall begin at the crown and work outwards to the outer edge. A six-inch strip along the crown should be left dry when the first half width is being done, so as to obtain a proper bond with the second half width, by repicking that when the second half width is taken in hand. It will generally be found that the asphalt pours fairly evenly and settles in properly. Any places where there is a deficiency of asphalt due to its sinking through, shall have a little extra poured over them.

3. As soon as the asphalt is laid on the surface, it shall be covered over while it is yet warm, with clean sharp and about ⅜" to 1/16" grade and about ¾" thick, and rolled at once. The rolling shall be continued at least a day for thorough consolidation. Traffic shall not be allowed on the finished surface for at least 24 hours, after the final rolling.

4. After traffic has been allowed on the finished surface it shall be kept covered with a coat of ⅛" sand for at least a fortnight, after which the surface may be allowed to be free of sand and so be free from dust.

5. The quantity of asphalt used will vary with the nature of the work. Where no resectioning of the road is necessary, *i.e.*, where the new 2" layer is uniform in thickness on the picked up old surface 0·9 cwt. or 100 lbs. per 100 sq. ft. will be sufficient, as the binding material in the old surface works up through the new metal. If, however, resectioning is necessary to any extent, there will be greater depths of new metal, and consequently greater

penetration, and the quantity will increase to about 140 lbs. per 100 square feet. As asphalt is the expensive item in this work, it will be much better to regrade the road correctly with metal properly consolidated and bound with murum or sand below the final 2" coat, the final 2" coat being bonded to the lower work by repicking the latter slightly to get a bond. The reduction to a minimum in quantity of asphalt used, mostly depends on the proper filling up of the voids in the metalled surface with gravel. Very special attention shall be paid to this, to see that the voids are reduced to a minimum by properly filling them up with gravel, and very strict instruction in this respect shall be issued to the establishment and workers on the job.

6. The asphalt shall be heated and melted in suitable boilers manufactured for the purpose. The small portable vertical type on wheels, capable of containing about 50 gallons, is perhaps the most suitable, and two of these at least should be in operation at once, so that while one is being heated up, the other is being drawn from. The temperature of the contents of the boilers shall be taken by a suitable thermometer kept in the material while it is liquid. Ordinary glass thermometers reading up to about 600° F. will be found very suitable. The melted asphalt, when ready for use, will be ladled out quickly into pouring cans and these cans shall be conveyed quickly to the work, which should be within 40 feet at the most of the boilers. If there is any extraneous matter in the liquid asphalt it should be skimmed off the surface with a strainer. A spoon ladle is also most useful for the purpose and also for touching up small bare spots on the road surface. The pouring can found most suitable, has its mouth square across for about 4 or 5 inches, with a cover over it leaving a slit about ¼" wide, through which the asphalt can be poured at a uniform rate on to the road surface. The width of this slit opening should be adjusted to suit the rate of pouring required.

Specification No. 168

2" Semi-grout Asphalt Macadam with Vitrified Brick Aggregate

(1) *Reconditioning.*—The old surface was scarified, and a layer of vitrified brick ballast 2" to 2½" gauge was spread evenly to a loose depth of 3", to the proper grade and to cross-slopes of 1 in 36. The surface was lightly rolled to avoid crushing of the aggregate. The metal sides were also laid and consolidated at the same time.

(2) *Base Course.*—The reconditioned surface was scarified and the base course of vitrified brick aggregate 2" to 2½" gauge spread evenly to a loose depth of 3", and consolidated with a 6-ton roller artificial watering being resorted to. Care had to be taken to avoid rolling too hard and crushing the aggregates, as this would result in clogging the interstices. The rolling was continued till the scarified lower material came to about halfway up the base course. When this material came up higher it was scraped out with stiff brushes.

(3) *Application of asphalt.*—After the base course was sufficiently dry, it was brushed clean of all loose and foreign materials, and finally fanned with gunny bags to remove the fine particles. The surface was then sprayed with asphalt heated to 350° F. at an average rate of 83 lbs. per 100 square feet (variations being introduced up to 10 per cent. more or less for experimental purposes).

(4) *Intermediate coat: Spreading and compacting.*—While the grouted surface was still warm, vitrified brickbat aggregate ½″to 1″ size was broadcast over it in a uniform layer of about 1″ and rolled with a 6-ton roller until the aggregate was firmly bedded. Any depressions found while rolling were resprayed, and given the necessary additional aggregate and form.

(5) *Seal Coat.*—The surface as rolled above was swept clean of all loose material and asphalt of 80-90 penetration heated to about 375° F. was applied uniformly at the average rate of about 40 lbs. per 100 square feet (variations being introduced up to 10 per cent. more or less, and so that the total quantity of asphalt in grouting and seal coating came to about 123 lbs. per 100 square feet).

(6) *Topping.*—While the seal-coated surface was still warm dry stone grit ⅛″ to ¾″ size was broadcast uniformly at the rate of about 4½ cubic feet per 100 square feet.

(7) *Final rolling.*—The surface was then thoroughly rolled to correct grade and cross-falls, any places where an excess of asphalt appeared being blined by additional stone grit and broomed and re-rolled.

Note.—(1) The cost of this work which was carried out near Ahmedabad in 1932-33 was as follows :—

	Rs.	a.	p.
(*a*) Reconditioning	7	0	0
(*b*) Improved surface of 2″ semi-grout asphalt macadam and seal coat.	18	1	0
Total ..	25	1	0 per 100 sq. ft.

(2) The width of improved surface was 12 feet with 2 feet wide water-bound macadam (metal) side widths.

(3) The traffic intensity was 133 tons per yard width per day in 1932.

TABLE No. C. L. I.

Results obtained on $1\frac{1}{2}''$ semi-grout asphalt Macadam Surface at Poona.

Road	Width of surface in feet	Asphalt type and quantity per 100 sq. ft.	Traffic tons per sq. yd. per day	Date of laying	Cost per 100 sq. ft.	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
					Rs. a. p.	
Sassoon Road	27′ to 30′	101 E Socony at 91 lbs.	787	November 1924	14 0 0	Sides replaced with cement.
Sir J. J. Road	27′	As above	1,457	Do.	14 0 0	As above.
Wellesly Road	28′ to 36′	191-E Socony, 104-E Socony } At 91 lbs.	844	Do.	14 0 0	Filling pot-holes and patch repairs and seal necessary in 1937-38.
Bombay Road	36′ to 50′	101-E Socony at 91 lbs.	582	November 1925	14 0 0	Relaid as premix asphalt $2\frac{1}{2}''$ in 1935-36.
Wellesly Road subway to J. J. Road.	39′	101-E Socony, at 91 lbs.	1,004	February 1926	14 0 0	In fair condition part redone in 1935-36.
Bund Road	28′ to 30′	101-E Socony, at 91 lbs.	..	May 1926	13 7 0	Patch repairs and seal necessary, 1937-38.

In contrast with these good results semi-grout laid in 1932-33 with brick-bat aggregate at Ahmedabad, asphalt used being Socony 101-E at 83-84 per 100 square feet for base coat and 40 lbs. per 100 square feet for seal, remained good for about 3 years and then ruts began forming. It required renewal in 1939. The cost was Rs. 14/13-0-0 per 100 square feet and the traffic was fairly light being 30 tons bullock-cart, 136 tons motors, per yard width per day. It would appear that with a soft aggregate which crushes readily, any stinting in the application of asphalt cement is not satisfactory.

IX. Asphalt Macadam (full grout)

Hot Bitumen.

Surface dressing one coat and two coat, and grouting were the only two types of asphalt road surface adopted in India for district roads up to 1930. Of the grouting methods, full grout was the earlier, and it is a method of construction which has proved itself very well in India. The most famous example of this type of treatment in the Bombay Presidency is the Bandra-Andheri section of the Bandra-Ghodbunder Road, which was laid between 1925 and 1928, and is still giving service, even under the enormous military traffic since 1940. This is a 2″ full grout asphalt macadam carrying a heavy traffic. Similar good results are obtained in other places. Nadiad-Kapadvanaj Road laid in 1928, was in good condition, and only required a thin seal in 1938. It carries a bullock-cart traffic of 77 tons per square yard per day and light motor traffic. On the East approach of the Ellis Bridge at Ahmedabad with a traffic intensity of 822 tons per yard width (mostly motor or rubber-tyred carriages), full grout asphalt macadam laid with vitrified brick aggregate, with a seal coat with hard trap chips, laid in 1931-32 is still in service. On the Bombay-Agra Road mile 10, a 3″ full-grout surface laid in 1929 was given a liquid seal coat in 1935. This mile is low-lying and often gets submerged. In spite of this fact it was reported that it stood very well. Success with this type is not confined to the Bombay Presidency. On the Calcutta-Jessore Road, a 2″ full grout surface laid in 1931-32, was very satisfactory with practically no maintenance till 1939; traffic about 500 tons per yard width per day. In the United Provinces also this method has proved highly satisfactory. The Qutab Road laid in 1926-27 gave highly satisfactory results. It is very important with this type of surface to see that too much asphalt is not used, as the extra asphalt has a tendency to work down towards the sides, making them very 'rich', and thus liable to form ruts under cart traffic, and corrugations under motor traffic. The surface also 'bleeds'. The only comparative failures with this type are where this has occurred.

Specification No. 169.

A. Three-inch thick full-grout Asphalt Macadam Surface

(*On a newly-laid water-bound macadam base.*)

(*i*) *Brushing.*—Prior to the spreading of metal for asphalt surface, the water-bound surface shall be swept very clean to remove all blinding material

so as to expose the metal surface. Over this a light priming coat, of heated Sprame at 60 degrees Fahrenheit, at the rate of 22 lbs. per 100 square feet will be given. This will be spread with bass-brooms so as to have an even thin layer.

(*ii*) *Three-inch Asphalt Macadam Surface.*—After the surface is treated as above and after removing all loose and foreign matter, the coarse aggregate of the approved quality shall be spread upon the base uniformly in a loose layer of 4½″ (about 36 cubic feet metal being used per 100 square feet). The size of metal shall be 2½ inch to 2 inch gauge. Every precaution shall be taken to prevent the aggregate from becoming mixed or coated with dust or other objectionable matter before and after spreading.

The coarse aggregate shall then be dry-rolled with a steam road-roller weighing not less than 10 tons. The rolling shall start longitudinally at the sides and proceeds towards the centre of the pavement over-lapping on successive strip by at least one-half of the width of the roller. The compacted coarse aggregate shall possess a fairly firm and even surface true to the grades and cross sections shown on the plans and present a texture which will allow a uniform penetration of the asphalt. If any irregularities appear during or after rolling, they shall be remedied by loosening the surface and removing or adding coarse aggregate as may be required after which the area disturbed including the surrounding surface shall be rolled until satisfactorily compacted to a uniform surface. All coarse aggregate which becomes coated or mixed with dirt, dust or foreign substances prior to the application of asphalt shall be removed and replaced by clean aggregate of the same kind and compacted as specified.

(*iii*) *First application of asphalt.*—(*a*) Upon the rolled coarse aggregate asphalt of the required grade and quality shall be uniformly applied at the rate of 130 to 170 lbs. per 100 square feet as directed by the Engineer.

(*b*) Asphalt shall be applied only when the coarse aggregate is throughly dry for its entire depth and is passed by the Engineer or his Assistant.

(*c*) Application of the asphalt shall be made by mean of a pressure distributor or with hand pouring pots but preferably by the former.

(*d*) The alphalt shall be heated in kettles to secure uniform heating of the entire content and shall be brought to a temperature of 300 degrees to 350 degrees Fahrenheit as directed by the Engineer. A thermometer must be provided, to determine the temperature of the asphalt during heating or prior to application.

(*e*) Hand pouring pots used for applying asphalt shall have a capacity of not less than 3 gallons and shall be equipped with slotted spouts so placed that when the can is emptied by carrying it forward with the end of the spout close to the road surface the width of application shall not be less than 8 inches. Each pot shall be measured off and the pouring operation conducted so that

the rate of application will be uniform as the pot is emptied. The direction of successive poruings shall be revised. Applications shall be made at such an angle to the centre line of the road or longitudinally as directed by the Engineer during the operation of pouring, the holes of the pot shall be kept within the 6 inches of the surface of the road. In distributing, slots shall be kept free from obstructions and shall be cleaned as necessary to insure a uniform distributing aperture. A narrow spout pouring pot may be used to apply asphalt. It is necessary to touch up all spots unavoidably missed during the original application.

(*iv*) *Filling Surface Voids with Intermediate Aggregate.*—After the first application of asphalt and if practicable while still worm, a thin layer of dry intermediate aggregate consisting of ½ inch to ¾ inch metal shall be broad-casted over the treated surface in such quantity as to fill the surface voids and just cover the treatment 4 to 6 cubic feet of metal per 100 square feet is required. It shall then be broomed, if necessary, to break up all heaps and produce a uniform covering; after which the pavement shall be steam-rolled until thoroughly compacted and inter-locked.

Suitable precautions shall be taken to prevent the distribution of intermediate aggregate over portion of the coarse aggregate which has not received the application of asphalt and in no case shall be dumped directly upon either the treated or untreated corse agreggate.

(*v*) *Seal Coat.*—After intermediate aggregate has been thoroughly rolled stiff, the pavement shall be swept clean of all loose material and treated with a second application of heated asphalt under the same condition and in the same manner as previously specified except that the rate of application shall be form 55 to 85 lbs. per 100 square feet.

If hand-pouring pots are used, the lines of distribution shall cross those of the first application at an angle of approximately 90 degrees. After the second application of asphalt and if practicable, while it is still warm, dry fine aggregate consisting of ¼ inch grit shall be broad-casted over the surface and rolled until thoroughly bounded to the road (quantity of grit per 100 square feet being 4 cubic feet). As required, additional fine aggregate shall be spreaid and broomed over the surface during rolling in sufficient quantity to take up all excess of asphalt.

Upon completion of the pavement, however, only a very light uniform covering of loose aggregate shall be allowed to remain on the road. The finished surface shall be uniform, free from ruts or irregularities in camber and true to the required grade.

(*vi*) *Protection of pavement.*—During the period, between the initial compaction of the coarse aggregate and completion of the seal-coat, the surface shall be protected from all traffic other than that absolutely essential.

Specification No. 170

B. 2″ Asphalt Macadam (Full-grout).

I. Brushing.—Prior to the spreading of 3″ metal for asphalt surface, the water-bound surface shall be swept clean to remove all blindage so as to expose the metal surface.

II. 2″ Asphalt Macadam surface.—(1) After the surface is cleaned as above and after removing all loose and foreign matter, the coarse aggregate shall be spread upon the base in a uniform loose layer of 3″. The size of metal shall be 1½″ to 2″. Every precaution shall be taken to prevent the aggregate from becoming mixed or coated with dust or any other objectionable matter, before and after spreading.

(2) The coarse aggregate shall then be dry rolled with a road-roller weighing not less than 10 tons. The rolling shall start longitudinally at the sides and proceeds towards the centre of the pavement, overlapping on successive trips by at least one-half of the width of the roller. The compacted coarse aggregate shall possess a fairly firm even surface, true to the grades and cross sections shown on the plans, and present a texture which will allow of uniform penetration of the asphalt. If any irregularities appear during or after rolling, they shall be remedied by loosening the surface and removing or adding coarse aggregate as may be required, after which the area disturbed, including the surrounding surface shall be rolled, until satisfactorily compacted to a uniform surface. All coarse aggregate which becomes coated or mixed with dirt, dust or foreign substance, prior to the application of asphalt shall be removed and replaced by clean aggregate of the same kind and compacted as specified.

(3) **First application of asphalt.**—(*a*) Upon the rolled coarse aggregate, asphalt of the specified grade and quality, shall be uniformly applied at the rate of from 1¼ to 1½ gallons per square yard, i.e., 140 to 168 lbs. per 100 sft. using gravel or coarse sand to reduce the interstices between the metal before the application, if it is found that the quantity of asphalt specified is insufficient to fill the interstices satisfactorily.

(*Note.*—If this method is adopted it may be advisable, to secure adequate penetration, to increase the temperature of certain asphalts to 400° or even 425° F.)

(*b*) Asphalt shall be applied only when the course is thoroughly dry for its entire depth, and passed by the Engineer or his assistant.

(*c*) Application of the asphalt shall be made by means of a pressure distributor or with hand-pouring cans.

(*d*) The asphalt shall be heated in special boilers to secure uniform heating of the entire contents, and shall be brought to a temperature of 300° to 350° F. as directed by the Engineer. A thermometer must be provided, to determine the temperature of the asphalt during heating and prior to application.

(*e*) Hand-pouring cans used for applying asphalt shall have a capacity of not less than 3 gallons, and shall be equipped with slotted spouts so placed, that when the can is emptied by carrying it forward with end of the spout close to the road surface, the width of application shall be not less than 8 inches. The area to be covered by the contents of each can shall be measured off, and the pouring operation conducted so, that the rate of application will be uniform

as the pot is emptied. The direction of successive pourings shall be reversed. Application shall be made at such angle to the centre line of the road or longitudinally, as directed by the Engineer. During pouring the holes of the pot shall be kept within 6 inches of the surface of the road and the slots shall be kept free from obstructions by cleaning as necessary, to ensure a uniform distributing aperture. A narrow-spout pouring pot may be used to apply asphalt necessary to touch up all spots unavoidably missed during the original application.

(4) **Filling surface voids with intermediate aggregate.**—After the first application of asphalt, and while the surface is still warm, a thin layer of dry intermediate aggregate consisting of ½″ to ¾″ metal shall be broadcast over the treated surface, in such quantity as to fill the surface voids and just cover the treatment. It shall then be broomed, if necessary, to break up all lumps and produce a uniform covering, after which the pavement shall be rolled until thoroughly compacted and inter-locked.

Suitable precautions shall be taken to prevent the distribution of intermediate aggregate over portions of the coarse aggregate which have not received the application of asphalt, and in no case shall it be dumped directly upon either the treated or untreated coarse aggregate.

(5) **Seal coat.**—After the intermediate aggregate has been thoroughly rolled stiff, the pavement shall be swept clean of all loose material, and then treated with a second application of heated asphalt under the same conditions and in the same manner as previously specified, except that the rate of application shall be 56 lbs. per 100 s. ft. i.e., one-half (0·5) gallon per square yard.

If hand-pouring cans are used, the lines of distribution shall cross those of the first application, at an angle of approximately 90 degrees.

(6) After the second application of asphalt and while it is still warm, dry fine aggregate consisting of ¼″ grit shall be broadcast over the surface and rolled, until thoroughly embedded. As required, additional fine aggregate shall be spread and broomed over the surface during rolling, insufficient quantity to take up all excess of asphalt. Upon completion of the pavement, only a very lignt uniform covering of loose aggregate shall be allowed to remain on the road. The finished surface shall be uniform, free from ruts or irregularities in contour, and true to the required grade and crossfalls.

III. Protection of pavement.—During the period between the initial compaction of the coarse aggregate and completion of the seal coat, the surface shall be protected from all traffic other than that absolutely essential to its construction.

C. 22″ Colas Macadam surface (Full-grout).

I. Brushing.—Prior to the spreading of 3″ metal, the water-bound surface shall be swept clean to remove all blindage so as to expose the metal.

II. 2″ Colas Macadam surface (penetration method).—(1) After the surface is cleaned as above and after removing all loose and foreign matter, coarse aggregate shall be spread upon the base in a uniform layer of 3″ thickness. The size of metal shall be graded from 2″ down to 1″, in about the following proportions :—

60 per cent.—2″.
30 per cent.—1½″.
10 per cent.—1″.

Care should be taken to preserve the proper grading of the aggregate throughout, and to prevent the aggregate from becoming mixed or coated with dust or other objectionable matter, before and after spreading.

(2) The coarse aggregate shall than be rolled, with or without water, by means of a road-roller weighing not less than 10 tons. The rolling shall start longitudinally at the sides and proceed towards the centre, overlapping on successive trips by at least one-half the width of the roller. The compacted coarse aggregate shall possess a fairly firm, even surface, true to the grades and cross sections required, and present a texture which will allow of uniform penetration of the Colas. If any irregularities appear during or after rolling, they shall be remedied by loosening the surface, and removing or adding coarse aggregate as may be required, after which the area disturbed including the surrounding surface, shall be rolled until satisfactorily compacted to a uniform surface. All coarse aggregate which becomes coated or mixed with dirt, dust, or foreign substances, prior to the application of Colas, shall be removed and replaced by clean aggregate and compacted as specified.

(3) **First application of Colas.**—(*a*) Upon the rolled coarse aggregate, Colas shall be uniformly applied at the rate of from 1¼ to 1¾ gallons per square yard, i.e., 140 to 196 lbs. per 100 s. ft. as directed by the Engineer.

(*b*) Colas shall be applied only when the coarse aggregate is thoroughly firm, and is passed by the Engineer or his assistant.

(*c*) Application of Colas shall be made by means of a pressure sprayer or with hand-pouring cans.

(*d*) Hand-pouring cans used for applying Colas shall have a capacity of not less than 3 gallons, and shall be equipped with special baffies so placed, that when the pot is emptied by carrying it forward with the end of the spout close to the road surface, the width of application shall not be less than 4 inches. The area to be treated by each filled can shall be measured and marked out, and the pouring operation conducted so, tnat the rate of application will be uniform as the pot is emptied. The direction of successive pourings, shall be made at an angle to the centre line of the road or longitudinally as may be directed by the Engineer. During pouring the baffle of the can shall be kept within 6 inches of the surface of the road and the pouring cans shall be kept free from obstructions by cleaning as necessary, to ensure a uniform distributing aperature. A narrow-spouted pot may be used, to apply Colas to touch up any spots, unavoidably missed during the first application.

(4) **Filling surface voids with intermediate aggregate.**—After the first application of Colas, and before the emulsion has had time to break, a thin layer of dry intermediate aggregate consisting of ½″ to ¾″ metal shall be broadcast, in such quantity as to fill the surface voids and just cover the treated surface. It shall then be broomed if necessary, to break up any lumps and produce a uniform covering, after which the pavement shall be rolled until thoroughly compacted and interlocked.

Suitable precautions shall be taken, to prevent the distribution of intermediate aggregate over portions of the coarse aggregate which have not received an application of Colas, and in no case shall it be dumped in heaps upon either the treated or untreated coarse aggregate.

(5) **Seal Coat.**—After the intermediate aggregate has been thoroughly rolled till firm, the pavement shall be swept clean of all loose material and treated with a second application of Colas, under the same conditions and in the same manner as previously specified, except that the rate of application shall be one-half gallon per square yard, i.e., 56 lbs. per 100 square feet.

If hand-pouring cans are used, the lines of distribution shall cross those of the first application at an angle of approximately 90 degrees. After the second application of Colas, and before the emulsion has had time to break, dry fine aggregate consisting of ¼" grit shall be broadcast over the surface, and rolled until thoroughly bonded to the road. Additional fine aggregate shall be spread and broomed over the surface, as required during rolling, in sufficient quantity to take up any excess of Colas.

Upon completion of the work only a very light uniform covering of loose aggregate shall be allowed to remain on the road. The finished surface should be uniform, free from ruts or irregularities in contour and true to the required grade and crossfall.

III. Protection of surface.—During the period between the initial consolidation of the coarse aggregate and completion of the seal coat the surface shall be protected from all traffic other than that absolutely essential to its construction.

D. 2" Full grout asphalt macadam with vitrified brick aggregate Ahmedabad

(1) **Reconditioning.**—The old surface which was rough and in a damaged condition was lightly scarified and over it a layer of vitrified brick ballast 3" loose and size 1½" to 2" was spread evenly, and rolled to compaction with a 6 ton roller, taking care to maintain proper grade and cross-fall.

(2) **Base course.**—Whe the surface of the reconditioned work was quite dry, all loose blindage material was swept off and the brickbat surface exposed and thoroughly cleaned, coarse aggregate of brick ballast 1½" to 2" guage, was spread uniformly in a 3" (loose) layer, and rolled lightly with a 6 Ton roller till a fairly firm even surface true to grade and cross-falls and with a fairly open texture to permit uniform penetration of asphalt, was obtained.

(3) **Application of asphalt.**—After it was dry, the base course was brushed, and all loose and foreign material completely removed by finally fanning with gunny bags. Asphalt with 30—40 penetration, heated to a temperature of 350 °F. in a boiler, was then spread as evenly as possible at the rate of about 110 lbs. per 100 square feet. Even spreading was assured as follows :—

(*a*) Buckets drawing asphalt from the boilers had perforated holes at 10 lbs. mark, so that extra asphalt ran out, and only 10 lbs. remained.

(*b*) The pouring cans were filled with three 10 lbs. buckets so that each can carried 30 lbs.

(*c*) An area of 27 square feet was marked out on which this quantity was to be spread.

(*d*) The coolies after a little experience could ensure that this quantity was evenly distributed over the area marked out.

Any uncovered spots were treated where necessary.

(4) **Intermediate coat ; sprending and compacting.**—After grouting as above, and while the surface was still warm, vitrified brick aggregate ½" to 1" size was broadcast in an even layer of about 1 inch to cover the treatment fully, and the surface was rolled with a six ton roller, until the aggregate was well embedded and the surface was thoroughly compact.

(5) **Seal coat.**—The surface was swept clean of all loose material, and asphalt of 80—90 penetration heated to 375°F., was applied at the rate of about 55 lbs. per 100 square feet, the lines of pouring in this case, being at right angles to those for the full-grout coat.

(6) **Topping.**—After the application of the seal coat asphalt, and while the surface was still warm, stone metal grit ⅛" to ¼" size, was broadcast over the surface uniformly, at the rate of about 8 cubic feet per 100 squre feet of area.

(7) **Final rolling.**—The surface was then thoroughly rolled, till it presented a uniform appearance true to grade and cross-falls.

Note.—(1) The cost of this work which was carried out at Ahmedabad in 1932-33 was as follows :—

	Rs. a. p.
(*a*) Reconditioning	11 11 0
(*b*) Improved surface of 8" brick aggregate asphalt macadam with seal coat.	25 13 0
	37 4 0 per 100 square feet.

(2) The width of improved surface was 20 feet with 5 feet water-bound macadam (stone metal) side widths.

(3) The traffic intensity so obtained from a census taken on 1st March 1933 was 822 tons per yard width per day.

Specification No. 171

E. 2" Tar and pitch Macadam (Fullgrout)

1. A pitch and tar-grouted surface should be laid on a firm solid bed, and the old road surface should be put in order about a month or so before it is proposed to start grouting work, any depressions being filled with metal and the road brought to the correct grade and cross-falls.

2. Before spreading metal for the grout coat, the surface of the road should be cleaned with bass brooms (or steel-wire brushes if the surface is caked badly), to remove caked mud and thus be exposed and thoroughly cleaned.

3. Screened road metal for the grout coat should be spread to the depth required for the finished coat ; for a 2" finished coat 3" unconsolidated depth is required. The metal used should be graded.

4. **Grouting mixture.**—(Mixture to be used two parts pitch and one part road tar No. 1 by weight). Depending on the size of the boiler or tank to be used, the requisite number of drums or casks of pitch should be broken open, the contents put into the boiler, and the fire lighted, a note having been taken of the net weight of pitch put into the boiler. During heating the contents of the boiler should be stirred occasionally with a wooden paddle. When all the pitch has melted, and no lumps can be felt on the bottom by the stirrer, the temperature will be 300° to 320°F. The pitch is now ready for the addition

of the road tar No. 1. The fire should be slackened, and the requisite quantity of road tar No. 1 added by means of a bucket. (By noting the nett weight of the tar in the first bucket added, and filling to the same mark each time, the number of buckets of tar necessary can be calculated). During the addition of the tar the contents of the boiler should be gradually stirred, and when all the tar has been added and the temperature is approximately 300 ° F. the mixture is ready for pouring.

5. **Grout coat.**—The grouting mixture should be drawn off into pouring cans with flat nozzles, and poured evenly over the rolled metal. For 2" finished work 14 lbs. of the mixture is required per square yard, i.e., 156 lbs. per 100 square feet. The road should be marked out into areas, corresponding to the area to be covered with one can full of the grouting mixture. As soon as the mixture has been poured, stone chips of ½" or ¾" gauge should be spread evenly over the surface. Rolling should be continued until the whole surface is compact and the grout mixture shows up.

6. **Seal Court.**—(Mixture to be used 1½ parts pitch to 1 part road tar No. 1 by wight). A day or so after the grout coat has been laid the surface of the road should be brushed free of loose chips, grits etc., and the seal coat mixture (prepared in exactly the same way as the grout mixture but in different proportions) poured over the surface at the rate of 4 lbs. per square yard or 45 lbs. per 100 square feet, and spread evenly by means of bass brooms or squeegees. Grit should then be spread evenly on to this surface and the whole rolled to consolidati·

Asphaltic Concrete

This type of bituminous surface, aims at obtaining density in a premix, by grading the aggregate so as to reduce voids to a minimum. A much denser surface then is obtained in the Macadam type is thus obtained. Asphaltic concerte has not been used much on district roads and the Public Works Department has only laid down asphaltic concrete surfaces in Poona City and on a length on the Bombay-Poona Road outside it. The Poona City surface—miles 107/4 to 107/6 was completed in June 1937, and had a finished thickness of 2½" laid over old waterbound macadam reconditioned with 2" new metal. The grading of the aggregate was——

	Per cent
Metal 1¼"	70
Metal ¾"	30
Sand	33

The asphalt cement used was—

Mexphalte 30/40 penetration	Two parts.
Shelmac 120/150 penetration	One part

the quantity used being 120 lbs. per 100 square feet of surface.

The surface shows bullock cart wheel-marks on the East side (the loaded bullock cart side) but otherwise it is said to be in good order.

Another stretch on the Bombay-Poona Road 70/2½ to 71/7 laid in 1937, had an asphaltic concrete surface 2" consolidated with liquid seal. It cracked at places and wore into pot-holes, and about 30 per cent. of the original surface had to be repaired in 1942.

The experience of Bombay is duplicated in other Provinces. In Madras on the Grand North Trunk Road a 1½" and 2" shelcrete surface laid in 1937-38, and carrying a mixed traffic showed wheel-tracks and depressions in 1940. At Delhi the Qutab road with heavy cart traffic, had a 2½" shelcrete surface laid in 1934 had a F. 70 liquid seal in 1937, and again in 1940. It is reported that the surface shows cracks and patch work is necessary. On the Grand Turnk Road a similar surface laid in 1934-35, showed marked depressions and few patches in 1937. The depressions were filled with coated metal and surface given a liquid-seal, and another seal coat in 1940, and is said to be standing up well now. Traffic is 287 tons per yard width per day, mainly consisting of 4-wheeled carts. The asphaltic concrete laid on the Cawnpore-Jhansi Road, though with most carefully graded aggregates and with the correct percentage of binder, eventually tracked under bullock cart traffic.

It is clear that this surface being denser than premix as phalt macadam, tracking under bullock cart traffic is less, but after some years pronounced tracking does appear under iron-tyred traffic.

Asphaltic cohcrete

(1) **Cleaning the water-bound macadam suface.**—Prior to spreading the precoated aggregate of the base coat, the road surface was brushed and all blindage material removed and then with wire brushes the material in the joints was loosened and also brushed away. Finally the surface dust was removed by fanning briskly with gunny bags.

(2) **Preparation of asphalt.**—Asphalt of 20/30 or 30/40 penetration is heated in a boiler to a temperature of about 375°F. The fires are then withdrawn, the temperature allowed to drop to about 275°F. and the soft grade slow-setting asphalt then added, in the proportion of 1 part by weight of the latter to two parts of the former, and the mixture thoroughly stirred. This opration of stirring being repeated several times as work proceeds, as a thorough admixture of the two grades of asphalt is very essential.

(3) **Aggregates.**—The coarse aggregate for this surface is graded 1½" to ½" size metal. The fine aggregate is usually sand; the proportion is two parts coarse aggregate to one part of sand.

(4) **Mixing.**—The aggregates and asphalt are mixed in power mixing plant. A measured quantity of clean dry metal is first loaded in the mixer, and half the total calculated quantity of asphalt is then added, and the mixer started and worked till the metal is fully coated, which takes about one minute; the measured quantity of sand usually half the quantity of metal is then charged, and the balance of the bitumen added. (The total asphalt cement to be used for a batch is calculated at the rate of 3 to 3½ lbs. per cubic foot of metal and 8 to 9 lbs. per cubic foot of sand, the lower limits being for the coarser sizes). The mixer is then worked till the whole aggregate is fully coated, segregation being guarded against. This takes 1½ to 2 minutes.

(5) **Spreading material.**—The coated material is then carried to site, and laid on the clean water-bound macadam surface evenly to the required camber and grade, berween previously fixd edgings or retaining side balk. These edgings or balks are kept ½" lower than the loose spread coated material so that after consolidation the road surface at edges will be at a level with them.

(6) **Consolidation.**—This is done with a 10 or 12 ton roller, the wheels of which are kept wet to prevent sticking and lifting of the road material. Rolling is continued till the surface closes up and futher rolling has no effect.

(7) **Opening to traffic.**—A slightly open texture at the conclusion of rolling is soon sealed by traffic. Traffic should be allowed on the road immediately after rolling is completed.

Sheet asphalt

Sheet asphalt is generally defined as a 'premix' of bitumen with or without a filler and sand and containing coarse aggregate not exceeding 30 per cent. This type is really a carpet but stone metal is discarded and chippings limited to 30 per cent. the rest being sand. This type of surface is not used on district roads but is used on City roads often on a cement concrete base. Sheet asphalt is laid in thicknesses varying from about 1" to 2". A pure sand carpet has a very smooth surface immediat ly after rolling, and it can be used with success for foot-paths drives and medium traffic road with asmall proportion of heavy bullock cart traffic. A sand carpet is invaluable in many parts, where stone is expensive and its quality unsuitable for hard wear. Sand, however, requires from 6 to 9 lbs. of asphalt per cubic foot, and a sand carpet is therefore comparatively costly. In India, therefore, to cut down the asphalt as well as to give a certain amount of mechanical stability, a proportion of the sand is displaced by chips. The proportion usually adopted is equal volumes of sand and stone chips, though this gives a stone chip proportion in excess of that laid down in the definition of sheet asphalt. The mixing operations resemble those for asphaltic concrete the stone chips being first coated and then sand added with the remaining asphalt. The mixing requires to be very carefully done in order to coat all sand particles fully, and this operation is generally carried out in a power mixer. The asphalt cement is used at the rate of 2½ to 3 lbs. per cubic foot of chips and 8 to 9 lbs. per cubic foot of sand.

The specification of 1" shelsheet laid in Delhi is as follows:—

The water-bound macadam base is prepared properly and must be perfectly true to grade and camber, as these thin carpets follow the inequalities in the base closely.

The surface was cleaned by brushing and fanning and a tack coat of hot asphalt 20/30 penetration dabbed at intervals.

The asphalt cement used was made up of a hard grade 20/30 penetration asphalt 2 parts mixed with a soft grade 200/300 penetration asphalt 1 part. The hard grade asphalt is heated first and completely liquefied, the fires are drawn till the temperature drops to about 275°F. and the soft grade asphalt then added and thoroughly incorporated by continuous stirring.

The stone aggregate is chips or grit passing through a 1" mesh but retained on a ¼" mesh, and sand, in equal proportions.

For mixing a measured volume of the stone chip or grit was first put into the drum, and the bitumen mixture added at the rate of 3 lbs. per cubic foot and the drum turned till the aggregate is coated fully; then sand was added, and finally the rest of the bitumen mixture at the rate of 9 lbs. per cubic foot of sand was poured in, and the mixer worked till the whole of the aggregate was fully coated.

The mixed material is then spread on the road and raked to a uniform layer of about 1¼″, while still hot, and thoroughly rolled with an 8 ton roller.

The road was opened to light traffic almost immediately, but carts were allowed on it after two or three days.

Some patching was required after two years.

Cement Macadam

A cement macadam surface is an attempt to evolve a comparatively cheap surface in which the binder is cement, for places where the costly cement concrete road is not justified. It is also an attempt to use ordinary water-bound macadam consolidation methods, for a cement-bound surface, with no machinery or tools which would not be used for water-bound macadam.

The first cement macadam surface was laid in December 1929 on the Nasik Station Road, according to the 'sandwich' method, i.e., a layer of metal 2¼″ in the loose was first laid, then a layer of 1:2 cement sand mortar 1½″ average depth, and finally another layer of 2¼″ loose metal, thus sandwiching the cement mortar between the two metal layers. The idea is that with watering and rolling the cement mortar would work into the interstices of the metal and form a solid slab. Very shortly after the work was finished, pot-holes began forming, and by 1935 the surface had cracked and disintegrated beyond repair. Other attempts at a thinner crust of 3″ with 1″ thickness of cement at Poona in 1930 and 1935, also failed, and in the latter case, pot-holes began forming in two weeks after completion. A specification for cement macadam as carried out at Nasik is given.

Other attempts were made with different specifications. In 1936 'roller-crete' a mixture of cement concrete 1 : 3 : 8 was rolled to a 4″ uniform thickness. This gave a fair surface for 2 years but became rough later and began to wear out. Another effort was made in 1939. In this case the surface was formed as ordinary water-bound macadam but blindage on top was not spread. Well-agitated cement slurry (proportion of cement and sand 1 : 2) was then poured into the voids and the surface tamped. This also did not succeed and soon wore into pot-holes. It will be seen that all efforts to obtain a satisfactory cement-bound surface have failed.

Specification No. 172
Cement Macadam Road

(1) **Materials.**—(*a*) *The Coarse Aggregate* or broken stone shall consist of a good, clean, hard wearing stone of approved quality, cubical in shape and free from flat or elongated pieces. It shall consist of a mixture of—

Fifty per cent. of 2″ to 1″ stone and 50 per cent. ½″ to ¼″ stone or 50 per cent. of 2½″ to 1½″ stone and 50 per cent. of ¾″ to ¼″ stone.

(*b*) *The Fine Aggregate* or sand shall consist of clean hard, durable, evenly graded material, absolutely free from any deleterious matter, with a loam content not exceeding 5 per cent. by volume.

A sieve analysis of the sand should conform as nearly as is economically possible to the following :—

Retained on ¼″ sieve	0 per cent.
Retained on ½″ sieve	25 per cent—25 per cent.
Retained on 1/50″ sieve	80 per cent—90 per cent.
Retained on 1/100″ sieve	96 per cent—98 per cent.

If required by the Engineer all fine aggregate shall be washed and/or screened and regraded.

(*c*) *Cement.*—The whole of the Portland Cement used shall be of Indian Manufacture, and shall conform to the latest British Standard Specification for Portland Cement, as issued and amended from time to time by the British Engineering Standards Association.

(*d*) *Water.*—The water used for mixing shall be clean, free from oil, acid, or vegetable matter, and should be of a quality fit for drinking purposes.

(*e*) *Mortar or binder.*—The mortar or binder shall consist of cement and sand mixed in the proportion of one bag of cement (110¾ lbs. nett) to two and a half cubic feet of clean dry sand thoroughly mixed dry. Where it is impossible to obtain properly graded coarse aggregate, the proportion of sand to cement may be increased to 2½ : 1.

(2) **Original surface.**—The original surface was ordinary water-bound macadam reconditioned and hence free from pot-holes or ruts. Should these, however, exist, such depressions should in the first instance be filled and rolled thoroughly, so that the surface will afford a uniform bearing.

(3) **Spreading initial layer of sand.**—Over this surface, a ½ inch layer of clean sand was first laid, in order to allow the slab when laid, slight freedom of movement.

(4) **Arranging forms.**—(*a*) *Side forms.*—Wooden scantlings of size 4 inches by 4 inches were then laid longitudinally along the road in two parallel lines, a distance apart of 16 feet, representing the width to be surfaced, and fixed securely to the road by means of spikes driven through the scantlings, and also on the outer edges, in order to prevent as far as possible any lateral movement, when subjected to the action of the roller.

(*b*) *End forms.*—A steel girder with a flange of four inches was then laid on its side, at each end transversely, and fixed securely by means of spikes as in the case of the wooden scantlings, the distance between girders being 62 feet 6 inches.

(5) (*a*) *Areas.*—The area thus enclosed by the longitudinal wooden scantlings and the girders was equal to 16 feet by 62 feet 6 inches, or 1,000 square feet, and the surfacing of this area in cement macadam for a finished thickness of four inches was taken finally as being one day's work. It is not advisable to have under consolidation an area larger than that which can be completed conveniently and easily within the period of time required for the initial setting of the cement used. For the cement used in this work the period was approximately two hours.

(*b*) *Sub-areas.*—The total length of 62 feet 6 inches was then marked off into sub-lengths each of 6 feet 3 inches wide, the area enclosed thus or 100 square feet, the object of these sub-areas being to facilitate the gauging of materials required for an area of that size.

(6) **Preparing cement and sand mortar.**—The mortar, composed of one part of cement to two parts of sand was then mixed thoroughly by hand in a dry state, this operation being performed on wooden platforms, conveniently placed to facilitate subsequent handling.

The gauge box for the sand was of the dimensions—5 feet by 5 feet by 6 inches in depth or 12½ cubic feet. To this volume 5 bags of cement were added, since this number is equivalent approximately to 6¼ cubic feet, as each bag of cement contained 1¼ cubic feet or one cwt. in weight.

(7) **Spreading of bottom layer of metal.**—The bottom layer of graded metal was then laid, true to camber (1 in 48) and grade, to a depth of 2¼ inches, after which the metal so laid was lightly consolidated, by passing the roller twice, over it. To ensure correctness of depth, wooden blocks each 2¼ inches thick were placed against the longitudinal forms and the metal laid to that level.

(8) **Spreading dry mortar.**—The dry mortar having been previously mixed as described, was then spread evenly over this bottom layer of metal, to a depth of 1½ inches, wooden blocks of this thickness being placed as guides to ensure accuracy as before. The mortar can conveniently be levelled off by means of a clean and dry wooden batten.

(9) **Spreading upper layer of metal.**—Over the dry mortar, the upper or second layer of graded metal was then laid to an average depth of 2¼ inches, wooden blocks of that thickness being used as guides. It is advisable in this connection to have the full depth of 2¼ inches or even a little more at the centre of the road in order to preserve the camber required, since later, under the action of the roller, the central portion tends to flatten or form a saucer. Great care should be taken at every stage, to ensure that both the required camber and grade are being retained, and for this purpose, frequent use of both template and level should be made.

(10) **Application of water.**—After the second layer of metal had been thus laid, the surface was lightly watered by means of watering cans fitted with roses. The quantity of water required was found to be approximately 35 to 50 gallons for 100 square feet, the quantity varying with the atmospheric temperature.

(11) **Rolling.**—After watering, the roller in this case a Barford and Perkins crude oil roller of approximately 10 tons weight, was brought over the surface, care being taken to see that the wheels were clean. The surface was then rolled, starting from the sides and working towards the centre for a period of from 1 to 1½ hours. During the rolling operations, the wheels of the roller were kept constantly wet.

After about ten minutes rolling, the mortar started to appear on the surface, which was brushed lightly with soft brushes to assist this action. At the beginning of the work, it was found that the mortar did not appear evenly on the surface, but in patches, and for this reason, dry mortar was thrown over and rolled in. Such action should, however, only be taken, when it is not possible to bring the mortar completely to the surface under roller action, since mortar thus applied tends to form a thin skim over the surface, which later breaks up under traffic. In subsequent lengths the need for the application of dry mortar was not felt, since the labour had by that time become more expert in the work.

(12) **Final screeding.**—On the completion of the rolling, a heavy wooden screed was used to tamp the surface, to remove any inequalities such as roller marks, etc. This screed was made of 9 inches by 6 inches timber, shaped on its under side to the required camber of 1 in 48, and of sufficient length to cover the width of the road. The screed in question was worked up and down, with a forward movement by hand.

The surface on completion should be fairly smooth and true to camber and grade, but should present a mosaic appearance, that is to say, the surface of the metal should be visible, each piece being held in position firmly, and voids filled by the mortar binder.

(13) **Joints.**—The joints, which of necessity occur between the lengths representing a day's work, have to be made and consolidated by hand tamping, since consolidation by roller can only be effected up to the joint and not over it. Actually, a length of about 3 feet between successive bays was made up by hand, great care being taken to see that the level across the joint was accurately maintained, frequent use of a steel straight edge being made to ensure this essential condition. On occasions a slight depression will be found to have been formed in the neighbourhood of the joints, due to the stopping and reversing of the roller ; where this occurs, the depression should be brought to grade by sprinkling ½ inch aggregate, and rolling it into the slab to the required level. The straight edge should be used frequently to detect the formation of such depressions.

No expansion joints were made for the early lengths of cement macadam laid neither was such provision at first thought to be necessary, but subsequently it was found that expansion joints were essential for reasons stated hereafter.

(14) **Curing**—(*a*) *Curing with water.*—Immediately after the completion of a length, empty cement bags thoroughly saturated with water, were laid over the surface which was kept constantly wet, the water being retained by the construction of small earthen bunds. The finished surface was kept wet in the manner described for a period of 14 days, after which the watering operations were discontinued, and the roadway opened to traffic a week later, that is three weeks elapsed between completion of each section, and the date when traffic was first allowed to proceed over the finished section.

(*b*) *With Colas.*—As an experimental measure, two lengths, one of 150 feet and the other of 80 feet were each treated with Colas for the full width of 16 feet, in order to ascertain the qualities of this material as a curing agent in comparison with the usual medium of water.

Colas was poured from cans and distributed lightly with brushes over the surface, within two hours of final rolling, the quantity thus applied being approximately one gallon of Colas to 4 square yards of surface.

Half of the portion treated was covered with clean river sand soon after the completion of Colas, but the portion thus treated shows no difference, in comparison with that, where Colas alone was applied.

(15) **Testing.**—The lengths were treated in December 1929, and in May 1930 two specimen pieces of the slab were cut out of the road for examination, one having been cured by Colas and the other by water. In both specimens the cement used was of the same variety, that is, Gwalior brand. As it was found almost impossible to detect usually any difference between the two specimens, it was thought advisable to ascertain as a basis for comparison the crushing strength of each, and for this purpose they were sent to the Poona Engineering College, since no facilities existed locally for applying such tests.

The specimens were divided into six portions and were tested in July 1930, their age then being $7\frac{1}{2}$ months. The results of these tests went to show, that after making due allowance for experimental errors, and the difficulty of cutting accurately shaped test pieces from a block of concrete no great difference existed between the water and Colas cured specimens, both having approximately the same strength.

(16) **Cracking of slab.**—Shortly after the first sections laid had been opened to traffic, it was found that in almost every case, a crack had occurred at the joints extending along the full width of the slab for a depth of from 1 to 2 inches. The formation of such cracks, soon after completion, goes to prove that an expansion joint is an essential provision.

Shortly after the monsoon of 1930, which was particularly intensive, it was noticed that longitudinal cracks had formed in furlong 2 along and near the crown of the road. To prevent disintegration of the surface, these were hacked out and filled in with cement and sand mortar, and finally painted over with hot asphalt (Socony Grade 104).

In addition to the cracks it was also found that a bump followed by a slight depression was evident at each joint, due to the movements of the roller and therefore the importance of accurate workmanship in constructing the joints, and frequent use of the straight edge to ensure preservation of level were fully realized and cannot be unduly emphasized.

(17) **Expansion joints.**—Profiting from the knowledge thus gained expansion joints were provided in all future lengths. These were formed by the insertion of a $\frac{3}{4}$ inch plank at the joint at the time of construction, the plank being withdrawn later, after the final completion of the section and the space thus left filled in with hot asphalt (Socony Grade 104).

(18) **Cost and date of completion.**—The work was completed on the 20th February 1930 at a total cost including cement of Rs. 24,030 or Rs. 2-9-0 a square yard of completed surface.

Note.—Since writing the above, repairs to the surface have been found to be necessary owing to the formation of pot-holes.

Cement Concrete

On account of its ability to stand up to heavy traffic of any kind and its comparative permanence, cement concrete has been much used in the United Provinces, Hyderabad (Deccan), and recently in Bombay Province. The main objections against a cement concrete surface are—

(1) its comparatively high cost,

(2) the greater care required in proportioning mixing and laying, and

(3) the length of time during which the road has to be closed while the concrete is being laid, consolidated, and cured.

As regards the first objection, efforts in the direction of cheapening have been made in the United Provinces and Hyderabad (Deccan) by different methods. In the former province, this result is obtained by progressively making the slabs thinner (slabs as thin as 2″ have been laid), while in Hyderabad economy was attained, by 2 course work, using lime concrete for the base course, and

cement concrete for the top course, the thickness of cement concrete being 3″. For a road with a 3″ lime concrete base and a 3″ cement concrete top course, the cost was about Rs. 26-12-0 per 100 square feet. The United Provinces arrive at about the same rate with their thin slabs.

Even for heavier sections, the high initial cost is subsequently offet by very low maintenance costs, about 1½ to 2 annas per 100 square feet per annum, *i.e.*, for a 20′ wide road Rs. 50 to 66 per mile per annum. The expenditure for the first *six* years on the Nasik Station Road was Rs. 97 for 2,220 square yards which is about an anna and a half per 100 square feet per annum.

Specifications No. 173

ONE COURSE CEMENT CONCRETE ROAD

The contractor is advised to read carefully through this specification and include in his rate for all items of work mentioned in this specification which will be strictly adhered to.

A. Materials

Cement.

(Specifications for cement are to be scored out when the supply of cement is controlled by P. W. D.)

1. *Quality of Cement.*—The Cement used on the works shall comply in every respect with the requirements of the latest British Standard Specification for slow setting cement as issued and amended from time to time by the British Engineering Standards Association. The cement used in the works shall be manufactured in India.

2. *Tests.*—No other cement but that approved by the Executive Engineer will be allowed on the works and the contractor may not change his source of supply without the approval of the Executive Engineer in writing. The contractor shall produce test certificate to show that cement is up to the specification and notwithstanding this the Executive Engineer may at his discretion order that cement delivered on the works which he may consider of doubtful character for any reason whatever, must be re-tested by testers approved by the Executive Engineer and fresh certificates of its soundness produced by the contractor and at his cost. Cement ordered for re-testing shall be withdrawn from the works pending the result of re-testing.

3. *Packages.*—The cement shall be supplied in sound and properly secured and sealed bags, weighing 1 cwt. gross and containing 110¼ to 110¾ lbs. of cement.

4. *Storage.*—Large stocks of cement shall not be kept at the works but only sufficient quantities to ensure continuity of the work. The contractors shall provide and maintain efficient storage sheds for cement on the works. The stand on which cement is stocked shall be raised at least 12 inches from the ground and the cement be covered over with Tarpaulin or any impervious material in order to protect the bags from moisture.

The cement bags should be neatly stacked in an orderly manner so as to admit of easy count. A regular day to day account of the cement received and used on the work together with the mention of the particular proportion and quantity of the work in which it was used, shall be maintained in ink separately

by the P. W. D. and the contractor and got countersigned daily at the end of day's work by the responsible representatives of the other party after verification. The account will have to be shown to the Executive Engineer whenever he asks for it.

Cement which has been affected by moisture or in any way damaged shall be removed at once from the site. Cement shall be used in the order in which the consignments are received and not stored for an unduly long period.

Fine Aggregate.

5. *Quality of Sand.*—All the fine aggregate shall consist of clean hard, strong, durable, uncoated and well graded particles. When incorporated in the concrete mixture, the fine aggregate shall be reasonably free from injurious amount of dust, clay, silt or earth shells, soft or flaky particles, shale, alkali, organic matter and other deleterious substances.

6. The sand constituting the fine aggregate shall be taken from a source approved by the Executive Engineer and it shall be washed and/or screened and regraded at the expense of the contractor, if considered necessary by the Executive Engineer.

7. In no case shall fine aggregate be accepted containing more than two per cent. by dry weight, nor more than three and half per cent. by dry volume, nor more than five per cent. by wet volume, of clay, loam or silt. If any sample of fine aggregate shows more than five per cent. of clay, loam or silt in one hour's settlement after shaking in an excess of water, the material represented by the sample will be rejected. If necessary silt test may be taken by the Executive Engineer.

8. *Storage.*—All fine aggregate shall be stored on the works in such a manner as to prevent the intrusion of foreign matter.

9. All sand shall pass through a sieve having meshes not more than ¼" wide and if the Executive Engineer shall require it, it shall be screened before use at the expense of the contractor. Use of clean stone screenings can be allowed only at the discretion of the Executive Engineer.

10. *Size.*—The fine aggregate shall conform as nearly as possible to the following sieve analysis :—

Retained on ¼" sieve ...	...	...	0 per cent.
Retained on ⅛" sieve ...	...	...	25 to 30 per cent.
Retained on No. 50 sieve	...	...	80 to 90 per cent.
Retained on No. 100 sieve	...	...	96 to 98 per cent.

A mixture which has the lowest possible void content shall be used.

11. This description of the fine aggregate shall not be interpreted as admitting the use of stone or slag screenings unless authorised.

Coarse Aggregate.

12. *Quality of coarse aggregate.*—The coarse aggregate shall be an inert material and shall consist of crushed rock or gravel with the sanction of the Executive Engineer, when the former is not obtainable at reasonable cost.

Gravel if taken from pits shall be washed to the satisfaction of the Executive Engineer before use. The particles of coarse aggregate shall be of clean hard tough, durable material, free from vegetable or other deleterious substance and shall contain no soft, flat or elongated pieces. Aggregates covered with stone dust will not be allowed unless they are properly cleaned.

13. All coarse aggregate shall be stored on the works in such a manner as to prevent the intrusion of foreign matter. If it is however considered necessary by the Executive Engineer he may order it to be washed and/or screened at the expense of the contractor.

14. *Grading of coarse aggregate.*—A mixture which has the lowest possible void content shall be used.

The coarse aggregate shall consist of —

(1) Metal No. 3, *i.e.*, 1″ to 2″	Roughly 66·6 per cent.
(2) Metal No. 2, *i.e.*, ½″ to 1″	
(3) Metal No. 1, *i.e.*, ¼″ to ½″	Roughly 33·3 per cent.

The whole of the aggregate shall all pass a screen having meshes not greater than 2″ square and shall be retained on a screen having meshes ¼″ square. The materials may be tested for voids before the work is commenced and at intervals during the course of construction as may be necessary, and the proportion of the different grades in the coarse aggregate fixed by the Executive Engineer so as to secure a well graded material varying from ¼″ to 2″. The testing will be at the expense of the contractor. The different grades of the coarse aggregate shall be measured by means of suitable boxes and in such proportions as may be approved by the Executive Engineer.

Water.

15. The water shall be reasonably sweet clean and free from oil, acid, alkali, organic or other deleterious substances. The quantity of water added to the materials for making concrete shall be properly under control and must be measured. If required, the contractor shall at his own expense get the quality of water tested.

Reinforcement (whenever required).

16. *Steel fabric.*—B. R. C. No. 9 or equivalent fabric or other steel reinforcement as may be shown on the plans shall be used at such places as will be ordered by the Executive Engineer.

17. *Storage.*—When in storage on the works, the reinforcement shall be protected from corrosion by placing it on a dry platform under a weatherproofing cover.

18. *Quality of reinforcement.*—It shall be of the best quality of mild steel and shall be reasonably free from rust, paint, etc., before being actually used in the slab. It shall conform in every respect with latest rules of the L. C. C. for this item, and samples will be got tested at the expense of the contractor by testers approved by the Executive Engineer.

19. The contractor shall quote a separate additional rate per 100 square feet of road surface where extra reinforcement over and above the dowel bars and the longitudinal continuous bars at the central junction as shown in the plan, are to be used.

General.

20. Tests shall be made when directed by the Executive Engineer in accordance with the standard practice. The testing will be at the expense of the contractor.

21. Representative samples (one cubic foot of each) of the aggregate shall be deposited in the office of the Executive Engineer and at the site of work after obtaining the approval to the source and quality of the materials. All deliveries shall be at least equal to or above the standard of the samples.

B. Concrete

Ingredients and measurement of materials.

22. The concrete shall be composed of water, Portland cement, fine aggregate and coarse aggregate, each material being previously approved by the Executive Engineer.

23. All sand and aggregate used on the works shall be carefully and accurately measured by volume in suitable gauge boxes and in quantities to the entire satisfaction of the Executive Engineer. Quantity of sand when partially wet shall be increased by the right amount, after determining the exact percentage of bulking. The water should be added to the dry mix in a manner in which it can be properly controlled and measured.

24. The cement shall be measured by weight. One bag of ordinary cement weighing 110½ lbs. net shall be considered equivalent to 1·20 cubic feet in volume and one bag of rapid hardening cement weighing 110½ lbs. net shall be considered equivalent to 1·40 cubic feet in volume. Volumetric measurement of cement will not be permitted. A whole sealed bag shall be used for each batch as far as possible. If loose cement is used it shall be weighed; 90 lbs. of ordinary cement and 80 lbs. of rapid hardening cement respectively shall be considered as 1 cubic foot. The contractor shall provide an accurate weighing apparatus on the work.

Proportion

25. The proportions of cement, sand and aggregate for the concrete shall be 1 : 2 : 4 by volume and shall generally consist of the quantities as given below per bag of cement. The wooden measuring boxes should be filled in loose with the materials and not shaken or otherwise compacted. This proportion can however be changed at the discretion of the Executive Engineer according to the nature of the sub-grade, and the result of tests of voids in the coarse and fine aggregates.

Table No. CLII

Proportions of ingredients (1)	Cement (2)	Quantity of materials per bag of cement: Sand (3)	Quantity of materials per bag of cement: Aggregate (4)
1 : 2 : 4	In case of ordinary cement. 1 bag=110½ lbs.	2·4 cft.	4·8 cft.
1 : 2 : 4	In case of rapid hardening cement. 1 bag=110½ lbs.	2·8 cft.	5·6 cft.

26. The quantity of mixing water shall not exceed $\frac{\text{6 gallons per bag of ordinary cement}}{\text{7 gallons per bag of rapid hardening cement}}$ except when the aggregates are of absorbant nature and shall include the free water carried by the aggregates but corrections shall be made to this quantity of water according to the wetness of the aggregate as per instructions of the Executive Engineer.

27. The proportion of the ingredients can be adjusted so as to give the most satisfactory mixture after ascertaining by tests the voids of coarse and fine aggregates. If after the voids test of coarse and fine aggregates and trials of workable sizes it is found necessary to change the proportion of coarse to fine aggregates then the proportion of cement content to the sum of aggregate volume shall be kept the same as in the proposed nominal mixture.

Example.—If in a nominal mixture of 1 : 2 : 4 it is found necessary to have a proportion of fine to coarse aggregates in ratio of 3 : 5, then the concrete proportion would be 1 : 2¼ : 3¾.

Consistency and slump test

28. It is necessary that the concrete shall have the desired workability and the maximum density.

29 When the correct proportions have been ascertained they must be carefully noted and adhered to until there is a change in the condition of material supplied.

30. In order to test the consistency of the mixed concrete a slump test shall be made by the contractor when and where required by the Executive Engineer, and these slump tests shall be carried out in the following manner.

31. The test shall be made in a mould made with No. 16 gauge galvanized iron metal sheet in the form of the lateral surface of the frustrum of a cone with the base 8″ in diameter, the upper surface 4″ in diameter and the altitude 12″ the base and top shall be open and parallel to each other and at right angles to the axis of the cone. The mould shall be provided with foot pieces and handles. The internal surface shall be smooth.

32. When the test is made at the mixer, the samples shall be taken from the piles of concrete immediately after the entire batch has been discharged.

33. The mould shall be placed on a flat non-absorbant surface such as a smooth plank or slab of concrete and the operator shall hold the form firmly in place while it is being filled by standing on the foot pieces. The mould shall be filled to about one-fourth of its height with the concrete which shall then be punned using exactly 30 strokes of ½″ rod pointed at the lower end. The filling shall be completed in successive layers similar to the first and top struck off so that the mould is exactly filled. The mould shall then be removed by being raised vertically immediately after being filled. The moulded concrete shall then be allowed to subside until quiescent and the height of the specimen measured.

34. The consistency shall then be recorded in terms of inches of subsidence of the specimen during the test which shall be known as slump.

Slum—12 inches—(minus) inches of height after subsidence.

35. The allowable slump for concrete in road slab shall be between 1½″ to 2½″ when reinforced and 1″ to 1½″ when no reinforcement is used.

36. *Machine mixing.*—The concrete shall be mixed in a batch mixer of approved type which will ensure a uniform distribution of the material throughout the mass so that the mixture is uniform in colour and homogeneous. The capacity of the drum shall be such that only whole bags of cement are used in each batch. Mixing shall continue for at least two minutes after all materials including water are placed in the drum and before any part of the batch is discharged. The drum shall be revolved not less than 14 nor more than 18 revolutions per minute. The drum shall be completely emptied before receiving materials for succeeding batch. The volume of the mixed material in each batch shall not exceed mixer manufacturer's rated capacity of the drum.

37. The drum shall be cleaned at frequent intervals while in use and shall be thoroughly washed out when mixing operations cease for any period longer than 30 minutes.

38. Suitable arrangements shall be provided for water storage, water measuring and time measuring devices.

39. Mortar or concrete which has partially set shall not be retempered by being mixed with additional material or water.

40. *Hand mixing.*—Hand mixing when allowed by the Executive Engineer, shall be carried out in the following manner, and shall be done on a water-tight platform or trough at least 7 feet by 12 feet with three sides of sufficient depth to prevent the materials from being shovelled off during the operation of mixing. The actual mixing shall be carried out by two or more men opposite each other using square ended shovels (not powras).

41. The specified quantity of sand for the batch of concrete shall be spread out first on the platform or trough-making a level heap about 6″ deep, and on the sand specified quantity of cement shall be spread. All the dry sand and cement shall be turned over with shovels at least three times until the mixture is of a uniform colour. Each shovelful should leave the shovel with a spreading as well as a turning action. The specified quantity of coarse aggregate shall now be added and the whole mixture turned over again at least three times. The specified quantity of water shall next be added slowly through a rose attached to a watering can while the process of turning the mixture over is being carried out. The mixing shall be continued until the whole batch has reached an even consistency and the mortar is spread evenly through the batch. Any other method of hand mixing of cement concrete in the dry state in vogue in the locality may be adopted, subject to the approval of the Executive Engineer.

42. The water must not be added from a bucket or bhisti's bag to the dry mixed materials where hand mixing is resorted to.

The concrete shall be placed in position within 20 minutes from the time of adding water to the mixture.

C. CONSTRUCTIONAL DETAILS

43. Dimensions in accordance with the sanctioned plans shall be adopted unless otherwise stated.

Preparation of sub-grade.

44. The sub-grade shall be constructed either with water-bound macadam or cement concrete (1 : 4 : 8) as may be directed by the Executive Engineer.

Sub-grade with water-bound macadam.

45. The sub-grade shall be constructed to have as nearly as practicable, *a uniform bearing power throughout its entire width* which should be 1 foot more than the width of the slab. Whenever the sub-grade extends beyond the lateral limits of an old roadway, or wherever an old gravel, macadam or other hard compacted crust comes within 6 inches of the elevation of the finished sub-grade such old roadway or crust should be ploughed, loosened or scarified to a depth of at least 6 inches and the loosened material redistributed across the full width of the sub-grade, adding suitable material when necessary, so that when compacted, to the required elevation, alignment, and cross section, the sub-grade will approach as nearly as possible a condition of uniform bearing power. Compression of the sub-grade material shall be accomplished with a roller weighing not less than 8 tons. Hand-tamping portion of the sub-grade may be directed by the Executive Engineer, when necessary. There shall not be left on the sub-grade or shoulders, berms or ridges of earth or other materials that will interfere with the immediate discharge of water from the sub-grade to the side ditches, and the sub-grade shall be maintained free from ruts so that it will at all times drain properly.

46. All depressions developing under traffic on the sub-grade or in connection with rolling shall be filled with suitable material. Rolling shall be continued until the sub-grade is uniformly compacted, properly shaped and true to grade and alignment. It is not intended that rolling shall be continued beyond that point as the purpose of rolling is not to produce a sub-grade that cannot be further compacted but to produce a *uniformly compacted sub-grade.*

47. All hauling shall be distributed over the width of sub-grade so far as practicable, so as to leave it in an niformly compacted condition.

48. All soft or spongy parts of the sub-grade shall be excavated and refilled with approved material well tamped in 6 inches layers or efficiently drained by tiles or trenches filled with stones whichever method the Executive Engineer shall decide, and no extra payment will be made to the contractor on that account.

49. *Checking and acceptance.*—Immediately prior to placing concrete on the sub-grade it shall be checked by means of an approved scratch template, resting on the side forms, having the scratch points placed not less than 8 inches apart and to the exact elevation and cross section for the sub-graded surface. The scratch template shall be drawn along the forms, so that the plan of the points will be at right angle to the grade line, and long axis of the template at a right angle to the centre line to the road. All high places indicated by the scratch points shall be removed to true grade and any low places back filled with suitable material and rolled or hand-tamped until smooth and firm. The sub-grade shall be checked and completed in accordance with the requirements for a distance not less than 100 feet in advance of the concrete. If hauling over the sub-grade after it has been finished and checked as above specified, results in ruts or other objectionable irregularitiee, it shall be rolled again or hand-tamped and placed in a smooth and satisfactory condition before the concrete is deposited upon it.

50. No concrete shall be laid on the sub-grade until subjected to normal traffic for a month and passed by the Executive Engineer.

51. The existing road surface should be brushed and all the blindage and loose materials removed. The surface should then be uniformly moistened and all inequalities of the sub-grade should be filled up with lean concrete (1: 4: 8) so

as to present a uniform cross fall of 1 in 60 or a superelevation as required by the Executive Engineer for the entire width, which should be 1 foot more than the concrete road slab. Where, over a large area the average thickness of the inequalities to be made up with the lean concrete is 1″ or less it shall consist of sand and metal No. 2 or metal No. 1 only as required. For greater thickness metal No. 3 can be used in addition to the small size metal as directed by the Executive Engineer. Whenever the width of the sub-grade has to be extended beyond the existing metalled surface it should be made up with lean concrete 1 : 4 : 8 the depth of which should at least be equal to that of the metal of the water-bound macadam which forms the base or 6″ whichever is less.

52. Lean cement concrete should be properly tamped and the concrete slab should be laid on it before it sets. To ensure this, the preparation of the sub-grade with lean concrete should be ahead of the laying of concrete slab by such length as could be covered by the slab within 15 minutes and this portion of finished sub-grade should be kept covered with gunny bags till the laying of concrete slab of the wearing course, in order to prevent intrusion of earth or other foreign matter by workmen working over it.

53. The quantity of lean concrete used for preparing the sub-grade will be measured on cubic feet basis. The method to be adopted for measuring the quantity would be as directed by the Executive Engineer to suit local conditions.

Crossfall.

54. The crossfall of the finished foundations shall be 1 in 60 as determined by the Executive Engineer.

55. *Road lining water-proof paper.*—A layer of clean medium grade sand about ½″ thick should be spread evenly on the sub-grade thus prepared to serve as an insulation layer. If sand is used it shall be hand-rolled or tamped properly.

Where the levels of the existing sub-grades require no alteration, base bounded concrete often proves successful. Base bonding merely means that the concrete is laid directly on the sub-grade after the latter has been brushed, cleaned and watered. This course should not be adopted except in the case of thoroughly consolidated sub-grades and without obtaining prior approval of the Executive Engineer in writing.

Forms.

56. *Wooden forms.*—Wooden forms shall be dressed equal in depth to thickness of the slab at the sides. Forms shall rest upon stakes driven into the ground within 1 foot of each end of each separate piece, and at intervals not greater than 5 feet elsewhere. Forms shall be held by stakes driven into the ground along the outside edge at intervals not more than 6 feet, two stakes being placed at each joint. They shall be firmly nailed to the side stakes and well braced at any point, where necessary, to resist the pressure of the concrete or the impact of the tamper. Forms shall be capped along the inside upper edge with 2″ angle irons.

57. *Metal forms.*—Metal forms shall be of shaped steel section such as channels, etc. They should be at least 10′ in length for tangents and for curves having radii (150′) and over. Smaller pieces up to 5′ may be used for curves having radii less than 150′. The depth of the forms must be the same as the thickness of the slab and sufficient bracing pins or stakes shall be used so as to prevent any displacement of forms due to pressure of concrete slab or impact of tamper.

58. *Setting forms.*—Forms shall be set to the exact grade and alignment at least 100 feet in advance of the point of depositing concrete. Before setting, the forms must be thoroughly cleaned. After setting, they shall be thoroughly oiled before concrete is placed against them. Forms in place will be subject to the check and correction of line and grade at any time.

59. It is essential that forms should be rigid as on this depends the even running of the finished surface.

60. No forms shall be removed until at least 24 hours have elapsed after the concrete has been deposited against them and every care should be exercised during their removal to ensure that the concrete is not in any way damaged. The forms shall be thoroughly cleaned before re-use.

Joints

61. *Transverse expansion joints.*—Transverse expansion joints shall be spaced as specified hereafter under paragraphs 75 and 79. A bulkhead cut to the exact section of the road shall be securely staked in place at right angles to the centre line and surface of the road. The premoulded joint filler shall be placed against the bulkhead and held in position by pins on which there is an outstanding lug for subsequent lifting. Concrete shall be deposited on both sides of the bulkhead before it is removed. After the concrete has been struck off, the bulkhead shall be removed by lifting it slowly from one end and replacing it with concrete as it is lifted, so that the joint filler will be left in the correct position. Intermediate joints should be oiled or painted with tar or asphalt.

62. When the concrete is sufficiently stiff the edges of the slab at the joint shall be rounded with a $\frac{3}{8}''$ edging tool.

63. The joint filler should be wider than the slab depth and must extend to the bottom. It is advisable to notch the joint into the sub-grade by scratching a groove therein with a pick and setting the filler into the groove and tamping earth against it ; the concrete is then placed on both sides and the bulkhead removed.

64. When the expansion joints are made at the end of the day's work, they shall be formed by finishing the concrete to the bulkhead, placed as before specified. When work is resumed the joint filler shall be placed against the hardened concrete and held in position by pins until fresh concrete is placed against it.

65. Before the road is open to traffic, the joint filler shall be trimmed off to a uniform height of $\frac{1}{2}''$ above the concrete surface and ironed down until flush with the concrete surface.

66. Where the plans require steel dowels across the transverse (expansion or construction) joints there shall be holes in the bulkhead spaced about 2′ centre to centre, about half way down the thickness of the slab. Half the length of each Bar (diameter of the bar being 3/4″ to $\frac{5}{8}''$ and length 4 feet) should be completely encased in heavy paper or coated with point or oil in such a manner as to prevent a bond between the steel and the concrete ; in addition some form of cap should be provided at the end of the bar to provide for sliding.

67. *Longitudinal Expansion Joints.*—Longitudinal expansion joints shall be ordinary butt joints. The surface of the concrete should be oiled, asphalted or tarred to prevent contact.

68. The edges of the slab shall be rounded with a $\frac{3}{8}''$ radius edging tool.

69. *Transverse construction joints.*—These shall be formed whenever it is necessary to stop concreting for 30 minutes or longer, except at expansion joints, by staking in place a bulkhead and finishing the concrete to the bulkhead. An edging tool shall be used along the bulkhead to make the construction joint a regular and well defined line. (For steel dowels across transverse joints in this bulkhead, there shall be holes spaced 2 feet centre to centre 2″ below the surface of the finished concrete through which $\frac{3}{4}''$ to $\frac{5}{8}''$ diameter plain round steel rods 4″ long shall be inserted with 2″ projecting).

70. When work is resumed, the bulkhead shall be removed care being taken not to disturb the rods or the concrete. The fresh concrete shall be placed directly against the face of the concrete previously laid and carefully worked around the rods.

71. These constructional joints shall be avoided as far as possible.

72. *Longitudinal Construction Joints.*—These shall be formed where required and must be straight and vertical. When so indicated on the plans, steel dowels of $\frac{3}{4}''$ diameter bars shall be used as provided in clause heretofore.

73. When the concrete is sufficiently stiff the edges of the slab at the joint shall be rounded with a $\frac{3}{8}''$ edging tool.

Methods of Construction

74. Either the alternate bay or the continuous method of construction may be adopted as directed by the Executive Engineer.

Alternate Bay Method

75. The concrete road slab shall be laid longitudinally in alternate bays and of the cross-sectional dimensions shown on the plan. The length of the alternate bays parallel to the axis of the road shall be about 30′ with expansion joint at every 120′. These lengths however may be varied by the Executive Engineer to suit the nature of the joints and the method of tamping.

76. The width of the slab in each bay shall be as ordered by the Executive Engineer.

77. The joints shall be plain butt joints at right angles to the longitudinal axis of the road.

78. *Alternate bays.*—The Executive Engineers shall decide the order of laying the bays and also the time that shall elapse before commencing the intermediate bays.

Continuous Method

79. The road slab shall be laid in continuous bays of 35 feet with pre-moulded expansion joint filler $\frac{3}{8}''$ thick at every joint.

80. The concrete road slab shall be constructed of the cross-sectional dimensions shown on the plans.

81. *Joints.*—Longitudinal joints shall be plain butt joints and the vertical surface of the concrete should be oiled, asphalt painted or tarred.

Surface finishing

82. All tools used and method of use must be approved by the Executive Engineer before the work is commenced.

83. Screeding and tamping shall be carried out either from the transverse forms or from the side forms as specified below whichever the Executive Engineer shall decide.

84. After the operation of screeding and tamping, the surface of the slab shall be floated longitudinally.

Placing concrete

85. Concrete shall be placed on a moist sub-grade but there should be no pools of standing water. If the sub-grade is dry, it shall be sprinkled with as much water as it will absorb readily. It may be advisable to have the sub-grade sprinkled or thoroughly wet from 12 to 24 hours in advance of placing concrete, where such procedure seems necessary. This is not necessary where road lining paper is used.

86. All operations from the time the mixing water is added to the completion of tamping, shall be completed within the setting time of the cement.

87. The mixed concrete shall be deposited rapidly on the sub-grade to the required depth, and for the entire width of the slab section in successive batches, and in a continuous operation without use of intermediate forms or bulkheads between joints. While being placed the concrete shall be vigorously sliced and spaded with suitable tools to prevent formation of voids or honeycomb pockets. The concrete shall be especially well placed and tamped against the forms. When concrete is placed in two horizontal layers to permit the use of steel reinforcement, the first layer shall be roughly struck off a template or screed, riding on the side forms at the correct elevation to permit placing the reinforcement in the specified position. The concrete above the reinforcement shall be placed within 15 minutes after the first layer has been placed. Any dust, dirt or foreign matter which collects on the first layer shall be carefully removed before the upper layer is placed.

88. All concrete shall be transported from the mixer or mixing board to the place of final deposit by methods which will prevent segregation or loss of ingredients.

Placing reinforcements

89. Steel fabric reinforcement of the size and weight shown on the plans and/or stated in the specifications shall be placed as shown, and parallel to the finished surface of the slab unless otherwise indicated. Fabric shall extend to within two inches of the sides and ends of slab. All laps of fabric sections shall be not less than three-fourths of the spacing of members in the direction lapped.

Steel bar reinforcement shall be placed as indicated on the plans and/or as stated in the specifications. Transverse bars shall extend to within 2″ of the margins of the slab. All intersections of longitudinal and transverse bars shall be securely wired or clipped together to resist displacement during concreting operations. The splices, in the bars shall be lapped for a length of forty diameters.

D. Surface Finishing

Screeding and tamping

90. The concrete shall be brought to the specified contour by means of heavy screed or tamper fitted with handles weighing not less than 7 lbs. per running foot and not less than three inches wide. This screed or tamper may be of steel. It shall be shaped to the cross section of the slab and have sufficient strength to retain its shape under all working conditions. The tamper or screed shall rest on the side forms and shall be drawn ahead with a sawing motion, in combination with a series of lifts and drops alternating with lateral shifts of about an inch. At transverse joints the tamper snall be drawn not closer than 3 feet towards the joint, and shall then be lifted and set down at the joint and drawn backwards away therefrom. Surplus concrete shall then be taken up with the shovels and thrown ahead of the joint. If the tamper is of wood, then it shall be provided with 3″ × ¼″ iron plate securely attached to the bottom after the wood is dressed to the required cross fall.

91. Immediately after the screeding or tamping has been completed, the surface shall be inspected for high or low spots and any needed correction made by adding or removing concrete.

Hand floating

92. *Floating.*—The entire surface shall then be floated with a float board not less than 2′-6″ long and 3″ wide. It shall be operated by a man on a bridge spanning the slab. The lower surface of the float board shall be placed upon the surface of the concrete with the long dimension parallel to the centre line of the road. The float is then drawn back and forth in slow streches about 2 feet long and advancing slowly from one side of the slab to the other. The purpose of this operation is to produce uniform even surface on the concrete free from transverse waves. When the entire width of slab has been floated in this manner from the bridge it is checked by a straight edge longer than the slab width and corrected where necessary. The floated surface shall then be finished by the brooming process specified as under.

Brooming

93. The broom shall be gently pulled over the surface perpendicular to the centre line of the road from edge to edge in such a manner that the corrugation will be uniform in depth and width. The sides of the slab and the joints shall not be edged until after the brooming process is completed.

94. This brooming shall be carried out immediately after the hand-floating. The broom shall be of the leaf rake type with flexible prongs on a handle long enough to reach half way across the slab.

Finishing at joints

95. A suitable float shall be used at all joints. The device shall be so arranged as to float the surface for a width of at least 6 inches on each side of the joint simultaneously, and shall be used in such a manner as to produce a level surface across the joint. Edges of the slab at the sides shall be levelled for a width of 2 inches and the transverse edges of the slab at the joints should be rounded to ⅜″ radius.

Trueness of surface

96. The finished surface of the slab must conform to the grade, alignment and contour shown on the plans. Just prior to the final finishing operation, the surface should be tested with a light straight edge 10 feet in length laid parallel to the centre line of the road.

The maximum deviation allowed shall be $\frac{1}{4}''$ in 10 feet.

Any deviation shall be immediately corrected.

Carborundum brick and water may be used to remove high spots.

E. Curing

Protection

97. Immediately after the final finishing operations the surface of the concrete slab shall be covered with wet empty cement sacks and these shall be sprinkled with water in such a manner that the surface of the concrete will not be damaged, and must be kept continuously moist by sprinkling until the concrete has taken its final set.

Ponding

98. As soon as it can be done without damaging the surface of the concrete, dykes or bunds shall be built along both edges of the slab with cross dykes at sufficiently frequent intervals and the surface flooded with sufficient water within the dykes to keep all portions of the concrete surface continuously covered with water for 14 days in case of ordinary cement and 7 days in case of rapid hardening cement or as determined by the Executive Engineer after the concrete is laid. The ponded water shall be treated with diluted saponified cresol to prevent mosquito breeding. Two table-spoonfuls of saponified cresol shall be mixed with three gallons of water so as to make it efficient larvacide.

Hardening concrete surface

99. A solution of Sodium Silicate shall be sprayed from a watering can and continuously brushed over the surface with a soft broom for several minutes to obtain an even penetration and left covered for 24 hours by a convas cover. Three applications shall be given in this manner allowing 24 hours to elapse between each and the canvas cover shall be replaced on surface between each application.

100. The solution shall be in the proportions of one part of a concentrated solution of P. 84 sodium silicate to six parts of water and one gallon of solution shall cover 200 square yards.

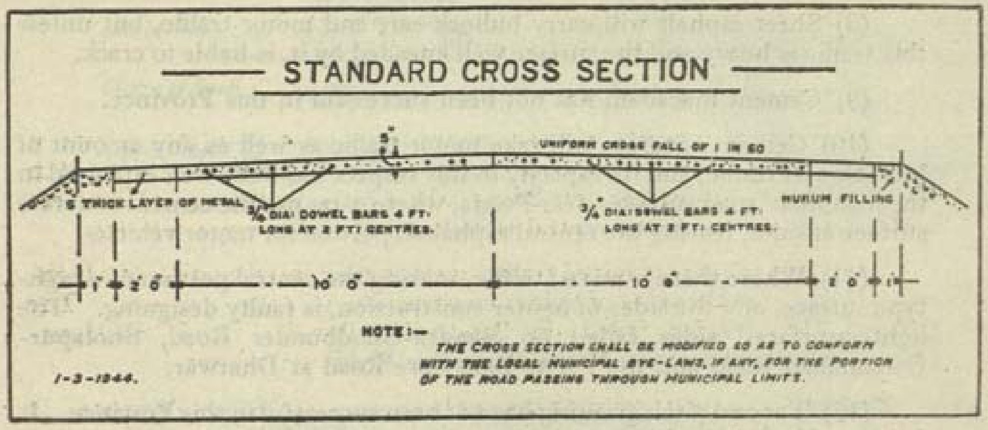
101. This solution may be applied either 14 days after the initial set or immediately after it. The surface of the concrete must be dry and free from dust before the application.

Cleaning

102. After $\frac{\text{14 days}}{\text{7 days}}$ if $\frac{\text{ordinary cement}}{\text{rapid hardening cement}}$ is used, the earth or other cover may be removed and surface will be thoroughly washed, brushed, cleaned and allowed to dry.

Opening to traffic

103. No traffic shall be allowed on the finished surface within 21 days of its completion in case of ordinary cement and 7 days in case of rapid nardening cement. This period may be decreased or extended if in the opinion of the Executive Engineer, tne weather conditions, type of cement or other reasons justify a revision.



GENERAL CONCLUSIONS

It will have been apparent from the remarks under each head of surface, that the nature of traffic (type and heaviness), decides the type. Tnis Province has made a large number of experiments and the following conclusions can now be drawn :—

(1) Road oils are useful only on low cost roads with light traffic. Their use on such roads as the Bandra-Ghodbunder Road and the Belgaum-Hinganmath Road, is bound to be unsatisfactory, as is proved by experience on the above two roads, the surface lasting only a matter of months.

(2) Single coat surface dressing is not a success, as the chips are soon ground into powder, and the surface also not being sufficiently sealed moisture enters and the base softens. We have had this experience on the Poona-Bangalore Road near Belgaum, where such surfaces laid with Trinidad paint coat and Colas, broke up almost witnin a year.

(3) Two coat surface dressing is satisfactory on a newly consolidated water-bound macadam road with intense motor traffic and light bullock-cart traffic. The approximately ¾" carpet gives a good cushin and a smooth running surface.

(4) If metal in the sub-grade is hard, and hard rolled to compaction, and if the foundation is good, a two coat surface-dressing will even carry a good amount of bullock-cart traffic.

(5) Premix asphalt macadam will give a good running surface under intense motor car traffic, but will track and later form deep ruts, under loaded bullock-cart traffic. It also has an open texture and will deteriorate unless given a hot seal coat.

(6) Full grout and semi-grout macadam give long lasting surfaces if well constructed, and in addition to intense motor traffic, will carry bullock-cart traffic also, if the metal is good, hard and tough.

Armour-coat is a thinner surface and is proportionately less strong.

(7) Asphaltic concrete will track under heavy loaded bullock-cart traffic, though to a much less extent than premix asphalt macadam.

(8) Sheet asphalt will carry bullock-cart and motor traffic, but unless this traffic is heavy and the surface well kneaded by it, is liable to crack.

(9) Cement macadam has not been successful in this Province.

(10) Cement concrete will take motor traffic as well as any amount of bullock-cart traffic, and its capacity in this respect has been well exploited in the 'conphalt' road surfaces near Poona, where carts use the cement concrete surface at sides, leaving the central asphalted portion for motor vehicles.

(11) Where there is mixed traffic, making the central portion of a high-type surface, and the sides of lighter construction, is faulty designing. The lighter-surfaced sides failed on Bandra-Ghodbunder Road, Sholapur-Osmanabad Road and the Poona-Bangalore Road at Dharwar.

(12) Tar and pitch grouting has not been successful in this Province. It failed on the Bandra-Andheri section and on the Nasik Station road.

(13) All bituminous surfaces require some sort of hard material edging, otherwise they are gradually worn out at the sides.

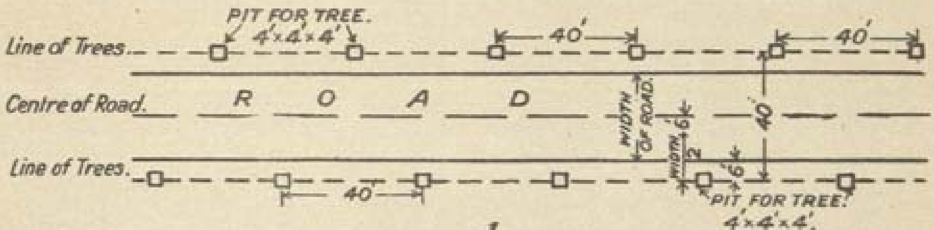
(14) Vitrified brick aggregate has been successfully used at Ahmedabad for both full grout and cement concrete; laid in 1931-32, both surfaces are still giving service.

(15) It is a waste of money to try to grout laterite, but after priming surface-dressing other surfaces can be laid over it, using hard metal chips the laterite merely serving as a base.

(16) We have had some expensive failures, e.g., 'Corroid' road surface laid in Poona,—cost about the same as for remix or a slightly thinner full grout-failed.

DETAILS OF ARBORICULTURE.

SPACING OF TREES.



1

PLAN OF A PERMANENT NURSERY.

2

AREA STATMENT
- BORDER .... 16,096 SQ.FT.
- MAIN ROAD .... 25,344 "
- CENTRAL 6 FT. PATHS .... 7,824 "
- 16 PLOTS EACH 6,000 SQ.FT. .... 96,000 "

TOTAL AREA .... 145,264 "
DITCH .... 5,200 "
GRAND TOTAL 150,464

CHAPTER VI—ROADSIDE ARBORICULTURE
(PLATES LXXIV & LXXV)

I. SELECTION OF AVENUE TREES AND SPACINGS

1. **Preliminary.**—The question of the provision and maintenance of trees along roadsides is one of real importance because of the welcome shade afforded thereby to wayfarers, the substantial addition to the beauties of the landscape, and the mitigation of the discomforts of long journeys by road.

2. **Selection of trees.**—The best general principle to follow is to select trees of those kinds which are found growing under similar conditions in the district.

As there will be several kinds of trees from which a selection can be made, the final choice should be governed by dense all-year shade, ease of propagation, and hardiness. The last two qualities being equal, a tree which affords the best shade during the hot months should be the first choice.

It is, however, an advantage in dry districts to space the comparatively slow-growing final trees at larger intervals of, say, 50 feet and interpolate fast-growing less valuable trees, so that some shade would be available as soon as possible. These intermediate trees should be cut down as soon as the more permanent trees attain a height of 10 or 12 feet.

3. **Suitable spacings of trees.**—The spacings of trees should vary according to the kinds of trees, from 30′ to 50′ (Fig. 1). For most of the trees a fair distance would be 33 feet, *i.e.*, 60 trees in a mile.

For karanj, nim, mango and tali	33 feet.
For siris, tamarind	40 feet.
For pipal and banyan or vad	50 to 60 feet.

4. **Distances from road centre.**—The distances of trees from the centre of the road will depend on the width of the various roads. No tree should be within 10 feet from the outer edge of the side width. A suitable minimum distance is 20 feet from the road centre which may be increased to even 30 or 40 feet in very moist localities.

Rows on opposite sides of the road should be staggered, i.e., each tree should come, not opposite a tree in the row on the other side, but mid way between two trees on that side as shown in Fig. 1.

Overhanging road-side trees should not be allowed on roads where the rainfall is over 30 inches a year, as otherwise the surface is ruined by drippings. Broad leaved trees are especially destructive.

II. RAISING TREES FORM LONG CUTTINGS AT ROAD SIDE

5. Cuttings begin to be useful for shade earlier than seedlings, etc., and they do not need to be protected so carefully against goats and cattle; cuttings of the ficus species, *viz.*, those of the Wad, Pimpri, Nandruk, etc., grow into as big trees as those reared from seedlings. Cuttings should not be planted near villages or grazing grounds, where mischievous children shake them up, and cattle rub against them, unless it is proposed to protect them by good enclosures.

Cuttings should normally be about 10 feet long, about 6 inches in diameter, and should be planted 3 to 4 feet deep, in an upright position, care being taken to press the soil alround it firmly down.

6. If the cuttings can be kept well-watered, the best season for planting is early spring before the trees prout, when however, watering as above cannot be arranged, cuttings should be planted not later than the end of June ; they thrive best then as the sap in the trees is still rising at the time the cuttings are taken, and the full period of cloudy weather is available for them after they are planted.

7. The rooting of the cutting may be ensured and growth encouraged by breaking through the bark in a few places along the part to be buried as well as by cutting the end buried with a sloping cut. The cuttings should not be more than 48 hours old when planted, and the earth in the pits in which they are planted should be fully moistened at the time of planting and kept moist with the aid of a buried pot filled with water throughout the first monsoon.

Cuttings should be encouraged to grow upwards by removing all sprouts, except those at the top, during the monsoon following that in which they are planted.

8. Such cuttings flourish well with moderate watering, especially in light muram or mixed soils and dry climates. In deep black cotton soils, and adjoining rice lands, they do not thrive well. In places where cartage from distant parts is required, their use becomes prohibitively expensive and the liability to failures in their growth great, since they will then have lost their freshness by the time they reach their destination.

III. PLANTING OUT BY THE ROAD SIDE

9. **Size and age at which are to be planted out.**—It is hardly necessary to point out the desirability of uniformity in the age and growth of trees in avenues, and the bad effect produced when some of the young trees die each year, to be replaced in subsequent years. To minimise the cost of providing and maintaining tree guards and fences and of watering trees scattered along a stretch of road, it is advisable to do as much of the work of tree growing as possible in the nursery and of planting on the road-side none but well grown healthy trees which will not require protection and watering for more than a brief period.

Trees planted in the streets of towns should, as a rule, have a stem free of branches for a height of 9 to 11 feet from the ground, and this rule should be followed whenever possible, with all road-side trees. No trees should be planted by the road-side before they are 5 feet high. Most of the failures in road-side planting are due to the use of too small seedlings or of trees which have not had their roots formed by being transplanted in the nursery. If trees are not transplanted, they may develop long tap roots and, as these have to be docked, before the trees can be planted out at the road-side, they are put out practically without any roots and have small chance of surviving.

The age at which the young trees attain the height required for road-side planting varies with the kind of tree and the soil and the climate.

10. **Season for planting.**—The best season for planting at the road-side is about the beginning of the rains after a good shower has soaked in the soil. Some trees, especially deciduous trees may be satisfactorily planted out in the cold weather, when the leaves have fallen.

11. **Selection of plants in the nursery.**—Only healthy plants should be taken from the nursery for plantingout. Plants with a single erect stem should always be chosen in preference to those whose stems are crooked or forked. The best time to ascertain whether plants are strong and healthy or the reverse

is when they are in full growth in the season before they are required for planting out. At this season the bark of healthy young trees is clear and free from the scaly appearance of sickly plants, and the under bark is a healthy transparent green and full of sap.

12. **Lifting the young plants with and without earth.**—Plants may be lifted and transported either with or without the soil round their roots. The former method is always the safer, where the young trees have been frequently transplanted in the nursery, if sufficient care can be taken to prevent any injury to the roots and the ball of soil containing them. By this method the roots, when planted out, remain in the same position as in the seed beds and there is hardly any check to the growth of the tree. During transport the roots should be prevented from drying by wrapping in damp straw, matting or gunny bags.

13. **Transporting.**—When a ball of earth is taken up round the roots of young trees in transplanting them, the risk of moving is reduced to a minimum. When the nursery is near the locality in which the planting is in progress, this may very easily be done, but it will add a great deal to the cost of carriage should it be necessary to send the plants any distance. It is well to keep the plants without water for ten days or a fortnight, since this will check the formation of tender roots and thereby lessen the risk. But, during the last two or three days before moving, water should be given, since this will greatly facilitate taking up balls of earth with the roots.

The precautions to be taken, while transporting, are those required to prevent the roots and tops from drying. Where the trees can be lifted with a ball of earth round the roots, the main difficulty will be to prevent the earth breaking away from the roots. If the trees are to be conveyed for a short distance only, they may be conveyed in baskets on men's heads when it will only be necessary to prevent the ball from drying. Where they must be conveyed in carts, special precautions must be taken to prevent the earth from being separated from the roots. Each ball may be bound with grass or matting or both, or the balls may be packed in baskets or boxes and the intervals tightly filled with good earth or leaf mould. When the trees have been lifted without the soil round their roots, it is even more necessary to take measures to prevent the roots from drying, and it may be advisable to dip the roots in a compost of cowdung and water of the consistency of cream, if the plants have to be conveyed for any distance. They should then be tied in bundles with straw between the stems, and placed recumbent in the cart, with the roots embedded in moist earth.

In the centre of the bundle should be a core of damp moss or leaves for the plants to lie against. They must be watered as frequently as may be required to prevent the roots becoming dry and the stems and tops may also be damped. Protection from sun and wind should be provided as far as practicable for all plants in transit, and when the plants are packed in bundles, matting or leaves should be bound over the whole bundle.

Plants should not be kept out of the ground longer than is absolutely necessary. While on the ground, waiting to be put into the pits, they should be kept in a shady place lightly covered with earth and watered in dry weather. Where possible, no more plants should be lifted from the nursery than can be planted in the same day. On arrival the plants should be put into the ground without delay. The plant should be held in position by one person while another shovels in the earth. The 'collar', or the place where the stem ends and the root begins, should be held slightly above ground-level. A perfect

junction should be made with the ball round the roots by pressing the soil well home. The planted seedings should be well-watered, after the soil has been pressed home as above.

14. **Preparing pits.**—The pits must be at least of the size required to take in the ball of earth or the roots, with sufficient space to firm the earth filling between the ball or roots and the sides. It is advisable to place a good sized "ghara" in each pit for economy and efficiency in watering. Unless the soil is naturally very rich it is advisable to have a good body of rich soil in the pit to push on the growth of the tree and reduce the period for which maintenance is required. For this reason the pits should be at least 4 feet wide at top and 3 feet wide at bottom and 3 feet deep or $4' \times 4' \times 4'$. In street planting, the size may, with advantage, be increased, but a depth of 4 feet is sufficient. The shape of the pit is immaterial.

The pits should be dug as long as possible before the planting is expected to commence, so that the soil taken from them may weather before it is required for filling in again. The upper soil to a depth of about 1 foot from the surface is the best, and should alone be used for mixing with the manure for filling near the plant. When digging the pit, it should, therefore, be kept on one side for that purpose. In March or April each pit should be half filled with dry leaves which will become saturated on the first fall of rain. In planting, the leaves should be drawn away from the middle and the bottom of the hole, so as to leave a clear space 3 feet deep by 2 feet in diameter, which should be filled in with prepared soil on the centre of which the tree should be planted. If there is any reason to think that a bed of sheet kankar underlies the pit, it should be dug out and removed.

15. **Soil for filling the pits.**—The best soil available should be used. Finally to encourage growth use manure. A cartload of good manure mixed with the soil in a tree pit, at the commencement of the monsoon, shortly after the cutting or plant has been planted will result in a saving of one year's cost of maintenance, which is a heavy item. Where manure cannot be obtained at reasonable rates, a cartload of black soil should be mixed with the soil in the pits in muram or red soil and one of red in black soil pits.

16. **Providing arrangements for watering.**—Watering charges are the main source of expenditure in tree planting and can be reduced by providing each tree pit with a sound earthen pot planted as deep as possible in the pit. A country roof tile (not divided in two for roofing purposes) should be inserted into the mouth of the pot to serve as a channel for the water and to prevent earth falling into the pot. The ordinary ghara holding about two gallons of water, will, when in contact with earth, exude sufficient moisture into the soil in the pit, to keep a sprouted cutting or young plant alive through the dry season. The rate at which water will pass through ghara into the earth depends on the nature of the ghara and of the climate, also on whether or not the gharas are clean and free from earth inside. If the gharas are free from cracks or holes through which water can pass, the water will last from 10 to 20 or more days. Since water carts hold from 100 to 200 gallons, a water cart, making two trips per day, will fill from 100 to 200 gharas per day, or, allowing 25 per cent. loss in cartage, filling gharas, etc., will fill 75 to 150 gharas per day. The gharas must be filled every ten days and one water cart will then serve 750 to 1,500 gharas according to the size of the cart. Where the source of supply is not far distant the smaller cart will fill the larger number.

With this system there is no danger of over-watering, and no waste of water, and at glance at the ghara will show at once whether the mali has been neglecting

his work. It is advisable to give each mali a bamboo pipe about four feet long or some similar arrangement by which he can direct the water with certainty into the ghara while standing outside the guard. Gharas which have been in use a year should be examined at the beginning of the hot weather and replaced, if they are broken, or if their pores have become choked by mud. Fig. 10.

The objection to the plan of using gharas is that unless the ghara is moved at intervals, tree roots are apt to grow lop-sided. A better arrangement is sketched in Fig.3. Good earth to which old manure if, possible, has been added, or road silt, dead leaves, etc., is filled in at the bottom of the hole. On this is built up drystone of the roughest and cheapest description (quarry rubbish, etc.), leaving a cylindrical space in which the seedling is planted, and is surrounded by good soil, and the top is finished off with clean porous material. When the seediling is watered, practically all the water descends evenly all round to the bottom of the drystone, very little is evaporated from the surface and the rootlets are thus induced to grow downwards and are thereby protected from drying by the sun. The holes cost a little, but much less than the value of the watering they save and they give the seedling a good start.

17. **Planting the tree.**—The pits should first be well soaked with water and then filled in with the prepared soil to such a depth that, when the soil has settled, the trees will stand at the right level. The trees should be set so that the earth will stand round the stems at about the same height as in the nursery, being not lower on the stems and not much higher.

18. **Level of planting.**—The following rules cover all ordinary cases :—

(*a*) When the land is high and well drained the trees should be planted flush with the surrounding soil.

(*b*) Where the trees are planted on the side of an embankment, no special precautions are necessary as water can escape down the sloping bank.

(*c*) Where the land is low-lying, the trees should be planted on mounds about one foot high, with a diameter at least three times the height and sides sloping very gently. If the sides are steep or the mound narrow, heavy rain may wash the earth away and expose the roots of the tree, which will then almost certainly die.

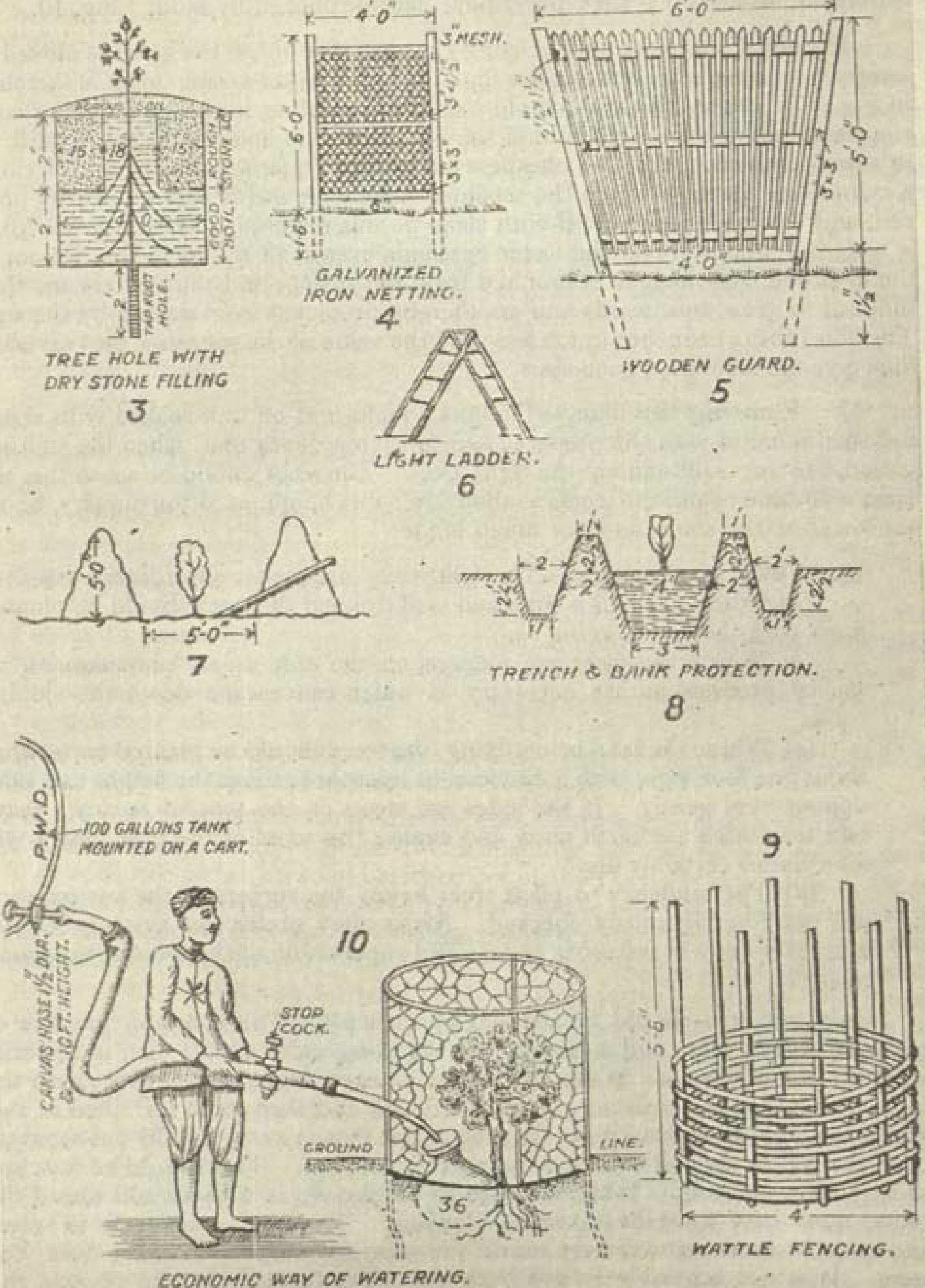
(*d*) The tendency to plant trees below the surface of the surrounding soil must be rigorously checked. Malis often prefer this system, because it saves trouble in watering and careful supervision of this points, therefore, essential.

Only one tree should be planted in each pit. The common practice of planting several trees and subsequently throwing away all but one, is not only wasteful but injurious. If the tree, to be planted, has a ball of soil round the roots, this ball may be placed on the filled soil, and then more soil filled in and firmly trodden down round it. It is essential that the soil should not separate from the ball as the ball will then dry and the tree die. This should be watched shortly after planting. When the tree to be planted is without soil round the roots, more care must be taken in planting. The best practice is to water and ram the earth immediately round the stem for about six inches from the stem. It is not advisable to cut back the roots further than to remove the injured portions with a sharp knife.

There shall always be two or three planters, one to hold the tree in its proper position with its collar at about the point where the final ground level is to be. the

Plate LXXV.

DETAILS OF ARBORICULTURE



others to shovel in the earth round the tree and tread it firmly in, taking care that it is broken up fine and not in large lumps.

The earth should be slightly raised round the stem and lower towards the edge of the hole, so that, when irrigated, the stem may stand in a little island.

If any damage has been done to the roots so that their growth has been in any degree checked, it is advisable to cut back or shorten some of the branches and to remove some of the leaves if excessive. This is of greater importance in proportion to the dryness of the air at the time of planting.

19. **Steadying the young tree.**—It is always necessary the keep the young tree steady until the roots have caught hold of the soil, as otherwise the formation and growth of the roots will be prejudicially affected. If stakes are provided for this purpose two should be used for each tree and these should be placed in the line of prevailing wind. The band or rope should not be tied round the tree, but should touch it for half its circumference only. The bark should be protected from danger by the rope by interposing a piece of cloth. The stakes and ties should be removed as soon as the tree is steady without their assistance.

IV. CONCENTRATION

It is a waste of time and money to start planting trees in scattered places. The whole effort should be concentrated in particular lengths of a road, so that supervision is easy and a maintenance-programme can be arranged. Where construction of a large bridge, etc., is contemplated, tree plantation should be undertaken at the start of the work, so that it may have a good growth by the time the work is finished. Conditions in this case are most favourable, as water is near, and the work can be continuously supervised by the bridge supervision staff. In new plantation work on a road, priority should be given to portions near villages. Great care should be taken to see that failures are immediately replaced, as there is nothing more heart-breaking than to try to fill in gaps in an avenue after the other trees have grown to a good height.

V. PROTECTION

20. The different methods in use are shown in plate LXXV and the decision which of them shall be adopted must depend on the circumstances of the locality. With all forms of guards it is essential that the mali should be able to reach the soil round the tree and to break up the surface with his kurpi.

(a) **Iron guards.**—(Figs. 4 and 10) These may be made of standards of iron hooped together and enclosed with wire netting. They must be strong enough, that is, the standards must be sunk sufficiently deep, to withstand an animal knocking against them. They must also be high enough to prevent animals reaching over the top. They are expensive, but suitable in and near towns where traffic is very heavy, and unsightly forms of guards are open to objection. The best pattern is that made of iron hoop lattice, in two pieces, each framed on iron bars, curved and tapered towards the top. When set up the two pieces are fastened together with wire. This pattern of guard stands firmly, and has the merit that it can be easily taken off a tree that has outgrown the need of it, and carried off for use in another place. X. P. M. bent in a Circle and attached to a strong post serves very well..

(b) **Wooden guards.**—(Fig. 5). Have usually been failures except to a limited extent in and near towns. The remarks made as to iron guards apply here also, while in addition they are often destroyed by white ants, or the materials used by the people for fuel.

(c) Live hedges.—Probably the cheapest protection is a hedge of cactus, not prickly pear; babul, agave and other thorny plants may also be used. They should be planted at least a year before the tree is to be planted so as to give the protection at the time when it is required. They may be made effective, but it is difficult to make them grow evenly and a very small space is sufficient to admit a goat inside the hedge. They should not be allowed too near the tree; four feet is the minimum distance that should be allowed, as otherwise they will compete with the young tree for the moisture in the soil. They must be regularly pruned twice a year in order to prevent their becoming too thick and so stopping light and air from reaching the tree. Where live hedges are adopted, the supervision over them must be constant and vigilant. Lantana should not be planted to form a hedge as it spreads and becomes a big pest.

(d) Thorns.—A circle of thorny branches fixed firmly in the ground round each tree may be very effective, if care is taken, and economical, if thorns are readily to be had in the neighbourhood. They must be firmly fixed in the ground and pegged down if necessary, and the hedge must be made thick and strong. The thorns will have to be renewed and the hedge repaired at least once a year, and careful supervision is required to insure that the hedge is always effective and especially to see that the mali fills up any gaps that he may have made in order to get at the ground round the young trees. To prevent this a light bamboo step ladder should be used (Fig. 6). These hedges have the disadvantage that they are liable to be broken down and stolen for fire-wood. Dry thorn loopings piled up round the trees, with the addition of a mud wall and ditch, may be made a real defence. The inside diameter of the circle enclosed by the wall should be at least six feet, the ditch being outside the wall. The ditch, to be useful, should be two feet deep. Such protections are useful on country roads.

(e) Mud walls.—(Fig. 7.) This is the commonest form of protection and is effective if the wall is kept in proper repair and enough thorns stuck into the top to prevent animals from reaching over it. The cost of this protection is rather high, and where it is adopted, supervision is required to see that the walls are not allowed to fall into disrepair, and that surplus water does not collect inside the guard in wet weather.

(f) Trenches.—The ordinary trench, dug with steep sides close to the young tree is most unsuitable. The tree is left standing on a narrow cylinder of earth which soon washes down into the trench and exposes the roots. Where space is available a trench and bank combined make perhaps the most effective guard of all, provided it is properly laid out.

The hole in which the young tree is planted should be at least 3′ deep and 4′ in diameter at top and 3′ at the bottom. Taking the middle of the tree hole as centre, draw two circles round it, one of 4′ radius and the other of 6′ forming two concentric circles of 8′ and 12′ diameter. Dig out the earth from the space between the two circles, and throw it up on the space between the tree hole and the inner circle, so as to make a trench (Fig. 8), 2½′ deep, 2′ broad at the top and 1′ broad at the bottom, with a sloping mud bank inside it 2′ broad and 2½′ high. Inside the mud wall will be the plant hole. The ditch will thus be at least 3′ distant from the roots of the young tree. Some babul thorns should be stuck into the top of the bank while the earth is wet.

The bank and ditch should be made during the rains after the tree has been planted. Little repair will be required and as soon as the tree is old enough to

dispense with it, the bank can easily be thrown back again into the ditch, and the ground neatly levelled. Before filling in the ditch, it will be as well to take the opportunity of 'mulching' the tree roots by half filling the ditch with dead leaves, and then saturating them with water. This will tend to draw out the roots and give the tree increased power of resisting drought.

(g) **Wire fencing.**—Is durable and not very costly. The wires must be close together for some height from the ground. The standards usually supplied are too light and are damaged by cattle. Near the sea-cost this type is easily destroyed by rust.

(h) **Wattle fencing.**—(Fig. 9.) Used where branches of trees, bamboos, or other suitable material is available; is made by interlacing long flexible branches, basket fasion, round stout uprights embedded in the ground. Such a fence costs little when the material for making it is available on the spot. It has, however, all the disadvantages of other wooden fences.

(i) Reinforced concrete tree guards are now coming into use. Though costly in first cost, they have much to recommend their use :—

(1) Such guards are practically permanent and may be used over and over again.

(2) While casting they may be stamped with the letters 'P. W. D.', and being fairly heavy, are not easily removed.

(3) If made in two or more pieces, they can be easily removed when the tree is well grown.

The best shape is circular in two halves held together by a collar. Half Hume pipes would do quite well.

No fence that does not permit a free circulation of air round a plant should be permitted. Mud or brick walling, and cement concrete pipes should have numerous perforations and the cement concrete pipe should have small openings.

Wind-breaks.—In situations where the young plants are exposed to strong winds, especially strong winds during the monsoon, it is necessary to have some sort of wind-break : while the plants are young, hedges especially if thick live ones, serve the purpose, but when the plant grows higher than the hedge, and the stem is still thin and yielding, to prevent leaning over, it may be necessary to to protect it by wind-breaks, to support the stem by poles, and to decrease resistance to the wind by removing as much foliage as possible without injuring growth.

21. **Removal of guards.**—It is not necessary to remove the tree guards immediately an avenue is classed as 'established'. This should be done only when the lower branches of the trees are sufficiently high to be out of reach of cattle and goats and the trunks are steady enough to withstand cattle. Live hedges should be destroyed at once as the risk of their growing into rank jungle and injuring the tree is too great to be run.

VI WATERING

22. **Need of irrigation.**—In ordinary cases trees require irrigation for the first three years after planting out, but no absolute rule can be laid down, as much depends on the soil and climate and also on the kind of tree. In the rains watering is necessary only during periods of fine weather, but then it is required at very short intervals ; in the cold weather the water lasts much longer, while from March to June constant attention is needed to save the trees from injury.

23. **Water-supply.**—At the time of deciding on the sections of road to be planted the question of water-supply should be considered. If there is no canal, or only one with an intermittent supply, existing wells can be used ; and if there are none, wells must be sunk at convenient distances.

24. **Conveyance to trees.**—Where the distance is not great, water can be carried in gharas, or preferably in kerosene tins, fitted so as to be slung from the shoulders. In this case it is usually necessary to give each mali a labourer as an assistant during the times when frequent irrigation is needed. It may be more economical to employ bhistis with mashaks, those in ordinary use holding about 8 gallons, or bullocks with pakhals holding about 30 gallons. Where the distance is great, economy can be secured by carting the water along the road. It can be carried in barrels mounted on small country carts or in such other way as may be suitable to the locality. It is advisable to give each mali a bamboo or other pipe about 4′ long so that he can direct the water to the required place while standing outside the tree guard. Most kinds of guards suffer a good deal of injury from the constant entrances of the mali.

25. **Application of water.**—The most effective way of applying water to a tree is by means of a ghara buried in the pit as described in paragraph 16, and shown in Fig. 10.

The ghara can be filled with certainty by means of a pipe as described in the last para. Where this method is not employed and water is applied to the surface of the soil, it must be remembered that no trees, except a few which are always found growing by water, will stand the constant application of water to their bark. Road-side trees are frequently killed by kindness of this sort. The bark is split by the sudden change of temperature and the sap-wood roots. It is the roots which need water, not the stem. It is, therefore, well to heap up the earth round the stem and to hollow it out at a distance into a circular ditch, so that, when the water is poured in, the tree stands on a small mound surrounded by water. It is better to give water in good quantity at interval of three or four days than to give smaller supplies daily, as his causes them to send their roots deeper into the soil where the natural moisture is greater and a more steady growth is the result. The best time for applying water is the afternoon.

26. **Loosening the surface soil.**—It is important to keep the surface soil for a foot distance all round the trees as loose as possible. A hard crust on the surface is injurious to the young trees, and in particular makes the oil below dry much faster than if the surface is kept loose. Where water is applied direct to the surface of the soil, the ground should be hoed with the kurpi after each watering ; where gharas are used, hoeing should be done whenever the surface is getting compact.

27. **Special measures in droughts.**—Special care is needed to secure that irrigation is adequate in seasons of drought. The responsible official must be on the alert throughout the rains, and when a break is prolonged he must take instant measures to secure that the trees are getting enough water. A year's work may often be thrown away by neglect for a very few days at this season.

28. **Replacing failures.**—If a length of road has been planted early in the rainy season, the trees should be examined carefully after three weeks or a month, and any that have not made a good start should be pulled up and replaced by new plants from the nursery.

VII. PRUNING AND LOPPING

29. **Object.**—The object of pruning is to obtain a straight shapely healthy tree. It should begin in the nursery and continue almost to the end of the life of the tree.

Since the tree must not interfere with the traffic on the road, it must have a clear stem free from branches for a height of 8 to 10 ft. If the branches grow horizontally, it may be necessary to shorten some of these; but the height of 11 feet to the first branch should not be exceeded.

30. **Forming straight boles in young roadside trees in nursery.**—The natural-tendency of many trees, notably the firs and pines, is to grow with a straight stem and regular conical crown. Other trees, including most of the broad leaf trees, are most irregular in their growth, and naturally have many trunks or great lateral branches. By a judicious pruning, of the lower branches, while the trees are young and small trees growing along roads may be given tall, straight stems.

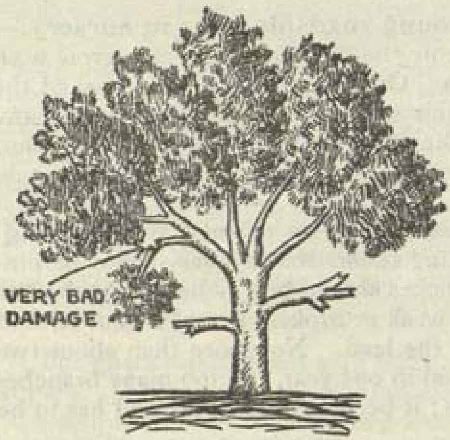
To obtain these conditions, the **trees should be pruned while young.** The terminal buds of any secondary leading shoots that appear should be pinched off at once; and the lowest lateral branches should be pinched off **each year** while they are **still small.** If the top is weak or broken, it may be cut off and one of the side branches allowed to take the lead. Not more than about two rows or tiers of branches should be removed in one year. If too many branches are removed, the health of the tree suffers; it becomes top heavy and has to be supported.

31. **Roadside pruning.**—Pruning at the roadside will follow the same lines until the stem is clear of branches for the desired height from the ground. After that, except for the removal of broken branches, the pruning will consist of removing superfluous branches with a view to keeping the tree shapely, to prevent it from obstructing the traffic, to reduce the shade when desirable in the interest of economical road maintenance, and sometimes to rid the trees of certain fungus diseases or insect pests.

32. **Axes not to be used in pruning.**—The pruning of road-side trees in this country is generally done by a coolie climbing the tree and hacking off the branch it is wished to remove at six inches or a foot from the stem, leaving a jagged, unsightly stump. These snags rot and bring about the quick decay of the tree. All this is avoided by using the saw instead of the axe and by cutting off the branches smoothly flush with the stem. Such wounds soon heal and become covered with bark. When cutting back lateral branches, always cut at a fork. Valuable timber trees are constantly hacked to admit a free circulation of the air, as it is called, and are in consequence rendered useless, except for firewood. There are few stations or roadside avenues where such eye-sores are not to be found. **The use of an axe by coolies should be strictly prohibited.**

All prunings should, therefore, be done with the saw or good sharp steel instruments. Small branches or twigs should be cut with a sharp pruning knife, larger branches with the saw or pruning chisel. In removing a large heavy branch first cut through the bark all round with the pruning knife or chisel. Then saw it off roughly about a foot from the trunk, cutting the **underside first,** and afterwards the upper a few inches further from the trunk, and finally saw off the stump : or the pruning chisel may be used first to cut all round the branch before using the saw. In this way there will be no tearing of the bark. After the branch has been removed, any jagged ends left should

be pared smooth with the pruning knife, and then the whole cut should be painted over with tar. The cut, where possible, should be vertical or slant in wards, so that rain water may not lodge on it, or get into the stem through the wound. Where the wound is necessarily large, it should always be covered with tar to protect it against moisture and decay.



TREE BADLY HACKED AND DAMAGED WITH AXE AND RENDERED UNSIGHTLY.

TREE PROPERLY PRUNED.

33. **Season for pruning.**—The end of the cold weather, just before the leaves appear, when growth is least active, is the best season for pruning, as the wounds are then left exposed for the shortest time possible. If done during winter, they remain uncovered too long ; if during the warm weather, when the trees are in full growth, the wounds bleed, and tar, if used, will not adhere to them.

34. **Lopping.**—The proper season is the winter, when the sap is down. A watch must be kept over the established avenue, particularly in the neighbourhood of towns, to see that branches are not being cut for fodder by camel drivers or goat herds. Trees suffer serious injury owing to the repeated stripping of leaves and young branches.

If telegraph and telephone posts are permitted in the close proximity of a tree avenue, the employees of the companies lop down every year, young shoots and branches which touch the wires. It is therefore advisable to keep a good distance between telegraph and telephone poles and the avenue. Where a new line is being laid, while granting permission to erect poles, a condition should be inserted that the poles should be erected at the edge of the road, and that crossings of the road should be at specified places, either underground or if above-ground the wires being kept at a height of 30 feet above the road surface.

VIII. NURSERIES, SEEDS AND SIMPLE INSECTICIDES

35. **General.**—Although avenues may, in some instances, be formed by means of direct sowings or by cuttings, set diredt *in situ*, it is nearly always more economical and satisfactory to plant out young trees which have been reared in nurseries. The first operation in carrying out a scheme for the formation of avenues will be the selection of sites for the nurseries that are required to supply the plants.

36. **Selection of site.**—A good site for a nursery must fulfil several conditions. It must be conveniently situated, both in regard to areas it is to supply with seedlings and to the exercise of efficient supervision.

The soil must be such as is suitable for a garden, i.e., it must be capable of being drained easily, and the most important consideration of all the locality should have a plentiful supply of water available near at hand, in the driest years.

It is often convenient to establish nurseries in the compounds of inspection bungalows and stores, houses and to place the caretaker in charge. This works very well where the caretaker happens to be a carefull gardener. Water is always to be had, the caretaker has plenty of leisure, and the nursery can be inspected by officers using the house. But everything depends on the skill of the caretaker.

37. **Size of nursery.**—Before selecting the site it will be well to determine, at least roughly, the size of the nursery required. This depends of course on the work it will have to do, that is, the number and the age of the seedlings, to be supplied annually. Space must be provided in accordance with the number of years it is intended to keep the young plants in the nursery. For instance, if the seedlings are not to be planted out until they are three years old, space must be provided for a three years' stock of seedlings. Provision must be made for the space required for the roads, which occupy a relatively large area in a well planned nursery, for trenches and paths between the beds, and also for allowing a portion, one-third or one-fourth of the whole area to lie fallow in rotation every year. A liberal percentage of failures, say about 25 per cent must be taken into consideration in fixing the area.

The calculation of the areas required can best be made on the form given, which also enables a record to be made of the work to be done. This should always be laid down from the commencement.

38. **Laying out the nursery.**—The site being settled, the next thing will be to clear the ground, fence, manure, work up and lay out the ground for work and make the requisite water channels. In all cases a nursery should be regular in shape, and rectangular, if possible. This facilitates laying out the beds and trenches and calculating the areas to be sown, etc. Fig. 2, plate LXXIV.

The soil of a nursery requires preliminary preparation before beds can be laid out. Big trees over-shadowing the nursery must be removed, and within the nursery area all shrubs should be pulled up the roots also being taken up. Herbaceous vegetation may be left till the whole area is dug up to a depth of about 18 inches, the soil being thrown up in ridges to permit thorough exposure to the sun and air. After two months of sunning and aeration, the ridges are levelled, are well dug over, and all lumps are broken up. This cultivation should be commenced after the rains and repeated several times before the sowing season. Moderately deep cultivation is sufficient, as for transplanting it is better that the roots should develop near the surface.

TABLE NO. CLIII

Working Scheme for a permanent nursery

Trees to be propagated	Number	How to be propagated	Quantity of cleaned seed required	Seed when to be sown, or cuttings, etc., when to be set	Seed how to be sown, or cuttings, etc., how to be set; distance apart, etc.	Area of seed beds required	Plants how long to remain in seed beds before transplanted
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
						Sq. ft.	
Sissu ..	12,000	Seed ..	2 Seers ..	April ..	In drills 1 ft. apart.	400	9 Months.
Farash ..	6,000	Cuttings..	Do. ..	March	6" apart in trenches 1 ft. apart.	..	..
Kikar ..	18,000	Seed ..	4 Seers ..	July ..	In drill 1 ft. apart.	300	9 Months.
Pipal ..	6,000	Cuttings..	Do. ..	March	6" apart in trenches 1 ft. apart.	..	..
Country mango.	2,000	Seed ..	1 Maund	July ..	In boxes or pots	..	9 Months.
Ber ..	8,000	Do. ..	30 Seers	April ..	In trenches 1 ft. apart.	8,000	Until planted out.
Plums ..	3,000	Cuttings..	Do. ..	March	Do. ..	..	..

Working Scheme for a permanent nursery

Trees to be propagated	Plants how to be planted in nursery lines, etc.	Area of nursery lines required	Age at which to be planted out	Total area of nursery lines required	Area to be left fallow each year	Area required for roads, etc.	Total area of nursery required	Remarks
(1)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
		Sq. ft.		Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	
Sissu ..	In raised trenches 1 ft. apart.	12,000	2 Years ..	24,400				
Farash ..	..	6,000	4 Months	6,000				
Kikar ..	In raised trenches 1 ft. apart.	18,000	2 Years ..	36,300				
Pipal ..	..	6,000	4 Months	3,000	24,000	33,000	146,700	For plan see plate LXXIV.
Country mango.	In raised trenches 1 ft. apart.	2,000	3 Years ..	6,000				
Ber ..	Not to be transplanted.	..	16 Months	8,000				
Plums ..	..	3,000	4 Months	3,000				

39. **Manuring the soil.**—In preparing the soil of a nursery for the first time it will generally be necessary to improve it by adding leaf mould or prepared soil according to its requirements. Stiff clay soil will be improved by the addition of sand or silt from a canal or of charcoal or brick-dust. Sandy soils will be improved by the addition of fine clay or silt from the bottom of a tank or stagnant pool. Lime may be added with advantage to broken up grass land ; both stiff clays and loose sands are improved by lime, but it must be used in small quantities and as old as possible. The best general addition to the nursery soil is, however, vegetable mould obtained from leaves and weeds which have been well decayed. Such mould should be prepared in every nursery, in pits two or three feet deep, situated in a shady place. One or more of these pits should be filled from time to time with leave weeds, etc., which should be kept damp by occasional slight waterings, and so allowed to decay slowly until ready for being mixed with the soil of the seed beds. The leaf mould manure should be laid over the levelled and prepared bed to a depth of 3 to 6 inches according to the poorness of the soil. No other manure should be used for young seedlings.

After the nursery has been some time in use and crops of seedlings have been removed, the soil will become exhausted unless its fertility is maintained by the addition of some strong manure. The manure which can be most easily procured is cow or sheep manure obtained by rotting the droppings of the animals in pits similar to those used for preparing leaf mould. This manure should never be used fresh, but should be very thoroughly rotted, as, otherwise, the grubs contained in it will attack the roots of plants. The dung as it is collected in the pit should be covered with a thin layer of earth to prevent the escape of valuable gases which are held together by the earth. Urine also should be collected and added to the common stock of cow-dung manure. It should never be used as manure unless it is diluted about four times with water. If possible, the manure should be at least two years old. From 300 to 400 maunds of such manure should be used per acre.

40. **Laying out the nursery beds.**—The ground must then be formed into beds for sowing. The trenches between the beds should be from nine inches to one foot deep. The beds ought not to be more than three feet broad, so that the coolies can reach half way across them from either side when weeding. But it will frequently be better to sow on parrallel ridges. Seedlings will grow with greater rapidity on ridges than in beds and will be more easily transplanted. The roads and paths should be laid out so as to meet local requirements and should be 1½ to 2 feet broad for inner paths and about 3 feet broad for the main central paths, and should divide the nursery into more or less equal rectangular divisions.

41. **Sowing in pots and boxes.**—The pots should have holes at the bottom and the boxes should have holes bored in the bottom to provide good drainage. To further ensure this, a layer or two of brick-pieces or potsherds is laid on the bottom, and over this is laid a layer of dry leaves or cocoanut or similar fibre, to prevent earth being washed out and choking the drainage layer. The receptacles are then filled with a compost of equal parts of soil, and leaf mould, to within an inch of the top, and finally half an inch of soil is sifted over it. Pots have mostly to be broken whole planting out on the road., R. C. C. pots can now be manufactured in halves held together by a ring which can be taken apart in planting and can thus be reused indefinitely. Though costly in first cost, they are permanent and therefore cheap in the long run.

42. **Collection of seed.**—Seeds should not be collected until they are ripe. As a rule sound seeds are moist, of full weight, and of a healthy colour and appearance when fit to gather. Many trees shed the seed as soon as it is ripe, and it is often easier to gather the seed while still on the tree. In other cases as sissu, babul, etc., the seed remains on the trees for a long time and keeps well. The seeds should be collected on dry days, and, when gathered, should be spread out to dry in the shade. Well dried seed should be kept in the house for some time in a cool but dry place and then stored in a convenient place. The bag containing the seed should have a little of napthaline powder added to it, and should be kept in an air-tight box. The most important thing to be remembered is that if it be kept in moist condition, it becomes mouldy and will not germinate or if it germinates, it will produce very sickly plants.

43. **Preparing seed for sowing.**—Where the seeds are contained in pods, the pods open naturally when dry and either shed their seed, or at most a little threshing or other manipulation will be required. Where the seeds are enclosed in a fleshy covering, as in the case of ber and edible stone-fruits, this covering can be rotted off by burying the fruit in layers in moist earth or sand. Some seeds, such as those of the teak and gul mohur have hard coverings, which can only be removed by prolonged treatment, by being soaked in water and frequently stirred for a considerable time, or by being buried in moist manure, where they will get both warmth and moisture, and kept there until they are about to germinate. Seeds of the ficus species germinate best if sown on the top of a layer of half-decomposed cowdung in a shady place. Babul seed gathered from goat yards germinate more freely than fresh seed.

44. **Testing seed.**—A rough practical test to ensure soundness, is to place some of the seed on an iron plate nearly red hot, when all the sound seeds will burst before burning, and the proportion of sound seed can then be judged.

45. **Sowing of seeds.**—

Time.—For seeds which deteriorate fast, sowing must be done immediately after they ripen. With those that keep, if there is no difficulty about water-supply, the best time is just before the rains.

Depth of sowing.—Seeds require moisture, warmth and oxygen for germination. If buried too deep oxygen will be deficient, if too near the surface, warmth and oxygen are available, but moisture is deficient. A general rule is to sow a seed to twice or thrice its depth, and if there is a hard testa up to a limit of 3″ deep.

Methods of sowing.—Small seeds are mixed with charcoal powder or sand and broadcast in boxes or pots.

When the seeds are large enough to handle individually, they are put in singly to the required depth.

Very small seeds are scattered as evenly as possible, and then covered with sifted soil, so that they will not be disturbed by watering

Downy seeds like those of the tamarish are mixed with sandy loam and water, and the mixture is spread evenly over the bed, and beaten into it with a flat-board. The watering in this case is done by percolation.

In seed beds, the sowing is done in transverse lines or drills, made with a pointed stick; the distance apart of the drills, and the depth of each hole, depend on the seed size. After the seed is put in, soil is sifted over the hole.

Watering.—The first watering should be given immediately after sowing and should be heavy enough for the moisture to reach the seed. The watering should

be done through fine 'roses' and the pot should be held low, so that the soil is not disturbed. In dry weather the waterıng should be repeated every morning and evening, till the seeds germinate. Posts and seed-beds should be shaded from the mid-day sun.

Guarding of seeds.—The seeds before they germinate must be protected from birds and insects. Birds will do no harm unless the seeds get uncovered. Red ants, however, should be guarded against as they carry away small seeds. The remedy is to surround the seed-box or pot by a water-barrier.

46. **Operation of pricking out.**—The operaton consists in gently lifting the seedlings out of the soil which must have been made moist previously by means of the weeding fork, taking care not to injue the tender roots.

Seedlings when four to six inches high may be transferred thus to a bed or to pots. For some time they should be protected from the hot sun and should not be watered heavily. By repeated tran planting the roots system is kpet under control till the seedling is 5 ft. high ; as far as possible small "kundies" should be used, for they are very easy to manage, besides watering expenses are reduced. They should have a hole which is covered with potshreds and dry leaves and then filled with river earth and manure in the proportion of 2 to 1. They should be kept in the shed for some time. Each pot may be given two handfuls of manure in two months or so according to the health of plants. Healthy plants may be given more manure, and sickly plants less or none Sheep manure should be avoided, or if it is to be given, it should be given in very small quantities and must be well rotted. Pots must be changed from place to place occasionally, lest roots come out. Roots require good aeration, and for this, the soil of the pot should be stirred from time to time . If the pots are buried in loose soil, watering can be reduced, and watering twice a week is sufficient, but when a watering is given it should be given thoroughly and copiously. Scanty watering at short intervals is very injurious.

The best time for pricking out is in the evening when the plant is in resting condition. When the ball of earth is removed from a pot some roots are necessarily injured, or they often cling close to the sides of pots. The roots which are injured, when removing should be cut off to healthy parts, and decayed roots, if any, may also be cut off. A small portion of the crown may be trimmed according to the injury of the roots. There should be a sort of balance between the roots and the leaves. After placing the plant in the pot, the roots should be firmly pressed with soil, and thoroughly watered. Watering should be carried out daily and for some time the plant kept in shade.

Plants may also be raised on a corrugated sheet which may be kept in trench three feet deep ; on this sheet, spread pieces of broken pots, dry leaves and 6 inches of soil, and seed may be sown over this. On this sheet plants may be kept for a long time, say for three years ; advantage of this method is that roots spread along the surface of the sheet, and the plants may be removed at any time. The danger of over-watering is also minimised to a great extent for the excess runs off along the channel into the trench down below.

47. **Watering and care.**—During dry weather, the plants will require to be watered every morning and evening for the first three or four days after being pricked out ; then every evening only, for the next week ; and after that, the interval should be gradually increased, till one good watering once a week is given for plants in nursery beds with subsoil moisture. For plants raised in pots, watering must be more frequent, but sufficient water must be given at each application to soak the soil right to the bottom. The beds of seedlings should always be kept well weeded.

48. **Sickness of plants.**—The health of plants can be ascertained by the general appearance of the leaves. If anything is wrong with the plants, the leaves are the first to indicate it and it can be recognised by the general examination of the plants.—

(1) If the leaves are cut or show any holes, insect disease may be suspected.

(2) If leaves show any mouldy spots which may be coloured in various ways, then fungus disease may be suspected.

(3) If the internodes are large and the leaves too broad, then over-watering may be suspected.

(4) The drying of tips of branches, short internodes and leaves lead to a suspicion, of scanty watering.

(5) The dropping of one side of branch with the remaining branches healthy, then injury to a particular root is suspected.

I. For the first the insects should be traced and destroyed.

II. Fungus disease often indicates over-watering and moist conditions ; if only a few leaves are affected they should be cut off and burnt, or Bordeaux mixture (insecticide) should be tried.

III. If the plant is sick owing to a cause other than the first, then the plant should be repotted in a small pot, using a greater proportion of sand and very little or no manure. While taking out the plant, examine the roots, and see if there are any earth worms or any decayed parts ; the latter should be cut off till healthy parts are reached and the crown, if possible, should be proportionately pruned ; if it is not possible to cut the crown, some of the lower leaves should be removed, and the plant should be kept in a cool shady place, and a very small quantity of water should be given. The soil of the pot should be stirred occasionally when the new leaves make their appearance ; the plant may be given a handful of well rotted cow-dung, and should be gradually removed to the open.

49. **Staff.**—There must be at least one competent mali in every nursery, and more if the size of the nursery requires it. Coolies will be employed under the mali for sowing, watering and transplanting. These coolies must be trained, as the success of the planting operations depends on skilled transplanting, and on regulating the distribution of water in accordance with the needs of plants. It would be advisable, if practicable, to shift the trained coolies to other nurseries in preference to dismissing them or employing them on other work.

50. **Simple insecticides.—1. Kerosine emulsion.**—Mix two "chataks" of hard or soft soap in half a gallon (2½ seers) of boiling water. Stir till the soap is well dissolved. Then add at once one gallon of kerosine oil. This forms a stock solution. For use, add eight parts of water to one part of this stock solution.

2. Copper sulphate solution.—Take two "chataks" of copper sulphate (tuntia), which may be purchased in any bazar. Dissolve in half a gallon (2½ seers) of boiling water. Add two gallons of cold water for use.

3. Tobacco water.—Boil four "chataks" of dried tobacco leaves in half a gallon of water for about half an hour. Dissolve in this one "chatak" of hard soap. Add three gallons of cold water for use.

51. **Treatment of established trees.**—Established trees should not be neglected. If they are well looked after, their life is extended. They are subject to decay, exposure of roots, and bark being removed ; and to prevent this their stems should be coal tarred 2′ high at least every alternate year, well prunned and wounds, if there be any, should be attended to. No excavation should be allowed near established trees which is likely to damage the roots.

VIII. LIST OF TREES

52. List of trees which are more or less suitable for avenues.

Latin name	Vernacular name or common names	Number or seeds in a seer (80 tolas); or in an oz.	Distance apart from avenues in feet
Acacia arbica	Kikar (H), Babul (M) ..	6,240 (200-300 per oz.)	30
Albizzia Lebbek	Siris (H), Chichola (M) ..	7,420 (140-350 per oz.)	30
Albizzia procera	Safed or Dun Siris (H) ..	900-1,000 per seer ..	30
Aleurites Moluccana	Candle nut tree (Belgaum walnut).	250-300 " ..	30
Artocarpus integrifolia ..	Jack, phanas (M), halasu (K)	150-200 " ..	30
Azadirachta indica	Nim	300-400 " ..	30
Coesalpinia coriaria	Divi divi tree	800-1,000 " ..	30
Calophyllum Inophyllum ..	Undi (M)	150 per seer, 6 fruits an oz.	30
Cedrela Toona	Tuna (H), Todu (M), Tundu (K).	365, 500 a seer (8,000-12,000 an oz.).	30
Dalbergia Sissoo	Shisham, Sissu, Tali ..	23,000 a seer ..	38
Dilenia indica	Motha Karmal (M), Kanagah (K).	46,000 " ..	30
Eucalyptus Tereticoruis ..	Grey gum ; forest red gum	2,000 a seer	20
Eugenia Jambolana	Jamun (H), Jambul (M), Nerale (K).	200 a seer	30
Ficus bengalensis	Banyan (H), Wad (M), Alada (K).	200,000 a seer. (Cuttings also).	40
Ficus religiosa	Pipal (H), Ashvatha (M), Arali (K).	15,000 a seer cuttings also ; not so good as F.B.	30
Ficus mysorensis	Bhurwar (M), Goni (K) ..	15,000 a seer ..	40
Ficus Tsiela	Pipri (M), Bili Basri (K) ..	..	30
Ficus retusa	Nandruk (M), Pilala ..	14,000 a seer. (Cuttings also).	40
Ficus Benjamina	..	12,000 " ..	40
Ficus glomerata	Umbar (M), Guler	10,000 " ..	30
Kigelia pinnata	Sausage tree	450 " ..	25
Mangifera indica	Mango, Am	42 " ..	30
Mesua ferrea	Nagachampa (M), Naga Sampighi (K).	5,800 " .. (150-200 per oz.).	20
Michelia Champaca	Champa (M), Sampighi (K)	500 a seer	25

Latin name	Vernacular names or common names	Number or seeds in a seer (80 tolas); or in an oz.	Distance apart from avenues in feet
Millingtonia hortensis ..	Indian cork tree, Akas nim (H).	..	20
Mimusops Elengi	Mulsari (H), Wovali (M), Bakul Pagade (K).	300 a seer	30
Mimusops hexandra	Khirni (H), Rayan (M) ..	5,450	40
Parkia biglandulosa	..	500 a seer	40
Peltophorum ferrugineum ..	..	1,000	25
Pithecolobium Saman ..	Rain tree	1,200 a seer. (Seeds and cuttings).	30 in dry climates, 50 in moist.
Poinciana elata	White gold mohur	..	25
Polyalthia longifolia	Asok (H), Asupal Devidari (G), Putranjivi (K).	400	30
Pongamia glabra	Karanj (M), Honge (K), Kanaj (G).	200 a seer .. .. 12·20 an oz.	30
Pterocarpus indicus	Padouk (Burma) (Malay Padauk).	1,000 a seer	30
Pterospermum acerifolium ..	(Burma) (North Kanara) ..	5,000	30
Pterospermum suberifolium ..	..	6,000	30
Pterospermum hyneanum ..	..	..	
Swietenia macrophylla ..	Large leaved Mahogany ..	1,000 a seer, 45 an oz.	30
Tamarindus indica	Imli (H), Chinch (M), Hunase (K).	500 a seer	40
Terminalia belerica	Behera (H), Balra Beheda (M), Jare (K), The Belleric Myro balan.	250 a seer	50
Terminalia Arjuna	Arjuna Kawa (H), Daula Sadar (G).	300 a seer	50
Thespesia populnea	Bhendi (M), Huvarasi (K)..	800 a seer	30
Vateria indica	Dhupada Gugli (K) ..	500 a seer	30
Casuarina equisetifolia ..	The beef wood tree ..	20,000 a seer ..	25

53. **Avenues in Sind.**—The trees commonly grown on roads in Sind are :—

bar (banyan), pipal, siris, nim, tali (or sinju), bahan, tun, lesuri, babul, jammu, pakria or pipri (ficus tsiela), and ber.

For resistance to drought and excess of water the babul is the best and ber the next best. The only other tree which approaches them is the bahan. In rice lands or very dry places it is best to grow nothing but babul with a few other kinds at the canal bridges for the sake of variety. For resistance to frost tali and bahan are the best, while the babul is about the worst in this respect. The mulbery and the Persian nim also resist frost, but are difficult to grow on the roadside in Sind. The babul and the ber are the only trees in this list

which will grow in real kalar. In sandy places the nim is the best and the tali and the bahan the next best. For shade all the trees in the list are good except the bahan, tun, babul and ber. The last two give fair shade from August to March, but not during the rest of the year when shade is most wanted.

(b) General rate abstracts (No. 134).

(1) For maintenance in a nursery.

Description	Quantity	Rate	Per	Amount	Remarks
		Rs. a. p.		Rs. a. p.	
Kundas at site	105 No.		100		5 per cent. for breakage.
Earth in kundas	52 cft.		100 cft.		
Manure do.	10 cft.		20 cft.		
Watering in the nursery for three years every alternate day $\frac{1}{6}$ of a coolie= $3 \times \frac{365}{2} \times \frac{1}{6}$	91 No.		1 No.		
Sundries such as supervision charges, etc.	Lot				
Total for 100 plant ..					
Rate per one plant ..					

(2) The carriage of the plants for plantation depends upon the lead. One cart generally takes about 30 plants and the cost per mile is Re. 0-3-0 ; so the cost per plant per mile=1/10 anna only.

(3) Maintenance of the plants on roadside including planting and watering, distance of latter being one mile average :—

Description	Quantity	Rate	Per	Amount	Remarks
		Rs. a. p.		Rs. a. p.	
Making pits 4′×4′×4′ in soil ..	100 No.		1 No.		
Filling same with made earth (Earth 5 to 1 manure).	100 No.		1 No.		
Planting trees including 10 per cent. for deaths.	110		1 No.		
New fences including thorn ..	100		1 No.		
Repairing fences 1st to 5th year ..	500		1 No.		
Weeding plants, twice a year from 1st to 5th year, 2×5×100.	1,000		1 No.		
Renewing fences 2nd to 5th year	400		1 No.		
Watering charges—					
1st year	100		1 No.		
2nd year	100		1 No.		
3rd year	100		1 No.		
4th year	100		1 No.		
Sundries such as supervision charges, etc.	..	Lot ..	..		
Total for 100 trees ..					
or cost per tree ..					

P. W. D. HANDBOOK
BOMBAY

Volume II
SECTION V

HYDRAULIC FORMULAE AND DATA, DRAINS, CULVERTS, ETC., ETC.

1949

CHAPTER VII—HYDRAULIC FORMULÆ AND DATA
(PLATES LXXVI—LXXIX)

Below is given a number of the more important hydraulic formulæ which are of general use in the P. W. D.

The following units and symbols are employed.

Units.—1 pound, 1 foot and 1 second are taken as the units of weight, length and time, respectively, except where otherwise expressly stated.

Symbols.—A = area of a cross section in square feet.

c = coefficient of discharge.

d = depth of water in feet, or diameter of pipe in feet, or rainfall in inches.

g = acceleration due to gravity, taken as 32 feet per second each second.

H = maximum head of water in feet.

h = head of water in feet.

h = head in feet required to produce velocity of approach.

L, l = length of a notch, weir, pipe, etc., in feet.

M = area of catchment basin in square miles.

μ = coefficient of fluid friction.

n = ratio of base to height of slopes.

p = pressure at a point in lbs. per square foot.

P_h = pressure at a depth of h feet in lbs. per square foot.

π = atmospheric pressure in lbs. per square foot.

Q = volume of discharge in cubic feet per second.

r = hydraulic mean depth in feet.

S = area of water surface in square feet.

s = sine of slope.

t = time in seconds.

v = velocity in feet per second.

w = weight in lbs. of a cubic foot of water=$62\frac{1}{2}$ lbs.

x = afflux in feet.

z = height of water surface in feet above datum.

Discharge through small orifices.

1. Pressure at a point h feet below the surface of water.

   $P_h = wh.$

2. Volume of flow.

   $Q = Av.$

3. If A, A_1 are the areas of two cross-sections of a stream, v, v_1 the mean velocities at those sections, then

$$\frac{v}{v_1} = \frac{A_1}{A}$$ or the velocities are inversely as the areas.

4. Discharge through small orifices.

Theoretic discharge $= Av = A\sqrt{2gh}$.

If Va = actual velocity, $Va = 0{\cdot}97\sqrt{2gh}$.

If c_c A = area of contracted jet, $c_cA = 0{\cdot}64A$.

Actual discharge $= Q = 0{\cdot}97 \times 0{\cdot}64A\sqrt{2gh}$.

$= 0{\cdot}62A\sqrt{2gh}$.

$= 5A\sqrt{h}$ approximately.

Expressed in terms of the total head, 38½ per cent. of it is employed in producing velocity and 61½ per cent. is lost by contraction and resistance. (Fig. 1.)

5. For bellomouths, discharge $Q = 0{\cdot}97A\sqrt{2gh}$.

The proportions of a bellmouth are as in Fig. 2.

6. Values of coefficients of discharge for different mouthpieces are a under :—

(*a*) Internal cylindrical mouthpiece (Fig. 3) .. .. 0·52
(*b*) Orifice in a thin plate (Fig. 4) .. .. 0·62
(*c*) External cylindrical mouthpiece (Fig. 5) .. .. 0·82
(*d*) Conical convergent (5°) mouthpiece (Fig. 6) .. .. 0·92
(*e*) Conical convergent (13° 24′) mouthpiece (Fig. 7) .. 0·94
(*f*) Mouthpiece of the form of countracted vein (Fig. 8) .. 0·97
(*g*) Conical divergent 5° mouthpiece (Fig. 9) .. .. 1·50

7. **Short pipes.**—As the cylindrical adjutage is gradually increased in length so as to become a short pipe, the frictional resistance increases, and the coefficient diminishes as follows :—

Length in diameters	1	2	3	5	10	15	25	50
Coefficient of discharge (for new pipes)	0·62	0·82	0·815	0·79	0·77	0·74	0·71	0·64
Coefficient of discharge (for old pipes)	0·62	0·79	0·78	0·76	0·72	0·69	0·63	0·53

Length in diameters	75	100	150	200	250	300	1000
Coefficient of discharge (for new pipes)	0·59	0·55	0·49	0·44	0·41	0·38	0·261
Coefficient of discharge (for old pipes)	0·47	0·43	0·36	0·32	0·29	0·27	0·155

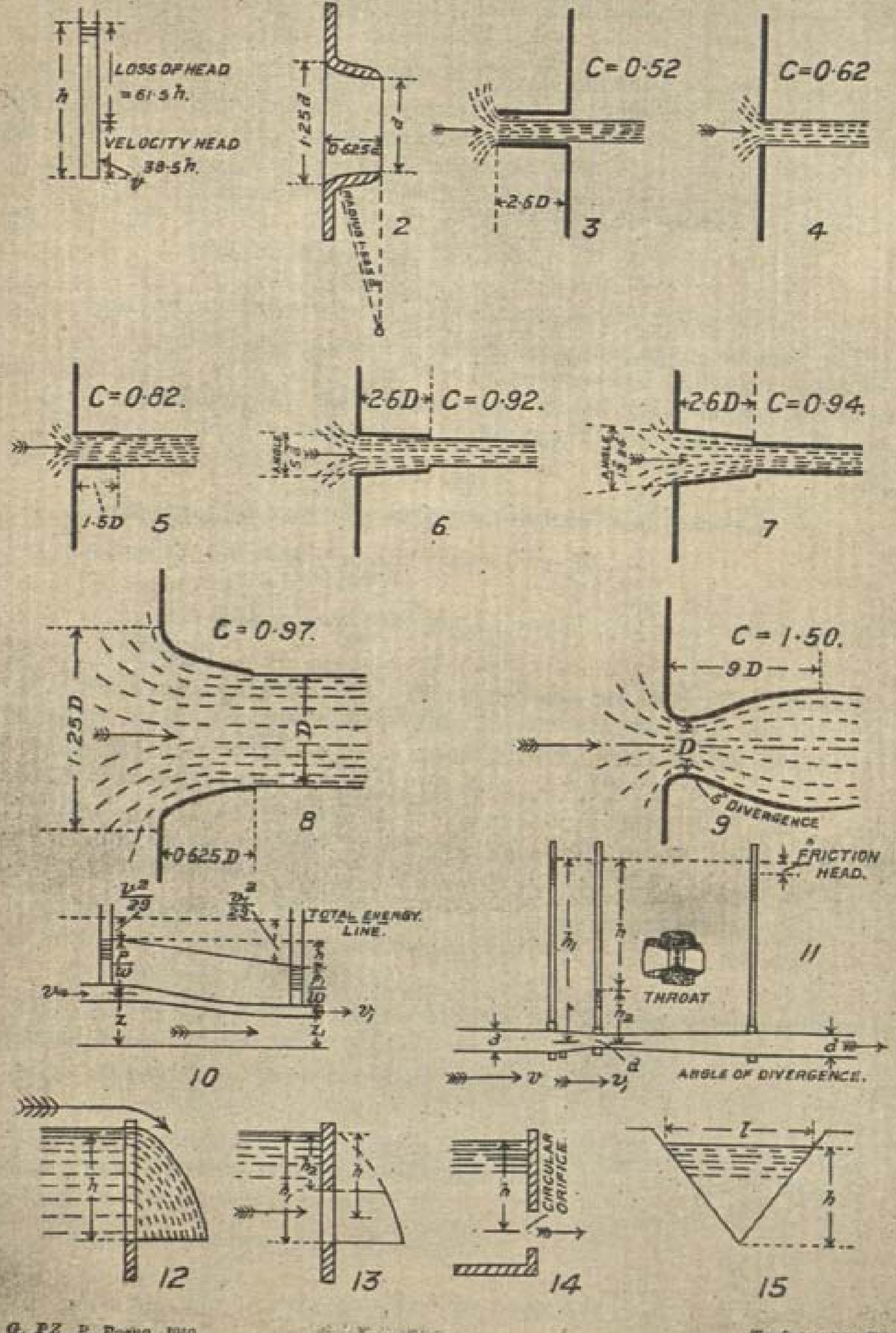
Discharge from large orifices

8. The Bernoulli's theorem, or the application of the law of conservation of energy to flowing water, is expressed algebraically as,

$$\frac{v^2}{2g} + \frac{p}{w} + z = \text{constant},$$ *i.e.*, the sum of the head due to velocity, head due to the pressure, and the height above datum, or the total energy per lb. of water, estimated with reference to the datum line, is uniformly distributed along the stream line.

Plate LXXVI.

DIAGRAMS FOR HYDRAULIC FORMULÆ.



G. PZ. P. Poona, 1919.

To face page 578

9. In a stream line the fall of surface level between two sections is the difference of heights due to velocities at those sections (Fig. 10), or $h = \frac{v_1^2 - v^2}{2g}$.

10. Application of the above principle has been made in the design of the Venturi meter (Fig. 11).

The ratio of the sections at the inlet and throat varies from 5 to 1 to 20 to 1, which is carefully determined by the maker, and the difference of the pressure heads at the inlet and throat is measured on a guage.

$$\text{Then } Q = \left\{ \frac{\pi d^2}{4} \sqrt{\frac{2g}{\frac{d^4}{d_1^4} - 1}} \times 60 \times 6\tfrac{1}{4} \right\} \sqrt{h} \text{ gallons per minute}$$

The figure within the brackets is the constant for the instrument.

A loss of head varying between 1′ and 5′ according to the velocity in the meter takes place. With this meter also an experimental coefficient must be introduced, determined by tank experiment. Coefficients ranging between 0·97 and 1·00 for throat velocities varying between 8′ per second and 28′ per second are to be used.

Discharges of notches, orifices, sluices and weirs.

11. **Rectangular notch** in a thin plate (Fig. 12).—

$Q = \frac{2}{3} c\, l h \sqrt{2gh}.$

where c = 0·62, a mean value for a thin plate for a somewhat varying coefficient.

12. For a rectangular notch in a thin plate, with two full end contractions, if the length of the notch is not less than three times the head, the formula $Q = \frac{2}{3} c\, (l - 0{\cdot}2h)\, h \sqrt{2gh}$ is more accurate. The value of the coefficient remains more constant and is equal to 0·606.

More accurate result is given by the formula $Q = 3{\cdot}10.\ l^{1{\cdot}02}.\ h^{1{\cdot}47}$, and applies to all wires up to at least 19 feet in length, and for thickness of plate $\frac{1}{8}$th inch with bevelled edge.

13. **Rectangular orifice** (Fig. 13). If l be the length of the orifice, h_1 and h_2, the heads to the bottom and top respectively,

$Q = \frac{2}{3} c l \sqrt{2g}\ (h_1^{\frac{3}{2}} - h_2^{\frac{3}{2}}).$

The value of c vary from ·600 to ·633, the highest values being obtained with small heads. Mean value is 0·62.

If his measured to the centre of the orifice,

$Q = cA \sqrt{2gh}.$

The greatest error that can occur is when $h_2 = 0$, *i.e.*, when the orifice becomes a notch, and the maximum error introduced by adopting this approximate formula is 6 per cent. too much.

14. **Circular orifice** (Fig. 14).—

$Q = cA \sqrt{2gh}.$

h = the depth of the centre of the circle and

c = 0·62.

The greatest error that can occur by using this approximate formula, *viz.*, when the circumference of the circle touches the surface, is 4 per cent. too much.

15. **Triangular notch** (Fig. 15). In this form of notch, the ratio $\frac{l}{h}$ remains constant for different heads, and the coefficient c, therefore, is subject to but little variation. This form of notch is, therefore, a good one for the measurement of discharge of small streams.

The approximate formula $Q = cA\sqrt{2gH}$, where H is the head to the centre of gravity of the water section, gives a result about 8 per cent. too high.

The correct discharge $Q = \frac{4}{5} cl \sqrt{2hg^{\frac{3}{2}}}$

The value of c for a right-angled notch, sharp-edged = 0·617 (Unwin).

The accepted formula for a sharp-edged rectangular V notch at present is $2{\cdot}48\ h^{2.48}$ (Barnes "Hydraulics Flow Reviewed") or $2{\cdot}48h^{2.49}$ (V. M. Cone). $2{\cdot}5h^{2.5}$ is near enough for all practical purposes and is easy to calculate and remember.

16. **Cippoletti weir or trapezoidal weir.**—For larer discharges a Cippoletti weir with $\frac{1}{4}$ to 1 side slopes may be used with a $\frac{1}{32}$" sill, cut away at 45°. The depth of water should never be more than $\frac{1}{3}$rd the length of sill. Discharge $=3{\cdot}5h^{\frac{3}{2}}$ nearly. With all these notches utmost care must be taken to see that the velocity of approach is practically nil, and there must be free overfall.

The following table gives the discharges of free overfall of trapzoidal weirs with end slopes, 4 vertical to 1 horizontal.

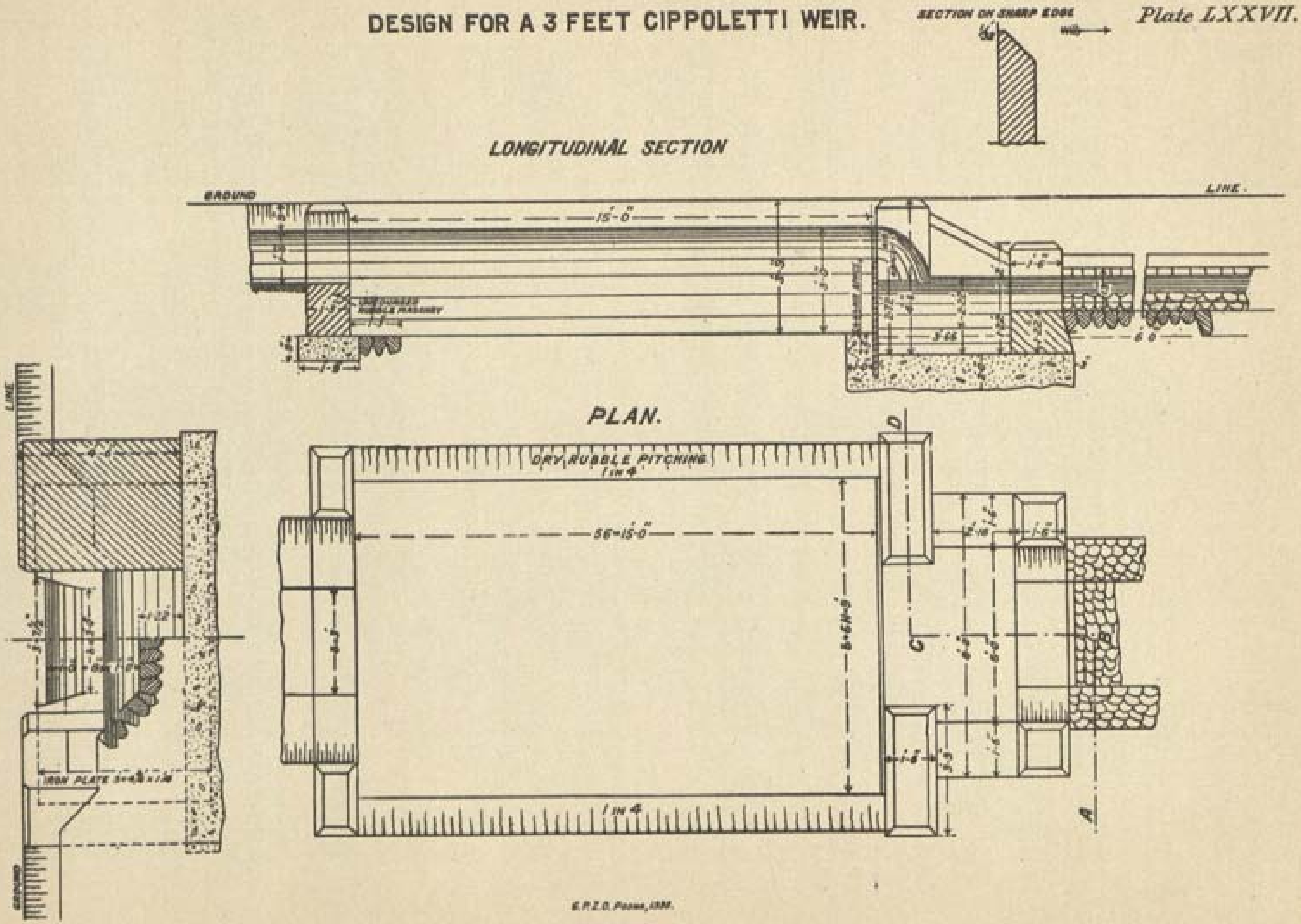
TABLE CLIV

Head	Length of crest			
Feet	6 inches	12 inches	24 inches	36 inches
0·2	0·151	0·301	0·600	0·910
0·3	0·288	0·553	1·110	1·670
0·4	0·463	0·852	1·698	2·566
0·5	0·669	1·200	2·374	3·588
0·6	0·906	1·603	3·132	4·740
0·7	1·186	2·066	3·964	5·992
0·8	1·492	2·565	4·864	7·303
0·9	1·832	3·105	5·801	8·692
1·0	2·194	3·686	6·860	10·190

Note.—The thick lines indicate the limit, $\frac{\text{depth}}{\text{length of sill}} = \frac{1}{3}$.

DESIGN FOR A 3 FEET CIPPOLETTI WEIR.

Plate LXXVII.



In the case of the Cippoletti weir fairly accurate results may be obtained, for partial submersion, by multiplying the figure for free overfall by a coefficient which will vary with the percentage of submersion as under :—

Per cent. submersion	Multiplier	Per cent. submersion	Multiplier
4	0·995	40	0·910
8	0·989	44	0·897
12	0·981	48	0·884
16	0·973	52	0·870
20	0·964	56	0·855
24	0·954	60	0·840
28	0·944	64	0·824
32	0·930	68	0·807
36	0·922	70	0·799

17. **Velocity of approach** (Fig. 16).—If v = the velocity of approach, the head, h, required produce this velocity is $\frac{V_a^2}{2g}$ and the rectangular notch of depth, h, becomes practically a rectangular orifice, the heads to bottom and top of which are (h + h) and h_a. Hence

$$Q = \frac{2}{3} cl \sqrt{2g} \left\{ (h + h_a)^{\frac{3}{2}} - h^{\frac{3}{2}} \right\}$$

The construction of a weir across a river causes an increase of water section immediately above the weir ; consequently the velocity of approach is less than the natural velocity of the stream.

Let A be the natural section, v the velocity,

A_a the section just above weir, v_a the velocity,

Then $v_a = v \frac{A}{A_a}$

18. **Submerged orifice** (Fig. 17).—Calling the difference of level between the water surfaces above and below the opening, h, and the area of the sluice A,

$$Q = cA \sqrt{2gh},$$

average value of c = 0·62 for rectangular orifice.

The coefficient for head sluices is ordinarily taken 0·80.

In bridge and sluice openings, provided with curved cutwaters and wing walls, c is 0·90 to 0·95.

19. **Partially submerged orifice** (Fig. 18).—In this case there are two parts of the discharge : the discharge passing through A, which is not submerged, and that passing through B, which is submerged.

In part A, the discharge is given by the formula—

$$Q_1 = c \times 1 \times \frac{2}{3} \sqrt{2g} \, (h^{\frac{3}{2}} - h_2^{\frac{3}{2}})$$
$$= c \times 1 \times 5{\cdot}35 \, (h^{\frac{3}{2}} - h_2^{\frac{3}{2}})$$

In part B, the discharge is given by the formula—

$$Q_2 = c_1 \times 1 \times (h_1 - h) \sqrt{:} \sqrt{h}$$
$$c_1 \times 1 \, (h_1 - h) \times 8{\cdot}025 \times \sqrt{h}$$

The value of coefficient, c, may be taken equal to 0·62

The value of coefficient, c_1, may be taken as given in the following table.

TABLE CLV

Description of orifice	alue of	
	c_1	$c_1\sqrt{2g}$
Sluices without side walls	0·66	5·30
Canal lock and dock gates	0·70	5·62
Sluices in lock gates	0·83	6·66
Narrow bridge openings	0·90	7·22
Very large well built sluices with side walls .. .. } Wide bridge openings .. .. }	0·94	7·54
Wide openings the bed of which is level with the bottom of the reservior.	0·96	7·70

$$Q = Q_1 + Q_2.$$

Where the difference between h and h_2 is small compared with h_1 the formlæ become—

$$Q{:}\ c_1 \times l\,(h_1 - h_2) \times \sqrt{2gh}.$$
$$c_1 \times l\,(h_1 - h_2) \times 8{\cdot}025 \times \sqrt{h}.$$

20. **Submerged notch** (Fig. 19).—If h_1 be the head to the bottom of notch, and h the difference of level between the water surfaces,

$$Q = cl\ \sqrt{2gh}\,(h_1 - \tfrac{h}{3}),$$

taking the coefficient the same for the two portions of the orifice, c is equal to 0·62

When $h = \frac{h_1}{-}$, standing wave conditions exist.

Then the discharge is $= 3{\cdot}1\ Lh^{1{\cdot}5}$, the downstream water level then having no effect on the discharge.

21. **Discharge of a weir clear overfall.**

$$Q = \tfrac{2}{3}\,cl\ \sqrt{2g}h^{\frac{3}{2}}.$$

The coefficient, c, may ordinarily be taken from the following table :—

Description of weir	Value of	
	c	$\frac{2}{3}c\sqrt{2g}$
Broad-crested or flat-topped weirs	0·577	3·09
Weirs with narrow crests	0·623	3·33
Weir overfalls where l = full width of the channel (*i.e.*, end contractions suppressed).	0·666	3·56

For broad created weirs $Q = 3{\cdot}1.l.\ h^{\frac{3}{2}}$.

22. Where the velocity of approach has to be taken into account, this formula becomes—

$Q = 3{\cdot}1 \times l\left\{(h + h_a)^{\frac{3}{2}} - h_a^{\frac{3}{2}}\right\}$, where h_a is the head due to the velocity of approach (Fig. 20).

Plate LXXVIII

DIAGRAMS FOR HYDRAULIC FORMULÆ

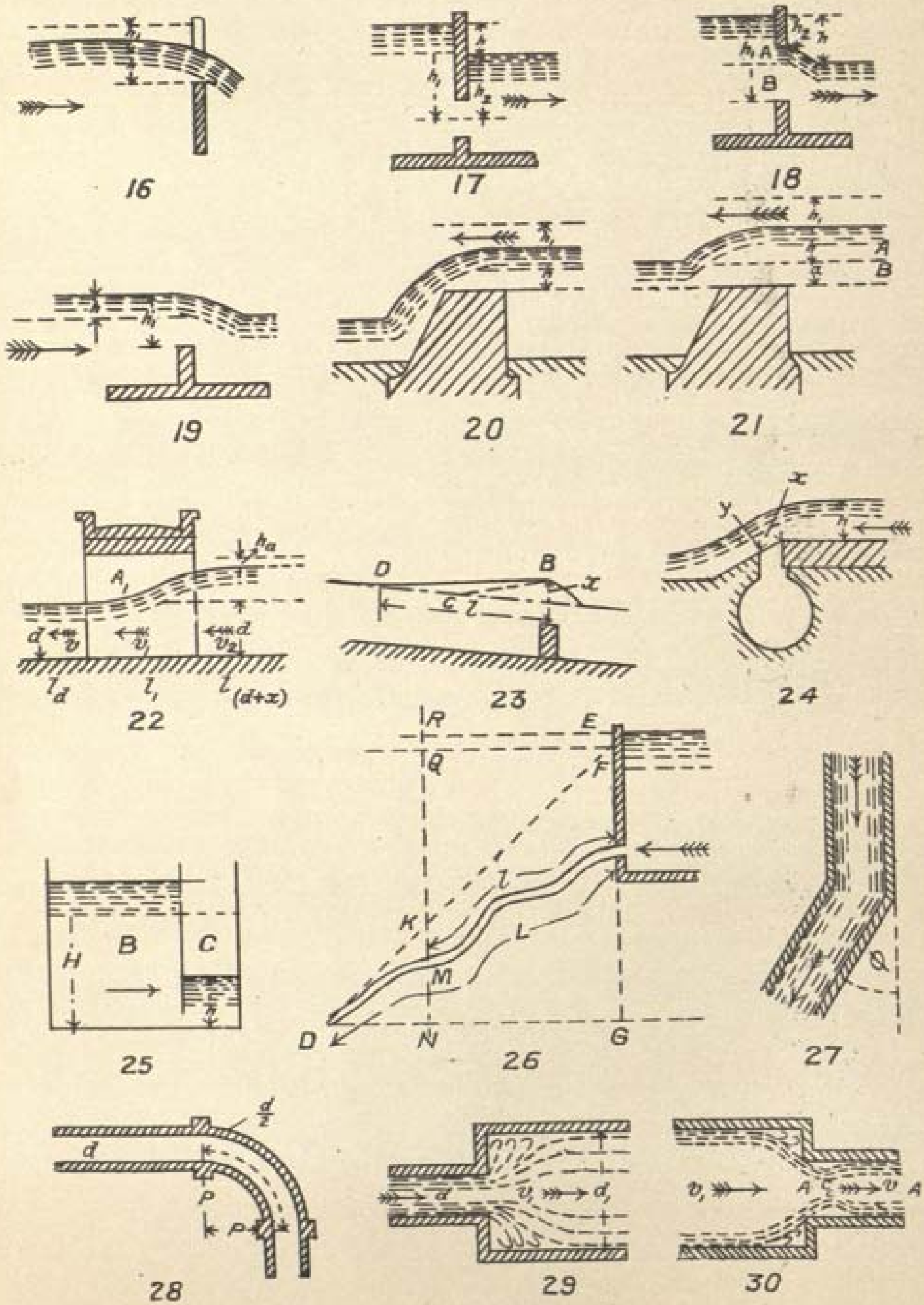


TABLE CLVI.

DISCHARGE IN CUBIC FEET PER SECOND OF WEIRS, WITH A CLEAR OVERFALL, PER LINEAL FOOT OF WEIR BASED ON FORMULAE, PARAGRAPHS 21 AND 22.

Depth on crest	Broad crested or flat topped weirs (c=0·577)					Weirs with narrow crest (c=0.623)				
	Velocity of approach					Velocity of approach				
	Nil.	3 ft.	4 ft.	5 ft.	6 ft.	Nil.	3 ft.	4 ft.	5 ft.	6 ft.
	Cubic feet per second					Cubic feet per second				
0·25	0·38	0·59	0·71	0·83	0·93	0·42	0·68	0·76	0·90	1·00
0·50	1·10	1·41	1·64	1·85	2·07	1·17	1·58	1·76	2·00	2·28
0·75	2·00	2·44	2·72	3·00	3·31	2·16	2·68	2·93	3·23	3·56
1·00	3·09	3·60	3·92	4·33	4·79	3·33	3·83	4·23	4·66	5·16
1·25	4·32	4·88	5·28	5·72	6·27	4·65	5·26	5·69	6·16	6·76
1·50	5·68	6·30	6·77	7·29	7·82	6·12	6·79	7·29	7·86	8·42
1·75	7·15	7·85	8·34	8·78	9·52	7·71	8·45	8·99	9·46	10·26
2·00	8·74	9·49	10·04	10·66	11·34	9·42	10·22	10·82	11·49	12·22
2·25	10·43	10·91	11·83	12·48	13·22	11·22	11·75	12·75	13·45	14·25
2·50	12·21	13·07	13·72	14·43	15·20	13·15	14·09	14·78	15·55	16·38
2·75	14·09	15·02	15·67	16·44	17·27	15·18	16·18	16·88	17·72	18·61
3·00	16·06	17·03	17·74	18·51	19·44	17·31	18·35	19·11	19·95	20·95
3·50	20·23	21·29	22·06	22·96	23·98	21·80	22·94	23·78	24·74	25·84
4·00	24·72	25·86	26·70	27·62	28·77	26·64	27·87	28·77	29·77	31·00
4·50	29·50	30·75	31·58	32·63	33·84	31·77	33·13	33·46	35·16	36·46
5·00	34·55	35·81	36·77	37·82	39·15	37·25	38·59	39·63	40·76	42·19
6·00	45·41	46·87	47·89	48·88	50·61	48·90	50·51	51·62	52·68	54·54

Example.—The water approaches a weir, having a clear overfall, with a velocity of 4 feet per second. The crest of the weir is a board 3 inches thick (narrow crest). The depth on the crest taken by gauge a little upstream of the actual crest) is 1·25 feet. The weir will discharge 5·69 cubic-feet per second for each foot run of weir. That is if the width of the weir is 10 feet, the discharge will be 56·9 cubic feet per second.

23. **Drowned weirs.** (Figure 21.)

Letd = depth of tail water on the crest.

h = actual head.

h_a = head due to velocity of approach.

Q_1 and Q_2, the discharges through h and d respectively.

$$\text{Then } Q_1 = \tfrac{2}{3}\, c_1\, l \sqrt{2g}\left\{(h+h_a)^{\frac{3}{2}} - h_a^{\frac{3}{2}}\right\}$$

$$Q_2 = c_2 l d \sqrt{2g\,(h+h_a)}$$

value oi $c_1 = 0{\cdot}577$

$c_2 = 0{\cdot}80$

$$Q = Q_1 + Q_2 = l\left[3{\cdot}1 \left\{(h + h^a)^{\frac{3}{2}} - h_a^{\frac{3}{2}})\right\} + 6{\cdot}4d\,(h + h_a)^{\frac{1}{2}}\right].$$

Note.—Usually c^2 may be taken equal to c_1 and equal to values of c given in paragraph 21. This is the most generel and useful formula, and its cheif use is to determine h for a known maximum ffood discharge.

The maximum flood discharge is obtained by observation of the rainfall on the catchment basin, checked by measurements of the velocity and the cross-section of the river. The value of h deduced from the formula is added to the given maximum depth at which the river flows, and this enables us to fix the height of the wing walls, head sluices, and flood banks, so that there may be no risk of there being overtopped by the flood. In this case the increased water section above the weir is unknown and he must be obtained by approximation.

Other question can, of course, be solved by above formula, such as (*a*) the amount of flood discharge for observed values of d and h; (*b*) the height to which weir must be built in order to raise the water by a given quantity, when the river is flowing at a given depth. In this latter case, we solve for d. The difference beween d and the depth of the river gives the height of the weir.

Without velocity of approach, and with same values for c for portions A and B, the formula becomes—

$$Q = 4{\cdot}63{\cdot}l.h^{\frac{1}{2}} (d + \tfrac{1}{3}h) \text{ for broad crested weirs.}$$

For standing wave condition see paragraph 20.

24. ***Discharging capacity of over fall weirs with pitched aprons sloped at 1 in 4.**—The discharging capacity of these will be less than those of clear over fall weirs, and greater than those of drowned channel weirs.

Their lengths may be calculated as those of clear overfall weirs and the following imperical percentage allowances added for the total highest flood depths noted below:—

H. F. depths	.. 12″	15″	18″	21″	24″
Percentage allowances to be added	.. 14	13	12	11	10

25. ***Discharging capacity of drowned channel weirs.**—The table below gives the discharging capacity of weirs with flood depths varying from 1 to 3 feet by quarters of a foot. Allowance for end contraction need not be made in this case as the water from the tank will enter the approach channel gradually.

TABLE CLVII

*DISCHARGES OF A WASTE-WEIR CHANNEL HAVING A BED-WIDTH OF 200 FEET AND A BED-SLOPE OF 1 IN 100.

Total depth.	Afflux height d_1	Tail depth d_2	Afflux coefficient, c_1	Channel coefficient, c_2	$\frac{D}{C_1W\sqrt{2g}}$	$\sqrt{d_1(d_2 + \frac{2}{3}d_1)}$	Mean velocity of tail channel.	Discharge, D	Discharge per foot run.
Feet	Feet.	Feet.					Feet per second.	Cusecs.	Cusecs.
1·00	0·30	0·70	0·60	41·00	0·495	0·495	3·40	476	2·38
1·25	0·41	0·84	0·60	44·42	0·707	0·710	4·04	679	3·40
1·50	0·52	0·98	0·60	47·30	0·946	0·956	4·65	911	4·56
1·75	0·63	1·12	0·60	49·90	1·217	1·221	5·23	1,172	5·86
2·00	0·74	1·26	0·60	52·10	1·510	1·505	5·78	1,457	7·29
2·25	0·86	1·39	0·60	54·20	1·830	1·820	6·34	1,763	8·82
2·50	0·98	1·52	0·60	55·90	2·150	2·150	6,83	2,076	10·38
2·75	1·10	1·65	0·60	57·60	2·510	2·500	7·33	2,419	12·10
3·00	1·23	1·77	0·60	59·10	2·870	2·870	7·80	2,761	13·81

*Indian Storage Reservoirs.

26. Discharge through bridge openings (Fig. 22).

Let l and d be the mean width and depth below the bridge; l_1 the lineal water way of the bridge; x the afflux—

$$x=\frac{v^2}{2g}\left\{\frac{l^2}{c^2 l_1^2}-\frac{d^2}{(d+x^2)}\right\}$$

This is a cubic equation for x which may be solved by trial or approximation. Value of c is 0·95.

Assuming the velocity of approach equal to velocity below the bridge, *i.e.*, neglecting x on the right hand side of the equation, we have the approximate formula,

$$x=\frac{v^2}{2g}\left\{\frac{1{\cdot}1\times l^2}{l_1^2}-1\right\},$$

a result which is sufficiently accurate for most practical purposes.

If there is no velocity of approach,

$$x=\frac{v^2}{2g}\left(\frac{1{\cdot}1\times l^2}{l_1^2}\right).$$

Molesworth's Formula for Afflux

V = Velocity of river previous to obstruction in feet per second.
A = Sectional area of river unobstructed in feet.
a = Sectional area of river at obstruction in feet.
R = Rise of water caused by the obstruction in feet.

$$R=\left(\frac{V^2}{58.6}+0{\cdot}05\right)\left\{\left(\frac{A}{a}\right)^2-1\right\}.$$

TABLE CLVIII.

RISE OF WATER OCCASIONED BY OBSTRUCTIONS

Velocity V	Rise in feet when amount of obstruction compared with sectional area of river=								
	1/10	2/10	3/10	4/10	5/10	6/10	7/10	8/10	9/10
1 ..	·01	·04	·07	·12	·20	·35	·67	1·60	6·63
2 ..	·03	·06	·12	·21	·35	·62	1·19	2·83	11·70
3 ..	·04	·11	·21	·36	·61	1·07	2·05	4·88	20·15
4 ..	·07	·18	·33	·57	·97	1·70	3·27	7·75	32·00
5 ..	·11	·27	·50	·85	1·43	2·50	4·81	11·43	47·18
6 ..	·15	·37	·69	1·18	1·99	3·48	6·71	15·93	65·75
7 ..	0·21	0·50	0·92	1·59	2·66	4·65	8·94	21·26	87·71
8 ..	0·27	0·64	1·19	2·04	3·43	6·00	11·52	27·41	113·06
9 ..	0·34	0·80	1·49	2·56	4·30	7·52	14·45	34·37	141·77
10 ..	0·40	0·96	1·77	3·05	5·12	8·96	17·21	40·94	168·89
11 ..	0·50	1·18	2·20	3·79	6·35	11·10	21·34	50·76	209·39
12 ..	0·60	1·38	2·56	4·40	7·37	12·90	24·79	58·97	243·24

Velocity caused by any obstruction $=\frac{1{\cdot}1AV}{a}$.

27. Back-water in an obstructed flowing stream.—If the river bed has a fairly, uniform breadth and slope, the length of the back-water, l (Fig. 23) is given by the equation, 1·5 to 1·9.. x. cosec i, sufficiently accurately for practical purposes i is the surface fall and x is the afflux caused by the obstruction.

28. Separating weir or jump weir (Fig. 24).

$$Y = \frac{x^2}{16\,h}.$$

This gives Y for any assumed values of x and h. h is the depth of water in the channel.

29. Discharge under variable head—

Time of emptying or filling under variable head.

Let S be the area of the water surface in the vessel,
H, its maximum depth above the orifice,
t, the time required for change of head from H to O or from O to H,
A = area of orifice or sluice,

$$t = \frac{2\,SH}{cA\sqrt{2gH}}$$

or the time is double that which would be required to discharge the same volume under a constant head, H.

30. If the head in above diminishes from H to h, or increases from h to H,

$$t = \frac{2\,S}{cA\sqrt{2g}}(\sqrt{H} - \sqrt{h}).$$

Let V_m = velocity through the sluice with the maximum head H in feet per second.

V_a = Average velocity during the time, t; that is, the velocity which would, if it were uniform during the time t, reduce the level in the tank to the same extent in the time.

$V_a = k\,V = k.c.\sqrt{2g}\sqrt{H}$, where k is a factor which bears the values given below for different values of h/H

TABLE CLIX.

$\frac{h}{H}$	k
·0	·500
·1	·658
·2	·724
·3	·774
·4	·816
·5	·854
·6	·887
·7	·918
·8	·947
·9	·974
1·0	1·000

31. **Discharge through a rectangular notch.**—If the discharge takes place from a prismatic vessel through a rectangular notch, and t be the interval during which the head diminishes from H to h.

$$t = \frac{3\,S}{c\,l\sqrt{2g}}\left(\frac{1}{\sqrt{h}} \quad \frac{1}{\sqrt{H}}\right)$$

c=0·62 for a thin plate and 0·577 for broad crested weirs.

32. **Discharge from one prismatic vessel into another.**—In this case, as the surface falls in one vessel, it rises in the other, and the effective head, or the difference of level between the two surfaces, diminishes more rapidly than in the case of free discharge from one vessel.

Let S_1 and S_2 be the water surfaces in the vessels, B, C, respectively (Fig. 25). Let the heads at any instant be H and h. It is required to find the time from that instant until the water has a common surface in the two vessels.

$$t = \frac{2S_1S_2\sqrt{H-h}}{c.A.\sqrt{2g}(S_1+S_2)}$$

Note.—1. The time is the same whichever be the discharging vessel

2. If the vessels are connected by a pipe, take c from article 7.

33. **Flow of water in pipes.**—If water flows with a velocity of v feet per second through a pipe l feet long, the head, h, absorbed in overcoming friction is

$$h = \mu \frac{l}{r} \frac{v^2}{2g}$$

where μ is the coefficient of fluid friction equal to

·005 for new well painted clean and smooth iron pipes.

·01 for old incrusted pipes.

·0026 for a varnished surface.

The above formula is a very useful one, and enables us to find the point on the hydraulic gradient line at any point, in the distribution system.

E G (Fig. 26) is the total head on the mouth of the pipe at D, discharging reely into air.

E F is the loss of head due to resistance of entry and other losses, plus the velocity head.

Then F G is the friction head used up in overcoming friction in length L.

Q K is the head absorbed in overcoming friction in length l, and $= \mu \frac{l}{r} \frac{v^2}{2g}$,

where $v = \frac{c\sqrt{r.\ F G.}}{L}$

Subtracting height QK from the reduced level of F, we get the reduced leval of the hydraulic gradient line at M M K represents the pressure head available at M.

34. There are the following other losses, which are all comparatively small quantities:—

(*a*) where the water leaves the reservoir and enters the conduit or pipe there is a loss of head equal to $\frac{1}{2}.\frac{v^2}{2g}$(resistance of cylindrical entry).

(*b*) loss of head at elbows (Fig. 27) $= (\frac{1}{2}\sin^2\phi)\frac{v^2}{2g} \times$ number of elbows where ϕ is the angle formed by the bent portion of the pipe with the prolongation of the original portion $= K_1$

(*c*) loss of head at bends (Fig. 28$=\left\{0{\cdot}13 - 1{\cdot}85\left(\frac{d}{2\rho}\right)^{\frac{7}{2}}\right\}\frac{v^2}{2g}\times$ number of bends where $\frac{d}{2p}$ is the ratio of the radius of the pipe to that of bend$=K$.

(*d*) loss of head in enlargements (Fig. 29) $= \frac{(v-v)^2}{2g} \times$ number of enargements $= K_3$

(*e*) loss of head in contractions (Fig. 30) $= \frac{v^2}{2g}\left(\frac{1}{c_c}-1\right)^2 \times$ number of contractions, where $c_c = 0{\cdot}6$; and hence loss of head in contractions $= 0{\cdot}44 \frac{v^2}{2g} \times$ number of contractions $= K^4$.

TABLE CLX.

Loss of head due to bends when mean velocity of flow is 1 foot per second. For other velocities, multiply by the square of the velocity:—

Radius of bend / Diameter of pipe	Loss of head for each degree of change of direction
1	0·000025
1·25	0·000018
1·5	0·000015
2·0	0·000013
3·0	0·000011
4·0	0·000011
5·0	0·000011

Example.—Find the loss of head caused by a bend of 20°, of 2 inches radius in a 1″ pipe; velocity of flow 4 feet per second.

$$\frac{\text{Radius of bend}}{\text{Diameter of pipe}} = \frac{2}{1}.\ \text{Hence loss of head} = 0{\cdot}000013 \times 20^\circ \times 4^2.$$

TABLE CLXI.

Loss of head due to elbows $= e\,V^2$, where e can be found from the following table :

A	10°	20°	30°	40°	50°	60°	70°	80°	90°
e	0·0001	0·0005	0·0011	0·0022	0·0036	0·0056	0·0083	0·0115	0·0152

35. The formula applicable to flow of water in pipes, taking frictional and all other losses into account, is expressed in the most general form as under (Fig. 31) :—

$$H = \cdot 5\frac{v^2}{2g} + \frac{v^2}{2g} + \mu\frac{1}{\mu r}\frac{v^2}{2g} + K_1 + K_2 + K_3 + K_4$$

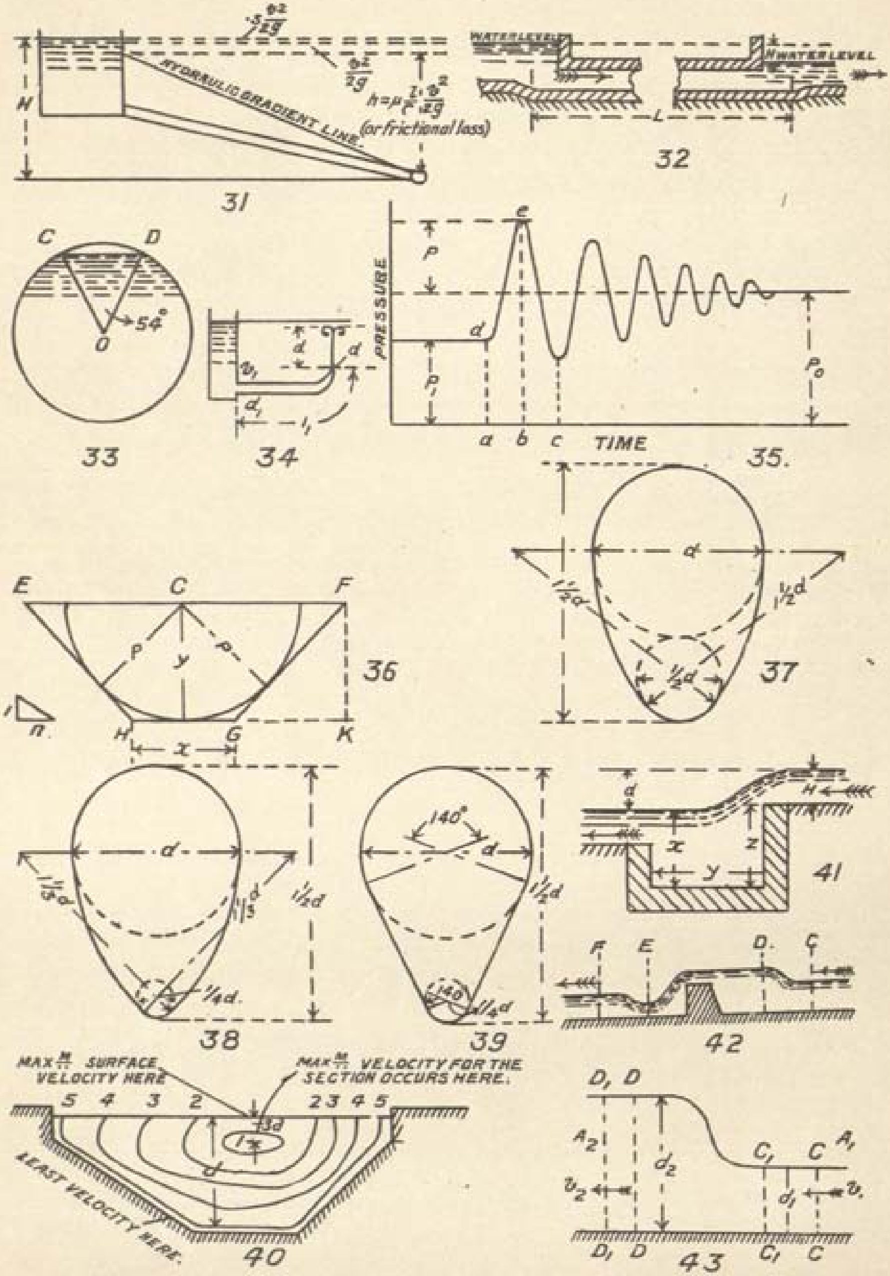
$$H = 1{\cdot}5\frac{v^2}{2g} + \mu\frac{1}{r}.\ \pi\frac{v^2}{2g} + \text{total minor losses.}$$

The total minor losses are a comparatively small quantity and may be left out for simplicity.

36. Transposing, and substituting value of $r = d/4$, velocity through a 'short' pipe is given by the expression

$$v = \sqrt{\frac{2g\,Hd}{1{\cdot}5d + 4\mu l}}$$

DIAGRAMS FOR HYDRAULIC FORMULÆ



G.P.Z.O. 1959.

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37. In long pipes (when the length of the pipe is greater than 1,000 diameters) the head due to velocity is a comparatively small quantity and the term $1{\cdot}5 \frac{v^2}{2g}$ may also be left out for simplification.

Velocity through long pipes is given by the expression,

$$H = \mu \frac{l}{r} \cdot \frac{v^2}{2g}$$

$$\text{or } v = \sqrt{\frac{2g}{\mu}} \sqrt{\frac{H}{l} r}$$

$$\text{or } v = c\sqrt{rS}, \text{ where } c = \sqrt{\frac{2g}{\mu}}.$$

For new pipes value of $\mu = {\cdot}005\,(1 + \frac{1}{12d})$

For old pipes value of $\mu = {\cdot}01\,(1 + \frac{1}{12d})$

For rough or trial calculations c may be taken as 78.

Note.—1. A pipe is said to be 'long' when its length is such that the error in computing v does not exceed 5 per cent; this will be the case when the length of the pipe is greater than 1,000 diameters.

Note.—2. No part of the pipe in a water-supply system should rise above the hydraulic gradient line. At all anticlinal bends air valves are placed to allow accumulated air at these places to escape. These valves cannot act unless the pipe is below the hydraulic gradient.

38. **Discharge through syphons.**—Syphons should be treated as 'short' pipes (para. 36). The loss of head through the barrel of a syphon, where there is no velocity of approach (Fig. 32) may be calculated by the formula, $H = (1 + f_1 + f_2 \frac{l}{r})\frac{v^2}{2g}$

Coefficient f_1 may be taken as 0·08 for a bell-mouthed syphon, and 0·505 for a cylindrical mouth.

Coefficient f_2 is $= \alpha\,(1 + \frac{\beta}{r})$, where the values of α and β are to be taken as follows:—

Inner surface of barrel.	a	B
Smooth iron pipes	0·00497	0·021
Incrusted iron pipes	0·00996	0·021
Smooth cement or planed timber..	0·00316	0·10
Ashlar, brickwork or planks	0·00401	0·23
Rubble masonry or stone pitching	0·00507	0·82

The mean velocity in the barrel when the head, H, is known is—

$$v = \sqrt{2g}\sqrt{\frac{H}{1+f_1+f_2\frac{l}{r}}} = 8{\cdot}025\sqrt{\frac{H}{1+f_1+f_2\frac{l}{r}}}$$

Where there is a velocity of approach (=va), the loss of head through the barrel of a syphon is—

$$H = (1 + f_1 + f_2\frac{l}{r})\,\frac{v^2}{2g} - 0{\cdot}0155\, v_a\, 2;$$

but the head due to the velocity of approach is often neglected to compensate for the loss of head due to the change in direction of the flow of water at the entrance and outflow.

39. The diameter of old pipes is given by the expression, $d = \cdot 2545 \sqrt{\frac{Q^2}{S}}$.

The diameter of new pipes is given by the expression, $d = \cdot 2220 \sqrt{\frac{Q^2}{S}}$.

The effect of doubling the coefficient of friction μ is to increase the diameter of the pipe requisite for a given discharge by 13 per cent.

TABLE No. CLXII.

COMPARATIVE DISCHARGING POWER OF PIPES.

Diameter of pipe	$d^{2\cdot5}$	Diameter of pipe	$d^{2\cdot5}$	Diameter of pipe	$d^{2\cdot5}$
Inches		Inches		Inches	
¼	·031	4	32·00	16	1024·0
⅜	·086	4½	42·96	17	1191·6
½	·177	5	55·90	18	1375
¾	·485	5½	70·94	20	1789
1	1·0	6	88·18	22	2270
1¼	1·747	7	129·6	24	2822
1½	2·756	8	181·0	26	3447
1¾	4·051	9	243·0	28	4149
2¼	5·657	10	316·2	30	4930
2	7·594	11	401·3	32	5793
2½	9·88	12	498·3	34	6741
2¾	12·54	13	609·3	36	7776
3	15·59	14	733·4		
3½	22·92	15	87·14		

40. A rough rule for finding the permissible velocities in town water-supply pipes is, $v = 1\cdot45d + 2$, where v is the velocity in a pipe of diameter d feet.

The following are the maximum velocities permissible in main and distributing pipes:—

Diameter in inches ..	4	8	12	15	24	36
Velocity in feet per second	2·5	3·0	3·5	4·0	5·5	6·5

In short supply pipes to turbines velocities of 7′ to 10′ per second are not unusual. The reason for adopting lower velocities in small mains is that otherwise the loss of head by friction would be excessive.

41. **Pipes not running full.**—The maximum discharge in such a condition is given when the angle C O D is about 54° (Fig. 33).

42. **Jets.**—Water issuing from a small orifice under pressure forms a jet. In order that a jet, supplied by a pipe, may ascend to the greatest height, the pipe adjutage should be of a form which gives a high coefficient of velocity (*e. g.*, 13° 24′ has a coefficient of discharge equal to 0·94).

If v be the velocity of efflux, v_1, the velocity in the conducting pipe (Fig. 34), d, the diameter of the nozzle, d_1, the diameter of pipe, l_1 its length,

$$\text{height of jet, } h = \frac{H}{1 + \mu \frac{4.l}{d_1}\left(\frac{d}{d_1}\right)^4}$$

Allowing for resistance of air, the actual height of jet would be, h (1—.003h).

43. **Water hammer.**—When a valve in a long water main is rapidly closed, the velocity of the column of water behind the valve is retarded and its momentum is destroyed. To change the momentum of water, a backward force must be exerted by the valve on the water, or conversely a forward pressure is exerted by the water on the valve and pipe, which, if the action is rapid enough, produces a shock termed "water hammer." This action is dangerous, and causes in many cases fracture of the pipe. It is provided against by arrangements which prevent a rapid closing of important valves.

If a steam engine indicator is fitted to the pipe, with an arrangement for moving the recording barrel uniformly, a diagram such as is shown in Fig, 35 is produce the abscissae being time, and the ordinates pressure. p_o is the statical pressure in the pipe when the valve is closed; p_1 is the initial pressure with the water flowing before the valve begins to close. If the valve begins to close at d, the pressure rises to a maximum at e, which is in excess of the statical pressure p_o by an amount p. a b is the time of closing the valve. Waves of pressure follow, gradually diminishing till the water in the pipe comes to rest.

Let the initial velocity of water be v and consider a column of water in the pipe of unit cross-section extending back from the valve a distance L feet ; and let t be the time of closing the valve and the pressure be in lbs. per square inch.

Then $p = \frac{0.027Lv}{t} - p_o + p_1$ .... (1)

and $p = 60v - p_o + p_1$ .... (2)

Equation (1) is to be used if t is greater than $\frac{L}{2250}$ seconds.

This equation gives $p = 0,\ t = \text{or} > \frac{\cdot 027Lv}{p_o - p_1}$, which is the condition to be satisfied in closing the valve, if there is to be no water hammer. The theory involves some assumptions, and must be taken only as a general guide.

Flow of stable channels in alluvium

Lacey's theory

From a statistical study of rivers and channels, Mr. Lacey found that a channel flowing in its own silt will, if continued uninterferred with, reach final stability, and where the conditions of discharge and silt remain constant final regime will be attained in time. Lacey's formulae are regime formulae and hence depend on regime conditions, *i.e.*, constant flow and constant silt charge.

Following are Lacey's formulae :—

Q = Discharge in cusecs.
A = Area in square feet.
P = Hydraulic width, commonly known as the wetted perimeter.
D = Hydraulic mean depth.

V = Regime mean velocity.

f = Silt actor which takes the size of silt into account and also the silt charge.

S = Slope.

Na = Absolute regosity coefficient which for a regime channel flowing in its own silt is constant for any particular grade of silt ; it does not vary with the size of a channel as Kutter's and Manning's N do ; hence it is called absolute rugosity, coefficient.

$$V=\frac{1 \cdot 3458}{Na} R^{\frac{3}{4}} \quad S^{\frac{1}{2}} \qquad \ldots\ldots(1)$$

$$4^3\sqrt{2gR^2S} \qquad \ldots\ldots(2)$$

$$= 8\sqrt{R/V}\sqrt{2gRS} \qquad \ldots\ldots(3)$$

$$= 3100 \quad \frac{RS}{f} \qquad \ldots\ldots(4)$$

$$= \frac{f^2}{2340S} \qquad \ldots\ldots(5)$$

$$= 59 \cdot 8\, f^{-\frac{1}{4}} R^{\frac{3}{4}} S^{\frac{1}{2}} \qquad \ldots\ldots(6)$$

$$= 1 \cdot 1512\sqrt{fR} \qquad \ldots\ldots(7)$$

$$Na=0 \cdot 0227\, f^{0 \cdot 25} \qquad \ldots\ldots(8)$$

$$R = \frac{0 \cdot 7340\, V^2}{f} \qquad \ldots\ldots(9)$$

$$S=370 \cdot 68 \times 10^{-6}\, f^{1 \cdot 5} \times R^{-0 \cdot 5} \qquad \ldots\ldots(10)$$

$$P=2 \cdot 6438\sqrt{Q} \qquad \ldots\ldots(11)$$

$$P/R=6 \cdot 9896^{V} \qquad \ldots\ldots(12)$$

Where conditions vary at different times of the year, the diviation from regime conditions which arise can be worked out and compared with regime conditions at maximum or mean discharge. It is then possible to design a chnnel of any size, for the same conditions of variable discharge, by allowing the same percentage deviation in the replicate. It is even possible to design for similar proportionate variations of discharge, for a different discharge and a different silt factor,—*vide* Bombay P. W. D. Technical Paper 46.

Warning—What must never be done, however, is to assume one dimension or a water slope, and then use Lacey's formulae to work out other dimensions, because the error in the assumption may be enormously exaggerated in some of the other dimensions, and will in general be reverse, so that ridiculous resulte are obtained.

Flow of water in channels

44. Velocity of water in an open channel—

Bazin's new formula (1897) is

$v=c\sqrt{rs}$, wher the value of c, the coefficient, is

$$c= \frac{157 \cdot 6}{1+\frac{m}{\sqrt{r}}}$$

The value of m varies with the nature of the channel, thus :—

I.	Very smooth—smooth cement, planed timber ..	0·109
II.	Smooth—plants, ashlar, brick	0·29
III.	Rough—rubble masonry	0·83
IV.	Rougher earth newly dressed, or pitched in whole or part with stone.	1·54
V.	Very rough—ordinary earth channels..	2·36
VI.	Excessively rough—canals encumbered with weeds and boulders.	3·17

TABLE No. CLXIII

BAZIN'S VALUES OF C IN THE EQUATION $V = C\sqrt{rs}$.

Hydraulic mean depth in feet	Values of c form—					
r	(i) 0.109	(ii) 0.290	(iii) 0.83	(iv) 1.54	(v) 2.36	(vi) 3.17
0·1	120·0	82·2	43·5	26·8	18·6	14·2
0·2	126·8	95·7	55·2	35·5	25·1	19·5
0·4	136·2	108·0	68·1	45·9	33·3	26·2
0·6	138·1	114·7	76·1	53·0	39·0	31·0
1..	142·0	122·5	86·2	62·1	47·0	37·8
2..	146·4	131·0	99·3	75·5	59·1	48·6
3..	148·2	135·2	106·5	83·6	66·8	55·8
4..	149·8	137·8	111·4	89·1	72·3	61·0
5..	150·2	139·8	115·0	93·4	76·8	65·3
6..	151·0	141·2	117·9	96·8	80·4	68·8
7..	151·8	142·2	120·2	99·7	83·3	71·7
8..	152·1	143·4	122·0	101·9	85·9	74·1
9..	152·4	143·9	123·4	104·3	88·2	76·8
10..	152·4	144·5	125·1	106·0	90·3	79·0
11..	152·4	145·3	126·2	107·8	92·3	80·7
12..	152·7	145·5	127·1	109·1	93·8	82·3
13..	153·3	146·0	128·2	110·7	95·4	83·9
14..	153·3	146·5	129·3	111·7	96·8	85·4
15..	153·3	147·0	130·1	112·9	98·0	86·7
16..	153·5	147·2	130·7	113·7	99·2	88·0
17..	154·1	147·4	131·3	114·8	100·3	89·1
18..	154·1	147·7	131·9	115·7	101·4	90·2
19..	154·1	147·9	132·6	116·6	102·4	91·4
20..	154·4	148·4	133·2	117·3	103·1	92·3
21..	154·7	149·0	135·2	120·6	107·0	96·5
36..	155.2	149·4	138·4	125·5	113·2	103·0

45. Kutter's coefficients.

$$c = \frac{41{\cdot}6 + \frac{1{\cdot}811}{N} + \frac{0{\cdot}00281}{s}}{1 + \left(41{\cdot}6 + \frac{0{\cdot}00281}{s}\right)\frac{N}{\sqrt{r}}}$$

where s = longitidinal slope

N = coefficient of rugosity, some of whose values are :—

Channels of well planed timber	·009
Channels of neat cement, glazed pipes, very smooth iron pipes ..	·010
Channels of plaster ; smooth iron pipes	·011
Channels of unplaned timber ; ordinary iron pipes	·012
Ashlar and brickwork	·013
Good stone work in fair order. Rough brickwork	·015
Brickwork and stone work in inferior condition	·017
Rubble masonry. Coarse brickwork .. .. Firm gravel	·020
Canals in earth, above the average in order and regimen	0·0225
Rivers and canals in earth, in good order and regimen	·025
Rivers and calans in earth, below the average in order and regimen	0·0275
Rivers and canls in earth, below the average in fair order	·030
Rivers and canals in earth, obstructed by detritus and in bad order and regimen.	0·035
Rivers and canals in earth, obstructed by detritus in rock cutting ..	·035
Torrents encumbered with detritus	0·050

This formula is situated to streams of all sizes, but the aid of tables is necessary.

TABLE CLXIV—*contd.*

KUTTER'S VALUES OF C IN THE EQUATION, $V = C\sqrt{r s}$.

Hydr-rad, r	Values of c for N—						Values of c for N—					
Feet	·010	·015	·020	·025	·030	·040	·010	·015	·020	·025	·030	·040
	Slope = 0·000025						Slope = 0·00005					
0·1 ..	57	33	23	17	14	10	67	39	26	20	16	11
0·2 ..	75	45	31	24	19	14	87	51	35	26	21	15
0·4 ..	97	59	42	32	26	19	109	66	46	35	28	20
0·6 ..	112	69	49	38	31	22	122	76	53	41	33	24
1·0 ..	131	83	60	47	38	28	140	89	64	49	40	29
1·5 ..	148	95	69	55	45	33	154	99	72	57	47	34
2·0 ..	160	104	77	61	50	37	164	107	79	62	51	38
3·28 ..	181	121	90	72	60	45	181	121	90	72	60	45
6·0 ..	206	142	108	88	74	57	199	137	105	85	72	56
10·0 ..	225	159	124	102	87	68	212	149	116	96	82	64
16·0 ..	242	174	138	115	100	79	223	160	126	106	91	73
30·0 ..	261	193	157	133	117	95	236	172	139	118	103	84
50·0 ..	274	207	170	147	130	107	245	181	148	127	112	93

TABLE CLXIV—*contd.*

Hydr-rad, r	Values of c for N—						Values of c for N—					
Feet	·010	·015	·020	·025	·030	·040	·010	·015	·020	·025	·030	·040
	Slope = 0·0001						Slope = 0·0002					
0·1 ..	78	44	30	22	17	12	85	48	32	24	18	12
0·2 ..	98	57	39	29	23	16	105	61	42	31	25	17
0·4 ..	119	72	50	38	31	22	125	76	53	40	32	23
0·6 ..	131	81	57	44	35	25	138	85	60	46	37	26
1·0 ..	147	98	67	52	42	31	151	96	69	54	44	32
1·5 ..	159	103	75	59	48	35	162	105	77	60	49	36
2·0 ..	168	109	81	64	53	39	170	111	82	64	54	40
3·28 ..	181	121	90	72	60	45	181	121	90	72	60	45
6·0 ..	195	134	102	84	71	54	193	132	100	82	69	53
10·0 ..	205	143	111	92	78	62	201	140	108	89	76	60
15·0 ..	212	150	118	98	85	68	207	145	113	95	82	65
30·0 ..	222	160	128	108	95	77	215	154	122	103	89	73
50·0 ..	227	166	134	114	100	83	220	158	126	108	94	78
	Slope = 0·0004						Slope = 0·001					
0·1 ..	89	50	34	25	19	13	94	54	36	27	21	14
0·2 ..	110	65	44	32	25	18	113	66	45	34	27	18
0·4 ..	129	79	55	42	33	23	131	80	56	43	34	24
0·6 ..	140	87	62	47	38	27	142	88	63	48	39	27
1·0 ..	154	98	70	55	45	32	155	99	71	56	45	33
1·5 ..	164	106	78	61	50	37	165	108	78	62	50	37
2·0 ..	170	112	83	65	54	40	171	112	83	66	54	40
4·0 ..	184	124	94	76	63	48	184	124	93	75	63	48
6·0 ..	191	130	99	81	69	53	190	130	99	81	68	52
10·0 ..	199	138	107	88	75	59	197	136	105	87	74	58
20·0 ..	207	146	115	96	83	66	205	144	113	94	81	65
50·0 ..	215	154	123	104	91	75	212	151	120	101	89	72
	Slope = 0·01											
0·1 ..	95	54	36	27	21	14						
0·2 ..	114	67	46	34	27	19						
0·4 ..	133	82	57	44	35	24						
0·6 ..	143	90	64	49	39	28						
1·0 ..	156	99	72	56	45	33						
1·5 ..	165	107	79	62	51	37						
2·0 ..	171	112	83	66	55	40						
3·28 ..	181	121	90	72	60	45						
6·0 ..	190	129	99	81	68	52						
10·0 ..	196	136	105	86	74	58						
20·0 ..	204	143	112	93	80	64						
50·0 ..	210	150	119	100	87	71						

Note.—For slopes steeper than 1 foot per 100 feet, the coefficient c remains practically constant for a given N and r and has the values given in the adjacent columns for S = 0·01.

When r = 3·28 feet the value of c is independent of the slope and its value is $\frac{1.811}{N}$

BEST FORM OF CHANNEL

46. **Channels of minimum border.**—A channel which has a maximum area for a given border, or a minimum border for a given area, is termed a channel of maximum discharge, or a channel of minimum border. Other things being the same, the excavation in a channel will be least when the border will be least.

(*a*) **Closed channels.**—If the channel is closed, *i.e.*, has boundaries on all sides of the water section, the circular is the best form, since this is the figure which has the least border for a given area. In this case H. M. D. $= \frac{d}{4}$, where d is the greatest depth. This form is generally adopted for pipes.

(*b*) **Open channels.**—If the channel is open, and has its greatest breadth at the water surface, the semicircle is the best form. In this case H. M D. = $\frac{\text{diameter}}{4} = \frac{d}{2}$, where d is the greatest depth. This form is adapted to channels cut in rock, or executed in concrete.

(*c*) **Trapezoidal channels.**—If the section of an open channel is polygonal, the best form is that which approaches nearest to the semicircle, *viz.*, a circumscribing regular semi-polygon with an indefinitely large number of sides. As the number of sides is in practical cases limited to three, the best, section for a trapezoidal channel is a semi-haxagon.

(*d*) **Trapezoidal channels with given side slopes.**—If x (Fig. 36) be the bottom width and y the depth of a channel with given side slopes n, the channel of maximum discharge has the following characteristics :—

(I) $x=2y(\sqrt{n^2+1}-n)$

(II) H.M.D.=y

(III) a circle described with c as centre and radius, y, will touch the three sides of the trapezoid, *i.e.*, p=y

(IV) The side slope is equal to half the top width, *i.e.*, CF=FG.

(V) The border is equal to the sum of the top and bottom widths.

The depth of a channel of maximum discharge, with side slopes n to 1, is given by the expression

$$d = \sqrt{\frac{A}{2\sqrt{n^2+1}-n}}$$

so that if any two of the quantities d, A and n are given, the third can be found.

The section of maximum discharge thus obtained can, in practice, be employed only for small channels. With large channels the depth becomes so great that the increased rate involved for extra lift neutralises the saving effected by the reduced area.

(*e*) **Rectangular channels.**—A rectangular channel is a trapezoidal channel with n=o. Then x=2y. The figure for maximum discharge will, therefore, be a half square. The H.M.D.=$\frac{d}{2}$. This form is employed for aqueducts of timber or masonry.

TABLE CLXV

"BEST DISCHARGING" CHANNELS

Side slopes	Depth of water in channel	Width of base of the channel	Width of the top of the channel	Hydraulic mean depth of the channel
	Square root of the area of the waterway of the channel multiplied by—			
Semicircle	·798	0	1·596	·399
0 to 1	·707	1·414	1·414	·354
½ to 1	·759	·938	1.697	·379
¾ to 1	·748	·675	1·996	·374
1 to 1	·740	·613	2·093	·370
1½ to 1	·689	·417	2·484	·345
2 to 1	·636	·300	2·844	·318

47. **Channels for variable discharge,**—When a channel has to carry a variable volume, it is desirable that the velocity should be nearly constant, (*i.e.* neglecting the variation of c), the H.M.D. should be constant, or the border should increase at the same rate as the area. This condition cannot conveniently be secured in earthern channels, but is possible, to some extent, in ovoidal sewers, which are intended for the constant discharge of sewage as well as for the occasional discharge of a comparatively large valume of rain water.

There are three ovoidal or egg-shaped sections generally in use as shown in the following table (Figs. 37, 38, 39) :—

TABLE CLXVI

Type	Depth of flow	Area	H.M.D.	Remarks
(I) The Metropolitan ovoid or old form.	Full ..	$1{\cdot}1485d^2$	$0{\cdot}2897d$	Radius of invert is ½ that of crown.
	⅔ Full ..	$0{\cdot}7558d^2$	$0{\cdot}3157d$	
	⅓ Full ..	$0{\cdot}2840d^2$	$0{\cdot}2066d$	
(II) The new form	Full ..	$1{\cdot}1150d^2$	$0{\cdot}2844d$	Radius of invert is ¼ that of crown.
	⅔ Full ..	$0{\cdot}7223d^2$	$0{\cdot}3074d$	
	⅓ Full ..	$0{\cdot}2543d^2$	$0{\cdot}1920d$	
(III) Jackson's peg.=top ..	Full ..	$1{\cdot}0385d^2$	$0{\cdot}2680d$	Do.
	⅔ Full ..	$0{\cdot}6458d^2$	$0{\cdot}280d$	
	⅓ Full ..	$0{\cdot}2422d^2$	$0{\cdot}190d$	

These culverts are generally executed in brickwork, and have transverse diameters up to 6′. Drains of this form, though covered in at the top, are technically open channels, since they are not intended to discharge under pressure.

48. **Variation in velocity in a cross section.**—The velocity is least in the neighbourhood of the bed and banks (Fig. 40), and greatest in the axis of the stream at a point 0.3d below the surface. If vs be the greatest surface velocity, v*b* the bottom velocity, and v the mean velocity, approximately, their relation is

$$v = {\cdot}8v_s = 1{\cdot}3v_b$$

The relation between *vb* and *vs* is useful, owing to the facility with which v can be measured by surface floats. The relation between v and *vb* enables us, in designing a channel, to assign a velocity which will not be injurious to bed and banks of known consistency of soil. The following mean velocities in feet per second should generally not be exceeded :—

Clay	0.75
Sand	1.50
Pebbles	3.00
Boulders	4.00
Stratified rock	6.00
Hard rock	10.00

Bazin found the following relation between the greatest surface velocity vs and the mean velocity v.

$v=\frac{c}{c+25}Vs$, c being the appropriate coefficient, under paragraph 44.

The following table gives the bottom velocity in a channel which just produces motion in the substances mentioned :—

TABLE CLXVII

Material	Feet per second	Material	Feet per second
Soft earth	0.25	Gravel and coarse sand ..	1.0
Fine clay	0.25	Pebbles 1 inch diameter ..	2.0
Soft clay	0.50	Pebbles, egg size	3.0 to 3.3
Finest clay	0.50	Stones 3 inches diameter ..	5.0
Fine sand	0.70	Boulders, 6″ to 8″ diameter..	6.6
Coarser sand	0.80	Boulders, 12″ to 18″ diameter	10.0

The following table gives the relation between mean velocity, hydraulic mean depth, and erosive or scouring power of a stream :—

TABLE CLXVIII

	There is no scour in a channel of H.M.D.	Until a mean velocity is reached of
	Feet	Feet per second
Fine silt	1.0	0.4
	2.5	0.7
	5.0	0.9
	10.0	1.5
Heavy silt and fine sand	1.0	0.9
	2.5	1.5
	5.0	1.75
	10.0	2.25
Coarse sand	1.0	1.75
	2.5	2.25
	5.0	3.0
	10.0	3.5
Small pebbles (size of peas) and gravel ..	1.0	2.25
	2.25	3.0
	5.0	3.5
	10.0	4.5
Large pebbles (hen's egg size) and coarse gravel	1.0	5.0
	2.5	6.0
	5.0	7.0
	10.0	9.0
Large stones	1.0	15.0
	10.0	23.0

49. **Critical velocity.**—Critical velocity for a channel is that mean velocity which for a channel of a given depth, will just keep the channel, all the year round, free from either silting or scouring its bed, when the water is running fully charged with silt up to the standard usually found in rivers.

The following table gives the critical velocities for varying depths for certain Punjab canals. In the case of canals in Sind, drawn from the Indus, the critical velocity has been assumed to be three-fourths of that applicable to canals in the Punjab :—

TABLE CLXIX

Depth in feet	Critical velocity	Depth in feet	Critical velo ci y
1	0.84	9	3·43
2	1.30	10	3·67
3	1.70	12	4·12
4	2.04	15	4·75
5	2.35	20	5·71
6	2.64	50	10·27
7	2.92	100	16·00
8	3.18		

As a canal, in ordinary soil, cannot usually be made with greater velocity than about 3.5 feet per second, and as the critical velocity is greater than that in canals which have a depth of over 9 feet, it is not desirable to design canals in ordinary soils which are neither to scour nor silt, with a greater depth than about 9 feet, unless the water is not silt laden, or unless the silt it bears is such that the critical velocity is less than that given in the table.

50. **Water cushions.**—(Fig. 41).

If X=the depth of the water-cushion-chamber.
D=the depth of channel or height of water over the top of the weir.
H=difference in the surface level of water above and below the fall.
Y=length of the water-cushion-chamber.
Z=difference in height between the crest of the weir and the bed of the water-cushion-chamber.

then :

$$X = D + \sqrt[3]{D \times \sqrt{H}} \quad \ldots\ldots (1)$$

$$Y = \tfrac{3}{4}\sqrt{Z \times D} \quad \ldots\ldots (2)$$

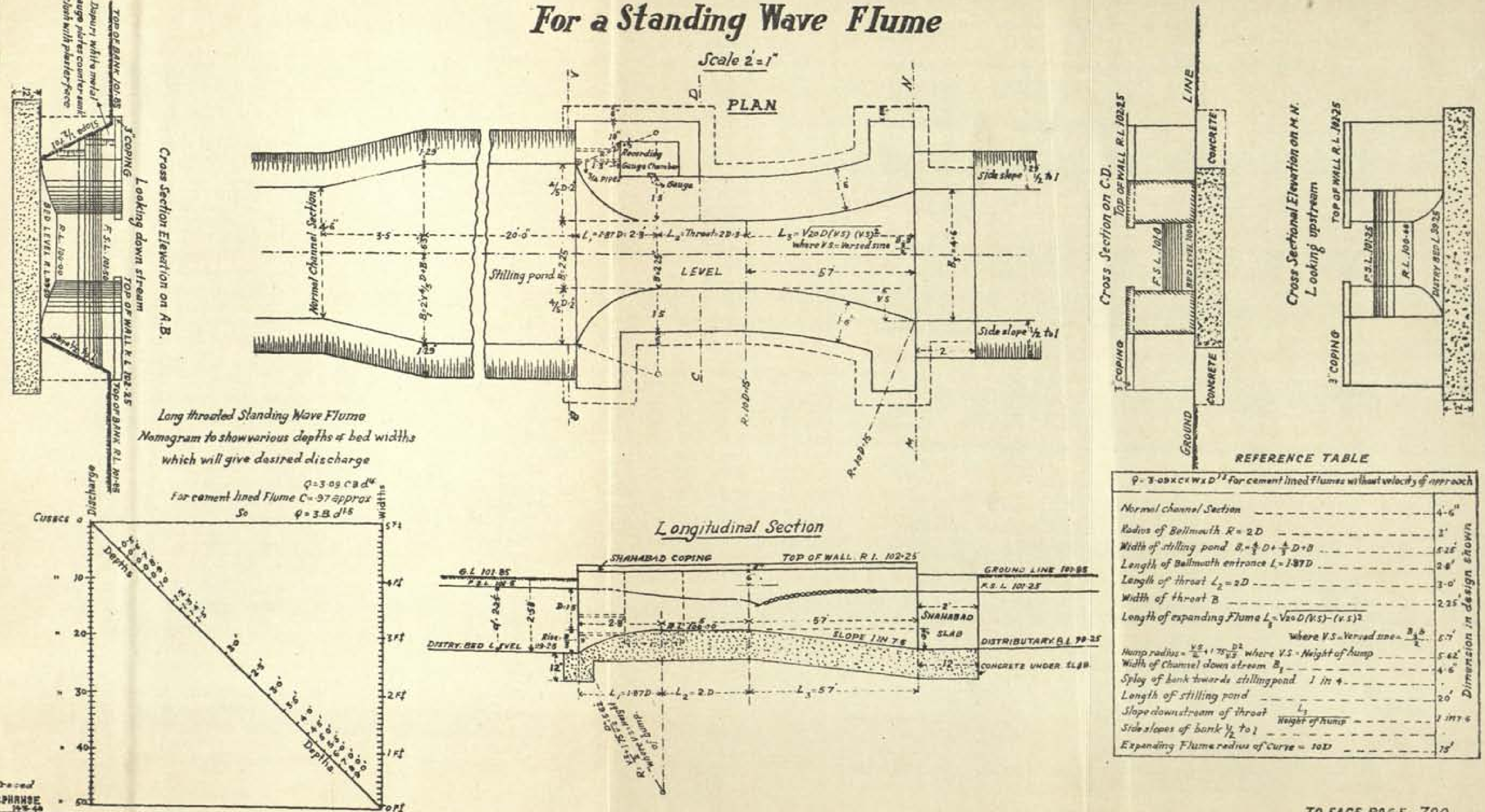
51. **Standing waves or hydraulic jumps.**—If the depth at which a stream is flowing be less than $\frac{v^2}{g}$ and if the depth be increased by any obstruction, then at the point where $d=\frac{v^2}{g}$ (critical depth) the water surface tends to become normal to the bed, and a standing wave is produced. This condition may occur either above or at the foot of a weir, and it may also be noticed on the down-stream side of bridges discharging in flood.

Thus in Fig.42 at the section C, $d < \frac{v^2}{g}$. As the water section increases towards the obstruction, v diminishes, and eventually $d=\frac{v^2}{g}$, between

TYPE DESIGN

For a Standing Wave Flume

PLATE LXXIX-A



REFERENCE TABLE

Q = 3.09 × C × W × $D^{1.5}$ for cement lined flumes without velocity of approach	Dimension in design shown
Normal channel Section	4'-6"
Radius of Bellmouth R = 2D	3'
Width of stilling pond $B_1 = \frac{4}{5}D + \frac{4}{5}D + B$	5.25'
Length of Bellmouth entrance L_1 = 1.87D	2.8'
Length of throat L_2 = 2D	3-0'
Width of throat B	2.25'
Length of expanding Flume $L_3 = \sqrt{20 D (V.S) - (V.S)^2}$ where V.S = Versed sine = $\frac{B_1 - B}{2}$	5.7'
Hump radius = $\frac{V.S}{2} + 1.75 \frac{D^2}{V.S}$ where V.S = Height of hump	5.62'
Width of Channel down stream B_1	4'-6"
Splay of bank towards stilling pond 1 in 4	
Length of stilling pond	20'
Slope downstream of throat $\frac{L_3}{\text{Height of hump}}$	1 in 7.6
Side slopes of bank ½ to 1	
Expanding Flume radius of Curve = 10D	15'

G.P.Z.P./T-285/3-59/20,000.

C and D, when a standing wave is formed. Again at E the depth is so small, and the velocity so great that d may be $< \frac{v^2}{g}$. As the bed generally consists here of a rough stone apron, the velocity rapidly diminishes, and a standing wave will be formed between E and F, as soon as $d = \frac{v^2}{g}$.

The height of the water surface is given by the formula (Fig. 43),

$$d_2 = \sqrt{\frac{2v_1^2}{g} d_1 + \frac{d_1^2}{4}} - \frac{d_1}{2}$$

The height of the standing wave is $d_2 - d_1$

For a standing wave to be possible in earthen channels, s must be greater than .003, or the inclination must not be less than about 16 feet per mile.

52. A SHORT NOTE ON HOW TO DESIGN A STANDING WAVE FLUME

1. **Type of Standing Wave Flume.**—There are two types of flumes—

(1) the weir type which has approximately the same bed-width as that of the channel ;

(2) the flume type (see Plate No. LXXIX-A), with a low hump and narrow throat.

Though the weir type has a certain advantage over the narrow flume type, viz.—

the loss of head is less, due to depth of water being less; yet standing wave flumes type, are almost always preferable to those of the weir type ; because

(*a*) they give nearly proportional supplies and hence do not cause ponding at low supplies ;

(*b*) being narrow they can be combined with road bridges ;

(*c*) small errors in gauge readings have less effect ;

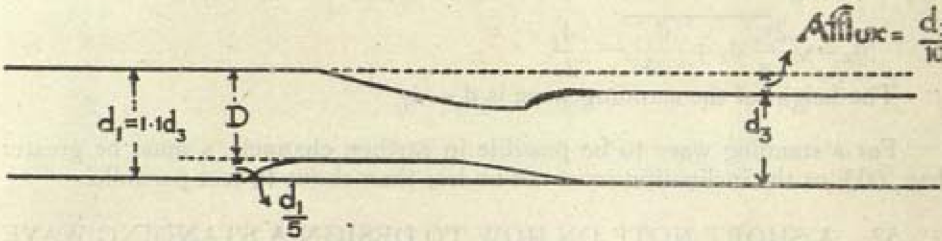
(*d*) velocity of approach has less effect.

This note deals primarily with the flume type (Plate LXXIX-A).

2. **Height of hump.**—The next point to be determined is the height of hump. In order to get a proportional discharge from full supply down to 4/9ths full supply, the height of the hump for Deccan conditions should approximate to $\frac{d_1}{5}$ where d_1 is the depth of water in the channel upstream. If we choose a higher hump, it may cause silting and weed growth for low supplies. Hence for standard designs, height of hump should be taken as $= \frac{d_1}{5}$, in the Deccan, and $\frac{d_1}{10}$ in the Northern India.

3. **Afflux.**—There will be a certain amount of heading up, or afflux, due to the construction of the flume. The amount of afflux, or head lost, will vary according to the design. With no expanding flume the loss of head will be at least $\frac{D}{3}$, whereas with the standard flume design the minimum loss

of head permissible is $\frac{D}{10}$. We can assume afflux to be $\frac{F.S.D}{10}$. or $\frac{d_3}{10}$, where d_3 is the depth of water in the channel downstream of flume, and so d_1, or the depth of water in channel upstream, will be $d_3+\frac{d_3}{10}=1.1d_3$



Knowing the height of the hump and upstream depth of water in the channel, we can find out D or depth of water over sill of flume upstream or $D+\frac{d_1}{5}= d_1$ or $D = 4/5d_1 = 4/5 \times 1{\cdot}1d_3 = {\cdot}88d_3$ and the bed width of the flume can be found out from the formula.

$$Q = 3\ B\ D^{1{\cdot}5}, \text{ where B is throat width in feet.}$$

4. **Channel section upstream and the velocity of approach.**—The velocity of approach should never exceed $\sqrt{D}$' which will give a theoretical error in discharge of 2 1/3 per cent, and a probable error of about $1\frac{1}{2}$ per cent. If it is found that V exceeds $\sqrt{D}$ then we should reduce V. This can be done by

(1) widening the channel section,
(2) deepening the channel,
(3) or both.

The channel should be widened for at least 40 feet upstream, so as to allow a sufficient length for the velocity to get reduced. It is generally best to widen the channel section and the new bed-width of the channel can be easily found out as follows :—

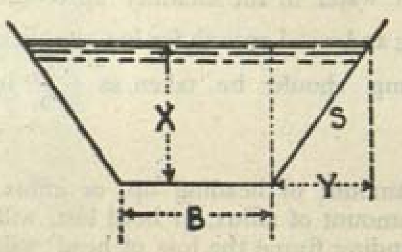


Fig. 2

$$V=\sqrt{D} \quad \& \quad Y=SX$$

$$Q=AV$$

$$=(B+Y)\,X\sqrt{D}$$

where S = ratio of side slope (*i.e.*, $\frac{\frac{1}{2}}{1}$ or $\frac{1}{2}$).

As we know Q, Y, X and D, we can find out B or the new width of the channel. The velocity of approach should also not be less than 0·6 times the non-scouring

and non-silting velocity of V_o or $V > 0{\cdot}6 \times {\cdot}84\, d_1{}^{0.64} = {\cdot}5 d_1{}^{0.64}$

5. **Details of the flume—**

Bell mouth portion.—The upstream radius of the sides = 2D and the length of the bell mouth flume from the beginning of the hump to the flume sill is 1·87D (see Drawing 14/C).

Radius of the hump can be found out as under :—

Let R = radius and X be the height of the hump then $(1{\cdot}87D)^2 = X(2R - X)$.

6. **Throat.**—The length of the throat = 2D.

7. **Expanding Flume.**—The divergence of the expanding flume = 1 IN 10 and the length of the expanding flume will depend upon the nature of foundations, bed strata and recovery of head desired. If it is murum, but little head available, the length can be 2·5D. If the bed is rocky and the head is not precious, the flume may be truncated, *i.e.*, with no expanding flume. In the case of black soil foundation the length of the expanding flume will vary from 3·5D to 5D with additional side protection downstream. The downstream glacis slope can be found out easily after the length of expanding flume and the height of hump have been decided thus —

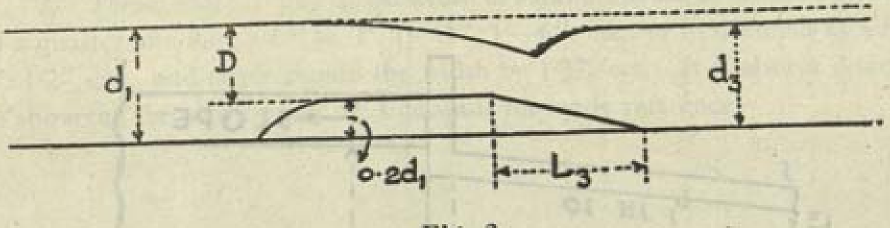


Fig. 3.

Suppose we keep L_3 or the length of the expanding flume as 2·5D and height of hump as $0{\cdot}2d_1$

$$\text{then } D = d_1 - 0{\cdot}2d_1 = 0{\cdot}8d_1$$

$$\text{and } L_3 = 2{\cdot}5D = 2{\cdot}5 \times {\cdot}8d_1 = 2d_1$$

$$\therefore \text{ the glacis slope is 1 in } \frac{2d_1}{0{\cdot}2d_1} = 1 \text{ in } 10.$$

$$\text{If } L_3 = 3D = 3 \times {\cdot}8d_1 = 2{\cdot}4d_1$$

$$\text{and glacis slope will then be 1 in } \frac{2{\cdot}4d_1}{{\cdot}2d_1} = 1 \text{ in } 12.$$

A general equation can be found as under :

Supposing the height of hump $= Xd_1$

and $L_3 = Y.D.$

then $D = d_1 - Xd_1 = d_1 (1-X)$.

and $L_3 = Y.D. = Y.d_1 (1-X)$.

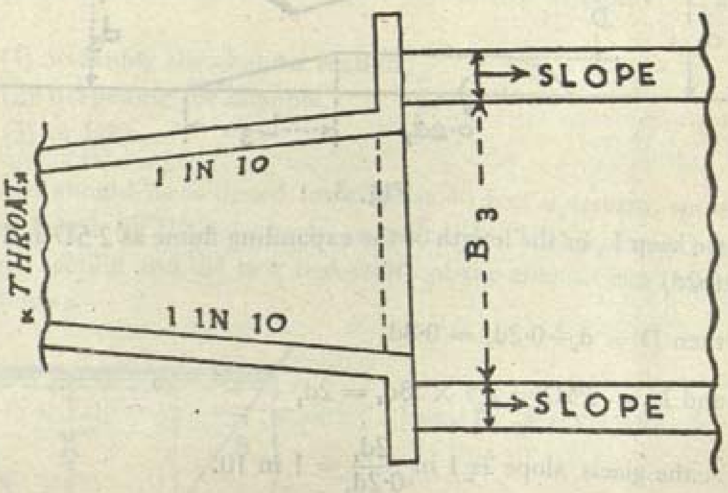
and the glacis slope is 1 in $\frac{Y.d_1 (1-X)}{Xd_1}$ or 1 in $\frac{Y (1-X)}{X}$

8. Stilling chamber upstream of the flume for reading guages.—Due to fluctuations in the water level upstream—due to wind—it may not be possible to read the gauge accurately. To damp out the fluctuations a stilling chamber should be constructed. This should be connected with the upstream face by means of one or two small pipes (Plate LXXIX-A).

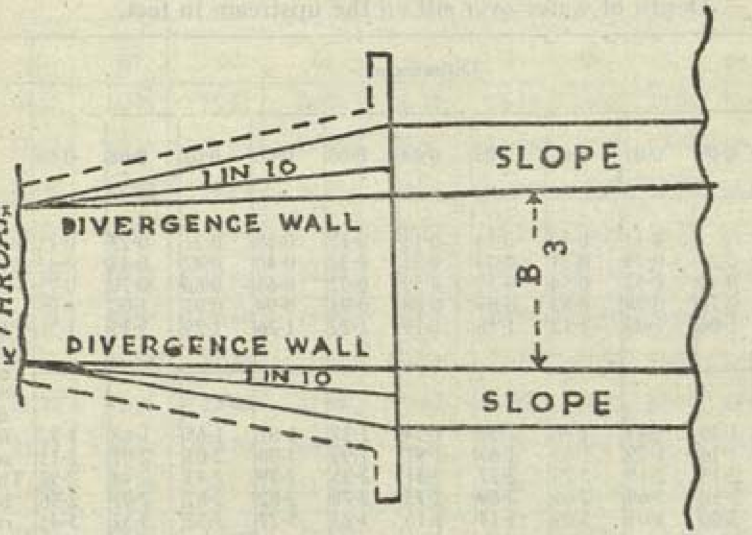
If only one pipe is used the sectional area of the pipe should be about $\frac{1}{400}$ × sectional area of the stilling chamber and if there are two pipes they may be $\frac{1}{600}$ × sectional area of the stilling chamber. At least one pipe must be fixed below minimum water level.

9. Connection of flume with the downstream channel.

(1) Where B3 is greater than the width of the normal 1 in 10 divergence a wall at right angles to the axis of stream should be built at the end of the flume as shown below :—



(2) Where B3 is less than the width of expansion with 1 in 10 divergence, the flume should be connected to the distributary sides as shown below, the sides being warped from the vertical at the throat with a gradually increasing slope :—



It should be borne in mind that where the sides of the downstream channel are friable, slab protection will be required.

2. *Throat width.*—The throat width of a flume should be an exact multiple of a quarter of a foot, such as, 1′, 1′—3″, 1′—6″, etc., or in decimals of a foot, 1′, 1·2″, etc., and never should the width be 1·37 feet. It is always desirable to show the throat width on the side walls for ready reference.

TABLE CLXX

DISCHARGES FOR CRUMP TYPE STANDING WAVE FLUME PER FOOT BREADTH AT THROAT.

$$Q = 3{\cdot}09 \times C \times B \times D^{1{\cdot}5}$$

Q = Discharge in cusecs ; B = Breadth at throat in feet ;
D = Depth of water over sill on the upstream in feet.

Value of D	Differences										Remarks
	0·00	0·01	0·02	0·03	0·04	0·05	0·06	0·07	0·08	0·09	
0·1 ..	..	0·11	0·12	0·14	0·16	0·17	0·19	0·21	0·23	0·25	Example—To find out discharge for D = 0·83, and B = 1·52. Below differences column 0·03 and opposite 0·8 in the first column reads 2·27. This multiplied by 1·25 = 2·84 cusecs.
0·2 ..	0·27	0·29	0·31	0·33	0·35	0·37	0·40	0·42	0·44	0·47	
0·3 ..	0·49	0·52	0·54	0·57	0·59	0·62	0·65	0·68	0·70	0·73	
0·4 ..	0·76	0·79	0·82	0·85	0·88	0·91	0·94	0·97	1·00	1·03	
0·5 ..	1·06	1·09	1·12	1·16	1·19	1·22	1·26	1·29	1·33	1·36	
0·6 ..	1·39	1·43	1·46	1·50	1·54	1·57	1·61	1·65	1·68	1·72	
0·7 ..	1·76	1·79	1·83	1·87	1·91	1·95	1·99	2·03	2·07	2·11	
0·8 ..	2·15	2·19	2·23	2·27	2·31	2·35	2·39	2·43	2·48	2·53	
0·9 ..	2·56	2·60	2·65	2·69	2·73	2·78	2·82	2·87	2·91	2·96	
1·0 ..	3·00	3·05	3·09	3·14	3·18	3·23	3·27	3·32	3·37	3·41	
1·1 ..	3·46	3·51	3·56	3·60	3·65	3·70	3·75	3·80	3·85	3·89	
1·2 ..	3·94	3·99	4·04	4·09	4·14	4·19	4·24	4·29	·34	4·40	
1·3 ..	4·45	4·50	4·55	4·60	4·65	4·71	4·76	4·81	4·86	4·92	
1·4 ..	4·97	5·02	5·08	5·13	5·18	5·24	5·29	5·35	5·40	5·46	
1·5 ..	5·51	5·57	5·62	5·68	5·73	5·79	5·85	5·90	5·96	6·01	
1·6 ..	6·07	6·13	6·19	6·24	6·30	6·36	6·42	6·47	6·53	6·59	Example—To find out discharge for D = 2·48′ and B = 3·′0. Below differences column 0·08 and opposite 2·4 in the first column read 11·72. This multiplied by 3 gives 35·16 cusecs.
1·7 ..	6·65	6·71	6·77	6·83	6·89	6·95	7·00	7·06	7·12	7·18	
1·8 ..	7·24	7·31	7·37	7·43	7·49	7·55	7·61	7·67	7·73	7·79	
1·9 ..	7·86	7·92	7·98	8·04	8·11	8·17	8·23	8·30	8·36	8·42	
2·0 ..	8·49	8·55	8·61	8·68	8·74	8·81	8·87	8·93	9·00	9·06	
2·1 ..	9·13	9·19	9·26	9·33	9·39	9·46	9·52	9·59	9·66	9·72	
2·2 ..	9·79	9·86	9·92	9·99	10·06	10·12	10·19	10·26	10·33	10·40	
2·3 ..	10·46	10·53	10·60	10·67	10·74	10·81	10·88	10·95	11·02	11·08	
2·4 ..	11·15	11·22	11·29	11·36	11·43	11·50	11·58	11·65	11·72	11·79	
2·5 ..	11·86	11·93	12·00	12·07	12·14	12·22	12·29	12·36	12·43	12·50	
2·6 ..	12·58	12·65	12·72	12·80	12·87	12·94	13·01	13·09	13·16	13·24	
2·7 ..	13·31	13·38	13·46	13·53	13·61	13·68	13·79	13·83	13·90	13·98	
2·8 ..	14·06	14·13	14·21	14·28	14·36	14·43	14·51	14·59	14·66	14·74	
2·9 ..	14·82	14·89	14·97	15·04	15·12	15·20	15·28	15·36	15·43	15·51	
3·0 ..	15·59	15·67	15·74	15·82	15·90	15·98	16·06	16·14	16·22	16·30	

1. In the above Table C in forrula $Q = 3{\cdot}09\ C.\ B.\ D.^{1{\cdot}5}$ is taken as ·97 and hence $Q = 3\ BD.^{1{\cdot}5}$.

This is correct for flumes from 1 to 2 ft. of normal Section (B about = $D^{1{\cdot}5}$).

for a 6″ flume 1 per cent may be deducted (C = ·96).

for a 6 feet flume 1 per cent more may be added (C = ·98).

for a 20 feet flume 2 per cent more may be added (C = ·99).

2. For throat sections which vary widely from B = $D^{1{\cdot}5}$ co-efficients will be slightly lower than shown in 1.

TABLE CLXX—*contd.*

TABLE OF DISCHARGES FOR CRUMP TYPE STANDING WAVE FLUME PER FOOT BREADTH AT THE THROAT.

$$Q = 3{\cdot}09\ C.B.D.^{1\cdot5}$$

Value of D	Difference									
	·00	·01	·02	·03	·04	·05	·06	·07	·08	·09
3·1 ..	16·37	16·45	16·53	16·61	16·69	16·77	16·85	16·93	17·01	17·09
3·2 ..	17·17	17·25	17·33	17·42	17·50	17·58	17·66	17·74	17·82	17·90
3·3 ..	17·98	18·07	18·15	18·23	18·31	18·39	18·48	18·56	18·64	18·73
3·4 ..	18·81	18·89	18·97	19·06	19·14	19·22	19·31	19·39	19·48	19·56
3·5 ..	19·64	19·73	19·81	19·90	19·98	20·07	20·15	20·24	20·32	20·41
3·6 ..	20·49	20·58	20·66	20·75	20·83	20·92	21·00	21·09	21·18	21·26
3·7 ..	21·35	21·44	21·52	21·61	21·70	21·79	21·87	21·96	22·05	22·14
3·8 ..	22·22	22·31	22·40	22·49	22·57	22·66	22·75	22·84	22·93	23·02
3·9 ..	23·11	23·19	23·28	23·37	23·46	23·55	23·64	23·73	23·82	23·91
4·0 ..	24·00	24·09	24·18	24·27	24·36	24·45	24·54	24·63	24·72	24·81
4·1 ..	24·91	25·09	25·09	25·18	25·27	25·36	25·45	25·55	25·64	25·73
4·2 ..	25·82	25·91	26·01	26·10	26·10	26·28	26·38	26·47	26·56	26·66
4·3 ..	26·75	26·84	26·94	27·03	27·12	27·22	27·31	27·41	27·50	27·59
4·4 ..	27·69	27·78	27·88	27·98	28·07	28·16	28·26	28·35	28·45	28·54
4·5 ..	28·64	28·73	28·83	28·92	29·02	29·12	29·21	29·31	29·40	29·50
4·6 ..	29·60	29·69	29·79	29·89	29·99	30·08	30·18	30·28	30·37	30·47
4·7 ..	30·57	30·67	30·76	30·86	30·96	1·06	31·15	31·25	31·35	31·45
4·8 ..	31·55	31·65	31·75	31·84	31·94	32·04	32·14	32·24	32·34	32·44
4·9 ..	32·54	32·64	32·74	32·84	32·94	33·04	33·14	33·24	33·34	33·44
5·0 ..	33·54	33·74	33·74	33·84	33·94	34·05	34·15	34·25	34·35	34·45
5·1 ..	34·55	34·65	34·76	34·86	34·96	35·06	35·16	35·27	35·37	35·47
5·2 ..	35·57	35·68	35·78	35·88	35·98	36·09	36·19	36·29	36·40	36·50
5·3 ..	36·60	36·71	36·81	36·92	37·02	37·12	37·23	37·33	37·44	37·54
5·4 ..	37·65	37·75	37·85	37·96	38·06	38·17	38·28	38·38	38·48	38·59
5·5 ..	38·70	38·80	38·91	39·01	39·12	39·22	39·33	39·44	39·54	39·65
5·6 ..	39·76	39·86	39·97	40·08	40·18	40·29	40·40	40·50	40·61	40·72
5·7 ..	40·83	40·93	41·04	41·15	41·26	41·36	41·47	41·58	41·69	41·80
5·8 ..	41·90	42·01	42·12	42·23	42·34	42·45	42·56	42·67	42·78	42·88
5·9 ..	42·99	43·10	43·21	43·32	43·43	43·54	43·67	43·76	43·87	43·98
6·0 ..	44·09	44·20	44·31	44·42	44·53	44·64	44·75	44·86	44·98	45·09

Value of D	Difference									
	·00	·01	·02	·03	·04	·05	·06	·07	·08	·09
6·1 ..	45·20	45·31	45·42	45·53	45·64	45·75	45·87	45·98	46·09	46·20
6·2 ..	46·31	46·43	46j54	46·65	46·76	46·88	46·99	47·10	47·21	47·33
6·3. ..	47·44	47·55	47·67	47·78	47·89	48·00	48·12	48·23	48·35	48·46
6·4 ..	48·57	48·69	48·80	48·91	49·03	49·14	49·26	49·37	49·49	49·60
6·5 ..	49·72	49·83	49·94	50·06	50·17	50·29	50·40	50·52	50·64	50·75
6·6 ..	50·87	50·98	51·10	51·21	51·33	51·45	51·56	51·68	51·80	51·91
6·7 ..	52·03	52·14	52·26	52·38	52·50	52·61	52·73	52·84	52·96	53·08
6·8 ..	53·20	53·31	53·43	53·55	53·67	53·78	53·90	54·02	54·24	54·26
6·9 ..	54·37	54·49	54·61	54·73	54·85	54·97	55·09	55·20	55·32	55·44
7·0 ..	55·56	55·68	55·80	55·92	56·04	56·16	56·28	56·40	56·52	56·64
7·1 ..	56·76	56·88	56·99	56·12	56·24	56·36	57·48	57·60	57·72	57·84
7·2 ..	57·96	58·08	58·20	58·32	58·44	58·56	58·68	58·81	58·93	59·05
7·3 ..	59·17	59·29	59·41	59·54	59·66	59·78	59·90	60·02	60·15	50·27
7·4 ..	60·39	50·51	60·64	60·76	60·88	61·00	61·13	61·25	61·37	61·50
7·5 ..	61·62	61·74	61·87	61·99	62·11	62·24	62·36	62·48	62·61	62·73
7·6 ..	62·86	62·98	63·10	63·23	63·35	63·48	63·60	63·73	63·85	63·98
7·7 ..	64·10	64·23	64·35	64·48	64·60	64·73	64·85	64·98	65·10	65·23
7·8 ..	65·35	65·48	65·60	65·73	65·86	65·98	66·11	66·24	66·36	66·49
7·9 ..	66·61	66·74	66·87	66·99	67·12	67·25	67·37	67·50	67·63	67·76
8·0 ..	67·88	68·01	68·24	68·26	68·39	68·52	68·65	68·78	68·90	69·03
8·1 ..	69·16	69·29	69·42	69·54	69·67	69·80	69·93	70·06	70·19	70·31
8·2 ..	70·44	70·57	70·70	70·83	70·96	71·09	71·22	71·35	71·48	71·61
8·3 ..	71·74	71·87	72·00	72·13	72·26	72·39	72·52	72·65	72·78	72·91
8·4 ..	73·04	73·17	73·30	73·43	73·56	73·69	73·82	73·95	74·08	74·21
8·5 ..	74·34	..	..	..	..	..	..	..	..	..

Remarks—

$C = \cdot 97$ is correct for flumes 1 to 2 feet broad at throat.
$C = \cdot 96$ for flumes 6″ broad.
$C = \cdot 98$ for flumes 6 feet broad.
$C = \cdot 99$ for flumes 20 feet broad.

To obtain correct discharges from the statement for sizes other than 1 to 2 feet :—

Deduct 1 per cent for 6″ flume.
Add 1 per cent for 6 feet flume.
Add 2 per cent for 20 feet flume.

Example.—What is discharge for a flume 20 feet wide with 6·07 feet depth of water over sill.

Statement shows 44·86 cusecs per foot.

$$Q = 44{\cdot}86 \times \frac{102}{00}\ 20 = 915 \text{ cusecs.}$$

Venturi flumes

When the head available to use a standing wave flume as a semi-module is not sufficient, venturi flumes can be advantageously used. In the case of a standing wave flume, the discharge is a function of the upstream depth only. In venturi flumes, the discharge varies with the difference of water levels upstream and in the throat.

The discharge formula of a venturi flume is :

$$Q = \sqrt{2g}\ \ B\ B_1\ d_1\ D_2 \sqrt{\frac{d_1 - D_2 - X}{B_1^2\ d_1^2 - B^2 D_2^2}}$$

Where B is the width at the throat

B_1 is the mean width at the upstream guage.

d_1 is the depth of water above the canal bed at the upstream guage.

D_2 is the depth of water over the sill in the throat.

x is the height of the hump in the throat.

The above formula does not take into account the loss of head due to friction. Allowing for friction loss, the formula becomes :

$$Q = \sqrt{2g}\ \ B\ B_1\ d_1\ D_2 \sqrt{\frac{d_1 - D_2 - X - h}{B_1^2 d_1^2 - B^2 D_2^2}}$$

where h_f is the loss of head due to friction

$$= \frac{L\,\overline{V}^2}{C^2\,\overline{R}^{1.5}} \quad \text{(Lacey)}$$

where L = length in feet, between two sections.

$$C = \frac{1{\cdot}346}{No}\ \text{(Lacey)}$$

$\overline{V}$ = mean velocity between two sections of the channel

$\overline{R}$ = mean hydraulic depth

It may be noted that Kutter's N gives a measure of relative rugosity—so that the larger the channel, the lower the value for the same roughness—whereas, Lacey's No gives the absolute rugosity—unaffected by the size of the channel; hence No is called the omnibus rugosity factor.

Values of No—Lacey's omnibus rugosity co-efficient are—

0·010 For cement plaster

0·013 Ashlar and good brickwork

0·015 Rough brickwork or good stonework

0·018 Stonework in poor condition.

0·020 Earthen channels in excellent order

0·0225 Earthen channels in moderate order.

0·025 Earthen channels in poor order.

0·0275 Earthen channels in bad order.

0·030 Earthen channels in very bad order.

HYDRAULIC DATA

Properties of water.—Pure water consists of two gases, hydrogen and oxygen, in chemical combination in the proportion of 2 volumes of hydrogen to 1 of oxygen, or 1 part of hydrogen by weight to 8 of oxygen. Bulk for bulk, oxygen (sp.gr. 1·102) is 16 times heavier than hydrogen (sp.gr. 0·0689).

Pure water becomes ice at 32° Fah., and steam at 212° Fah. at sea level. It boils at about 1° less for every 520 feet of elevation above sea level for heights within 1 mile.

Water attains its maximum density at 39·2° Fah. It is then about 815 time heavier than atmospheric air. It expands $\frac{1}{12}$ on becoming ice and evaporates at all temperatures.

The compressibility of water under pressure is very slight and it recovers its original volume when the pressure is removed. Under a pressure of one atmosphere (14·75 lbs. sq. inch), a column of water 1 foot high would be compressed about $\frac{1}{1800}$ of an inch.

2. **Weight and measurement of water.**—The gallon and the cubic foot are both frequently employed, as units of capacity, in hydraulic calculations. The gallon enables any given weight of water to be readily expressed in terms of its volume or *vice versa*. But as lineal measurements are usually represented in feet, the cubic foot is preferable to the gallon as a measure of capacity.

1 gallon of water weights 10 lbs.

1 cubic foot of water weights 62·425 lbs. (Molesworth)

= say 1,000 oz.

1 gallon = ·16 cubic foot = 8 pints

1 cubic foot = 6·24 gallons

or say 6¼ gallons.

1 gallon of water weights 70,000 grains

(1 lb. avoir. = 7,000 grains).

and contains nearly 277 cubic inches = 4·543 litr

1 cubic foot of water = ·557 cwt.

= ·028 ton.

One cubic yard of water weighs 14·905 cwts. = ·75034 tons, contains 27 cubic feet = 168·3 gallons.

One cubic metre weighs 2,198·08 cwts. = nearly 1 ton.

One fluid ounce weighs 437·5 grains avoirdupois, and contains 1·735 cubic inches.

One pint weighs 8,750 grains = approximately 1·25 lbs. and contains ·02 cubic foot = 34·56 cubic inches.

1 ton of water	= 224 gallons.
	= 35·9 cubic feet.
	= 3·3 feet cube.
1 cwt. of water	= 11·2 gallons.
	= 1·8 cubic feet.
	= 1·216 feet cube.
1 cubic inch of water	= ·0361 lb.
	= ·578 oz.
	= 252·87 grains.

1 cubic foot of ice weighs 57·8 lbs. : S. G. = ·9175

1 cubic foot of sea water weighs 64·11 lbs. (or 1¾ lb. more than fresh water).

At its greatest density (39·2° Fah.), 1 cubic foot of water weighs 62·425 lbs. The weight decrease with a rise in temperature, and at 100° Fah., it is exactly 62 lbs. (Fanning).

The Standards Department Board of Trade in 1890 fixed the weight of water at 1 cubic foot=62·2786 lbs. at 62° Fah., barometric pressure 30 inches of mercury (Molesworth).

3. Flood discharge due to rainfall—

Run-off of 1 inch per hour from 1 square mile
=645·33 cubic feet per second
(approximately 645 cub. ft. per sec.)

Run-off of 1 inch per hour from 1 acre

$$=\frac{1}{120}\text{ cubic feet per second}$$

(approximately 1 cub. ft. per sec.)

4. Supply due to rainfall—

A run-off of one inch of rainfall from 1 square mile of catchment yields a supply of

$$\frac{5280 \times 5280}{12}\text{ cubic feet.}$$

= 2,323,200 cubic ft.
=14,497,000 gallons
(approximately 14½ mill. gallons).

Inches of rainfall × 2,323,200
= cubic feet per square mile.

Inches of rainfall × 3,630
= cubic feet per acre.

One inch per hour per acre equals nearly 1 cubic foot per second per acre =22,634 gallons or 101 tons per acre per hour.

One inch per hour on a square mile equals 645·32 cubic feet per second per square mile.

One inch per annum per acre will give a supply equal to a run off of ·000115 cubic foot per second, or about ·007 cubic foot per minute, or ·4 cubic foot per hour, 10 cubic feet per day during the year.

One inch per annum per square mile will give 6,414·9 cubic feet = 40,000 gallons per day during the year.

5. **Storage and continuous flow**—

1 Million cubic feet storage =·03171 (approximately ·032) cubic foot per second throughout the year.

1 Cubic foot per second continuous supply for a year =A storage of 31·536 million cubic feet.

1 Cubic foot per second =374·4 gallons per minute.
=539,136 (approximately 540 thousand) gallons per day=2,400 tons per day; sufficient for 54,000 persons at a duty of 10 gallons daily.

1 Cubic foot per second	=3,600 cubic feet per hour		
	=86,400	,,	day
	=2,592,000	,,	month of 30 days.
	=2,678,000	,,	,, 31 days.
	=2,419,200	,,	,, 28 days.

One mot is a common term amongst irrigators, and may be taken to mean $\frac{1}{16}$th cubic foot per second.

1 Gallon per minute =·00267 cubic foot per second
1,440 gallons per day; sufficient for 144 persons at 10 gallons per head.

A town with a population of 10,000 inhabitants.	*will require*, at a rate of 10 gallons per head, 1 lakh of gallons daily or 5·85 million cubic feet per year (*i.e.*, 585 cubic feet per head of population).
An effective storage of 1 million cubic feet.	*will suffice* for 1,706 persons throughout the year at a daily rate of 10 gallons per head.
The supply due to an effective rainfall of 1 inch from 1 square mile of catchment (or 2,323,200 cubic feet).	*will give* throughout the year a continuous supply of ·07367 cubic foot per second; will supply 3,967 persons at the rate of 10 gallons per head daily; or will irrigate 15 acres at a duty of 200 acres per cubic foot per second.

6. **Data for pipe calculations**

In a circle of diameter D,

Circumference............=3·14159D

Area .... $\cdot 7854D^2$

Mean hydraulic radius $=\frac{\text{area}}{\text{circumferance}}=\frac{D.}{}$

A pipe is known by the diameter of its bore which is usually given in inches A·9 inch pipe means a pipe having a bore or internal diameter of 9 inches.

1 inch=·0833 foot.

Area of a circle of

1 inch diameter=·005454 sq. ft.

Thus, a pipe of diameter d inches or ·0833d feet has a sectional area ·005454 d^2 square feet.

Take a pipe of 13 inches diameter. The corresponding diameter in feet =0·833×13=1·083 and the area in square feet=·005454×13^2=·922.

To find the contents of a pipe, square the diameter in inches and the product gives the number of gallons in a length of 30 feet of pipe.

If v be the velocity in feet per second, the delivery in gallons per minute through a pipe of d inches diameter

=2·04vd^2 or say 2vd^2.

7. Pressure of water.—Since the weight of a cubic foot of water is 62·425 lbs., a column of water 1 foot high exerts a pressure of 62·425 lbs. per square foot of its base or ·4335 lb. per square inch.

1 lb. per square inch represents the pressure exerted by a column of water 2·307 feet high.

The pressure of water is expressed either in pounds per square inch or in terms of the corresponding vertical height of its surface.

If P= Pressure of water in lbs. per square inch,
H = Head of water in feet,
P = ·4335H,
H = 2·307P.

Thus a pressure of 200 feet of water means the pressure due to, or equivalen to, a vertical column of water 200 feet high, or what is the same thing, 86·7 lbs per square inch.

1 lb. per sq. inch=·064286 ton per sq. ft.
1 ton per sq. ft=15·56 lbs. per sq. inch.

8. Atmospheric pressure.—The atmosphere is found to extend to a height of at least 45 miles above sea level. Its pressure at the sea level is 14·706 lbs. per square inch, equal to that exerted by a vertical column of water 33·9 feet, or of mercury 29·92 inches, high. This is usually expressed as follows :—

One atmosphere or 14·706 lbs.
=33·9 feet of water.
=29·922 inches of mercury.

For all calculations not requiring extreme accuracy, one atmosphere may be taken equal to 15 lbs. or to 34 feet of water or 30 inches of mercury.

One foot of water at 52·3 Fah.=·0295 atmosphere (Rankine).

9. Water power.—A *horse power* (H. P) is the standard by which the power of one force may be compared with another. It is the standard unit for measuring the mechanical power of steam engines, pumps, turbines, etc.

1 H. P. =33,000 lbs. raised 1 foot high in 1 minute.

=550 lbs. do do in 1 second.

=Power exerted by 8·8 cubic feet of water falling 1 foot in 1 second.

The theoretical *horse power* represented by a volume of Q cubic feet of water falling through a vertical height of H feet in 1 second $= \frac{Q \times H}{8 \cdot 8}$

$= \cdot 1135$ QH.

Water power.—8·814 cubic feet, falling 1 foot per second or 528·84 cubic feet falling 1 foot per minute=33,000 pounds, falling 1 foot per minute=one horse power (theoretical).

Rule :—

$$\frac{62 \cdot 4 \times \text{cubic feet falling per second}}{550} \times \text{height of fall in feet} = \text{horse power.}$$

Coefficients for various motors (theoretical)		=1·00
Poncelet's undershot water wheel		=0·60
Breast wheel	do.	=0·55
Overshot wheel	do.	=0·60
Turbines	do.	=0.70
Hydraulic ram	do.	=0·60

Note.—In modern types of turbines an efficiency is claimed up to 80 per cent.

The term *horse power* is somewhat misleading. James Watt who wanted a standard to measure the power of the steam engine caused some very powerful horses to draw a weight from a deep well and ascertained that the maximum power exerted was 33,000 foot-pounds per minute which he adopted as his standard. While some very powerful horses can exceed Watt's maximum, the power which an average horse, working regularly for 8 hours a day, will exert is about two-thirds of this, or 22,000 foot-pounds per minute. The term, therefore, does not represent the actual power of a horse. It should be understood merely as a standard unit established by custom and representing the power necessary to raise a weight of 33,000 lbs. 1 foot high in 1 minute.

10. **Gauging.**—The number of cubic inches of rain-water (or ounces of water $\times \frac{1}{1 \cdot 735}$) gauged, divided by area of funnel of guage in inches, equals depths of rainfall in inches.

11. **Memoranda for conversion of quantities**—

Equivalent rates—

1 per second	=60 per minute.
	=3,600 per hour.
	=86,400 per day.
	=31,536,000 per year.
Feet per second × ·682	=miles per hour.
Feet per minute × ·01136	=miles per hour.
1 mile	=5,280 feet.

1 chain (Gunter's)	=66 feet.
	=·0125 mile.
1 chain (100 feet)	=·0189 mile.
Feet × ·0151	=chains (Gunter's).
Feet × ·000189	=miles.
80 chains (Gunter's)	=1 mile.
52·8 chains (100 feet)	=1 mile.
1 acre	=43,560 square feet.
	=4,840 square yards.
	=10 square chains (Gunter's).
	=·0015625 square miles.
1 square mile	=27,878,400 square feet (or say, 28 mill. square feet).
	=3,097,600 square yards (or say, 3 mill. square yards).
	=640 acres.
Square feet × ·000023	=acres.
Square yards × ·000000323	=Square miles.
Acres × ·0015625	=Square miles.
A strip of land 1 mile long × 8¼ feet wide.	=1 acre.
Acres in 1 mile of road or canal	=·1212 average breadth between boundary lines.
Cubic feet × ·037	=cubic yards.

Metric system—

1 Metre =39·37079 inches.
=3·28 feet nearly.
1 foot =·3047945 metre.
1 mile =1,609·3149 metres.

Thermometers—

1 Fahrenheit degree	=·55555 Centigrade degree.
1 Cent grade ,,	=1·8 Fahrenheit degrees.
1 Reaumur ,,	=2·25 Fahrenheit degrees.
Temperature of melting ice	=32° on Fah. scale.
	=0 on Cent. scale.
	=0 on Reau. scale.
Temperature of boiling water	=212° on Fah. scale.
	=100° on Cent scale.
	=80° on Reau. scale.

CHAPTER VIII DRAINS, CULVERTS AND BRIDGES

1. The provision of suitable structures to provide for the passage of drainage across a proposed road is an important part of the work of drawing up a road project. It is desirable in order to lessen work in Executive Engineers' offices that the designs for masonry works of ordinary size should be, as far as possible , of one type. With this object in view, a set of plans of drains, culverts and bridges up to 30 feet span is included in this volume.

These may be termed "average plans", but they are not intended as "standard plans", since no drawings can be suitable for all formation heights. In order to facilitate estimating, the following tables are given :—

Table No. CLXXI—Run-off from catchments, 0 to 1,600 square miles.

Table No. CLXXII—Areas of arch rings.

Table No. CLXXVI—Contents of wing wall foundations for drains and culverts.

Table No. CLXXVII—Contents of wing walls.

Table No. CLXXX—Contents of wing wall foundations for bridges.

Table No. CLXXXI—Contents of wing walls for bridges.

Table No. CLXXXII—Areas of cut-waters.

TABLE CLXXI.

Flood Discharge from Catchments Calculated by Dicken's Formula $D=CM^{\frac{3}{4}}$.

Statement to accompany Mr. Beale's curve.

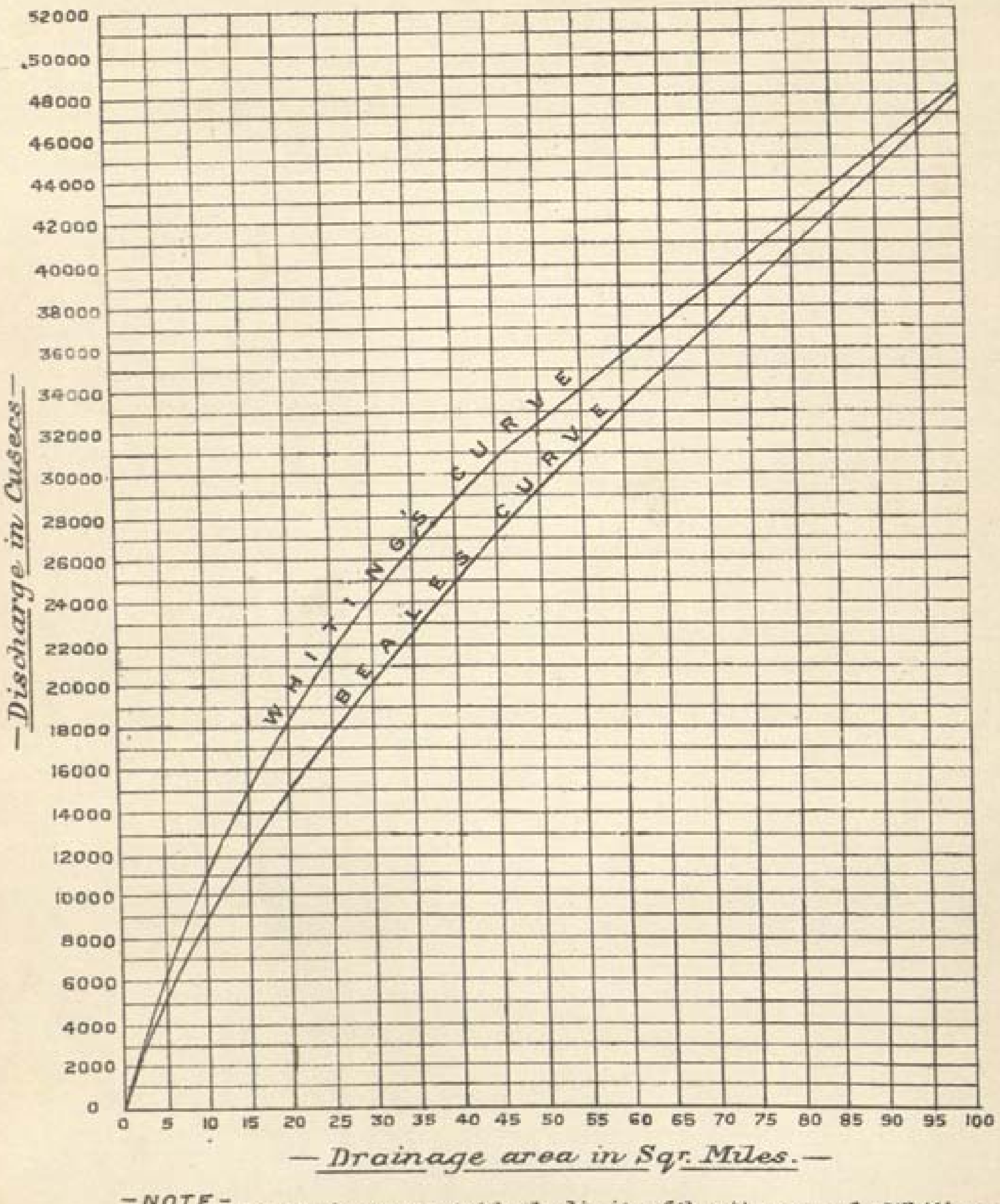
Catchment area, square miles	Proposed maximum run-off in inches per hour	Discharge in cusecs	Value of C by Dicken's formula	Catchment area, square miles	Proposed maximum run off in inches per hour	Discharge in cusecs	Value of C by formula
20	1·17	15,120	1,600	100	0·75	47,969	1,514
30	1·05	20,294	1,586	140	0·64	57,500	1,410
45	0·94	27,200	1,572	200	0·50	64,530	1,213
70	0·83	37,247	1,539	1,600	0·25	256,000	1,012

Note by Mr. A. Hill on the discharge of catchment areas and on the design of drainage works.

In the Bombay Presidency and in the greater part of India, the maximum floods which are likely to occur from small catchment areas, up to a limit of one thousand square miles, may be very accurately calculated in terms of run-off in inches per hour. Neglecting extreme cases, the volume of the maximum flood depends very slightly on the nature of the catchment, for in India, the storms which give these great floods are, in duration and intensity, sufficient to saturate any ordinary catchment, and hence the maximum floods depend on the area and not on the character of the catchment area or on its slope.

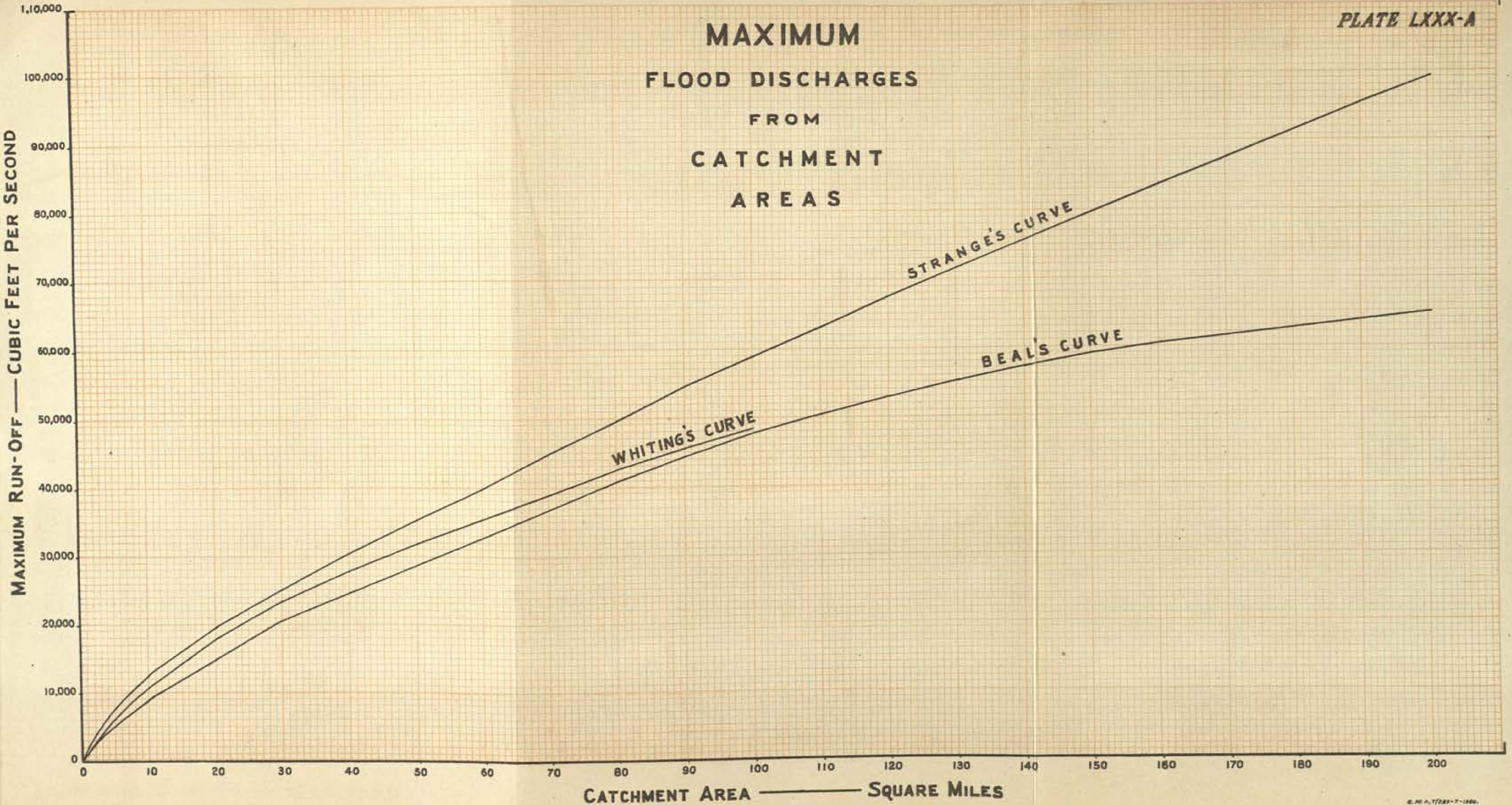
— DISCHARGE CURVES —

— Scales — Vertical 8000 Cusecs to an Inch —
— Horizontal 20 Sq.r Miles to an Inch —



— NOTE — For discharges outside the limits of the diagram for Whitings Curve a straight line up to ¼ inch run off at 1000 Sqr. Miles & for Beale's Curve a straight line up to ¼ inch run off up to 1600 Sqr. Miles may be taken.

PLATE LXXX-A


MAXIMUM
FLOOD DISCHARGES
FROM
CATCHMENT
AREAS
STRANGE'S CURVE
BEAL'S CURVE
WHITING'S CURVE
MAXIMUM RUN-OFF —— CUBIC FEET PER SECOND
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
1,10,000
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
CATCHMENT AREA —— SQUARE MILES

The frequency with which these maximum, floods will occur is quite another question, and catchment areas of hard material or with a steep fall will have maximum floods much more frequently than catchments of porous material with a slight fall ; and when designing drainage works it is often necessary to decide whether it is worth while providing for the maximum flood, or whether it will not be more economical to allow great floods to pass over the work and risk some damage, and then the character of the catchment need be considered. The diagrams given for areas from 0 to 100 miles were prepared by Mr. Whiting from measured discharge of maximum flood and by Mr. Beale from similar data obtained later and checked by comparison with the water-ways of works which had successfully passed floods of 20 years or more, the works on the Nira canal being specially considered. Mr. Beale, however, advocates a slightly less velocity of discharge through his drainage works than Mr. Whiting, and there is really no practical difference between the results obtained by these experienced officers in the size of water-way for drainage works for canals. For catchment area of 1,000 square miles, $\frac{1}{4}$ inch per hour may be taken as the run-off or 160,000 cubic feet a second, and for areas between 100 and 1,000 miles the discharge may be found by proportion. In most parts of the Deccan the natural slope of the ground is so great that the velocity of a maximum flood is at least 10 feet per second in the natural *nala* above and below the site of the drainage work; and for drainage works for roads that velocity must be expected, and the works founded in a manner able to resist the same. Increasing the water-way will not reduce the natural velocity in the *nala*, but will merely result in part of the water-way of the drainage works silting up.

For roads the level of the road surface is usually very little above the crown of the arch, and there is but a small space for any heading up above the top of the archway, and for drainage works for roads, unless it is decided that the maximum floods may flow over the road-way, it is usual to estimate the water-way up to the springing level only, and Mr. Beale's curve, with a velocity of 10 feet per second, will give suitable size of water-way.

For drainage works for canals, the problem for decision is quite different to the case of drainage works for roads. The arch has to carry the canal, and the banks of the canal, or the side walls of the aqueduct, rise to several feet above the arch, and are already in ordinary course exposed to saturation from the water of the canal, and hence there is no danger in allowing flood waters to head up above the crown of the entrance arch of the drainage work under a canal, and the extra velocity that can be obtained by this heading up should be reckoned upon when designing the work. When this extra velocity, due to the extra heading, is accepted, it is then necessary to ascertain that there is no risk of the arch of the masonry work being blown up. To do this correctly the natural level of the flood in the unobstructed *nala* downstream of the canal should be ascertained and shown on the plans. If this natural level of the flood is below the level of the crown of the soffit of the arch-way of the drainage works then there is no risk of the arch being blown up and almost all the head that can be obtained above the crown of the arching up-stream will be available for increasing the velocity through the drainage work ; a little head will be lost in friction on the sides but there is no risk of the arch being blown up.

A further and very important fact, that is not sufficiently understood, is that if the level of the natural flood in the *nala* downstream is below the crown of the arch-opening, then the arch-opening will never entirely silt up; and as the

floods can head up above the arch up-stream, and create a velocity up to 15 feet a second or more, the silt deposited beneath the arch-way, and all soft material, will be rapidly scoured out down to the pavement or rock level. The water-way available for canal drainage works, where such heading up is admissible, is then not merely the space between the surface of the sand of the natural *nala* bed and the crown of the arch, but is the whole area between the crown of the arch and the topmost layer of *nala* bed that will not scour out, and this is usually either an artifical apron of concrete, or *muram* or rock.

General Remarks

Hence in designing the water-way for drainage works for roads, use Beale's curve and a velocity of 10 feet per second, protect the foundation for this velocity and calculate water-way up to the springing level only. In designing the water-way for drainage work of canals, if possible, keep the canal bed, and crown of arch-way, above the natural flood level in the *nala* ; and then use Whiting's curve and a velocity of 10 to 12 feet for small *nalas* and 12 to 15 feet per second for large aqueducts, and calculate as available the area of water-way between the crown of the arch and rock or apron level ; and when constructing the work, take care to excavate down to this calculated level, under the whole length of the work, so that there may be nothing left which the water cannot readily remove with a velocity of 12 to 15 feet a second.

It is not necessary to continue this excavation down the *nala* bed to meet the *nala* bed level, for if the water can get through the drainage work and down the *nala*, then it will flow away, and it has been specified that the crown of the arch is to be above the natural flood level ; the flood will pass away in the natural channel, and there is no necessity to lower it by excavation.

Note.—In designing cross drainage works over *nalas* with catchments up to one square mile the following formula will give the water-way to be provided :—

If x be the number of acres in the catchment,

(*a*) For areas up to 100 acres, water-way should be $\frac{x}{2{\cdot}5}$ square feet.

(*b*) For areas from 100 to 700 acres, water-way is given by the empirical formula,

$A = 0{\cdot}225x + 17{\cdot}5$, A being the area of water-way in square feet.

While for irrigation works, the whole area between the *nala* bed and the intrados should be considered as available, in the case of road bridges the area up to the springing only should be counted upon.

Note.—It has been abundantly proved that Beale's curve cannot be applied indiscriminately to all catchments, and its limitations must therefore be borne in mind when designing water-ways for cross-drainage works. Beale's curve really applies to those catchments only, "which run easterly from the ghats, so that the rainfall is very intense at the upper end of the catchment,and comparatively small some 20 to 30 miles to the east of the ghats." Even for such catchments Sir Claude Inglis has shown* that it is of the wrong form for catchments of more than 200 square miles.

Beale's curve cannot apply to the Konkan strip where the rainfall is uniformly very intense over the whole catchment, and it does not apply to Gujrat catchments, especially Gujrat catchments North of the Tapti river, where the nature of the rainfall is uniformly lighter than in the Ghats but wide areas are covered by heavy falls.

The method of design given in General Remarks, cannot be adopted in Gujrat North of the Tapti, as velocity *of* 10 *feet per second is not warranted by the ground* slopes. For cross-drainage works on the coastal strip, due allowance must also be made for tides, if the works are located in stretches of the rivers subject to tidal influence.

*Sir Claude Inglis divides catchment area into two types *viz*., the "normal single catchment" and the "multiple or fan catchment". The former is a catchment where the flood does not continuously go on obtaining additions as it flows down, from tributaries joining the parent stream all along its course. In the multiple or fan catchment, the additions to the flood from tributaries are continuously occurring. It is plain that the discharge in the latter case goes on increasing continuously while in the former case, there is a limit, beyond which the lengthening of the catchment does not

mean additional discharge, and may even mean decreased discharge with further lengthening. Sir Claude thinks this limit is 100 square miles for which the discharge is about 70,000 cusecs, which slowly increases to a maximum of 75,000 cusecs for a catchment area of 200 square miles, and then decreases. Sir Claude gives the following formula :—

Fan catchment.—Maximum discharge $=7,000\sqrt{A}$ where A is the area of the catchment in square miles.

Normal single catchment.—(100 to 600 square miles).

Maximum discharge $=7,000\sqrt{A}-240\,(A-100)$.

For the Konkan catchments, after several bridges, the water-ways of which were calculated by Beale's curve were over-topped by floods, Government have ordered the use of Strange's curve with an addition of 10 per cent. to the discharge thus arrived at :

For North Gujrat conditions it would probably be advisable to design small water-ways, allowing a velocity of 5 feet per second instead of 10 feet per second. Then

$$\text{for areas up to 100 acres water-way} = \frac{A}{8}$$

$$\text{for areas 100 to 700 acres water-way} = \frac{A}{9} + 17{\cdot}5$$

where A is the catchment area in acres.

Hume Pipes

For small catchment areas up to about 30 acres at the most, Hume pipes can be used conveniently, and are cheap in comparison to other forms of drainage works. A battery of Hume pipe drains can be used for higher discharges, but except where the conditions are exceptionally favourable, the cost will be higher than that of the orthodox R.C. slabbed drains.

The foundations should be taken out for the two head walls, as for curtain walls in slabbed drains, and the pipes should be supported throughout by at least 9″ of concrete bedding. This concrete should be brought up in layers, to a height of half the diameter of the pipe, *i.e.*, it should provide a shoulder half-way up the pipe, the space above being made up with well-packed hard *muram* or kankar.

The pipe walls are smoother than ordinary masonry, the coefficient of rugosity being about 0·115 against ·017 for masonry. For this reason it is often proposed to cut down the water-way area, but this is inadvisable because :—

(1) Drains are very short "pipes" and small variations in the coefficient of rugosity have no appreciable effect on the discharge, and

(2) The channel of a *nalla* is usually roughly trapezoidal, a section which allows water to enter the orthodox rectangular openings without serious energy losses at entry. In the case of a pipe the energy losses are more serious.

It is desirable that Hume pipes should have a cover at top of at least 12″.

Downstream protection is required when passing a discharge through a cross-drainage work or over road dips in erodible soil. The nature of this protection, *i.e.*, the length and depth of the apron and the depth of the toe-wall depends on the velocity of emergence, the nature of the bed material, and the drop downstream if any. In all cases, however, it is desirable to destroy as much energy as possible before the stream emerges on erodible material. A cheap method is to leave staggered projecting headers above the general slope of the pitching.

TABLE CLXXII
FOR CALCULATING THE AREA OF THE ARCH RING AND SEGMENT OF INTRADOS OF ANY ARCH OF THE UNDERMENTIONED RISE AND THICKNESS

Thickness of arch ring	RISE = 1/3 SPAN			RISE = 1/4 SPAN			RISE = 1/5 SPAN			RISE = 1/6 SPAN			RISE = 1/7 SPAN			Thickness of arch ring
	Area of segment	Area of arch ring		Area of segment	Area of arch ring		Area of segment	Area of arch ring		Area of segment	Area of arch ring		Area of segment	Area of arch ring		
		Multiply	Add		Multiply	Add		Multiply	Add		Multiply	Add		Multiply	Add	
Inches 6	$\cdot240878 \times (Span)^2$	·6370	·2940	$\cdot174724 \times (Span)^2$	·5795	·2318	$\cdot137505 \times (Span)^2$	·5517	·1902	$\cdot113543 \times (Span)^2$	·5362	·1608	$\cdot096778 \times (Span)^2$	·5267	·1391	Inches 6
9		·9555	·6615		·8693	·5216		·8276	·4280		·8043	·3619		·7901	·3131	9
12		1·2740	1·1760		1·1591	·9273		1·1034	·7610		1·0725	·6435		1·0535	·5566	12
15		1·5925	1·8375		1·4489	1·4489		1·3793	1·1890		1·3406	1·0054		1·3169	·8697	15
18		1·9110	2·6460		1·7387	2·0864		1·6552	1·7122		1·6087	1·4478		1·5803	1·2523	18
21		2·2295	3·6015		2·0285	2·8398		1·9310	2·3306		1·8769	1·9707		1·8437	1·7046	21
24		2·5480	4·7040		2·3182	3·7092		2·2069	3·0440		2·1450	2·5740		2·1071	2·2264	24
27		2·8665	5·9535		2·6080	4·6944		2·4828	3·8526		2·4131	3·2577		2·3705	2·8178	27
30		3·1850	7·3500		2·8978	5·7956		2·7586	4·7563		2·6812	4·0219		2·6339	3·4787	30
33		3·5035	8·8936		3·1876	7·0127		3·0345	5·7551		2·9493	4·8665		2·8973	4·2093	33
36		3·8220	10·5840		3·4773	8·3456		3·3104	6·8491		3·2175	5·7915		3·1605	5·0094	36
	Radius = 5416 × Span.			Radius = ·625 × Span.			Radius = ·725 × Span.			Radius = ·83 × Span.			Radius = ·946428 × Span.			

EXAMPLE

Given, span .. .. .. 30 feet.
 ,, rise .. .. .. 1/5 span.
Thickness of arch ring .. 18 inches.

Then area of arch ring = (1·6552 × 30) + 1·7122 = 51·36 square feet.
 ,, ,, segment of intrados = ·137505 × 30² = 123·75 ,,
 ,, Radius of circle .. .. = ·725 × 30 = 21·75 feet.

TABLE CLXXII—*contd.*

AREAS OF ARCH RINGS, SEGMENTS, ETC.

	Area of segment	Rise=½ span, Thickness of ring Inches: 9	12	15	18	21	24	27	Area of segment	Rise=⅓ span, Thickness of ring Inches: 9	12	15	18	21	24	27
	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.
V ..	9·81	6·77	9·42	12·2	15·3	..	..	..	6·02	5·43	7·54	9·80	12·2	..	..	..
VI ..	14·1	7·95	10·9	14·2	17·6	..	..	..	8·67	6·39	8·82	11·3	14·1	..	..	..
VII ..	19·2	9·13	12·5	16·2	20·0	..	..	..	11·8	7·35	10·0	12·9	16·0	..	..	..
VIII ..	25·1	10·3	14·1	18·1	22·3	..	..	..	15·4	8·30	11·3	14·5	17·9	..	..	..
IX ..	31·8	11·4	15·7	20·1	24·7	..	..	..	19·5	9·26	12·6	16·1	19·8	..	..	..
X ..	39·2	12·6	17·2	22·0	27·0	32·2	..	..	24·0	10·2	13·9	17·7	21·7	25·8	..	..
XII ..	56·5	15·0	20·4	26·0	31·8	37·8	..	..	34·6	12·1	16·4	20·9	25·5	30·3	..	..
XV ..	88·3	18·5	25·1	31·9	38·8	46·0	..	..	54·1	14·9	20·2	25·7	31·3	37·0	..	..
XVIII ..	127	..	29·8	37·8	45·9	54·2	62·8	..	78·0	..	24·2	30·5	37	43·7	50·5	..
XX ..	157	..	32·9	41·7	50·6	59·7	69·1	..	96·3	..	26·6	33·6	40·8	48·1	55·6	..
XXV ..	245	..	40·8	51·5	62·4	73·5	84·8	..	150	..	33·0	41·6	50·4	59·3	68·4	..
XXX ..	353	..	..	61·3	74·2	87·2	100	113	216	..	..	49·6	59·9	70·4	81·1	91·9
XXXV ..	481	..	..	71·1	86·0	101	116	131	295	..	..	57·5	69·5	81·6	93·8	106
XL ..	628	..	..	80·9	97·7	114	131	149	385	..	..	65·5	79·0	92·7	106	120
XLV ..	795	..	..	90·8	109	128	147	166	487	..	..	73·5	88·6	103	119	134
	Radius of circle=·5 Span.								Radius of circle=·541 Span.							

TABLE CLXXII—*contd.*

AREAS OF ARCH RINGS SEGMENTS, ETC.

	Area of segment	Rise=¼ span, Thickness of ring Inches: 9	12	15	18	21	24	27	Area of segment	Rise=⅕ span, Thickness of ring Inches: 9	12	15	18	21	24	27
	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.	S.F.
V ..	4·36	4·86	6·72	8·69	10·7	..	..	..	3·43	4·56	6·27	8·08	9·98	..	..	..
VI ..	6·29	5·73	7·88	10·1	12·5	..	..	..	4·95	5·39	7·38	9·46	11·6	..	..	..
VII ..	8·56	6·60	9·04	11·5	14·2	..	..	..	6·73	6·22	8·48	10·8	13·2	..	..	..
VIII ..	11·1	7·47	10·2	13·0	15·9	..	..	..	8·80	7·04	9·58	12·2	14·9	..	..	..
IX ..	14·1	8·34	11·3	14·4	17·7	..	..	..	11·1	7·87	10·6	13·6	16·6	..	..	..
X ..	17·4	9·21	12·5	15·9	19·4	23·1	..	..	13·7	8·70	11·7	14·9	18·2	21·6	..	..
XII ..	25·1	10·9	14·8	18·8	22·9	27·1	..	..	19·8	10·3	14·0	17·7	21·5	25·5	..	..
XV ..	39·3	13·5	18·3	23·1	28·1	33·2	..	..	30·9	12·8	17·3	21·8	26·5	31·2	..	..
XVIII ..	56·6	..	21·7	27·5	33·3	39·3	45·4	..	44·5	..	20·6	26·0	31·5	37·0	42·7	..
XX ..	69·8	..	24·1	30·4	36·8	43·4	50·0	..	55·0	..	22·8	28·7	34·8	40·9	47·1	..
XXV ..	109	..	29·9	37·6	45·5	53·5	61·6	..	85·9	..	28·3	35·6	43·0	50·6	58·2	..
XXX ..	157	..	..	44·9	54·2	63·6	73·2	82·9	123	..	..	42·5	51·3	60·2	69·2	78·3
XXXV ..	214	..	..	52·1	62·9	73·8	84·8	95·9	168	..	..	49·4	59·6	69·9	80·2	90·7
XL ..	279	..	..	59·4	71·6	83·9	96·4	109	220	..	..	56·3	67·9	79·5	91·3	103
XLV ..	353	..	..	66·6	80·3	94·1	108	122	278	..	..	63·2	76·1	89·2	102	115
	Radius of circle=·625 Span.								Radius of circle=·725 Span.							

TABLE CLXXII—*contd.*
AREAS OF ARCH RINGS, SEGMENTS, ETC.

SPAN	Area of segment	RISE = ⅙ SPAN — Thickness of ring Inches							Area of segment	RISE = 1/7 SPAN — Thickness of ring Inches						
		9	12	15	18	21	24	27		9	12	15	18	21	24	27
	S. F.	S. F.	S. F.	S. F.	S. F.	.F.	S. F.	S. F.	S. F.	S. F.	S. F.	S. F.	S. F.	S. F.	S. F.	S. F.
V	2·83	4·38	6·00	7·70	9·49	.	.	..	2·41	4·26	5·82	7·45	9·15	..	..	..
VI	4·08	5·18	7·07	9·04	11·1	.	..	..	3·48	5·05	6·87	8·77	10·7	..	..	..
VII	5·56	5·99	8·15	10·3	12·7	.	..	..	4·74	5·84	7·93	10·0	12·3	..	..	..
VIII	7·26	6·79	9·22	11·7	14·3	.	..	..	6·19	6·63	8·98	11·4	13·8	..	..	..
IX	9·19	7·60	10·2	13·0	15·9	..	..	..	7·83	7·42	10·0	12·7	15·4	..	..	..
X	11·3	8·40	11·3	14·4	17·5	20·7	.	..	9·67	8·21	11·0	14·0	17·0	20·1	..	..
XII	16·3	10·0	13·5	17·0	20·7	24·4	..	..	13·9	9·79	13·1	16·6	20·2	23·8	..	..
XV	25·5	12·4	16·7	21·1	25·5	30·1	..	..	21·7	12·1	16·3	20·6	24·9	29·3	..	..
XVIII ..	36·7	..	19·9	25·1	30·4	35·7	41·1	..	31·3	..	19·5	24·5	29·6	34·8	40·1	..
XX	45·4	..	22·0	27·8	33·6	39·5	45·4	..	38·7	..	21·6	27·2	32·8	38·5	44·3	..
XXV	70·9	..	27·4	34·5	41·6	48·8	56· .	..	60·4	..	26·8	33·7	40·7	47·7	54·9	..
XXX	102	..	..	41·2	49·7	58 2	66·9	75·6	87·1	..	..	40·3	48·6	57·0	65·4	73·9
XXXV ..	139	..	..	47·9	57·7	67·6	77·6	87·7	118	..	..	46·9	56·5	66·2	75·9	85·7
XL	181	..	..	54·6	65·7	77·0	88·3	99·7	154	..	..	53·5	64·4	75·4	86·5	97·6
XLV ..	229	..	..	61·3	73·8	86·4	99·0	111	195	..	..	60·1	72·3	84·6	97·0	109
	Radius of circle = ·83 Span.								Radius of circle = ·946 Span.							

TABLE CLXXIII
DEPTHS OF KEYSTONE FOR FIRST CLASS CUT-STONE ARCHES, CIRCULAR OR ELLIPTIC. FOR SECOND CLASS ADD ABOUT ONE-EIGHT PART. FOR BRICK OR FAIR RUBBLE ADD ABOUT ONE-THIRD PART

Span	Rise in parts of the span.						
	½	⅓	¼	⅕	⅙	⅛	1/10
Feet	Key Feet	Key Feet	Key Feet	Key Feet	Key Feet	Key Feet	Key Feet
2	·55	·56	·58	·60	·61	·64	·68
4	·70	·72	·74	·76	·72	·83	·88
6	·81	·83	·86	·89	·92	·97	1·03
8	·91	·93	·96	1·00	1·03	1·09	1·16
10	·99	1·01	1·04	1·07	1·11	1·11	1·26
15	1·17	1·19	1·22	1·26	1·30	1·40	1·50
20	1·32	1·35	1·38	1·43	1·48	1·59	1·70
25	1·45	1·48	1·53	1·58	1·64	1·76	1·88
30	1·57	1·60	1·65	1·71	1·78	1·91	2·04
35	1·68	1·70	1·76	1·83	1·90	2·04	2·19
40	1·78	1·81	1·88	1·95	2·03	2·18	2·33
50	1·97	2·00	2·08	2·16	2·25	2·41	2·58
60	2·14	2·18	2·26	2·35	2·44	2·62	2·80
80	2·44	2·49	2·58	2·68	2·78	2·98	3·18
100	2·70	2·75	2·86	2·97	3·00	3·32	3·55

Note.—The above figures are derived from the formula—

$$\text{Depth of keystone in feet} = \frac{\sqrt{\text{Red} + \text{half span.}}}{4} + 0{\cdot}2 \text{ foot.}$$

In large arches it is advisable to increase the depth of the archstones towards the springs; but when the span is under 100 feet, this is not necessary, if the stone is good, although the arch will be stronger if it is done. In practice this increase even in the largest spans, does not exceed from $\frac{1}{4}$ to $\frac{1}{3}$ the depth of the key.

Piers

Each should be calculated to resist the thrust when one of the arches it supports is covered with a travelling load and the other, unloaded. Thickness of piers, generally from $\frac{1}{6}$ to $\frac{1}{8}$ span. Short piers have vertical sides. High piers may have batters of $\frac{1}{12}$ on the sides. In long bridges one pier in every 4 or 5 should be thickened as an abutment pier, with thickness at the springing equal to $\frac{\text{Rad}}{5} + \frac{\text{Rise}}{10} + 2$ feet.

TABLE CLXXIV

THICKNESS OF ABUTMENTS FOR ARCHES OF 120° CURVATURE

(RISE $= \frac{1}{3\cdot5}$ SPAN. RADIUS = 0·577 SPAN)

(Hurst)

Span of arch	Height of abutment in feet					
	5	7½	10	15	20	30
	Feet	Feet	Feet	Feet	Feet	Feet
5	2·02	2·15	2·20	2·30	2·40	2·42
6	2·18	2·36	2·44	2·57	2·68	2·75
7	2·35	2·57	2·68	2·84	2·96	3·04
8	2·51	2·78	2·82	3·11	3·24	3·33
9	2·68	2·99	3·16	3·38	3·52	3·63
10	2·84	3·20	3·40	3·65	3·80	3·94
12	3·16	3·55	3·84	4·17	4·34	4·50
14	3·48	3·95	4·27	4·68	4·87	5·05
16	3·80	4·10	4·70	5·12	5·40	5·60
18	4·10	4·70	5·05	5·65	6·00	6·36
20	4·40	5·00	5·40	6·10	6·60	7·10
25	5·00	5·67	6·10	6·90	7·55	8·40
30	5.52	6·25	6·80	7·70	8·50	9·39
35	6·04	6·80	7·50	8·50	9·40	10·67
40	6·56	7·45	8·20	9·30	10·30	11·93
45	7·08	8·06	8·93	10·23	11·30	12·83
50	7·59	8·68	9·65	11·16	12·30	13·74

The thickness of abutment for a semi-circular arch may be taken from the above table, by considering it as approximately equal to that for anarch of 120° having the same radius of curvature; therefore, by dividing the span of the semi-circular arch by 1·155 it will give the span of the 120° arch requiring the same thickness of abutment.

Note.—Trautwine's rule for thickness of abutment at springing in feet, when the height of abutment does not exceed 1½ times the base of abutment, is $\frac{\text{Radius in feet of soffit}}{5} + \frac{\text{rise in feet of earch}}{10} + 2$ feet, from which the thickness shown in the plates are derived. The back batter for abutment in this case is given by the expression, $\frac{24 \times \text{rise in feet.}}{\text{Span in feet.}}$

TABLE CLXXV

THICKNESS OF ABUTMENTS FOR ARCHES OF 60° CURVATURE

RISE = ¼ SPAN, NEARLY. RADIUS = 0·946 SPAN

(*Hurst*)

Span of arch.	Height of abutment in feet					
	5	7½	10	15	20	30
Feet	Feet	Feet	Feet	Feet	Feet	Feet
5	2·41	2·50	2·60	2·70	2·78	2·85
6	2·61	2·96	3·05	3·15	3·21	3·28
7	3·02	3·31	3·45	3·54	3·60	3·71
8	3·32	3·68	3·83	3·95	4·00	4·14
9	3·63	4·05	4·23	4·30	4·40	4·57
10	3·93	4·30	4·55	4·68	4·78	5·00
12	4·42	4·85	5·02	5·30	5·49	5·82
14	4·91	5·30	5·50	5·77	6·10	6·65
16	5·40	5·85	6·12	6·55	6·85	7·47
18	5·81	6·26	6·59	7·05	7·43	8·15
20	6·22	6·68	7·00	7·50	7·95	8·84
25	7·05	7·60	7·97	8·69	9·36	10·81
30	8·01	8·80	9·35	10·30	11·20	12·91
35	8·62	9·54	10·21	11·30	12·33	14·45
40	9·24	10·18	10·90	12·20	13·49	16·00
45	10·01	10·91	11·70	13·25	14·73	17·68
50	10·78	11·70	12·56	14·28	15·97	19·36

Wing Walls

2. In these designs two general types of wing walls have been adopted, one for drains and culverts up to 10 feet span, and the other for small bridges from 15 to 30 feet span. In the former the walls are plumb-faced, with batter at the back 1 in 4, and are 15 inches broad at the top on the square, having a stability about equal to that of rectangular walls with bases equal to one-fifth their height. In the latter, the walls have a face batter of 1 in 12, a back batter of 1 in 6 built in steps, a top breadth of 18 inches, and stability of rectangular walls with bases equal to two-ninths the height.

All wing walls start from the top of the head-wall or the road level.

The following notes on the calculation of wing walls for drains and culverts will explain the tables :—

The contents of wings are obtained by the "prismoidal formula". *Areas* are taken parallel to the axis, or longitudinal direction of road, *i.e.*, parallel to the face of the bridge; and *lengths*, perpendicular to it or parallel to the axis of bridge, *i.e.*, parallel to the line of abutments and direction of course of the *nala*. Tables CLXXVI to CLXXXI give the quantities of wings for each foot in height.

When a wing is cut off short [as shown by heavy lines in figure 8, plate LXXXI], its content is arrived at by substracting the tabular content of a wing of the height of the point at which it is cut off from the tabular content of the wing of the height the drain [*see* example, page 726].

When a wing is "stepped" up the bank, assume a "give and take" plane *pp* [*see* figure 8, plate LXXXI] along the line of steps as a practical approximation, and if x be the height of base at the end of the wall over the level of base at shoulder then the content of this wall is approximately found by multiplying its length (which is the tabular length due to the given height x) by the mean area due to the height of the drain.

When a wing has other splay than 1 to 1 ($\phi=45°$) its content is obtained by multiplying the tabular content by the secant of the new angle of splay*, and dividing by 1·4 (the secant of 45°), and this will include with sufficient accurancy the traingles and pyramids at back, if the angles ($\phi+B$) are kept constant.

Particular attention should be paid to the introduction of "weep hoeles", *a, a*, through the bases of all high walls ([Fig. 8, plate LXXXI] ; and such walls should be drained at the back by a packing or filling of waste stone, chips and shivers, laid behind them as the work proceeds.

Calculations for brick wing walls, 13½″ & 18″ thick below 5′ and above 5′ heights respectively.

The splay of the wing walls is taken at 45° as usual.

Breadth at top b in feet=1·125′ ; r=batter, one in four ;
H=Height of wing wall in feet ;

Breadth at base b in feet=1·125+r.H.=1·125+

Breadth at top parallel to road will be 1·125 sec. 45°=1·125 × 1·414 = 1·59.

Breadth at base parallel to road=1·125 × 1·414+rH.
=1·59 × ·317H.

(r=·317 instead of ·25 due to the splay of the wing wall)

Example (1).

Let the height of the wing wall, 13½″ thick at top, be 5′ ; to find out breadths at base and top, parallel to the road.

Breadth at base parallel to the road =1·125×1·414+rH.
=1·59+·317×5=3·18′

Breadth at top parallel to the road=1·125×1·414=1·59, say 1·60′

Example (2).

Height of wing wall, 18″ thick at top is 10′.

Find out breadths at bottom and top parallel to the road.

Breadth at base parallel to the road=1·5×1·414+rH.
=2·12+·317×10=5 29

Breadth at top parallel to the road=1·5×1·414=2·12

---

*Sec Φ= sec of the angle of splay $=\sqrt{1+\text{(ratio of splay)}^2}$. The *angle of the splay* is the angular deviation of the axis of the wing from the direction of the axis of the bridge or *nala*. The ratio of splay is the length the axis of wing deviates in 1 foot measured in the direction of axis of bridge. The ratio of splay in these plans = 1.

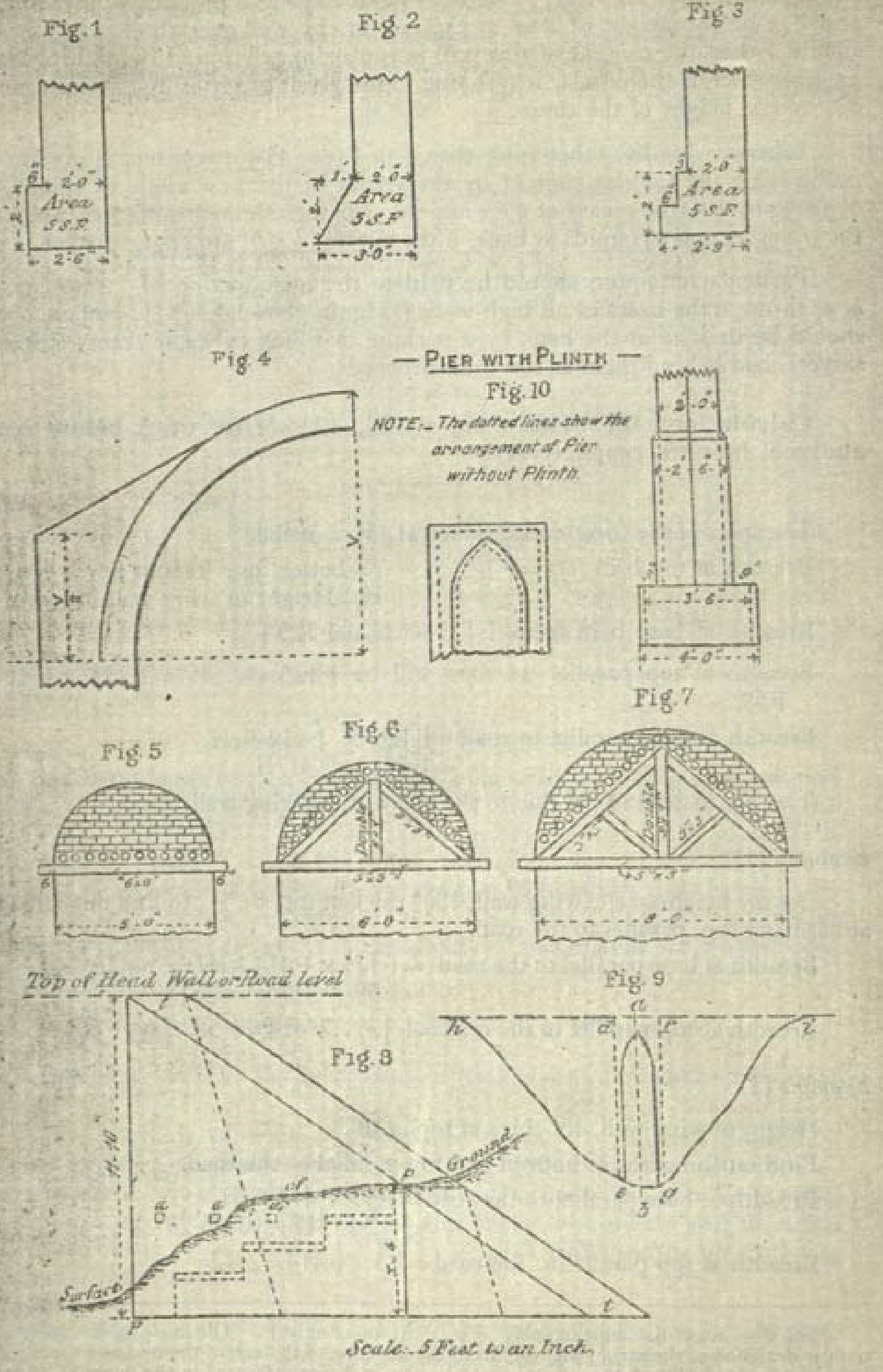
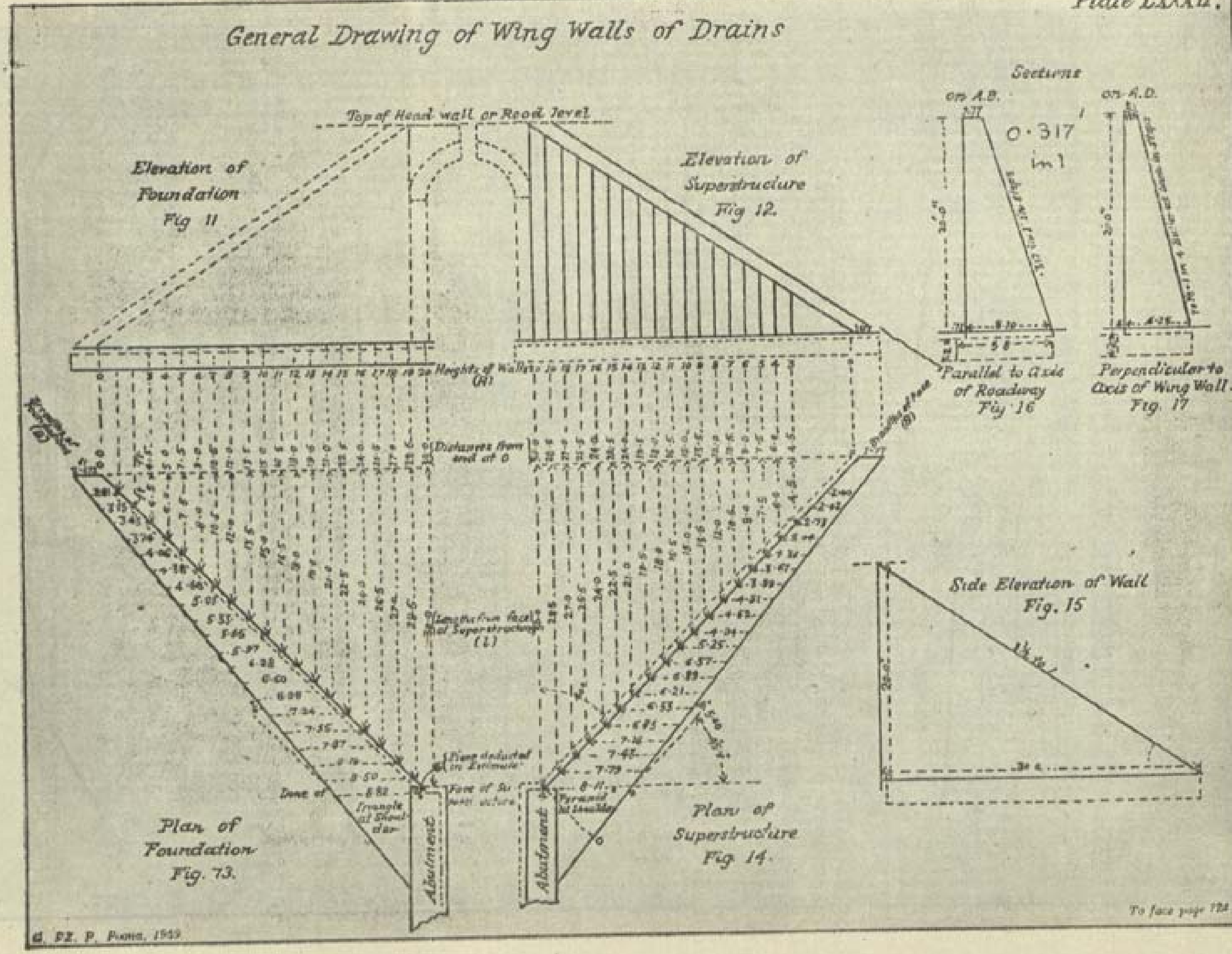


Fig. 1
Area
5 S.F.
Fig. 2
Area
5 S.F.
Fig. 3
Area
5 S.F.
Fig. 4
— Pier with Plinth —
Fig. 10
NOTE:– The dotted lines show the arrangement of Pier without Plinth.
Fig. 5
Fig. 6
Fig. 7
Double
Top of Head Wall or Road level
Fig. 8
Fig. 9
Ground
Surface
Scale:– 5 Feet to an Inch.



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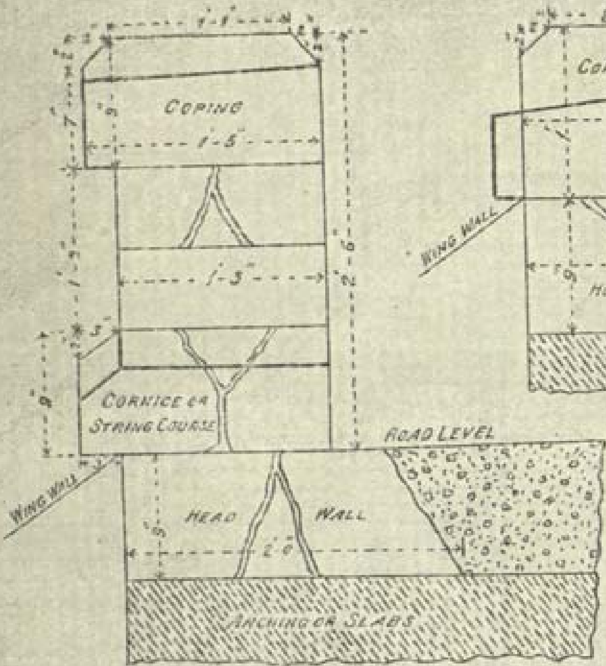
G. PZ. P. Poona, 1919

— DETAILS —

— Scale 1 foot to an inch —

— ENLARGED SECTION OF PARAPET — WHERE REQUIRED. —

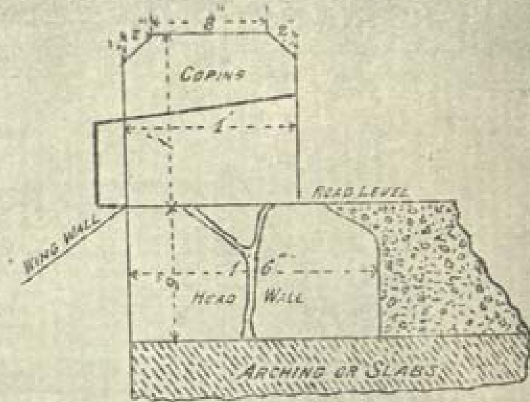
Fig 18



Area of Coping = 1·06 S.F.
Area of Parapet = 1·25 S.F.

— ENLARGED SECTION OF COPING — WHERE PARAPETS ARE NOT REQUIRED. —

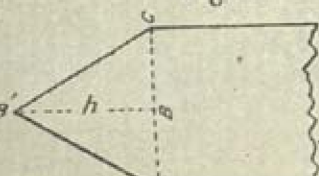
Fig 19



Area of Coping = 1·S.F.
According to black lines = ·63 S.F.

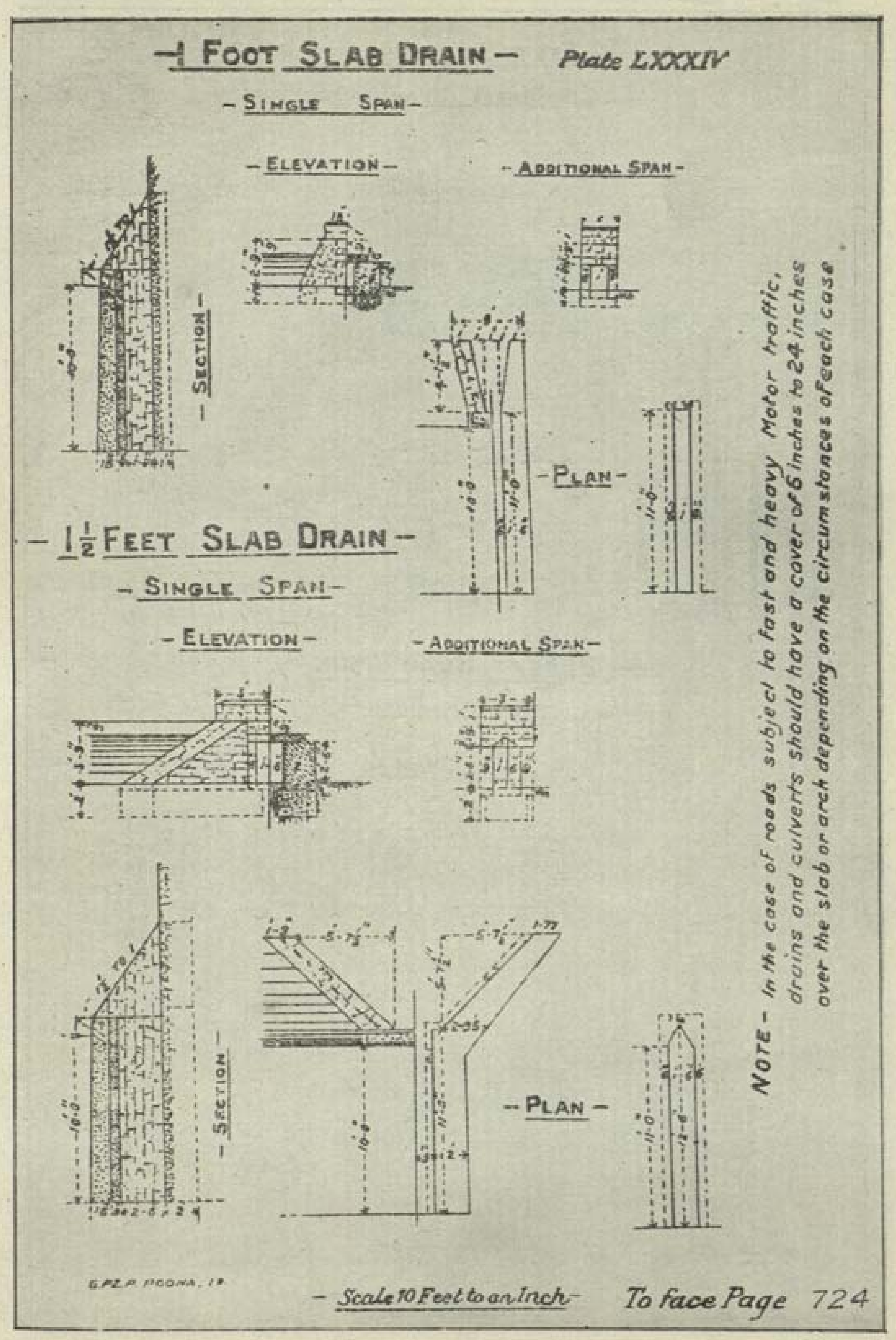
— NOTE: — *Where Trapean rocks are scarce and those of a slaty character abundant, Copings and Cornices as shewn by Black lines may be used where area of Coping = 0·813, area of Parapet = 1·56*

Fig 20



— PLAN — OF — CUTWATERS —

Fig 21



—1 FOOT SLAB DRAIN—
Plate LXXXIV
—SINGLE SPAN—
—ELEVATION—
—ADDITIONAL SPAN—
—SECTION—
—PLAN—
—1½ FEET SLAB DRAIN—
—SINGLE SPAN—
—ELEVATION—
—ADDITIONAL SPAN—
—SECTION—
—PLAN—
NOTE - In the case of roads subject to fast and heavy Motor traffic, drains and culverts should have a cover of 6 inches to 24 inches over the slab or arch depending on the circumstances of each case
G.P.Z.P. POONA, 19
—Scale 10 Feet to an Inch—
To face Page 724

J-1136—15-A.

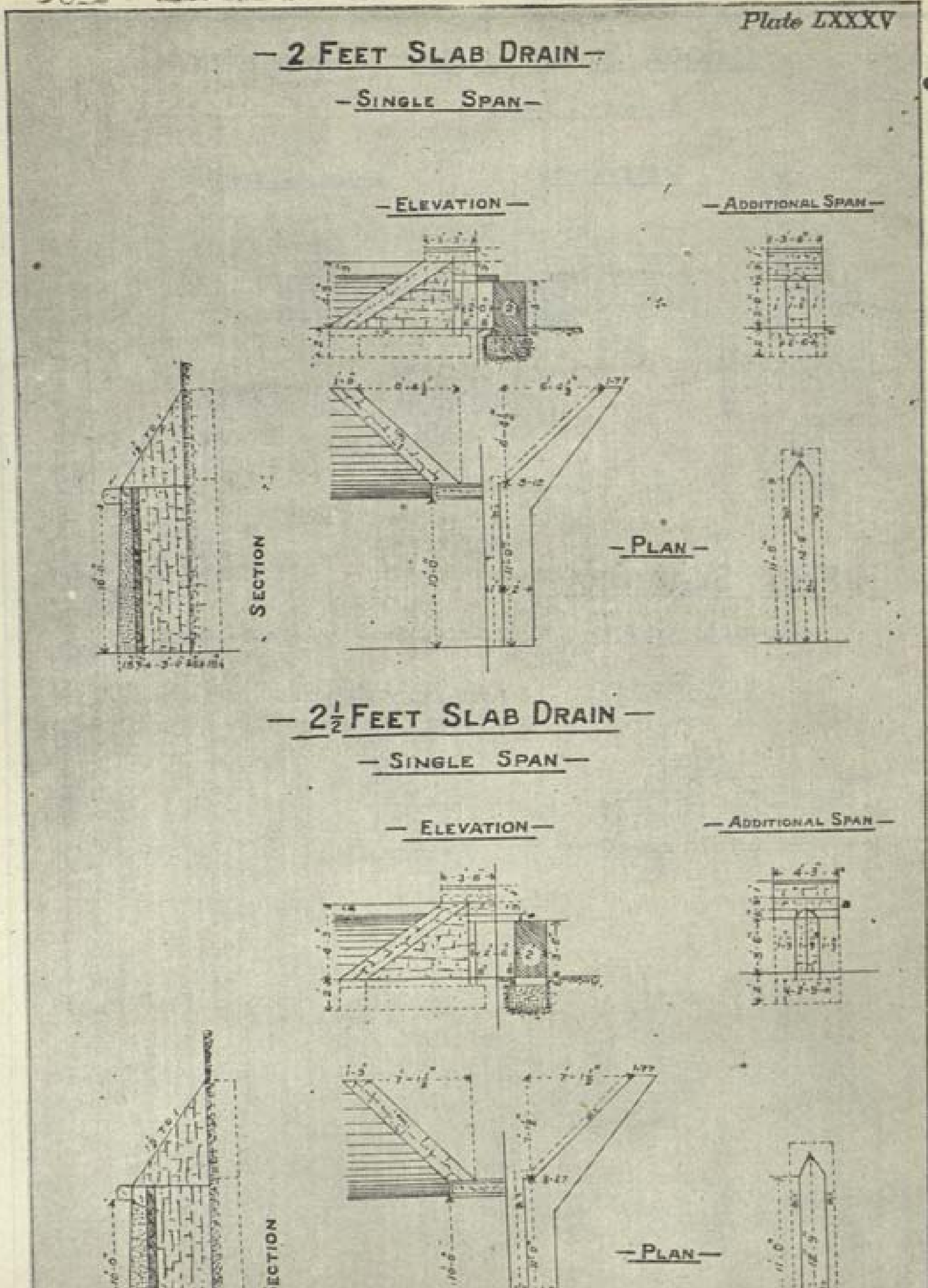


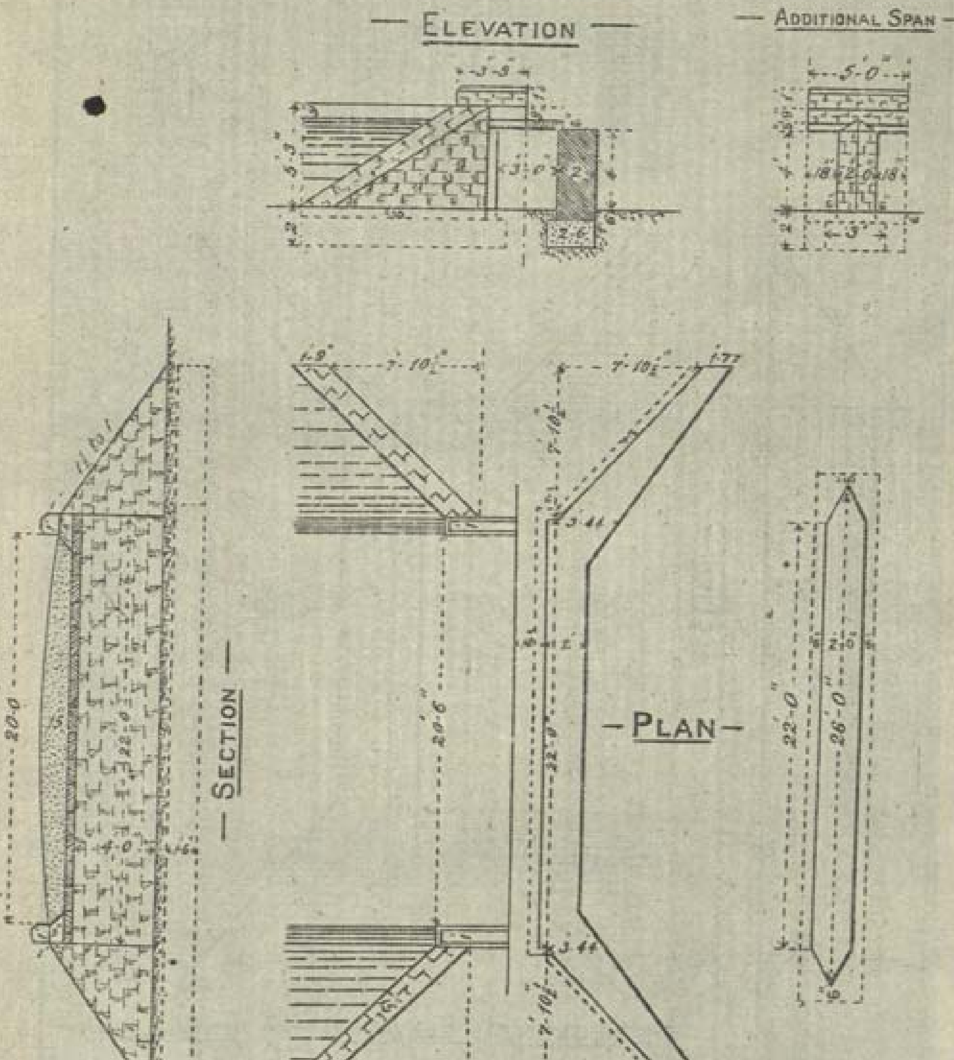
Plate LXXXV
— 2 Feet Slab Drain —
— Single Span —
— Elevation —
— Additional Span —
Section
— Plan —
— 2½ Feet Slab Drain —
— Single Span —
— Elevation —
— Additional Span —
Section
— Plan —
Scale 10 Feet to an Inch
To face page 214

J-1136—15-B.

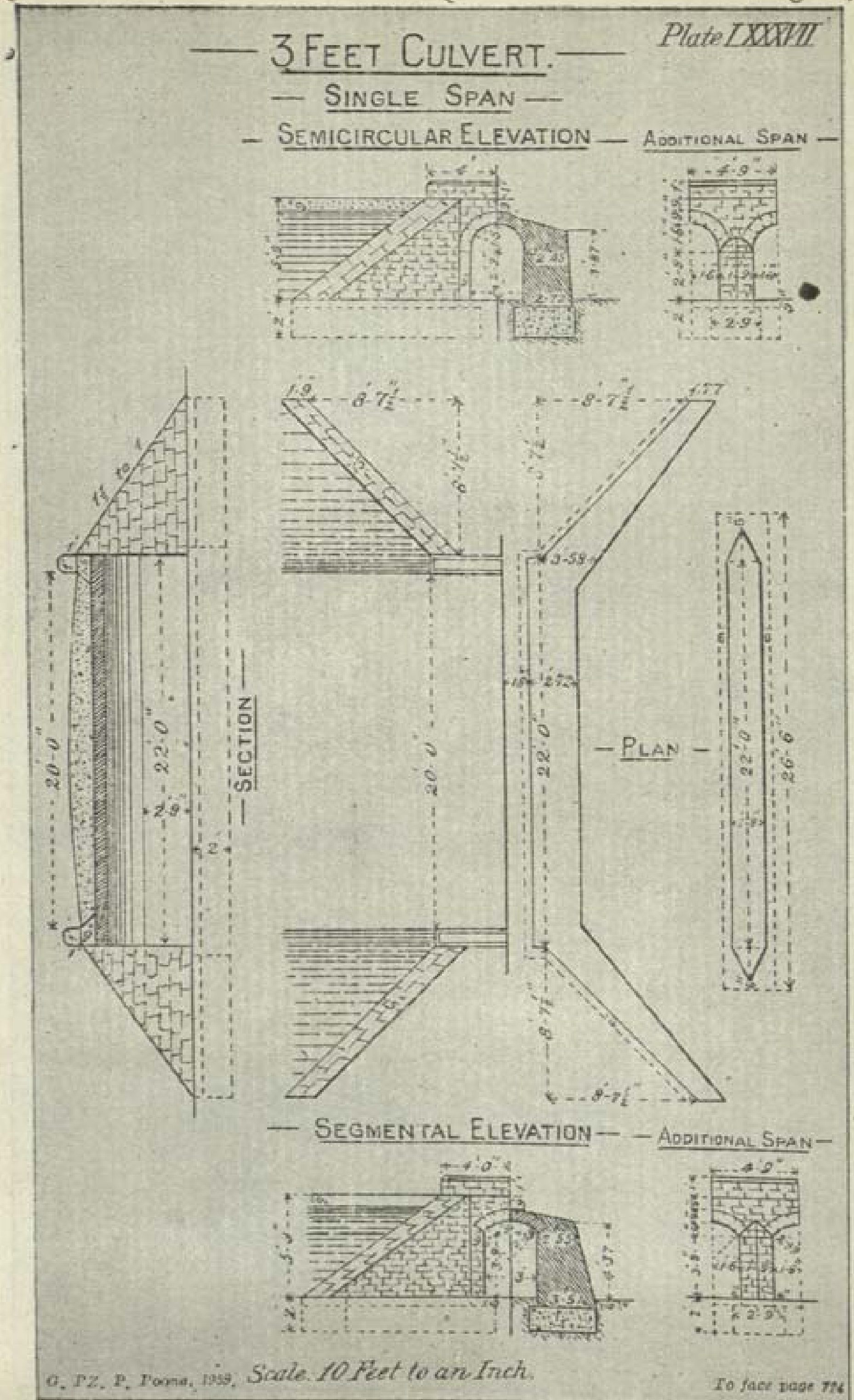
Plate LXXXVI

3 Feet Slab Drain

Single Span.



Scale: 10 Feet to an Inch.

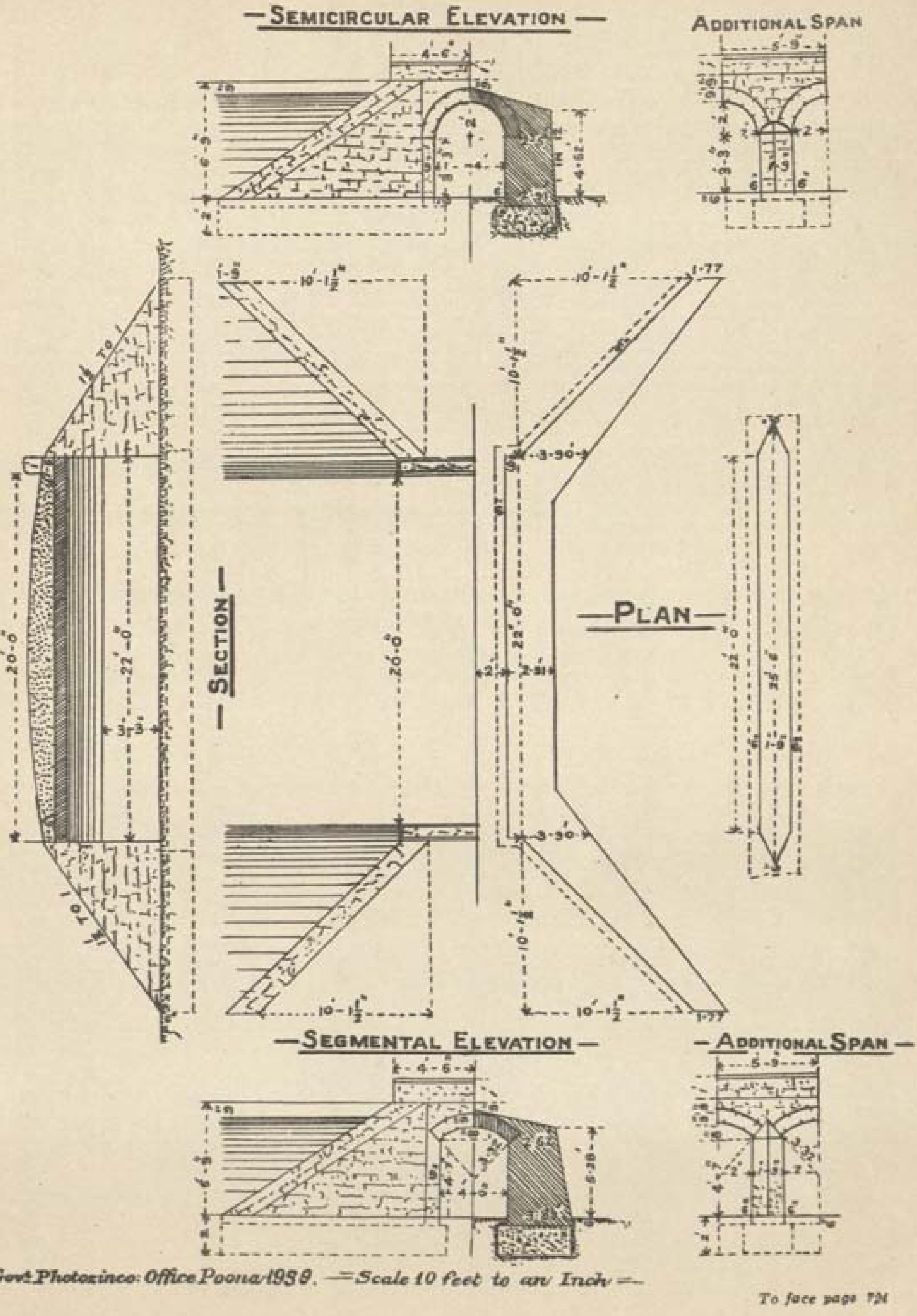


To face page 774

— 4 FEET CULVERT —

Plate LXXXVIII

— SINGLE SPAN —

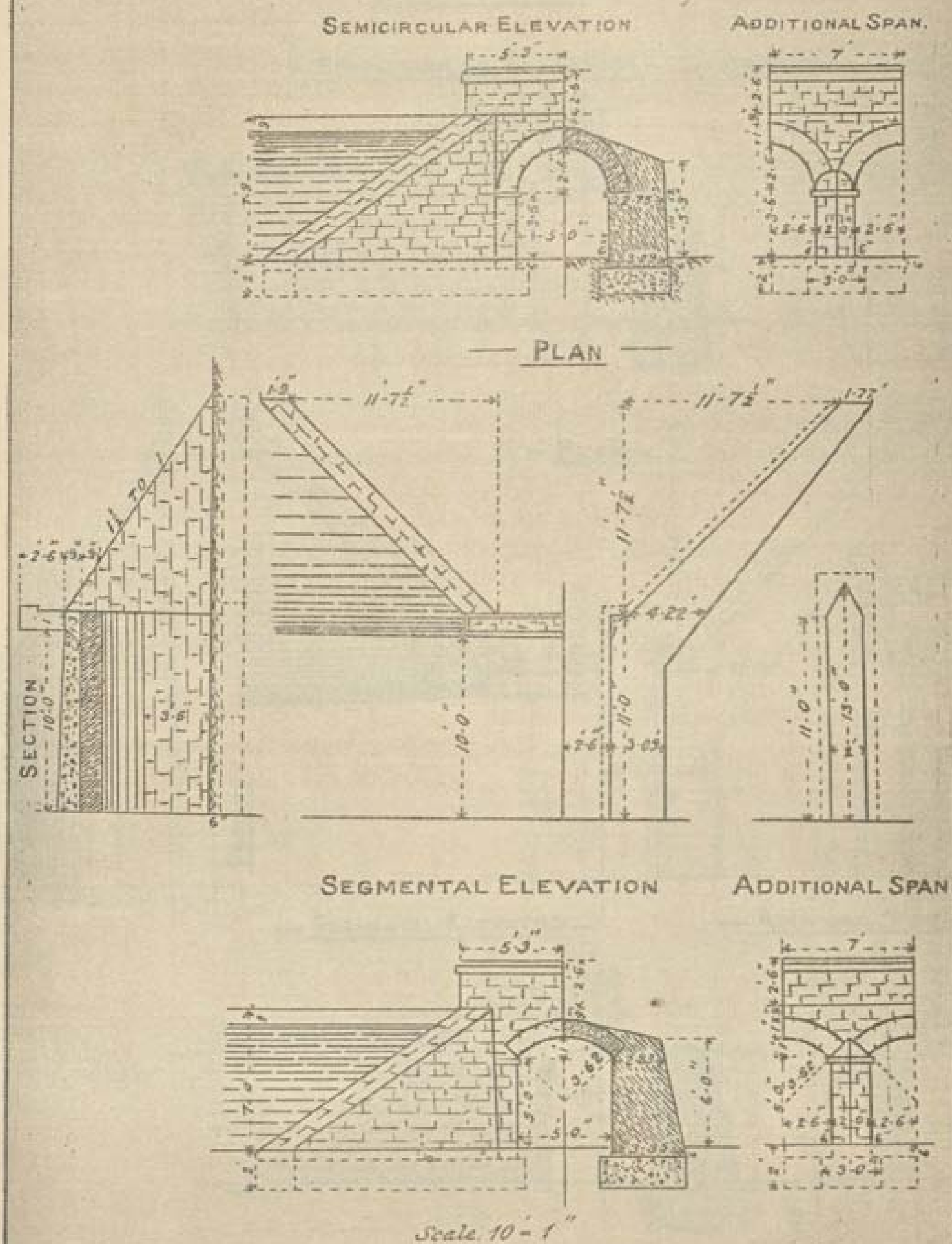


Govt. Photozinco: Office Poona 1938. — Scale 10 feet to an Inch —

— 5 Feet Culvert —

Plate LXXXIX

— Single Span —

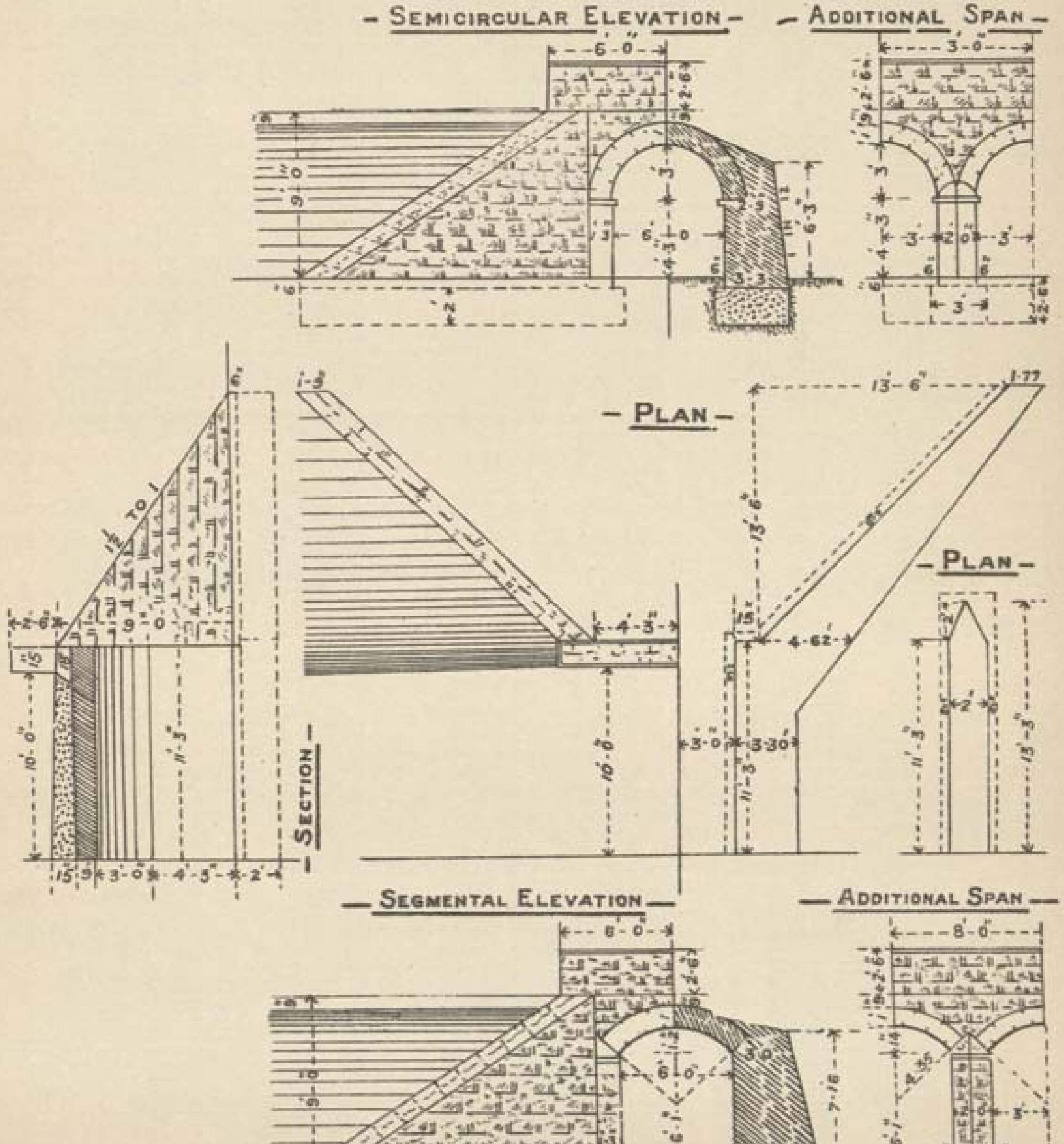


G. PZ. P. Poona, 1939.

To face page 784

—6 FEET CULVERT—

— SINGLE SPAN —

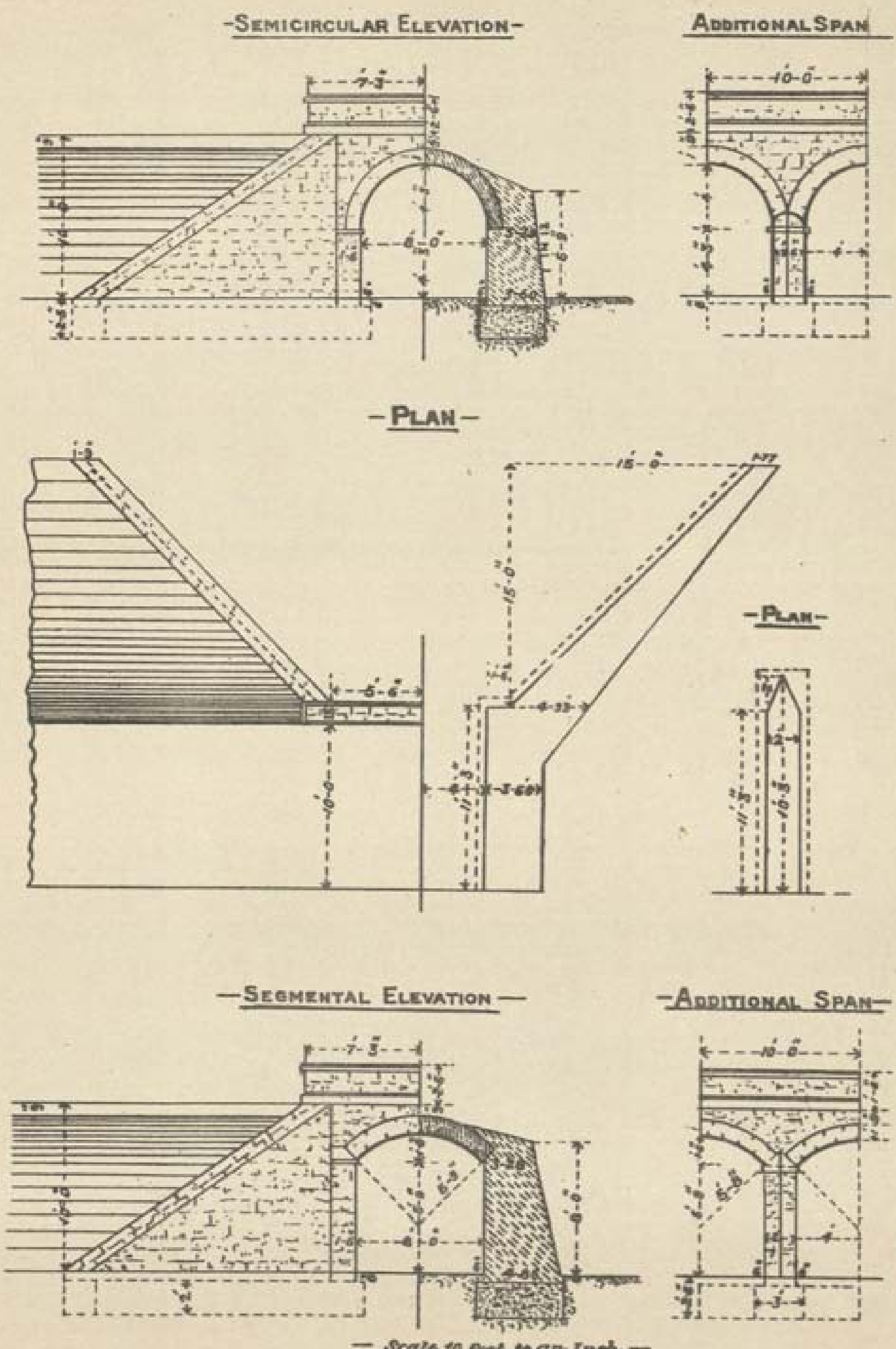


Gov^t. Photozinco: Office, Poona 1959. *Scale 10 feet to an Inch*

To face page 724

—8 Feet Culvert—

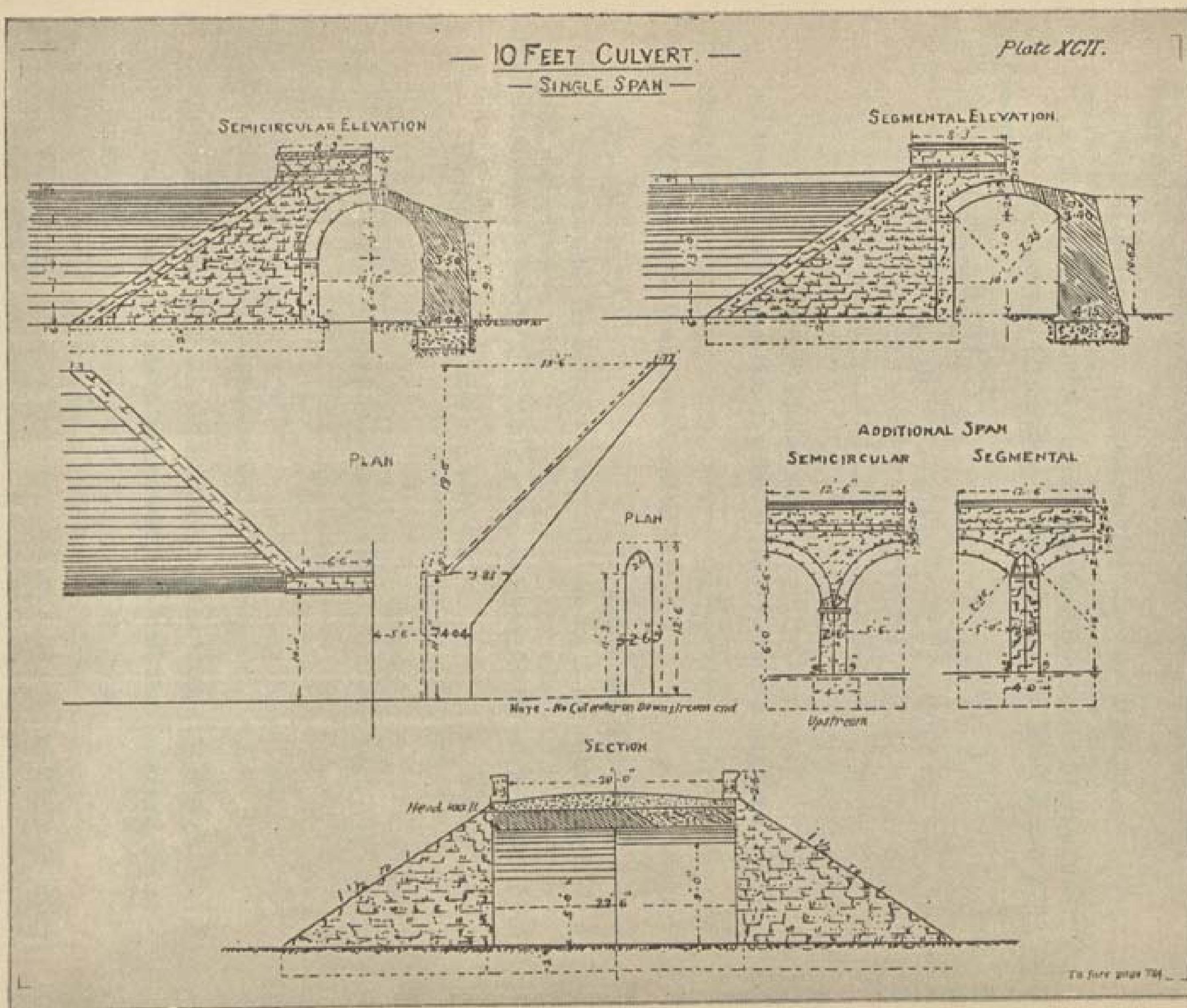
—Single Span—



To face Page 621.

Gov: Photozinco Office Poona 1930.

To face page 726



10 Feet Culvert.
Single Span
Plate XCII.
Semicircular Elevation
Segmental Elevation
Plan
Additional Span
Semicircular
Segmental
Plan
Note - No Cut water on Downstream end
Upstream
Section
Head wall

For finding out the mean area the prismoidal formula is to be applied as under :—

Area found by prismoidal formula $Ap = \frac{A + 4 \text{ middle } A' + O}{6}$

Example (B).

Find out the mean area of a wing wall $13\frac{1}{2}''$ thick and $5'$ height.

A=area at shoulder end ; A′=middle area.

From example (1) breadths at top and base for A=1·6′ and 3·18′ respectively;

Also from example (2) breadths at top and base for A′=1·6′ and 2 39′ respectively.

therefore $A_p = \frac{A + 4A' + O}{6}$

$$= \frac{\frac{1{\cdot}6 + 3{\cdot}18}{2} \times 5 + \left(4 \frac{1{\cdot}6 + 2{\cdot}39}{2}\right) \times 2{\cdot}5 + 0.}{6}$$

$= 5{\cdot}33$ square feet.

Contents with slopes $1\frac{1}{2}$ to 1, will be $5{\cdot}33 \times 7{\cdot}5 = 39{\cdot}97$ or say 40·00.

Example (A).

10′ height of wing wall, and thickness 18″ ;

Shoulder area A ; Middle area A_1.

From example (2) breadths at top and base for A are equal to 2·12′ and 5·29′ respectively.

Similarly worked out breadths at top and base for A′ are 2·12′ and 3·70′ respectively.

Therefore A_p in this case $= \frac{A + 4A' + 0}{6}$

$$= \frac{\frac{2{\cdot}12 + 5{\cdot}29}{2} \times 10 + 4\left(\frac{2{\cdot}12 + 3{\cdot}70}{2}\right) \times 5 + 0}{6}$$

$$= \frac{37{\cdot}05 + 58{\cdot}20}{6} = 15{\cdot}88 \text{ square feet.}$$

Contents with bank side slopes $1\frac{1}{2}$ to 1, will be $\underset{Ap}{15{\cdot}88} \times \underset{L}{15} = 238{\cdot}20$ cubic ft.

The formula for mean prismoidal area can also be expressed as—

$A_p = {\cdot}0528\ H^2 + {\cdot}8H$ in case of wing walls $13\frac{1}{2}''$ thick.

$A_p = {\cdot}0528\ H^2 + 1{\cdot}06$ in case of wing walls 18″ thick.

The final formula in each case for contents, will be as under by multiplying

$L = 1{\cdot}5\ H$, where side slopes are $1\frac{1}{2}$ to 1 ; contents ;

$C = {\cdot}0792\ H^3 + 1{\cdot}2\ H^2$; for $13\frac{1}{2}''$ thick wing walls ;

$C = {\cdot}0792\ H^3 + 1{\cdot}59\ H^2$; for 18″ thick wing walls.

Example (1).

Height of wing wall 5′ ; thickness 13½′ ; side-slopes 1½ to 1 ; find out contents.

Contents $= \cdot 0792 \times H^3 \times 1\cdot 2\ H^2 = 9\cdot 90 + 30 = 39\cdot 90$ or say 40·00 cubic feet.

Example (2).

Height 10′ ; thickness 18″ ; side-slopes 1½ to 1 ; find contents ;
Contents $= \cdot 0792\ H^3 \times 1\cdot 59\ H^2 = 238\cdot 20$ cubic feet.

For the area of pyramids at shoulders, formula is as under :—

$$\cdot 63\ (B-\gamma)^2 = A\ ;\ \text{Contents} = \frac{A \times h}{3}$$

Example (1).

The height 5′ ; thickness of wing 13½″ ; find out area and contents of pyramids.

$Y = 1\cdot 35'$ constant.

$A = \cdot 63\ (B-Y)^2 = \cdot 63\ (3\cdot 18 - 1\cdot 35)^2 = 2\cdot 109$ square feet.

$$\text{Contents} = \frac{A\,H}{3} = \frac{2\cdot 11 \times 5}{3} = 3\cdot 52 \text{ cubic feet.}$$

Example (2).

Height 10′ ; thickness 18″ ; $\gamma = 1\cdot 8'$.

$A = \cdot 63\ (B-\gamma)^2 = \cdot 63\ (5\cdot 29 - 1\cdot 8)^2 = 7\cdot 673$ square feet

$$\text{Contents} = \frac{7\cdot 673 \times 10}{3} = 25\cdot 58 \text{ or say } 25\cdot 60 \text{ cubic feet.}$$

For foundations.—The foundations are wider due to concrete offsets, and the breadth will be more than that of the superstructure at base by $\cdot 5 \times 1\cdot 414 = \cdot 71$. The contents can be found out by applying the above formulae.

EXAMPLES ON THE USE OF TABLES NOS. CLXXV AND CLXXVII.

3. **Example 1.**—When a wing 10 feet high is cut off at a point where it is 4 feet high, to find its contents.

Foundations, 121·9—37·4=85 cubic feet (table CLXXVI).
Superstructure, 212·3—26=186 cubic feet (table CLXXVII).

Example 2.—Where the ground on which a wing is founded proves to be hard and should be sloped up (*vide* Fig. 8,plate LXXXI), to find the contents of the wing. Let $H = 19$, $x = 4$; $\therefore$ $H - x \times 15$.

For foundations, the mean breadths are unaltered, therefore, the breadth is that due to H or 8·5, and l, as before, $= 22\cdot 5$; the depth$=2$,$\therefore$ $c' = 8\cdot 5 \times 22\cdot 5 \times 2 = 382\cdot 5$ cubic feet.

For superstructure, the mean area is that due to the height H, for the end areas have not altered ; the length is that due to $H - x$, hence, from table CLXXVII.

Ap.$=35\cdot 95$ and $l = 22\cdot 5$; $\therefore$ $c = 35\cdot 95 \times 22\cdot 5 = 808\cdot 87$ cubic feet.

NOTE.—(*a*) Height of wings is taken from the concrete offset in the foundation to the top of head wall.

(*b*) Concrete in foundation should invariably be stopped 6 inches below ground level, and the height of wing walls to be taken from this level.

(*c*) Where the height of wing wall is taken at the ground level, an allowance for 6 inches of extra masonry should be made in table CLXXVII.

TABLE CLXXVI

DRAINS

Foundations of wing walls

	BODY OF WING				TRIANGLES AT SHOULDERS OF WINGS				BODIES AND TRIANGLES COMBINED		
					Slab drains, $y = 1{\cdot}5$.		Culverts, $y = 1{\cdot}25$.			Slab drains	Culverts
Height of wings	Breadth of base at shoulder parallel to axis of road	Length perpendicular to axis of road	Area of one	Cubic feet in one	Area of one	Cubic feet in one	Area of one	Cubic feet in one	Height of wings	Cubic feet in four	
H	B′	L	A′	C′	A″	C″	A″	C″	H	4 (C′ × C″)	
2	·11	3	8·4	16·8	·5	1·1	·9	1·7	2	72	74
3	3·43	4·5	13·3	26·6	1·0	1·9	1·4	2·7	3	114	117
4	3·74	6	18·7	37·4	1·5	3·0	2·0	4·0	4	161	165
5	4·06	7·5	24·5	49·1	2·2	4·4	2·8	5·6	5	214	219
6	4·38	9	30·9	61·7	3·0	5·9	3·7	7·4	6	271	276
7	4·69	10·5	37·6	75·3	3·9	7·8	4·7	9·5	7	333	339
8	5·01	12	44·9	89·9	5·0	10·0	5·9	11·8	8	399	407
9	5·33	13·5	52·7	105·5	6·1	12·3	7·2	14·3	9	471	479
10	5·65	15	60·9	121·9	7·5	14·9	8·6	17·2	10	547	556
11	5·97	16·5	69·7	139·4			10·1	20·3	11		639
12	6·28	18	78·8	157·7			11·8	23·5	12		725
13	6·60	19·5	88·5	177·1			13·6	27·1	13		817
14	6·92	21	98·7	197·4			15·5	30·9	14		914
15	7·24	22·5	109·3	218·7			17·6	35·1	15		1,015
16	7·55	24	120·3	240·7			19·8	39·5	16		1,121
17	7·87	25·5	131·9	263·9			22·0	44·0	17		1,232
18	8·19	27	144·0	288·1			24·5	48·9	18		1,348
19	8·50	28·5	156·5	312·9			26·9	53·9	19		1,467
20	8·82	30	169·0	339·0			29·6	59·3	20		1,593

NOTE.—To extend this table to foundations of increased breadth, multiply the number in column 4 of next table (CLXXVII) by the increase of breadth, and add the product to column 4 of this table; this gives *area* of the required foundation, *e.g.*, the area of a bed of concrete under wing of a 10-feet high drain of increased breadth $(g) = 1$ foot; $\therefore A' + gL = 60{\cdot}9 + (1 \times 21{\cdot}2) = 82{\cdot}1$, which multiplied by depth of bed gives the content.

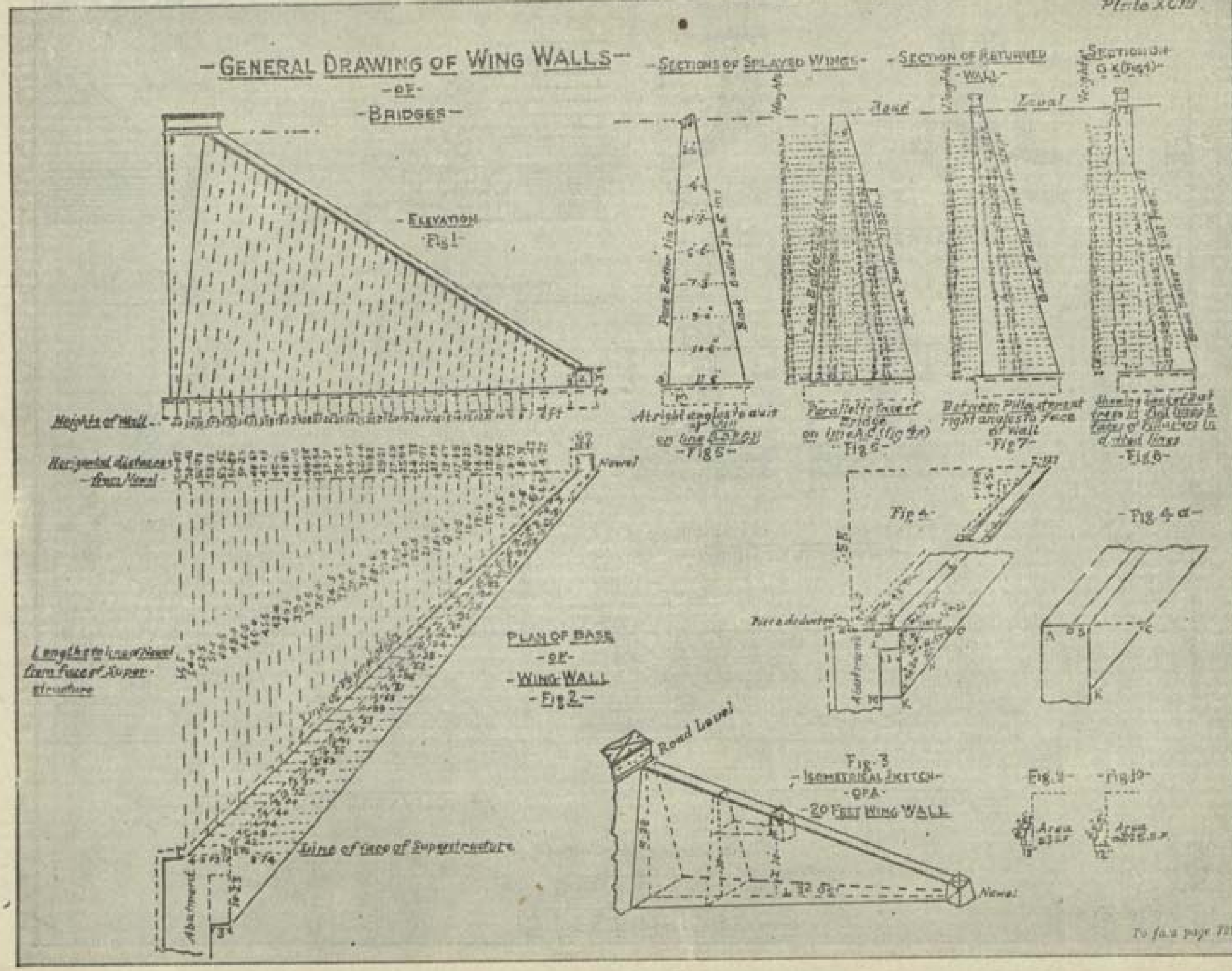
TABLE CLXXVII

DRAINS

Superstructure of wing walls

Height of wings	BODY OF WINGS: Breadth of baseparallel. To axis of road.	BODY OF WINGS: Lengths: Perpendicular. To axis of road.	BODY OF WINGS: Lengths: Parallel to axis of wings	BODY OF WINGS: Area: Shoulder parallel to end axis of road	BODY OF WINGS: Area: True mean prismoidal	BODY OF WINGS: Cubic feet in one	PYRAMIDS AT SHOULDERS: Slab drains: Cubic feet in one	PYRAMIDS AT SHOULDERS: Culverts: Cubic feet in one	Height of wings	PYRAMIDS AND BODIES COMBINED: Slab drains: Cubic feet in four	PYRAMIDS AND BODIES COMBINED: Culverts: Cubic feet in four
H	B	l	L	A	Ap	C	$\frac{A''H}{3}$	$\frac{A''H}{3}$	H	$4\left(C+\frac{A''H}{3}\right)$	
2	2·42	3	4·2	4·2	1·98	6	·4	·9	2	25	26
3	2·73	4·5	6·4	6·8	3·13	14	1·0	1·4	3	60	62
4	3·04	6	8·5	9·6	4·39	26	2·0	2·7	4	112	115
5	3·36	7·5	10·6	12·8	5·75	43	3·6	4·7	5	187	191
6	3·67	9	12·7	16·3	7·22	65	5·9	7·4	6	284	289
7	3·99	10·5	14·8	20·2	8·79	93	9·1	11·0	7	406	414
8	4·31	12	17·0	24·3	10·47	126	13·3	15·7	8	557	567
9	4·62	13·5	19·1	28·8	12·26	166	18·4	21·4	9	738	750
10	4·94	15	21·2	33·6	14·15	212	24·8	28·6	10	948	963
11	5·26	16·5	23·3	38·7	16·15	267		37·1	11		1,214
12	5·57	18	25·5	44·0	18·25	329		47·0	12		1,502
13	5·89	19·5	27·6	49·8	20·46	399		58·7	13		1,831
14	6·21	21	29·7	55·9	22·79	479		72·3	14		2,203
15	6·53	22·5	31·8	62·3	25·20	567		87·8	15		2,619
16	6·85	24	33·9	69·0	27·73	666		105·3	16		3,083
17	7·16	25·5	36·1	75·9	30·36	774		124·7	17		3,595
18	7·48	27	38·2	83·3	33·10	894		146·7	18		4,163
19	7·79	28·5	40·3	90·8	35·95	1,025		170·6	19		4,780
20	8·11	30	42·4	98·8	38·90	1,167		197·6	20		5,458

NOTE.—The content of a wing of other splay Φ than $45° = C = \frac{\text{tabular content} + \sec\Phi}{1\cdot414}$ and of one of other ratio of slope of bank than $1\frac{1}{2}$ to 1 = tabular content × other ratio ÷ 1·5.
Areas for intermediate heights may be got by interpolation.



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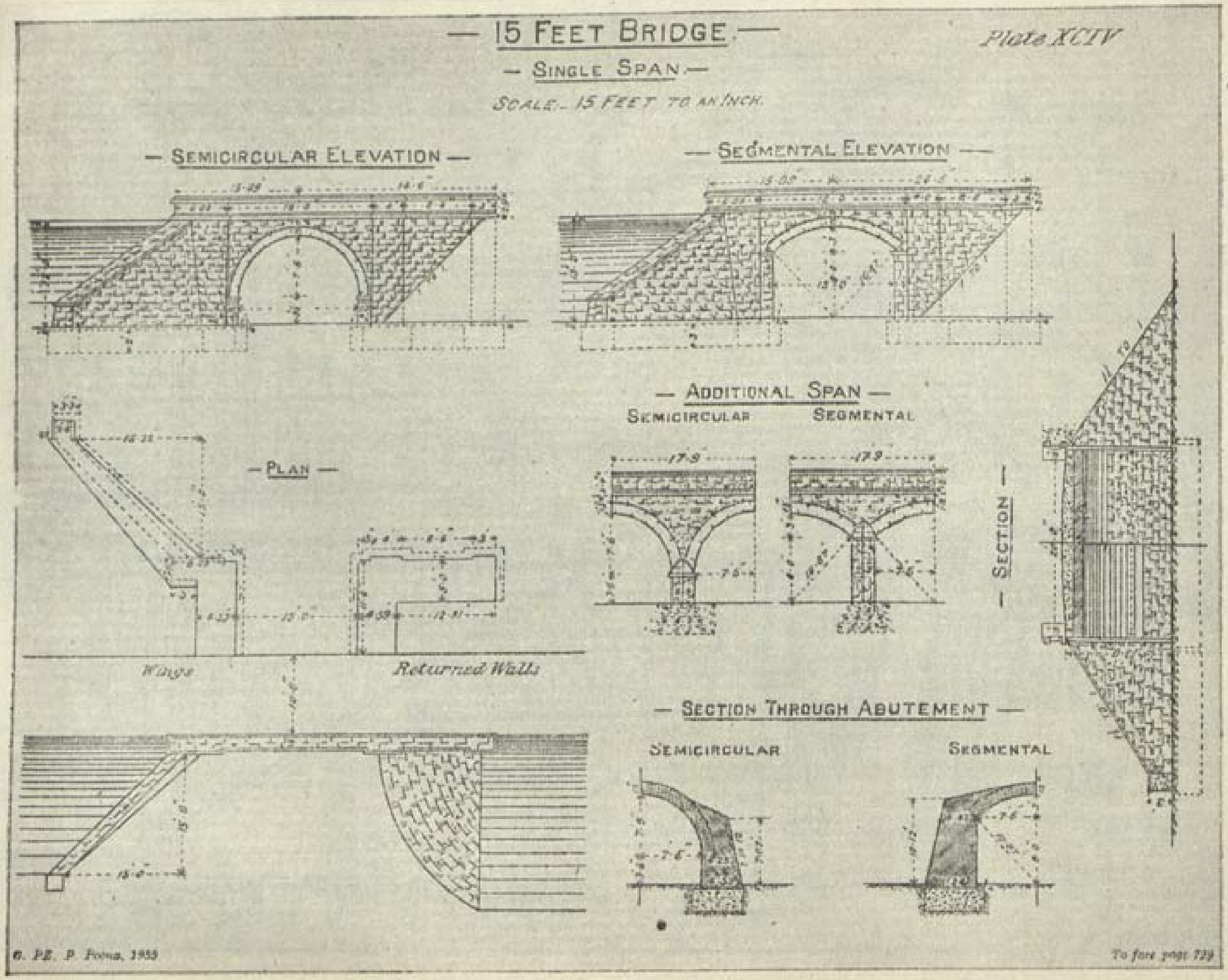
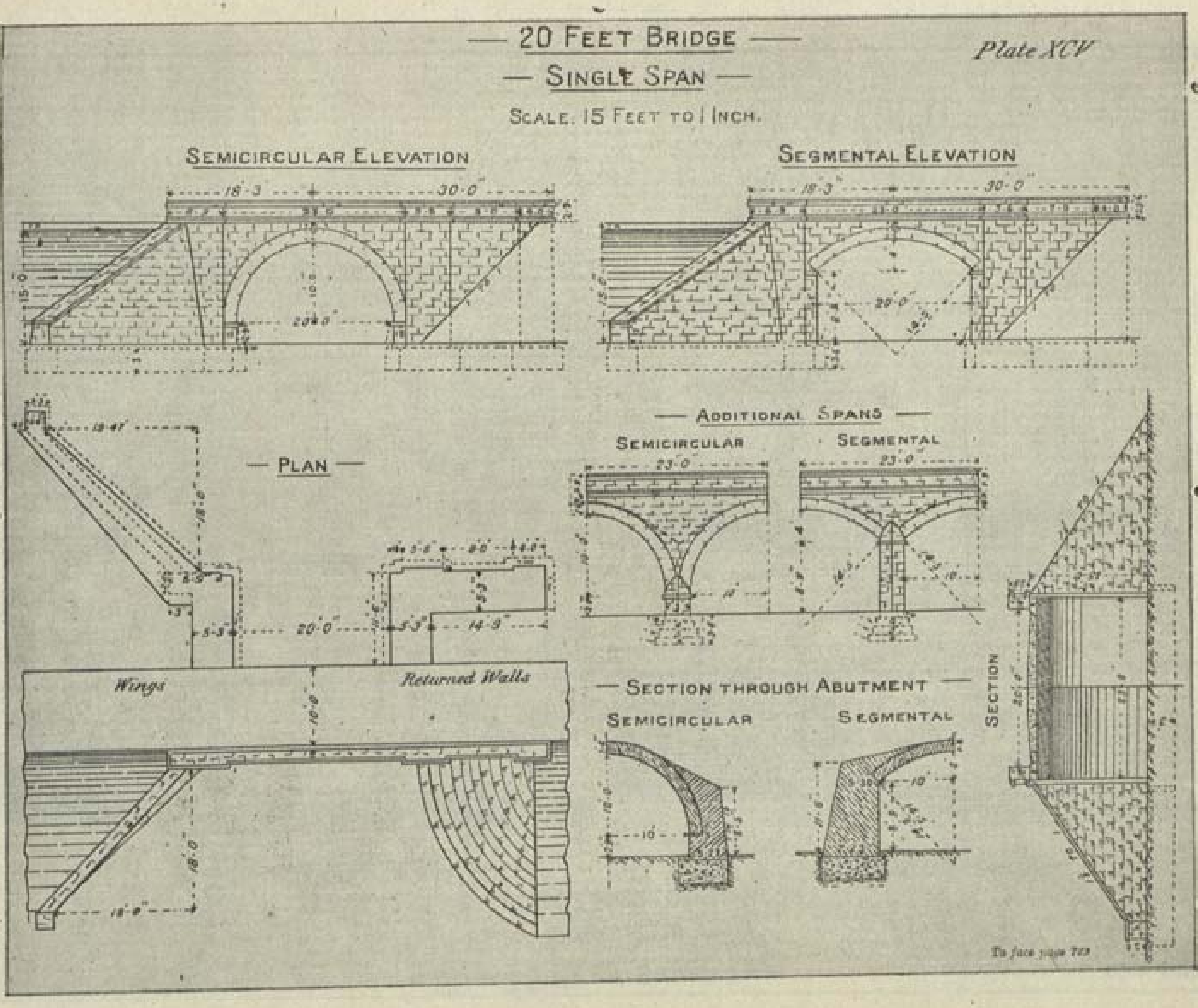
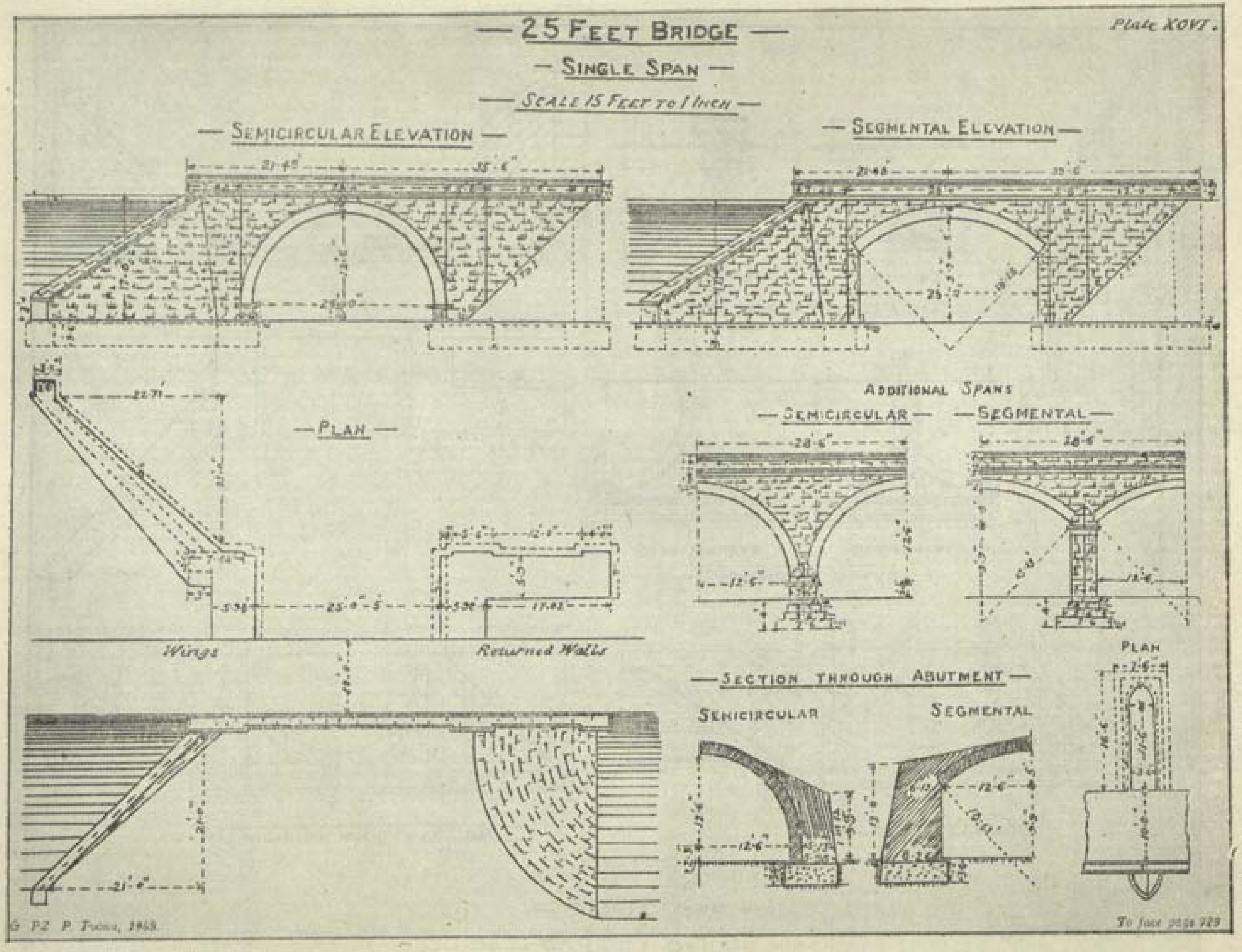

— 15 FEET BRIDGE —
Plate XCIV
— SINGLE SPAN —
SCALE:- 15 FEET TO AN INCH
— SEMICIRCULAR ELEVATION —
— SEGMENTAL ELEVATION —
— PLAN —
Wings
Returned Walls
— ADDITIONAL SPAN —
SEMICIRCULAR
SEGMENTAL
— SECTION —
— SECTION THROUGH ABUTEMENT —
SEMICIRCULAR
SEGMENTAL
G. PE. P. Poona, 1935
To face page 739



— 20 FEET BRIDGE —
— SINGLE SPAN —
SCALE. 15 FEET TO 1 INCH.
Plate XCV
SEMICIRCULAR ELEVATION
SEGMENTAL ELEVATION
— PLAN —
Wings
Returned Walls
— ADDITIONAL SPANS —
SEMICIRCULAR
SEGMENTAL
— SECTION THROUGH ABUTMENT —
SEMICIRCULAR
SEGMENTAL
SECTION
To face page 723



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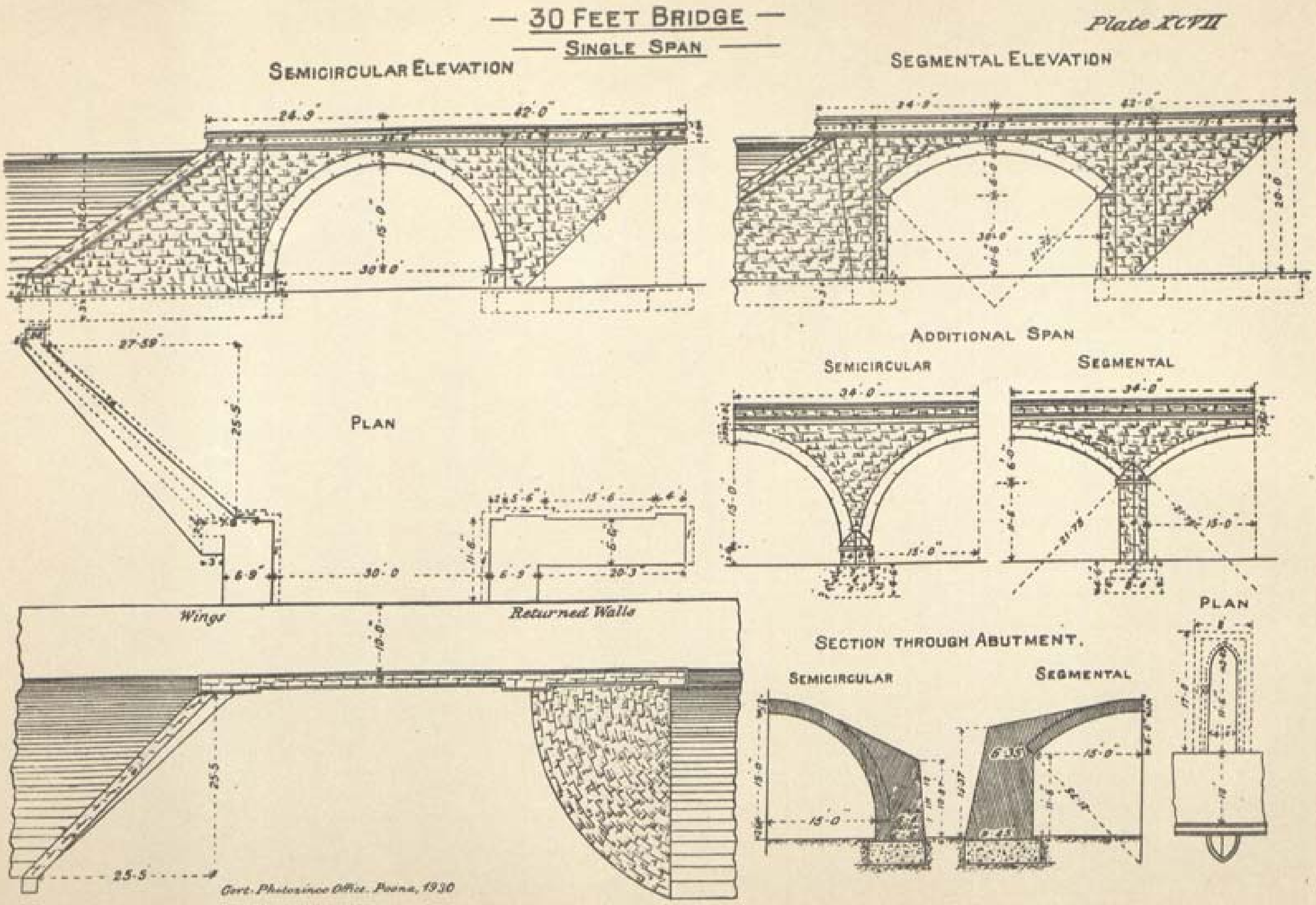
— 30 FEET BRIDGE —
— SINGLE SPAN —
Plate XCVII
SEMICIRCULAR ELEVATION
SEGMENTAL ELEVATION
PLAN
Wings
Returned Walls
ADDITIONAL SPAN
SEMICIRCULAR
SEGMENTAL
SECTION THROUGH ABUTMENT.
SEMICIRCULAR
SEGMENTAL
PLAN
Govt. Photozinco Office, Poona, 1930

EXAMPLES ON TABLES CLXXX AND CLXXXI

4. When the ground on which a wing is founded slopes upward, the wing will be shortened, as shown by dotted lines in Fig. 3, plate XCIII.

There are two ways of calculating the contents of such a wing.

One, by assuming a give and take plane along the foundations from the shoulder to the newel; the other, by taking out each step separately. The tables will facilitate the calculations either way, but the first will give the most practical approximation, especially when the steps are *frequent* and *small*. Call x the height of the end of wall over the level of the base at the shoulder of the wing.

The mean area will be that due to the height H; but the length (l) will be that due to the height H—x; for the values of these, see tables, columns A_p and l.

Let $x=10$; $H=20$; $H-x=10$.

Then area due to H=51·1; length due to H—x=10·5; and content 51·1×10·5=536·5 (vide Table CLXXXI).

In *foundations*, mean breadth for 20 feet$=\frac{\text{area}}{\text{length}}=\frac{182{\cdot}4}{25{\cdot}5}=7{\cdot}15$; length=10·5 ∴content=75×3=225.

The quantities by the second method are obtained by deducting the quantities due to a wall of the height of the ends at the several steps, from the quantities due to the shoulder-heights; thus if we have a wall built in 2 steps, as shown in Fig. 3, by dotted lines; the first step being at a point in the wall 16 feet high; and the rise of the step being 10 feet;

Then—

Content due to	20 feet=1,303 c.ft.	∴ content of 1st block=562c. ft.
less content due to	16 „ = 741	
and content due to	6 „ = 59	∴ content of end block = 59
		Total content of wall =621

The content of *foundations*=547—378+64=233 cubic feet.

This method is the more accurate one when the steps are *few* and *large*.

5. When the approaches of a bridge have other ratio (r') of slope than 1½ to 1 or, θ' other than 33°41′,

$$\text{the content of a wing} = \textit{tabular content} \times \frac{r'}{1{\cdot}5} = \text{tabular content} \times \frac{\cot \theta 1^\circ}{\cot 33^\circ 41'}$$

6. When a wing has other splay, ϕ', than 45°; or 1 to 1,

$$\text{the content of a wing} = \text{tabular content} \times \frac{\sec \phi'}{1{\cdot}414}$$

7. When a wing has other splay and approaches other slopes,

$$\text{the content of the wing} = \text{tabular content} \times \frac{r' + \sec \phi'}{2{\cdot}121}.$$

TABLE CLXXVIII

CULVERTS AND DRAINS (FOUNDATIONS OF WINGS FOR BRICK WORK)

	BODY OF WINGS				TRIANGLES AT SHOULDER					BODIES AND TRIANGLES COMBINED		
					Slab drains		Culverts					
Height of wing in feet	Breadth or base at shoulders parallel to axis.	Length perpendicular to axis.	Area of one	Cubical contents of one	Area of one	Cubical contents of one.	Area of one	cubical content of one.	Height of wing in feet.	Slab drain	Culvert	Remarks
H	B	L	A′	C′2=A′	A″	C″	A″	C″	H	4 (C′+C″)		
2	2·94	3	7·9	15·8	0·49	1·0	0·78	1·56	2·00	67·2	69·4	
3	3·26	4·5	12·5	25·0	0·91	1·82	1·29	2·58	3·00	107·2	110·3	*Slab drain*
4	3·57	6·0	17·6	35·2	1·43	2·86	1·90	3·80	4·00	152·24	156·0	y=1·35+0·71
5	3·89	7·5	23·2	46·5	2·11	4·22	2·68	5·36	5·00	02·88	207·4	= 2·06 up to 5′ height.
6	4·73	9·0	34·00	68·0	3·11	6·22	4·00	8·00	6·00	296·9	304·0	y=1·8+0·71.
7	5·04	10·5	41·3	82·6	4·02	8·04	5·05	10·10	7·00	362·6	370·8	=2·51 above 5′ height.
8	5·36	12·0	49·1	98·3	5·12	10·24	6·25	12·50	8·00	434·1	443·2	*Culverts.*
9	5·68	13·5	57·4	114·9	6·34	12·68	7·58	15·16	9·00	506·3	520·2	y=1·12+0·71.
10	6·00	15·0	66·2	132·4	7·68	15·36	9·04	18·08	10·00	591·0	601·9	=1·83 up to 5 height.
11	6·32	16·5	75·5	151·0			10·64	21·28	11·00		689·1	y=1·5+0·71.
12	6·63	18·0	85·1	170·2			12·30	24·60	12·00		779·2	=2·21 above 5′ height.
13	6·95	19·5	95·3	190·7			14·15	28·30	13·00		876·0	
14	7·27	21·0	106·1	212·1			16·14	32·28	14·00		977·5	
15	7·59	22·5	117·2	234·5			18·23	36·46	15·00		1083·8	

N. B.—Upto 5′ height the width of the wing wall is taken 13½″; Splay of wings at 45° to the road axis.

Above 5′ height the width of the wing wall is taken 18″; Bank Slopes 1½ to 1.

The depth of foundation is taken 2′; if it is more than 2′ contents may be found out separately by multiplying area × depth (actual).

TABLE CLXXIX

DRAINS AND CULVERTS (SUPERSTRUCTURE OF WINGS IN BRICK WORK)

Height of wing in feet	BODY OF WINGS						PYRAMIDS AT SHOULDERS		Height of wing	TOTAL CONTENTS ALL FOUR WING BODIES AND PYRAMIDS COMBINED IN CUBIC FEET.		Remarks
	Breadth of base at shoulders parallel to axis of road in feet	Length perpendicular to axis of road in feet	Length at 45° angle to axis of road in feet.	Area of one wing at shoulder in square feet	Mean prismoidal area in squre feet.	Cubical contents of one wing	Slab drain	Culverts		Slab drain	Culverts	
H	B	L	L	A′	A/P	C	AH/3	AH/3	H	4 (C+AH/3)		
2	2·23	3·00	4·2	3·83	1·81	5·43	0·33	0·52	2·00	23·04	23·80	
3	2·55	4·5	6·4	6·22	2·87	12·74	0·90	1·29	3·00	54·56	56·12	Slab Drain.
4	2·86	6·0	8·5	8·92	4·04	24·24	1·91	8·53	4·00	104·60	107·08	y=1·35 up upto 5′ height.
5	3·18	7·5	10·6	11·95	5·33	39·98	3·52	4·47	5·00	174·00	177·80	y = 1·80 above 5″ height.
6	4·02	9·0	12·7	18·42	8·26	74·84	6·22	8·00	6·00	322·24	329·36	Culverts.
7	4·33	10·5	14·8	22·57	10·00	105·00	9·38	11·78	7·00	457·52	467·12	y = 1·12 up to 5′ height.
8	4·65	12·0	17·0	27·08	11·85	142·20	13·65	16·66	8·00	622·60	635·44	y = 1·5 above 5″ height.
9	4·97	13·5	19·1	31·95	13·83	186·71	19·02	22·74	9·00	822·92	837·80	
10	5·29	15·0	21·2	37·05	15·88	238·20	25·60	30·13	10·00	1055·20	1073·32	
11	5·61	16·5	23·3	42·51	18·05	297·83		39·01	11·00		1347·36	
12	5·92	18·0	25·5	48·24	20·32	365·76		49·20	12·00		1659·84	
13	6·24	19·5	27·6	54·34	22·71	442·85		61·32	13·00		2024·68	
14	6·56	21·0	29·7	60·76	25·20	529·20		75·32	14·00		2418·08	
15	6·88	22·5	31·8	67·50	27·80	625·50		91·15	15·00		2866·60	

N. B.—Up to 5′ height the width of the wing wall is taken 13½″; Splay of wings at 45° to the road axis.

Above 5′ height the width of the wing wall is taken 18″; Bank slopes 1½ to 1.

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TABLE CLXXX.

BRIDGES

Foundations of wing walls(splayed)

Height of wings	BODY OF WINGS IN FORNT OF FACE OF BRIDGE — Breadth at shoulder B′	Gross area A′	Gross content of one. A′ × 3	Deduct for overlap of foundations of pilaster — Area. O′	Content	Net Content of one	SHOULDERS — Area of one shoulder a′	Content of one shoulder	Total net content of 4 wings, and shoulder buttresses.	NOTE, ETC
6	5·28	21·45	64·3	3·25	9·7	54·6	1·0	3·0	230	
7	5·62	29·62	88·9	3·37	10·1	78·8	1·4	4·2	332	
8	5·961	38·30	114·9	3·50	10·5	104·4	1·8	5·4	439	
9	6·302	47·49	142·5	3·62	10·9	131·6	2·3	6·9	554	
10	6·642	57·20	171·6	3·75	11·2	160·4	2·9	8·8	677	
11	6·983	67·41	202·2	3·87	11·6	190·6	4·3	12·9	814	
12	7·3.4	78·14	234·4	4·00	12·0	222·4	5·7	17·2	958	
13	7·665	89·38	268·1	4·12	12·4	255·7	7·2	21·6	1109	
14	8·006	101·13	303·4	4·25	12·7	290·7	8·7	26·2	1268	
15	8·347	113·40	340·2	4·37	13·1	327·1	10·3	30·9	1432	
16	8·688	126·17	378·5	4·50	13·5	365·0	11·9	35·8	1603	
17	9·029	139·46	418·4	4·62	13·9	404·5	18·6	40·9	1782	
18	9·370	153·26	459·8	4·75	14·2	445·6	15·4	46·1	1967	
19	9·711	167·57	502·7	4·87	14·6	502·7	17·2	51·5	2217	
20	10.052	182·37	547·1	5·00	15·0	532·1	19;0	57·1	2357	
21	10·393	197·72	593·2	5·12	15·4	577·8	20·9	62·8	2562	
22	10·734	213·55	640·6	5·25	15·7	624·9	22·9	68·8	2775	
23	11·075	229·92	689·8	5·37	16·1	673·7	24·9	74·8	2994	
24	11·416	246·78	740·3	5·50	16·5	723·8	27·0	81·1	3220	
25	11.757	264·16	792·5	5·62	16·9	775·6	29·2	87·5	3452	
26	12·098	282·05	846·1	5·75	17·2	828·9	31·4	94·1	3692	
27	12·439	300·45	901·3	5·87	17·6	883·7	33·6	100·9	3938	
28	12·780	319·35	958·0	6·00	18·0	940·0	35·9	107·8	4191	
29	13·121	338·79	1016·4	6·12	18·4	998;0	38·3	114·9	4452	
30	13·462	358·71	1076·1	6·25	18·7	1057·4	40·7	122·1	4798	
31	13·803	379·17	1137·5	6·37	19·1	1118·4	43·2	129·6	4992	
32	14·144	400·13	1200·4	6·50	19·5	1180·9	45·7	137·2	5272	
33	14·485	421·60	1264·8	6·62	19·9	1244·9	48·3	144·9	5559	
34	14·826	443·58	1330·7	6·75	20·2	1310·5	50·9	152·8	5853	
35	15·167	466·08	1398·2	6·87	20·6	1377·6	53·6	160·9	6154	
36	15·508	486·06	1458·2	7·00	21·0	1437·2	56·4	169·2	6426	
37	15·849	512·60	1537·8	7·12	21·4	1516·4	59·2	177·7	6776	
38	16·190	536·60	1609·8	7·25	21·7	1588·1	62·1	186·3	7098	
39	16·531	561·17	1683·5	7·37	22·1	1661·4	65·0	195·0	7426	
40	16·872	586·19	1758·6	7·50	22·5	1736·1	68·0	204·0	7760	

NOTE, ETC:

B′ is the skew breadth of foundation of wall on line AC, (Fig. 4) = .341 H + 3·231, is made up of the breadth of superstructure base + 1·111. The breadth at the small end is constant and = 4·253.

A′ is the total horizontal area of wing in front of face line of drain.

O′ = area of part of pilaster overlapping wing in Fig. 4 = $\frac{H}{8} + 2·5$ nearly.

a′ the area of the buttress at the shoulder.

The lengths *l* and L are the same as in Table CLXXVII.

Note 1.—The contents of the shoulders are correct only when :

(1) the pillasters extend three feet beyond the rear toes of the abutments;

2) the pillasters are 2′—6″ wide; and

(3) the abutment has no rear batter.

For other conditions, the contents of the shoulders should be worked out.

Note 2.—All the drawings of drain, culvert and bridge foundations, show no offset on the rear side of the abutments. An offset of about 6′ 'on the rear would be an improvement as:—

(1) It would provide a good concrete base for the abutment rear toe, which otherwise would rest on soil, if there is the slightest mistake in alignment.

(2) The edges of concrete in soil are usually not as well rammed as the middle portion and the offset would provide a margin of safety against starting the abutment on bad concrete.

(3) If the bank behind the abutment is washed away, the rear concrete offset, in the case of arched-culverts, helps in keeping the pressure over the sodden foundation base within safe limits,

TABLE CLXXXI

SUPERSTRUCTURE OF WING WALLS (SPLAYED)

Height of wings	BODY OF WING IN FRONT OF FACE OF BRIDGE					SHOULDER		NOTES, ETC.
	Breadths of base at shoulder	Lengths perpendicular to face of bridge	Lengths on axis of wing	Prismoidal, or true mean area	Content of one wing (body)	Content of one buttress	Total content of 4 wings and shoulder buttresses	
H	Bh	*l*	L	A_p	C	c	4 (C+c)	
6	4·17	4·5	6·36	13·1	59	2·0	244	
7	4·51	6·0	8·48	15·1	91	3·2	377	
8	4·85	7·5	10·61	17·2	129	4·8	535	
9	5·191	9·0	12·73	19·4	175	6·8	727	
10	5·531	10·5	14·85	21·7	228	9·3	949	
11	5·872	12·0	16·97	24·1	289	13	1209	
12	6·213	13·5	19·09	26·7	360	13	1514	
13	6·554	15·0	21·21	29·3	440	24	1856	
14	6·895	16·5	23·23	32·1	530	32	2248	
15	7·236	18·0	25·45	35·0	630	42	2688	
16	7·577	19·5	27·57	38·0	741	53	3176	
17	7·918	21·0	29·69	40·9	859	66	3700	
18	8·259	22·5	31·82	44·3	997	80	4308	
19	8·600	24·0	33·94	47·6	1142	96	4952	
20	8·941	25·5	36·06	51·1	1303	115	5672	
21	9·282	27·0	38·18	54·7	1477	135	6448	
22	9·623	28·5	40·30	58·3	1662	156	7272	
23	9·964	30·0	42·42	62·1	1863	180	8172	
24	10·306	31·5	44·54	66·0	2079	206	9140	
25	10·646	33·0	46·66	70·1	2313	234	10188	
26	10·987	34·5	48·78	74·2	2560	265	11300	
27	11.328	36·0	50·90	78·5	2826	297	12492	
28	11·669	37·5	53·02	82·8	3105	332	13748	
29	12·010	39·0	55·15	87·3	3405	369	15096	
30	12·351	40·5	57·27	91·9	3722	408	16520	
31	12·692	42·0	59·39	96·6	4057	450	18028	
32	13·033	43·5	61·51	101·4	4411	495	19624	
33	13·374	45·0	63·63	106·3	4784	542	21304	
34	13·715	46·5	65·75	111·4	5180	591	23084	
35	14·956	48·0	67·87	116·3	5597	664	24964	
36	14·397	49·5	69·99	121·2	6034	699	26932	
37	14·738	51·0	72·11	127·2	6487	756	28972	
38	15·079	52·5	74·23	132·7	6967	817	31136	
39	15·420	54·0	76·35	138·4	7474	881	33420	
40	15·761	55·5	78·47	145·1	8053	947	36000	

Notes:

Bh is the skew breadth, that is, on the line parallel to the face of the bridge.

The skew breadth of top of wall =2·12 1
Face batter = ·1225H
Back ,, =2185H
l = 1·5 (H—3).
L=1·5 (H—3) secant ϕ°

The content of the shoulder buttress (c) is made up of a pyramid and a wedge.

8. **Cut-waters.**—Cut-waters may be formed by describing an equilateral triangle with plain sides on the ends of the pier, and this is found to be a convenient form; or by a similar triangle with curved sides. The following table gives the area of such cut-waters :—

TABLE CLXXXII

B	at= 433 B²	A= ·615B²	h= ·866B	l= 1·047 B	B	a_t= ·433 B²	A= ·615 B²	h= ·866 B	l= 1·047 B
1.50	0·97	1·38	1·30	1.57	5.25	11·93	16·95	4·55	5·50
1.75	1·32	1·89	1·52	1.83	5.50	13·10	18·60	4·76	5·76
2.00	1·73	2·46	1·73	2·09	5.75	14·31	20·33	4·98	6·02
2.25	2·19	3·11	1·95	2.36	6.00	15·59	22·14	5·20	6·28
2.50	2·71	3·84	2·17	2.62	6.25	16·91	24·02	5·41	6·54
2.75	3·27	4·64	2·38	2.88	6.50	18·29	25·98	5·63	6·81
3.00	3·90	5·54	2·60	3.14	6.75	19·72	28·01	5·85	7·07
3.25	4·57	6·49	2·81	3.40	7.00	21·21	30·14	6·06	7·33
3.50	5·30	7·53	3·03	3.66	7.25	22·75	32·32	6·28	7·59
3.75	6·08	8·65	3·25	3.93	7.50	24·36	34·59	6·50	7·85
4.00	6·93	9·84	3·47	4.18	7.75	26·01	36·94	6·71	8·11
4.25	7·81	11·10	3·69	4.44	8.00	27·75	39·36	6·93	8·38
4.50	8·76	12·45	3·90	4.71	8.25	29·47	41·86	7·14	8·64
4.75	9·76	13·87	4·11	4·98	8.50	31·28	44·43	7·36	8·90
5.00	10·82	15·38	4·33	5·24	8.75	33·15	47·09	7·58	9·16
					9.00	35·07	49·82	7·79	9·42

9. **Abutments.**—Thickness of abutment at springing in feet when the height of the abutment does not exceed $1\frac{1}{2}$ times its base $= \frac{R}{5} + \frac{r}{10} + 2.$

where R = radius of the arch in feet

r = rise of the arch in feet.

In the case of semi-circular arches the abutments have a back batter of 1 in 12 and in the case of segmental arches the batter is variable (see Trautwine's *Pocket Book*).

10. **Abutment piers.**—In bridges composed of numerous arches, every 4th or 5th pier ought to be strong enough to act as an abutment, its top width being the same as that of the abutment, and its sides having a batter of 1 in 12 High piers (above $11\frac{1}{2}$ feet) should have a batter of 1 in 24.

11. **Centres.**—For culverts centres will be of mud and stone or *muram* supported on a framework of timber as may be convenient.

For bridges they will-be of framed timber and will consist of braced ribs about 5 feet to 6 feet apart. The rib to be of double planking 2 to 3 inches thick, bolted together and tied at the feet. Laggings to be 2 inches thick and from 3 to 5 inches broad ; one out of every three to be nailed to the rib.

The ribs to be lowered by sand boxes or cylinders ; over and under these to be longitudinal one-inch planks which tie the feet of the ribs and the tops of the lower props axially together. The props or supporting posts to rest on the abutment footings if not too high ; otherwise on corbels left in the walls or on temporary piers of rubble masonry.

The cost of centres and their erection and removal to form a separate item in the estimate.

TIMBER-TOPPED CULVERTS

1. These culverts are much in use in places where the supply of timber is ample and cheap.

The structure consists of abutments sufficiently strong to resist the earth pressure at the back with girders to span the opening between them. The floor of the culvert may be either of planking or of corrugated iron, or of teak bullies laid close together ; in the first case the surface may be left bare, being sprinkled with a little sand only ; in the other two the surfacing material should be carried over the covering. Two thickness of 20 B. W. G. iron will form a good floor.

2. Tables Nos. CLXXXIII and CLXXXIV give scantlings and iron work necessary for such culverts with the loads due to ordinary cart traffic.

TABLE

SCANTLINGS FOR TIMBER-TOPPED

For a clear road

Description of scantlings	4 ft. span.				
	Number	Length	Breadth	Depth	Cubic contents
		Ft. in.	In.	In.	Ft.
Girders	6	5 6	3	5	3·44
Wall plates to girders	4	9 0	4	3	3·00
Railing: Sill	2	9 0	4	5	2·50
Railing: Top rail	2	4 6	4	4	1·00
Railing: Middle rail	2	4 6	4	3	·75
Railing: End posts	4	3 3	4	4	1·44
Railing: Intermediate posts			None		
Railing: End struts	4	3 3	3	4	1·08
Railing: Side struts	4	2 9	3	3	·69
Planking	5	11 5	8	3	9·51
Do.	5	8 2	8	3	6·80
Do. projected to carry struts	2	13 5	9	3	5·03
	2	10 2	9	3	3·81
			Total c.ft.	..	39·05

Description of scantlings	8 ft. span				
	Number	Length	Breadth	Depth	Cubic contents
		Ft. in	In.	In.	Ft.
Girders	6	9 6	4¾	7¾	14·57
Wall plates to girders	4	9 0	4½	3	3·37
Railing: Sill	2	13 0	4	5	3·61
Railing: Top rail	2	8 6	4	4	1·89
Railing: Middle rail	2	8 6	4	3	1·42
Railing: End posts	4	3 3	4	4	1·44
Railing: Intermediate posts	2	2 6	4	4	·55
Railing: End struts	4	3 3	3	4	1·08
Railing: Side struts	6	2 9	3	3	1·03
Planking	8	11 5	10	3	19·03
Do.	8	8 2	10	3	13·61
Do. projected to carry struts	3	13 5	9	3	7·55
	3	10 2	9	3	5·72
			Total c. ft.	..	74·87

CLXXXIII.

CULVERTS, SINGLE SPANS.

way of 18 *feet.*

5 ft. span					6 ft. span				
Number	Length	Breadth	Depth	Cubic contents	Number	Length	Breadth	Depth	Cubic contents
	Ft. in.	In.	In.	Ft.		Ft. in.	In.	In.	Ft.
6	6 6	3¼	5½	4·84	6	7 6	3¾	6¼	7·32
4	9 0	4	3	3·00	4	9 0	4	3	3·00
2	10 0	4	5	2·78	2	11 0	4	5	3·06
2	5 6	4	4	1·22	2	6 6	4	4	1·44
2	5 6	4	3	·92	2	6 6	4	3	1·08
4	3 3	4	4	1·44	4	3 3	4	4	1·44
		None.			2	2 6	4	4	·55
4	3 3	3	4	1·08	4	3 3	3	4	1·08
4	2 9	3	3	·69	6	2 9	3	3	1·03
6	11 5	8¾	3	12·49	6	11 5	9¼	3	13·20
6	8 2	8¾	3	8·93	6	8 2	9¼	3	9·44
2	13 5	9	3	5·03	3	13 5	9	3	7·55
2	10 2	9	3	3·81	3	10 2	9	3	5·72
		Total c. ft. ..		46·23			Total c. ft. ..		55·91

10 ft. span					12 ft. span				
Number	Length	Breadth	Depth	Cubic contents	Number	Length	Breadth	Depth	Cubic contents
	Ft. in.	In.	In.	Ft.		Ft. in.	In.	In.	Ft.
6	12 0	5½	9½	25·44	6	14 0	6½	10½	39·81
4	9 0	5	3½	4·37	4	9 0	5	3½	4·37
2	15 0	4	5	4·17	4	9 0	4	5	5·00
2	10 6	4	4	2·33	2	12 6	4	4	2·78
2	10 6	4	3	1·75	2	12 6	4	3	2·08
4	3 3	4	4	1·44	4	3 3	4	4	1·11
2	2 6	4	4	·55	4	2 6	4	4	1·11
4	3 3	3	4	1·08	4	3 3	3	4	1·08
6	2 9	3	3	1·03	8	2 9	3	3	1·37
10	11 5	10¼	3	24·38	12	11 5	9¾	3	27·83
10	8 2	10¼	3	17·44	12	8 2	9¾	3	19·91
3	13 5	9	3	7·55	4	13 5	9	3	10·06
3	10 2	9	3	5·72	4	10 2	9	3	7·62
		Total c. ft. ..		97·25			Total c. ft. ..		126·46

TABLE

Description of scantlings	15 ft. span				
	Number	Length	Breadth	Depth	Cublic contents
		Ft. in.	In.	In.	Ft.
Girders	6	17 6	7½	12½	68·36
Wall plates to girders	4	9 0	6	4	6·00
Railing — Sill	4	10 6	4	5	5·83
Railing — Top rail	2	11 0	4	4	3·78
	2	6 0			
Railing — Middle rail	6	5 0	4	3	2·50
Railing — End posts	4	3 3	4	4	1·44
Railing — Intermediate posts	4	2 6	4	4	1·11
Railing — End struts	4	3 3	3	4	1·08
Railing — Side struts	8	2 9	3	3	1·37
Planking	15	11 5	10½	3	36·57
Do.	15	8 2	10½	3	26·16
Do. projected to carry struts ..	4	13 5	9	3	10·06
	4	10 2	9	3	7·62
			Total c. ft.	..	171·88

CLXXXIII—*contd.*

18 ft. span					20 ft. span				
Number	Length	Breadth	Depth	Cubic contents	Number	Length	Breadth	Depth	Cubic contents
	Ft. in.	In.	In.	Ft.		Ft. in.	In.	In.	Ft.
6	21 0	8½	14½	107·84	6	23 6	9½	15½	144·18
4	9 0	6	4	6·00	4	9 0	6	4	6·00
4	12 0	4	5	6·67	4	13 0	4	5	7·22
4	10 0	4	4	4·44	4	11 0	4	4	{4·89 3·33
8	4 6	4	3	3·00	8	5 0	4	3	1·44
4	3 3	4	4	1·44	4	3 3	4	4	1·67
6	2 6	4	4	1·67	6	2 6	4	4	1·08
4	3 3	3	4	1·08	4	3 3	3	4	1·72
10	2 9	3	3	1·72	10	2 9	3	3	47·57
20	11 5	9	3	42·81	20	11 5	10	3	34·03
20	8 2	9	3	30·62	20	8 2	10	3	12·58
5	13 5	9	3	12·58	5	13 5	9	3	}9·53
5	10 2	9	3	9·53	5	10 2	9	3	
		Total c. ft. ..		229·4			Total c. ft. ..		275·24

TABLE

IRON WORK FOR TIMBER

Description	4 and 5 feet spans					6, 8 and 10 feet spans				
	Number	Length	Breadth	Thickness	Weight in lbs.	Number	Length	Breadth	Thickness	Weight in lbs.
(*Straps to be countersunk*)		Ft. in.	In.	In.			Ft. in.	In.	In.	
Securing the top rail to the end posts.	8	1 0	1¼	1 5/16	6·24	8	1 0	1¼	5/16	6·24
Securing the top rail to the intermediate.	..	..	None	..	..	2	1 4	1¼	5/16	2·08
Holding down plates in the masonry.	4	1 0	8	¼	26·67	4	1 0	8	¼	26·67
Total ..					32·91					34·99
	No.	L.	Diar.	T.	Weight	No.	L.	Diar.	T.	Weight
Bolts										
Holding down securing sill to masonry.	8	2 0	¾	..	23·62	8	2 0	¾	..	23·62
Square heads and nuts to do..	8	·55	lbs. per	pair	4·40	8	55 lbs.	per pai	r	4·40
Washers to Do.	8	..	1½	1½	·55	8	..	1½	⅛	0·55
To straps securing top rail to end posts.	12	0 4½		7/16	2·26	12	0 4½	7/16	..	2·26
Do. do. intermediate do...	..	..	None	..	..	2	0 4½	7/16	..	·38
Bolts securing end struts to sill..	4	1 0	½	..	2·62	4	1 0	½	..	2·62
Do. side do. top and bottom	8	0 8	½	..	3·50	12	0 8	½	..	5·25
Strap do. posts to sill and planking.	4	0 11½	1¼	⅜	5·98	6	0 11½	1¼	⅜	8·97
Bolts to do. through sill and posts.	8	0 4½	7/16	..	1·51	12	0 4½	7/16	..	2·26
Add—for square heads and nuts to above. To ½ in. bolt Pairs.	12	·164 lb	s. per	pair.	1·97	16	164lbs.	per	pair	2·62
Add—for square heads and nuts to above. To 7/16 in. bolts. Pairs.	20	·12 lbs.	per	pair	2·40	26	·12 lbs.	per pa	ir.	3·12
Do. Washers to above ..	33	..	1½	⅛	1·80	42	..	1½	⅛	2·36
Total weight ..Lbs.					50·81					58·11

Spikes for planking 6 inches long 6 to the lb.					
Span	4	5	6	8	10
Number	42	48	54	66	78
Weight in lbs.	7	8	9	11	13

CLXXXIV

TOPPED CULVERTS

12 and 15 ft. spans					18 and 20 ft. spans				
Number	Length	Breadth	Thicknes	Weight in lbs.	Number	Length	Breadt	Thickness	Weight in lbs.
	Ft. in	In.	In.			Ft. in.	In.	In.	
8	1 0	1¼	5/16	6·24	8	1 0	1¼	3/16	6·24
4	1 4	1¼	5/16	4·16	6	1 4	1¼	3/16	6·24
4	1 0	8	¼	26·27	4	1 0	8	¼	26·67
				37·07					39·15
No.	L.	Diar.	T.	Weight	No.	L.	Diar.	T.	Weight
8	0 2	¾	..	23·62	8	2 0	¾	..	23·62
8	.55 lbs.	per pair		4·40	8	·55 lbs.	per pair.		4·40
8	..	1¾	⅛	0·55	8	..	1¾	⅛	0·55
12	0 4½	7/16	..	2·26	12	0 4½	7/16	..	2·26
4	0 4½	7/16	..	0·75	6	0 4½	7/16	..	1·13
4	1 0	½	..	2·62	4	1 0	½	..	2·62
16	0 8	½	..	7·00	20	0 8	½	..	8·75
8	0 11½	1¼	⅜	11·96	10	0 11½	1¼	⅜	14·95
16	0 4½	7/16	..	3·01	20	0 4½	7/16	..	3·76
20	·164 lbs.	per pair.		3·28	24	·164 lbs.	per pair.		3·94
32	·12 lbs.	per pair.		3·84	38	·12 lbs.	per pair.		4·56
32	..	1½	⅛	2·92	62	..	1½	⅛	3·50
				66·21					74·04

12	96	16
15	114	19
18	150	25
20	0	25

Splays of wings.—Except in the case of very small drains a 45° splay is the best. When a narrow splay is combined with less water-way than specified above, water heads up on the up-stream side and works its way behind the wings and eats into the road.

Road dams

For small roads, where the saving of cost is of more importance than the interruption to rapid traffic, the cross-drainage is frequently best effected by the use of road dams or dips, also called Irish bridges. A plan for road dams is given in plate XCVIII.

Many existing road-dams have been constructed on wrong principles. The wall or dam should in all cases be kept as low as circumstances will admit, the ends being carried well into the solid banks of the approaches, and generally above the highest flood level. The coping should be solid, of uniform width and depth, and having the upper surface horizontal. The outer edge of the coping should be in the same line as the kerbing of the approaches. The level portion of the wall should have a minimum length of 10 feet.

The side-channels should be eased off as they approach the dam.

The filling at the back of the wall, which should be well consolidated hard *muram* must be brought up flush with the inside of the coping, and should be truly horizontal in section, having no central rise as in the case of ordinary roads. Metal should not be used as a top dressing, hard *muram* being preferable.

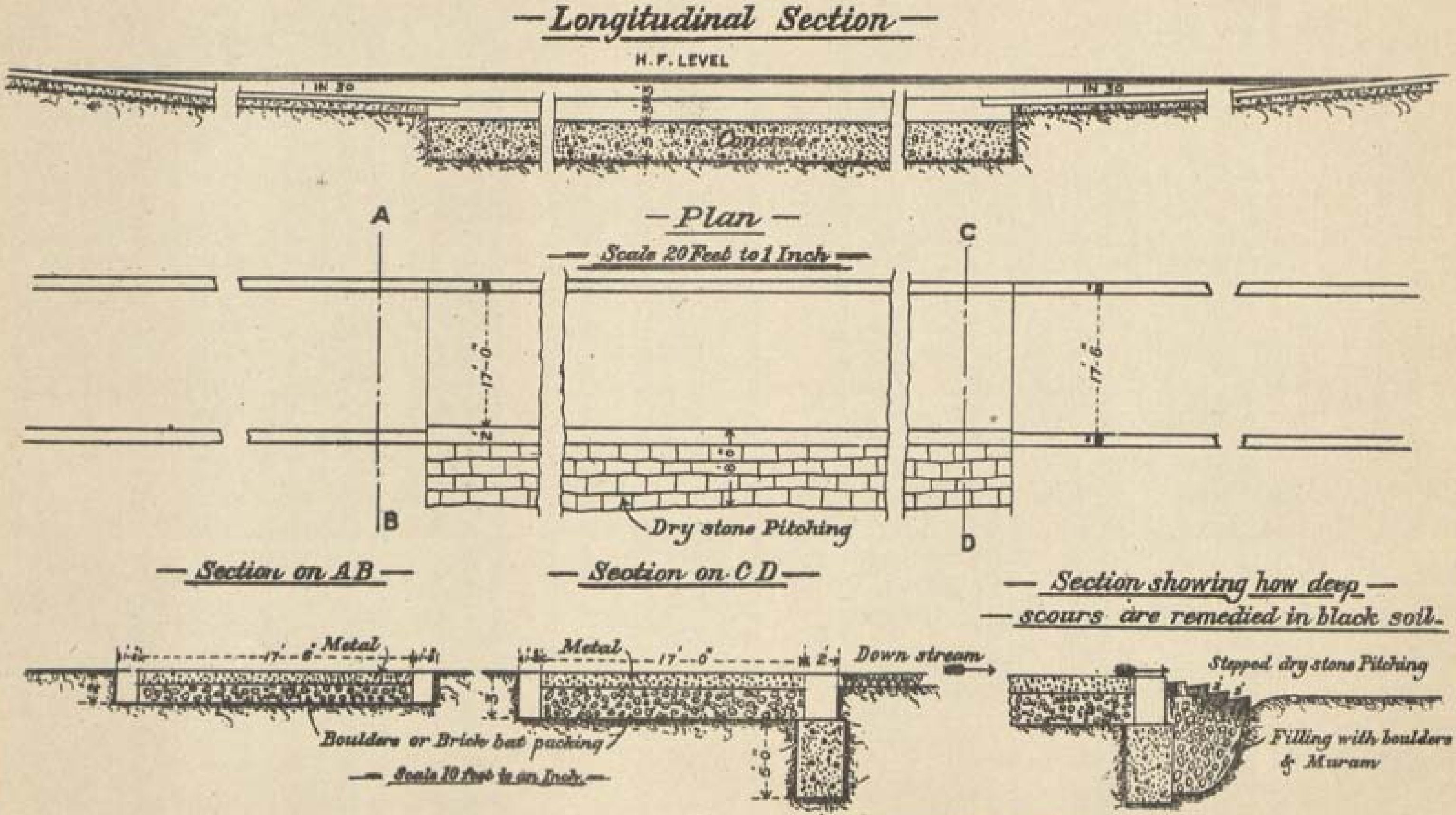
The depth of foundation must be modified so as to be beyond the reach of scour, and in bad cases may be protected by the addition of a curtain wall on the lower side.

The level portion of "paved" dips should be from 6 to 9 inches higher than the *nala* bed on the downstream side, so that there may be no silt deposit on the pavement.

The dry stone pitching shown in the plate is frequently omitted.

Plate XCVIII

— METAL CAUSEWAY —



Govt. Photozinco: Office, Poona, 18

Notes on the design of high level causeways.

1. **Survey work.**—The instructions given in paragraphs 9 to 15 on pages 547 to 549, chapter V, hold good also in the case of causeways and the following additions may also be made :—

(*a*) If due to changes of material in the river bed or banks or due to any other causes, abrupt changes occur in the bed fall or cross sections of the stream in the course of half a mile downstream and upstream of the proposed site the end cross sections and the longitudinal section of the river should be taken at shortest distances than laid down in paragraph 11 on page 548, chapter V. Usually 1,000 feet to 1,500 downstream and a similar distance upstream will suffice.

(*b*) In rivers with deep sandy beds, the depth of sand must be ascertained, as raft foundations are generally considered suitable for causeways constructed in rivers with deep sandy beds.

2. **Designed waterway.**—Causeway waterway design is governed by the periods during which it is permissible to have the road closed to traffic. Consequently there are four main designs.—(1) the modest low causeway with a few openings to pass the flow in the cold and hot seasons.

(2) The somewhat higher causeway with more openings, passing not merely cold and hot weather discharges, but also the flow during the end of the monsoon period.

(3) The high-level causeways or submersible bridges passing all ordinary floods.

Flood observations on a stream for as many seasons as possible, fix the total average period of closure of the causeway during the monsoon, as also the longest continuous period during which it will remain closed, and the frequency of this priod. It will be realised that for small streams with steep grandients, the floods come rapidly and recede rapidly, but for larger streams and rivers the floods are generally more sustained. It follows that if the permissible closure is the same for both, the causeways over the smaller streams need pass a much smaller proportions of the flood, than the causeways over larger streams.

Cheapness.—Causeways cause obstruction to traffic, small or big according to the design.. The main reason for adoption of this type must therefore be less cost, and in every case it has to be decided whether the saving in first cost is such as is worthwhile, considering the inconvenience.

Standards laid down by the Conference of Chief Engineers.—Submersible bridges may be provided on National Highways, Provincial Highways and District roads. 'Major' and 'other', when serious interruption (*i.e.*, a stoppage of traffic, for many periods exceeding 12 hours at a time, or more than 6 days in the year, or frequent stoppages for shorter periods), is not likely to occur.

In the case of village roads, interruption to traffic may be, up to 3 days at a time and up to six times a year.

Suitability of a site.—'The factors which determine the suitability of of site for a submersible bridge are —

(1) a fairly straight stretch of river,
(2) well-defined fairly high banks,
(3) small width of stream,
(4) good foundations.

A straight stretch is important in siting a bridge also, but in the case of a submersible bridge, it is very important, as the danger of outflanking is much greater.

Well-defined high bank:—absolutely essential to permit of approaches in cutting. Approaches in high bank have to be protected by return walls or pitching thus adding greatly to the cost.

Small stream width, and good foundations, lead to cheapness : It should be remembered that the velocities in the stream are enhanced by afflux just before the causeway is topped by a flood.

Silt in approaches.—Though it is advisable to have the approaches in cutting such approaches when at right angles to the stream-flow accumulate a depth of silt during floods ; if the stream carries silt approaches inclined to the stream at a smaller angle and with the rising gradient from the causeway level formation going upstream suffer much less from silt.

Siting near villages.—If possible a submersible bridge should be placed upstream of a village. If it is just downstream of a village the raising of the flood level by afflux may submerge portion of the village and/or its fields.

Wing or return walls.—Submersible bridges usually have no wing walls. Return walls are usually provided till the approach reaches above H. F. L. These return walls should never be started in the stream. It is advisable to have one or two land-spans, and the return walls started from points inside the banks. When the bridge is submerged, any obstruction in the stream flow near the banks, sets up dangerous eddies which erode the banks and destroy fields.

Afflux.—The afflux should be as small as possible, and in order to attain this, the combined obstruction due to piers and arches or slabs should be a minimum.

Loads.—The live load on submersible bridges is the same as for bridges proper. It has also to carry dead loads depending on its design, and in addition the horizontal thrust, and lift due to flood waters, when live loads are absent.

The forces acting on it when the level of flood is just at formation level are :—

(1) Static head due to afflux,
(2) Horizontal loads due to water currents,
(3) Friction of water against piers and soffit,
(4) Uplift on the slab or arch=head from water surface to soffit,
(5) *Floation due to submergence.*—An upward force decreasing pier weights by as much as 65 lbs. per cubic foot if water is very muddy.

Static head due to afflux.—Acts normal to the whole horizontally projected area of obstruction, and is equal to $w \times h$ where w is the weight of water in l bs. per cubic foot and h is the height of afflux in feet. (In the height 'h' it will actually increase from o at the surface to h at bottom lower down, but the difference is trifling).

Horizontal loads due to water currents.—Any part of the structure of a road bridge which may be submerged in running water, shall be designed to sustain safely the horizontal pressure due to the force of the current.

The pressure shall be calculated from the formula:—

$$P = k\ AV^2$$

where P = total pressure in pounds due to water current

A = area in square feet of vertical projections of the submerged parts.

V = velocity of current in feet per second

k = a constant having the following values :—

	k value
For square ended piers and for superstructure.	1·24
For circular piers	0·62
For piers 5 or 6 times as long as broad with cut waters the faces of which make an angle of 30°.	0·46

When the bridge or causeway floor is supported on two or more piles or trestle columns, across the direction of flow, the group shall be treated as a solid pier of same overall width, and the value of k taken as 1·24.

(3) Friction $F = f.p\left(\frac{v}{10}\right)^2$ when 'f' is the coefficient of friction between masonry and water ; v the velocity in feet per sec ; and p = surface exposed to friction. 'f' may be assumed as 0·588 lb. per square foot for well dressed surfaces without brushing. For rough surfaces assume 1 lb. per square foot.

(4) Uplift on slab $= W\left\{\frac{(h+h_1)-(v^2-v_1^2)}{2g}\right\}$ where W=weight of water in lbs. per cft. h = afflux and h^1 = slab thickness in feet v = vel. in opening and v_1 = vel. in natural stream in feet per sec. Of the horizontal forces (*i*) is by far the greatest. All horizontal forces are increased by debris blocking the waterway, and an allowance for this must be made.

When causeways were constructed of heavy massive masonry, arching and filling, the horizontal forces were not of much importance, but in large comparatively light R. C. C. spans, the design must be checked to see that the resultant falls in the middle third of piers, allowing for decrease in masonry weight due to 'floatation'.

If the piers rest on piles bending in piles must be taken into account and countered if necessary by raking piles.

Spandrel filling and road surface.—If masonry or concrete arches are used, the spandrels are usually filled with lime concrete and paved with stone. For R. C. C. slabs the surface may be 3″ Cement concrete or stone paving, the former laid with the slab and bonding with it being preferable.

3. **Waterway calculations.**—Having found out the accurate bed fall of the river and the cross sections of the natural stream at the various levels, *viz.*, at the flood level at which the causeway is intended to be made passable and at the H. F. L. the natural velocities at these various levels may be found out by Kutter's formula.

In making the waterway calculations in the case of causeways, the aim should be to see that the following two conditions are satisfied :—

(*i*) that the causeway is so designed as to allow the whole of the discharge of the river to pass with the least possible afflux through its openings, at the ordinary flood level at which it is intended to be made fordable and that the flood is not allowed to rise higher than that level, and

(*ii*) that it must present the minimum of obstruction to all the discharge of the river above the ordinary flood level.

There would then arise two cases for investigation. In case (*i*) the causeway may be considered as a bridge, and in case (*ii*) it may be considered as an anicut or weir with under-sluices.

For case (*i*) the following formula is considered suitable :—

$$R = \left(\frac{v^2}{58{\cdot}6} + 0{\cdot}05\right) \left\{\left(\frac{A}{a}\right)^2 - 1\right\}$$

where R= rise of water caused by the obstruction in feet.

V = velocity of river previous to obstruction in feet per second.

A = sectional area of river unobstructed in feet.

a = sectional area of river at obstruction in feet.

The formula in its above form enables us to discuss the various aspects of the causeway ; let the ratio $\frac{A}{a}$ be denoted by K, then the formula stands as,

$$R = \left(\frac{v^2}{58{\cdot}6} + 0{\cdot}05\right) (K^2 - 1).$$

Now with a given velocity or in other words for a fixed flood level of the river $R = O$, when $(K^2 - 1) = O$

that is, when $K = 1$

or when $A = a$

In this case we get an imaginary structure in which the obstructed waterway is equal to the natural area of the river. On the other hand for a given velocity,

R = Infinity, when $K^2 - 1$ = infinity, or K^2 = infinity, that is, when $a = o$ and in this case we get a complete obstruction of the river with no waterway at all.

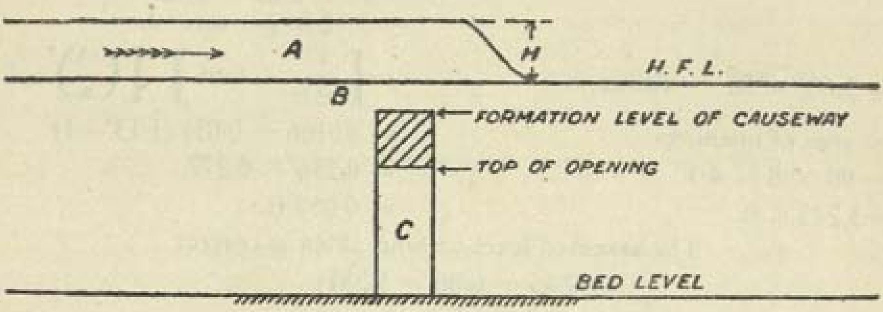
The practical case of a causeway must lie between these two limits and for a given velocity of water, in order that R should be as small as possible, K must exceed 1 by as small a quantity as possible or in other words A must exceed a by as small a quantity as possible.

In the practical cases of causeways, the height of top over the bed level being always limited, the width of each individual opening is also limited, thus necessitating the provision of piers and abutments, which form the obstruction ; and for a given height and length of causeway, the size of openings can often be so based as to make the obstruction in the form of piers and abutments to be the minimum possible.

In the case of high level causeways, therefore, and more especially in the case of those in rivers with deep sandy beds the value of K must be so based as to give the *minimum value of R*, and this is the most important point to be kept in view in designing high level causeways.

Having thus found the value of a, we get a complete design of the causeway ; and the conditions so obtained should then be tested for case (*ii*).

In case (*ii*) the causeway as designed is under the H. F. L. In this case, as already stated above, the causeway is an anicut or weir with undersluices, and the aim of the calculations is to see that a heavy afflux is not caused at the H. F. L. by the causeway.



Having found the discharge of the river, Q, at the H. F. L. and also the velocity the discharge of the river at the causeway is made up of the discharges through portions A, B and C, say Q_A, Q_B and Q_C, Let sectional areas of portions A, B and C be A_A, A_B and A_C.

then $$Q = Q_A + Q_B + Q_C \quad \text{(i)}$$

where $$Q_A = A_A \times \tfrac{2}{3} C\sqrt{2g} \times \frac{(H + h_a)^{\frac{3}{2}} - h_a^{\frac{3}{2}}}{H} \quad \text{(ii)}$$

$$Q_B \times A_B \times C \times \sqrt{2g} \times \sqrt{H + h_a} \quad \text{(iii)}$$

$$Q_C \times A_C \times C \times \sqrt{2g} \times \sqrt{H + h_a} \quad \text{(iv)}$$

in all the above equations ha is the head due to the velocity of approach and can be easily found out.

In equations (ii) and (iii) the value of C may be taken to be 0·625 and in equation (iv) 0·9 when curved cut waters are provided. The solution can be obtained by assuming values of H and solving the equations.

Type calculations for a causeway across the Bhima river at Takli on the Sholapur Bijapur road are given below :—

Velocity calculations :—

H. F. L. in the river .. .. R. L. 85·5

Top leve of the level portion of the causeway R. L. 52·50

Case (i)......when the flood water just begins to overtop the causeway.

Assume flood level without afflux .. .. R. L. 52·45

Water way at this level .. .. 3,665 s. ft.

Wetted perimeter 870

Hydraulic mean depth .. .. 4·21

$N = 0{\cdot}025$; $\sqrt{S} = 0{\cdot}02$; $\sqrt{r} = 2{\cdot}05$.

$$\begin{aligned} V &= C\sqrt{rs} \\ &= 76 \times 2{\cdot}05 \times 0{\cdot}02 \\ &= 3{\cdot}12 \text{ ft. per second.} \end{aligned}$$

$A = 3{,}665$ s. ft. Afflux, h $= \left[\frac{V^2}{58{\cdot}6} + 0{\cdot}05\right]\left[\left(\frac{A}{a}\right)^2 - 1\right]$

a = area of openings $= (0{\cdot}166 + 0{\cdot}05)\,(1{\cdot}13^2 - 1)$

$= 90 \times 8 \times 4{\cdot}5$ $= 0{\cdot}216 \times 0{\cdot}277$

$= 3{,}243$ s. ft. $= 0{\cdot}059$ ft.

The assumed level without afflux is correct

$(52{\cdot}45 + 0{\cdot}06 = 52{\cdot}51)$

Velocity through the openings, 90 in No. and each

$8 \times 4{\cdot}5$ will be

$$v' = \frac{1{\cdot}1 \times A \times V}{a} = \frac{1{\cdot}1 \times 3665 \times 3{\cdot}12}{3240} = 3{\cdot}88 \text{ ft. per second.}$$

A = water way at R. L. 52·45.

a = area of openings.

Case (ii)..............when the causeway is submerged under the highest flood.

Discharged at H. F. L. = 488,546 cusecs.

Full discharge is the sum of the discharges through parts, A, B and C shown in the sketch.

Assume afflux............H = 1·10 ft.

Additional area due to afflux = 2,016 s. ft.

Area at H. F. L.................. = 45,916 s. ft.

Total area = 47,932 s. ft.

Velocity at H. F. L. = 10·19 ft. per second.

Velocity of approach $= \frac{45916 \times 10{\cdot}19}{47932} = 9{\cdot}76$ ft. per second.

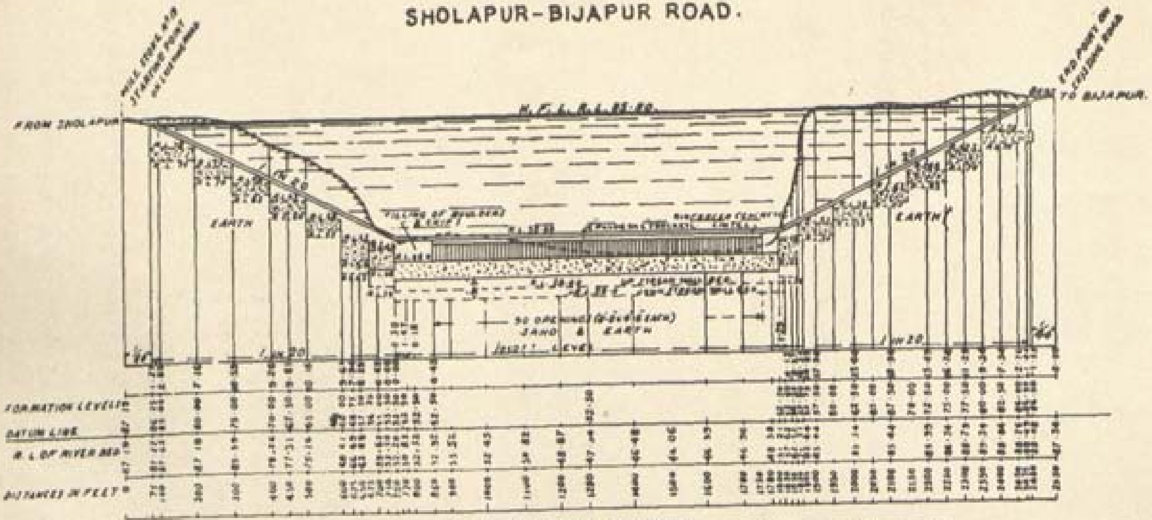
Head due to velocity of approach, ha $= \frac{9{\cdot}76^2}{2} = 1{\cdot}49$ ft.

Total head = H + ha = 1·10 + 1·49 = 2·59 ft.

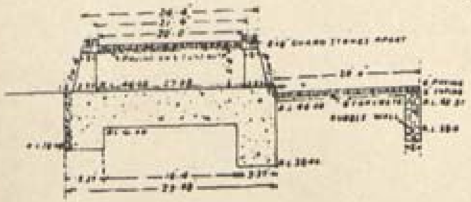
Area of portion A = 2,016 s. ft.

Plate XCIX.

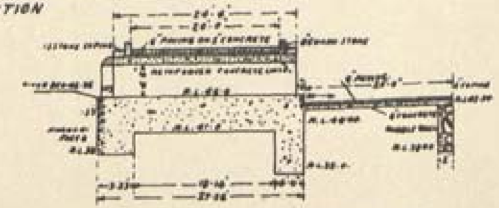
HIGH LEVEL CAUSEWAY
SHOLAPUR-BIJAPUR ROAD.



LONGITUDINAL SECTION



CROSS SECTION AT CHAINAGE 800.



CROSS SECTION AT CHAINAGE 900.

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G.P.Z.P. POONA, 1959

SOME HIGH LEVEL CAUSEWAYS.

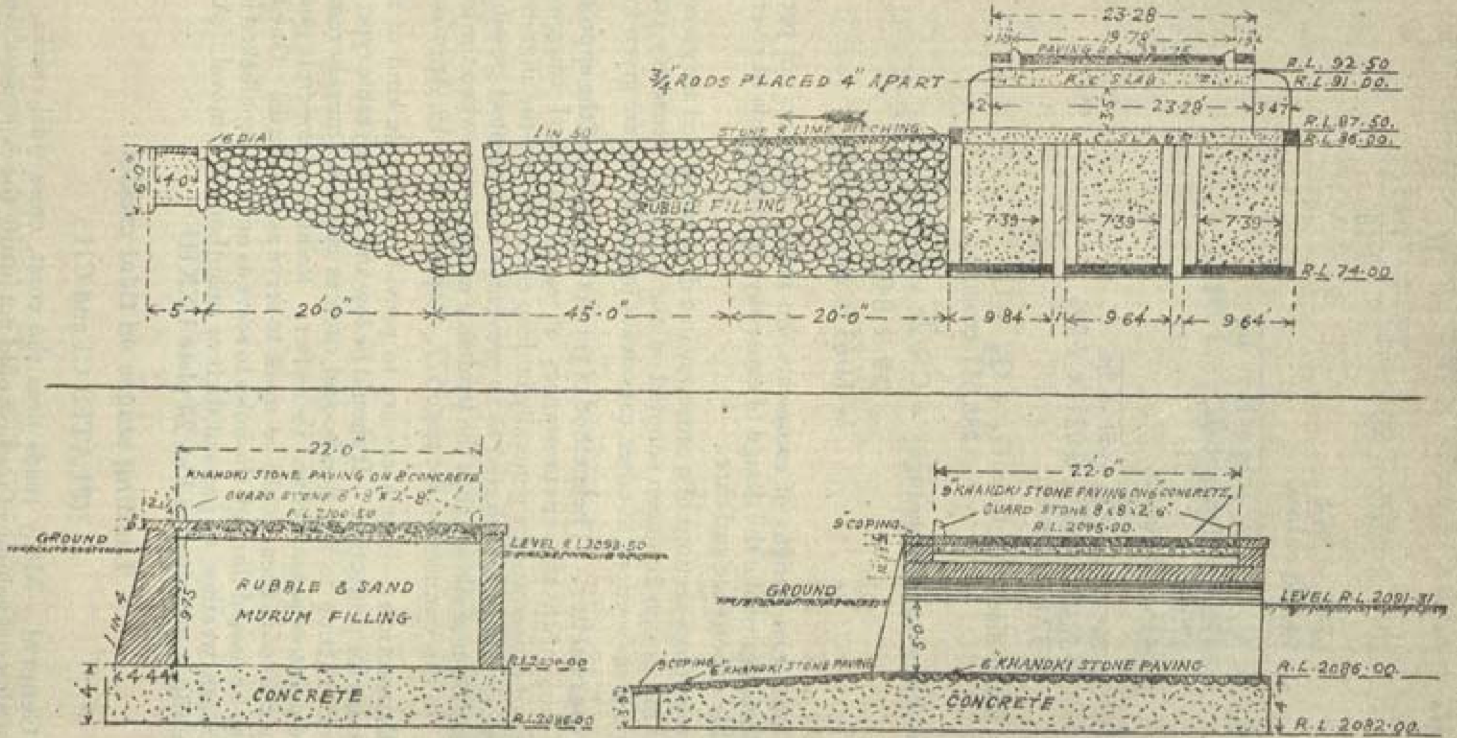

PLATE C

$$\text{Then } Q_A = A_A \times C \times \tfrac{2}{3}\sqrt{2g} \times \frac{(H + ha)^{\frac{3}{2}} - ha^{\frac{3}{2}}}{H}$$

$$= 2016 \times 0{\cdot}625 \times 5{\cdot}35 \times \frac{2{\cdot}59^{\frac{3}{2}} - 1{\cdot}49^{\frac{3}{2}}}{1{\cdot}10}$$

$$= 6741 \times 2{\cdot}14$$
$$= 14{,}426 \text{ cusecs.}$$

$$Q_B = A_B \times C \times \sqrt{2g}\sqrt{H + ha}$$
$$= 42206 \times 0{\cdot}8 \times 8{\cdot}025 \times 2{\cdot}59^{\frac{1}{2}}$$
$$= 270962{\cdot}5 \times 1{\cdot}61$$
$$= 436{,}250 \text{ cusecs.}$$

$$Q_C = A_C \times C\sqrt{2g}\sqrt{H + ha}$$
$$= 3240 \times 0{\cdot}9 \times 8{\cdot}025 \times 2{\cdot}59^{\frac{1}{2}}$$
$$= 37{,}675 \text{ cusecs.}$$

$$\therefore \text{Total discharge } Q = Q_A + Q_B + Q_C$$
$$= 488{,}351 \text{ cusecs.}$$

$$\text{Velocity under openings} = C\sqrt{2g}\sqrt{H + ha}$$
$$= 0{\cdot}9 \times 8{\cdot}025 \times 1{\cdot}67$$
$$= 11{\cdot}63 \text{ ft. per second.}$$

4. The actual designs of causeways, on **rocky beds** do not present any special difficulties, while the design of causeways in sandy beds of rivers require considerable experience and care.

Two type cross sections of a causeway in a deep sandy bed are given in plate XCIX. This design has been adopted on the proposed causeway referred to above Type cross sections of other causeways in sandy bed are given in plate C.

5. **Approaches.**—The method of correct designing of the approaches will naturally vary with the circumstances of each individual causeway. The approaches of causeways are generally in deep cuttings, and the alignment of the approaches should be so selected as to prevent, to the greatest possible extent, the accumulation of silt which is the tendency which occurs when the high floods subside. In this connection see page 577, chapter V, item 19, Approaches.

6. **Protection.**—It is necessary to provide a suitable kind of railing on both the sides for protection. It should be low and of a moveable type, so as not to cause obstruction to the floods, and such as could be quickly removed just before the monsoons, and refixed thereafter. Reinforced concrete guard stones with proper holes in them could be made to serve as standards. One line of gas piping may be passed through the holes to serve as rail and kept locked in position during the fair weather, to prevent theft or unauthorised removal. A sketch of such a railing is indicated in Fig. 24 plate LXXIII.

Landing stages on tidal creeks.

(PLATES CI and CII.)

1. **General.**—Many roads near the coast, cross tidal creeks, and cases occur in which the volume of traffic would not justify the expense of constructing bridges across the creeks. It would, in such cases, be a very great convenience

LANDING STAGES ON TIDAL CREEKS.

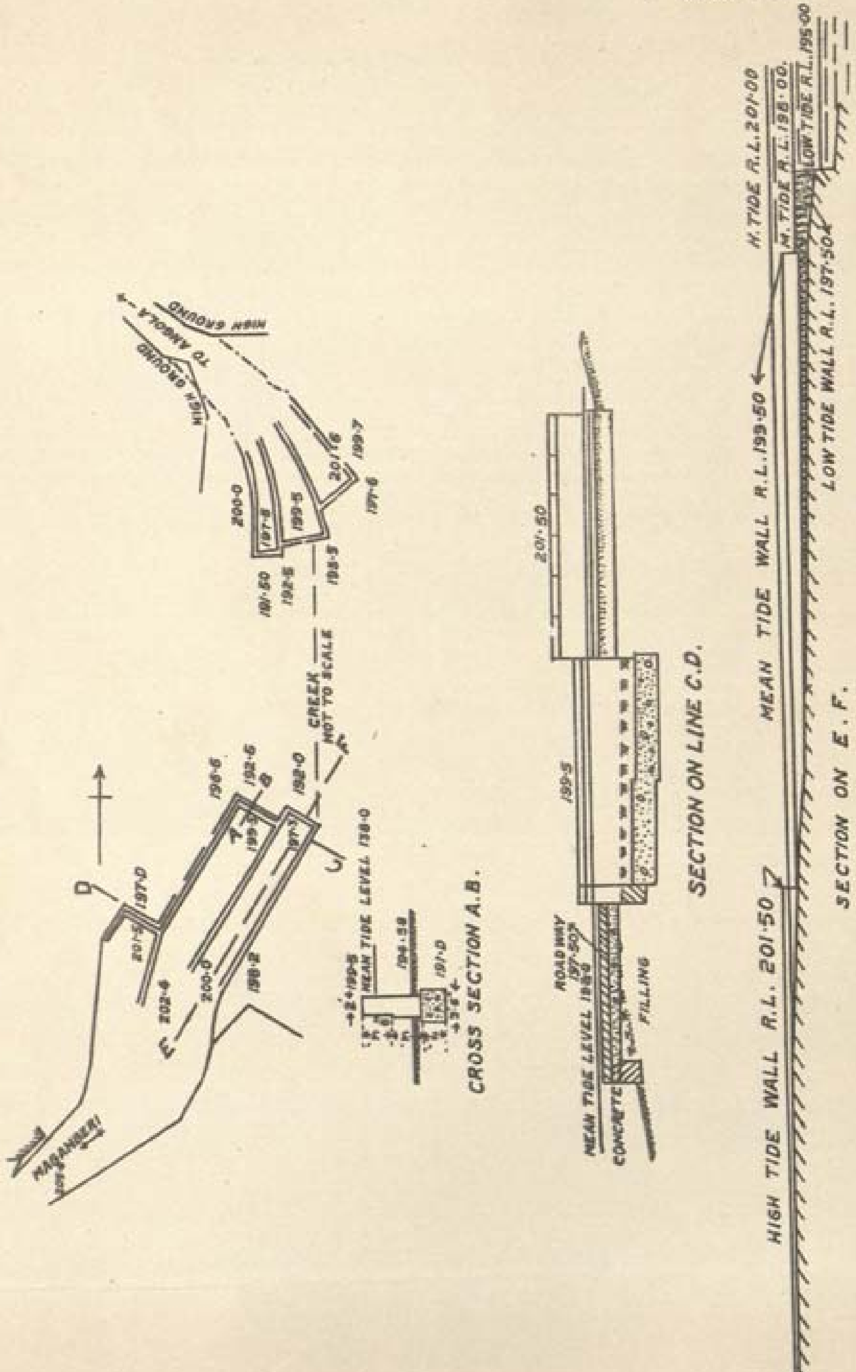

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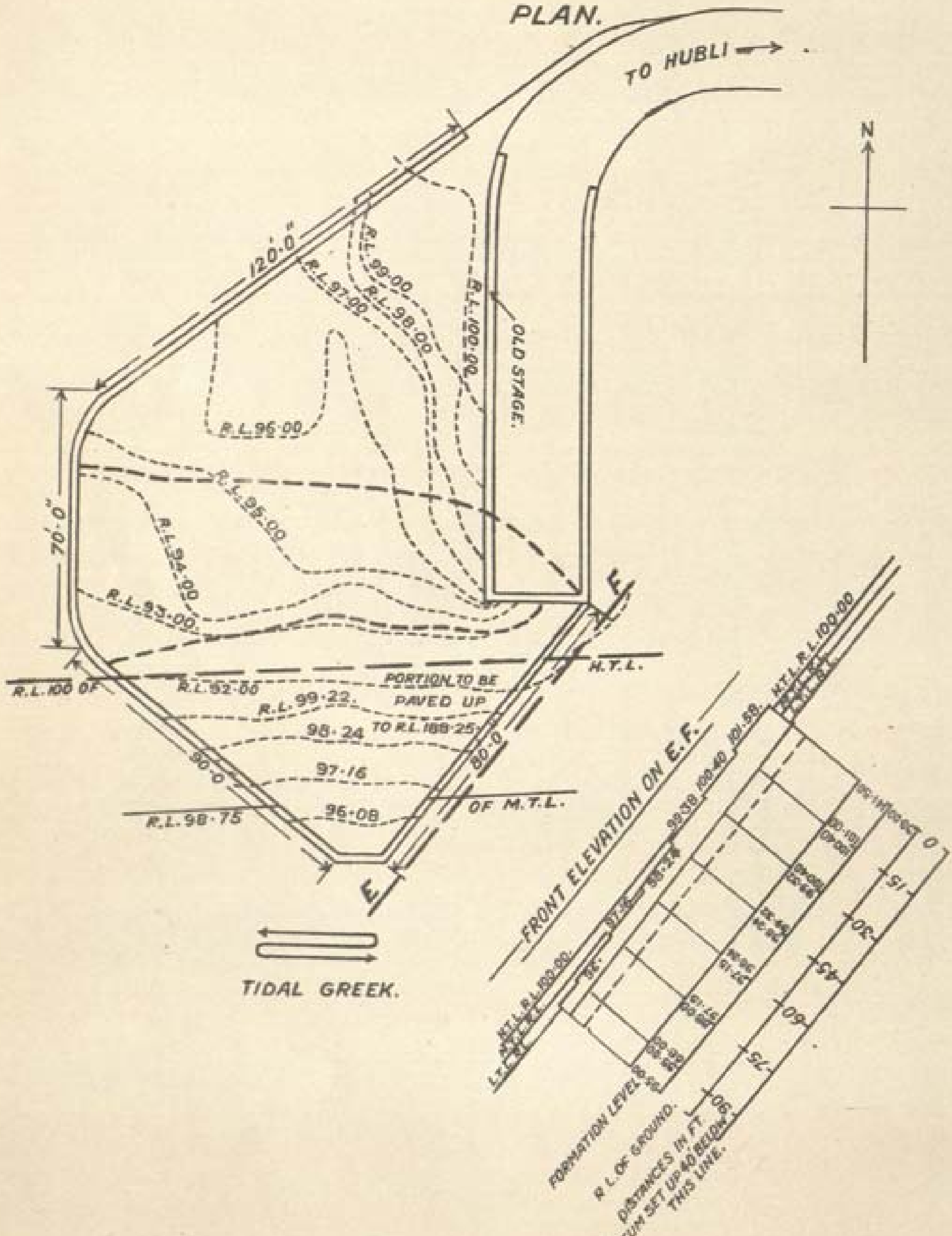
Plate CII

ALTERNATIVE SLOPING PLATFORM DESIGN

TIDAL RANGE 8 FEET.

Scale 20'-1"



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to construct suitable ramps or landings on the banks of the creeks to permit of motor cars and carts being run on to a ferry boat which carries them across to the other side.

In the Kanara district the range of the tide is from 6 to 7 feet between low and high water. A number of landing stages have been constructed, which have proved simple, cheap, convenient and satisfactory.

2. **Conditions to be satisfied.—**

(1) They should permit of motor cars being embarked and disembarked at any stage of the tide.

(2) There should be a length of straight so that vehicles may run on or off the 'jangal' without having to turn.

(3) The slope of the loading board should not be steeper than 1 in 4.

(4) The landings should be in sheltered positions.

(5) The loading side of 'jangal' should be in shallow water so that boatmen may be able to stand in the water and steady the jangal during loading and unloading.

(6) The landings should not extend so far into the creek as to cause an obstruction to the current.

3. **Adjustment of levels of stages.**—An outline of the construction of one of these landing stages is given in plate CI. The whole tidal range is divided into two stages, and three landings are provided at each place, one for the middle tide, one for the high tide, and one for the low tide. The deck of the 'jangal' or ferry boat being 1′ 6″ above the water level when loaded, the level of the middle tide stage is kept 1½ feet above the middle tide level. The high level stage is designed to the tide level 1 foot below the mean high tide level, *i.e.*, its edge is kept 6 inches above mean high tide level. The low tide stage is designed to a tide level 1 foot above the mean low tide, *i.e.*, its level is kept 2½ feet above mean low water level.

During rains when the flood waters rise above the high level landing, it is not possible to cross, but this only occurs for a few days in the year, or an additional stage may be added at a small cost for this purpose.

4. **Jangals.**—These consist of a pair of boats supporting a platform or deck, with railing all round. When loaded, the deck of the jangal is about 18 inches above the water line, and the draught is a little over 2 feet. It is necessary to provide a spare boat for jangal,as the boats require oiling at intervals of about a month, otherwise they depreciate rapidly. When the deck of the jangal is level with the stage, no loading board need be used.

5. **Construction.**—The foundations have to be laid under water, and often in silt. Work is possible only for a few hours in the day, when the tide level is below the top of the cofferdam. Lime concrete is unsatisfactory, as the lime, being too green, gets washed out. It is better to build the foundations with large boulders laid in mortar. The addition of a little cement to mortar just before laying is useful.

It is advisable to pave the low and mean tide landings for a distance of about 15 feet from the loading edges.

6. **Cost.**—The cost of the three stages on each bank is about Rs. 2,500, in the Kanara district, and that of the jangal, with spare boat Rs. 2,500, so that each river crossing costs about Rs. 7,500.

Plate C III

TEMPORARY CROSSINGS FOR MOTOR CARS AND FERRY ANCHORAGES

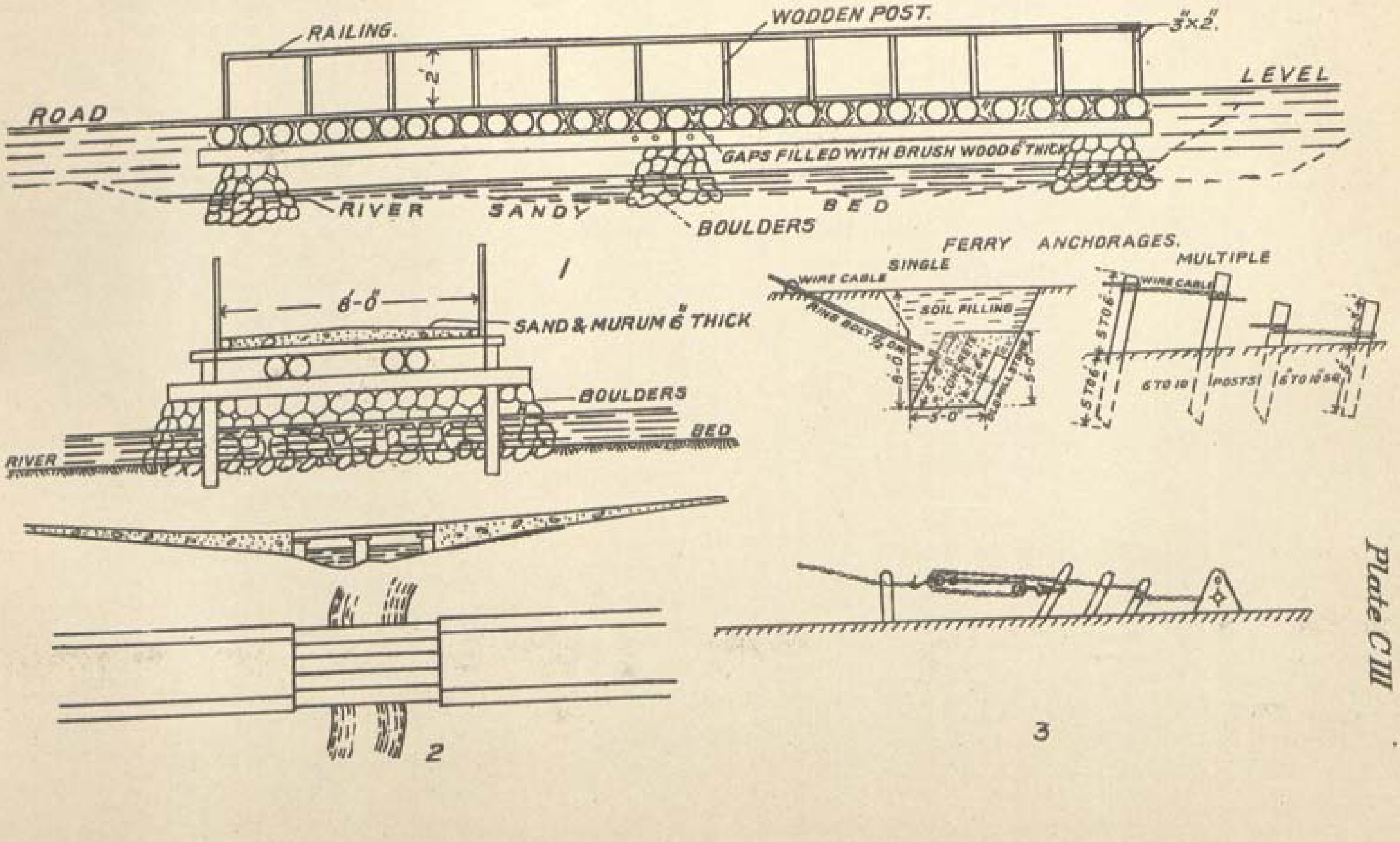

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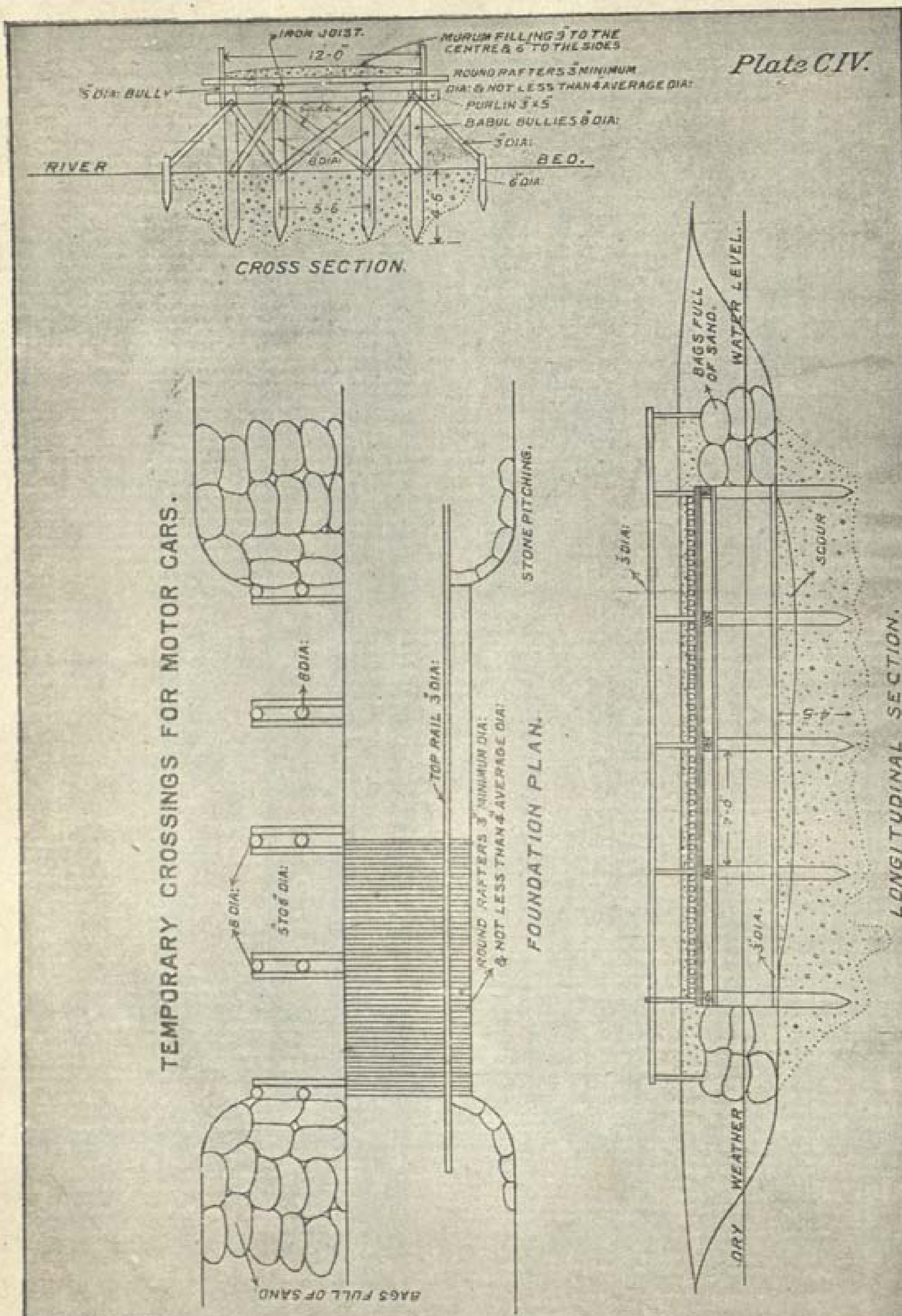
Plate CIV.


TEMPORARY CROSSINGS FOR MOTOR CARS.
IRON JOIST.
MURUM FILLING 3" TO THE CENTRE & 6" TO THE SIDES
12-0"
ROUND RAFTERS 3" MINIMUM DIA: & NOT LESS THAN 4 AVERAGE DIA:
5" DIA: BULLY
PURLIN 3 x 5
BABUL BULLIES 8" DIA:
3" DIA:
RIVER
BED.
8" DIA:
6" DIA:
5-6
4-6
CROSS SECTION.
STONE PITCHING.
8 DIA:
TOP RAIL 3" DIA:
ROUND RAFTERS 3" MINIMUM DIA: & NOT LESS THAN 4" AVERAGE DIA:
FOUNDATION PLAN.
8 DIA:
5" TO 8" DIA:
BAGS FULL OF SAND
BAGS FULL OF SAND.
WATER LEVEL.
DRY WEATHER
3" DIA:
SCOUR
4-6
7-0
LONGITUDINAL SECTION.

Notes on ferries

1. Ferries mostly in use can be divided into 4 classes:—

(*a*) Double iron pontoon or wooden ferry covered with timber platform capable of taking 1 motor car or two bullock carts and working along a wire rope.

(*b*) Single iron pontoon ferry covered with timber platform capable of taking 1 bullock cart and working along a rope.

(*c*) Single wooden ferry covered with timber platform capable of taking 1 bullock cart rowed across unattached to any wire rope.

(*d*) Small passenger boat for rowing across.

2. (*a*) is essential to main roads, (*b*) is sufficient on roads not used by motors, while (*c*) is inclined to be an unstable arrangement, that has the disadvantage of crossing the river obliquely and so striking the opposite bank down stream of the landing place, to which it has to be man hauled, (*d*) if not overloaded meets the requirements of purely passenger traffic.

3. Landing stages are provided usually in the form of a masonry ramp, running down either parallel with or at right angles to the river. In the latter case metalled approaches are often provided.

4. Landing boards are made of 2½″ to 3″ timber and measure 10′ to 12′ long and 3′ wide. They are used in pairs.

5. Removable railing is composed of C. I. posts connected with chain and standing in C. I. sockets round the ferry platform.

6. Ferry rope straining device consists of a roller under which the rope passes, a crab winch round which the rope turns and which gives the strain, with or without a differential pulley block and 2 or 3 anchorages in between. The winch must be securely fixed in an anchorage of concrete by means of Lewis bolts (Plate CIII, Fig. 3).

7. Ferry contractors should carefully look to the tethering of boats not working along wire ropes. Sudden floods have been the cause of the complete loss of several boats not properly tethered. Anchors shoud not be allowed to lie free on the river.

Temporary crossings

(PLATE CIII, Fig. 2.)

Fair weather crossings on perennial rivers and streams are formed by fixing thick boards over the number of openings required, with abutments and piers of sand boxes or dry rubble. The approaches are made up of boulders, muram and sand. Where muram is not available, as in parts of Guzerat, suitable approaches are made by spreading a layer of grass or brushwood, 6 inches thick, over the sandy bed of the river and covering it over with a 3 to 6 inch layer of good non-sticky earth with a top dressing of sand. Belak soil should never be used. To prevent the approaches being cut up into deep dust, it is necessary to keep them just wet by watering at suitable intervals.

For larger crossings see plates CIII and CIV.

CHAPTER IX—MASONRY DAMS AND RETAINING WALLS
(PLATE CV.)

1. There are two ways in which masonry dam may resist the thrust of the water, *viz.*, (1) by the resistance of the masonry to sliding forward or to overturning (gravity dam) and (2) by the thrust of the water being resisted by the transmission of the thrust laterally to the side hills (abutments) by the arch like action of the masonry (arched dam). Here only the gravity type is dealt with.

2. **Failure** of a masonry wall or dam can occur in three ways: (1) by sliding along a horizontal plane, (2) by overturning or rotating and (3) by the crushing of the masonry. In order that failure may not occur, the design should be so made that the structure may have such size and weight that sliding, rotation or crushing cannot occur.

The most common cause of failure of dams and retaining walls is a defective foundation. Scour around the foundation of a wall may cause its destruction.

3. **Sliding stability** is secured by giving the structure a sufficient weight so that there is no danger of motion along a joint at the base. For the horizontal joint in figure 1, let H be the horizontal pressure and W the sum of all the vertical weights above the joint. Motion occurs when $H = fW$, where f is the coefficient of friction. In order that there may be no motion, let n be a number greater than unity, called the factor of safety ; then if W is sufficiently large so that $nH = fW$, stability is secured. A common value of n for use in designing is 2.

Another method of consideration is by means of the angle B, which the resultant R makes with the normal to the joint. For stability the angle B should be less than p, the angle of repose for masonry upon masonry. Proper security requires $n \tan B = \tan p$. Where necessary, this safety should be secured, by inclining the bed joints, so as to decrease the angle B. Fig 2.

The following table gives the coefficients and angles of friction:—

TABLE

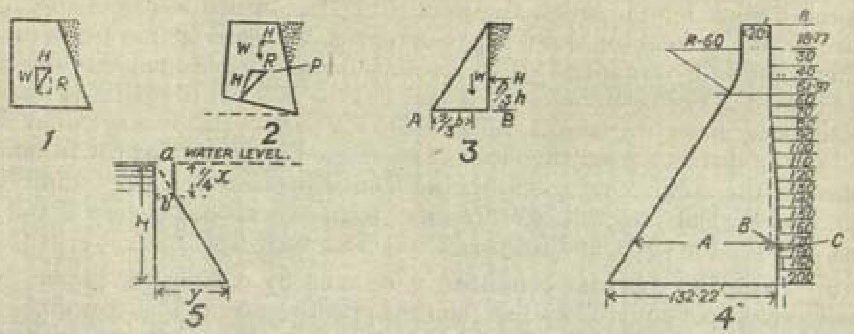
Kind of surface	Coefficients of friction	Angle of friction	
Granite, limestone, marble—			
Soft dressed upon soft dressed	0·70	35°	00′
Hard dressed upon hard dressed	0·55	28°	50′
Hard dressed upon soft dressed	0·65	33°	0′
Stone, brick or concrete—			
Masonry upon masonry	0·65	33°	0′
Masonry upon dry clay	0·50	26°	40′
Masonry upon wet or moist clay	0·33	18°	20′
Masonry upon sand	0·40	21°	50′
Masonry upon gravel	0·60	31°	0′

Certain experiments carried out in Sind gave the following values of the Coefficients of friction.

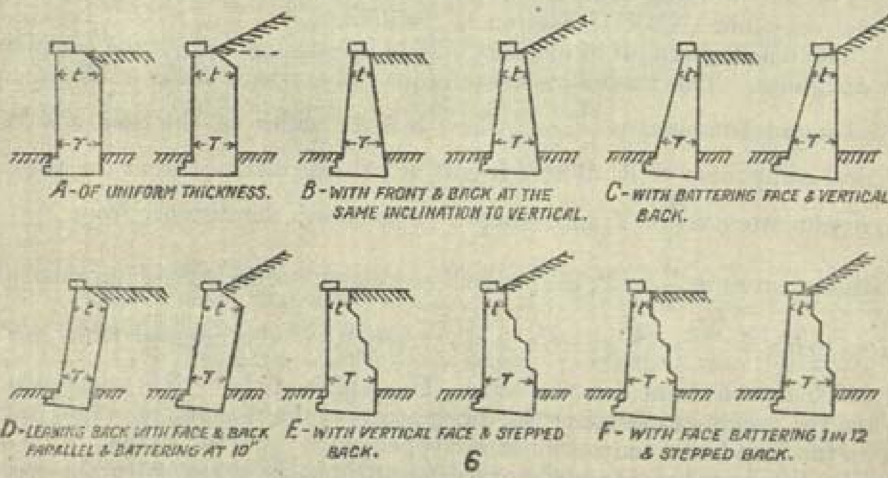
Nature of surface	Coefficient of friction	
(1) Dry brick over dry brick	Minimum	0·75
	Maximum	0·84
(2) Wet birck over wet brick (immediatly after laying in mortar).	Minimum	0·78
	Maximum	1·43
(3) Wet brick over wet brick (24 hours after laying mortar).	Minimum	2·36
	Maximum	4·68

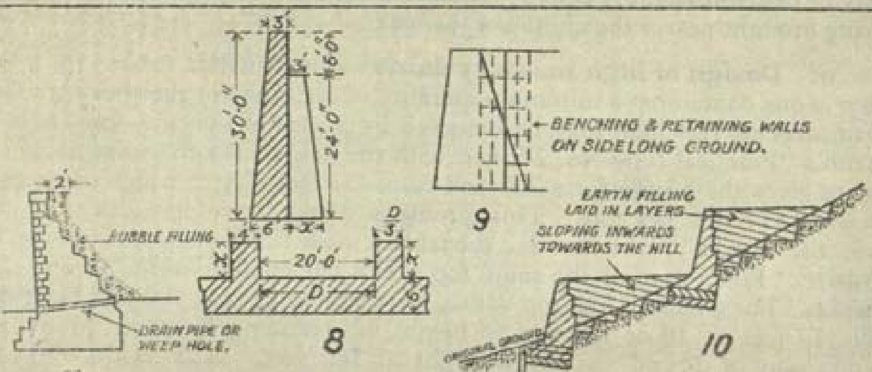
Plate CV.

MASONRY DAMS AND EARTH RETAINING WALLS.



PROFILES OF MASONRY RETAINING WALLS.





The mortar used was of the following proportions:—

1 lime : 1 surkhi : 1 sand.

4. **Stability against rotation** is secured by giving the wall or dam such size and weight that R, the resultant of all the external forces above the joint, cuts the base A B well within the joint. Fig. 3. When R passes through A, failure occurs by rotation, and if R passes near A, the material may begin to crush so that rotation is imminent. For masonry dams R should cut the base at the middle third. For retaining walls R may cut the base at $\frac{1}{4}$th to $\frac{1}{8}$th of the width of the base from the face of the wall and for wing-walls, it may cut at $\frac{1}{10}$th to $\frac{1}{20}$th* of the distance from the face. The safety factor, n, against rotation is defined as the number by which the horizontal pressure must be multiplied in order that R shall pass through the toe. n may be taken between 2 and 3 for dams, 1·5 to 2 for walls, and from 1·25 to 1·5 for wing walls.

5. **Stability against crushing** is secured by making the greatest compressive stress per square foot less than the crushing strength of masonry. The wall or dam must be given such size that the safe working pressure shall not be exceeded.

For safe working compressive stresses for masonry set in hydraulic lime mortar see table XXVIII Section II (Buildings).

The tensile strength of masonry should be taken as zero in the calculations for designing. The maximum stress for masonry, where R, the resultant, cuts a $\frac{1}{3}$rd distance from face is $\frac{W}{b} \times 2$, where b is the width of the base, and W the vertical component of R. Where it cuts at $\frac{1}{5}$ th the distance from the face, the maximum stress is $\frac{W}{b} \times \frac{10}{3}$; and where it cuts at $\frac{1}{8}$th the distance from the face maximum stress is $\frac{W}{b} \times \frac{16}{3}$; the general expression for the maximum intensity of stress being $\frac{2}{3} \frac{W}{b} \times \frac{1}{n}$ where n is the fraction of the breadth from the face at which the resultant cuts the base. The length of the wall is taken as unity. When the maximum stress at the toe approaches the working stress on foundations, the foundation courses must be stepped out at the front, so that the pressure may be distributed more equally on the foundations, by the centre of the pressure being brought nearer the middle of the base.

6. **Design of high masonry dams.**—An economic section for a gravity dam is one containing a minimum quantity of masonry for the above conditions. Dam over 60 feet high may be designed by means of figure 4, known as Wegmann's 'Practical type No. 2", and with the help of the following table. The figure gives the profile for a 200 feet dam, the masonry of which is assumed to weigh 145·8 lbs. per c.ft. This profile is drawn for a top width of 20 feet or $\frac{1}{10}$th the height of the dam and the table is made for the same ratio of top width to base. For a dam of the same top width cut off the section at any desired height. For a dam of less top width, for example 12' and 100 feet high, draw a dam 12 feet × 10 or 120 feet in height, by reducing the given profile in the proportion of $\frac{120}{200}$ and cut off a height of 100 feet. If the width of the top of the dam is less or greater than 20 feet, the pressures in columns 6 and 7 must be reduced or increased proportionately.

*In the case of wing walls shown in plate XCIII, the resultant cuts the base at about 1/20th of the base from the toe.

TABLE CLXXXV.

Elements of Wegmann's practical profile No. 2

Depth of water below top of dam in feet	Length of joint in feet				Maximum pressure, tons per square foot		Tangent of resultant with vertical
	A	B	C	Total	Reservoir full	Reservoir empty	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
18·77	20·00	0	0	20·00	1·89	1·36	0·20
30	21·07	0	0	21·07	3·68	2·37	0·31
40	23·89	0	0	23·89	5·03	3·53	0·41
51·97	30·04	0	0	30·04	5·53	4·91	0·50
60	35·38	0	0	35·38	5·59	5·63	0·54
70	42·03	0·62	0	42·65	5·94	6·11	0·58
80	48·68	1·25	0	49·93	6·45	6·59	0·61
90	55·33	1·87	0	57·20	7·02	7·09	0·62
100	61·98	2·50	0	64·48	7·62	7·61	0·63
110	68·63	3·12	0	71·75	8·26	8·15	0·63
120	75·28	3·74	0	79·02	8·90	8·69	0·63
130	81·93	3·74	0·62	86·29	9·55	9·46	0·64
140	88·58	3·74	1·25	93·57	10·22	10·22	0·64
150	95·23	3·74	1·87	100·84	10·89	10·96	0·64
160	101·88	3·74	2·49	108·11	11·56	11·71	0·64
170	108·53	3·74	3·12	115·39	12·25	12·44	0·64
180	115·18	3·74	3·74	122·66	12·95	13·18	0·64
190	121·83	3·74	4·37	129·94	13·63	13·91	0·64
200	128·48	3·74	4·99	137·21	14·32	14·65	0·64

For a dam having a top width of 12 feet and a height of 120 feet, the maximum pressure on the base for the reservoir full is $14{\cdot}32 \times \frac{12}{20} = 8{\cdot}59$ tons per square foot and for reservoir empty $14{\cdot}65 \times 0{\cdot}6 = 8{\cdot}79$ tons per sq. ft The minimum width of the top of a dam over 60 feet should be at least 8 feet, and this width must often be arbitrarily increased, for example, to allow for a road way, etc. The profiles and tables are for dams upon impervious rock.

7. **Low dams of masonry.**—Fig. 5.

x = Height of dam at high water level.

y = width of base of dam.

a = width at top and at $\frac{1}{4}x$ from top.

w = weight of masonry per cubic foot.

If w =	120	130	140	150 lbs. per cubic foot.
y =	·72x	·70x	·68x	·66x
a =	·18x	·175x	·17x	·165x

8. **Masonry retaining walls.**—A vertical wall backed with earthy material is subject to a lateral pressure which tends to overturn it, as well as cause it to slide. The pressure is the greater the heavier the material, and the less the angle of repose.

The horizontal pressure is in the ratio of $\frac{1 - \sin}{1 + \sin\phi}$ of the vertical pressure at any

depth, due to the weight of earth, wher ϕ is the angle of repose for the materials; transformed, this is also equal to $\tan^2(45-\frac{1}{2}\phi)$ times the vertical pressure. The resultant horizontal pressure in lbs. of the earth against the back is

$$\tfrac{1}{2}\, wh^2 \frac{1-\sin\phi}{1+\sin\phi};\ \text{or}\ \tfrac{1}{2}\, wh^2 \tan^2(45-\tfrac{1}{2}\phi),$$

applied at $\frac{1}{3}$ h above the base.

TABLE CLXXXVI.

The following are the weights and angles of repose of different materials of filling:—

Kind of earth	Slope of repose	Angle of repose, Φ	Sine of angle of repose	Weight in lbs. per cubic foot	$\frac{1-\sin\Phi}{1+\sin\Phi}$ or $\tan^2(45-\frac{1}{2}\Phi)$
Sand, clean	1·5 to 1	33° 41′	·554	90	·287
Sand and clay	1·33 to 1	36° 53′	·600	100	·25
Clay, dry	1·33 to 1	36° 53′	·600	100	·25
Clay, damp, plastic	2 to 1	26° 34′	·447	100	·382
Gravel, clean	1·33 to 1	36° 53′	·600	100	·25
Gravel and clay	1·33 to 1	36° 53′	·600	100	·25
Gravel, sand and clay	1·33 to 1	36° 53′	·600	100	·25
Soil	1·33 to 1	36° 53′	·600	100	·25
Soft rotten rock	1·33 to 1	36° 53′	·600	100	·25
Hard rotten rock	1 to 1	45° 00′	·707	100	·171
Bituminous cinders	1 to 1	45° 00′	·707	45	·171
Anthracite ashes	1 to 1	45° 00′	·707	30	·171

TABLE CLXXXVII.

Material excavated by a wet or a dry process, and dumped into water, as at the back of a sea wall, has weights and slopes approximately as follows:—

Kind of material	Slope of repose	Angle of repose, Φ	Sine of angle of repose	Weight, lb. per cubic foot	$\frac{1-\sin\Phi}{1+\sin\Phi}$ or $\tan^2(45-\frac{1}{2}\Phi)$
Sand, clean	2 to 1	26° 34′	·447	60	·382
Sand and clay	3 to 1	18° 26′	·316	65	·520
Clay	3½ to 1	15° 57′	·275	80	·569
Gravel, clean	2 to 1	26° 34′	·447	60	·382
Gravel and clay	3 to 1	18° 26′	·316	65	·520
Gravel, sand and clay	3 to 1	18° 26′	·316	65	·520
Soil	3½ to 1	15° 57′	·275	70	·569
Soft rotten rock	1 to 1	45° 00′	·707	65	·171
Hard rock, riprap	1 to 1	45° 00′	·707	65	·171
River mud	8 to 1	0° 00′	0	90	1

When the material is excavated by suction dredging and pumped back of a retaining wall which has efficient drains to carry off the water, the weight per c. ft. may be taken at 110 lbs. and the slope of repose 2 to 1 for sand and clay, clay and gravel, or clay, gravel and sand combined. River mud may be taken at 100 lbs. per cubic foot with a slope of 3 to 1.

TABLE CLXXXVIII.

9. The following table gives the thicknesses required for masonry retaining walls of moderate heights, not exceeding about 60 feet. Weight of earth 120 lbs. per cft., and weight of masonry =140 lbs. per cft.:—

Profile (Figure 6)	Earth—natural slope, Φ = 30°		Earth—natural slope, Φ = 45°		Water
	Earth level on top	Earth sloping at Φ = 30°	Earth level on top	Earth sloping at Φ = 45°	
	T. t.	T. t.	T. t.	T. t.	T. t.
A	40 40	45 45	30 30	35 35	50 50
B	40 2*	45 2*	30 2*	35 2*	55 2*
C	40 16	45 18	30 12	35 14	50 20
D	30 30	35 35	25 25	30 30	45 45
E	45 2*	50 2*	35 2*	40 2*	65 2*
F	45 2*	50 2*	35 2*	40 2*	65 2*

Height of wall 100, measured from actual surface of ground. T = thickness at base of wall. t = thickness at top of wall, * 2=2 feet, an assumed minimum thickness of wall. Centre of stress a fifth of T in from face of wall

TABLE

The following table gives the base lengths of retaining walls for loose earth to 1. Weight of masonry 120 to 125 lbs. per cubic foot. The resultant pressure back of the wall is taken as effective.

Height of wall	Front batter 1 in 4			1 in 6			1 in 8		
	Top width			Top width			Top width		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
8 ..	3·68	..	..	3·81	3·65	..	3·92	3·78	..
9 ..	4·16	..	..	4·30	4·15	..	4·42	4·29	..
10 ..	4·64	..	..	4·79	4·65	..	4·92	4·80	4·63
11 ..	5·11	4·96	..	5·28	5·15	4·98	5·43	5·31	5·15
12 ..	5·59	5·44	..	5·77	5·65	5·48	5·93	5·82	5·67
13 ..	6·07	5·92	..	6·26	6·14	5·98	6·43	6·32	6·18
14 ..	6·55	6·40	..	6·75	6·63	6·48	6·93	6·83	6·69
15 ..	7·02	6·88	..	7·24	7·13	6·98	7·43	7·33	7·20
16 ..	7·50	7·36	7·20	7·73	7·62	7·48	7·93	7·84	7·71
17 ..	7·98	7·84	7·68	8·22	8·11	7·97	8·43	8·34	8·22
18 ..	8·45	8·32	8·16	8·71	8·60	8·47	8·93	8·84	8·72
19 ..	8·93	8·80	8·64	9·20	9·09	8·96	9·43	9·34	9·23
20 ..	9·41	9·28	9·12	9·69	9·58	9·46	9·93	9·85	9·74
21 ..	9·88	9·75	9·60	10·18	10·07	9·95	10·44	10·35	10·24
22 ..	10·36	10·23	10·08	10·66	10·56	10·44	10·94	10·85	10·75
23 ..	10·83	10·71	10·56	11·15	11·05	10·94	11·44	11·35	11·25
24 ..	11·31	11·19	11·04	11·84	11·54	11·43	11·94	11·86	11·75
25 ..	11·79	11·66	11·52	12·13	12·03	11·92	12·44	12·36	12·26
26 ..	12·26	12·14	12·00	12·62	12·52	12·41	12·94	12·86	12·76
27 ..	12·74	12·62	12·48	13·11	13·01	12·90	13·44	13·36	13·26
28 ..	13·21	13·09	12·96	13·60	13·60	13·39	13·94	13·86	13·77
29 ..	13·69	13·57	13·43	14·09	13·99	13·88	14·44	14·36	14·27
30 ..	14·17	14·05	13·91	14·57	14·48	14·38	14·94	14·86	14·77
31 ..	14·64	14·52	14·39	15·06	14·97	14·87	15·44	15·36	15·27
32 ..	15·12	15·00	14·87	15·55	15·46	15·36	15·94	15·86	15·78
33 ..	15·59	15·48	15·35	16·04	15·95	15·85	16·44	16·37	16·28
34 ..	16·07	15·95	15·82	16·53	16·44	16·34	16·94	16·87	16·78
35 ..	16·55	16·43	16·30	17·02	16·93	16·83	17·44	17·37	17·28
36 ..	17·02	16·91	16·78	17·51	17·42	17·32	17·94	17·87	17·78
37 ..	17·50	17·38	17·26	17·99	17·91	17·81	18·44	18·37	18·28
38 ..	17·97	17·86	17·73	18·48	18·40	18·30	18·94	18·87	18·79
39 ..	18·45	18·33	18·21	18·97	18·88	18·79	19·44	19·37	19·29
40 ..	18·93	18·81	18·69	19·46	19·37	19·28	19·94	19·87	19·79

For resultant cutting at ·82	1/5 from toe multiply ·79	base lengths by ·78
For resultant cutting ·76	at 1/8 from toe multiply ·73	base lengths by ·71
For resultant cutting ·75	at 1/10 from toe multiply ·71	base lengths by ·69

Note.—1. Two points are made very clear by this table, *viz.*, the importance of as great a front has very little effect in decreasing the base length required.

2. It also shows how useless a stability diagram is for judging whether a design is economical high with a front batter of 1 in 4, a top width of 1 foot and a base length of 18·93 feet, and a wall of pressure is the same in both cases, and the line of thrust will pass exactly through the centre requires 27 per cent, more material than the former.

3. The above table is based on Rankine's formula, and gives somewhat higher results for low and 24 feet, 95 per cent. of the above may be adopted. For walls of more than 24 feet, the full.

4. The back of the wall should be stepped.

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and sand weighing 95 to 100 lbs. per cubic foot with natural slopes $1\frac{3}{4}$ to $1—1\frac{1}{2}$ cuts the base at the extremity of the middle third. The weight of earth on the

1 in 12			Vertical			Height of wall
Top width			Top width			
(1)	(2)	(3)	(1)	(2)	(3)	
4·06	3·94	3·75	4·44	4·36	4·21	8
4·58	4·46	4·29	5·01	4·93	4·79	9
5·10	4·99	4·83	5·57	5·50	5·38	10
5·61	5·51	5·37	6·13	6·06	5·96	11
6·13	6·04	5·91	6·69	6·63	6·54	12
6·65	6·56	6·43	7·25	7·20	7·11	13
7·16	7·08	6·96	7·81	7·76	7·68	14
7·68	7·60	7·48	8·37	8·32	8·25	15
8·20	8·12	8·01	8·93	8·89	8·82	16
8·71	8·64	8·53	9·49	9·45	9·38	17
9·23	9·16	9·06	10·05	10·01	9·95	18
9·75	9·67	9·58	10·61	10·57	10·51	19
10·26	10·19	10·10	11·17	11·14	11·08	20
10·78	10·71	10·62	11·73	11·70	11·64	21
11·29	11·23	11·14	12·29	12·26	12·21	22
11·81	11·74	11·66	12·85	12·82	12·77	23
12·33	12·26	12·18	13·41	13·38	13·33	24
12·84	12·78	12·70	13·97	13·94	13·89	25
13·36	13·30	13·22	14·53	14·50	14·46	26
13·87	13·81	13·73	15·09	15·06	15·02	27
14·39	14·33	14·25	15·64	15·62	15·58	28
14·91	14·85	14·77	16·20	16·18	16·14	29
15·42	15·36	15·29	16·76	16·74	16·70	30
15·94	15·88	15·81	17·32	17·32	17·26	31
16·45	16·40	16·32	17·88	17·86	17·83	32
16·97	16·91	16·84	18·44	18·42	18·39	33
17·48	17·43	17·36	19·00	18·98	18·95	34
18·00	17·94	17·88	19·56	19·54	19·51	35
18·52	18·46	18·39	20·12	20·10	20·07	36
19·03	18·98	18·91	20·68	20·66	20·63	37
19·55	19·49	19·43	21·24	21·22	21·19	38
20·06	20·01	19·94	21·80	21·78	21·75	39
20·58	20·52	20·46	22·36	22·34	22·31	40

·76	·72	
·68	·64	
·66	·62	

batter as possible for economy of design, and the fact that an increase in the top width of the wall

or not. For example, as far as stability is concerned there is nothing to choose between a wall 40 feet the same height with vertical face, a top width of 3 feet, and a base length of 22·31 feet. The earth third point of each base. Theoretically the two sections have equal value, but practically the latter

walls. For walls up to 12 feet high 90 per cent of the above results, and for walls between 12 feet theoretical values, as given in the tables may be adopted.

TABLE

Base lengths of retaining walls for loose earth and sand
Resultant cuts base at 1/5 from toe.

Height of wall	Front								
	1 in 4			1 in 6			1 in 8		
	Top width			Top width			Top width		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
8 ..	3·02	..	..	3·00	..	..	3·02	..	..
9 ..	3·41	..	..	3·39	..	..	3·41	3·31	..
10 ..	3·80	..	..	3·78	..	..	3·80	3·70	..
11 ..	4·20	..	..	4·17	4·06	..	4·19	4·09	..
12 ..	4·59	..	..	4·55	4·55	..	4·58	4·48	..
13 ..	4·98	..	..	4·94	4·84	..	4·97	4·87	4·76
14 ..	5·37	..	..	5·33	5·23	..	5·35	5·26	5·15
15 ..	5·77	..	..	5·72	5·62	..	5·74	5·65	5·54
16 ..	6·16	6·04	..	6·11	6·01	5·89	6·13	6·04	5·93
17 ..	6·55	6·43	..	6·50	6·39	6·28	6·52	6·43	6·32
18 ..	6·94	6·83	..	6·88	6·78	6·67	6·91	6·82	6·71
19 ..	7·33	7·22	..	7·27	7·17	7·06	7·30	7·21	7·10
20 ..	7·73	7·61	..	7·66	7·56	7·45	7·69	7·60	7·49
21 ..	8·12	8·00	..	8·05	7·95	7·84	8·08	7·84	7·88
22 ..	8·51	8·40	..	8·44	8·34	8·23	8·47	8·38	8·27
23 ..	8·90	8·79	..	8·83	8·73	8·62	8·86	8·77	8·67
24 ..	9·30	9·18	9·06	9·22	9·12	9·01	9·25	9·16	9·06
25 ..	9·69	9·57	9·45	9·60	9·51	9·40	9·63	9·55	9·45
26 ..	10·08	9·97	9·84	9·99	9·90	9·79	10·02	9·94	9·84
27 ..	10·37	10·36	10·24	10·38	10·29	10·18	10·41	10·33	10·23
28 ..	10·86	10·75	10·63	10·77	10·67	10·57	10·80	10·72	10·62
29 ..	11·26	11·14	11·02	11·16	11·06	10·96	11·19	11·11	11·01
30 ..	11·65	11·54	11·42	11·55	11·45	11·35	11·58	11·50	11·40
31 ..	12·04	11·93	11·81	11·93	11·84	11·74	11·97	11·89	11·79
32 ..	12·43	12·32	12·20	12·32	12·23	12·13	12·36	12·28	12·18
33 ..	18·21	12·71	12·60	12·71	12·62	12·52	12·75	12·67	12·57
34 ..	12·22	13·11	12·99	13·10	13·01	12·91	13·14	13·06	12·97
35 ..	13·61	13·50	12·38	13·49	13·40	13·30	13·52	13·45	13·36
36 ..	14·00	13·89	13·78	13·88	13·78	13·68	13·91	13·84	13·75
37 ..	14·39	14·28	14·17	14·26	14·17	14·07	14·30	14·23	14·14
38 ..	14·79	14·68	14·56	14·65	14·56	14·46	14·69	14·62	14·53
39 ..	15·18	15·07	14·96	15·04	14·95	14·85	15·08	15·01	14·92
40 ..	15·57	15·46	15·36	15·43	15·34	15·24	15·47	15·40	15·31

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weighing 100 lbs. per c.ft. with natural slope $1\frac{3}{4}$ to 1—$1\frac{1}{2}$ to 1.
Weight of masonry 125 lbs. per c. ft.

Batter

1 in 12			Vertical			Height of wall
Top width			Top width			
(1)	(2)	(3)	(1)	(2)	(3)	
3·07	2·95	..	3·20	3·11	..	8
3·46	3·35	..	3·61	3·52	3·41	9
3·85	3·74	..	4·01	3·93	3·83	10
4·25	4·14	4·03	4·42	4·33	4·25	11
4·64	4·53	4·43	4·82	4·74	4·66	12
5·03	4·93	4·83	5·23	5·15	5·08	13
5·42	5·32	5·22	5·64	5·56	5·49	14
5·81	5·72	5·62	6·04	5·96	5·91	15
6·21	6·11	6·01	6·45	6·37	6·32	16
6·60	6·51	6·41	6·85	6·78	6·74	17
6·99	6·90	6·80	7·26	7·19	7·15	18
7·38	7·30	7·20	7·67	7·60	7·55	19
7·77	7·69	7·59	8·07	8·00	7·96	20
8·16	8·09	7·99	8·48	8·41	8·37	21
8·56	8·48	8·38	8·88	8·82	8·78	22
8·95	8·88	8·78	9·28	9·23	9·18	23
9·34	9·27	9·17	9·70	9·64	9·59	24
9·73	9·66	9·57	10·10	10·04	10·00	25
10·12	10·06	9·96	10·51	10·45	10·41	26
10·52	10·45	10·36	10·91	10·86	10·81	27
10·91	10·84	10·75	11·32	11·27	11·22	28
11·30	11·23	11·15	11·72	11·67	11·63	29
11·69	11·63	11·54	12·13	12·08	12·04	30
12·08	12·02	11·94	12·54	12·49	12·44	31
12·48	12·41	12·33	12·94	12·90	12·85	32
12·87	12·80	12·73	13·35	13·31	13·26	33
13·26	13·20	13·12	13·75	13·71	13·67	34
13·65	13·59	13·52	14·16	14·12	14·07	35
14·04	13·98	13·91	14·57	14·53	14·48	36
14·43	14·37	14·31	14·97	14·94	14·89	37
14·83	14·77	14·70	15·38	15·34	15·30	38
15·22	15·16	15·10	15·78	15·75	15·70	39
15·61	15·55	15·49	16·19	16·16	16·11	40

TABLE

Base lengths of retaining walls for loose earth and sand
Weight of masonry 125 lbs. per cubic foot.

Height of wall	Front								
	1 in 4			1 in 6			1 in 8		
	Top width			Top width			Top width		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
8 ..	..	..	..	2·74	..	..	2·74	..	..
9 ..	..	..	..	3·10	..	..	3·09	..	..
10 ..	3·53	..	..	3·45	..	..	3·45	3·34	..
11 ..	3·90	..	..	3·81	..	..	3·80	3·70	..
12 ..	4·26	..	..	4·16	4·06	..	4·19	4·05	..
13 ..	4·62	..	..	4·52	4·42	..	4·51	4·41	..
14 ..	4·99	..	..	4·88	4·77	..	4·86	4·76	..
15 ..	5·35	..	..	5·23	5·13	..	5·22	5·12	5·02
16 ..	5·72	..	..	5·59	5·49	..	5·57	5·47	5·38
17 ..	6·08	..	..	5·94	5·84	..	5·93	5·93	5·74
18 ..	6·44	..	..	6·30	6·20	6·10	6·28	6·18	6·09
19 ..	6·81	..	..	6·66	6·56	6·46	6·63	6·54	6·45
20 ..	7·17	7·10	..	7·01	6·91	6·82	6·99	6·89	6·80
21 ..	7·54	7·46	..	7·37	7·27	7·17	7·34	7·25	7·16
22 ..	7·90	7·83	..	7·72	7·62	7·53	7·70	7·60	7·51
23 ..	8·26	8·19	..	8·08	7·98	7·88	8·05	7·96	7·87
24 ..	8·63	8·55	..	8·44	8·34	8·24	8·40	8·31	8·22
25 ..	8·99	8·91	..	8·79	8·69	8·60	8·76	8·67	8·58
26 ..	9·36	9·27	..	9·15	9·05	8·95	9·11	9·02	8·93
27 ..	9·72	9·64	..	9.50	9·41	9·31	9·47	9·38	9·29
28 ..	10·08	10·00	..	9·86	9·76	9·67	9·82	9·73	9·65
29 ..	10·45	10·36	..	10·21	10·12	10·02	10·18	10·09	10·00
30 ..	10·81	10·72	10·51	10·57	10·48	10·38	10·53	10·44	10·36
31 ..	11·17	11·08	10·88	10·93	10·83	10·73	10·88	10·80	10·71
32 ..	11·54	11·45	11·26	11·28	11·19	11·09	11·24	11·15	11·07
33 ..	11·90	11·81	11·64	11·64	11·55	11·45	11·51	11·51	11·42
34 ..	12·27	12·17	12·02	11·99	11·90	11·80	11·95	11·86	11·78
35 ..	12·63	12·53	12·39	12·35	12·26	12·16	12·30	12·22	12·13
36 ..	12·99	12·89	12·77	12·71	12·61	12·52	12·65	12·57	12·49
37 ..	13·36	13·25	13·14	13·06	12·97	12·87	13·01	12·93	12·84
38 ..	13·72	13·62	13·50	13·42	13·33	13·23	13·36	13·28	13·20
39 ..	14·08	13·98	13·87	13·77	13·68	13·58	13·72	13·64	13·55
40 ..	14·45	14·34	14·23	14·13	14·04	13·94	14·07	13·99	13·91

J—1136—18-B.

CLXXXIX (*b*)

weighing 100 lbs. per c. ft. with natural slope 1¾ to 1—1½ to 1.
Resultant pressure cuts base at 1/8 from toe.

Batter						
1 in 12			Vertical			Height of wall
Top width			Top width			
(1)	(2)	(3)	(1)	(2)	(3)	
2·76	..	..	2·83	2·75	..	8
3·11	3·01	..	3·19	3·11	3·01	9
3·47	3·37	..	3·55	3·47	3·38	10
3·82	3·72	..	3·91	3·84	3·75	11
4·18	4·08	..	4·27	4·20	4·12	12
4·53	4·43	4·33	4·63	4·56	4·48	13
4·89	4·79	4·69	5·00	4·92	4·85	14
5·24	5·14	5·04	5·36	5·29	5·22	15
5·59	5·50	5·40	5·72	5·65	5·59	16
5·95	5·85	5·76	6·08	6·01	5·95	17
6·30	6·21	6·11	6·44	6·37	6·32	18
6·66	6·57	6·47	6·80	6·73	6·68	19
7·01	6·92	6·83	7·10	7·10	7·05	20
7·37	7·28	7·18	7·52	7·46	7·41	21
7·72	7·63	7·54	7·88	7·82	7·77	22
8·07	7·99	7·90	8·24	8·18	8·14	23
8·43	8·34	8·25	8·61	8·55	8·50	24
8·78	8·70	8·61	8·97	8·91	8·86	25
9·14	9·05	8·96	9·33	9·27	9·22	26
9·49	9·41	9·32	9·69	9·63	9·58	27
9·85	9·77	9·68	10·05	9·99	9·95	28
10·20	10·12	10·03	10·41	10·36	10·31	29
10·55	10·48	10·39	10·77	10·72	10·67	30
10·91	10·83	10·75	11·13	11·08	11·03	31
11·26	11·19	11·10	11·49	11·44	11·39	32
11·62	11·54	11·46	11·85	11·80	11·75	33
11·97	11·90	11·82	12·21	12·17	12·10	34
12·33	12·25	12·17	12·58	12·53	12·46	35
12·68	12·61	12·53	12·94	12·89	12.82	36
13·03	12·97	12·89	13·30	13·25	13.17	37
13·39	13·32	13·24	13·66	13·62	13.53	38
13·74	13·68	13·60	14·02	13·98	13·88	39
14·10	14·03	13·96	14·38	14·34	14·24	40

TABLE

Base lengths of retaining walls for loose earth and sand weighing
Weight of masonry 125 lbs. per c. ft.

Height of wall	Front								
	1 in 4			1 in 6			1 in 8		
	Top width			Top width			Top width		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
8 ..	..	..	..	2·67	..	..	2·68	..	..
9 ..	..	..	..	3·02	..	..	3·02	..	..
10 ..	..	..	..	3·37	..	..	3·37	..	..
11 ..	3·78	..	..	3·71	..	..	3·71	3·60	..
12 ..	4·14	..	..	4·06	..	..	4·06	3·95	..
13 ..	4·50	..	..	4·41	4·36	..	4·40	4·29	..
14 ..	4·86	..	..	4·76	4·70	..	4·74	4·64	..
15 ..	5·21	..	..	5·10	5·04	..	5·08	4·98	..
16 ..	5·57	..	..	5·45	5·39	..	5·43	5·33	5·23
17 ..	5·93	..	..	5·80	5·78	..	5·77	5·68	5·58
18 ..	6·29	..	..	6·15	6·07	..	6·12	6·02	5·92
19 ..	6·65	..	..	6·49	6·42	6·28	6·46	6·37	6·27
20 ..	7·01	..	..	6·84	6·76	6·63	6·81	6·72	6·62
21 ..	7·36	7·26	..	7·19	7·10	6·98	7·15	7·06	6·96
22 ..	7·72	7·62	..	7·54	7·44	7·33	7·49	7·41	7·31
23 ..	8·08	7·97	..	7·88	7·79	7·68	7·84	7·75	7·65
24 ..	8·44	8·33	..	8·23	8·13	8·03	8·18	8·10	8·00
25 ..	8·80	8·69	..	8·58	8·48	8·38	8·52	8·44	8·35
26 ..	9·15	9·04	..	8·92	8·82	8·73	8·87	8·79	8·69
27 ..	9·51	9·40	..	9·27	9·17	9·07	9·21	9·13	9·04
28 ..	9·86	9·76	..	9·61	9·52	9·42	9·56	9·48	9·38
29 ..	10·22	10·11	..	9·96	9·86	9·77	9·90	9·82	9·73
30 ..	10·57	10·47	..	10·30	10·21	10·12	10·24	10·17	10·07
31 ..	10·93	10·82	..	10·65	10·56	10·46	10·59	10·51	10·42
32 ..	11·29	11·18	11·06	10·99	10·90	10·81	10·93	10·86	10·76
33 ..	11·64	11·54	11·42	11·34	11·25	11·16	11·27	11·20	11·11
34 ..	12·00	11·89	11·78	11·68	11·60	11·51	11·62	11·55	11·45
35 ..	12·35	12·25	12·13	12·03	11·94	11·85	11·96	11·89	11·80
36 ..	12·71	12·61	12·49	12·37	12·29	12·20	12·31	12·23	12·14
37 ..	13·06	12·96	12·85	12·72	12·64	12·55	12·65	12·58	12·49
38 ..	13·42	13·32	13·21	13·06	12·98	12·90	12·99	12·92	12·83
39 ..	13·77	13·67	13·56	12·41	13·33	13·24	13·34	13·26	13·18
40 ..	14·13	14·03	13·92	13·75	13·68	13·59	13·68	13·61	13·52

CLXXXIX (*c*)

100 lbs. per c. ft., with natural slope $1\frac{3}{4}$ to 1—$1\frac{1}{2}$ to 1.
Resultant pressure cuts base at 1/10 from toe.

Batter						Height of wall
1 in 12			Vertical			
Top width			Top width			
(1)	(2)	(3)	(1)	(2)	(3)	
2·67	..	..	2·74	2·65	..	8
3·01	2·92	..	3·09	3·00	..	9
3·36	3·27	..	3·44	3·35	3·26	10
3·70	3·61	..	3·79	3·70	3·61	11
4·05	3·96	..	4·14	4·06	3·97	12
4·39	4·30	4·21	4·48	4·41	4·32	13
4·73	4·65	4·56	4·83	4·76	4·67	14
5·08	5·00	4·91	5·18	5·11	5·03	15
5·42	5·34	5·25	5·53	5·46	5·38	16
5·76	5·69	5·60	5·58	5·81	5·73	17
6·11	6·03	5·94	6·23	6·16	6·09	18
6·45	6·38	6·29	6·58	6·51	6·44	19
6·80	6·73	6·64	6·92	6·87	6·80	20
7·14	7·07	6·98	7·27	7·22	7·15	21
7·48	7·42	7·33	7·62	7·57	7·50	22
7·83	7·76	7·67	7·97	7·92	7·86	23
8·17	8·11	8·02	8·32	8·27	8·21	24
8·51	8·45	8·37	8·67	8·62	8·56	25
8·86	8·80	8·71	9·02	8·97	8·91	26
9·20	9·14	9·06	9·37	9·32	9·26	27
9·55	9·49	9·40	9·71	9·67	9·61	28
9·89	9·83	9·75	10·06	10·01	9·96	29
10·23	10·17	10·09	10·41	10·36	10·31	30
10·58	10·52	10·44	10·76	10·71	10·66	31
10·92	10·86	10·78	11·11	11·06	11·01	32
11·26	11·20	11·13	11·46	11·41	11·35	33
11·61	11·55	11·47	11·81	11·76	11·70	34
11·95	11·89	11·82	12·16	12·11	12·05	35
12·30	12·24	12·16	12·50	12·46	12·40	36
12·64	12·58	12·51	12·85	12·80	12·75	37
12·98	12·92	12·85	13·20	13·15	13·10	3
13·33	13·27	13·20	13·55	13·50	13·45	39
13·67	13·61	13·54	13·90	13.85	13·80	40

TABLE

Base lengths of retaining walls loose earth and sand weighing 100 lbs. Weight of masonry 150 lbs. per cubic foot. Resultant

Height of wall	Front								
	1 in 4			1 in 6			1 in 8		
	Top width			Top width			Top width		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
8 ..	3·38	..	..	3·59	..	..	3·75	3·56	..
9 ..	3·84	..	..	3·06	3·84	..	4·24	4·05	..
10 ..	4·30	..	..	4·53	4·31	..	4·73	4·54	..
11 ..	4·75	..	..	5·01	4·79	..	5·21	5·03	4·81
12 ..	5·21	..	..	5·48	5·26	..	5·70	5·52	5·30
13 ..	5·66	5·38	..	5·95	5·74	5·49	6·10	6·01	5·79
14 ..	6·12	5·84	..	6·43	6·21	5·96	6·68	6·50	6·28
15 ..	6·57	6·29	..	6·90	6·69	6·44	7·16	6·99	6·77
16 ..	7·03	6·75	..	7·37	7·16	6·92	7·65	7·47	7·27
17 ..	7·48	7·21	..	7·48	7·64	7·39	8·14	7·96	7·76
18 ..	7·94	7·67	..	8·32	8·11	7·87	8·63	8·45	8·25
19 ..	8·39	8·14	..	8·79	8·58	8·35	9·11	8·94	8·74
20 ..	8·85	8·60	8·28	9·26	9·06	8·82	9·60	9·43	9·23
21 ..	9·30	9·05	8·74	9·74	9·53	9·30	10·09	9·92	9·72
22 ..	9·76	9·51	9·20	10·21	10·01	9·78	10·58	10·41	10·21
23 ..	10·21	9·96	9·65	10·68	10·48	10·25	11·06	10·90	10·70
24 ..	10·66	10·42	10·11	11·16	10·96	10·73	11·55	11·39	11·19
25 ..	11·11	10·87	10·57	11·63	11·43	11·21	11·04	11·88	11·68
26 ..	11·57	11·33	11·03	12·11	11·91	11·68	12·53	12·36	12·17
27 ..	12·02	11·78	11·49	12·58	12·38	12·16	13·01	12·85	12·66
28 ..	12·47	12·24	11·95	13·05	12·85	12·64	13·50	13·34	13·16
29 ..	12·93	12·69	12·41	13·52	13·33	13·11	13·99	13·83	13·64
30 ..	13·38	13·15	12·86	13·99	13·80	13·59	14·48	14·32	14·13
31 ..	13·83	13·60	13·32	14·47	14·28	14·07	14·96	14·81	14·62
32 ..	14·29	14·06	13·78	14·94	14·75	14·54	15·45	15·40	15·12
33 ..	14·74	14·51	14·24	15·41	15·23	15·02	15·94	15·79	15·61
34 ..	15·20	14·97	14·70	15·88	15·70	15·50	16·43	16·28	16·10
35 ..	15·65	15·42	15·16	16·36	16·18	15·97	16·91	16·77	16·59
36 ..	16·10	15·88	15·62	16·83	16·65	16·45	17·40	17·25	17·08
37 ..	16·56	16·33	16·07	17·30	17·12	16·93	17·89	17·74	17·57
38 ..	17·01	16·79	16·53	17·78	17·60	17·40	18·38	18·23	18·06
39 ..	17·47	17·24	16·99	18·25	18·07	17·88	18·86	18·72	18·55
40 ..	17·92	17·70	17·45	18·72	18·54	18·35	19·35	19·21	19·04
For resultant cutting at 1/5 from toe, multiply base length by	·81			·78			·76		
For resultant cutting at 1/8 from toe, multiply base length by	·75			·71			·69		
For resultant cutting at 1/10 from toe, multiply base length by	·74			·69			·67		

CXC

per cubic foot with natural slope $1\frac{3}{4}$ to 1—$1\frac{1}{2}$ to 1.
pressure cuts base at extremity of middle third.

Batter.						
1 in 12			Vertical			Height of wall
Top width			Top width			
1	2	3	1	2	3	
3·93	3·81	..	4·43	4·36	4·24	8
4·44	4·32	4·11	4·99	4·92	4·80	9
4·95	4·83	4·62	5·55	5·48	5·37	10
5·45	5·33	5·13	6·11	6·04	5·93	11
5·96	5·84	5·64	6·67	6·60	6·49	12
6·47	6·35	6·15	7·23	7·17	7·06	13
6·97	6·86	6·66	7·79	7·73	7·62	14
7·48	7·36	7·17	8·35	8·29	8·18	15
7·99	7·87	7·68	8·91	8·85	8·75	16
8·50	8·38	9·19	9·47	9·41	9·31	17
9·00	8·89	8·70	10·03	9·97	9·87	18
9·51	9·39	9·21	10·59	10·53	10·43	19
10·02	9·90	9·72	11·15	11·10	11·00	20
10·52	10·41	10·23	11·71	11·65	11·56	21
11·03	10·92	10·74	12·27	12·22	12·12	22
11·54	11·42	11·25	12·83	12·78	12·69	23
12·05	11·93	11·76	13·39	13·34	13·25	24
12·55	12·44	13·27	13·95	13·90	13·81	25
13·06	12·95	12·78	14·51	14·46	14·38	26
13·57	13·45	13·29	15·07	15·02	14·94	27
14·07	13·96	13·80	15·63	15·59	15·50	28
14·58	14·47	14·31	16·19	16·15	16·06	29
15·09	14·98	14·82	16·75	16·71	16·63	30
15·60	15·48	15·33	17·31	17·27	17·19	31
16·10	15·99	15·84	17·87	17·83	17·76	32
16·61	16·50	16·35	18·43	18·39	18·32	33
17·12	17·00	16·86	18·99	18·95	18·88	34
17·62	17·51	17·37	19·55	19·51	19·44	35
18·13	18·02	17·88	20·11	20·08	20·01	36
18·64	18·53	18·39	20·67	20·64	20·57	37
19·15	19·04	18·90	21·23	21·20	21·13	38
19·65	19·54	19·41	21·79	21·76	21·70	39
20·16	20·05	19·92	22·35	22·32	22·23	40
·74			·70			
·66			·62			
·64			·60			

TABLE

Base lengths of retaining walls for loose earth and sand weighing 100 lbs.
Weight of masonry 150 lbs. per cubic foot.

Height of wall.	Front								
	1 in 4			1 in 6			1 in 8		
	1	2	3	1	2	3	1	2	3
8 ..	..	..	..	2·77	..	..	2·82	..	..
9 ..	..	..	..	3·14	..	..	3·19	..	..
10 ..	..	..	..	3·51	..	..	3·57	3·36	..
11 ..	3·86	..	..	3·88	..	..	3·94	3·74	..
12 ..	4·23	..	..	4·25	4·06	..	4·31	4·11	..
13 ..	4·60	..	..	4·62	4·43	..	4·68	4·49	..
14 ..	4·97	..	..	4·99	4·80	..	5·06	4·86	..
15 ..	5·34	..	..	5·36	5·17	..	5·43	5·24	5·02
16 ..	5·71	..	..	5·73	5·54	..	5·80	5·61	5·40
17 ..	6·08	..	..	6·10	5·91	..	6·18	5·99	5·78
18 ..	6·45	..	..	6·47	6·28	6·08	6·55	6·36	6·15
19 ..	6·82	..	..	6·84	6·65	6·45	6·92	6·74	6·53
20 ..	7·19	..	..	7·21	7·02	6·82	7·29	7·11	6·91
21 ..	7·56	7·34	..	7·58	7·40	7·19	7·67	7·49	7·29
22 ..	7·93	7·71	..	7·95	7·77	7·57	8·04	7·86	7·66
23 ..	8·30	8·08	..	8·32	8·14	7·94	8·41	8·24	8·04
24 ..	8·67	8·45	..	8·69	8·51	8·31	8·78	8·61	8·42
25 ..	9·04	8·82	..	9·07	8·88	8·68	9·16	8·99	8·79
26 ..	9·42	9·19	..	9·44	9·25	9·05	9·53	9·36	9·17
27 ..	9·79	9·56	..	9·81	9·62	9·43	9·90	9·74	9·55
28 ..	10·16	9·94	..	10·18	10·00	9·80	10·28	10·11	9·92
29 ..	10·53	10·31	..	10·55	10·37	10·17	10·65	10·49	10·30
30 ..	10·90	10·68	..	10·92	10·74	10·54	11·02	10·86	10·68
31 ..	11·27	11·05	10·82	11·29	11·11	10·91	11·39	11·24	11·06
32 ..	11·64	11·42	11·19	11·66	11·48	11·29	11·77	11·61	11·43
33 ..	12·01	11·79	11·56	12·03	11·85	11·66	12·14	11·99	11·81
34 ..	12·38	12·16	11·93	12·40	12·22	12·03	12·51	2·36	12·19
35 ..	12·75	12·53	12·30	12·77	12·59	2·40	12·89	12·74	12·56
36 ..	13·12	12·91	12·68	13·14	12·97	12·77	13·26	13·11	12·94
37 ..	13·49	13·28	13·05	13·51	13·34	13·14	13·63	13·49	13·32
38 ..	13·86	13·65	13·42	13·88	13·71	13·52	14·00	13·86	13·70
39 ..	14·23	14·02	13·79	14·25	14·08	13·89	14·38	14·24	14·07
40 ..	14·60	14·39	14·16	14·62	14·45	14·26	14·75	14·61	14·45

CXC (*a*)

per cubic foot with natural slope 1¾ to 1—1½ to 1
Resultant pressure cuts base at 1/5 from toe.

Batter: 1 in 12			Vertical			Height of wall
Top width in feet			Top width in feet			
1	2	3	1	2	3	
2·85	..	..	3·07	2·90	..	8
3·23	3·09	..	3·47	3·30	3·12	9
3·61	3·47	..	3·86	3·70	3·53	10
3·99	3·85		4·26	4·11	3·94	11
4·37	4·23	..	4·66	4·51	4·35	12
4·75	4·61	4·41	5·05	4·91	4·76	13
5·13	4·99	4·79	5·45	5·31	5·17	14
5·51	5·37	5·18	5·84	5·71	5·58	15
5·89	5·75	5·56	6·24	6·12	5·99	16
6·26	6·13	5·93	6·64	6·52	6·39	17
6·64	6·51	6·33	7·03	6·92	6·80	18
7·02	6·89	6·72	7·43	7·32	7·20	19
7·40	7·27	7·10	7·83	7·72	7·61	20
7·78	7·65	7·49	8·22	8·12	8·01	21
8·16	8·03	7·87	8·62	8·53	8·41	22
8·54	8·41	8·26	9·01	8·93	8·82	23
8·92	8·79	8·64	9·41	9·33	9·22	24
9·30	9·17	9·02	9·87	9·73	9·62	25
9·68	9·54	9·40	10·20	10·12	10·02	26
10·06	9·92	9·78	10·60	10·52	10·41	27
10·44	10·30	10·16	11·00	10·92	10·81	28
10·82	10·68	10·54	11·39	11·31	11·21	29
11·20	11·06	10·92	11·79	11·71	11·61	30
11·58	11·44	11·30	12·18	12·11	12·01	31
11·96	11·82	11·68	12·58	12·51	12·41	32
12·33	12·20	12·06	12·98	12·90	12·80	33
12·71	12·58	12·44	13·37	13·30	13·20	34
13·09	12·96	12·82	13·77	13·70	13·60	35
13·47	13·34	13·20	14·17	14·09	14·00	36
13·85	13·72	13·58	14·56	14·49	14·40	37
14·23	14·10	13·96	14·96	14·89	14·79	38
14·61	14·48	14·34	15·35	15·28	15·19	39
14·99	14·86	14·72	15·75	15·68	15·59	40

TABLE

Base lengths of retaining walls for loose earth and sand weighing
Weight of masonry 150 lbs. per cubic foot.

Height of wall in ft.	Front								
	1 in 4			1 in 6			1 in 8		
	Top width in feet			Top width in feet			Top width in feet		
	1	2	3	1	2	3	1	2	3
8 ..	..	..	..	2·52	..	..	2·54	..	..
9 ..	..	..	..	2·86	..	..	2·88	..	..
10 ..	..	..	..	3·20	..	..	3·22	..	..
11 ..	..	..	..	3·54	..	..	3·55	..	..
12 ..	..	..	..	3·88	..	..	3·89	3·70	..
13 ..	..	..	..	4·22	..	..	4·23	4·04	..
14 ..	4·60	..	..	4·56	4·36	..	4·57	4·38	..
15 ..	4·94	..	..	4·90	4·70	..	4·90	4·72	..
16 ..	5·28	..	..	5·24	5·04	..	5·24	5·06	..
17 ..	5·62	..	..	5·58	5·38	..	5·58	5·40	5·20
18 ..	5·97	..	..	5·92	5·72	..	5·92	5·74	5·55
19 ..	6·31	..	..	6·26	6·06	..	6·26	6·08	5·89
20 ..	6·66	..	..	6·60	6·40	..	6·59	6·42	6·23
21 ..	7·00	..	..	6·94	6·73	6·53	6·93	6·76	6·57
22 ..	7·35	..	..	7·28	7·07	6·87	7·27	7·10	6·91
23 ..	7·69	..	..	7·62	7·41	7·21	7·61	7·44	7·25
24 ..	8·03	..	..	7·96	7·75	7·55	7·95	7·78	7·60
25 ..	8·38	..	..	8·30	8·09	7·89	3·28	8·12	7·94
26 ..	8·72	..	..	8·63	8·43	8·23	8·62	8·45	8·28
27 ..	9·07	8·84	..	8·97	8·77	8·57	8·96	8·79	8·62
28 ..	9·41	9·18	..	9·31	9·11	8·91	9·30	9·13	8·96
29 ..	9·75	8·52	..	9·65	9·44	9·25	9·63	9·47	9·30
30 ..	10·10	9·87	..	9·99	9·78	9·59	9·97	9·81	9·64
31 ..	10·44	10·21	..	10·33	10·12	9·93	10·31	10·15	9·98
32 ..	10·79	10·55	..	10·67	10·46	10·27	10·65	10·49	10·32
33 ..	11·13	10·90	..	11·01	10·80	10·61	10·99	10·83	10·66
34 ..	11·48	11·24	..	11·35	11·14	10·95	11·32	11·17	11·00
35 ..	11·82	11·58	..	11·69	11·48	11·29	11·66	11·51	11·35
36 ..	12·16	11·93	..	12·03	11·82	11·63	12·00	11·85	11·69
37 ..	12·51	12·27	..	12·37	12·15	11·97	12·34	12·19	12·03
38 ..	12·85	12·61	..	12·71	12·49	12·31	12·67	12·53	12·37
39 ..	13·20	12·96	..	13·05	12·83	12·65	13·01	12·87	12·71
40 ..	13·54	13·30	13·09	13·39	13·17	12·99	13·35	13·25	13·05

CXC (*b*)

100 lbs. per cubic foot, with natural slope 1¾ to 1—1½ to 1.
Resultant pressure cuts base at 1/8 from toe.

Batter.						
1 in 12			Vertical			Height of wall in feet
Top width in feet			Top width in feet			
1	2	3	1	2	3	
2·66	..	..	2·70	2·53	..	8
3·00	..	..	3·05	2·89	..	9
3·33	3·07	..	3·40	3·25	3·05	10
3·67	3·42	..	3·75	3·61	3·42	11
4·00	3·76	..	4·10	3·97	3·78	12
4·34	4·10	..	4·45	4·32	4·15	13
4·67	4·45	4·25	4·80	4·68	4·52	14
5·01	4·79	4·60	5·15	5·04	4·88	15
5·35	5·13	4·95	5·50	5·40	5·25	16
5·68	5·48	5·29	5·85	5·75	5·61	17
6·02	5·82	5·64	6·20	6·11	5·96	18
6·35	6·16	5·99	6·55	6·46	6·32	19
6·69	6·51	6·33	6·90	6·81	6·67	20
7·02	6·85	6·68	7·25	7·16	7·03	21
7·36	7·19	7·03	7·60	7·52	7·38	22
7·69	7·54	7·37	7·95	7·87	7·74	23
8·03	7·88	7·72	8·30	8·22	8·09	24
8·37	8·22	8·06	8·65	8·57	8·44	25
8·71	8·56	8·40	9·00	8·92	8·79	26
9·05	8·80	8·75	9·35	9·27	9·15	27
9·39	9·24	9·09	9·70	9·62	9·50	28
9·72	9·58	9·43	10·05	9·97	9·85	29
10·06	9·92	9·77	10·40	10·32	10·20	30
10·40	10·26	10·11	10·75	10·67	10·55	31
10·74	10·60	10·46	11·10	11·02	10·91	32
11·08	10·94	10·80	11·45	11·37	11·26	33
11·42	11·28	11·14	11·80	11·72	11·61	34
11·76	11·62	11·48	12·15	12·07	11·96	35
12·10	11·96	11·82	12·50	12·42	12·31	36
12·43	12·30	12·16	12·85	12·77	12·66	37
12·77	12·64	12·51	13·20	13·12	13·02	38
13·11	12·98	12·85	12·55	13·47	13·37	39
13·45	13·32	13·19	13·90	13·82	13·72	40

TABLE

Base length of retaining walls was for loose earth and sand weighing
Weight of masonry 150 lbs. per cubic foot.

Front

Height of wall	1 in 4			1 in 6			1 in 8		
	Top width			Top width			Top width		
	1	2	3	1	2	3	1	2	3
8 ..	..	..	..	2·45	..	..	2·46	..	..
9 ..	..	..	..	2·78	..	..	2·79	..	..
10 ..	..	..	..	3·11	..	..	3·12	..	..
11 ..	..	..	..	3·44	..	..	3·45	..	..
12 ..	..	..	..	3·77	..	..	3·78	3·59	..
13 ..	..	..	..	4·10	..	..	4·11	3·92	..
14 ..	..	..	..	4·43	..	..	4·44	4·25	..
15 ..	4·82	..	..	4·76	4·57	..	4·77	4·59	..
16 ..	5·16	..	..	5·09	4·90	..	5·10	4·92	..
17 ..	5·50	..	..	5·41	5·23	..	5·42	5·25	..
18 ..	5·83	..	..	5·74	5·56	..	5·75	5·58	5·38
19 ..	6·17	..	..	6·07	5·89	..	6·08	5·91	5·72
20 ..	6·50	..	..	6·40	6·23	..	6·41	6·24	6·05
21 ..	6·84	..	..	6·73	6·56	..	6·74	6·58	6·39
22 ..	7·17	..	..	7·06	6·89	6·68	7·07	6·91	6·72
23 ..	7·51	..	..	7·39	7·22	7·01	7·40	7·24	7·06
24 ..	7·84	..	..	7·72	7·55	7·34	7·73	7·57	7·39
25 ..	8·18	..	..	8·05	7·88	7·67	8·06	7·90	7·72
26 ..	8·51	..	..	8·38	8·21	8·00	8·39	8·23	8·05
27 ..	8·85	..	..	8·71	8·54	8·33	8·71	8·56	8·38
28 ..	9·18	..	..	9·04	8·87	8·67	9·04	8·89	8·71
29 ..	9·52	9·44	..	9·37	9·20	9·00	9·37	9·21	9·04
30 ..	9·85	9·76	..	9·70	9·53	9·33	9·70	9·54	9·37
31 ..	10·19	10·08	..	10·03	9·86	9·66	10·03	9·87	9·70
32 ..	10·52	10·39	..	10·36	10·19	9·99	10·36	10·20	10·03
33 ..	10·86	10·71	..	10·68	10·51	10·32	10·68	10·53	10·36
34 ..	11·19	11·03	..	11·01	10·84	10·65	11·01	10·86	10·69
35 ..	11·53	11·34	..	11·34	11·17	10·98	11·34	11·19	11·02
36 ..	11·86	11·66	..	11·67	11·50	11·32	11·67	11·52	11·35
37 ..	12·20	12·00	..	12·00	11·83	11·65	12·00	11·84	11·68
38 ..	12·53	12·33	..	12·33	12·16	11·98	12·32	12·17	12·01
39 ..	12·87	12·67	..	12·66	12·49	12·31	12·65	12·50	12·34
40 ..	13·20	13·00	..	13·99	12·82	12·64	12·98	12·83	12·67

CXC (*c*)

100 lbs. cubic foot, with natural slope $1\frac{3}{4}$ to 1—$1\frac{1}{2}$ to 1.
Resultant pressure cuts base at $\frac{3}{10}$ from toe.

Batter						
1 in 12			Vertical			Height of wall
Top width			Top width			
1	2	3	1	2	3	
2·52	..	..	2·60	2·44	..	8
2·85	..	..	2·94	2·78	..	9
3·18	2·98	..	3·28	3·13	..	10
3·51	3·32	..	3·62	3·47	3·30	11
3·84	3·65	..	3·96	3·81	3·65	12
4·16	3·98	..	4·29	4·15	4·00	13
4·49	4·32	4·21	4·63	4·50	4·34	14
4·82	4·65	4·54	4·97	4·84	4·69	15
5·15	4·98	4·87	5·31	5·18	5·03	16
5·48	5·31	5·19	5·65	5·52	5·38	17
5·81	5·65	5·52	5·99	5·87	5·72	18
6·14	5·98	5·85	6·33	6·21	6·07	19
6·47	6·31	6·17	6·67	6·55	6·42	20
6·79	6·64	6·50	7·00	6·89	6·76	21
7·12	6·98	6·83	7·34	7·24	7·11	22
7·45	7·31	7·15	7·68	7·58	7·45	23
7·78	7·64	7·48	8·02	7·72	7·80	24
8·11	7·97	7·81	8·36	8·26	8·14	25
8·44	8·30	8·14	8·69	8·60	8·48	26
8·77	8·63	8·47	9·03	8·93	8·82	27
9·10	8·96	8·81	9·37	9·27	9·16	28
9·42	9·29	9·14	9·70	9·61	9·50	29
9·75	9·62	9·47	10·04	9·95	9·84	30
10·08	9·95	9·80	10·38	10·29	10·18	31
10·41	10·28	10·13	10·72	10·63	10·52	32
10·74	10·61	10·46	11·05	10·96	10·85	33
11·07	10·94	10·79	11·39	11·30	11·19	34
11·40	11·27	11·12	11·73	11·64	11·53	35
11·73	11·60	11·46	12·06	11·98	11·87	36
12·05	11·93	11·79	12·40	12·32	12·21	37
12·38	12·26	12·12	12·74	12·65	12·55	38
12·71	12·59	12·45	13·07	12·99	12·89	39
13·04	12·92	12·78	13·41	13·33	13·23	40

13. *Drainage.*—To facilitate drainage at the back of the wall, rubble stone 9 to 12 inches in size should be packed up against the back, about 2 feet in thickness. Fig. 7. Near the bottom of the wall, but at such height above the surface of the ground as will permit of free discharge of the water, drain pipes not less than 3″ in diameter or through weep holes, 6″ in width and one course of masonry in depth, should be provided. These drains or weep holes should be at every 10 to 25 feet of the length of the wall. Where weep holes are distributed throughout the face of the wall, one weeper to every four square yards of the face of wall should be of provided, the weepers being 2 or 3 inches broad and of the depth of a course masonry. The treads of the steps of the back should also have a slope of at least one inch, as shown in Fig. 6, sketch E.

14. *Counterforts.*—Retaining walls are often built with counterforts or buttresses, at short distance apart, which allow of the average section of the wall being made less than would otherwise be the case, by enlarging the base of the structure in a greater proportion than its mass. Care must be taken thoroughly to bond the masonry of the counterfort with that of the wall, or the latter may be forced forward leaving the counterfort behind.

The size of counterforts will depend on the height of the retaining wall but about one-eighth of the calculated mass of masonry may generally with advantage be thrown into this form. The distance of the counterforts form each other may range between the limits of 20 feet for high, to 10 for low walls. They need not reach to the top of the revetment, by double the thickness of the wall at top ; their length at top may be equal to the thickness of the wall, and their breadth one-fifth of their distance apart. From these dimensions the length of the counterfort at bottom may be found. Fig. 8.

Thin counterforts at frequent intervals are more satisfactory than thicker counterforts at longer intervals.

Thus in a wall 30′ high, 3′ thick at top, 6 feet thick at bottom, with counterforts 20 feet apart, the length of these counterforts is found easily, their breadth being 4 feet. For one-eighth of mass of wall equals that of counterforts, so that making the length between the counterforts 20 feet, we have

$$\frac{x+3}{2}(30-6)\times 4 = 1/8\left[\frac{6+3}{2}\times 30\times 24+\frac{x+3}{2}(30-6)\times 4\right]$$

which gives $x=6{\cdot}64$ feet.

P. W. D. HANDBOOK

BOMBAY

Volume II

SECTION IV

IRRIGATION WORKS AND STORAGE FOR HYDRO-ELECTRIC PROJECTS

1949

CHAPTER X—IRRIGATION WORKS

NOTES ON THE PREPARATION OF IRRIGATION PROJECTS

1. **Reconnaissance.**—A careful study of the topographical sheets, 1 mile to 1 inch, will give a good idea of the suitability of any valley for storage and for irrigation, but a personal inspection of the whole area is necessary before commencing extensive surveys.

2. The first step is to examine the area to be irrigated, noting soil, crops, population, possible canal location, probable difficulties in construction, and communications.

3. **Approximate figures.**—Let A be the estimated gross command in acres—

then culturable area $= 0{\cdot}8$ A acres.

possible irrigable area $= 0{\cdot}3$ A acres.

discharge required at head of canal $= \dfrac{0{\cdot}3\text{ A}}{100}$ c.ft. per Second.

total supply required per annum at head of canal. $= \dfrac{0{\cdot}3\text{ A}}{5}$ million c.ft.

From this the storage requirements can be given, and the upper part of the valley should then be examined.

4. The rough cost of the whole scheme will be from 90 A rupees for straight forward projects to 160 A rupees for difficult ones, in the Deccan area.

5. **Water-supply.**—Observations of discharge will show for how many months the tank should be relied upon for the supply. When the observations have not been made an approximate estimate of the flow must be made from rainfall records or by comparison with other catchments similarly conditioned.

6. If the usual water-supply proves insufficient the command of the canal must be curtailed accordingly.

7. The discharge of the worst year may be taken at about half the average on rivers which are known never to fail altogether, and in forecasts of revenue the probable number of bad years should be taken into account.

8. **Surveys : M.S.L. datum.**—If surveys are commenced from a B. M. with an arbitrary datum, this should be connected on to a B. M. with Mean Sea Level datum as soon as possible, and all the levels for a project should be reduced to M. S. L. datum.

9. **Surveys : tank.**—For tanks, a base line should be levelled up the valley and cross-sections taken at intervals (one or two-mile intervals are convenient for large projects). Bench marks should be fixed at the ends of the cross-sections. If the results are favourable, contours can then be run and tied on to the cross-sections and base line. The volume of a tank can be accurately obtained from contours. The formula to be used is that for a frustum of a pyramid.

10. Meanwhile the various dam sites should be thoroughly surveyed and examined. Trial pits at 1,000 feet, then at 500 feet, and at closer distances should be taken at the more favourable sites.

11. To ascertain the best site for the waste weir close contouring and trial pits up and downstream are necessary.

12. Trial pits should go down to rock, and bore holes should be driven at least 10 feet into the rock to ascertain whether it is sound or not.

13. When the F. S. L. of the tank has been more or less determined the nature of land to be submerged, assessment, and crops grown should be noted, the houses and villages below F. S. L. should be valued and population recorded. From this the probable compensation can be estimated, and the loss compared with the anticipated advantages to be gained by making the canal.

14. **Surveys : canal.**—The first operation generally is to run a rapid contour falling 8″ to 24″ per mile according to the size of the work, from the tank or proposed headworks of the canal to the limit of the command. At difficult places, *viz.*, high or steep ground, large *nalas*, etc., a few alternative lines can be roughly levelled over and sufficient information collected to enable the proper alignment to be selected fairly well on the second survey. The principal purpose of the preliminary contour is to ascertain the area likely to be commanded—a matter of vital importance. Time should not be wasted over alternative alignments until the area under command has been reported.

15. The second or proper alignment is to be set out in straight lines, neglecting minor irregularities of the ground and choosing the best lines for cuts and crossings. Sharp angles and right angles should be avoided. Cross sections are required at every mile, and more often in difficult places, and bench marks at every mile. Notes should be made of the soil and the features of the country passed through. Trial pits, on the average about 8 per mile, should be dug down to proposed canal bed, but not into rock, if met with. Trial pits are required for all masonry works.

16. While the work described above is in progress, and independent set of check levels should be run on a direct line connecting at the permanent bench marks, so as to discover, as soon as possible, any error that may have occurred.

17. The alignment is to be set out for the main canal and branches, but surveys for the distribution of water by minors and distributaries need not, as a rule, be made for the first estimate of a project.

18. **Designs and estimates : drawings.**—The drawings required are :—

No. of drawing	Description	Scale
	A.—Maps—	
1	Index map of the whole project (Indian Atlas sheet).	4 miles to 1 inch.
2	Do. tank site and its drainage area.*	1 mile to 1 inch.
3	Do. canal showing distributaries and area under command.*	Do.
4	Soil map for land commanded by the canal.*	Do.

**Note.*—These maps may be toposheets or tracings from toposheets.

No. of drawing	Description	Scale
	B.—Storage and Headworks—	
5	Village maps showing the land to be submerged by the tank.	660 ft. to 1 inch.
6	Plan and longitudinal section of dam site ..	400 ft. to 1 inch horizontal. 20 ft. to 1 inch vertical.
7	Design for masonry dam and waste weir showing details and stability diagrams.	10 ft. to 1 inch.
8,9,10	Similar plans, etc., for pick-up weir headworks.	
	C.—Canal—	
11	Village maps showing the position of the canal line.	660 ft. to 1 inch.
12	Longitudinal section of whole canal (one sheet).	4,000 ft. to 1 inch. horizontal. 20 ft. to 1 inch vertical.
13	Longitudinal section and plan of canal ..	400 ft. to 1 inch horizontal. 20 ft. to 1 inch vertical.
14	Cross-sections and ridge and *nala* sections for the canal.	Do.
15	Design for aqueducts	10 ft. to 1 inch.
16	Do. culverts	Do.
17	Do. super-passages	Do.
18	Do. regulators and escapes	Do.
19	Do. road bridges	Do.

19. **Estimates : dam and weir.**—The dam, and pick-up weir, if any, must be carefully estimated in detail. The foundation should be estimated from 5 to 10 feet below sound rock level (according to the size and importance of the work) to allow for faults in the rock. The nearest 6″ in height is quite close enough for estimating, and decimals should be omitted in the quantity column. Provision should be made for construction of kilns, store and office sheds, work-roads, testing machines and sanitary arrangements.

20. The dam should preferably be of masonry. If, however, this is impossible or prohibitive in cost, and if an earthen dam (of limited height) is designed, the puddle or concrete trench should go a foot or two into rock, and the whole seat of the dam should be founded on sound material : salty soil (*kalar*), teacherous earth (*shadu*) and all vegetable growth should be carefully removed and provision made for drains under the dam.

21. **Estimates : canal.**—In estimating for the canal excavation and banks for any large project, the depths and heights can be taken to the nearest 6″ and distances 200 feet to 400 feet apart. For final alignment before

struction and for small projects the levels must be 100 feet apart and depths taken more accurately, but decimal places should be omitted in the quantity column always, except in the case of very high-rated work.

22. A separate estimate is required for all large masonry works and type estimates for the smaller ones.

23. A lump sum of from 1 rupee to 4 rupees per acre of gross command, according to length and nature of ground, will cover the cost of minors and distributaries.

24. **Soil map.**—The classification of soil should be shown on the village maps for all the land likely to be brought under command. The information is to be extracted from the Revenue Survey Records showing how the land has been assessed. After the village maps have been coloured the results should be transferred to the toposheets by reduction. The classification adopted for Protective Irrigation Projects is :—

Classification of Soil

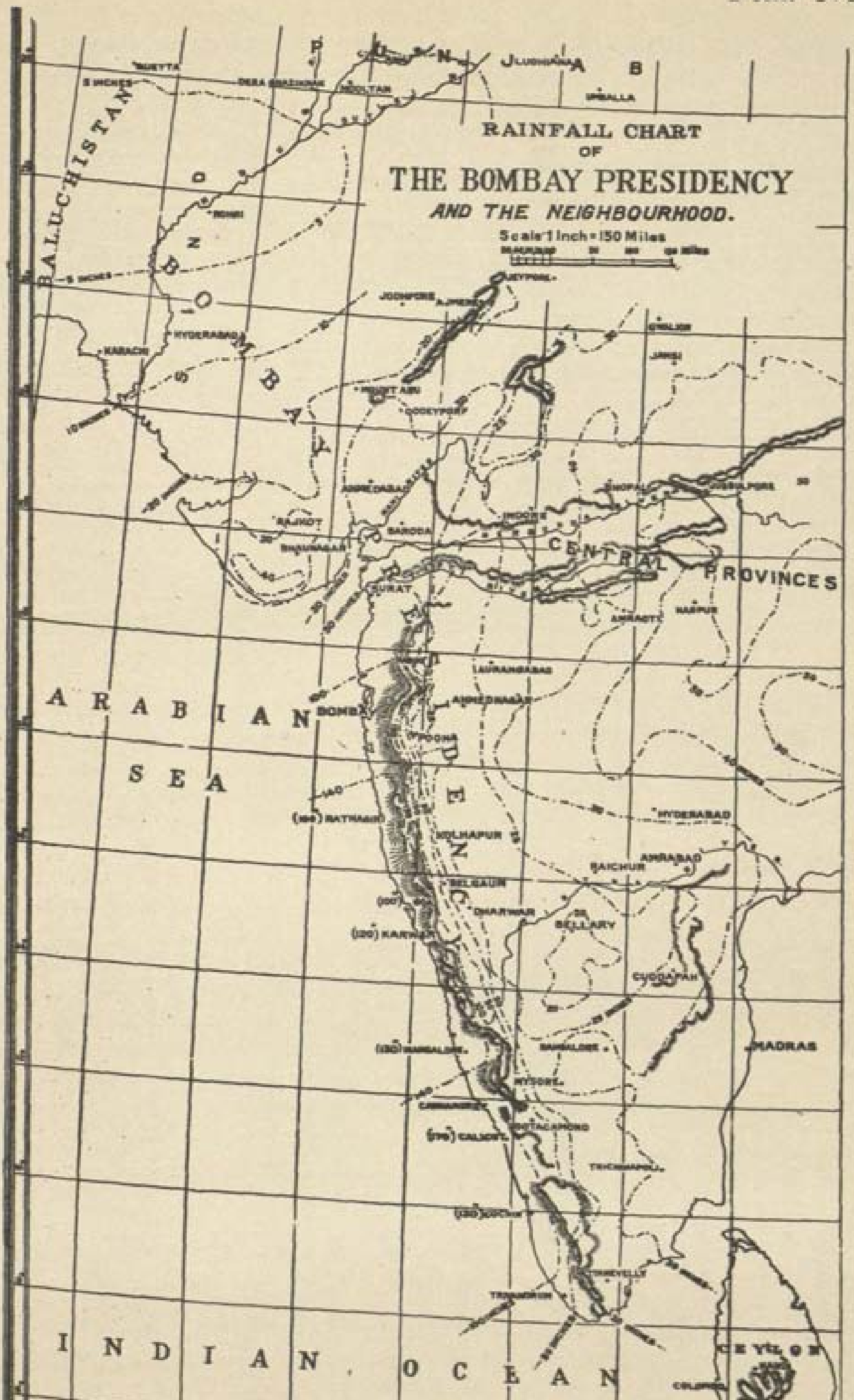
Anna valuation per acre	Colour	Description of soil
A—Over 10 as to 16 as ..	Dark sepia ..	The best fertile soil, some of which may possibly be unsuitable for heavy irrigation.
B—Over 5 as to 10 as ..	Light sepia ..	Good soil, probably the most suitable for irrigation.
C—Up to 5 as	Burnt sienna ..	Light soil, which will be improved.
D—*Nil*	Yellow ochre ..	Barren soil, uncultivable waste or Forest Reserve.

Small areas outlined in red show the portions called *kharab* (bad) in village numbers.

25. **Sub-soil water.**—It is instructive to record the sub-soil water level before and also after the construction of a project. Wells should be selected at distances of about ½ mile, 1 mile, 2 miles and 4 miles from the canal and noted on a register. When a project has been sanctioned for construction, the normal water level in these wells should be recorded once in each month in the year.

26. **Rainfall.**—The records of rainfall over the whole valley and the country under command should be reported. New rain-gauge stations should be set up, if necessary, especially in the catchment area of the proposed tank.

27. **Measuring the discharge of the river.**—The discharge of the river should be measured throughout the year at the sites selected for the storage works and for the headworks of the canal. The rainfall returns cannot be relied upon for the calculation of even approximate discharges for the catchment area but they are useful for comparison with older and long established rain-gauges in the neighbourhood and from them determining whether the year is one of good or bad supply. For the actual supply of water the discharge of the river must be measured carefully.


RAINFALL CHART
OF
THE BOMBAY PRESIDENCY
AND THE NEIGHBOURHOOD.
Scale 1 Inch = 150 Miles
BALUCHISTAN
BOMBAY
PRESIDENCY
CENTRAL PROVINCES
ARABIAN
SEA
INDIAN OCEAN
CEYLON
HYDERABAD
KARACHI
MOUNT ABU
AHMEDABAD
RAJKOT
BARODA
INDORE
SURAT
AURANGABAD
AHMEDNAGAR
BOMBAY
POONA
(160) RATNAGIRI
KOLHAPUR
BELGAUM
DHARWAR
(120) KARWAR
RAICHUR
BELLARY
CUDDAPAH
MADRAS
(130) MANGALORE
BANGALORE
MYSORE
(170) CALICUT
TRICHINOPOLY
TINNEVELLY
NAGPUR
COLOMBO

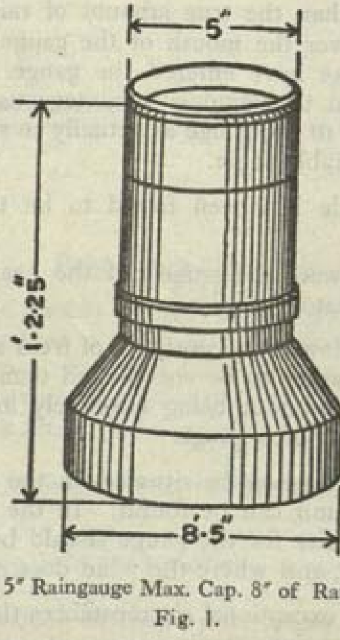
28. **Miscellaneous information.**—The population of the valley, the nature of land assessment, the existing system of cultivation, the liability to famine, the existing and proposed road and railway lines, the markets for sale of produce, the probable results to be expected from the introduction of irrigation and the liability of the soil to water logging or otherwise should be reported. The labour and material available for the construction of the work should be very carefully considered, and the rates for the work, and the probable time for construction, estimated accordingly.

29. **Report.**—The instructions contained in the Public Works Code should be followed and full information given. As soon as sufficiently definite figures are available a short description of the project should be sent to the Revenue and Agricultural authorities whose opinion should be obtained for embodyment in the report. The financial forecast of revenue must be approved and signed by the Collector and Commissioner before being submitted to Government.

"A NOTE ON RAINGAUGES"

Pattern of raingauge

1. In cases of doubt as to the desirability of starting new gauges and changing the sites of old ones the Director of Observatories will be glad to advise controlling officers.

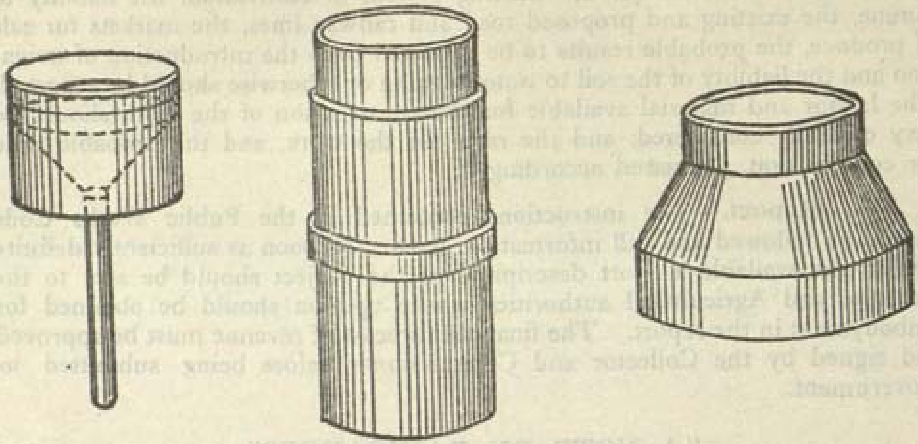


5" Raingauge Max. Cap. 8" of Rain.

Fig. 1.

2. The Government of India regard it as desirable that Symons raingauge should be the only gauge used in India. This pattern of gauge is shown in Fig 1. The gauge is built up of three parts: (*a*) the base, (*b*) the body and (*c*) the funnel. These are showing in Fig. 2. Inside the body is placed a glass bottle into which the rain passes through the tube part of the funnel.

RAINGAUGE



Top part of Funnel — Middle part or Body — Bottom part or Base

Fig. 2.

Exposure of Raingauge

3. In recent years it has been found that a raingauge exposed on a perfectly open space registers less than the true amount of rain. This arises because the wind forms as eddy over the mouth of the gauge and carries away small drops that would otherwise have entered the gauge. Accordingly a certain amount of protection from the wind is advantageous; at the same time no obstacle should be so near to the gauge as actually to shield it from rain which may be falling at a considerable angle.

4. The following rule has been found to be the most satisfactory in practice :—

"The distance between the gauge and the nearest object should be at least twice the height of that object."

5. If this rule is followed the presence of trees and bushes in the neighbourhood of a gauge is rather to be encouraged than otherwise; but as trees may be allowed to grow without being effectively lopped no tree should be planted within thirty yards of a gauge.

6. The gauge should never be situated on the side or top of a hill if a suitable site on level ground can be found. In the hills where it is difficult to find a level space the site for the gauge should be chosen where it is best shielded from high winds, and where the wind does not cause eddies.

7. Only under very exceptional circumstances the gauge be ex-posed on a roof.

8. If it is impossible to choose a site in conformity with the above stipulations a detailed report should be made to the local officer controlling the rainfall registration of the province, and his sanction obtained for erecting the gauge in the abnormal site proposed.

Erection of the gauge

9. A masonry or concrete foundation for the gauge should be provided, the best form being a cube of 2 feet side sunk into the ground so that its top is just above the general level of the ground. Into this foundation the base of the gauge (a, Fig. 2) is firmly cemented so that the top of the complete gauge is exactly one foot above the ground level (*see* Fig. 3). Great care must be taken when setting the gauge to ensure that the mouth is perfectly level.

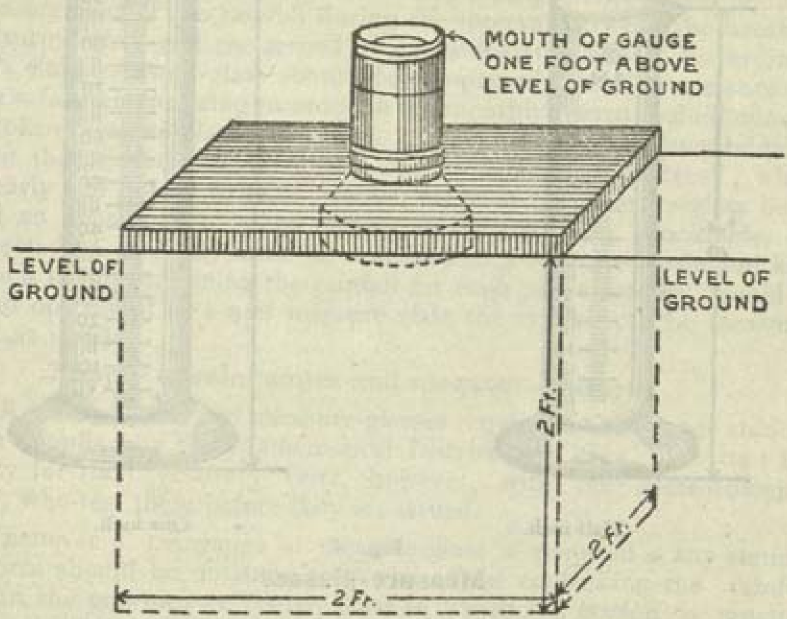


Fig. 3.

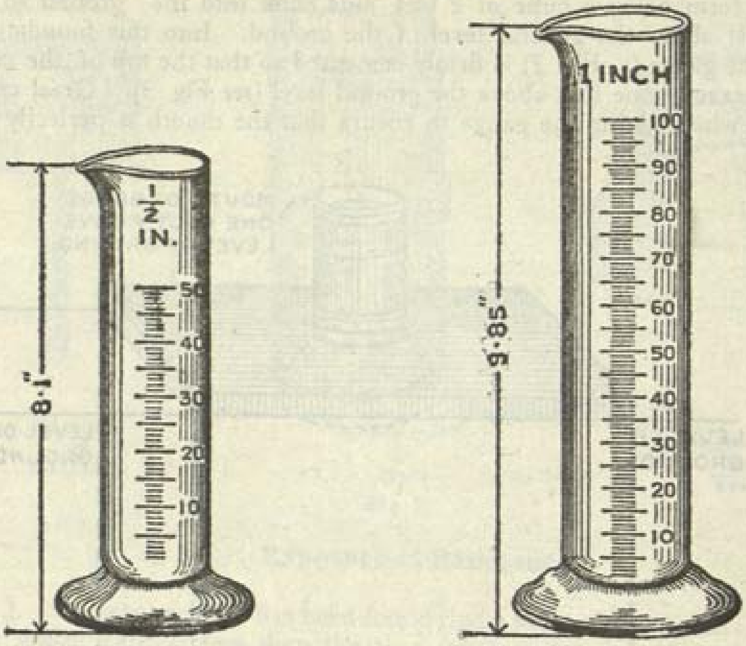
Protection of gauge

10. It is often desirable to protect the gauge from being damaged by cattle, and for this purpose a fence may be erected around it. This can be made of any suitable material but it must be of such a size that the top of the fence is not higher above the mouth of the gauge than half its distance from the gauge (*see* paragraph 4 above).

Measurement of the Rainfall

11. To measure the rainfall the water in the receiver is to be poured into the glass measuring cylinder provided. Each of the graduations on this cylinder represents one-hundredth of an inch, and the observer must count the number of the divisions covered by the water. In order to facilitate this numbers are engraved on the glass at 10, 20, 30, 40, etc., divisions (*vide* Fig. 4). If the water comes up to the third division above the line marked 20 the rainfall is twenty-three hundredths of an inch. In writing up the amount recorded the observer has simply to put the number of inches in front of a decimal point, and the number of hundredths after it. Thus if he has measured one

inch and thirteen hundred he writes 1·13. It should be very carefully noted that if the number of hundredths is less than ten, say one, two, three or four, then rainfall must not be written, ·1, ·2, ·3 or ·4, but ·01, ·02, ·03 or ·04.



Half inch. One inch.

Fig. 4.

Measure-glasses

The observer will make no mistake if he always writes two figures after the decimal point, for he will then realise the difference between ·30 and ·03, the first being thirty hundredths and the second three hundredths.

12. If there is more water in the receiver than the measure-glass will hold, the glass should be carefully filled to the top graduation mark, and then the water poured away and the glass refilled. The total rainfall is the sum of all the measurements. Thus, if the measure-glass holds ·50 inch of rain, and it is filled up to the 50 mark three times and finally to the 23 mark, the quantity of rain is ·50+·50+·50+·23, or 1·73 inches.

13. The rain water in the gauge should be measured every day at 8 a.m., and the raingauge shou ld be examined every day at that hour even when in the observer's opinion no rain has fallen. During heavy rains it must be measured three or four times in the day, lest the receiver fill and overflow; but the last measurement should be taken at 8 a.m., and the sum total of all the measurements during the previous 24 hours entered as the rainfall of the day.

14. The receiving bottle, as a rule, does not hold more than three or four inches of rain. During heavy falls this quantity is frequently exceeded. If, owing to neglect of the above directions, the receiving bottle has overflowed the outer cylinder must be taken up, and its contents measured and added to that of the receiver.

Breakage of the measure-glass

15. It is desirable that every rain-gauge station should be supplied by the local authority with an extra measure-glass. When the measure-glass in regular use is broken the spare measure-glass should be at once brought into use, and another measure-glass should be at the same time indented for in the manner prescribed in paragraph 18 below.

16. If it should happen that the measure-glass at any station not provided with a spare one should be broken, the following arrangements should be made for the measurement of the rainfall during the interval between the breakage of the measuring-glass and the arrival of a new measure-glass. An ordinary apothecary's fluid measure-glass should be temporarily used to measure the rainfall (the measurement being recorded in the monthly return in fluid ounces) until the broken measure-glass is replaced. In such a case care must be taken to strike out the printed work "inches", and to substitute "ounces", which must be clearly and boldly written. In the event of the measure-glass being broken and an apothecary's ounce measure-glass not being procurable, the rainfall collected on each day must be stored up in a separate bottle and kept corked. Each bottle containing the rainfall for each particular day should be labelled, and on receipt of a new measure-glass the rainfall can be measured and entered as usual.

Supply of raingauges and measure-glasses

17. All raingauges and measure-glasses required at raingauge stations in India are supplied by the Mathematical Instrument Office, Calcutta; the responsibility for their accuracy rests, however, with the Meteorological Department, who test them before they are issued.

18. Whenever a raingauge or measure-glass is required at any station, an indent form should be obtained from the officer controlling the rainfall registration in the province or Native State in which the station is situated and after being filled in should be returned to him for countersignature. The indent will be forwarded by the controlling officer to the Mathematical Instrument Office who will on its receipt send the rain-gauge or measuringglass direct to the station requiring it, and will recover the cost from the local authority signing the indent. In the case of instruments whose cost is met by the Meteorological Department, the procedure will be somewhat different; the indents should, after signature by the controlling officer, be sent to the Meteorologist, Calcutta, who will forward them to the Mathematical Instrument Office for compliance.*

19. In the case of breakage of the glass bottle within the gauge, another bottle should be obtained locally, either from the bazaar or nearest dispensary. The exact shape of the bottle is not important, so long as it fits within the gauge and will hold about 5 inches of rain.

Inspection of raingauges

20. It is of great importance that raingauges should be inspected as the observers often allow large changes to take place in the exposure of a gauge without being aware that action is necessary.

*NOTE.—The procedure described in this paragraph applied only to gauges used in connection with the rainfall organisation of the Government of India. Gauges required for departmental purposes by Military, Public Works, Forest or other officers not controlled by the officers of the Government of India, may be obtained from the Mathematical Instrument Office in the same way as other scientific instruments required for the public service.

21. The object of the inspecting officer should be to determine—

(*a*) Whether the instrument is suitably placed and is in good order ;

(*b*) Whether the observer can make the rainfall measurement correctly and enter them properly in the rainfall records ;

(*c*) Whether the rainfall records are properly and neatly kept up and are in good order , and

(*d*) Whether the observer makes his measurements at 8 a.m.

22. In order to determine whether the instrument is suitably placed and in thoroughly good order he should ascertain—

(1) Whether there are any trees growing up or houses being built which are likely to affect the exposure.

(2) Whether the gauge is firmly fixed, so that it is not likely to be blown over.

(3) Whether the rim, when pressed home, is level. As all gauges are made level when first erected it will not be necessary for the inspector to use a spirit level. He will only need to see that no obvious displacement of the gauge has taken place.

(4) Whether the rim or mouth of the funnel is circular. All gauges are accurately measured before being issued. And unless the rim is obviously damaged or out of shape, it is not necessary to measure the diameters.

23. In order to ascertain whether the observer can measure the rainfall accurately and make the entries correctly, the glass receiver should be partially filled two or three times with different quantities of water, and the observer required to measure them and write down the entries. If he can do this correctly, nothing further is necessary ; if not, the inspecting officer should teach him fully.

24. The inspector should also see that the rainfall book is in good condition and the entries in it carefully and neatly made. He should also verify that the rainfall observer knows how to make the entries in the various rainfall returns for local or Imperial authorities.

NOTE ON RIVER GAUGING

1. **Purpose.**—The information to be gained from river gauging is —

(*a*) the whole discharge of the river for certain periods or for the whole year ;

(*b*) the volume of the daily discharge for any period , and

(*c*) the maximum flood discharge to be allowed for.

Information under (*a*) and (*b*) is wanted in connection with canal supply and storage in reservoirs, while that under (*c*) enables suitable provision to be made for waste water overflow at the reservoir or at the headworks.

2. Period of gauging for canal supply.—When a canal is to be supplied direct from a river, without any storage work, it is only necessary to gauge the stream when its flow is likely to fall below the supply required.

The monsoon discharge in Deccan ghat rivers is generally vastly in excess of the cannal requirements in July, August and September ano somethimes longer, but it is important to note the dates between which this abundant supply may be counted on, and gauging should commence as soon as the water level goes below a fixed point and should continue as long as there is a useful discharge.

The highest flood level should be recorded.

3. Period of gauging for tank supply.—When water is to be stored, the gauging should continue throughout the monsoon and should only be stopped when the discharge becomes insignificant. In the ghat area of the Deccan this period generally extends from 1st June till end of October. Sometimes the river rises earlier, and after the monsoon a good flow may often be maintained till January or February.

In the eastern districts the flow is different. The heaviest floods are often in October, and the hot-weather storms may add a good supply to a small tank, while for the remaining months in the year the *nala* or stream may be practically dry.

4. Methods of discharge observations.—The methods of observing discharges in channels in good order, and in rivers with irregular channels, are markedly different. Velocities in channels in good order are normally observed with discharge rods. Whereas, in rivers the velocities are observed with current meters if the observations are of great importance, or by surface flots, or from slope observations, if the cost of metering cannot be justified.

5. Rivers with irregular channels : Large discharges.—Where current meter observations are possible they should be taken. Otherwise velocities may be taken—

(*i*) by surface float observations ;

(*ii*) by slope observations.

Small discharges.—When the flow of a river falls to such an extent that there is no clearly defined channel, a channel with straight sides 50 feet to 150 feet long should be prepared, and the whole of the river flow led through it ; the discharge can then be measured with a central surface flota.

Very small discharges.—For still smaller discharge a notch across the rivers can be used. A portable standard standing wave flume—see Bombay P. W. D. Technical Paper No. 15—is, however, much better because less head is required and so leakage is reduced.

6. Rivers with regular channels.—Price's current meters give reliable results for all velocities above 1 foot per second.

In channels less than 9 feet deep, "Lacey-Dapuri" adjustable discharge rods (obtainable from the Executive Mechanical Engineers and Works Manager, Government Central Workshops, Dapuri, P. O. Kirkee), submerged to ·94 depth, give accurate results.

Standing wave flumes, properly designed and with a low velocity of approch, give discharges of very high accuracy.

Where the effect of velocity of approach (MV /2) exceeds 1*p* per cent of upstream depth over sill, the effect of velocity of approach (the velocity being calculated on the section of channel above the sill and equal in width to the flume width) must be allowed for. The approximate effect may be taken as $1\frac{1}{2}$ times $V^2/2g$.

When only a surface float is available, a surface central velocity gives useful results for a normal channel.

Slope observations are absolutely essential in connection with the checking of Lacey's or of any other fundamental formula. Slopes should be observed with extreme accuracy.

In a large river, the upper gauge should be fixed two river widths above the discharge section, and the lower gauge one river width below the discharge section.

In smaller channels of uniform section, the gauges must necessarily be further apart, and provided the section is uniform, this is not objectionable; but where the channel is not highly uniform, it is advisable to determine energy slopes, by observing water levels with a very high degree of accuracy by means of hook gauges in stilling chambers, making an addition for velocity head (Energy head $\frac{V^2}{2g}+d$). The two gauges should have the same datum and should be read to 1/100th foot.

The position of the gauge should be carefully marked upon a tracing of the village map (corrected if necessary), and a permanent bench mark should be built in the vicinity, the value of which should be marked on the plan. The drawings required are—

(*a*) a small scale plan and longitudinal section of the site; on the latter the average bed slope should be drawn;

(*b*) 5 cross sections of the river, horizontal scale 100 feet to 1 inch, vertical scale 10 feet to 1 inch, showing the area for each ½ foot above the bed level.

7. General instructions for discharge observations.—The name of channel, site, observer, the date, gauge reading, length of run, state of wind (direction and strength) and a sketch of the cross section should be noted.

In taking the cross sections of the channel, all distances should be measured from the left bank, unless otherwise specified, and the soundings should be equidistant.

In the case of channels with a clearly defined bed portion, the side slope portions should be separated from the central bed portion.

Soundings should be taken on the velocity observation lines (*i.e.*, the middle of each compartment), and between compartments. The mean depth on the line of the float run for the 3 cross sections should be worked out. The length of run may vary from 25 feet to 200 feet according to the size of the stream.

In the compartment method, which was followed until recently, the side slopes and bed were divided into compartments which were marked by streamers and the velocity was observed at the middle of each compartment using floats or current meters. The area of each compartment was then multiplied by the velocity at the middle of each compartment—which gave the discharge of each compartment—and these added together gave the total discharge.

Where a high degree of accuracy is required as in rating flumes or collecting data in connection with the checking of divergence from regime, the discharge should be calculated for each vertical on which velocities are observed and the total discharge worked out either by Simpson's rule or by measuring the area contained by a natural curve drawn through the ordinates indicating the discharges observed at various points. Simpson's rule is—

$$Q=B/3\,(q_0+q_n+4\,(q_1+q_3+\ldots\ldots+q_{n-1})+2\,(q_2+q_4+\ldots\ldots+q_{n-2})$$

where B=width of each compartment; q_0; q_1; q_2 being v_0d_0; v_1d_1; v_2d_2 r etc., and q_0 and q_n being the values at the extreme ends.

If Simpson's rule is used and the bed and side slopes are not markedly defined ; then it is convenient to divide the whole width into an odd number of equal compartments and to observe the velocity and calculate the discharge of one foot width at the middle of each such compartment.

When the side slope compartments are of a different width to the central compartment, the side slope and central compartment discharges must be worked out separately and added together—the central portion by Simpson's rule and the side slope compartment by the old compartment method—if there are less than 3 side compartments ; but by Simpson's rule if there are 3 compartments or more—as is usual in the case of rivers—

The suitable number of velocity points in the bed portion is —

Discharge			Discharge points
30	100 cusecs	... ...	3
100	500 ,,	... ...	5
500	2,000 ,,	... ...	7
2,000	10,000 ,,	... ...	9

In cases where the verticals of a cross section are not equidistant, the discharges observed on each vertical should be plotted carefully on squared papers, and the discharge curve can be drawn by eye and the contained area measured with a planimeter.

8. **Discharges observed with surface floats.**—Wooden surface floats 3″ dia. and ¾″ deep and painted orange colour—any in general be used ; but an orange makes the best surface float ; because it is affected little by wind. Full notes about direction and strength of wind should be recorded.

If a channel is symmetrical, with a normal section, the mean channel velocity can be obtained from the surface velocity observed in mid-stream with considerable accuracy by using the co-efficient shown in the table below. The velocity of the wind should not exceed about 6 feet per second.

TABLE CXCI

Table showing values of C in $V = C \times V$.

S. C. (Surface Velocity at Centre)

Value of R. in feet	Values of No—Lacey's omnibus rugosity co-efficient								
	0·016	0·018	0·020	0·0225	0·025	0·030	0·035	0·040	0·050
0·50	0·74	0·71	0·69	0·67	0·64	0·60	0·56	0·53	0·48
0·75	0·75	0·73	0·71	0·69	0·66	0·62	0·58	0·55	0·50
1·00	0·77	0·75	0·73	0·70	0·68	0·64	0·60	0·57	0·52
1·50	0·78	0·76	0·74	0·72	0·70	0·66	0·62	0·59	0·54
2·0	0·80	0·78	0·76	0·74	0·72	0·68	0·64	0·61	0·56
3·0	0·81	0·79	0·78	0·76	0·74	0·70	0·66	0·63	0·58
4·0	0·82	0·80	0·79	0·77	0·75	0·71	0·68	0·65	0·60
5·0	0·83	0·81	0·80	0·78	0·76	0·72	0·69	0·66	0·61
7·0	0·84	0·82	0·80	0·79	0·77	0·73	0·70	0·67	0·62
10·0	0·85	0·84	0·82	0·81	0·79	0·76	0·73	0·70	0·65
15·0	0·87	0·85	0·84	0·82	0·81	0·78	0·75	0·72	0·67
20·0	0·88	0·86	0·85	0·83	0·82	0·79	0·76	0·74	0·69
30·0	0·89	0·87	0·86	0·84	0·83	0·81	0·78	0·76	0·71
50·0	0·90	0·88	0·88	0·86	0·85	0·82	0·80	0·78	0·74
100·0	0·91	0·90	0·89	0·88	0·87	0·85	0·83	0·81	0·77

Note.—Values of C in the above table are calculated as under :—

Bazin's formula correlating V and $V_{s.c.}$—$V_{s.c.}$ being surface central velocity in feet per second is $V = V_{s.c.} - 25{\cdot}5\sqrt{R.\,S.}$

$$C = \frac{V}{V_{s.c.}} = \frac{V}{V + 25{\cdot}5\sqrt{R.\,S.}}$$

Lacey's formula for V is

$$V = \left\{ \frac{1{\cdot}346}{N_o} \; R^{\frac{1}{4}} \right\} \sqrt{R.\,S.}$$

Combining the two formulae, we get

$$C = \frac{V}{V + \dfrac{25{\cdot}5\;V\;N_o}{1{\cdot}346\;R}}$$

$$\frac{1}{1 + \dfrac{18{\cdot}98\;N_o}{R^{\frac{1}{4}}}}$$

If the channel is unsymmetrical or abnormal, the central velocity method is not suitable and surface floats should be timed at various points across the section.

The mean velocity on a vertical relative to the surface velocity is shown in Table below.

Table : Ratios of mean to surface velocities on a vertical (not near the sides of a channel)—based on Bellasis—

Depth on verticals (feet)	Values of N_o				
	0·016	0·020	0·025	0·030	
0·5	0·87	0·84	0·82	0·78	N_o will depend on roughness of bed material.
1·0	0·87	0·84	0·82	0·78	
5·0	0·90	0·90	0·89	0·85	
10·0	0·91	0·91	0·90	0·86	
20·0	0·91	0·91	0·91	0·88	

The discharges on each vertical (=V×d) should be plotted and the area contained worked out.

9. **Slope method of measuring discharges.**—In the past, Kutter's formula was used for determining discharge by assuming a value of N ; except where the surface slope is very flat, Manning's formula—

$V = \frac{1{\cdot}486}{N}, R^{\frac{2}{3}} S^{\frac{1}{2}}$—is equally good and much simpler to use but Lacey's formula $V = \frac{1{\cdot}346}{N_o} R^{\frac{3}{4}} S^{\frac{1}{2}}$ is better than either.

The Table below shows the values of N_o for various materials and corresponding values of N for various values of R.

Table showing values of N_o for various materials and corresponding value of N for various value of R.

Materials of Channel	N_o	N			
		R=1	4	10	25
Cement Plaster	0·010	0·011	0·010	0·009	..
Ashlar and good brick-work.. ..	0·013	0·014	0·013	0·012	..
Rough brick-work or good stone-work.	0·015	0·0165	0·015	0·0135	..
Stone-work in poor condition ..	0·018	0·020	0·018	0·0165	0·015
Earthen channel in excellent order ..	0·020	0·022	0·020	0·018	0·017
Do. do. moderate order	0·0225	0·025	0·022	0·0205	0·019
Do. do. poor order ..	0·025	0·0275	0·0245	0·023	0·021
Do. do. bad order ..	0·0275	0·030	0·027	0·025	0·023
Do. do. very bad order ..	0·030	0·033	0·0295	0·0275	0·0255

[*Note.*—N_o—Lacey's omnibus co-efficient of rugosity in his formula $N_o = \frac{1·346}{V} R^{\frac{3}{4}} S^{\frac{1}{2}}$ is a constant for any particular rugosity. N in Kutter's and Manning's formulas varies inversely as $R^{1/12}$. The relationship between Manning's N in $N = \frac{1·486}{V} R^{\frac{2}{3}} S^{\frac{1}{2}}$ and N_o is $\frac{N}{N_o} = 1·104 R^{1/12}$.

In all the above methods of calculating the discharge it is necessary to know N or N_o; but where an erodible channel is in initial regime—i.e., has been flowing steadily for some time—the velocity can be determined approximately from Lacey's formula.

$$V = 4\sqrt[3]{2 g R^2 S}$$

even though N_o is unknown.

10. **Discharges observed with velocity rods.**—Where possible, stout ropes should be fixed across the channel at the upper, middle and lower section. On these, streamers should be fixed, showing the middle end limits of each compartment (white and red respectively).

The rod floats should pass under the middle streamers. If the float deviates more than 1/5th of the width of the compartment to either side of the line of streamers, the observations should be rejected. The mean timing of 3 or more rods should be worked out for each vertical.

'Lacey—Dapuri' rods which can be adjusted to 0·05 feet lengths should be used.

In large canals, the rods may be 6″ clear of the bottom. Accurate discharges will be obtained when the length of submerged rod is 0·99 times the depth of water. For other lengths, the following corrections should be made :—

Deccan formula for Q=270 to 400 cs. on Nira Left Bank Canal

$$C = V/v_r = 1{\cdot}045 - 0{\cdot}232\sqrt{1-\frac{L}{D}}$$

Where V is the true mean velocity on a vertical

V_r is the rod velocity

L=Length of rod submerged

D=Depth of water along the vertical

Sind formula for Q=600 to 1,100 cusecs

$$C = 1{\cdot}019 - 0{\cdot}206\sqrt{1-\frac{L}{D}}$$

Francis—*vide* "Hydraulics with working Tables" by Bellasis—carried out experiments in masonry flumes and he got

$$C = 1{\cdot}012 - 0{\cdot}116\sqrt{1-\frac{L}{D}}$$

In the U. P. with masonry flumes

$$C = 1{\cdot}012 - 0{\cdot}095\sqrt{1-\frac{L}{D}}$$

11. **Discharges observed with current meter.**—The operations for soundings and the spacings of compartments are the same as in the case of discharges with rods ; except that soundings need only be taken on one cross section.

The mean velocity on a vertical is normally measured at 0·6 x the depth of water. The current meter is fixed to a rod at a depth from the surface equal to 0·6 x the depth at the centre of each compartment and total revolutions in say 60 or 100 seconds observed. 2 or 3 observations should be made for each compartment and the mean revolutions per second worked out from $\frac{\text{revolutions.}}{\text{seconds}}$

This when multiplied by the factor giver for each instrument, will give the required velocity. The discharge of each vertical=q=V×d should be worked out and the total discharge calculated—as already explained.

12. **Calculations.**—The discharge is to be calculated by taking the product of the average of the surface velocities (the readings near the bank count only as half) and the average of the sections (the end sections counting as half).

The values of the coefficients to reduce surface to mean velocity, in the case of channels with bed and sides of earth, are as under :—

TABLE CXCII

Hydraulic mean depth	Value of coefficient
1·0	0·65
2·0	0·71
3·0	0·73
4·0	0·75
5·0	0·76
6·0	0·77
9·0	0·78
12·0	0·79
20·0	0·80
70·0	0·81
Inf."	0·81

13. As a check the discharges should be calculated also by the formula $D=a\,v=a\,c\sqrt{r\,s}$, using Kutter's coefficients. The observed surface slope is liable to be a little irregular, and will be different in a rising and falling river. But when many readings have been obtained the discharge formula will be found to afford a good check on the observations. As soon as it can be done, a standard discharge table or curve should be prepared which will be valid as long as the river section remains unchanged.

14. **Changes in river.**—The river sections should be levelled over every year to see whether any appreciable change has taken place. This is particularly necessary in the case of rivers with sandy bed.

CANALS

(MAINLY APPLICABLE TO CANALS IN DECCAN)

Construction

1. **Excavation.**—The excavation shall be carried out according to design, with accurately graded bedfall and sides properly sloped.

The following slopes are those usually adopted in the Deccan :—

In soil	1½ to 1
In soft *muram*	1 to 1
In hard *muram*	½ to 1
In rock	¼ to 1 to vertical.

2. **Method of working.**—The excavation shall be done by first cutting a centre trench with vertical sides and then trimming the slopes. In cuttings in hard rock smooth sides cannot be obtained, and it must suffice that the canal is excavated to the full section and depth.

In enlarging channels existing side slopes shall be maintained.

3. **Spoil banks.**—The excavated material, if not required for embankment, should be thrown up in spoil banks, in 12-inch layers, with neatly made slopes and top, a suitable berm being left between the toe of the bank and the edge of excavation. Wherever a side embankment is required to retain water, its limits should be lined out before starting the excavation, so that the spoil may be properly disposed of.

4. **Bed stones.**—Bed stones to be placed in the centre of the canal at every furlong. Such stones shall be at least $6'' \times 6'' \times 12$ inches and shall be firmly bedded, tail downwards, with the top exactly level with the "formation" level of the canal.

5. **Furlong stones.**—Furlong stones shall be fixed at every furlong near the outer edge of the inspection path. Such stones shall be at least $6'' \times 6'' \times 18$ inches and shall be dressed true on top and sides for at least 6 inches. The stone shall bear the number of the mile on the top, and the furlong number on one side, the figures being neatly cut in the stone and painted black. The stone shall be whitewashed. Where necessary the stone shall be embedded in a small block of rubble masonry or concrete to prevent it being moved.

6. **Embankments.**—Where the banks have to retain water, they shall be formed with a core of sound red or brown earth, or a suitable mixture of black soil and *muram* or sand, with a covering, if available, of *muram*. The hearting should extend to 2 feet above F.S.L. in banks of more than 8 feet height, and should be 3 feet wide at top, with side batter of at least 1 in 4 (if sufficient earth be available the batter should be 1 to 1). The banks will be from 2 to 4 feet above F.S.L., and 2 to 4 feet wide at top, according to the size of the canal, and having slopes generally of $1\frac{1}{2}$ to 1, but in canals with more than 6 feet of water an outer slope of 2 to 1 is rcommended.

7. **Construction of bank.**—Before commencing the embankment the site should be cleared of stones and vegetation. If the soil in which the bank is to be placed is very porous, a trench should be dug to below "formation" level or into sound ground, and filled with a hearting of good soil carefully rammed ; the width of this hearting to be equal to the depth of water in the canal but not more than 4 feet. The bank will be raised in 6-inch layers, the soil being slightly moistened, if necessary, and thoroughly consolidated by ramming or rolling.

8. **Berms.**—A berm of from 2 to 5 feet in width (depending on the size of the canal) shall be allowed between the toe of the canal bank and the edge of excavation, but where the canal is wholly in bank this will be omitted.

9. **Borrow pits.**—As far as possible the material from the excavation will be used for the banks. If insufficient, land should be taken up to provide borrow pits for the construction and repair of banks. This is particularly of importance where the embankment is high, to enable breaches to be rapidly dealt with.

10. **Inspection path.**—An inspection or riding path should be prepared and kept clear on the top of one bank of the canal, with suitable inclines at intervals for approaches from the land side.

11. **Pitching.**—Pitching is sometimes required to protect embankments from scour, or to bring the banks up to a masonry work with a steeper slope. A depth of from 6 to 9 inches is generally sufficient, the stones being laid with the broad end on a bedding of *muram* or chips against the bank. When completed the pitching should be packed with chips and *muram*. The bed of the canal can be pitched or paved with flat stones if required.

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12. **Masonry.**—The masonry works are to be carried out according to design with sound materials. The foundations shall be on rock or as may be approved by the Executive Engineer. Masonry shall in all cases be similar in construction to the several classes of masonry already specified in Chapter III. The greatest care is necessary that all joints shall be completely filled with mortar so as to prevent leakage.

13. **Wing walls.**—Wing walls should be designed with curved or straight return walls of full height, sufficiently long to bring the embankment up to them without excessive reduction in section. They will be provided with "staunching forks" to make a watertight junction with the bank.

Maintenance

14. **Removal of obstructions.**—The waterway of the canal shall be kept free from all obstructions. Any obstructions to the flow of water, such as the branch of a tree, a bunch of reeds, etc., causes an accumulation of silt. Any such obstruction occurring should be removed at once.

15. **Silt clearance.**—The clearance of silt which may be deposited in the canal should be taken up in systematic way, such clearance being carried out in long lengths.

16. **Inlets and escape.**—If storm-water is admitted to the canal at any place, the canal immediately above and below the inlet should be inspected after storms, and any silt or sand that may have been brought down should be cleared away at the earliest possible moment. A bank of loose stone thrown across the inlet will, while allowing water to pass through it, prevent the admission of a considerable quantity of silt, and such a bank may be used with advantage when a temporary ponding up of the water is not objected to. Escapes should be kept clear.

17. **Erosion.**—A watch should be kept on concave banks which, if soft, are frequently eroded. The erosion to be stopped, if excessive, by pitching. Rain furrows in deep cuts with soft sides to be filled in with flat stone.

18. **Inspection paths.**—Inspection paths to be kept clear of brushwood overhanging branches, etc., to be neatly *muramed* and to have a slight slope, if the ground permits, away from the canal, so as to prevent the scour of the inner slopes of cutting or bank.

19. **Trees, bushes, etc.**—No trees shall be allowed to grow on canal embankments nor within 20 feet of their toe. Small bushes and grass are, however, useful in protecting the embankment from damage.

20. **Aloe fence.**—In order to prevent trespass by cattle and sheep as much as possible, the aloe (*ghayal*) fence along the canal should be frequently replanted the gaps being filled with thorns to protect the young plants.

21. **Repair of banks.**—All banks damaged by cattle or rain or which are below their proper height should be repaired as soon as possible, *muram* being used in preference to earth for the purpose, the banks being made up to full height and section.

22. **Dangerous banks.**—When banks show signs of slipping owing to saturation they may be protected in one of the following ways :—Trenches to be dug at the outer toe parallel with the canal, and also cross-trenches into the bank and to be filled with dry rubble, the outer wall being carefully built up with dry stone. The object is to divide the bank into sections each of which will be drained and rendered comparatively dry. The cross-drains, however, tend to fill up.

The second method is more satisfactory. Dig a trench 2 feet wide on the inside of the bank parallel to the canal, from F. S. L. to the natural ground, or deeper, according to the nature of the materials. This trench to be filled with good clay puddle made in the usual way, the top 1½ feet near the surface being made up with earth and *muram*.

The above method is also applicable for filling in cracks which should be dug out and refilled as above.

23. **Breaches.**—If a breach occurs in any bank, the wet earth to be carefully removed and a trench 3 feet wide and from 2 to 3 feet deep, depending on the soil, to be dug across the breach, extending well into the banks on either side. This trench to be filled with good clay puddle, laid as dry as is consistent with proper consolidation, and in layers not exceeding 4 inches in thickness, and to be well rammed. The sides of the breach to be stepped back in good long steps, and a tongue cut into the old banks 2 feet long × 3 feet wide. The whole to be filled with good selected soil, moistened as required, laid in 6-inch layers and thoroughly rammed.

24. **Masonry works.**—All masonry works to be carefully examined and repainted where necessary. The foundations to be inspected after heavy floods to ascertain if there is any danger of undermining. Any vegetation growing on masonry to be removed, as also all trees growing dangerously near to the masonry works.

25. **Iron work.**—All iron work of outlets, distributaries, etc., to be carefully inspected each year and to be repainted when required. All working parts to be oiled every year.

SPECIFICATION No. 174

FOR CANAL EXCAVATION

1. **Full cutting.**—The canal is to be excavated down to the bed level to the designed width of the canal and the side slopes are to be taken out afterwards to the slopes at which the excavation will stand, and finished off neatly. Measurement ridges should be left at intervals of 100 feet. For additional measurement ridges, if any such are required, express order of the Sub-Divisional Officer should be obtained. The classification of the excavation will be made from the measurement ridges which must be removed immediately after final measurements have been taken except where orders are especially given to retain the ridges. No dead men are allowed and only the correct depth and width shall be paid for.

The type section for cutting shall be as shown in plate CVII. The soil is to be uniformly deposited so that the spoil bank has a neat appearance and is of an approximately uniform height. The hardest material will be deposited on the top and slopes and the top of the spoil banks should slope slightly away from the canal.

2. **Partial cutting.**—Cutting portion as above. Section as shown in plate CVII. The banks shall be formed of a core, as shown, consisting of selected material. The clods must be broken and the whole rammed in layers. No water to be used. The core shall then be covered with the hardest material available from the cutting and the balance of excavation shall be deposited neatly

CROSS SECTIONS OF CANALS.

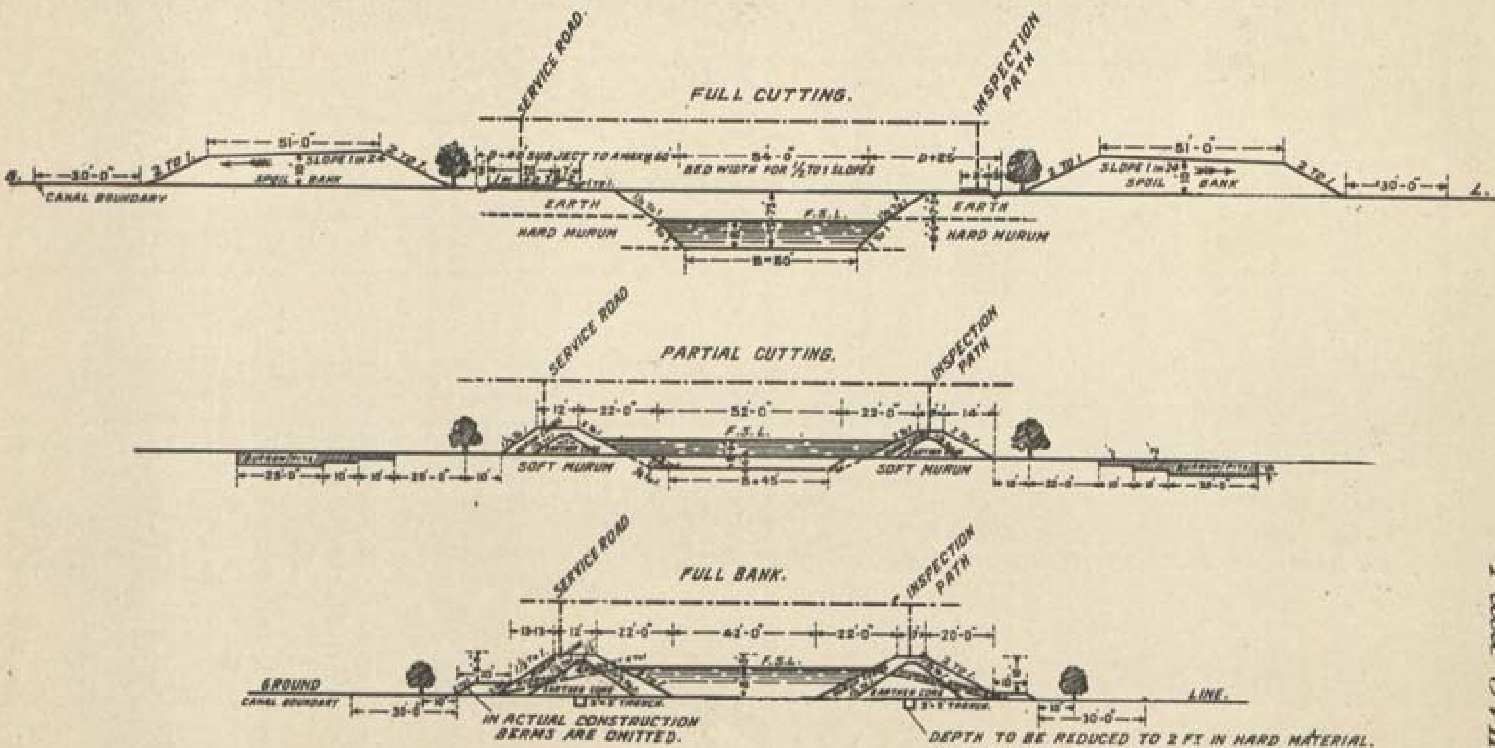
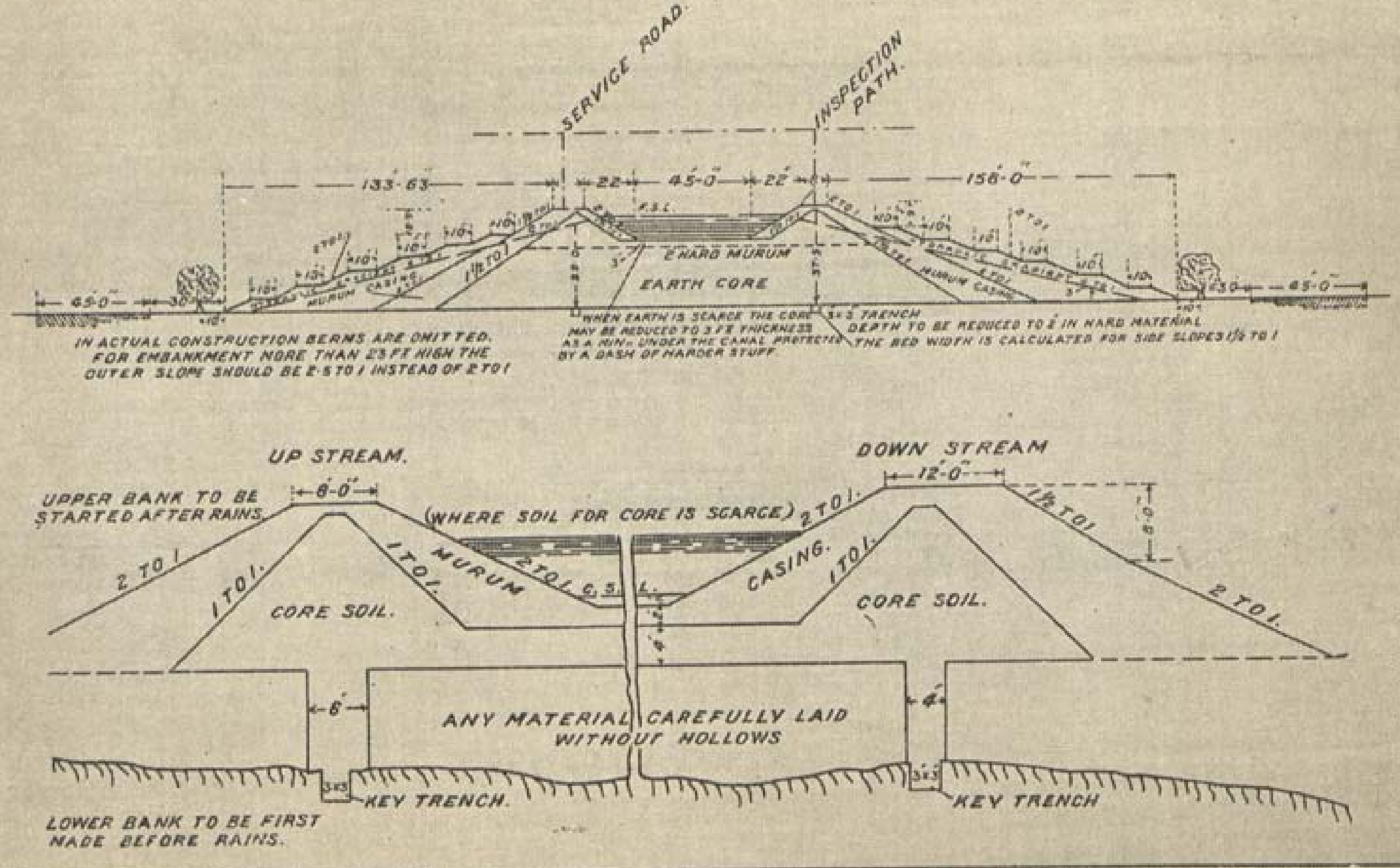


Plate CVII.

Plate CVIII

CROSS SECTIONS OF CANALS IN FULL BANK



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as under "cuttings". Where the excavation is sufficient to form the banks, no extra material shall be paid for. Borrow pits, where necessary, should be made neatly at sides selected by the Sub-Divisional Officer. The lead shall average as a rule 100 feet, not more.

3. **Full bank.**—As above. Section as in plate CVII. The core of the bank shall be designed of earth, rammed and made watertight. The top width of the core shall be 2 feet, and 1½ feet above F. S. L. and shall have side slopes 1½ to 1 down to ground level.

SPECIFICATION No. 175
FOR HIGH EMBANKMENTS OF CANALS
(PLATE CVIII)

1. As a rule embankments shall be made in long stretches 500 to 800 feet in lengths and not in small bits.

2. The embankment consists of—

(*a*) Central core.

(*b*) Service road and 2nd berm at Bed level.

(*c*) Casing of *muram* 1′ to 1½′ thick all over the core, the road and the berm.

Material for the core shall generally be brown soil ; yellow soil is preferable. Soil mixed with *muram* in the proportion of 1 of the former to 2 of the latter will make a very good core. Black soil shall not be used unless there is no other alternative. Avoid using "karal" earth and "shadu" that contains lime kankar in a bank.

Where soil is scanty, all that is available must be reserved for core and used very economically.

Service road and berm may be of any soil. Casing shall be of soft *muram*. If *muram* is not available, it should be of white or yellow earth ; but if none of the above is available, then it may be of the best soil available. If *muram* can be had from the spoil of the adjacent cutting, it should be used so far as the cost of its conveyance and spreading approaches to that of the *muram* casing, for the portion in question.

For longer leads special orders should be obtained. No spoil shall be removed before it is measured and orders given for its removal.

3. The selected soil shall be laid in even layers of 6″ on core portion of the embankment, the service road, and the casing being also simultaneously raised along with the core, so as to allow the carts as much room as possible to consolidate the core (*vide* paragraph 4 below), and also in order that the whole embankment may be raised evenly. Up to the bed level of the canal the whole shall be consolidated ; above this level, the core only is to be consolidated.

All clods in the core portion shall be broken down 1″ cubes, while on the road portion clods and small stuff as they come from the pits may be used ; making the road embankment wholly of clods is strictly prohibited.

4. Consolidation of core up to 1 foot below F. S. L. or even higher, if practicable, shall be done by means of half-loaded carts drawn by bullocks which should go all over the core portion, one cart to every 20 workmen or 10 donkeys, if "wadars" are working, or to 1,000 c.ft. outturn per day being allowed.

The top 2′ height of the core shall be consolidated by being rammed by wooden rammers.

5. All measurements shall be given by pit measurements, but when it is not practicable to do so and section measurements have to be given, a deduction of 15 per cent. from the section measurements shall be made to reduce them to pit measurements.

MASONRY DAMS

1. **Details of construction.**—The masonry is to consist of stone of a durable nature thoroughly bedded in mortar consisting of hydraulic lime and clean sharp sand, and to be of the following classes, *viz.*:—

(1) Outer casing of block-in-course masonry facing backed with coursed rubble, or the whole of the outer casing may consist of good rubble.

(2) Inner casing of uncoursed rubble.

(3) Hearting of uncoursed rubble or concrete.

2. **Face casing.**—The casing of the outer face of the dam to average 1 foot to 3 feet in thickness and to consist of a facing of block-in-course masonry laid at right angles to the face plane and a backing of coursed rubble masonry, or entirely of rubble masonry as may be specified.

The height of the courses shall not be less than 7 inches and no stone shall be less in length or breadth than one foot or less in breadth than $1\frac{1}{4}$ times its depth.

3. **Joints and beds in facing.**—The joints and beds of all stones in the facing to be truly vertical and normal to the face plane, and to be rough tooled true and square, for at least the same distance in from the face as the thickness of the course in which they occur, but the face and back of the stones may be left rough.

4. **Break of joint.**—The stones in alternative layers shall break joint, and bond in every direction, the break of joint on the face being at least equal to half the height of the course, and all stones to be set full in mortar.

5. **Coursed rubble backing.**—The face work shall bond well into the coursed rubble backing, each stone of which is to be of the full depth of the course, and to have parallel beds; the side joints may be of any form.

6. **Mode of laying.**—The stones of the backing are to be fitted together as closely as is possible without much dressing, all stones to be well wetted before laying in mortar, and then driven down and into contact with the adjacent stones with a light mallet.

7. **Finishing.**—The face joints to be neatly struck with a trowel, but not pointed or raised. The back of the rubble casing is to be left rough, so that the stones may bond into the uncoursed rubble or concrete used to form the hearting of the dam.

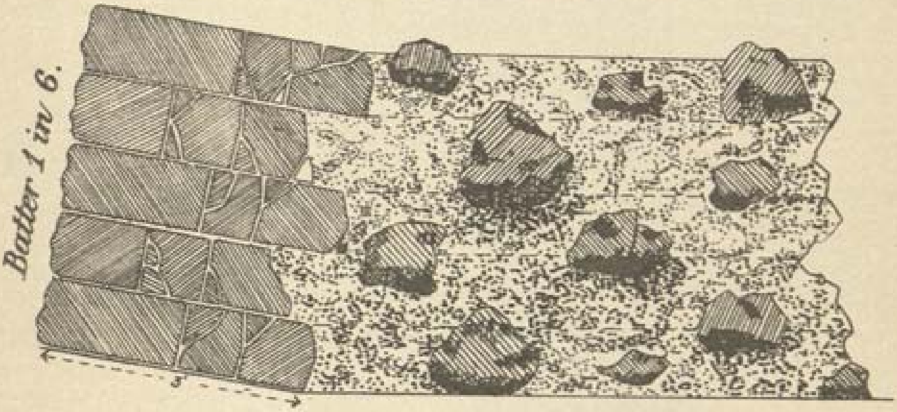
8. **Back casing and hearting.**—The interior or hearting and the back casing of the dam shall be of coursed or uncoursed rubble masonry, the latter consisting of flat-bedded stones carefully laid on their proper beds, and bedded full in mortar. Chips and spauls may not be put under stones, but may be wedged into the side joints to fill up intertics and so save mortar and increase the weight of the masonry and care should be taken that no dry or hollow spaces are left anywhere in the masonry. The back casing shall be laid carefully to profile, and shall be of specially selected stones, carefully fitted together without pinnings on the face. The surface of the rubble work shall not be brought to a uniform level, but shall be left rough and uneven, and the stones shall be bedded and driven home, stone upon stone, with a light mallet.

— MASONRY DAM — *Plate CIX*

— *Sectional Elevations.* —

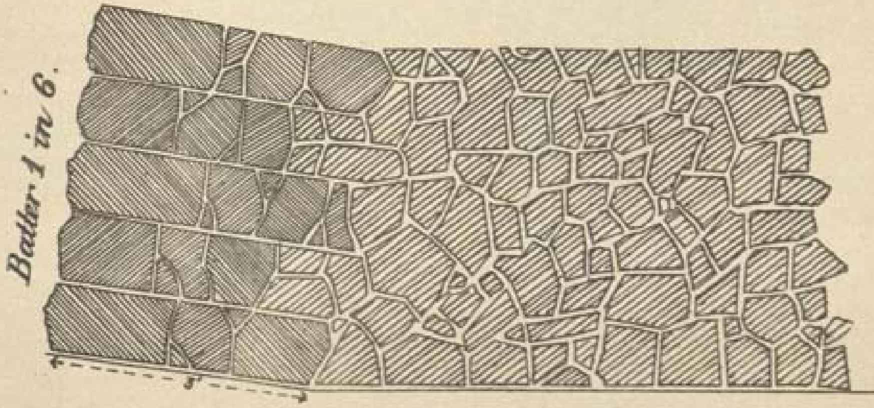
— *Fig. I* —

— *Casing of hammer squared rubble facing* —
— *with rubble backing and concrete hearting* —



— *Fig II* —

— *Casing of hammer squared rubble facing with* —
— *rubble backing and uncoursed rubble hearting* —



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The hearting shall be laid and bonded closely into the casings as soon after the latter are built as possible, and shall extend horizontally between the inner edgings of the casings.

9. Uncoursed rubble masonry shall be used to fill all parts of the interior of the dam that may be subject to a pressure of more than 60 lbs. per square inch, and concrete filling may be used where the pressure is less than 60 lbs.

10. **Watering.**—All stones used in the work shall be well cleaned and soaked in water before being laid, and all masonry and concrete work shall be kept wet for a month at least or until the next course is laid on it.

Foundations

11. **Good rock necessary.**—The foundations must be carried down to rock well able to bear the weight of the masonry and staunch enough not to leak under the pressure of the water impounded. Where subject to overfall, the foundations must be deep enough to be beyond danger of scour.

12. **Record plan.**—A foundation plan should be carefully prepared and maintained showing the reduced levels of the whole area of the foundations.

13. **Preparation of foundations.**—The general surface of foundation should be cleaned and roughened to give a good foothold to the dam.

14. **Blasting.**—Blasting will almost always be necessary for the preparation of foundations. Care must be taken when nearing the foundation level that the bed rock is shaken as little as possible, and that all shattered rock is removed with bars or heavy hammers before masonry is commenced.

15. **Treatment of different kinds of foundations.**—If the rock is sound, not fissured and not liable to weather, the surface need only be roughened to give the masonry a hold. If, however, it is of such a character that it will not stand exposure, the foundation must be carried well into the rock (from 3 to 6 feet) and the rock protected, if not covered with earth, by a covering of concrete or stone masonry in width equal to about $\frac{1}{3}$rd height of dam.

In case of fissured rock, the fissures, if large, should be cleared and filled with masonry, until there is no danger of leaking under the base of the dam.

Mortar for Masonry Dams

16. The mortar for concrete and masonry is to be prepared as follows, where ordinary *ghanies* are used :—

Well-burnt hydraulic lime is to be placed in the *ghanies* (*i.e.*, the ordinary native mortar mills with stone-wheels) in an even layer and to be well sprinkled with water, but not drowned unless the lime be of such a nature that it will not slake without being flooded with water at first, and for this special orders must be obtained from the Executive Engineer.

17. After an hour it is to be wetted thoroughly ; at the end of two hours it is to be stirred up and then covered with water and allowed to slake for two hours more, in all five hours slaking, after which all unslaked lumps are to be removed. It is then to be ground for three hours, water being added whenever it becomes stiff.

18. Thoroughly wetted sand is then to be added evenly through the *ghani* in the proportions of two of sand to one of slaked lime.

The sand and lime to be ground together for two hours : in all five hours' grinding.

19. The mortar to be scraped up occasionally to prevent the sand from caking on the bed of the *ghani*.

20. The mortar turned out of the *ghani* is to be made into a square heap about 9 inches deep for measurement.

21. If it is not used within 6 hours it is to be heaped up about 3 feet high, with water standing in a pool on the top. Mortar used after 12 hours is to be handmixed before being carried away. No mortar more than 24 hours old is to be used for the face-work and none over 48 hours for concrete. Mortar more than 48 hours old is to be unconditionally rejected and removed from the site of the platforms.

22. **Hydraulic test.**—The mortar shall be tested for hydraulicity and strength as follows :—

Briquettes (2-inch and 3-inch cubes) shall be made with two of sand to one of lime or such proportions as will be used in the work. They shall be allowed to remain in moulds and kept damp for 24 hours ; shall be then taken out, and covered up with wet sand and kept damp for 24 hours ; to be then removed and placed in water. If they keep their shape and continue to set, the lime will be passed as good hydraulic lime.

23. **Compressive test.**—Passed briquettes will be allowed to remain in water for not less than six months, and then be tested for compressive strength. The average result for good lime should be 700 lbs. to the square inch with mortar of two sand to one lime. At ten days the strength should generally be about 70 lbs. to the square inch.

This specification for mortar refers more especially to the very hydraulic limes which will not slake freely. For the less hydraulic limes generally met with, slaking may be done in the usual way, and lime stored and mixed as a powder with the sand for mortar. The mortar resulting must, however, pass the hydraulic test lead down in paragraph 22 above.

Note on the preparation of mortar in power-driven Iron Mills (as prepared on Lloyd dam—Bhatghar)

24. **Lime.**—Hydraulic kankar is calcined with coal fuel, and after slaking and screening the resulting lime at the various depots, it is carted to Bhatghar and kept in large bins until required. In the working season the lime is used within a month or so, but in order to provide a stock to begin each season's work, the bins are filled before the end of the hot weather and covered with a 2" to 3" layer of mortar as a protection from the rain. Such storage has been found to keep the lime in good condition, and no deterioration in strength has been ascertained while testing.

25. **Sand.**—No river sand being available, sand is obtained by crushing rubble and quarry chips (otherwise wasted) in Baxter's machines to pass a 5/8ths inch gauge. All dust is included in mixing the mortar, as dust does not decrease the strength, and is necessary for filling the voids. The rock used should not be too hard, nor yet too soft, as there would then be too little or too much dust. The average amount of sand and dust obtained from 25 c.ft. of quarry chips works out to be 20 c.ft. sand and 6 c.ft. dust, and this proportion has been found satisfactory.

26. **Mortar.**—The mortar is ground in power-driven pans of 8 feet diameter, arranged in sets of ten, and each set of ten is driven by an 80 B. H. P.

motor. Each pan is revolved at about 18 R. P. M., thereby giving 36 grindings P. M., and the outturn is about 10¼ c.ft. every 20 minutes or 250 c.ft. per pan per 8-hour day.

The operation of grinding is specified as follows, sand and lime being ready in 10 and 5 c.ft. pharas, respectively, on the adjacent platform :—

I. The lime is first filled into the pan, about 0·3 c.ft. of water being added at the same time, the operation taking about 2 minutes—36 grindings (mean).

II. The lime is ground alone for 5 minutes—180 grindings.

III. The sand, after having been thoroughly wetted, is filled in, occupying three minutes, at the same time adding a further 2·5 c.ft. of water (about)—108 grindings on lime, 54 grindings on sand (mean).

IV. The sand and lime are mixed thoroughly by further grinding for 5 minutes—180 grindings on mortar.

V. The motor is removed from the pans while revolving, taking 5 minutes—90 grindings on mortar (mean).

This is tabulated as follows :—

Operation	Time in minutes	Number of grindings			Total	
		Lime	Sand			
Filling lime	2	36	...	...	Lime ...	216
Grinding lime ...	5	180	...	...		
Filling sand	3	108	...	54	Mortar ...	234
Mixing mortar ...	5	...	180	...		450
Emptying mortar ...	5	...	90	...		
					Emptying ...	90
						540

Total time taken 20 minutes.

27. It is most necessary to see that the sand is not ground too much, resulting in pulverisation and a pulpy mortar. The time shown above for mixing mortar, *viz.*, 5 minutes, should be reduced to 2 mnutes (about) for new pans, and the time gradually increased as the fit of the scrapers becomes slack, etc.

The time for grinding lime should be watched most carefully and should not be decreased.

Note.—The amount of water to be added depends largely on the materials; sufficient water should, however, be given, without making too sloppy a mortar, to enable it to be removed from the revolving pans without difficulty and to admit of its being poured down chutes conveniently.

Comparison with three-wheeled ghanies (i.e., three stone-wheels worked by bullocks)

During the 5 hours grinding the three stones of a 44-feet diameter *ghani* together revolve over the mortar 432 times as a maximum against 540 as above.

28. **Sand.**—The sand used to be sharp, clean and not too fine, and to be carefully washed to free it from admixture with earth. For concrete the sand may with advantage be coarser than when the mortar is required for masonry.

Concrete for masonry dams

29. The concrete to consist of broken stone and clean gravel, or shingle intimately mixed with mortar of hydraulic lime after having been well wetted. The materials to be of all sizes up to what can be conveniently turned and rammed, generally 3 incnes maximum for metal and gravel and ½ inch minimum for gravel. The proportions should be chosen so that all interstices are filled up completely, and the mortar just creams up on being rammed for three hours with rammers as heavy as can be continuously used by labourers (varying from 9 lbs. to 20 lbs.).

30. The mortar will usually consist of two parts of sand and one of slaked lime; and the usual proportions of the concrete will vary between the following :—

4 metal.		2 metal.	
4 gravel.		2 gravel.	
3 mortar	{ 2 sand. 1 lime.	2 mortar	{ 1½ sand. 1 lime.

31. The concrete is to be laid in courses equal to those of the face-work, if less than 9 inches. To be laid on alternate days, the adjacent masonry being well wetted and the concrete carefully worked up by stakes so as to join it closely. The edges of the masonry should be plastered with from ½ inch to 1 inch mortar after having been wetted, in order that the concrete may unite with it firmly. The concrete layers to be thoroughly rammed for at least 3 hours.

32. Heavy stones and boulders to be inserted in the concrete as it is being laid, with their broadest ends downwards, and to project beyond the upper surface of the layers so as to bond that layer with the next above and also to add to the weight. These stones should generally form ¼th to ⅓rd of the whole mass, and should be well wetted before being laid. They should be placed so as to allow of ramming freely between and all around them.

33. All masonry and concrete is to be watered constantly from the moment the mortar in it sets sufficiently to allow of water being thrown over it, for at least one month or until the next layer is added.

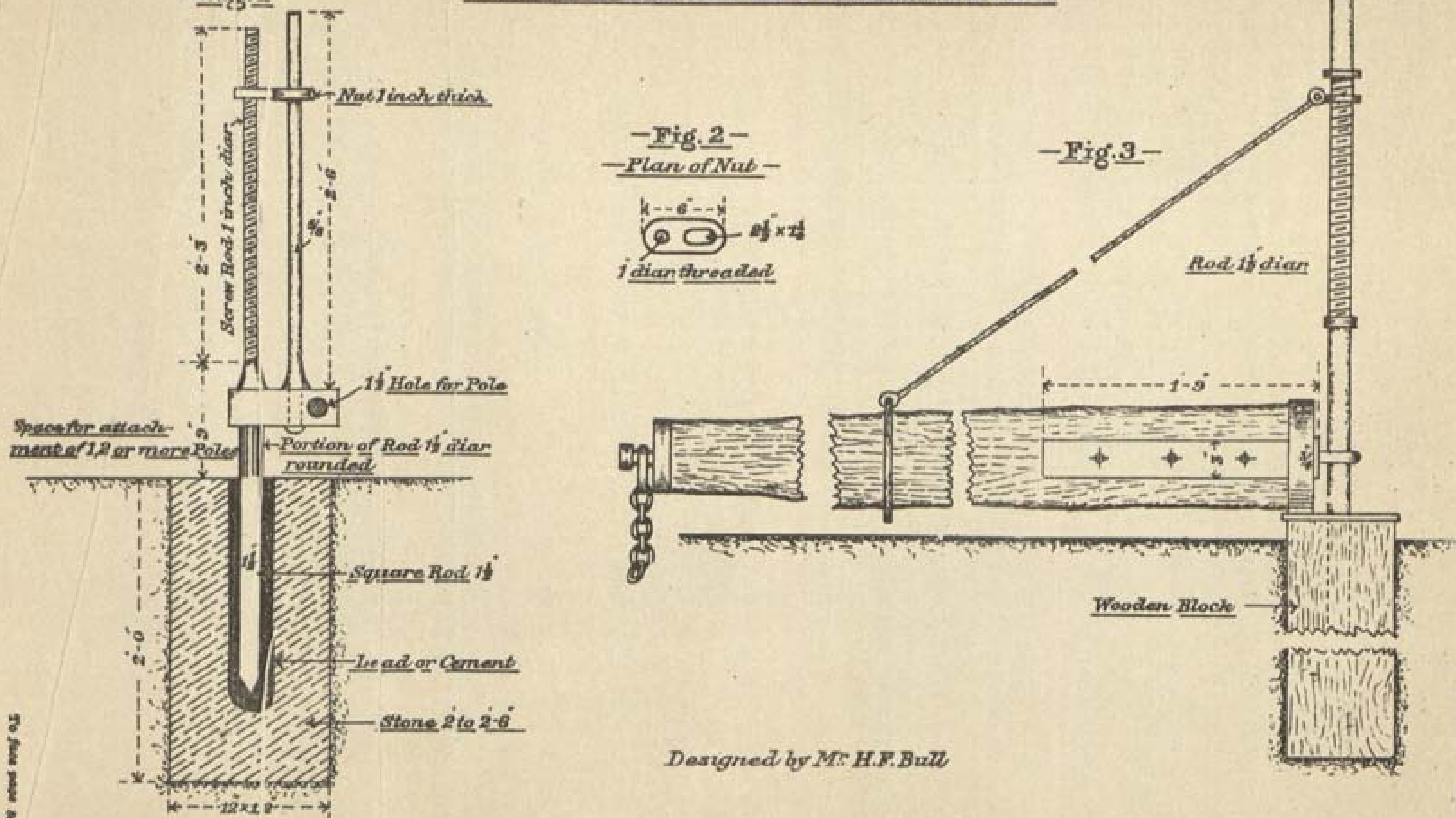
Note.—Both for masonry and concrete it is very desirable that the grinding of the mortar shall be properly done. In using ordinarily *ghanies* some check is required on the bullockmen. This is effected by the gauge screw designed at Bhatghar by Mr. H. F. Beale.

GAUGE SCREW FOR THE DECCAN MORTAR MILL OR GHANI

This is a device for checking the number of turns made by each set of bullocks, when grinding mortar. It consists of a vertical central rod about 4½ feet long, which forms the central pivot of the mill, round which the stone or stones are made to revolve. The lower portion of this rod is square, of 1½ inch side, for a length of 18 inches, and is to be fixed in a buried stone with lead or cement or some other material, which will prevent its turning in its socket, or being removed. The middle portion of the rod is round, and of 1½ inch diameter. The length of this is taken at 9 inches, but may be varied according to the space required for the attachment of the mortar mill poles.

The top 27 inches length of the rod is of 1-inch diameter, and screwed with dies of Whitworth pattern, giving 8 threads to the 1 inch. This screw is provided with a special nut 1 inch deep and 6×2½ inches in plan. Near one extremity a hole is bored out, and tapped to fit on to the 1-inch central screw, and near the other extremity a slotted hole, 2½×1½ inches, is made, into which fits loosely a small rod, ⅝ inch diameter and about 2½ feet long. This small rod is riveted

-GAUGE SCREWS FOR MORTAR MILLS-



Designed by Mr. H.F. Bull

at its lower end into the attachment of the mill pole (the upper one, when there is more than one pole), and actuates the nut, which is moved up or down the screw rod, according to the direction in which the mill-stone is being drawn round. It is important that the $\frac{5}{8}$ inch rod be permanently fixed to the pole, so that it cannot be withdrawn or tampered with.

The work done is indicated by the altered position of the nut. When it has passed through, say 12 inches, each wheel has made $12 \times 8 = 96$ rounds and, therefore, in a 3-wheeled mill, the mortar has been ground $3 \times 96 = 288$ times.

The reading need only be taken each grinding, the length of screw above the nut being recorded.

It is plain that the mill-stones must be drawn round in an opposite direction at each grinding, but this offers no difficulty.

The cost of this gauge, with central attachment for 2 poles, is about Rs. 24 delivered in Bombay.

The first gauges were designed for the loose central attachment in use at Bhatghar, which did not allow of the centre rod being leaded in, and also required a larger loop for the $\frac{5}{8}$ inch rod to work in. In such cases an iron plate, $\frac{3}{4}$ inch thick, with a square hole, can be fixed into the top of the centre stone, a pin being previously passed through the square portion of the rod below the plate, in order to prevent the rod being drawn out. The loop of the nut can be made in the shape of a circular hoop of 4 or 5 inches diameter, to allow ample play, the metal of the hoop being $\frac{5}{8}$ inch square.

The arrangement is shown in plate No. CX.

SPECIFICATION No. 176

EARTHEN RESERVOIR DAMS

(Drawn up by the late Mr. A. Davidson about the year 1890).

1. The specifications under this head are arranged in 3 sections as follows :—

I.—Earthen dams for large reservoirs.

II. Special forms of construction.

III.—Type designs.

The description and type designs are not intended as a standard, but as types for selection or adaptation accroding to the circumstances of the reservoir site.

Earthen dams for large reservoirs

2. **General description.**—The dam is to consist of an earthen embankment with puddle trench, or concrete and puddle trenches, arranged according to a selected design or as shown in the drawings.

3. **Preparations.**—The following preparations should precede the commencement of the dam :—

The land taken up for the work should be properly demarcated, and a plan and register kept on the work.

The soil and other materials available for the embankment, puddle trench, etc., and the sufficiency of each description of material required, as well as the cost of carriage, should be considered, and the best selection consistent with economy determined.

The officer carrying out the work should provide himself with detailed drawings of the puddle trench, or concrete and puddle trenches, and a working section of the dam with the widths marked at convenient intervals of height. If the hearting and casing of the dam are separately specified for, their respective widths shall be shown at each such interval on the section.

4. **Clearing site and preparing foundations.**—The whole site must be cleared to the full width of the seat of the dam, of all trees, shrubs, grass rubbish of all sorts, loose stones and soft stuff. All roots to be dug out, and the loose surface soil to be scraped off to a depth of 6 inches or till the firm natural soil is uncovered.

If the natural soil in any part of the seat of the embankment is found to be compressible or to contain salts, or otherwise has suspicious appearance, the orders of the Executive Engineer should be obtained before commencing the embankment.

5. Where the line of embankment crosses the bed of the river or feeder, gravel and sand and all artificial deposits are to be carefully removed down to some solid and unyielding material.

All decayed and undermined strata in the sloping river banks should be removed.

6. **Disposal of excavated material.**—The rock and debris excavated from the concrete and puddle trenches may be used, if suitable, and with the permission of the Executive Engineer, in the construction of the outer slope of the dam.

Such material, if not fit for use, as well as all other removed from the seat of the dam, shall be carried off the site of the work and deposited, outside the tank, in places to be pointed out where it will not interfere with the execution of the work.

7. The seat of the dam when thus cleared shall be watered and opened with a pick or harrow, and all clods and lumps shall be broken. The new material is then to be mixed with the excavated soil and consolidated, as described hereafter, to form the first layer of embankment.

8. **Draining the base of dam in rear of puddle trench.**—Provision should be made for draining the water leaking beyond the puddle trench, so as to prevent the saturation of the rear toe of the dam or the ground underneath or immediately beyond the toe. The base of the dam in rear of the puddle trench should, as far as possible, be kept dry and firm. Otherwise the saturation, and occasionaly also the unbalanced hydrostatic pressure resulting from it, may lead to the movement of the subsoil, and slips and settlements, in the rear slope of the dam.

The amount of leakage to be expected varies with the nature of the subsoil and with the depth and pressure of water against the dam which is greatest in the river bed.

The leakage should be collected and led away, clear of the rear toe, by drains constructed at the ground surface below the dam, or by filling for at least 2 feet deep, the whole base of the dam in rear of (and from 5 to 10 feet clear of) the puddle trench with large rubble, gravel or other heavy material forming porous substructure. All pools and saturated subsoil close to the outer slope of the dam should be thoronghly drained.

The work should be carried out according to a selected design or as shown in the drawings.

Puddle trench

9. **Excavation.**—A trench for the puddle is to be excavated along the centre line of the dam embankment to extend, unless otherwise specified, till the ground under the dam attains a level of 2 feet above full supply level.

The lengths of trench opened out should not be more than can be quickly filled in.

The excavation in all cases, and particularly in the rear bed, to be carried down to, and for at least 2 feet in depth, into solid rock, or 3 feet into *maun* earth or other water-tight and impervious soil approved by the Executive Engineer. The excavation below the surface of the rock or the water-tight subsoil may be narrower than the trench above, or carried down with slopes of about 1 to 1.

10. **Size of trench.**—The breadth of the puddle trench, unless otherwise specified, to be 1/10th the height of the dam + 3 feet. It may be gradually diminished from the centre to the ends as the height of the dam diminishes. The minimum breadth should not be less than 6 feet.

The sides of the trench, when not otherwise specified, to be left vertical. When the excavation cannot stand with a vertical face, the side slopes shall be as steep as they can stand, without shoring, for the period the trench is likely to remain unfilled.

Shoring may be resorted to, but only when absolutely necessary.

Vertical steps longitudinally in the trench are to be avoided, level stages with steep inclines being preferable.

11. **Springs.**—All water met with in the foundations must be collected in sumps, shoots or pipes, and pumped or baled out, or otherwise conveyed out of the trench without being allowed to spread on the puddle as it is being laid.

All springs of consequence to be carefully plugged up or caulked before the puddle is laid.

12. **The puddle.**—The trench, when ready, is to be filled with good clay puddle made out of clean, tough and retentive clay of the best quality available near the site. The most suitable clay is of the description used for tile making. Soft, sludgy, peaty, sandy, salt or puffy clays should be rejected.

The clay is to be worked up into puddle before use by turning it over and over again with *powras*, watering and treading with men's feet into one plastic homogeneous mass of the toughest consistency. Experience will show the proper quantity of water to use to make stiff yet plastic puddle, neither too wet nor too dry.

13. **Laying the puddle.**—The bottom of the trench should be washed, if the excavation is in rock, before puddle filling is commenced. The bottom layers should be made of puddle tempered upon the surface and thrown or dashed into the trench in balls to fill in inequalities. The puddle should be worked up on the surface in the same way when the trench is deep or there is not enough room to work.

Generally, however, after the first few layers are laid the clay may be put on in the trench itself in layers not exceeding 9 inches in depth and there worked up with *powras* and men's feet into stiff, dough-like mud. The layers of the puddle should be kept as level and uniform as possible.

If too much water has been used, the layers must be excavated and removed from the trench before another layer is laid upon it.

Puddle is never on any account to be allowed to dry ; should the surface of puddle crack at any time, the cracked surface is to be dug up and the puddle re-made.

On Sundays and holidays coolies should be specially employed to keep the surface of puddle wet.

Ramming.—As the surface of the puddle layer dries up, it should be thoroughly consolidated with rammers. Before a new layer of puddle is laid the surface of the previous layer, if not newly made, should be lightly sprinkled with water by means of watering-pots.

When puddle is finished, it should be at once covered up in the work or when this is impossible, with wet earth or grass.

14. The surface soil is to be removed on both sides of the puddle trench, for a breadth equal to that of the top of the trench, and for 2 feet deep, and refilled with selected clay or other material used for the hearting and consolidated in the same way.

This filling is to be carried up with the puddle wall to a height of 2 feet above ground level and joined with the hearting.

15. **Concrete trench.**—When the trench is filled entirely with concrete or partly with concrete and partly with puddle, the work should be done according to a selected design, or as shown in the drawing.

A concrete trench is required only in the river crossing and it should not ordinarily be less than 5 feet in bottom width.

The concrete should be prepared and laid as in specification.

Embankment

16. **Construction of embankment.**—The embankment is to consist of a water-tight hearting of clay or clayey earth, with a casing, both in front and back, of clay mixed with *muram* or gravel.

The clay hearting is intended to make the dam water-tight, and the casing to afford protection to the hearting against the effects of alternate saturation and extreme dryness.

The casing both in front and back shall be 3 feet thick at full supply level measured at right angles to the slope, increasing at the rate of 1 foot for every 20 feet of vertical depth below that level.

17. **Material.**—The material for the hearting should be of the most clayey or retentive earth obtainable within one-half mile of the site, unless otherwise specified ; and, where possible, the whole of the hearting should be made of the same kind of material throughout to ensure equal settlement. It must be free of salts, large stones and rubblish of every kind.

The casing should be made of clay and *muram* or, where good *muram* is not obtainable gravel in the proportion of two of clay to three of *muram* or gravel, unless otherwise specified. Preference should be given to a ready-made natural mixture where available, such as clayey *muram* or gravel, or *maun* soil with large admixture of nodules of *kankar*.

All stones which do not pass through a ring of $1\frac{1}{2}$ inch diameter to be rejected.

18. **Forming embankment and consolidation.**—The material, freed of all clods and lumps, shall be laid in continuous layers with a slight slope towards the centre, making a concave curve, the centre being 3 to 6 inches lower than the outward edges.

The material shall be spread in even layers of 5 or 6 inches or such other thickness as will roll down to about 4 inches when finished. If a steam roller is used, the thickness of the layer may be increased to 9 or 12 inches or as may be determined after actual trial.

All the earth used in the embankment should be such as is naturally moist in itself or is made so before it is spread.

No watering should be allowed until the layer has been completely rolled.

Water should be sprinkled to sink about $\frac{3}{8}$ inch in depth into the completed layer just before the next layer is spread so as to ensure complete union between the two.

If the earth available is too dry for use it shall be moistened before being spread on the dam. This is done either by wetting the site of the borrow pits a few days previously, and allowing the surface to dry before actual excavation, or by heaping the dry soil in layers of about 12 inches, each layer being thoroughly soaked before the next is laid until the heap attains a convenient height. The material is then mixed with *powras*, carried to the dam and spread in the usual way. If proper supervision is available, there is no objection to making the heaps on the dam itself.

Note.—The use of the soils which are moist by reason of the presence of salts in them should be avoided.

19. **Rolling.**—Rollers may be made of stone or iron, and of such a size and weight that they will give a pressure of $\frac{3}{8}$ to $\frac{1}{2}$ ton per foot length of roller. It is sometimes advisable to pass a light roller quickly over a newly spread layer in order to bring it to a surface before working a heavy roller.

To prevent the material sticking to the rollers, dry earth should be sprinkled on the surface before or during consolidation, as may be necessary. The rollers should be kept clean by means of suitable scrapers.

Ramming.—In parts of embankment which rollers cannot be worked on or cannot reach, the consolidation should be done with heavy rammers worked by lines of men moving in union backwards and forwards on the surface till the layer is thoroughly consolidated. When the consolidation is effected by ramming, the materials should be spread in layers not exceeding 3 inches in thickness. Where manual labour is used for carrying the materials, the work-people should as much as possible, be made to walk over the rolled portion of the dam, but not in single file.

20. **Allowance for settlement of earthwork.**—In setting out the half widths of embankment, it is desirable to allow for the settlement of the material, by adding, unless otherwise specified, at the rate of 1 foot for every 24 feet of height of dam ; that is, the half widths calculated on the cross-section for a height of 24 feet above ground level should be actually set out at 25 feet above that level.

21. **Junctions of earthwork.**—When new embankments are joined to old, the surface of old work is to be removed to a slope and the junction to be dug up 2 feet deep and both new and old stuff mixed and watered to the extent necessary for consolidation and rammed.

22. **Protecting outer slope.**—Where it is proposed to protect the outer slope of embankment with *hariali* or other binding creeping grass, the outer casing should be finished off with a top layer containing a sufficient admixture of soil favourable for the growth of the grass.

23. **Borrow pits.**—No excavation shall be made on the inside of a dam nearer the toe of slope than twice the height of the dam opposite, nor on the outside of the dam nearer than three times the height of the dam.

Nor is any excavation within 100 yards of the dam to exceed 5 feet in depth without the special sanction of the Executive Engineer.

Care should be taken that no porous strata are unconvered on the inner or tank side of the dam.

All pits should be arranged with a certain amount of regularity, having regard to the convenience of the work during the execution and to its safety and an appearance of finish after its completion.

Pitching

24. **Stone pitching.**—The inner slope of embankment shall be protected with stone pitching from the level of 2 feet below the sill of outlet sluices to 3 feet over the highest flood level, unless otherwise specified.

When circumstances permit, one rainy season should be allowed to elapse after constructing the slope, to allow for consolidation before pitching is commenced.

25. **Stone.**—The stone to be good, hard, quarry or boulder stone such as will not weather on the surface. It is to be roughtly hewn or squared with the hammer to ensure the stones fitting fairly one on the other so as not to expose the earthwork below.

26. **Laying.**—The stones are to be laid with their broadest faces downwards and firmly bedded on a layer of *muram*, spauls (or gravel) at least 6 inches in thickness.

They are to be packed against each other with the hammer or mallet so as to fit closely for at least 3 inches in height and to lie generally perpendicular to the slope. No pinning is to be allowed between the sides of stones, and the use of chips should be confined to hollows and inequalities in the bed and for packing, after the stones are laid, on the surface to form a uniform slope.

The surface packing should not be allowed to proceed till the previous work is inspected and approved.

Size of stone.—The depth of pitching, unless otherwise specified, to be 6 inches at the bottom of slope, increasing uniformly by increments of about 3 inches to 18 inches at the highest flood level and again decreasing in the same way to 12 inches at the top.

The topmost course shall consist of roughly dressed headers projecting 9 inches above the face of the pitching and shall be laid in a continuous level line.

27. **Slope.**—The face slope of the pitching when complete is to be that specified for the dam, so that the varying depths of the stone and the thickness of the *muram* or gravel bedding must be allowed for in the earthwork.

The surface of the work when complete shall be fairly uniform and left clean of all refuse.

Special forms of construction

28. Deviations from the above general specification will be necessary to meet particular cases of material or construction which require special treatment.

Low dams.—The following modifications apply to low dams, generally below 40 feet in greatest height :—

The material of the *nala* bed on the downstream side of puddle or concrete trench may be left, if it is firm and unlikely either to compress or shift in case of leakage from springs. All vegetable soil and rubbish of every sort should however, be removed.

A concrete trench is not necessary ; the puddle wall may be continued throughout.

Unless the subsoil is particularly porous, no special drainage works are necessary for preserving the outer slope of the dam in a dry state. In the *nala* crossing, the outer toe may be built of dry rubble stone or large gravel for 2 or 3 feet deep, and extending not less than 10 feet into the dam.

The pitching should not be less than 6 inches thick up to 5 feet below the highest flood level, nor less than 9 inches above that up to the top.

29. **Mixture of materials for puddle.**—Where good natural clay is not obtainable in sufficient quantity, soft *muram* or sand may be mixed with it. Gravel may be added to wet puddle clay, with the consent of the Executive Engineer, in proportions not exceeding 1 to 1 when it is necessary on economical grounds.

Black soil.—Puddle may also be made by a mixture of soft *muram* or sand with black soil ; 3 parts of pure black soil to 2 of sand or *muram* broken fine will make a good mixture but the proportions should in each case be determined by experiment. The soil should be free from all impurities. All stones or unbroken lumps larger than a hen's egg and all grass or rubbish should be carefully removed.

30. **Laying puddle.**—Puddle may also be laid in the following manner :—

After the bottom of the trench is filled for 2 or 3 feet with well-kneaded and well-trodden clay, such as ball puddle, the remainder of the trench may be filled with thin layers of wet clay and consolidated as on the embankment. The clay is thrown in layers of 3 or 4 inches, and trampled and rammed, dependence being placed on thorough ramming to ensure homogeneity of the mass.

31. **Mixture of materials for the dam.**—Pure black soil swells when wet and cracks when dry. It should not be used for embankments, except in combination with some foreign material such as *muram* broken to small size or with gravel or sand. Two or 3 parts of black soil to 1 of *muram* broken fine makes a good mixture. The exact proportions should be determined after experiment in each case.

When the mixture is made by the hand, the materials are to be placed clear of the work, the dry *muram* and black soil are to be laid on each other in layers not more than 9 inches deep ; they are then to be mixed with *powras* by turning the stuff over and over.

The materials, when thoroughly mixed, are spread in a layer 12 inches thick or heaped in such layers, to a convenient height, each layer being soaked with

water before the next is laid. The mass is left over for a time (usually one night). It is then mixed with *powras* spread on the dam in layers, and rolled.

The soaking should be such that the material when ready for use should be just damp enough to crumble easily in the hand. Great care is necessary to avoid both unequal moistening and the use of too much water.

32. **Pitching.**—Pitching on large dams may also be constructed with a uniform thickness of not less than 12 inches. Where stones 12 inches thick are not obtainable, or are very expensive to procure, smaller stones, but not less than 9 inches thick, may be used. In the latter case, rows of headers or the longest stones available are to be laid down in continuous horizontal lengths at intervals of 5 feet on the slope.

Type designs

33. Fig. 1 (plate CXI) shows a form of cross-section of dam in general use.

Slopes.—Section of dam, inner or waterside face .. 3 to 1 up to highest flood level and 2 to 1 above.

Outer face .. 2 to 1 throughout.

Principal dimensions (Fig. 1)—

d=depth of maximum flood over crest of waste weir.
h=clear height of top of dam above level of highest flood.
t=top width of dam.

The value of d is obtained by calculation. Those of t and h are ordinarily as below :—

Greatest height of dam—	t	h
Up to 40 feet	6 feet.	6 feet.
40 to 60 feet	7 "	.. 7 "
60 to 80 feet	8 "	.. 7 "
80 feet and above	10 to 12 feet.	8 to 10 feet.

The top width (t) may be reduced at the height of the dam diminishes from the deepest point to the ends. The margin above highest flood level (h) is usually the same throughout as at the deepest part of the dam.

Outer casing.—To be 3 feet thick measured perpendicular to the slopes at the highest flood level and to increase by regular increments of 1 foot for every 20 feet of depth below that level.

On the inner or water side slope the thickness of casing to be allowed for, exclusive of pitching and its *muram* or gravel bedding.

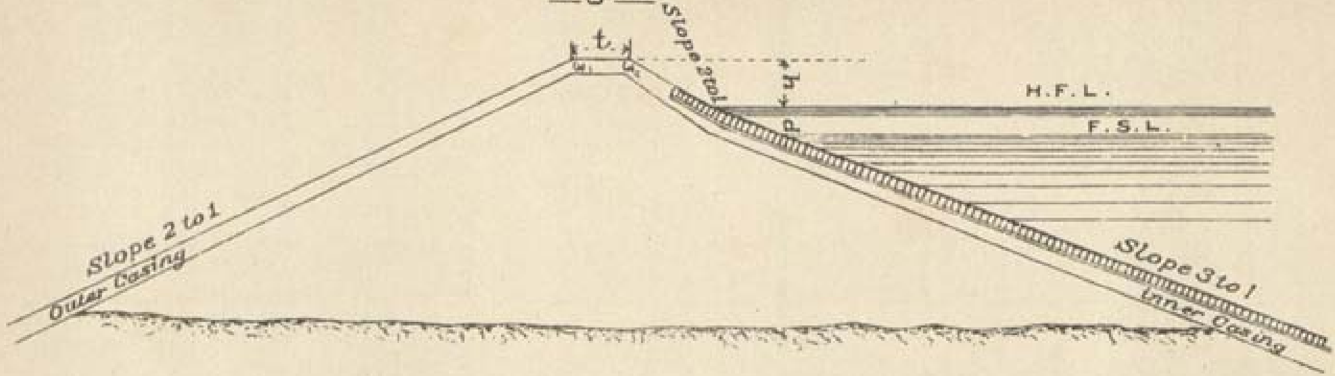
34. The section of dam recommended where sufficient clayey soil is not available is shown in Fig. 2 (plate CXI).

Where sufficient clayey soil is not to be had, only a core of that material may be provided in the middle of the embankment directly over the puddle trench.

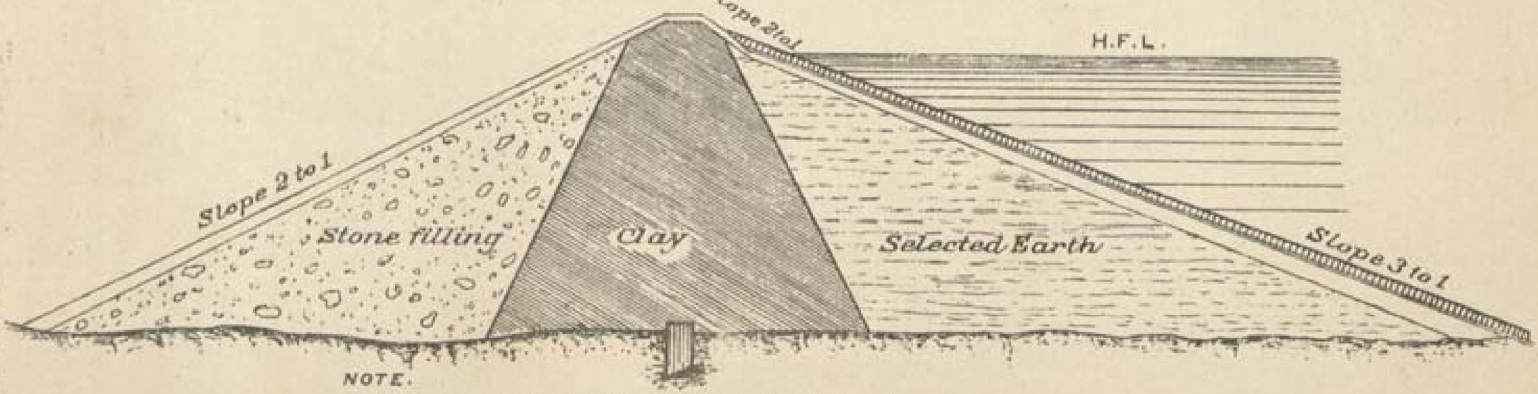
The space between the core and the outer casing should be filled with some selected material for the front half of the dam, while rock debris, gravel or sandy soil should be preferred for the part in the rear of the core.

— Section of Earthen Dam —

— Fig. 1 —



— Fig. 2 —



NOTE.
See the late Mr. Davidson's suggested Specification

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Plate CXII

—Base Drains—

Fig 1

Plan of Seat of Embankment

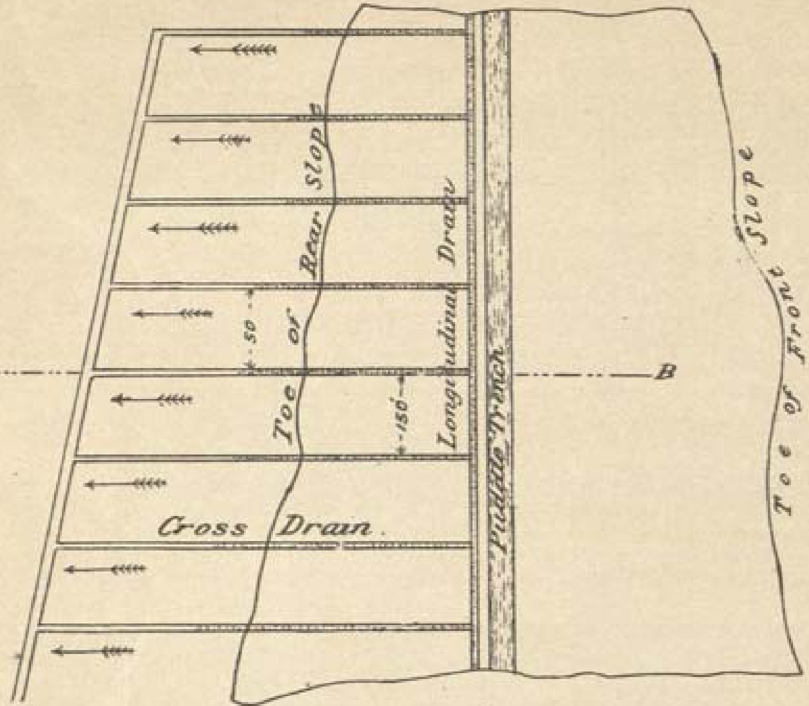
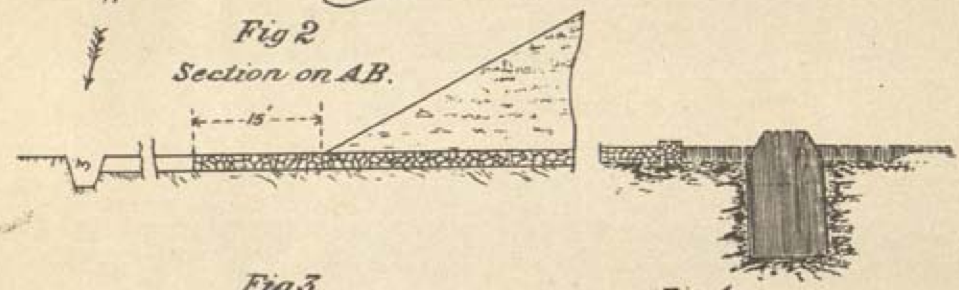
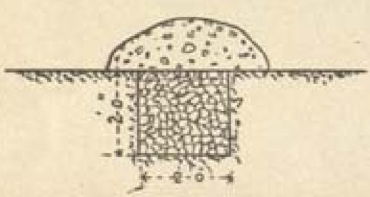


Fig 2

Section on A.B.





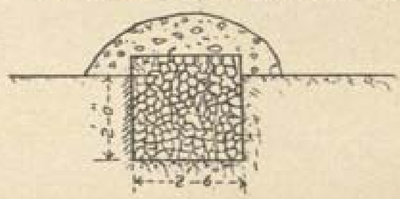


Fig 3

Section of Cross Drain.

Fig 4

Section of Longitudinal Drain

Fig 5

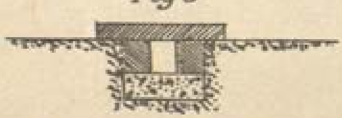
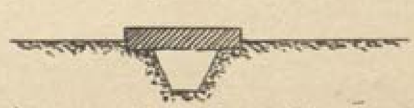


Fig. 6



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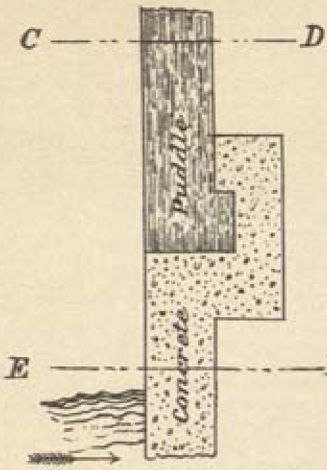
Note, See the late Mr. Davidson's suggested Specification.

Plate CXIII

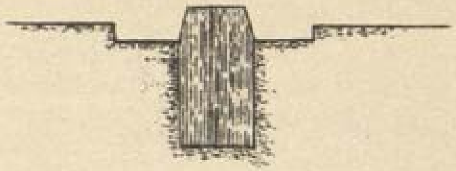
– Puddle & Concrete Trenches –

– Fig 1 –



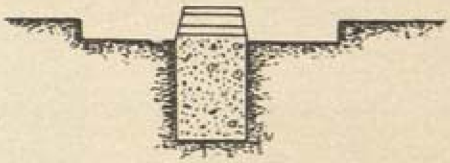
– Fig 2 –

Section on C.D.

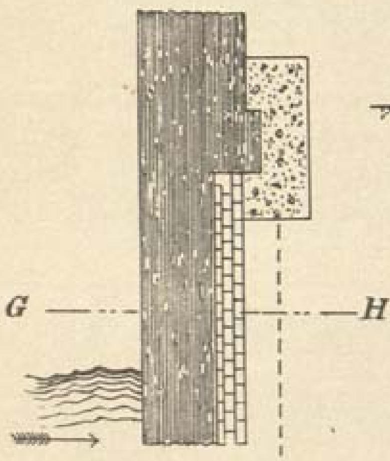


– Fig 3 –

– Section on E F. –

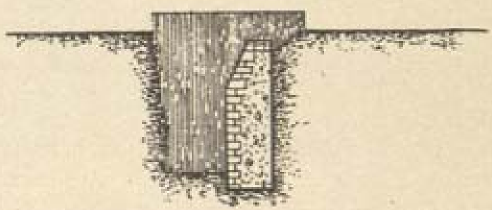


– Fig 4 –

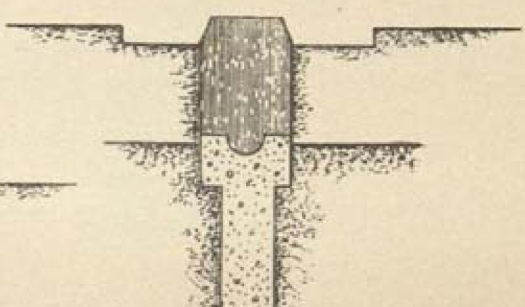


– Fig 5 –

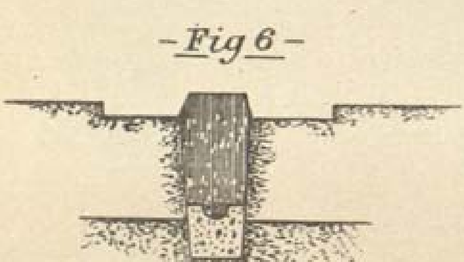
– Section on G.H –



– Fig 7 –



– Fig 6 –



NOTE:– See the late Mr. Davidson's suggested Specification

The space in the rear of the core, as well as depth of 2 feet at the bottom of rear casing, may be filled with heavy porous material, such as rubble stone, rock debris, hard *muram*, gravel, etc., the heaviest and most porous stuff being placed in the bottom layers nearest the outer toe.

Where the connection between the porous backing and the clay hearting is not gradual, the clay should be prevented from being washed out by interposing a layer of quarry refuse or gravel, or by setting the stone in clay for a short distance from the place of union.

35. **Base drains.**—Plate CXII (Figs. 1 to 4) shows the ordinary type of stone drains for draining the base or lower part of embankment in rear of the puddle trench.

There should be one longitudinal drain close to and parallel to the puddle trench and cross-drains from it at intervals of about 50 feet. If the bottom width of the dam is considerable or the subsoil previous, additional longitudinal drains may be provided between the drain behind the puddle trench and the rear toe.

The longitudinal and cross-drains should join at the same level, and the latter should be laid with a bed fall of not less than 1 in 100. The greater the slope available the better.

The drains shall be filled with irregular shaped rubble or gravel about 4 inches in diameter covered on the top (and also on the sides where any portion of the drain is in embankment) by quarry refuse, small stone or turf sods, permitting the escape of the water, but preventing the earth being washed into and choking the drains.

Where the expense is justifiable, the drains may be made with a bottom of lime concrete, rough square rubble for the sides, an d stone slabs set dry on the top (Fig. 5).

In hard *muram* or rock, the drains may be cut into the ground and covered over with slabs as shown in Fig. 6.

36. **Puddle and concrete trenches.**—Plate CXIII shows type designs of puddle and concrete trenches.

A concrete trench should be provided under the embankment in the bed of the river or feeder and puddle trenches on the banks. For low dams, as already stated, or where the foundations are good, concrete may be dispensed with, puddle being continued across the feeder also.

Figs. 2 and 3 show type sections of a puddle and a concrete trench respectively. The sides are shown vertical but they may also be excavated sloping, when necessary, as described in the general specification.

A suitable junction of concrete with the puddle wall should be made by adding a tongue or wall of concrete as shown on plan in Figs. 1 and 4.

When a trench is filled with concrete and puddle side by side, as in Figs. 4 and 5, the concrete in contact with the puddle should be faced with rubble masonry to aid in the consolidation of the concrete.

Figs. 6 and 7 illustrate the use of concrete in the lower parts of the trench with puddle filling above.

Concrete is more reliable under great pressure and is better adapted than puddle for deep narrow trenches.

THE USE OF STEAM ROLLERS ON EARTHEN DAMS

1. **Roller.**—The use of steam instead of bullock rollers for consolidating earthen dams was tried during the 1897 famine, and subsequently, on the Shetphal tank, Poona district. The roller used was an Aveling and Porter roller, in weight about 8 tons and length 5 feet.

2. **Method of rolling.**—Experience has shown that the dam should be rolled in the direction of its length, the width of the dam being made from 2 to 3 feet greater on each side than the finished width, this extra width being subsequently trimmed off and utilised in the higher layers.

The layers should be formed of material just so moist that it will bind properly when rolled. Each finished layer should be lightly watered before being covered with the new soil. If there is any tendency to stick to the roller this may be prevented by sprinkling a little dryearth over the layer.

3. **Thickness of layers.**—The thickness of the layers will depend on the material used, but 12-inch layers have been successfully used at Shetphal, the layer being laid in strips commencing from the side on which the stacks of earth are made so that the work-people trample over the new layer before it is touched by the roller.

4. **Extent of consolidation.**—The extent of consolidation is greater than with ordinary 3-ton bullock rollers, amounting generally to about 30—33 per cent. for earth and 12—15 per cent. for *muram*, while the bollock roller gives about 19-20 per cent. only for earth. Owing to this increased consolidation it is not necessary to provide for the subsequent settlement of the dam.

5. **Cost and amount of work done.**—It has been found that a steam roller such as described above is, under ordinary circumstances, able to consolidate about 20,000 cubic feet rising in favourable circumstances to about 25,000 cubic feet of finished bank per day, the daily cost of labour and material amounting to about Rs. 22-8-0 per day. Experiments have shown that the roller should be passed 4 times over each layer to ensure complete consolidation.

6. **Advantages.**—The steam roller possesses the following advantages over the bullock roller for earthen dams :—

(*a*) It permits of the concentration of a much larger number of workmen in a given length of dam, since one roller will do as much work as 3 to 4 bullock rollers.

(*b*) The consolidation is much more perfect.

(*c*) The cost is somewhat less per cubic foot of completed bank.

(*d*) It does away with the use of bullocks, which are frequently very difficult to obtain.

SPECIFICATION No. 177

FOR AN EARTHEN EMBANKMENT FOR A STORAGE RESERVOIR

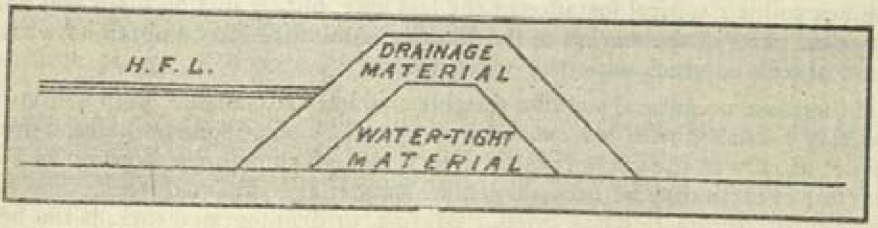
(Drawn up by Mr. A. Hill in 1909.)

1. In constructing an earthen embankment to form a tank it is necessary to make the embankment so that it may support its own weight as well as hold up water. Clay is a good material through which water will not flow freely, but it will not withstand high pressures when saturated, Experiments have been

made in the Bombay Presidency to ascertain the extent to which earthen embankments of storage reservoirs are saturated, and showed that the water penetrated into the interior of the embankment, free water being found in the holes bored in the bank. Clay used in an embankment to prevent loss of water will become wet when the reservoir is full, and when making a bank it is necessary to provide at the sides some material whose consistency is not affected by water and which will allow the water to drain away freely and hold up the wet clay and prevent it from slipping.

The *muram* of the Deccan, gravel and small boulders are all suitable materials for the casing of the clay hearting of a bank, and the best method of arranging them is with the finer material next to the selected material of the water-tight hearting, and the coarse material on the outside.

The general cross-section of an earthen embankment should be as in the figure shown below :—



The selected material of the hearting should be of some water-tight material, and the outer casing of the best drainage material available.

2. When selecting the material for the hearting it is necessary to remember that the material will not be always, wet, but that when the tank is empty for long periods it will become dry, and many kinds of earth are liable to shrink and crack when dried after being wetted. The black soil of the Deccan is a notable instance ; in the dry season the black soil is broken up by very large cracks, but in the wet weather the soil swells and the cracks disappear. This is, therefore, by itself the most unsuitable material for the hearting of a bank, but it can be made suitable by a proper admixture of *muram* or sand with it.

The material selected for the hearting must not crack seriously when dried after being wetted, and must retain water.

As a rule, brown or grey soils are good material for the hearting of a dam, but there are some soils of these colours which are most unsuitable. In the Deccan the local name of "*karal*" earth is given to them, but they can often be distinguished by the way the earth breaks up when excavated. Any grey or brown soil which, when excavated, breaks up into pieces with sharp angles and smooth shining surface is probably bad, and on the other hand any grey or brown soil which, when excavated, is tough and not brittle, and when fractured tears irregularly, instead of breaking off in smooth surfaces, is probably good. But inspection only must not be relied upon, and the first thing to do when commencing the construction of an earthen dam is to make the following test :—

One or more small tanks should be constructed entirely of the material selected for the "hearting". These tanks may be about 5 feet square at the bottom, and with the sides formed of earthen banks about 5 feet high, and with side slopes of $1\frac{1}{2}$ to 1.

These tanks should then be filled with water, and kept filled until the banks are thoroughly saturated.

Note.—It will, therefore, be convenient to make these trial tanks near the water supply.

After these banks and material have been thoroughly saturated for at least seven days (the longer the better), the tank should be allowed to dry, and should be left until the materials are thoroughly dried. The behaviour of the material during the test should be watched.

If when wet and saturated, it shows signs of melting and flowing, then it is not suitable and should be rejected.

If it is a sound clay when wet and saturated, and when thoroughly dried does not crack or shrink, then it is a very good material and may be freely used in the hearting.

If it is a sound bank when wet and saturated, but cracks and shrinks when thoroughly dried, then it is not suitable for use in its pure from, but can be made so by a suitable mixture of other material.

Black soil is a typical instance of the last case, but by mixing black soil with about equal parts of the *muram* of the Deccan, a mixture can be obtained which will not shrink or crack seriously when dried.

If therefore no natural soil of a suitable character is available, then a mixture of the clay available with *muram*, or with gravel or some similar material must be made, usually in the proportion of 1 to 1, though sometimes as much as 2 of *muram* to 1 of earth may be necessary, until a material is obtained which does not crack or shrink seriously when dried. *Muram*, or disintegrated rock, is the best material for such a mixture. Gravel or broken stones are good, and sand is also a useful material for such mixtures, but not so good as the others mentioned.

In effect the process of preparation is really soil-stabilization which has been discussed previously in the section on ' Roads '. In this case, however, the stabilized material is to be protected from the heat of the sun by the casing, and there is no need to add any hard material to resist abrasion. Being protected from the sun and the action of heavy loads, a larger proportion of clay can be used and without detriment.

Karal is a kind of ' slacking clay ' from which it is impossible to make a ' stabilized ' material, and its use either for a road surface or for any portion of a dam is to be strictly prohibited.

Supposing a good material for the hearting to have been selected, and *muram* or gravel, or some similar good drainage material, to be available for the outer portion of the dam, then the foundation may be prepared for construction.

3. In considering the treatment of the foundations they may be divided into three parts :—

First.—The part under the upstream casing.

If the surface here is of black soil it is desirable to remove it entirely ; but if of a soil which does not crack, or if of sand or gravel, then it may be allowed to remain. It is the least important part of the foundation.

Second.—Under the heart of the dam, the foundation for the selected water-tight material.

This hearting or water-tight material should be founded throughout on good material ; as a rule, in the Deccan, this material will be either *muram*, or good clay soil other than black soil. Black soil, or sand, or gravel, must be entirely removed, and the good foundation obtained. It is not necessary to excavate good clay to get down to *muram* unless there is a layer of sand under the clay, and the clay is not of great depth.

When the foundation on which the hearting of water-tight material is to be placed is *muram*, a trench must be dug into the *muram* and filled with the best water-tight material available. This trench should be dug down to rock, or for 20 feet depth, whichever is less. It is not as a rule necessary to dig more than 20 feet into *muram*.

When the foundation is of good clay, as good as the material of which the bank is to be constructed, no benefit is gained by digging a deep trench into it, and it will be sufficient to dig a trench two feet deep, or to dig a few small trenches in the surface of the clay to form a good junction with the base of the hearting.

Third.—For the foundation, under the downstream casing of drainage material, it is desirable that all the earth be removed and the bank founded on *muram*, or good drainage material. Gravels mixed with silt and liable to slip are not suitable and should be removed, but *muram* or rock are good foundations.

4. When the foundations are rock, impervious to water, it follows that all the percolations and leakage must appear at the toe of the dam, and hence the toe of a dam on rock foundation should invariably be made of boulders, or clean large gravel, or broken stone, through which the percolated water may drain freely.

When the foundations under the downstream casing are sound clay, of great depth, then it is necessary to take precautions against the clay foundation becoming saturated when the tank is full; the clay should be excavated for 5 feet depth under the downstream casing and replaced by *muram* or good drainage material, and at the toe of the bank a trench 10 feet wide should be excavated for an additional 5 feet depth, or 10 feet in all below top of clay, and filled with *muram*, broken rock or gravel, or the best drainage material available, and this trench should be drained by cross-trenches, of similar construction, cut wherever the ground admits of facilitating the drainage. The object of these drains is to keep the natural ground at the toe of the dam as dry and sound as possible so that the toe of the dam is not likely to slip.

In places where *muram*, or gravel, is not readily available for the downstream portion of the dam, and it is necessary to construct the bank almost entirely of earth or clay, then the berms or benches must be made on the downstream slope of the dam, in order to provide a mass of dry material which will prevent the saturated material of the heart of the bank from sliding down. The experiments to ascertain the line of saturation in earthen embankments of storage tanks in the Deccan indicate that in clayey material the line is not steeper than a slope of 1 in 4, and if the clay is very retentive it may be flatter than this. The berms must, therefore, be arranged so that they are clear of a line drawn, with a gradient of 1 in 4, from the maximum water level of the tank.

Drains should also be constructed in the rear portion of the bank with the object of keeping it dry and so able to resist the sliding of the saturated hearting, but these drains should be arranged so that the material in the berm is also kept dry.

5. **Filling the puddle trench.**—For the filling of the trench dig down to rock or 20 feet into *muram*. When the foundations are porous it is not necessary to use wet puddle, unless the trench itself is wet.

When the trench is wet, the clay to fill it may be made into good puddle on the surface and then transferred to the trench and well trodden down and rammed into a viscous mass.

When the trench is dry, nothing is to be gained by making wet puddle to put in the trench, but, on the contrary, the moisture will probably dry out, or be absorbed, before the tank can be completed, and the material is liable to crack badly. In dry trenches, the selected materials should be put in dry, and thoroughly consolidated, care being taken to break up the dry pieces into less than half-inch cubes. There is no objection to a little water being used to damp the material during construction, but it is not necessary, and, as a rule, the use of water in a dry trench should be prohibited.

6. The selected material in the heart of the dam should be thoroughly consolidated, and it must be deposited in thin layers and thoroughly rammed and rolled, the material being broken up into less than half-inch cubes.

The material as deposited must therefore be spread out into as thin layers as practicable; they should not exceed 6 inches in thickness, but layers of 3 inches or less are better.

The best method of consolidation is by carts. Carts lightly loaded should be kept on the embankment, and be constantly driven in all directions over the surface of the earth as it is deposited. In this manner, the whole of the material up to the very edge of the dam can be consolidated. Carts can be used amongst the workmen and hence 3-inch layers are easily obtained and consolidated when carts are used.

The next best method to using carts is to consolidate by steam rollers. The intensity of pressure and final consolidation by steam rollers is not equal to that obtained by carts, and there is risk of the layers being deposited in greater thickness than is desirable, when steam rollers are used instead of carts.

Ramming by hand rammers is an inferior method of consolidation, and should only be resorted to when carts cannot be used.

7. **Pitching.**—When the embankment has been completed it is necessary to protect the surface on the water side, from erosin by waves. Wave actions washes out earth, and the best kind of pitching is formed by first depositing a layer of not less than six inches of broken metal, or screened gravel of about 2½ inch guage, upon the earthen surface of the bank, and then laying upon this metal, or gravel, ordinary quarry rubble, or boulders, packed by hand so closely that the waves cannot wash out the broken metal through the joints of the rubble.

The quarry rubble must be large enough to remain unmoved by the blow of the waves, and for small tanks stones of 40 lbs. weight will be ample size, but for larger tanks at the top of the dam it will be desirable to have stones of 60 to 80 lbs. weight, and to pack between them with smaller rubble.

8. If the above explanations have been read then the more concise specification now given below will be readily understood.

Note.—The height of waves in feet is given by the formula—

$$H = 1{\cdot}5\sqrt{F} + (2{\cdot}5 - \sqrt[4]{F})$$

where F is the "fetch" (or distance for which it acts on the water) of the wind in miles.
H = hight in feet.

SPECIFICATION No. 178

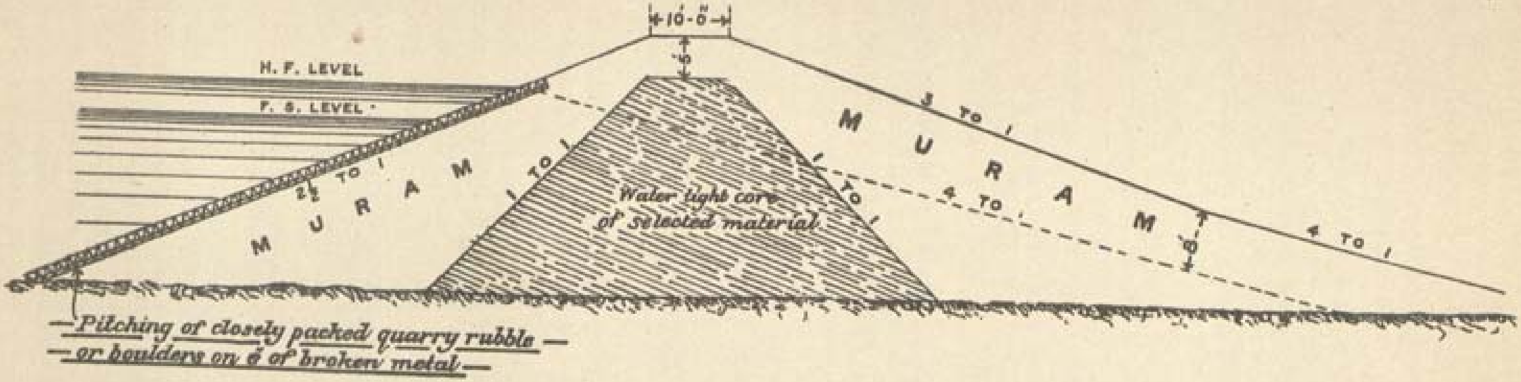
FOR AN EMBANKMENT FOUNDED ON MURAM OR ROCK OR SIMILAR SOUND FOUNDATION, AND WHEN MURAM OR GRAVEL IS AVAILABLE FOR CONSTRUCTION

1. *Vide* plate CXIV. The bank to consist of hearting of selected material which will retain water, and which will not crack when thoroughly dried after being wetted.

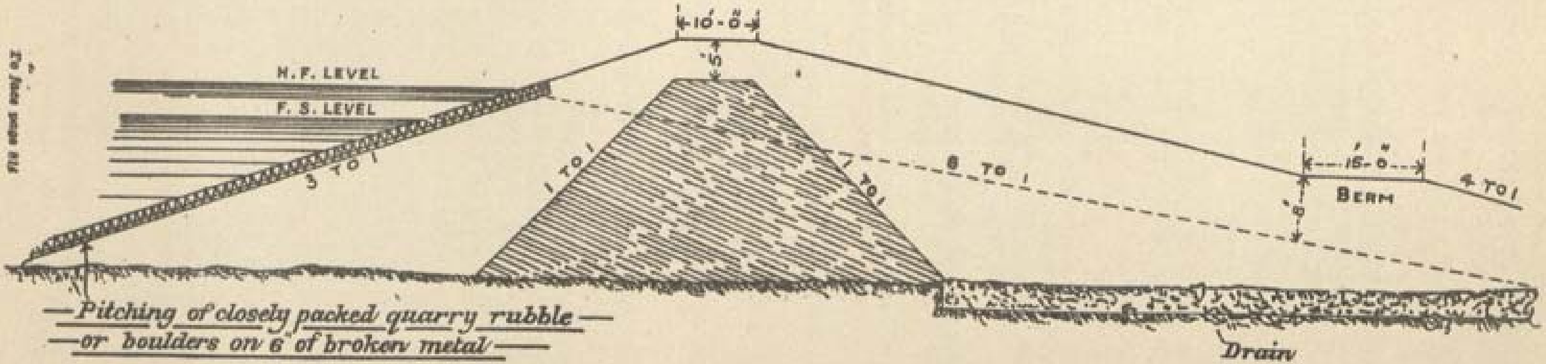
The top width of this material to be 10 feet at the highest flood level and the side slopes to be 1 to 1.

—SECTION OF EARTHEN EMBANKMENT—

—When Muram or good Drainage material is available—



—All Earth, no Drainage material available cheaply—



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The top of this selected material hearting is kept 2 feet above the H. F. L., and if this selected material is available in sufficient quantity, the side slopes may be eased to 1½ to 1.

The whole of the selected material to be enclosed in a case of *muram* and similar good drainage material.

The top of the bank to be not less than 5 feet above the maximum flood level and 10 feet in width. The slope on the water face to be not less than 2½ to 1 and on the downstream face to commence at 3 to 1 and to be kept at least 8 feet above the position of a line commencing at the maximum flood level on the water or upstream face of the bank and drawn with a slope of 1 in 4. Should the downstream face approach nearer to this 1 in 4 line than 8 feet, berms 15 feet wide are to be provided.

The cover over the line of saturation commencing at the full supply level of the tank, should be 8 feet only in the *nalla* or river bed portion, and should gradually decrease to 4 feet only on the sides.

The water face of the dam to be protected by pitching.

If the bank be founded on porous material a trench of not less than 10 feet width to be dug along the centre line and filled with water-tight material.

2. **Preparation of foundation.**—The foundations under the whole of the embankment are to be cleared of surface soil and of all black soil.

Under the central hearting a trench to be excavated down to rock or not less than 20 feet into soft *muram*; the width to be 10 feet at the bottom.

For the foundation under the downstream casing all earth to be cleared away down to the *muram* or sound porous foundation.

The surface soil and black soil removed should be carried beyond the downstream toe and deposited in a neat bank.

The *muram* excavated for the trench may be at once placed in the outer casing of the bank.

3. **The filling of the trench.**—The trench is to be filled with the selected water-tight material described.

If the trench be wet, the material may be formed into puddle balls of convenient size and the balls thoroughly rammed and trodden into a solid mass in the trench as they are deposited.

If the trench be dry, water should not, as a rule, be used, but the selected material should be spread in 3″ layers and thoroughly consolidated after being broken into pieces not larger than half-inch cubes. For consolidating the material in the trench a convenient plan is to employ a continuous row of men provided with rammers weighing 20 lbs.; the consolidation to be as complete as practicable.

4. **Construction of the embankment.**—The material is to be deposited in layers not more than 6 inches thick, and if possible 3 inches in thickness. To obtain this the earth deposited must be spread out. In the water-tight hearting all pieces must be broken to not more than half-inch cubes, and the material thoroughly consolidated by carts lightly loaded and driven in all directions over the bank; steam rollers may be used for consolidation, and also hand rammers, but carts are the best. The feet of cattle are of wonderful efficacy in consolidating a bank, and hence the carts should be drawn by cattle and not by gangs of labourers.

The *muram* casing, both upstream and downstream, should be deposited simultaneously with the hearting, and in layers of about the same thickness, and should be consolidated in a similar manner, but it is not necessary to break the pieces to half-inch cubes.

The *muram* of the upstream casing may be all fine or small *muram*, but for the downstream casing care should be taken to arrange the material as far as possible in the manner of a filter, with the small material against the water-tight hearting, the medium size in the centre, and the coarse material and boulders on the outside.

When the foundations are rock, the toe of the embankment must be formed of broken stone or boulders, admitting of free drainage, for a width of at least 20 feet and depth of 5 feet or more.

The borrow pits from which the materials are obtained for the construction of the embankment should be on the upstream or tank side of the embankment and at least 100 feet distant from the toe of the bank ; the side of the borrow pit nearest to the bank to slope at 1 in 5.

No borrow pits are to be excavated on the downstream side of the bank.

5. **Pitching**—When the upstream slope of the bank is completed, it is to be dressed true to slope, and a layer of broken metal, or screened gravel, of not more than 2½ inch guage is to be deposited. Upon this quarry metal in pieces of not less than 40 lbs. weight is to be closely packed by hand. The thickness of the hand-packed rubble to be 12 inches for the lowest 10 feet depth of water, and to increase by 6 inches for every extra 10 feet depth.

The rubble is to be packed so closely that the metal or gravel cannot pass through the spaces between the rubble. Quarry spauls of less than 10 lbs. may be used to fill up spaces between the large 40-lb. stones.

6. **Drainage.**—When the downstream casing of the bank has to be founded on clay, the clay should be excavated for the depth of 5 feet, and at the extreme toe of the bank a trench 10 feet wide should be dug 5 feet deeper, and filled with the best drainage material available. This trench should be drained by cross drains laid out to suit the fall of the ground and about 300 feet apart.

7. **Berms.**—*Vide* plate CXIV. When *muram*, or gravel, or good drainage material, is not available in sufficient quantities to construct the outer third of the embankment entirely of *muram*, then the cross-section of the bank must be increased, the upstream slope to 3 to 1, and the downstream slope so as to provid 8 feet of dry material over a line drawn from the point where the highest flood level touches the bank at a slope of 1 in 6, and a wide berm must be provided at the downstream toe of the bank.

The height and width of this berm to be approximately equal to one-third of the height of the bank.

The ground beneath the berm, and beneath the downstream third of the embankment, to be drained by dry stone drains, 100 feet apart, leading into a main drain, 10 feet by 10 feet, of good drainage material at the toe of the berm. This main drain to be provided with cross-drains or outlets to suit the fall of the ground at about 300 feet intervals.

8. **Limitations of earthen embankment.**—As a rule the depth of water to be stored by an earthen embankment should be limited to 50 feet.

SMALL TANKS

Where large reservoirs are to be constructed to store water, the discharge is guaged for some years and the quantity of water availableis generally ascertained with accuracy. For small tanks constructed on *nallas*, with catchment areas rarely above 25 square miles, discharge observations are not usually available, and the supply available (on which the height of the dam depends), is arrived at from the rainfall records in an empirical way. In Beale's Report on Investigation of Minor Irrigation Works, a replenishment of 1/6th of the total average rainfall on the whole catchment is proposed. In the Northern Circle, it is usual to assume 1/5th of the average annual rainfall on the whole catchment, for the Panch Mahals District, and 1/7th of the average annual rainfall in the Kaira and Ahmedabad Districts. Another method adopted is to take as the figure of annual replenishment :—

1/6th of the rainfall over catchment, for average daily falls of 1/2" to 3/4".
1/3rd of the rainfall over catchment, for average daily falls of 3/4" to 1".
1/2 of the rainfall over catchment, for average daily falls of 1" and above.

Mr. Inglis (Technical Paper No. 30) gives the run off from non-ghat catchments away from the hills, as roughly

$$\text{run off} = \frac{\text{rainfall in inches (mean annual)} - 7''}{100} \times \text{rainfall in inches.}$$

For non-ghat catchments away from the hills the top width of the dam is reduced to 6 feet only, while the top of the selected material is kept 1' above H. F. L. the width of this at top, being also kept at 6 feet. For tanks such as those occurring in the Ahmedabad District, and other places where the water-spread is extensive but the depth does not exceed 10 feet, the clearance above H. F. L. to the dam top, may be only 3 feet.

The section adopted for dams in the Panch Mahals District, has two halves, the inner half of the dam being made up of earth given a slope of 1 in 3, and blanketted with a 2 feet depth of *muram*, while the outer half is made up of *muram*, given the same slope as the inner half. A puddle trench is provided and filled with puddle, and in addition, soil is stripped from tne upstream half, and a 2 feet layer of puddle blanket laid over the ground, while a similar 1 foot blanket is laid over the downstream half.

In the Dharwar District, the Sirur tank at Mundargi has a 2½ to 1 one slope on the water side, a 3 to 1 on the land-side, and the dam has a puddle trench, and puddle core above it, the latter being 2 feet wide at H. F. L. and widening at ¼ to 1 towards the base. The dam to the water-side of the core-wall is made up with soil and soft katak, the land-side portion being made up with hard katak (*muram*) and rock.

Run off for Waste-weir provision.

In Northern Gujrat the following provisions are usual :—

Panch mahals District		Kaira and Ahmedabad Districts	
Catchment Area	Inches per hour on catchment	Catchment area	Inches per hour on catchment
Up to 300 acres	3"	Up to 200 acres	2½"
Above 300 acres to 1 square mile..	2½"	Above 200 acres to 500 acres ..	2"
Above 1 square mile to 3 square miles	2"	Above 500 acres to 2 square miles ..	1¾"
Above 3 square miles to 5 square miles.	1½"	Above 2 square miles to 5 square miles.	1¼"
Above 5 square miles to 10 square miles.	1¼"	Above 5 square miles to 10 square miles.	1"

Mr. Strange proposes the following provisions :—

Catchment area in square miles	Average run off from total catchment area in inches per hour
Up to 1	3·00
Over 1 up to 2	2·85
Over 2 up to 3	2·65
Over 3 up to 4	2·49
Over 4 up to 5	2·36
Over 5 up to 6	2·25
Over 6 up to 7	2·16
Over 7 up to 8	2·08
Over 8 up to 9	2·01
Over 9 up to 10	1·95
Over 10 up to 15	1·69
Over 15 up to 20	1·51
Over 20 up to 25	1·40
Over 25 up to 50	1·10

In the Central Provinces it is usual to make an allowance of 12″ rainfall in 12 hours from the catchment area, after the reservoir is full.

Village tanks

Usually not much care is taken in designing and constructing these shallow tanks. The usual procedure is to dig pits upstream of the dam position, some distance away from the inside toe, and to use the material in bunding. The spill is arranged on one of the flanks.

If the tank is to retain water, however, care is necessary at least on the following points :—

(1) *If the strata dip, this dip should not be from the tank basin to the outside of the dam.*—Especially, if the material is trap *murum* which is very permeable. There are some tanks in the Bijapur District (Sindgi, Huvinhippargi, etc.), the water from which emerges in strong springs outside the dam on account of such strata.

(2) With permeable bed material a cut off wall carried down to impervious clay or rock is essential.

(3) The waste-weir provision should not be skipped.

Tank dam failures

There have been two tank dams constructed in the eighties of the last century, which have given trouble off and on throughout their existence.

The Waghad tank dam has a black soil core and *murum* casing is founded on rock in the gorge portion, and on *murum* and boulders at flanks. It was started in 1883 and the downstream portion slipped in April 1884 between chainages 4700—4800 where the dam bank had a height of 85 feet. A second slip occurred in August 1907, also on the downstream, but near chainage 1100 in a length of 110 feet, the bank height being about 29 feet. A third slip occurred on the 24th April 1919 at chainages 4700—4800 but on the *upstream* side. It is noteworthy that the slips in the 4700—4800 high bank portion occurred when the water-level in the tank was exceptionally low. The slip in the chainage 1100 portion, occurred after excessive rains for about a month. During all slips longitudinal cracks appeared in the dam.

The Ashti dam was completed in 1881 and is said to be wholly made of a mixture of earth and *murum*. It has been slipping continuously.

The first slip occurred in November 1883, chainage 5370 to 5525, bank height 43·5′.

The second slip occurred in 1893, chainage 7300 to 8000, bank height 36′.

The third, fourth and fifth slips occurred in January 1933, January 1935 and August 1935, between chainages 7200—7700 ; bank height about 36′.

All the slips occurred on the downstream side, the fifth after heavy rainfall, and the rest all in the years of heavy rainfall.

In the first slip the downstream portion sank 6·4′ on the first day, and the sinking increased to 8·6′ on the second day.

In the 1932 monsoon, the water-level in the tank rose 1 foot above F. S. L in July, and a one-foot depression occurred in the bank. In January 1933, the dam sank 4 feet rapidly. Similar phenomena in 1935, when pits showed that the dam rested on saturated jelly like 'karal'.

In August 1935, the water-level rose by 12 feet very suddenly, and there was movement, mud slurry being forced out downstream, and causing dome-shaped blisters to appear in the swampy ground behind the dam rear toe.

Undoubtedly the dam is constructed of a poor material, 'karal', which is a sort of slaking clay totally unsuitable for a dam, as it disintegrates in contact with water.

The slips in January, no doubt occurred when the water-level sank, thus removing the 'floatation' and increasing the pressure on the slushy bed. The same explanation applies to the slips in the Waghad dam when the water-level was unusually low.

FLOOD ABSORPTION IN TANKS

To calculate length of clear overfall waste-weirs of tanks and reservoirs allowing for flood absorption

Let A=mean area of water spread of tank in square miles, *i.e.*, the mean areabetween the area at level of crest of waste-weir and that at the highest level of water due to a rise, h feet above the crest.

Q=maximum discharge coming in per second (cusecs) due to a maximum run off from the whole catchment.

L=length of waste-weir crest in feet.

T=time in hours taken for the reservoir to rise from crest level to h.

The particular or critical value of h for an assumed value of T, which will make the length of crest sufficient to pass the maximum run off or flood is given by the equation

$$h = \frac{QT}{12894A}; \text{ or } h = \frac{QT}{12900A} \text{ very approximately} \qquad (1)$$

Having chosen a height of flood greater than the critical value given by equation (1), the length of crest can be calculated by the formula,

$$L=\left\{Q-\frac{7744A.h}{T}\right\}\frac{1}{1{\cdot}33\,h^{3/2}} \quad \text{—(2)}$$

The maximum rate of rainfall, and the maximum duration of time during which this maximum run off lasts (T), vary with the situation, size and nature of catchment. This has to be ascertained for each region. The maximum discharges are given by the curve on plate LXXX. The following duration T=time to be taken in calculation, is adopted in parts of the U.P. and is given here as a guide.

TABLE CXCIII

For catchment area in square miles—	Duration in hours.
0 to 5	2
5 to 15	3
15 to 30	4
30 to 50	5
50 to 100	6
100 to 200	6 to 9
200 to 300	9 to 12
300 to 400	12 to 15
400 to 500	15 to 18
500 to 1,000	18 to 21
Over 1,000	21 to 24

OBSERVATIONS TO ASCERTAIN SUPPLIES OF WATER AVAILABLE FOR IRRIGATION WORKS IN TANKS AND RESERVOIRS

1. The following rules are for tanks with a Deccan catchment. For tanks having a ghat catchment they are not suitable : for these tanks it is sufficient to guage the total losses by reading the water levels, and the losses by evaporation in a box. A note in the remarks column should indicate clearly what observations are taken then :—

A.—Loss by leakage

If advisable, the leakage can easily be measured—

(*a*) by a pipe discharging into a vessel of a known capacity,
(*b*) by a notch in still water,
(*c*) by a Cippoletti weir.

B.—Loss by evaporation

A thoroughly water-tight metal box, 6′×6′ by 3 feet deep with the portion above the proposed water level protected by wood and painted within and without with a water-proof paint, should be kept immersed in water and filled once a week up to a line which should be clearly marked on all the 4 sides. The hook guage should be used for finding out the vertical loss in feet.

C.—Loss by absorption

This can only be found by gauging the whole loss and deducting A and B from it.

To guage the whole loss is a very difficult operation.

2. The following arrangement appears to be suitable and satisfactory :—

The observations may be made for 4 continuous days or more, at or near the middle of each month. They should be—

(*i*) gauging in flow—

(*a*) if small, the Cippoletti weir should be adopted ;

(*b*) if too much for this, the flow should be measured as for hot weather flow in rivers ;

(*c*) for large inflows, no measurements are necessary and all observations may cease.

It is only the visible inflow with which we are concerned and it would be sufficient to decide in each case what extent of flow is of importance.

If, for example, we take the Nher tank, area of surface at full supply = 676 acres = 29·5 million square feet. Taking half this area,

the evaporation at $\frac{1}{4}''$ = 306,750 c. ft. per diem.

the evaporation at $\frac{1}{2}''$ = 613,500 c. ft. per diem.

The latter is equal to 7 cusecs, the former to $3\frac{1}{2}$ cusecs.

In such a case the inflow of 3 to 7 cusecs would be a very appreciable addition to the lake, neutralizing entirely the loss by evaporation.

If we take the Ashti tank the surface at F.S.L. is 2,830 acres = $123\frac{1}{2}$ million sq. ft. Half this area = 62 million s. ft.

		Per diem c.ft.		Cusecs.
Evaporation at $\frac{1}{4}''$	=	1,300,000	=	15
Evaporation at $\frac{1}{2}''$	=	2,600,000	=	30

In this case small discharges of 3 cusecs would be negligible.

(*ii*) gauging outflow—

(*a*) The easiest system is to take the discharges through the known sluice opening with a proper co-efficient (say 0·7) under the difference of head between the tank and canal ;

(*b*) but this can easily be checked occasionally by observations on a suitable gauge in the first $\frac{1}{4}$ mile.

Note.—Special care will have to be taken that there is no fluctuation of discharge during the time or that, if there is, the discharge for each period is calculated separately. It is better, however, to make observations on days when there is no outflow if it be possible to keep the sluices closed ; then (ii) vanishes.

(*iii*) Reading the water level—

To procure a still surface, a gauge chamber or gauge pipe and float is necessary.

Note.—An automatic guage recorder is a useful instrument, but probably sufficiently accurate readings can be got without it.

The volume of the tank should be worked out for each foot in height, from the areas of the known contours, and a curve should be drawn on such a scale that the required intermediate areas can easily be read off.

To the apparent loss obtained from (*iii*) above, add the inflow (*i*) above and deduct the outflow (*ii*) above (if any). This will give the total loss for the period considered. Then deduct A and B to find the balance C.

No observations should be taken on rainy days, or on days when water is entering the tank from numerous streams.

EVAPORATION FROM TANKS

There is not much data available for the monsoon, and the figures for this period inevitably refer only to observations taken during breaks in the monsoon, and hence must be appreciably higher than the average.

The following statement shows losses in feet per day :—

—	Monsoon	Nov. to Feb.	March	April	May
Ghat tanks ..	0·010′—0·018′	0·012′—0·015′	Min. 0·018′ Av. 0·021′ Max. 0·029	0·023′ 0·025′ 0·031′	0·024′ 0·027′ 0·033′
Deccan tanks ..	0·010′—0·024′	0·016′—0·022′	Min. 0·016′ Av. 0·023′ Max. 0·034′	0·020′ 0·030′ 0·035′	0·030′ 0·038′ 0·046′

It thus appears that for ghat tanks the average loss throughout the year is 0·017′ per day or 6·2′ per year, as against 0·022′ per day or 8′ per year on the mean area for Deccan tanks ; while the figures for the fair season from 15th October to 14th June may be taken as 5 feet and 6 feet, respectively.

RULES REGARDING OBSERVATIONS TO ASCERTAIN THE DISCHARGES OF CANALS AND THE LOSSES IN DISTRIBUTION, ETC.

1. The observations to ascertain the discharges of canals and the losses in the distribution are of three kinds—

(*i*) Observations to determine the value of N in Kutter's formula, to ascertain the efficiency of discharge of each canal.

(*ii*) Observations to determine the loss of water by evaporation and absorpion, to show the comparative tightness of channels in different parts of the country.

(*iii*) Observations to determine the quantity of water required to give an acre of ground one watering, to ascertain the practice of cultivators when irrigating various kinds of crops.

2. Each of these observations requires great skill, care and thought for proper execution and certain preliminary arrangements are necessary before they can be carried out.

3. **Two men or more for each observation.**—All observations should be taken by two men at least and it would be well for officers to be always accompanied by two or more men for the purpose of instruction and for the demonstration of the care required in the operations.

4. **All details to be recorded in bound books.**—The observations and calculations in connection with them must be entered in bound books, properly paged, numbered and registered for the purpose.

5. If an observation is done badly or is wrong in any important respect, the results should be rejected at once, and the observer should be directed to make a fresh observation. Unexpected results are not necessarily wrong and the Executive Engineer should try to discover reasons for variations from normal results, if he is unable to find any flaw in the work submitted to him.

6. **Limit of accuracy in calculation.**—The limit of accuracy in calculations should be 1 per cent. Thus for all figures of 100 or more, no decimals are required.

Preliminary Arrangements

7. **Gauge runs.**—For the first and second observations gauge runs have to be selected. A length of 100 feet is about as much as can usually be managed because of the difficulty of getting the velocity rods to run down the proper lines parallel to the centre of the canal. In small canals the gauge run will be shorter.

8. Three wires of steel cables should be stretched across the canal, one at each end, and one at the centre of the run ; on these wires tags should be hung at regular intervals to divide the canal into compartments. The distance apart of the tag will be 10 feet, 5 feet or as little as 1 foot, according to the size of the canal.

There must be a gauge fixed in still water, reading to 1/100 foot at the centre of the run, and the canal section should be as regular as possible.

9. **Selection of site.**—The run must be chosen in such a place as to be free from disturbance, far from curves, rapids, regulators, falls, and other masonry works.

For the second observations a portion of canal in ordinary cutting should be selected for the gauge run and lined, so as to preserve a good sectional area, but wherever this is not feasible, aqueducts, though not quite suitable, may be used.

10. **Measuring the surface slope.**—For the purpose of the first set of observations it is necessary to ascertain the surface slope of the water. This being a small dimension compared with the length, it should be measured very accurately on as long a length as possible, extending equally above and below the gauge run. This length may be considerable on the large Sind canals, *viz.*, 3,000 to 5,000 feet, but in the Deccan, where the canals are mostly in contour and often pass through rock cuttings and over aqueducts the length will be comparatively short. In most rock cuttings a small drop and an increased bed fall are given, and drops are often given at aqueducts also. The observation of water surface should be away from the influence of such disturbances and the places for the upstream and downstream gauges must, therefore, be selected with very great care.

11. The two gauges must have exactly the same zero level (for this purpose very careful check levelling should be done), then the difference of reading will give the slope accurately.

12. The gauge should be fixed on well founded masonry pillars or firm iron rails so as to be immovable and permanent, and they should be placed in a recess, so as to be free from wave action.

13. **Velocity rods.**—For observing the means velocity, rods of uniform diameter should be used, weighted so as to float vertically and clear of the bottom. An increase of diameter in any part of the rod will give incorrect results. In large canals the rods may be 6″ clear of the bottom, but in smaller channels it should be less, and several rods of different lengths may be required for canals of uneven section.

Discharges of the Nira Left Bank Canal are observed in aqueducts which are of restricted section, causing high and various velocities ; but on the newer canals lined gauge runs have been constructed. In perfect sections of this type it is probable that observing the discharges with discharge rods—weighted so as to float at 94 per cent of the full depth—give highly accurate results : but in less favoured situations current meters are more reliable.

For observing the losses from small channels—especially where there is ample gradient—standing wave flumes or orifices should be employed for observing the discharges, but if not available, a Cippoletti weir can be used for discharges from 2½ to 40 cusecs.

For very small discharges a properly constructed sharp-edged rectangular V notch ($Q = ^{2.5} H^{2.5}$) is the best.

14. **Stop-watches.**—For timing the rods, stop-watches should be used.

15. **Measurement of small discharge on to fields.**—For the third set of observations the principal difficulty is to measure the water used. The discharge is necessarily small and should be measured by Cippoletti weir, or by a suitable notch, or by filling cisterns. The latter can be used only for very small discharges, *viz.*, when water is lifted by animal power.

Details of Observations

16. **Observation to ascertain the value of N.**—For the first set it is important to obtain the surface slope uninfluenced by any heading up or draw-off. The sectional area of the canal should be measured at the top, middle and end of the gauge run, the velocity should be read three times for each division of the run ; then the discharge for each division will be the average area multiplied by the average velocity , and the sum of these discharges will be the whole discharge of canal = D. Dividing this by the sum of the average areas, A will give the average velocity V. The average wetted perimeter P must also be calculated, then the value of N can be deduced. A description of the canal section should be given stating materials and condition of canal, also a note of wind and its direction.

17. In taking the velocity readings the rods should be put into the canal 50 feet (or if less, as far as possible) above the gauge run. Any rod touching the bottom or sides should be taken out and restarted. No co-efficient of correction is necessary if the length of the rods is carefully regulated. The rods should pass down each individual section for a satisfactory observations to be obtained.

18. The level of the canal must of course be steady during the observation. With the water level fluctuating from day to day the surface fall cannot be correctly obtained.

19. **Observation for loss of water.**—For the second set of observations the discharge will be gauged as just described ; only the average area and velocity are required at each place. The difference in discharge at the upper and lower gauge run will give the actual loss by evaporation and absorption, if no water has been taken off between. The discharge at the lower station should be

taken $\frac{\text{distance in mile}}{\text{mean velocity in miles}}$ hours after the upper observations to enable the water to traverse the distance between the two. In calculating this it must be pointed out that the mean velocity of a canal is practically always lower than that of the discharge sites, and where an aqueduct is used as a discharge observation station, as on the Nira Left, the mean velocity is very much less than the aqueduct velocities. The time of each observation should be recorded.

20. The longest possible distance should be experimented with, but it will often be difficult to operate on a length of more than 2 to 3 miles of a canal without any draw-off. But every extra measurement made for any draw-off will diminish very much the value of the observation because the error in readings varies considerably in large and small channels. In carrying out canal loss experiments all off-takes in the length in which losses are to be measured should, therefore, be closed at least 24 hours before the upper discharge is observed, and the draw-off below the lower section must also be steady for at least 24 hours before the lower observation is taken to prevent any fluctuation of water level, which would affect the observation.

21. **Observation for quantity of water used for one watering.**— For the third set of observations the matter resolves itself into a question of time. The observer must be present throughout the experiment so as to discover any variation in flow over the notch, or to count the number of cisterns filled and emptied. He should note the area of the ground watered, the kind of crop growing, the nature of the ground (both the material and the condition), the method of watering whether the quantity appeared to be what was required, and particularly the date of the last watering and whether rain had fallen in the interval.

THE RESULTS OF OBSERVATIONS OF LOSSES FROM CANALS

1. Losses from tanks and canals are due to evaporation and seepage; seepage losses include those due to percolation and absorption.

2. The loss by evaporation from tanks is measured as previously described by observing the loss from a small metal cistern kept floating in the tank; but evaporation losses from canals are not calculated separately being but a small fraction of the total losses 1/10th to 1/60th.

3. In percolation the pressure is positive as in pipe flow. In absorption the pressure is negative and flow is due to capillarity.

Although subsoil flow almost always starts as percolation in soils the pressure is damped out almost at once and so losses are very little affected by the head of the water in the canal, and may be looked on as due to absorption, and hence affected only by the extent of the wetted perimeter. This is the case in Sind and in soils generally.

In the Deccan, however, most of the loss takes place through the highly permeable murum stratum and rock fissures and so is in the form of percolation and hence the loss increased directly with depth.

Probably owing to the horizonal stratifications of Deccan trap it is found that the loss through the beds of Deccan canals is small as compared with the loss through the sides, and it may be ignored for normal working depths.

Hence as the loss varies as the surface of the side slope (which is proportional to the depth) and also as the depth, it varies as depth squared and the formula for losses takes the form, losses $=$ C.D.^{2}, the co-efficient C being a measure of the permeability of the strata of the canal.

4. C is high for new canals ; but rapidly diminishes where there is a constant flow ; but where the flow is intermittent or ceases altogether in the hot weather the co-efficient remains high:—

Canal and section	Canal opened.	C in loss = C.D.^{2}
Nira Left, perennial section	1885	0·023
Godavari Right Bank Canal, perennial section ..	1912	0·038
Godavari Left Bank Canal, perennial section ..	1915	0·051
Pravara Left Bank Canal, perennial section ..	1929	0·042
Nira Left, non-perennial section		0·10
Godavari Right Bank		0·21
Pravara Right Bank		0·12
Pravara Right Bank, tail section		0·67

5. It so happens that the discharges of Deccan canals also vary approximately as D^2, and so once the percentage figure has been ascertained by experiments the losses for any particular section of a canal can be calculated more easily as a percentage than on a D^2 basis. It must be emphasised, however, that this only holds for a particular section of a single channel and if water is not headed up by regulators or weed growth, and it must also be remembered that the percentage only holds when C remains constant, and as C largely depends on the constancy of supply, the same canal if run with a fluctuating water level will have a higher loss than one, run with a constant uniform discharge.

6. From the formula it will be seen that losses are greatly affected by depth and they are only slightly affected by bed width ; hence the loss from a wide shallowish canal will be much smaller percentage of discharge than from a narrow deep canal.

This is exemplified in the case of the Godavari and Pravara canals.

Canal	C. in loss = C. D^2	Loss per % mile
Godavari Right Bank Canal (large)	0·038	0·42
Godavari Left Bank Canal (medium)	0·051	0·76
Pravara Left Bank Canal (large)	0·042	0·63
Pravara Right Bank Canal (small)	0·12	1·6

Bearing the above in mind and also that all canals so far constructed will have to be enlarged, and that widening is almost out of the question for a perennial canal, the advisability of constructing wide channels to start with is manifest.

Losses from distributaries and watercourses.—In perennial distributaries with normal soil section,

loss in cusecs per mile $= 0{\cdot}16 \sqrt{Q}$ approx.

Where Q is the mean discharge of the channel.

In the case of Dy. 8 of the Nira Left Bank Canal which is partly in murum cutting and which runs on a ridge,

loss per mile is cusecs $= 0{\cdot}22 \sqrt{Q}$

When the outlet channel is fully in murum cutting and the channel flows along a falling contour of say 1 in 1,000, the losses are very heavy, *viz.*, loss per mile per cusec $= 0{\cdot}53 \sqrt{Q}$, in the case of one such channel[1], puddling the bed and sides of the channel may be necessary.

GLOSSARY OF IRRIGATION TERMS APPLICABLE TO THE DECCAN CANALS

1. **A canal** is the main channel of an irrigation scheme from which as a rule, no direct irrigation takes place.

2. **A branch canal** is a channel taking off from the main canal, which has the same function as the main canal, *viz.*, carrying water to distributaries.

3. **Distributary**—

(*a*) **A major distributary** is a channel taking off from the main canal or a branch canal, and its main function is to supply water to minor distributaries and outlets.

(*b*) **A minor distributary** is a channel taking off from a major distributary, and supplying water to outlets.

4. **An outlet** is a regulating device through which water is supplied to water-courses. They are numbered serially from head to tail of the distributary or minor, and where two face each other the one on the right bank has the lower number.

5. **A minor** is a branch of a distributary and has the same functions as a distributary. A minor is given the name of the village mainly served by it.

6. **A water course** is a channel taking off from a Government channel and irrigating fields.

7. **A ghat-fed canal** is a canal fed from a storage which derives its supply from unfailing monsoon rain in the "ghats"

8. **A tank-fed canal** is a canal fed from a storage which obtains an unreliable supply from a non-ghat catchment.

9. **A perennial canal** is a canal that receives a supply of water throughout the year.

10. **A non-perennial canal** is a canal that normally does not receive a supply of water throughout the year.

11. **A balance or balancing tank** is a subsidiary reservoir for storing excess river water which is utilised during periods of short supply.

12. **A tail tank** is a reservoir supplied with water from a canal whenever in excess of canal requirements, having its own command and usually situated near the tail of a canal.

13. **A pick-up weir** is a masonry weir constructed across a river at the head-works of a canal to raise the level of water sufficiently high for it to flow into the canal.

14. **A bandhara or haran or nala pick-up weir** is a weir across a nala to divert water into a channel for irrigation.

15. **Rotation** means, in the case of outlets and distributaries, a recurring supply of water to them according to a fixed programme ; in the case of canals, it means a recurring concentration of irrigation in particular lengths.

16. **A module** is a device for ensuring a constant discharge of water passing from one channel into another, irrespective of the water level in each, within certain specified limits.

17. **A semi-module** is a device the discharge through which varies according to the head of water in the parent channel, but is unaffected by the downstream fluctuation.

Note.—The term 'rateable' may be applied either to modules or semi-modules and means 'that can be rated or set'. A semi-module is said to be proportional when it draws off a supply directly proportional to the discharge flowing in the parent channel.

18. **A meter** is a device for measuring quantities of water passed or rate of flow.

19. **Base** is the period on which a 'duty' is calculated. There are three bases in common use in the Deccan.

(For 'duty' see item 46).

Base periods

(*a*) Rabi ..	.. ..	15th Oct. to 14th Feb.	1 cusec for 123 days. =10·627 M. C. Ft. =246 acre-feet.
(*b*) Hot weather	..	15th Feb. to 14th June	1 cusec for 120 days. =10·368 M. C. Ft. =240 acre-feet.
(*c*) Monsoon	.. ..	15th June to 14th Oct.	1 cusec for 122 days. =10·541 M. C. Ft. =244 acre-feet.

20. **Daily discharge** (in cusecs) is the total flow (in cubic feet) in a day divided by number of seconds in 24 hours (86,400).

20 A. **Discharge** at any (normal to flow) section is the quantity of water passing that section in unit time.

21. **Supply** is water which enters a canal head less water escaped into nalas or tail tanks.

22. **Mean supply** is the sum of the 'daily discharges' utilised (*i.e.*, less escapage) divided by the number of days of 'base' period.

23. **Mean discharge** is the sum of the daily discharges of any 'base' period divided by the number of days.

Note.—If the whole discharge is utilised mean supply and mean discharge are the same.

24. **Open discharge** is the number of 'day-cusecs' passed into a channel divided by the number of days the channel was open or in other words the 'mean discharge' for days in flow.

25. **Day-cusec** is a unit of quantity of water equal to 86,400 cubic feet and is equivalent to 1 cusec flowing for 24 hours.

25 A. **A cusec** is the unit of discharge, and means a discharge of one cubic foot per second.

Note.—11½ day cusecs = 1 M. C. Ft. (very approximately).
1 day cusec = 2 acre-feet (very approximately).

26. **Acre-foot** is a quantity of water equivalent to one foot depth on one acre.

Note.—1 Acre-foot = 43,560 cubic feet.
= 12 hours cusecs (very approximately).
23 Acre-feet = 1 M. C. Ft. (very approximately).

27. **Capacity** is the full supply discharge of a channel.

28. **Capact factor** is the ratio of mean supply to 'capacity'.

29. **Rabi capacity factor** is the ratio of mean supply of rabi season to 'capacity' (50 per cent to 60 per cent for Deccan canals).

30. **Full suppl y co-efficient.**—The number of acres irrigable per cusec of capacity of a channel at its head.

Note.—The controlling factor in the design of a channel is the rabi 'full supply co-efficient'. This varies in the Deccan according to types of crops to be grown being as low as 50 for cane, and as high as 120 for rabi crops only. The record year on the Nira gave 92, and 80 is a fair figure for ordinary proportions of crops on perennial canals.

31. **Time factor** of a channel is the ratio of the number of days the channel is in flow to the 'base'. The most convenient 'base' for this calculation is the normal ten-day rotation period. If in a ten-day period the channel flows for 4 days and nights, and 6 days, the time factor is 7/10ths.

32. **Gross area** is the total area included within the farthest limits up to which the canal water is proposed to be supplied.

33. **Gross commanded area** is the area arrived at after deducting from the 'gross area', such areas within irrigation limits, as are commanded by the Project.

34. **Actual command** is the area on which water will flow from a complete canal system as constructed or likely to be constructed.

35. **Culturable commanded area** is the portion of 'gross commanded area' which is culturable.

36. **Actual irrigable command** is the portion of the 'actual command' which is suitable for irrigation.

37. **Area irrigated** is the area to which water is actually supplied.

38. **Area assessed** is the area on which assessment is charged.

39. **Intensity** is the percentage of the 'area irrigated' bears to the 'actual irrigable command'.

40. **Eight months' leases** are permits for a term of years under which sufficient water is reserved for rabi irrigation in the leased area, the rate being the rabi rate for that area ; instead of rabi crop such proportion of other crops which require the same amount of water during the rabi season may be grown (*e.g.*, 1 acre of 8 months for 1½ acres of rabi). In the monsoon season the lessee may grow monsoon crops up to the full area or such area of other crops as require the same amount of water on payment of the seasonal rate.

41. **Block Areas** are demarcated areas for which water is sanctioned for a term of years and within which any crop may be grown in the monsoon and rabi seasons subject to the proviso that not more then ⅓rd the area shall be under sugarcane. During the hot weather season only cane or any equivalent area of other crops is allowed (*e.g.*, 1½ acres 'hundi' or other perennial=1 acre cane).

42. **Overlapping** cane is old sugarcane crop which remains uncut after the new cane is planted.

Note.—This is usually allowed because 'pundia' cane is a thirteen months' crop and also because a cultivator may not be able to crush his cane at the proper time owing to shortage of labour, etc.

43. **Adsali** cane is sugarcane which is watered beyond the period of original sanction. **Long term adsali** is cane which is not cut till after the end of the monsoon.

44. **Khodva** is first ratoon, *i.e.*, crop which spring from the 1st cutting. *Nidva* is second ratoon, *i.e.*, crop which springs from the 2nd cutting. *Rodva* is third ratoon, *i.e.*, crop which springs from the 3rd cutting.

45. **Delta** is the total volume of water delivered.

(at the field or at the outlet or at the head of a canal), divided by the area on which it has been spread.

46. **Duty** is the area irrigated in a 'base' period divided by 'mean supply' of 'base' period.

47. **Nominal duty** is the area for which permits have been granted for a 'base' period divided by 'mean supply' of 'base' period.

Note.—Duties pertain to three seasons :—

1. Hot weather,
2. Monsoon,
3. Rabi,

and the various crops irrigated must be reduced to a common basis. On the larger Deccan canals the hot weather duty is calculated on a sugarcane basis, thus :—

Sugarcane for three months counting as $\frac{3}{4}$th sugarcane crop for four months season.

Do.	1	do.	$\frac{1}{4}$th	do.	do.
Do.	1 watering	do.	1/12th	do.	do.
$1\frac{1}{2}$ acre hot weather or ordinary perennial			1 acre	do.	do.

The monsoon and rabi duties are calculated on a seasonal basis, thus :—

1 acre sugarcane = 3 acres seasonal crops.
1 acre 8 months' = $1\frac{1}{2}$ acres do.
1 single watering = $\frac{1}{3}$rd of a seasonal crop.

48. **Capacity co-efficient** is the number of acres irrigated in one day per cusec of supply. (As this figure is affected by the rotation period it is necessary to state this also, and the full wording will be 'Capacity Co-efficient on a 10-day rotation basis' etc.).

49. **Crop ratio** is the ratio the sugarcane area bears to eight months' rabi and monsoon areas.

50. **Canal losses** consist of losses by percolation, absorption and evaporation.

Note.—Hitherto losses have been calculated at eight cusecs per million square feet of wetted area uniformly throughout the system. This was based on the assumption that losses took place uniformly from the bed and sides.

In the Deccan, however, losses are chiefly due to percolation by sidelong flow and hence losses are mainly affected by the depth of water in the canal and the strata through which the canal passes. This has been borne out by a recent consideration of availabe data which showed that for usual depth the losses from the perennial section of the Nira Left Bank canal varied very approximately according to the depth of water; while percentage losses per mile, square feet were much greater from small than from large channels.

IRRIGATION SEASONS, CROPS AND WATER RATES

TABLE CXCIV.

The following table gives the irrigation seasons, crops and water rates charged at present on the Deccan canals :—

Serial No.	Season.	Base period	Usual crops	Water-rate. Season	Water-rate. Single watering	Water turn	Remarks.
				per acre			
1	Hot weather ..	15th Feb. to 14th June.	Hundi and fodder crops like kadwal, kandya.	Rs. 7	Rs. 2	15 to 20 days.	
2	Monsoon ..	15th June, to 14th Oct.	Bajri, maka, mug, tur, udid, matki, rala vara, howri, hulga, kadwal, karala.	Rs. 3	Rs. 1 ..	20 to 30 days.	
3	Rabi ..	15th Oct. to 14th Feb	wheat, gram, linseed, jowari, kardal, javas.	Rs. 5	Rs. 2	.. Do.	
4	Eight months ..	15th June. to 14th Feb.	Onions, turmeric, chilles, brinjals, sal (rice) ground-nuts, cotton, to-bacco, sweet potatoes, tur, ratale, garlic.	Rs. 12 ..		10 days to 12.	
5	Perennial (A) ..	12 months ..	Sugarcane	R . 45 ..		Do.	
	Perennial (B) ..	12 months ..	Pan garden	Rs. 30 ..		Do.	
	Perennial (C) ...	12 months ..	Plantain, mango and other fruit, lucerne and vegetable.	Rs. 22-8		Do.	
6	Perennial block	12 months ..	$\frac{1}{4}$ Sugarcane + $\frac{3}{4}$ Bhusar crop.	Rs. 20 ..		According to crop	See foot note for bhusar crops.

Note:—(1) Bhusar crops.—All monsoon, rabi, and 8 monthly crops are called bhusar crops.
(2) The above rate hold good only if the sanction for taking water is obtained befor irrigating any crops.
(3) Permission for irrigation shall ordinarily be given for areas which are multiples of twenty gunthas. Assessment shall be levied on multiples of 10 gunthas, any area smaller than 10 gunthas being treated as 10 gunthas unless otherwise specifically sanctioned.

QUANTITIES OF WATER REQUIRED FOR WATERING VARIOUS CROPS

When it is known what volume of water is required to irrigate an acre of ground, then with suitable allowances for the losses in canal and distributary channels, the area a canal can irrigate can be accurately ascertained. The canal cannot irrigate a larger area than it can water, with the minimum depth required to cover the ground, during the interval between two waterings required for the crops under consideration. In the case of an inundation canal, the volume may vary at the time when most waterings are required, but in the case of canals supplied from a weir or storage where the canal can be run full whenever required the maximum area the canal can irrigate at any one time is ascertained by deducting the losses in distribution and dividing the product of the remaining discharge for a day and the number of days between two waterings by the volume required to water one acre.

The figures for the quanti of water required to give an acre of ground one watering for some of the crops are shown below :—

TABLE CXCV.

Serial No.	Name of crop	Volume of water required per acre in c. ft. for one watering	Average depth of water required in inches
1	Rice	15,000 to 20,000 ..	4·1 to 5·5
2	Jawari and Bajri ..	10,000 to 12,000 ..	2·7 to 3·3
3	Sugarcane	11,000 to 15,000 ..	3·0 to 4·1
4	Gram	8,000 ..	2·2
5	Wheat	5,000 ..	1·4
6	Groundnut	6,000 ..	1·7
7	Maize and Sadak 1½ month old.	5,000 ..	1·4
8	Lucerne grass ..	8,500 ..	2·3
9	Plantain-garden ..	9,000 ..	2·5
10	'Pan' garden ..	3,000 ..	0·8
11	Vegetable	7,000 ..	1·9
12	Turmeric	4,000 ..	1·1
13	Sweet potatoes ..	4,500 ..	1·2
14	Carrots	5,500 ..	1·5
15	Onions	8,000 ..	2·2
16	Tomato	10,000 ..	2·8

TABLE CXCVI.

The following table gives the number of waterings required on an average for various crops :—

Sugarcane	30 to 35 waterings.
Bajri and other monsoon crops	2 to 3 waterings.
Jawari and other rabi crops	3 to 4 waterings.
Eight months crops	10 to 13 waterings.

TABLE CXCVII.

The following table gives the duties that are adopted in preparing irrigation forecasts. The duties are at the head of canals :—

Sugarcane or rice	40 to 45 acres per cusec.
Cotton	80 to 85 ,, ,,
Eight months	80 to 100 ,, ,,
Rabi	120 to 150 ,, ,,
Hot weather	45 to 50 ,, ,,
Monsoon	180 to 200 ,, ,,

TABLE CXCVIII.

Duty to be assumed on a sliding scale in the design of distributaries.—The following statement gives the duties and discharges for distributaries with various commands. The statement is prepared from the mean curves of discharge obtained from Mr. Beale's sliding scale of duties, *viz.* :—

0	2,000 acres.	80 duty.
2,000	5,000 ,,	115 ,,
5,000	20,000 ,,	150 ,,
20,000	and above	200 ,,

Command	Discharge in cusecs	Duty
100	2	80
160	2	80
250	3·1	80
500	6·3	80
750	9·4	80
1,000	12·5	80
1,500	16	94
2,000	20	100—2,000
2,500	23	106
3,000	27	111
3,500	30	116
4,000	33	121
4,500	36	125
5,000	39·5	128—5,000
5,500	42	131
6,000	45	133
6,500	48	135
7,000	51	137
7,500	54	139
8,000	57	141

Command	Discharge in cusecs	Duty
8,500	60	142
9,000	63	143
9,500	66	144
10,000	69	145
11,000	74·5	148
12,000	80	150
13,000	85	154
14,000	89	157
15,000	93	160
16,000	97·5	164
17,000	101	168
18,000	105	171
19,000	109	174
20,000	114	176—20,000
22,500	124	181
25,000	134	187
27,500	144	191
30,000	154·5	194
32,500	165	197
35;000	175	200—35,000

Note.—1. For intermediate commands not worked out in this table take the proportionate mean of discharges in cusecs.

2. For commands of 35,000 acres and over a duty of 200 acres per cusec should be taken.

3. This statement has been adopted for designing distributaries in the perennial section of the Nira Right Bank canal under construction.

CONCRETE COUNTERWEIGHT FOR AUTOMATIC WASTE WEIR GATES, USED ON THE DARNA DAM

This form of counterweight, which is practically non-absorbent and lighter than the ordinary concrete, is composed of engine ashes and lime with cement and ashes for the outer casing which is 3 inches in thickness. The cement is used to prevent the rapid absorption of water and to form a hard outside surface. The counterweight in reinforced with an iron plate on the bottom to which are attached two iron rods of suitable dimensions and to these rods the chains suspending the gate are attached.

This form of counterweight will weigh about 100 lbs. per cubic foot in air including the iron work, or 105 lbs. after long submersion in water.

For a gate 10 feet square the following dimensions are suitable :—

Weight of gate	=2·75 tons.
Force of closing 2,000 lbs.	= ·89 ,,
Total weight of counterweight	=3·64 tons.

A counterweight 4′—0″ diameter and 6′—9″ high will weigh 12·57 × 6·7 × 100= 8,485 lbs. =3·8 tons nearly: or taking 105 lbs. per cubic foot it will weigh 3·98 tons (by actual experiment).

This provides for a little concrete that may have to be provided to fill the hollow spaces in the side frames of the gate itself, say, 2·38 cubic feet.

The gate will then weigh 2·91 tons. The concrete counterweight will weigh less in water by an amount equal to the water displaced :—

84·85 × 62=5,260 lbs.=2·34 tons.

Weight of counterweight	3·64 tons (dry).
Water displaced	—2·34 ,,
∴Weight of counterweight in water	1·30 tons (dry).
Or when saturated	1·48 ,,
Weight of gate	2·91 ,,
Weight of counterweight in water	1·30 ,,
∴Force available for opening gate=	1·61 tons.

It is advisable to have an excess force to open the gate and to overcome upward thrust (about 500 lbs.).

The force available for opening is thus about 3,100 lbs. As a rod through the counterweight might break, it is advisable to place these in tubes or piping so that they can be removed.

The proportions used are one part ashes to one part lime or cement. Quantities used in actual practice are given below :—

6 casks of Portland cement.

67 c.ft. of engine ashes.

50 c.ft. of slaked *kankar* lime.

The suspending rods are one-inch diameter each, the bottom plate half an inch thick and the spacing bar is 3″ × ½″.

The whole of the iron work should be carefully coated with two coats of bituminous paint before construction.

The centering used should be a carefully constructed iron centering in four section bolted together.

The counterweight must all be made in one day, otherwise cracks develop between each day's work. Watering must be continuous and plentiful for three months and should preferably be carried out by allowing a tap to drip on the conterweight day and night, the whole counterweight being sewed up in gunny bags.

TABLE CXCIX

Conversion Table

Rates per Minute, Hour, Day, Year, equivalent to rate per Second.

S.	Min.	Hour.	Day (24 H.)	Year	S.
1	60	3600	86400	31536000	1
2	120	7200	172800	63072000	2
3	180	10800	259200	94608000	3
4	240	14400	345600	126144000	4
5	300	18000	432000	157680000	5
6	360	21600	518400	189216000	6
7	420	25200	604800	220752000	7
8	480	28800	691200	252288000	8
9	540	32400	777600	283824000	9
10	600	36000	864000	315360000	10

Rates per Second, Hour, Day, Year, equivalent to rate per Minute.

M.	Second	Hour	Day (24 H.)	Year	M.
1	·016667	60	1440	525600	1
2	·033334	120	2880	1051200	2
3	·050000	180	4320	1576800	3
4	·066667	240	5760	2102400	4
5	·083334	300	7200	2628000	5
6	·100000	360	8640	3153600	6
7	·116667	420	10080	3679200	7
8	·133334	480	11520	4204800	8
9	·150000	540	12960	4730400	9
10	·166666	600	14400	5256000	10

Example.—If 3 c.ft. are discharged by a pipe per second, what is the discharge per day? By 1st Table in 4th column × 259,200 cubic feet.

TABLE CXCIX—*continued.*

Rate per Second, Minute, Day, Year, equivalent to rate per Hour.

H.	Second	Minute	Day (24 H.)	Year	H.
1	·0027778	·0166667	24	8760	1
2	·0055556	·0338334	48	17520	2
3	·0083334	·0500001	72	26280	3
4	·0111112	·0666668	96	35040	4
5	·0138890	·0833335	120	43800	5
6	·0166668	·1000002	144	52560	6
7	·0194446	·1166669	169	61320	7
8	·0222224	·1333336	192	70080	8
9	·0250002	·1500003	216	78840	9
10	·0277778	·1666667	240	87600	10

Rates per Second, Minute, Hour, Year, equivalent to rate per Day.

Day (24 H.)	Second	Minute	Hour	Year	Day (24 H.)
1	·000011574	·0006944	·041666	365	1
2	·000023148	·0013888	·083333	730	2
3	·00003472	·0020832	·125000	1095	3
4	·00004629	·0027776	·166666	1460	4
5	·00005787	·0034720	·208334	1825	5
6	·00006944	·0041664	·250000	2190	6
7	·00008101	·0048608	·291666	2555	7
8	·00009259	·0055552	·333333	2920	8
9	·00010416	·0062496	·375000	3285	9
10	·00011574	·0069444	·416666	6350	10

TABLE CC

Equivalent rates

Per second	Per minute	Per hour	Per day (24 H.)	Per year
1·	60·	3600·	86400·	31536000
·016667	1·	60·	1440·	525600
·000694	·016667	1·	24·	8760
·000011574	·000694	·041667	1·	365
·0000003171	·0000019	·00011415	·0027397	

TABLE CCI

Conversion of cubic feet into gallon and gallons into cubic feet

Cubic feet	Gallons	Cubic feet	Gallons	Gallons	Cubic feet	Gallons	Cubic fee t
1	6·2355	6	37·4130	1	·16037	6	·96223
2	12·4710	7	43·6485	2	·32074	7	1·12260
3	18·7065	8	49·8840	3	·48112	8	1·28298
4	24·9420	9	56·1195	4	·64149	9	1·44335
5	31·1775	10	62·3550	5	·80186	10	1·60372

TABLE CCII

Annual discharge per second and minute uniformly spread over 12 months for storage tanks having a given capacity as in 1st column

Capa-city cubic feet	Uniform discharge, cubic feet per second	Uniform discharge, cubic feet per minute	Capacity, cubic feet	Uniform dis-charge, cubic feet per second	Uniform dis-charge, cubic feet per minute	Capacity in million cubic feet	Uniform discharge, cubic feet per second	Uniform discharge, cubic feet per minute
25	·000000793	·00004756	9,000	·000285	·017123	1	·03171	1·9026
50	·000001585	·00009513	10·000	·000317	·019026	2	·06342	3·8052
100	·000003171	·00019026	20,000	·000634	·038052	3	·09513	5·7078
200	·000006342	·00038052	30,000	·000951	·057078	4	·12684	7·6104
300	·000009513	·00057078	40,000	·001268	·076104	5	·15855	9·5130
400	·000012684	·00076104	50,000	·001585	·095130	6	·19026	11·4156
500	·000015855	·00095130	60,000	·001903	·114156	7	·22197	13·3182
600	·000019026	·00114156	70,000	·002219	·133182	8	·25368	15·2208
700	·000022197	·00133182	80,000	·002537	·152208	9	·28539	17·1234
800	·000025368	·00152208	90,000	·002854	·171234	10	·31710	19·026
900	·000028539	·00171234	100,000	·003171	·19026	31·536	1·0000	60·00
1,000	·00003171	·0019026	200,000	·006342	·38052	100	3·1710	190·26
2,000	·00006342	·0038052	300,000	·009513	·57078	200	6·3420	380·52
3,000	·00009513	·0057078	400,000	·012684	·76104	300	9·5129	570·78
4,000	·00012684	·0076104	500,000	·015855	·95130	400	12·6839	761·04
5,000	·00015855	·0095139	600,000	·019026	1·14156	500	15·8549	951·30
6,000	·00019026	·0114156	700,000	·022187	1·33182	600	19·0259	1141·56
7,000	·00022197	·0133182	800,000	·025368	1·52208	700	22·1969	1331·82
8,000	·00025368	·0152208	900,000	·028539	1·71234	800	25·3678	1522·08
						900	28·5388	1712·34
						1,000	31·7970	1902·60

TABLE CCIII

For rainfall in inches per annum, the rate of accumulation on (or uniform runoff from) acres and square miles per second, minute, or year

(Cubic feet.)

Rain-fall in year	On acre			Rain-fall in year	On square mile		
	Per second	Per minute	Per annum		Per second	Per minute	Per annum
Inches				Inches			
1	·000115107	·0069064	3,630	1	·07366819	4·4200913	2,323,200
2	·00023021	·0138128	7,260	2	·14733638	8·8401826	4,646,400
3	·00034532	·0207192	10,890	3	·22100457	13·2602739	6,969,600
4	·00046043	·0276256	14,520	4	·29467276	17·6803652	9,292,800
5	·00057554	·0345320	18,150	5	·36834095	22·1004565	11,616,000
6	·00069064	·0414384	21,780	6	·44200914	26·5205478	13,939,200
7	·00080575	·0483448	25,410	7	·51567733	30·9406391	16,262,400
8	·00092028	·05525136	29,040	8	·58934552	35·3607304	18,585,600
9	·00103599	·06215778	32,670	9	·66301371	39·7808217	20,908,800
10	·00115111	·0690642	36,300	10	·73668190	44·2009130	23,232,000
11	·00126622	·0759706	39,930	11	·81035009	48·6210043	25,555,200
12	·00138132	·0828770	43,560	12	·88401828	53·0410956	27,878,400
13	·00149643	·0897835	47,190	13	·95768647	57·4611869	30,201,600
14	·00161154	·0966899	50,820	14	1·03135466	61·8812782	32,524,800
15	·00172665	·1035963	54,450	15	1·10502285	66·3013695	34,878,000
16	·00184175	·1105027	58,080	16	1·17869104	70·7214608	37,171,200
17	·00195686	·1174091	61,710	17	1·25235923	75·1415521	39,494,400
18	·00207197	·12431556	65,340	18	1·32602742	79·5616434	41,817,600
19	·00218707	·13122196	68,970	19	1·39969561	83·9817347	44,140,800

TABLE CCIV

Quantities of water in cubic feet and gallons, on acres and square miles, equivalent to rainfall in inches

Inches of rain	On acre		On square mile		Inches of rain
	Cubic feet	Gallons	Cubic feet	Gallons	
1	3,630	22,635	2,323,200	14,486,314	1
2	7,260	45,270	4,646,400	28,972,627	2
3	10,890	67,905	6,959,600	43,458,941	3
4	14,520	90,539	9,292,800	57,945,254	4
5	18,510	113,174	11,616,000	72,431,568	5
6	21,780	135,809	13,939,200	86,917,882	6
7	25,410	158,444	16,262,400	104,404,195	7
8	29,040	181,079	18,585,600	115,890,509	8
9	32,670	203,714	20,908,800	130,376,822	9
10	36,300	226,349	23,232,000	144,863,136	10
11	39,930	248,984	25,555,200	159,349,450	11
12	43,560	261,619	27,878,400	173,835,763	12

TABLE CCV

Rate of accumulation or runoff per second, minute, hour or day per acre, or square mile, for rainfall in inches per day and hour

Rainfall		Cubic feet on acre per				Cubic feet on square mile per			
Per day, inches	Per hour, inches	Second	Minute	Hour	Day (24 H.)	Second	Minute	Hour	Day (24 H.)
1	1/24	·0420129	2·52083	151·25	3,630	26 8883	1,613·333	96,800	2,323,200
2	1/12	·0840258	5·04166	302·50	7,260	53·7766	3,266·66	193,600	4,646,400
3	⅛	·1260387	7·56249	453·75	10,890	80·6659	4,839·99	290,400	6,969,600
4	1/6	·1680516	10·0833	605·00	14,520	107·5532	6,453·33	387,200	9,292,800
5	5/24	·200645	12·60416	756·25	18,150	134·4415	8,066·66	484,000	11,616,000
6	¼	·2520774	15·12499	907·50	21,780	161·3298	9,679·99	580,800	13,939,200
7	7/24	·2940903	17·64583	1058·75	25,410	188·2189	11,293·33	677,600	16,262,400
8	⅓	·3361032	20·16666	1210·00	29,040	215·1064	12,906·66	774,400	18,585,600
9	3/8	·3781161	22·68749	1361·25	32,670	241·9947	14,519·99	871,200	20,908,800
10	5/12	·4201290	25 2083	1512·50	36,300	268·8883	16,133·33	968,000	23,232,000
11	11/24	·4621420	27·7288	1663·75	39,930	295·7713	17,746·66	1,064,800	25,555,200
12	½	504155	30 2500	1815·00	43,560	322·6596	19,359·99	1,161,600	27,878,400
18	¾	·7562324	45·3750	2722·50	65,340	483·9894	29,039·99	1,742,400	41,817,600
24	1	1·0083098	60·5000	3,630	87,120	645·3192	38,719·99	2,323,200	55,756,800
48	2	2·0166196	121·0000	7,260		1,290·6384	77,439·98	4,646,400	
72	3	3·0249294	181·5000	10,890		1,935·9576	116,159·97	6,969,600	
96	4	4·0332392	242·0000	14,520		2,581·2768	154,879 96	9,292,800	
120	5	5·041535	301·5000	18,150		3,226·5960			
144	6	6·049858	362·9915	21,778					

NOTE.—A very convenient item for general use of the above table is the runoff of 1 inch per hour equalling 1 cubic foot per second per acre.

TABLE CCVI

Table of totals of units per second up to 31 days and for one year

Days	Units per second such as cubic feet each								
	1	2	3	4	5	6	7	8	9
1	86400	172800	259200	345600	432000	518400	604800	691200	777600
2	172800	345600	518400	691200	864000	1036800	1209600	1382400	1555200
3	259200	518400	777600	1036800	1296000	1555200	1814400	2073600	2332800
4	345600	691200	1036800	1382400	1728000	2073600	2419200	2764800	3110400
5	432000	864000	1296000	1728000	2160000	2592000	3024000	3456000	3888000
6	518400	1036800	1555200	2073600	2592000	3110400	3628800	4147200	4665600
7	604800	1209600	1814400	2419200	3024000	3628800	4233600	4838400	5443200
8	691200	1382400	2073600	2764800	31560000	4147200	4838400	5529600	6220800
9	777600	1555200	2332800	3110400	3388000	4665600	5443200	6220800	6998400
10	864000	1728000	2592000	3456000	4320000	5184000	6048000	6912000	7776000
11	950400	1900800	2851200	3801600	4752000	5702400	6652800	7603200	8553600
12	1036800	2073600	3110400	4147200	5184000	6220800	7257600	8294400	9331200
13	1123200	2246400	3369600	4492800	5616000	6739200	7862400	8985600	10108800
14	1209600	2419200	3628800	4838400	6048000	7257600	8467200	9676800	10886400
15	1296000	2592000	3888000	5184000	6480000	7776000	9072000	10368000	11664000
16	1382400	2764800	4147200	5529600	6912000	8294400	9676800	11059200	12441600
17	1468800	2937600	4406400	5875200	7344000	8812800	10281600	11750400	13219200
18	1555200	3110400	4665600	6220800	7776000	9331200	10886400	12441600	13996800
19	1641600	3283200	4924800	6566400	8208000	9849600	11491200	13132800	14774400
20	1728000	3456000	5184000	6912000	8640000	10368000	12096000	13824000	15552000
21	1814400	3628800	5443200	7257600	9072000	10886400	12700800	14515200	16329600
22	1900800	3801600	5702400	7603200	9504000	11404800	13305600	15206400	17107200
23	1987200	3974400	5961600	7948800	9936000	11923200	13910400	15897600	17884800
24	2073600	4147200	6220800	8294400	10368000	12441600	14515200	16588800	18662400
25	2160000	4320000	6480000	8640000	10800000	12960000	15126000	17280000	19440000
26	2246400	4492800	6739200	8985600	11432000	13478400	15724800	17971200	20217600
27	2332800	4665600	6998400	9331200	11664000	13996800	16329600	18662400	20995200
28	2419200	4838400	7257600	9676800	12096000	14515200	16934400	19353600	21772800
29	2505600	5011200	7516800	10022400	12528000	15033600	17539200	20044800	22550400
30	2592000	5184000	7776000	10368000	12960000	15552000	18144000	20736000	23328000
31	2678400	5356800	8035200	10713600	13392000	16070400	18748800	21427200	24105600
365	31536000	6307200	94608000	126144000	157680000	189216000	220752000	252288000	28324000

PRACTICAL CONDITIONS IN DETERMINING THE VALUE OF WATER-POWER FOR ELECTRICAL PURPOSES

1. **Classification.**—As the basis of all water power is the number of foot-pounds available in a given time it follows that to get power on a considerable scale it is necessary to have—

(i) a large flow of water under a small head ; or
(ii) a moderate flow of water under a medium head ; or
(iii) a small flow of water under a high head.

Cases where a large flow can be utilized under a high head are comparatively rare, and such cases are merely an extension of (iii), giving the maximum available power. By "head" is meant the vertical difference of height in feet between the head and tail waters, for low heads using pressure turbines ; and the difference between the top of the supply pipe and the wheel, in all other cases where draft tubes are not used. This is the gross head, and the net or effective head is thus diminished by the loss in the pipes, etc. For project purposes the gross head may safely be taken.

2. **Basis of power available.**—The theoretical water horse-power available is in every case :—

$$\text{W.H.P.} = \frac{\text{Flow in lbs. per second} \times \text{feet head}}{550}$$

$$= \frac{\text{Cuesecs} \times \text{feet head}}{0{\cdot}81}$$

Neglecting quite small sizes, the full load efficiency of turbine wheels varies from about 80 per cent. in moderate sizes up to 85 per cent. in large wheels of good design, and pipe losses may be considered covered also by these values. Therefore the brake horse-power availabe on the turbine shaft is—

$$\text{B.H.P.} = \frac{\text{Cusecs} \times \text{feet head}}{11{\cdot}0 \text{ to } 10{\cdot}36}$$ according to size and design. The commercial efficiency of altérnators of correspounding size, at full load, varies from 95 per cent. to 97 per cent., corresponding to the limits of turbine efficiency above. Therefore, assuming direct driving without belts or gearing, the electrical horse-power at the generator terminals will be :

$$\text{E.H.P.} = \frac{\text{Cusecs} \times \text{feet head}}{11{\cdot}58 \text{ to } 10{\cdot}68}$$ according to size and design. Converting to kilowatts (kw.), where 1 E.H.P. = 0·746 kw. we have

$$\text{kw. at terminals} = \frac{\text{Cusecs} \times \text{head in feet}}{15{\cdot}52 \text{ or } 14{\cdot}32}$$

For quite small powers the divisor will be about 19 for direct drive and 20 for a belt or gear drive, but we are not concerned with these.

For all practical industrial purposes it will be sufficient to assume that the overall efficiency of turbine and generator will be :—

For	500 kw.	..	74 per cent.
,	1,000 ,,	..	76 ,,
,,	1,500 ,,	..	78 ,,
,,	2,000 ,,	..	80 ,,
,,	3,000 and over	..	82 ,,

3. **Available kilowatts.**—To ascertain the available kilowatts then we have:

kw.=cusecs × head in feet × ·0626 for about 500 kw.
·0643 for about 1,000 kw.
·0660 for about 1,500 kw.
·0677 for about 2,000 kw.
·0694 for about 3,000 kw or more.

The largest *single unit* of plant is not likely to exceed 5,000 kw. The largest water turbine hitherto made is of 25,000-h.p. capacity, working on 465 feet head.

4. **Localities.**—It is clear that of the 3 cases enumerated in paragraph 1 No. (i) is only found in the rivers and canals of the plains and No. (iii) only among the hills, while No. (ii) may especially be looked for where there are rivers of moderate size in comparatively rough country, near the foot of the hills or on undulating ground.

5. **Low head projects—canals.**—By low heads are meant such as are ordinarily dealt with by pressure or reaction type turbines using draft tubes; heads, that is to say, from 3 feet upwards to an undefined limit of 100 feet or so. For various reasons heads as low as 3 feet are seldom worth consideration, though capable of development. Such falls in rivers would almost invariably involve variations in the level of the head and tail waters, above and below the wheels, much greater than the working head. As a comparatively small difference in the effective head would mean a large percentage of the total head and power, and as an enormous flow, involving very large wheels, is required to give substantial power, such propositions are seldom satisfactory. On canals, where regulation maintains a fairly even flow, a fall as low as 3 feet might be utilized; but here the periodical closures and the restricted flow at times when irrigation water is not needed come in and involve intermittent power. For high level irrigation by pumping from the canal itself, or from tube wells, the closure is no disadvantage; but for industrial power it is fatal. In low head installations it is immaterial whether the wheels are placed at the top or the bottom of the fall, *i.e.*, whether the head is mainly above the wheel or in the suction tube, within the ordinary limits. Owing to the low speed of these wheels an indirect drive is necessary, as otherwise the cost of such slow speed generators would be prohibitive. Alternating current generators must be run at a speed of $\frac{3,000}{\text{number of pairs of poles}}$ in order to give the standard frequency of 50 periods; *i.e.*, at 250, 300, 333, 375, etc., revolutions per minute. By the use of double or quadruple wheels a higher speed can be obtained for a given horse-power, but this is hardly practical where large powers are in question. Not such is generally necessary in the way of a subsidiary canal.

6. **Rivers**—Wherever a river of considerable volume has a fair bed slope, so that water led from it into a canal with a very small slope will in a short distance (a mile or two), acquire a head capable of utilization, investigation is indicated. The head should preferably be from 20 feet or as much more as possible, and should be largely in excess of the maximum difference between the head and tail levels. If the river is narrowing down at the point where the tail race would come back to it, so that in times of flood the tail waters would back up more than the head water, the project offers difficulties. Evidently the most promising conditions are where either the course of the river is winding, so that a short cut by tunnelling or otherwise will give a reasonable

head, or where the bed slope is considerable owing to rapids or an actual waterfall. If the large volume of water has to be carried for a long distance in a canal the cost rises seriously. A definite waterfall in the river is however not necessary. The mere flow of a river, where the bed slope is comparable to that of a canal, is useless for power development. Storage is generally both unnecessary and impracticable.

7. **Medium fall projects.**—There is no standard of a medium head, which merges into the extreme cases, but heads of from about 100 feet up to 300 or 400 feet are meant, where it is usual to employ mixed flow or impulse turbines (the Girard is a type) without draft tubes. These can generally be directly connected to the generator, running one of the correct standard speeds. Projects of this class, to give large power, must be looked for on rivers with a substantial flow at all times of the year and with either large falls or a steep bed slope. For this reason it is necessary to look in the hills, above the point where irrigation canals take off, and in the case of large rivers further back according to the flow available. The best examples in India are the Cauvery and Jhelum schemes, the former utilizing a waterfall and the latter rapids. Of course medium heads may also be utilized on hill streams, but here the flow is generally only sufficient for very moderate power development. In projects of this nature the length of canal or flume necessary to carry the water from the headworks on the river to the point where the pressure pipes run to the turbines is important. In the most favourable cases the supply can be piped all the way, but as the pipes should be as short as possible these cases are rare. If an earth channel is practicable this is the next best arrangement. Failing either of these alternatives an artificial flume is required, and this is both expensive to erect and troublesome to maintain when dealing with a large flow. Whether storage of water is necessary on this class of undertaking depends on the minimum flow of the river and the liability to breakdown of the headworks and flume; whether it is practicable depends on the formation of the ground, as the quantities involved are such that only a dam across the stream bed will be of any use beyond mere regulation (paragraph 12). Where such a dam is practicable it may of course be at any distance upstream of the headworks. Silting up will have to be faced.

8. **High fall projects—bill streams.**—When the fall is such that jet impulse wheels of the Pelton type are indicated—from about 400 feet upwards—the project may be classified as high head. There are several instances of heads upwards of 2,000 feet being utilised, and one over 5,000 feet is under construction. Vertical drops of this order, conveniently situated on a stream are comparatively infrequent; it is therefore generally necessary to develop the fall as in the previous case, by carrying a flume practically along contours until a point is reached where a short pipe-line will give the maximum available drop. It follows that situations where this is possible will generally be at fairly high altitudes, at least so far as the headworks are concerned. As however the flow required is comparatively small, hill streams with a fairly large catchment area and a moderate minimum flow are required. A flume—and generally a long flume—will be required, but on very high heads it will be of modest dimensions and not very expensive to construct unless much tunnelling is involved. As a few extra feet loss of head amount to but little per cent. a larger slope can be allowed than on earth channels, which are seldom practicable in these cases. This has the advantage of preventing silt settling in the flume to some extent at least. The problem of silt and stones becomes a serious one in the case of hill streams in flood time, and special provision is

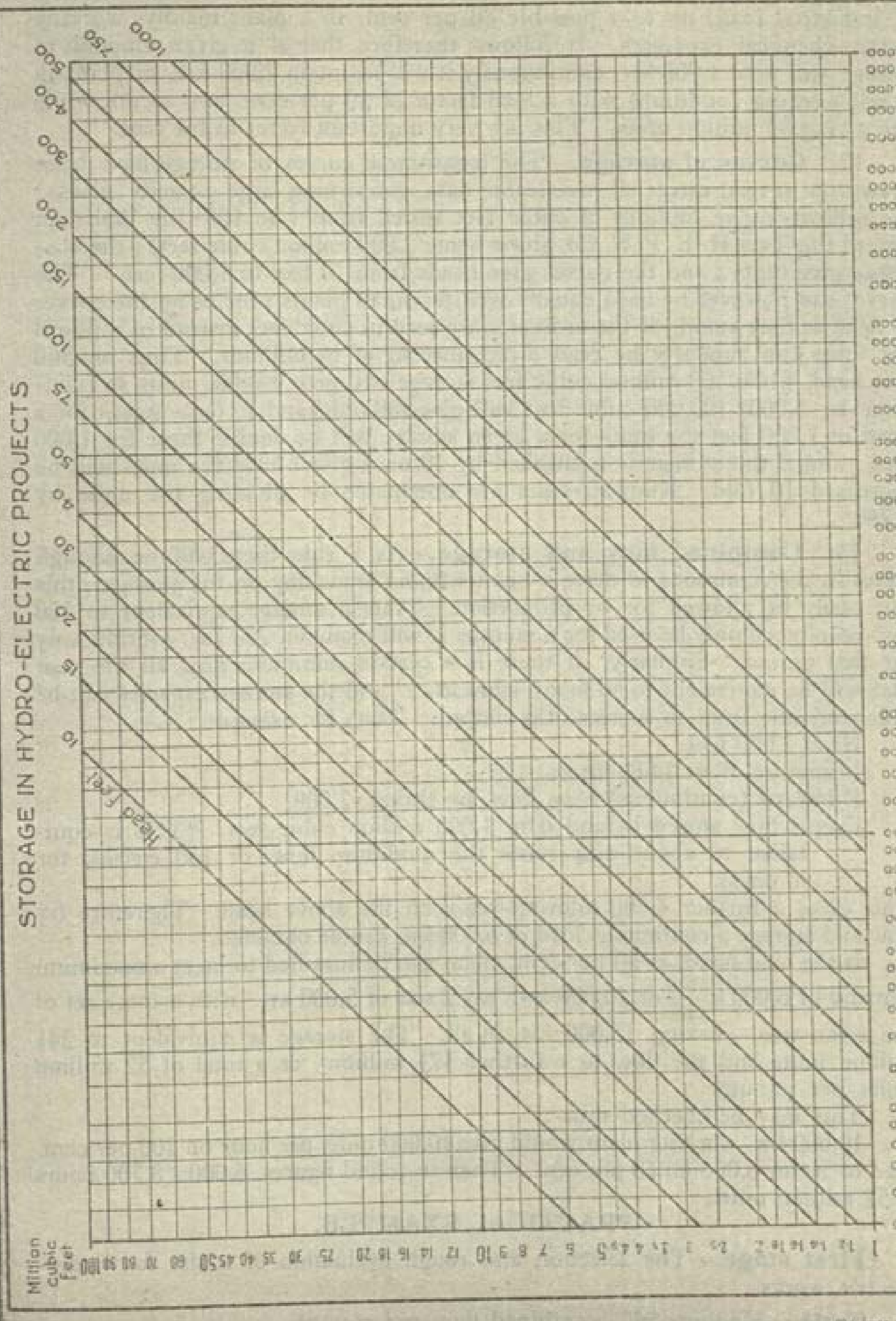
always required to deal with it. Owing to the length of vulnerable flume and the liability to damage on it and at the headworks from landslips, a certain amount of storage is always indicated. With very high heads however an artificial reservoir may be sufficient to tide over these occurrences; though a dam either in the main stream or at some point on the flume line would generally give greater storage for a given cost. Evidently it is desirable that the storage should be as near the pipe-head, and as far from the headworks as possible where there is any choice. The silting up of such a reservoir, even when sand traps are first traversed, is always to be feared; and clearing is very expensive. As in the case of medium heads, an upstream dam may be practicable, and in this way far greater reserve obtained (paragraph 12).

9. **High fall storage projects.**—A different type of scheme altogether is that dependent entirely on the storage of monsoon rainfall, of which the Tata hydro-electric scheme is the first example. Here there is practically no natural inflow during the greater part of the year, but sufficient water is impounded behind dams to carry over the plant from one monsoon to the next. Here every available foot of head is of the utmost importance, as there is an economic limit to the expenditure on the dams, and therefore to the total weight of water stored. Evidently such schemes are only possible where there is heavy monsoon rainfall coupled with valleys, at a fairly high altitude, flat enough and wide enough, and of such a formation as to store large volumes of water, behind a practicable dam. Furthermore, these valleys must be within reasonable reach of a steep fall of 1,500 feet or more—the more the better, as both the length of canal to reach this point and the length of pipe from thence to the power station are factors in the cost of development. If necessary, tunnelling will take the channel to the opposite side of a watershed.

10. **Storage on hydro-electric schemes.**—As already stated, storage of water is seldom either applicable or necessary in low head installations; it is frequently a natural feature of medium head installations and is essential on most high head plants. It will therefore be desirable to refer to it in greater detail. While a given flow of water represents (according to the head) a certain rate of output in kilowatts, a reservoir of given capacity represents (again according to the head) an amount of energy stored, in horse-power-hours or (here) in kilowatt-hours or B. O. T. units. It is unnecessary in this case to consider variable efficiency as there are many variables, and an overall efficiency of pipe, generator and turbine of 76 per cent. may be taken. Now to obtain 1,000 kw.-continuously on 1,000 feet head requires a flow of 15·54 cusecs on this efficiency; this represents $1\frac{1}{3}$ million cubic feet a day or 490 million cubic feet a year. As 1 kw.-year represents 8,760 kilowatt-hours or units per annum, 1,000 kw years represents $8\frac{3}{4}$ million units, on the assumption of continuous working or 100 per cent. load factor. We have then as our data, that on 1,000 feet head 490 million cubic feet of storage represent 1,000 kw.-years or $8\frac{3}{4}$ million units generated per annum. The storage may be taken in direct proportion to the units generated on this head; and to get this number of units the storage varies inversely as the head

11. **The effect of load factor.**—No plant is working at full load throughout the year or even the day; nor is the actual maximum load on the plant (which may of course be less than the maximum possible) at any one time maintained. The ratios between actual output and maximum output on these two bases stated as a percentage are called the load factors. In this case we must consider the ratio of the actual output to the maximum possible if the plant were at full load continuously. This will vary in India from about 20 per

Plate CXIV-A



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G. PZ. P., Poona, 1939.

cent. in the worst cases (towns with a short hot weather and not much heating or industrial load) up to a possible 80 per cent. in a plant mainly working electro-chemical processes. It follows, therefore, that if a given amount of storage will give 1,000 kw. continuously it will maintain 2,000 kw. of plant in actual working conditions with a load factor of 50 per cent. and so on, while still giving 8¾ million units. This is a very important factor in the case.

12. **Curves of storage.**—The logarithmic curves of storage have been drawn up to read direct all practicable data concerning large capacity plants; the ordinates give millions of cubic feet stored from 1 to 100 (the Walwhan lake of the Tata H. E. P. S. Co. stores some 2,800 million cubic feet) ; the abscissae give units ; and the curves give heads from 10 feet to 1,000 feet. The curves can however be used equally well for small plants ; for using the curves of head as they stand, if the ordinates are read in cubic feet instead of millions the units can similarly be read direct instead of in millions. Thus on 500 feet head, while 100 million cubic feet storage will give 900,000 units so (dividing by 1,000) 100,000 cubic feet will give 900 units and so on. Again for a head of 2,000 feet the units for a given storage will be double those for 1,000 feet ; and if the storage is multiplied by 10 on a given head the units will be increased 10 fold. Kilowatt-years are obtainable by dividing the units by 8,760.

13. **Combined flow and storage.**—As a rule there will be enough water in the monsoons to drive a plant without trenching on the storage ; this can easily be allowed for by proportion. Thus if storage equivalent to 100 kw.-years need only be used for 6 months it will maintain 200 kw. continuously for that period. Similarly, if there is a certain minimum flow all the year that will be equivalent to so many kilowatts ; and the storage capacity can be independently used to increase the output. Thus for example :

Head 2,000 feet.

Minimum flow 14·8 cusecs.

Kilowatts (continuous) from flow, by curves, 2,000.

Excess flow stored behind dam 1,000 million cubic feet. (This is equivalent to about nine times the minimum flow, or 130 cusecs, for 90 days).

This gives a further 4,000 kilowatt-years on the above head. Therefore by flow and storage a continuous load of 6,000 kw. can be obtained.

If the load factor is 60 per cent. plant can be installed to meet a maximum demand of $6{,}000 \times \frac{100}{60}$ or 10,000 kw.; say 2 sets of 5,000 kw. with a spare set of the same size, making 15,000 kw. in all. The storage is equivalent to 34½ million units and the flow to a further 17½ million, or a total of 52 million units per annum.

This may be checked thus :

10,000 kw. working plant would give 10,000 units per hour on 100 per cent. load or factor 6,000 on 60 per cent. Then in round figures, $6{,}000 \times 8{,}700$ hours $=52$ million units.

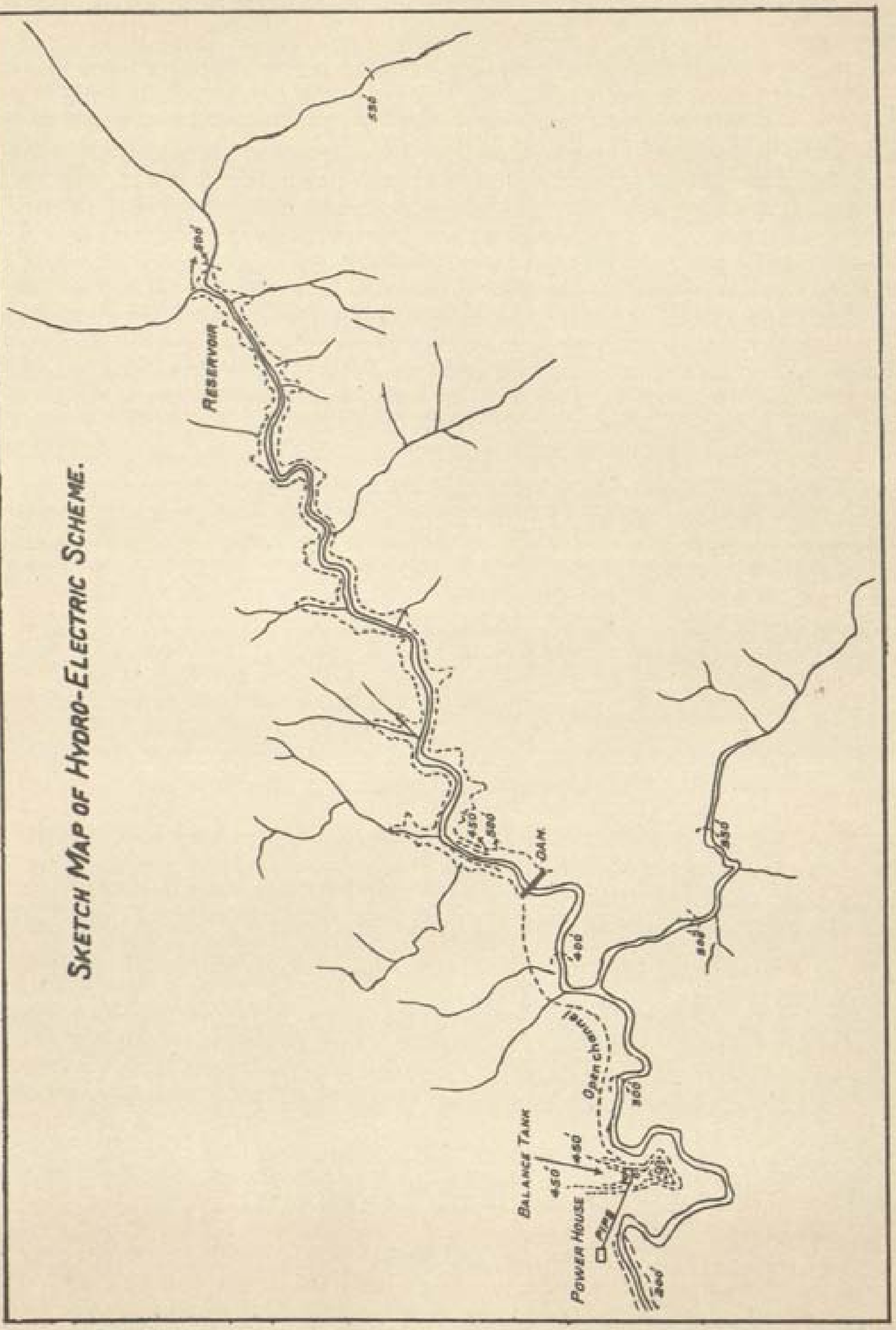
PRACTICAL EXAMPLE.

First stage.—The selection and rough evaluation of a site for hydro-electric works.

Type.—Medium fall ; combined flow and storage.

Local information.—Information was received that the river in question had a very considerable perennial flow, and, judging by other known streams

Plate CXIV-B



G.P.Z.D. 1339.

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in the locality, the *minimum* discharge seemed likely to be about 150 cusecs, in the dry period from February to April or May. Steps were therefore at once taken to get the minimum flow of the year ascertained by periodical gaugings from February onwards.

Maps.—Examination of the 1″-1 mile contoured survey map, from which the attached sketch plan has been drawn, showed that there was a fairly steep fall from about where the 450 feet contour crossed the river to where the 200 feet contour crossed it. Below the latter point the river bed is practically flat. Above the 450 feet point there is a long stretch of comparatively level bed before the 500 feet contour is reached. Unfortunately the banks are shown by the contour lines to be steep, so that the valley is for the most part narrow. It was evident, however, that a dam somewhere between R. L. 400 feet and 450 feet, reaching at least to R. L. 500 feet—i.e., from 50 feet to 100 feet in height—would impound a considerable volume of water. The fall available would be from about the 450 feet level to the 200 feet level, or say 250 feet. All the data at this stage are the merest approximations for the purpose of seeing whether a detailed survey is justified. The purpose of this note is to show how such information is expressed in power, and what is required further.

Rainfall and runoff.—The catchment area of the river above the dam site is shown by the maps to be about 300 square miles, and as the average rainfall is not less than 100 inches a year—up to 250 inches in parts—it is clear that (apart from any question of the runoff) there is a huge excess in the monsoon in this particular instance that cannot be utilized by any storage scheme. The general rainfall is found from the rainfall contour map of the Meteorological Department. Variations from this may often be obtained from local rain gauges not included in the official register. A range of hills will often give much excess over a limited area, as in this instance.

Power from perennial flow.—Assuming a fall of 250 feet and a minimum flow of 150 cusecs, and taking for safety $\frac{\text{cusecs} \times \text{feet}}{20} = \text{kilowatts}$ we have in round figures 1,800 kilowatts available night and day. If only enough storage were provided to impound 12 hours supply, or say six million cubic feet of water, this flow would give double the power or 3,600 kilowatts for the ordinary 12-hour working day. Actually it would be good for more, as the plant would not be working at full load all the 12 hours, while the unutilized flow would be impounded.

Storage.—The contoured plan shows that a dam between 50 feet and 100 feet high at some spot between R. L. 400 and 450 would form a lake, bounded more or less by the 500 feet contour, some 11 miles long. The upper mile or two, where the depth would be negligible, would be of little value, however, and we may take the effective length as not less than 8 miles. The banks are steep on both sides, and though the surface width of the lake might average over half a mile, it would be safer to take an average width of ¼ mile at top level, giving an area of 2 square miles of water on the surface of the lake. If 40 feet of depth could be utilized over the whole of this, as seems probable, there would be about 1,000 million cubic feet of water in hand after the monsoon. Now as (after allowing for losses) some 35 million cubic feet will give a cusec throughout the year, some 12 million cubic feet will give a cusec for the 4 dry months, when the minimum flow is only about that assumed above. (In many cases 2 months would be nearer the mark.) Therefore this reservoir,

if practicable, will give about 1,000/12 or say 80 cusecs extra constantly through the dry season. This means a further $\frac{80 \times 253}{20} = 1,000$ kilowatts continuously or 2,000 kilowatts on the 12 hours basis. During the rest of the year the flow alone will give far more water than is required.

Total probable power.—Combined with the power from the flow the fotal comes to some 5,600 kilowatts (or say 5,000) for 12 hours a day throughout the year on a conservative estimate. If the ground proves unfavourable for a high dam it may not be possible to develop above 3,000 kilowatts, whereas if all conditions are more favourable than is assumed the site may be good for 10,000 kilowatts, or more. It will therefore be seen that even if the first values have been over-estimated there are ample grounds for further investigation.

Effect of load factor.—(See paragraphs 11 and 13 of note.) The probable power assumed above is on the basis of continuous working throughout the 12-hour day at full load. Such a condition is rarely attained, and load factors in India generally vary from 30 to 40 per cent. Taking the estimate of 5,000 kilowatts therefore as the most probable value of the site, it would generally be practicable to lay down plant to meet a "peak load" of not less than double that amount, or say 10,000 kilowatts ; this would depend on the nature of the load.

Conclusion.—This preliminary work can be carried out by any one with local knowledge and the aid of the one-inch contoured maps. Where only provisional maps are available so that " form-lines " take the place of actual contours, it becomes more difficult to discover possible sites by inspection. The "spot levels" will however give an indication of where there is a rapid drop or, on the other hand, such a very gradual drop that a reservoir site may be possible. The map will also show the nearest point that can be reached by rail or river, and the road communications (if any exist) to the neighbourhood of the site. It is unnecessary here to detail the subsequent stages in the investigation of a promising power site, consisting of a survey of the ground, propoer examination of the runoff and of the character of the ground, etc., under expert supervision.

P. W. D. HANDBOOK

BOMBAY

Volume II

SECTION VII

WATER SUPPLY AND SANITARY ENGINEERING

1949

CHAPTER XI—WATER SUPPLY

1. The source of supply may be either from—

(1) Wells.

(2) Borings.

(3) Storage reservoirs.

(4) Springs or streams.

In all cases it is essential that the source shall be free from contamination. The limiting amounts of impurities which are permissible in drinking water are free ammonia 0·008 parts per 100,000 by weight; albuminoid ammonia 0·01 parts per 100,000; hardness, not less than 3° to 5° on the Clark's scale, and, not more than about 15° (extreme limit 25°) and poisonous metals, and pathogenic bacteria, nil. As a general rule, shallow wells, *i.e.*, wells which derive their supply from a permeable stratum not overlaid by an impermeable stratum, are to be avoided if near any possible source of contamination. The catchment areas of storage reservoirs should be, as far as possible, uncultivated and uninhabited land. Streams are, in India, nearly always to be regarded with suspicion but supplies from this source may be made fit for consumption by suitable treatment. In selecting any source of supply, analyses extending over at least one whole year are necessary to enable a fairly reliable estimate of purity of supply to be made. These analyses should be both chemical and bacteriological. Before deciding on any source of supply, the opinion on its suitability should be obtained from the Director of Public Health for the Government of Bombay, who should be addressed through the Sanitary Engineer to Government. These officers will arrange to carry out the necessary analyses, and arrangements should be made to draw such samples as may be called for, or to make such tests as may be prescribed from time to time.

2. **Taking Samples.**—Care should be taken in selecting the sample that it is an average one. The bottle in which the sample is taken, which should be about ½ gallon, must be scrupulously clean. Before being filled, it should be rinsed out 2 or 3 times with the water that is to be analysed. The bottle ought to have a glass stopper and it is well to cap it with leather, the string being sealed with sealing wax. If, for any reason, a stoppered bottle cannot be obtained an ordinary cork may be used, but it must be a clean new one, and it also ought to be capped as described.

The following particulars, when applicable, ought to accompany each sample :—

(1) Source of the water, *viz.*, from tanks or cisterns, main or house pipe, spring, river, stream, lake or well.

(2) Position of source,—strata as far as they are known.

(3) In a well,—depth, diameter, strata through which sunk, whether imperviously protected in the upper part and far down. Total depth of well and depth of water to be given.

(4) Possibility of impurity reaching the water, distance of well from cesspools, drains, middens, manure heaps, stable, etc.; whether drains or sewers discharge into streams or lakes, and proximity of cultivated land.

(5) Whether a surface water, or rain water, or nature of collecting surface and conditions of storage.

(6) Date on which sample was taken, and meteorological conditions with references to recent drought or excessive rainfall.

(7) A statement of the existence of any disease supposed to be connected with the water supply or any special reason for requiring analyses.

(8) Each bottle should be distinctly labelled, so as to correspond with the official letter or invoice.

(9) Any other particulars to which it is desirable that attention should be called.

In collecting samples of water for bacteriological examination, it is essential that the bottles shall be sterile, *i.e.*, absolutely free from bacteria. To ensure this, it is well to obtain the bottles from the bacteriologist who is to make the examination. Also the samples should be well packed, as directed by the bacteriologist and forwarded without any delay, because at ordinary temperatures any organisms, which may be present, will rapidly increase in number, and it is important that such a tendency to increase should, as far as possible, be prevented during transit.

3. **Quantity.**—The daily allowance of supply per head of population should generally be from 15 to 30 gallons per head per day, the rate varying according to the quantity of water available at the source and the nature of town conditions, such as drainage, industries, mills, pilgrim centres, floating population, etc.

For purposes of fixing the average daily rate of supply the following classification may be adopted :—

Class A	..	Town of less than 10,000 population.
B	..	Town of from 10,000 to 25,000 population.
C	..	Town of from 25,000 to 50,000 population.
D	..	Town of from 50,000 to 100,000 population.
E	..	Town of from 100,000 to 200,000 population.

and the requirements per head for various purposes may be provided for as under —

Class	A	B	C	D	E
	Gallons per head per day for				
Domestic consumption	5	6	6	6	6
Bathing and washing purposes ..	5	6	6	6	6
Public latrines and urinals, road watering and public gardens including public fountains, etc.	2	3	5	5	5
Sewer and drain flushing, etc., and private water closets.	3	3	3	3	3
Leakage from mains, etc. ..	0·5	0·5	1	1	1
Filter wash water	0·5	0·5	1	1	1
Sundries (stables, cowhouses, dhobi ghats).	2	3	3	3	3
Private gardens	2	3	3	5	5
Industries, etc.	Special provision according to size.				
Fire service	Special provision according to circumstances.				
Total ..	20	25	28	30	30

Pilgrim population should be provided for at the rate of 5 gallons per head per day. The same rate may also be provided for non-residential floating population.

A suitable allowance should also be made for increase in population.

The maximum daily demand should be taken at $1\frac{1}{2}$ times the mean daily consumption, and the absolute maximum rate of consumption, at twice the mean daily consumption.

4. The source of supply having been chosen, it will then be necessary to decide on the treatment of the water before its delivery to consumers. Water from wells, bores and springs should not need settlement, but for supplies from reservoirs or streams it will usually be necessary to provide settling tanks and filtration works.

Settling tanks

5. **Use.**—These are intended to provide for the settlement of matters in suspension either by giving a complete period of rest for a certain duration or by making the water pass through at a very slow rate. Settling tanks are also used to provide storage against fluctuations in supply and demand. Settlement is always necessary before filtration.

Location.—These are located in a water supply system generally as near the place of distribution as possible and at such a height as may be permissible by the natural configuration and the required head of pressure.

Types of tanks.—There are two types of these tanks named after the way in which they are used. Ordinary settling tanks are those which provide complete rest, and continuous flow settling tanks are those in which the supplies are passed continuously from one end of the tank to the other with a very slow velocity.

Capacity.—The capacity of settling tanks will generally depend on the maximum turbidity of the water and also on the character of the silt which may be held in suspension. The total capacity of these, all the compartments taken together, should be kept generally equal to one day's requirements, extra provision being made when other considerations such as occasional interruption due to canal closures and the like, require additional storage to keep the supply continuous.

Type design.—The ordinary settling tanks should be designed in two or more compartments for facility of cleaning and the depth of water should vary between 6 and 12 feet, the smaller depth being used for comparatively smaller capacities. The proportion of breadth to length in each compartment should generally be 2 to 3. The inlet should be above the designed F.S.L. and the outlet should be about 6 inches above the floor level, the draw-off being from a floating elbow pipe so arranged that the draw-off will take place at from 15 to 18 inches below the surface. Each compartment should be provided with inlet, outlet, wash-out and overflow, the last two being sometimes arranged through a common set of piping. All control valves should be outside the water and fitted with proper head stocks. The tanks should be quite water-tight and roofed over where connected to the distribution system, for direct use. The floor should slope towards a central drain.

Continuous flow settling tanks.—These are built in long narrow compartments with baffle walls to make the supply flow with a slow velocity of about 1″ per hour. These tanks are more useful where loss of head is to be avoided but are very expensive as compared with the ordinary settling tanks.

Filters

6. These are used after settling tanks. They may be of two types : (*i*) slow sand type and (*ii*) rapid mechanical type. In the Bombay Presidency filters of slow sand type are in use at Dhulia, Satara camp, Karad, Bijapur and Kirkee while Hubli and Poona have filters of the rapid type.

Slow sand filters

7. **Capacity.**—The capacity of the filters is to be measured on the effective area of the sand surface required.

Rate of filtration.—This depends much on the quality of sand used, and the thickness of the layers of different materials used in making up the filter bed. The usual rate is 450 gallons per square yard per day with a 5 feet filtering material, half of which is fine sand.

Design.—The required filtering area should generally be provided in sets of four units, any three of which being sufficient to filter the required quantity and having in the centre a regulating well. Each unit should have its sides in the proportion of 2 to 3, and constructed in masonry with bottom and sides perfectly water-tight, and the floor having a central drain along its diagonal. The filtering material to be filled in each unit should generally be in the following order. The central drain should be first covered with stone slabs with spaces between the adjoining faces. The whole floor of the filter should be covered with two layers of hard bricks with wide joints so as to form drains all over the floor leading to the collecting drains.

Above this false bottom of 6 inches, should be laid—

6 inches of broken stone (metal rings 2″ to 3″).
6 inches layer of large gravel.
6 inches layer of small gravel.
6 inches layer of coarse sand.
2 feet layer of fine sand (residue left between 70 and 100 meshes to the inch).
6 inches layer of very fine sand.

Total, 4 feet 6 inches.

The top 3 feet layer of sand above, should be, as nearly as possible, of pure silica.

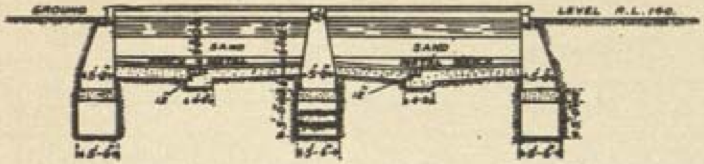
Vertical air pipes, passing through the sand, should be provided for the passage of air to and from the bottom of bed, to avoid the disturbance of the filtering layers.

Regulation of filters.—The usual system adopted is that known as the Berlin system which was in operation at the Poona Cantonment water works before the new rapid filter system was installed (see sketch, plate CXVI).

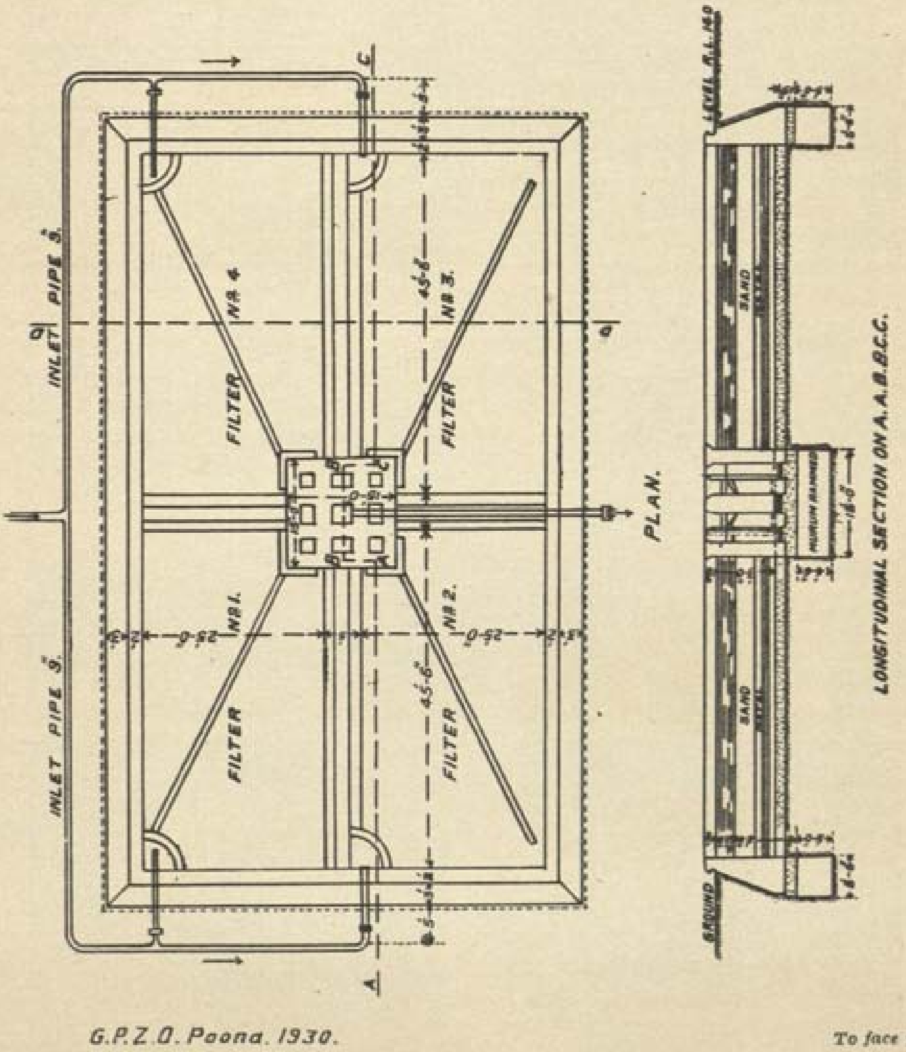
In this system there are three small regulating wells for each filter unit, the filtered water finally passing out over a V notch and stored in a pure water tank. Out of these three wells the first is for the reception of filtered water from which it is passed down through control valves to the second chamber having a notch fixed in one of its sides. The third chamber receives the notch discharges and is called the clear water well which may be common to all the filter units forming the plant at any place. From a system of float gauges arranged from each of these regulating wells the relation of the rate and the head of filtration for each

Plate CXV.

SAND FILTRATION PLANT AS AT KARAD.



CROSS SECTION ON D.D.



G.P.Z.O. Poona. 1930.

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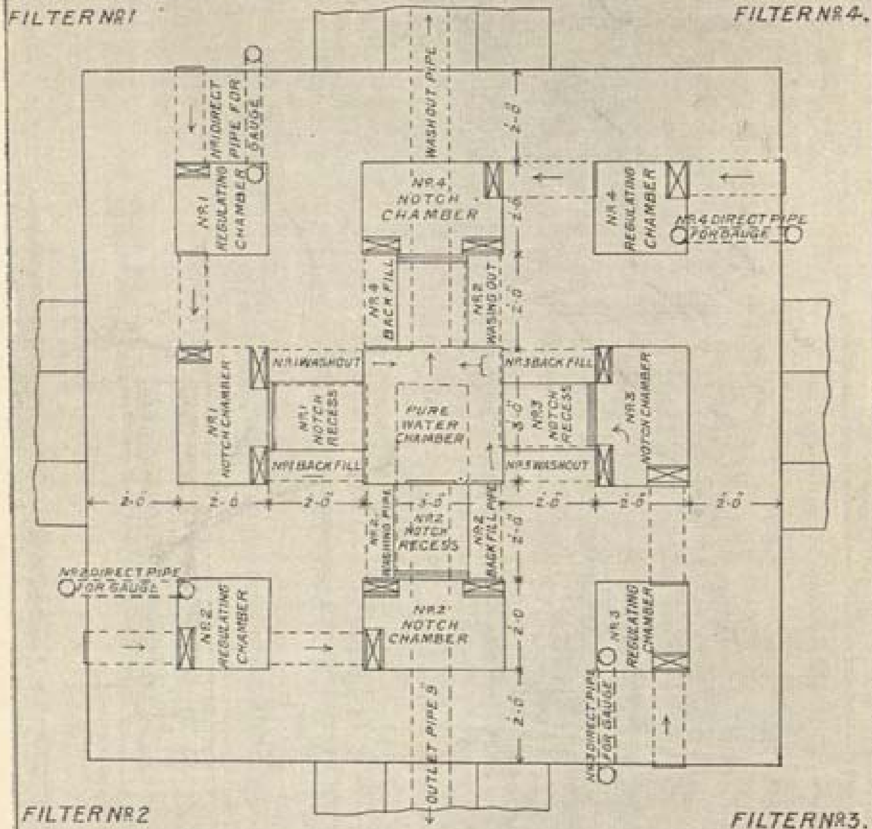
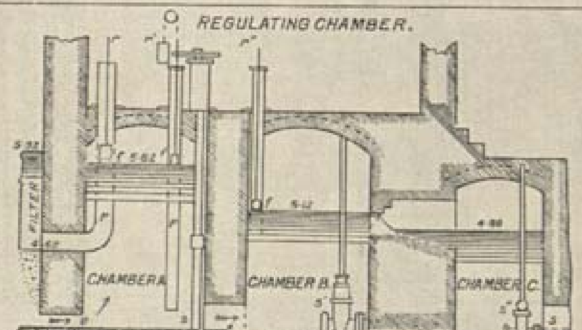
Plate CXVI

REGULATING SPEED OF FILTRATION HEAD

ENLARGED PLAN OF CENTRAL PORTION OF PLATE. CXV.





ARRANGEMENT FOR REGULATING SPEED OF FILTRATION HEAD

To face page 332.

unit can be ascertained at any period of its working. It is very important to keep these gauges always in working condition and keep a daily record of their observations, as from these alone the condition of the filters is to be watched as regards their efficiency and the desired degree of purification. Slow sand filters are worked under a maximum permissible filtration head of 2′-6″, but in practice this head should not exceed 18″. The general rule in this respect is, the ratio, maximum filtration head/depth of sand bed should not exceed 2/3. The water level over the filter beds should be kept constant, generally from 2 to 3 feet. The action of filter beds is best when a thin film is formed over the surface, and on this account, filters should be worked as long as possible. When the maximum head is reached, the beds should be thrown out of work, the surface pared, and when required again, the bed should be filled by filtered water from below. Instructions for scraping, washing and starting the filters should be made out for each plant suitable to the conditions of its design and these should be given to the man-in-charge on the spot.

In no case should the bye-pass valves be used, unless it is with the written permission of the Executive Engineer. Example of a small installation of sand filters, as constructed at Karad, is given in plate CXV.

Degree of bacterial purity and cost.—A water that is efficiently filtered, should not contain more than 100 harmless micro-organisms in 1 cubic centimetre of the filtered water. The total colonies in the mechanical filter effluent in Poona Cantonment are less than 25 colonies per c. c. agar count, the limit fixed being 50 colonies per c. c. agar count. In Poona the total cost of purification and slow sand filtration of 592 million gallons of water (one year's discharge) used to be 159,424 annas or 0·268 annas per 1,000 gallons, or roughly 1 quarter anna per 1,000 gallons. The cost of purification by means of Paterson filtration system of the above quantity is 133,424 annas or 0·225 annas per 1,000 gallons, or under one quarter anna per 1,000 gallons. The cost of sterilization, by means of bleaching powder, after the water is filtered, works out to 0·066 annas per 1,000 gallons, in addition, or roughly ¾ of one pie per 1,000 gallons, in both cases.

Rapid filters

8. There are mainly two types of these filters, the gravity type and the pressure type. These are more economically and efficiently used where large quantities of daily supplies are to be dealt with. These use a small dose of alum to effect a quick settlement of suspended solids, and the rapid formation of the filtering skin. Various makes of these filters are patented ; in the Bombay Presidency filters of gravity type of two makes are in operation : (I) the Jewell plant at Hubli and (II) the Paterson plant at Poona. The Jewell plant makes use of mechanical rakes for sand washing and the Paterson plant provides air blast for the same purpose by means of compressed air, stored in receivers.

The general method of their operation is as follows :—Raw water is dosed (1/3 to 2 grains per gallon) with a coagulant, generally sulphate of alumina, and allowed to settle for a period varying between 4 and 6 hours, after which it is admitted to the filters, which are generally worked at the rate of about 80 gallons per square foot *per hour* (20,000 gallons per square yard per day) equivalent to nearly 40 times the rate admissible with slow sand filters. The filtration head in rapid filters varies from 5 to 12 feet.

The filtered water passes over a V notch weir, the level of discharge over which controls automatically the rate of filtration, by patented mechanical devices. The complete sterilization of the filtrate is effected by chlorination

at the tail end of the pure water channel to which the various filter units are connected. With a good sample of bleaching powder (30 per cent. available chlorine), average water requires about 15 pounds per million gallons.

The dosing solutions are prepared by manual labour and stored in solution tanks in duplicate for each chemical use and at a sufficient elevation above the raw water inlet.

At the inlet side, the measuring and supply gear controls automatically the dose of chemical solution to be given and the Paterson type has a patented design for this portion of the filter plant.

Rapid filters are usually found more satisfactory in India, provided the necessary skilled supervision can be given.

The general arrangements for a Paterson filter plant are shown in the sketch plan of the Poona Cantonment water works (see plates CXVII and CXVIII).

9. **Pure water tanks.**—From the filters, the water will be delivered into the pure water tank or distributing reservoir. The contents of these tanks vary with requirements but from a sanitary point of view should not contain more than is required to compensate for variations in the rate of draw-off. About 8 hours' supply is enough for this purpose, but the tanks should be in duplicate and are generally made to hold 24 hours' supply, to provide for any temporary breakdown of the filters, or of the supply to these. The depth is generally 9 to 15 feet, increasing with the capacity. They should be provided with wash-out valves and gauges and should be covered and provided with ventilators.

10. **Design of pipe distribution system in towns.**—The system begins with a supply main from the pure water tanks, branching off into district or subsidiary mains to different parts of the system.

The lay-out of the system should be designed so as to have the larger mains passing through portions of the greatest supply and connected to the supply main in as direct a route as possible.

The pipes should be designed generally so as to have the discharging capacity approximately equal to twice the average flow, and the resulting effective pressures at the time of maximum draw-off should, generally, be between 20 to 30 feet above the ground level for towns with two-storied buildings, the minimum being 10 feet in rare cases.

The system should be divided into the high, medium and low level supply areas according to the configuration of the ground and each of these systems should be arranged to be supplied from an independent service reservoir of at least a day's capacity.

The connection mains to these service reservoirs, from the principal pure water tank, may be designed to deliver the day's requirements in 16 to 24 hours.

11. **Mains.**—For distribution, cast iron pipes are generally used, laid, as far as possible, in straight lines. In excavating the trench for pipe laying, it is important that the pipes shall be properly bedded so that there may be no danger of pipes cracking or joints being opened by settlement. This is best done by carefully levelling the bottom of the trench for the greater part of the length of the pipe and cutting a hollow to receive the socket end of it. The pipe

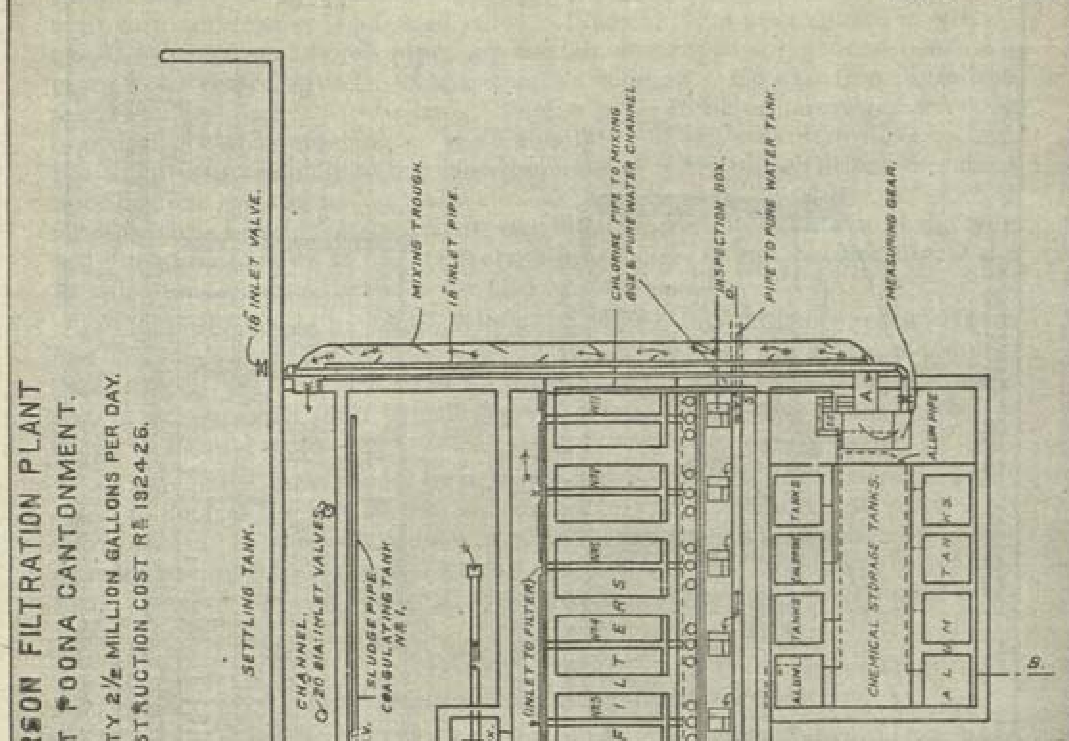
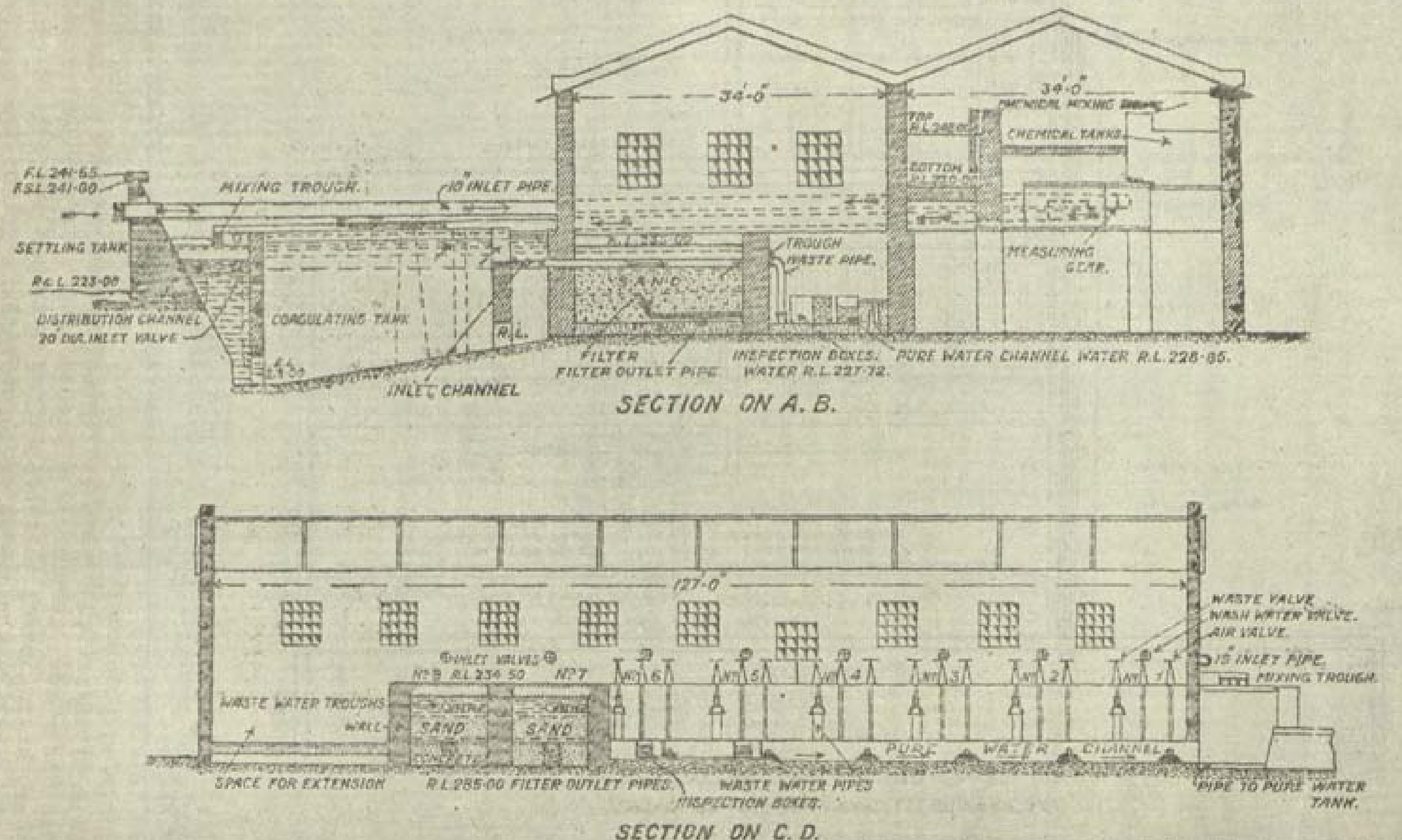

PATERSON FILTRATION PLANT
AT POONA CANTONMENT.
CAPACITY 2½ MILLION GALLONS PER DAY.
CONSTRUCTION COST Rs 192426.
SETTLING TANK.
A
DISTRIBUTION CHANNEL.
20" DIA INLET VALVE
16" INLET VALVE.
MIXING TROUGH.
16" INLET PIPE.
SLUDGE PIPE COAGULATING TANK No 1.
SLUDGE PIPE COAGULATING TANK No 2.
S.V.
S.V.
CHLORINE MIXING BOX.
INLET CHANNEL
INLET TO FILTER
F I L T E R S
CHLORINE PIPE TO MIXING BOX & PURE WATER CHANNEL.
INSPECTION BOX.
PIPE TO PURE WATER TANK.
MEASURING GEAR.
ALUM PIPE
CHEMICAL STORAGE TANKS.
ALUM TANKS
A L U M T A N K S
B.
PURE WATER CHANNEL.
INSPECTION BOX
NOTE:- IN PRACTICE THE CHLORINATION IS CARRIED OUT AFTER THE WATER IS FILTERED.
PLAN.
C
AIR RECEIVERS

Plate CXVIII

PATERSON FILTRATION PLANT AS AT POONA CANTONMENT.



G. P.Z. P. Poona. 1929.

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should usually be spigot and socket pipes of British standard specifications with yarn and lead or solid lead joints. Flanged pipes are required in special cases. Turned and bored pipes are not recommended for general use. All pipes to be coated with Dr. Angus Smith's solution. No cast iron pipes less than 3 inches diameter to be laid. Smaller pipes to be of galvanized wrought iron, but generally speaking no main should be of less size than three inches. For the pressure usually to be resisted class B of water pipes (British Standard Specifications), tested to a pressure of 400 feet head, is suitable. All special pipes, such as bends, tees, junctions, etc., shall whenever possible be of the type and dimensions shown in the list of standard special castings, accompanying the British Standard Specifications for C. I. pipes.

The pipes should be designed by using Unwin's or the more recent Hazen and William's formula, for the latter of which separate tables are made out. (See table CLVII). Calculations for determining sizes of pipes should be made out, in the attached form, which gives the residual effective heads in feet as based on normal service.

Each district main should be properly metered and its readings periodically taken to control the distribution and detect leakage. All scour valves and air valves should be tested at least once in every three months and effective pressures, actually resulting in the mains during the hours of maximum supply, should also be similarly ascertained by pressure gauges and recorded at least once every half year.

WATER SUPPLY

Table of calculations for effective heads.

(1) Whole population,——; (2) Rate of supply,——gallons per head per day; (3) Delivery period,——hours; (4) Formula used,——

Point on main (refer plan)	Population in section	Total population served by main	Estimated supply, discharge in gallons per minute	Main details				Levels on datum		Effective head in feet
				Diameter in inches	Length in feet	Rate of friction for discharge in column (4)	Total friction loss in section feet	Hydraulic gradient level	Ground level	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)

Special notes :—

12. **The appurtenances of a pipe line** are—

(1) **Air valves** which are placed at every summit in the pipe line to permit the escape of air when the main is filled and afterwards if any air is carried into the main. They are also placed on long stretches of nearly level main. They are generally, ball valves lighter than water, which close the air vent if air accumulates.

(2) **Scour valves** are placed at the bottom of all depressions for emptying the main or letting out sediment.

(3) **Reflax valves.**—On ascending parts of the main are flap valves which open in the direction of flow, but which automatically close if a burst occurs and the water flows back. They diminish the damage done by the escape of water at a burst.

(4) **Safety or relief valves.**—These are fixed at the downstream ends of long lengths of mains, or where water hammer may take place, so as to reduce to the normal any excessive pressure that may occur.

(5) **Sluice stop-valves** worked by hand or by a hydraulic cylinder for closing the main or regulating the flow. In the case of large mains the pressure on a large sluice-valve is very great, and the force required to move the sluice when starting from the closed position is very great. Thus on a 36-inch valve under 250 feet of head the pressure would be nearly 50 tons, and the frictional resistance to moving the valve perhaps seven tons. To facilitate opening, the valve is sometimes divided into three parts which can be opened separately. In other cases the valve is made about one-third the area of the pipe.

The pipe is gradually contracted to the area of the valve, and gradually enlarged again. Then, though there is some loss of head at the valve, it is not very serious.

CAST IRON PIPES

Specification No. 179

1. **Straight pipes and special castings.**—The pipes shall be of cast iron, straight spigot and socket pipes and special castings, with plain sockets.

2. **Quality of metal used in casting the pipes.**—The metal used for casting the pipes shall be pig iron alone, or pig iron and scrap, and shall be remelted in the cupola or air furnace. The pig iron shall be best tough grey foundry pig iron, and the scrap shall be clean, unburnt and of good quality. There shall be no admixture of cinder, iron or any material calculated to render the metal inferior in quality and the resulting casting shall not be white or vitreous on fracture.

3. **Strength of metal used.**—The quality of metal used shall answer the tests specified in the latest British Standard Specifications, *viz.*,—

(*a*) The transverse test bars 3′ 6″ × 2″ × 1″, placed, with the depth in the direction of the load, on knife edges, 3 feet apart, shall sustain a load of 28 cwts., applied at the centre, and shall also show before rupture a deflection of not less than 0·33 inch.

(*b*) The tensile breaking strength of the metal shall be not less than 9½ tons per square inch.

4. **Mode of casting.**—The straight pipes shall be cast vertically in dry sand moulds formed from turned iron patterns and in accurately faced and truly jointed boxes, and without the use of core nails, chaplets, or thickness pieces, or any

substitute therefor. They shall be cast with a sufficient head of metal to ensure soundness, which head shall be afterwards cut off in a lathe, and the finished pipe left the length and shape required.

All straight spigot and socket pipes shall be cast socket downwards.

5. **Moulds and cores.**—The sand used in the moulds and cores during manufacture shall be sufficiently fine and fresh to produce a smooth and regular surface ; the cores shall be smoothly finished and the moulds and cores, where dry sand is used, shall be properly blackwashed and carefully dried.

6. **Removal from moulds.**—The pipes shall not be removed from the moulds until cooling has proceeded so far as to prevent all risk of straining, cracking or other injury consequent on their removal.

7. **Freedom from defects, and permissible variation in diameter and thickness.**—The pipe shall be of the full specified dimensions, as shown in columns 1, 2 and 3 of rate abstract No. 135, and shall be straight or curved in the axis as may be required. They shall be in all respects sound good castings, easily worked with a drill or file, free from laps or other imperfections ; shall be neatly dressed and carefully fitted so that no lumps or rough places shall be left in the barrels or sockets ; their inner and outer surfaces shall be smooth, and the inner edge of the socket shall be left reasonably square.

The thickness of the barrels of the straight pipes shall be not less than nine-tenths of the prescribed standard thickness, whether the reduction in thickness be due to want of concentricity or other cause, except that, in the case of pipes of 12 inches diameter and over, the thickness in an area extending over not more than 6 inches × 6 inches, or its equivalent, may be not less than seven-eighth of the prescribed standard thickness.

In no case shall the external diameters be more than one-sixteenth inch above or below the standard external diameters shown in column 3 of rate abstract No. 135, page 886.

8. **Sockets.**—Great care shall be taken to ensure that the sockets will, in all cases, receive the spigots, and the spigots will in all cases enter to the bottom of the sockets. The internal diameter of the sockets of the straight pipes shall not deviate by more than one-eighth inch above or below the specified diameter, and the internal diameter of the sockets of the special castings shall not deviate by more than 3/16 inch above or below the specified diameter.

9. **Length of straight pipes.**—The standard lengths of the straight spigots and socket pipes (exclusive of the internal depth of the sockets) shall be as follows :—

Nominal internal diameter of pipe	Length of pipe
3 inches	9 feet.
4 to 12 inches inclusive ...	9 feet or 12 feet (as may be specified).
14 to 24 inches inclusive ...	12 feet.
26 to 48 inches inclusive ...	12 feet.

10. **Permissible variation in length of straight pipes.**—The lengths of the straight spigot and socket pipes shall be not more than ½ inch, under or over the standard lengths given in paragraph 9, but on average such pipes shall be not less in length than the standard lengths given in paragraph 9.

11. **Hydraulic test.**—Before being coated, the straight pipes shall be tested at manufacturer's works, and they shall withstand a test pressure of 400 feet head, without showing any leakage, sweating or other defects of any kind.

The pressure shall be steadily applied by approved means and maintained sufficiently long for proof and inspection with accurate pressure gauges.

While under the test pressure each pipe shall be smartly struck with a suitable hand hammer weighing not less than 1½ pounds.

12. **Coating.**—As soon as each pipe has satisfactorily withstood the foregoing tests, and before it shall have become affected by rust, it shall be heated to a suitable temperature not exceeding 250° F., and perfectly coated, in the most approved manner, by being dipped in a bath of approved composition maintained at a temperature of not less than 300°, nor more than 330° F., according to Dr. Angus Smith's process. When the pipe is removed from the bath, it shall be properly drained, and the coating must fume freely and set hard within an hour. If the coating does not so fume and set, the pipe shall be recoated.

13. **Weighing and marking of weights.**—After coating, each pipe shall be weighed, and its weight distinctly marked thereon in oil paint, and, wherever practicable, on the inside of the socket. Pipes under 5 inches in diameter may, unless otherwise specified, be weighed in batches of 15 cwts. or thereabouts.

14. **Permissible deviation from standard weights.**—The following variation in weight above or below the standard weights of the straight pipes given in columns 4, 5 and 6 of table shall be allowed :—

Nominal internal diameter of pipe in inches	Limit of deviation from standard weight above or below
3 to 7	4 per cent.
Over 7 to 16	3½ per cent.
Over 16 to 24	3 per cent.
Over 24 to 32	2½ per cent.
Over 32 to 42	2 per cent.
Over 42 to 48	1½ per cent.

15. **Defective coatings.**—No pipes shall in any way be stopped, repaired or altered and any pipe which has been so treated, shall be rejected, notwithstanding that it may have been previously passed.

LAYING AND JOINTING CAST IRON PIPES

Specification No. 180

1. **Excavation of trench.**—The trenches shall be excavated to the grade and depth and on the line showed on the approved drawings ; the minimum cover shall be 2½ feet. Before the trench excavation is commenced, sight rails shall be erected every 100 feet and at all changes of direction or gradient at a definite and, as far as practicable, uniform height above the invert of the pipes, the centre line being clearly marked on each rail. The depth of excavation and the level of the pipe invert shall be checked by means of boning rods of appropriate length. The bed of the trench, if in soft earth, shall be well rammed before laying the pipes ; if in rock, the excavation shall be taken down to 6 inches below

the bed line, and refilled to this level with well rammed earth. Before lowering the pipes into the trench, hollows shall be cut in the bed, and in a narrow trench the width of excavation increased opposite the joints to receive the socket and to give adequate room for caulking the lead joints.

2. **Materials excavated.**—The various materials excavated to be separated and stacked so that in refilling they may be again relaid in the same order, and thus the least possible damage be done to public roads, cultivated fields, etc.

3. **Width.**—The sides of trenches to be as nearly vertical as possible, the width at bottom being at least 12″ wider than the socket of the pipe, so as to allow room for ramming the refilled material under and at the sides of the pipe. Shoring will not usually be resorted to, except in very bad ground and in places such as streets, roads, etc., where a wide excavation is not permissible.

4. **Lighting, etc.**—If trenches have to be kept open at night in frequented places, a chowkidar must be employed, and light placed at each end and at intervals along the trench, and, if necessary, the trench must be further protected by a rough fence.

5. **Stacking of pipes.**—The pipes shall be laid out along the side of the trench, each pipe in its proper position for laying with an extra pipe after every 20 to allow for cutting. Where the trench crosses a road or place where such distribution is inadmissible, the pipes shall be stacked in heaps at each end sufficient to fill in the length. Small pipes below four inches diameter may be stacked in heaps at every 100 feet.

6. **Preparation of pipes.**—The pipes before being laid shall be brushed throughout to remove any soil or stones that may have accumulated therein, the inside of the socket and outside of the spigot being carefully cleaned. For small pipes, they should be tilted up to remove any accumulation.

Use of old pipes.—Old pipes, when used, should be thoroughly tested for soundness and cracked portions cut out. Incrustation should be scraped out, and all holes in pipe walls should be thoroughly plugged up by screwed plugs and pipes tested under hydraulic pressure, equivalent to a head of at least 300 feet. The pipes should then be dipped in hot Angus Smith's solution and should not be used before one week.

7. **Laying.**—The pipes shall then be laid in position the socket ends of all pipes facing up hill, irrespective of the direction of the water flow. Any deviation, either in plan or elevation of less than 11¼° shall usually be effected by laying the straight pipes round a flat curve, of such radius that the minimum thickness of lead at the face of the socket shall not be reduced below ¼″, or the opening between the spigot and socket increased beyond ½″ at any joint. A deviation of about 2½° at each joint can be effected in this way. If the joints are used spigots and socket joints, the spigots shall be carefully centered in the socket by one or more laps of white hempen spun yarn, sufficient yarn only being forced into the socket to leave a depth of lead as shown in table CCVII. The proper depth of each joint shall be tested before running the lead by passing completely round it a wooden gauge notched out to the correct depth of lead, the notch being held close up against the face of the socket. The pipes shall be carefully packed underneath so that they shall bear properly throughout their whole length.

For turned and bored joints the joints shall be carefully cleaned and then smeared with Russian tallow, the spigot end of one pipe being placed in the socket

of the other and driven home by three or four blows of a wooden mallet. (The next pipe is sometimes slung on a rope and used for this purpose).

8. **Leading the Joints.**—The pipes shall then be again examined for line and level and the space left in the socket shall be filled in generally by pouring in melted lead. This may be done best by using proper leading rings or, if these are not available, by wrapping a ring of hemp rope, covered with clay round the pipe at the end of the socket, leaving a hole into which the lead shall be poured. For large pipe it is also necessary to leave one or more air vents around the lower half of the joints. The lead shall be rendered thoroughly fluid and each joint shall be filled at one poring. If the pipe is too large for the joint to be filled from one ladle two or more ladles shall be used. The lead used should be soft and free from admixture of tin. Best blue pig lead makes the best joints.

9. **Caulking.**—After a section of a convenient length has been leaded, caulking shall be commenced. The lead shall be freed from the leading pipe, outside of the socket of the other pipe, with a flat chisel, and then caulked round 3 separate times, with the proper caulking tools of increasing thickness and a hammer 4 to 5 lbs. in weight in such a manner as to make the joints sound and water-tight. After being well and evenly set up, the joint is to be left flush neat and even with the socket.

Joints under water shall be made with lead wool inserted in strings not less than one-fourth inch thick and very thoroughly caulked.

10. **New flanged joints.**—Flanged joints should be made by painting the facing of the flange with red lead freely and bolting up evenly on all sides.

A thin fibre of lead wool may be very useful in making the joints water-tight, where facing of the pipes is not true.

Where packing must be used, it should be of rubber insertion cloth, three ply, and of approved thickness. The packing should be of the full diameter of the flange with proper pipe hole and bolt holes cut, and even at both the inner and outer edges.

Where the flange is not fully faced, the packing may be of the dimension of the facing strip only. Its proper placing should be tested before another pipe is jointed on.

11. **Testing.**—After each section of the pipe line has been completed, it shall be tested for water-tightness before being covered in. This can be done by closing each end by means of a valve, blank flange, cap or plug, and filling the pipe with water. The pressure should then be raised by means of a small hand force pump till it registers 15 per cent above the highest working pressure in the section, and the test pressure should be ascertained by means of a reliable gauge. When the pipe is laid on any appreciable gradient, the test should be carried out at the lower end of the section. Any leaking joints should be made good, and the above test reapplied until no further leaks are apparent.

12. **Filling in.**—If the joints are found to be water-tight, the trench shall be filled in by replacing the excavated stuff in 6-inch layers, watering and ramming. To prevent excessive expansion owing to pipes being exposed to the sun, it is advisable in India to cover the greater part of the pipe as soon as possible, leaving the joint only exposed.

13. **Weight of lead.**—The weight of cast iron pipes of class B and that of the lead required for jointing are given approximately in table CCVII and rate abstract No. 135, page 886.

Bolan

TABLE CCVII

SHOWING WEIGHT OF C.I. PIPES AND THE MATERIAL REQUIRED PER JOINT FOR JOINTING THEM, AS PER BRITISH STANDARD SPECIFICATIONS

Dimensions of pipes in inches	Length of pipe in feet	Thickness of pipe in inches	Weight of each pipe			Total depth of socket in inches	Weight of lead per joint in lbs.	Weight of hemp per joint in lbs.	Depth of lead in inches
			Cwt.	Qrs.	Lbs.				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
3″	9′	0·38	1	0	17	3·0	4·5	0·25	2·00
4″	9′	0·39	1	2	4	3	5·5	0·38	2·00
5″	9′	0·41	2	0	4	3½	7·0	0·44	2·50
6″	9′	0·43	2	2	6	3½	8·0	0·44	2·40
7″	9′	0·45	3	0	9	3½	9·5	0·50	2·40
8″	9′	0·47	3	2	24	4	12·0	0·63	2·90
9″	9′	0·49	4	1	9	4	13·5	0·69	2·90
10″	12′	0·52	6	2	2	4	14·75	0·75	2·90
12″	12′	0·57	8	1	6	4	17·0	1·06	2·90
14″	12′	0·61	10	1	15	4½	21·5	1·38	3·25
15″	12′	0·63	11	1	21	4½	23·0	1·50	3·25
16″	12′	0·65	12	2	7	4½	24·25	1·63	3·25
18″	12′	0·69	15	0	5	4½	31·50	2·07	3·10
20″	12′	0·73	17	2	11	4½	34·50	2·25	3·10
21″	12′	0·75	18	3	25	4½	36·25	2·38	3·10
22″	12′	0·77	20	2	8	5	38·25	2·50	3·60
24″	12′	0·80	23	1	..	5	41·25	2·66	3·60
26″	12′	0·83	26	0	4	5	44·50	2·84	3·50
27″	12′	0·85	27	2	13	5	46·75	2·94	3·50
28″	12′	0·86	28	3	20	5	50·25	3·06	3·50
30″	12′	0·89	31	3	26	5	58·25	3·22	3·40
32″	12′	0·92	35	0	16	5	63·0	3·38	3·40
33″	12′	0·94	37	0	5	5	67·56	3·63	3·25
36″	12′	0·98	42	0	4	5	71·50	4·13	3·25

TABLE CCVIII

STANDARD WEIGHTS OF CAST IRON BENDS, COLLARS, TAIL PIECES AND HYDRANTS

Nominal Internal diameter	Bends 90°	Bends 45°	Bends 22½°	Bends 11¼°	Collars	Tail pieces: Flanged sockets	Tail pieces: Flanged spigots	Hydrants 3″ for all sizes	Remarks
	C. Q. L.	C. Q. L.	C. Q. L.	C. Q. L.	C. Q. L.	C. Q. L.	C. Q. L.	C. Q. L.	
3″	0 1 13	0 1 18	0 1 18	0 1 18	0 1 4	0 0 27	0 0 18	0 2 18	
4″	0 2 4	0 2 5	0 2 5	0 2 5	0 1 14	0 1 8	0 0 25	0 3 9	
5″	0 2 27	0 3 4	0 3 4	0 3 4	0 2 7	0 1 23	0 1 8	1 0 8	
6″	1 0 4	0 2 27	0 3 27	0 3 27	0 2 23	0 2 7	0 1 16	1 1 8	
7″	1 1 2	1 0 27	1 0 27	1 0 27	0 3 7	0 2 18	0 1 25	1 2 7	
8″	1 3 0	1 2 6	1 2 6	1 2 6	1 0 11	0 3 11	0 2 14	2 0 7	
9″	2 0 7	1 3 14	1 3 14	1 3 14	1 1 0	0 2 26	0 2 26	2 1 13	
10″	2 2 22	2 0 25	2 0 25	2 0 25	1 1 14	1 0 18	0 1 16	2 3 4	
12″	3 2 1	2 3 23	2 3 23	2 3 23	1 3 27	1 1 17	1 0 14	3 1 25	
14″	4 1 23	3 3 22	3 3 22	3 3 22	2 2 16	1 3 10	1 2 8	4 3 3	
15″	5 0 27	4 1 25	4 1 25	4 1 25	2 3 6	1 3 26	1 2 24	5 0 25	
16″	5 3 0	4 2 17	4 3 17	4 3 17	3 0 8	2 0 19	1 3 16	5 2 23	
18″	6 3 20	6 0 13	6 0 13	6 0 13	3 3 3	2 2 20	2 1 1	7 1 19	
20″	8 2 13	7 1 25	7 1 25	7 1 25	4 1 6	3 1 24	2 2 21	8 2 19	
21″	9 3 15	8 1 6	8 1 6	8 1 6	4 2 13	3 2 27	2 3 17	9 1 8	
22″	11 2 1	9 1 0	9 1 0	9 1 0	5 2 3	4 0 24	3 1 16	10 3 27	
24″	13 2 23	10 2 27	10 2 27	10 2 27	6 0 16	4 3 2	3 3 13	12 1 13	
26″	15 2 21	12 1 3	12 1 3	12 1 3	6 3 27				These sizes will be special castings for which no standard weights are available.
27″	17 1 26	14 0 11	14 0 11	14 0 11	7 1 9				
28″	18 1 6	14 3 1	14 3 1	14 3 1	7 2 20				
30″	20 1 6	16 1 3	16 1 3	16 1 3	8 1 22				
32″	23 1 4	19 1 1	19 1 1	19 1 1	9 0 13				
33″	24 2 7	20 1 7	20 1 7	20 1 7	9 3 5				
36″	27 3 11	23 0 3	23 0 3	23 0 3	10 3 13				
38″	31 3 0	26 3 18	26 3 18	26 3 18	11 3 21				
40″	34 0 2	28 3 9	28 3 9	28 3 9	12 3 1				
42″	36 2 26	31 0 14	31 0 14	31 0 14	13 2 20				
44″	41 2 10	35 3 17	35 3 17	35 3 17	15 2 26				
46″	44 2 17	38 2 5	38 2 5	38 2 5	16 2 23				
48″	47 1 9	40 3 10	40 3 10	40 3 10	17 2 2				

TABLE CCIX

TABLE

SHOWING STANDARD WEIGHTS OF C. I. PIPE TEES

Nominal internal diameter	Sizes 3″	4″	5″	6″	7″	8″	9″
	C. Q. L.			*Cast*			
3″	0 2 27						
4″	0 3 19	0 3 27					
5″	1 0 17	1 0 25	1 1 14				
6″	1 1 18	1 1 25	1 2 11	1 2 21			
7″	1 2 16	1 2 24	1 3 11	1 3 22	2 0 6		
8″	2 0 17	2 0 23	2 1 10	2 1 20	2 2 4	2 2 21	
9″	2 1 23	2 2 3	2 2 18	2 3 1	2 3 13	3 0 2	3 0 17
10″	2 3 14	3 0 20	3 0 9	3 0 19	3 1 6	3 1 27	3 2 12
12″	3 2 7	3 2 17	3 3 3	3 3 18	4 0 1	4 0 23	4 1 7
14″		4 3 20		5 0 21		5 1 27	
15″		5 1 13		5 2 14		5 3 21	
16″		5 3 11		6 0 13		6 1 20	
18″		7 2 8		7 3 10		8 0 17	
20″				9 0 3		9 1 11	
21″				9 2 20		10 0 1	
22″				11 1 11		11 2 20	
24″				12 2 25		13 0 7	
26″						15 3 25	
27″						16 3 11	
28″						17 2 10	
30″						20 3 13	
32″							
33″							
36″							
38″							
40″							
42″							
44″							
46″							
48″							

Nominal internal diameter	22″	24″	26″	27″	28″	30″	32″
22″	14 3 12						
24″		16 3 2					
26″		19 2 4	20 0 10				
27″		20 1 20		21 0 25			
28″		21 0 22			22 0 24		
30″		24 3 8				26 2 0	
32″		26 3 1				28 1 24	29 0 1
33″		27 3 23				29 2 18	30 0 18
36″		34 1 24				36 0 23	36 3 1
38″		37 0 7				38 3 8	39 1 15
40″		41 1 12				43 0 15	43 2 23
42″		44 1 1				46 0 5	46 2 14
44″		49 2 9				51 1 16	51 3 25
46″		52 3 13				54 2 22	55 1 4
48″		55 2 26				57 2 9	58 0 20

CCIX

OF BRITISH STANDARD SPECIFICATIONS

of Branches

10″	12″	14″	15″	16″	18″	20″	21″
	Iron		*Standard*			*Tees*	
3 3 2 4 1 27	4 2 27						
5 3 3 6 0 25 6 2 25 8 1 23 9 2 17 10 1 7 11 3 27 13 1 23	6 0 4 6 1 25 6 3 26 8 2 25 9 3 27 10 2 18 12 1 10 13 2 27	6 1 9	7 0 10 7 2 11 9 1 11 10 2 7 11 0 26 12 3 19 14 1 8	7 3 0 9 2 7 10 3 4 11 1 23 13 0 16 14 2 6	10 0 19 11 1 16 12 0 8 13 3 1 15 0 20	11 3 6	12 2 22 14 1 20 15 3 11
16 1 8 17 0 21 17 3 21 21 1 0 23 0 17	16 2 14 17 2 1 18 0 18 21 2 12 23 2 2 24 2 21 31 0 16		17 0 27 18 0 13 18 3 15 22 1 4 24 0 22 25 1 15 31 3 11	17 1 21 18 1 8 19 0 8 22 2 1 24 1 20 25 2 12 32 0 9	17 3 23 18 3 10 19 2 11 23 0 8 25 0 0 26 0 21 32 2 19		18 2 14 19 2 2 20 1 3 23 3 8 25 3 1 26 3 22 33 1 22
			34 1 19 38 2 21 41 2 6	34 2 18 38 3 20 41 3 6 47 0 12 50 1 13 53 0 23	35 1 0 39 2 23 42 1 17 47 2 24 50 3 26 53 3 8		36 0 4 40 1 8 43 0 23 48 2 23 51 3 5 54 2 18

33″	36″	38″	40″	42″	44″	46″	48″
30 2 11	38 0 11 40 2 26	41 1 25					
	45 0 8 48 0 0 53 1 13 56 2 18 59 2 10		46 1 22	50 0 16 55 2 2 58 3 12 61 3 4	56 2 17	60 3 8	64 1 24

TABLE

SHOWING STANDARD WEIGHTS OF C. I. PIPE TEES AND ANGLE

Nominal internal diameter	Sizes 3″	4″	5″	6″	7″	8″	9″
	C. Q. L.			*Cast*		*Iron*	
3″	0 3 10						
4″	1 0 1	1 0 13					
5″	1 1 1	1 1 13	1 2 4				
6″	1 2 0	1 2 11	1 3 3	1 3 21			
7″	1 2 26	1 3 11	2 0 2	2 0 21	2 1 13		
8″	2 0 6	2 0 18	2 1 10	2 2 1	2 2 21	2 3 20	
9″	2 1 9	2 1 22	2 2 14	2 3 5	2 3 26	3 0 25	3 1 21
10″	2 2 23	2 3 8	3 0 0	3 0 20	3 1 13	3 2 12	3 3 2
12″	3 1 8	3 1 22	3 2 15	3 3 7	4 0 1	4 1 1	4 1 26
14″		4 1 0		4 2 15		5 0 10	
15″		4 2 12		4 3 27		5 1 23	
16″		5 0 0		5 1 17		5 3 13	
18″		5 3 21		6 1 11		6 3 8	
20″				7 1 2		7 2 27	
21″				7 3 2		8 0 27	
22″				8 1 24		8 3 22	
24″				9 1 20		9 3 19	
26″						11 0 20	
27″						11 2 26	
28″						12 0 23	
30″						13 1 6	
32″							
33″							
36″							
38″							
40″							
42″							
44″							
46″							
48″							

Nominal internal diameter	22″	24″	26″	27″	28″	30″	32″
22″	20 0 9						
24″		23 0 9					
26″		25 0 25	27 2 22				
27″		26 2 3		29 2 4			
28″		27 1 13			32 1 8		
30″		28 3 27				36 0 25	
32″		31 0 2				38 2 0	41 1 14
33″		32 0 26				39 3 15	42 3 9
36″		35 1 16				43 2 0	46 2 18
38″		39 3 14				46 0 19	47 2 15
40″		41 1 22				48 2 9	52 0 1
42″		42 1 10				51 1 16	54 3 26
44″		44 3 27				54 0 10	58 0 11
46″		49 3 21				57 1 13	58 3 8
48″		52 2 6				60 3 5	64 0 9

CCX

BRANCHES OF BRITISH STANDARD SPECIFICATIONS

of			Branches				
10″	12″	14″	15″	16″	18″	20″	21″
			Angle		*Branches*		
4 3 6 5 3 3	6 1 4						
6 3 9 7 1 9 7 3 21 9 0 18 10 1 14 11 0 5 11 3 19 13 0 25	7 1 12 7 3 12 8 1 18 9 2 20 10 3 20 11 2 11 12 2 8 13 3 5	8 0 3	8 3 18 10 0 1 10 3 1 12 0 6 12 2 21 13 2 11 14 3 20	10 1 27 11 3 21 13 0 26 14 0 1 14 3 20 16 1 14	13 2 0 15 0 2 15 3 0 16 3 5 18 1 11	15 3 11	7 1 23 8 1 25 20 0 6
14 3 23 15 2 24 16 1 12 17 3 10 19 1 12	15 2 1 16 1 2 16 3 19 18 1 18 19 3 24 20 3 19 23 1 13		16 2 12 17 1 14 18 0 3 19 2 4 21 0 11 22 0 7 24 2 4 26 1 14	18 0 26 19 0 8 19 3 4 21 1 20 23 0 11 24 0 16 26 3 9 30 2 17	20 1 12 21 1 2 22 0 4 23 3 8 25 2 21 26 3 6 29 2 25 33 2 26		22 0 5 22 3 23 23 3 1 25 2 6 27 1 16 28 2 2 31 1 23 35 2 8
			28 0 0 29 3 20	32 2 11 32 3 0 35 0 8 39 1 26 42 1 0	33 3 12 36 0 14 38 2 12 43 0 19 43 2 1		35 2 17 37 3 21 40 1 20 45 0 3 45 1 11

33″	36″	38″	40″	42″	44″	46″	48″
44 2 10	52 2 4 55 2 3	57 2 11					
	58 0 23 61 1 12 64 2 15 68 0 1 70 3 25		64 1 8	71 3 21 75 2 4 79 1 24 82 2 18	79 1 0	85 0 13	93 3 13

TABLE CCXI

SHOWING STANDARD WEIGHTS OF CAST IRON TAPER PIPES

Socket large end			Socket small end		
Internal bore		Weight	Internal bore		Weight
Socket end.	Spigot end.		Socket end	Spigot end	
		Cwt. qrs. lbs.			Cwt. qrs. lbs.
4	3	0 2 8	3	4	0 2 6
5	4	0 3 5	4	5	0 2 25
5	3	0 2 25	3	5	0 2 16
6	5	1 0 0	5	6	0 3 24
6	4	0 3 20	4	6	0 3 8
6	3	0 3 12	3	6	0 2 26
7	6	1 0 24	6	7	1 0 21
7	5	1 0 15	5	7	1 0 7
7	4	1 0 5	4	7	0 3 18
7	3	0 3 26	3	7	0 3 8
8	7	1 2 1	7	8	1 1 19
8	6	1 1 19	6	8	1 1 5
8	5	1 1 9	5	8	1 0 18
8	4	1 0 27	4	8	1 0 1
8	3	1 0 20	3	8	0 3 20
9	8	1 3 3	8	9	1 2 25
9	7	1 2 18	7	9	1 2 3
9	6	1 2 8	6	9	1 1 17
9	5	1 1 26	5	9	1 1 2
9	4	1 1 17	4	9	1 0 14
10	9	2 0 9	9	10	2 0 4
10	8	1 3 24	8	10	1 3 13
10	7	1 3 13	7	10	1 2 20
10	6	1 3 3	6	10	1 2 6
10	5	1 2 20	5	10	1 1 19
12	10	2 3 9	10	12	2 3 2
12	9	2 2 18	9	12	2 2 7
12	8	2 2 4	8	12	2 1 14
12	7	2 1 19	7	12	2 0 19
12	6	2 1 6	6	12	2 0 3
14	12	3 2 14	12	14	3 1 22
14	10	3 1 19	10	14	3 0 11
14	9	3 0 17	9	14	2 3 14
15	14	4 0 17	14	15	4 0 13
15	12	3 3 8	12	15	3 2 13
15	10	3 2 4	10	15	3 1 1
16	15	4 2 7	15	16	4 2 0
16	14	4 1 15	14	16	4 1 5
16	12	4 0 8	12	16	3 3 5
18	16	5 1 10	16	18	5 0 13
18	15	5 0 18	15	18	4 3 14
18	14	4 3 27	14	18	4 2 20
20	18	6 1 0	18	20	6 0 15
20	16	5 3 13	16	20	5 2 3
20	15	5 2 23	15	20	5 1 7
21	20	6 3 24	20	21	6 3 14
21	18	6 2 6	18	21	6 0 20
21	16	6 0 19	16	21	5 2 27
22	21	7 2 20	21	22	7 1 17
22	20	7 1 24	20	22	7 0 11
22	18	7 0 6	18	22	6 2 9

TABLE CCXI—*contd.*

Socket large end			Socket small end		
Internal bore		Weight	Internal bore		Weight
Socket end	Spigot end		Socket end	Spigot end	
		Cwt. qrs. lbs.			Cwt. qrs. lbs.
24	22	8 1 27	22	24	8 1 9
24	21	8 1 2	21	24	7 3 9
24	20	8 0 6	20	24	7 2 5
27	24	10 3 18	24	27	10 3 4
27	21	10 0 16	21	27	9 2 18
27	18	9 1 17	18	27	8 3 4
30	27	12 3 10	27	30	12 2 25
30	24	11 3 12	24	30	11 2 16
30	21	11 0 11	21	30	10 2 1
32	30	14 1 17	30	32	14 1 7
32	27	13 2 1	27	32	13 1 11
32	24	12 2 5	24	32	12 1 2
33	32	15 1 12	32	33	15 1 10
33	30	14 3 8	30	33	14 2 19
33	27	13 3 24	27	33	13 2 23
36	33	16 3 22	33	36	16 3 4
36	30	15 3 23	30	36	15 2 16
36	27	15 0 11	27	30	14 2 20
40	36	19 2 4	36	40	19 1 11
40	33	18 2 7	33	40	18 0 14
40	30	17 2 8	30	40	16 3 26
42	40	21 3 4	40	42	21 2 15
42	36	20 1 20	36	42	20 0 1
42	33	19 1 24	33	42	18 3 15
48	42	25 2 8	42	48	24 2 27
48	40	24 3 8	40	48	23 3 10
48	36	23 1 25	36	48	22 0 24

WROUGHT IRON PIPES

Specification No. 81

1. **Pipes.**—Pipes shall in all cases be best galvanized wrought iron pipes and shall be provided with sockets for jointing, screwed to fit the screw thread on the pipe. Pipes whose galvanizing has been damaged should be rejected.

2. **Excavation.**—The excavation for the pipes shall be carried out in the same way as for cast iron pipes described above, the material excavated being replaced in the same order.

3. In jointing pipes the socket and the screwed end of the pipe shall be rubbed over with white lead and a few turns of fine hemp yarn wrapped round the screwed end of the pipe, which shall then be screwed home in the sockt. with a pipe wrench.

DISCHARGE THROUGH PIPES

1. The discharge through a pipe of cast iron or other material depends on the age and amount of incrustation of the pipe. For ordinary purposes either Unwin's formula for dirty pipes ($S = \frac{0 \cdot 044}{d^2} \cdot \frac{v^2}{64 \cdot 36}$) or Hazen and William's formula for incrusted pipes (about 30 years old).

($v = 90\ r^{0.63}\ s^{0.54} \times 0 \cdot 001^{-0.04}$) or ($v = 118 \cdot 62\ r^{0.63}\ s^{0.54}$), may be used, where

d= diameter of pipe in feet.

v=velocity in feet per second.

r=hydraulic mean radius in feet.

s=slope or inclination of the hydraulic gradient.

For service pipes supplying from a pure water tank or service reservoir, the discharging capacity should be approximately equal to twice the average flow.

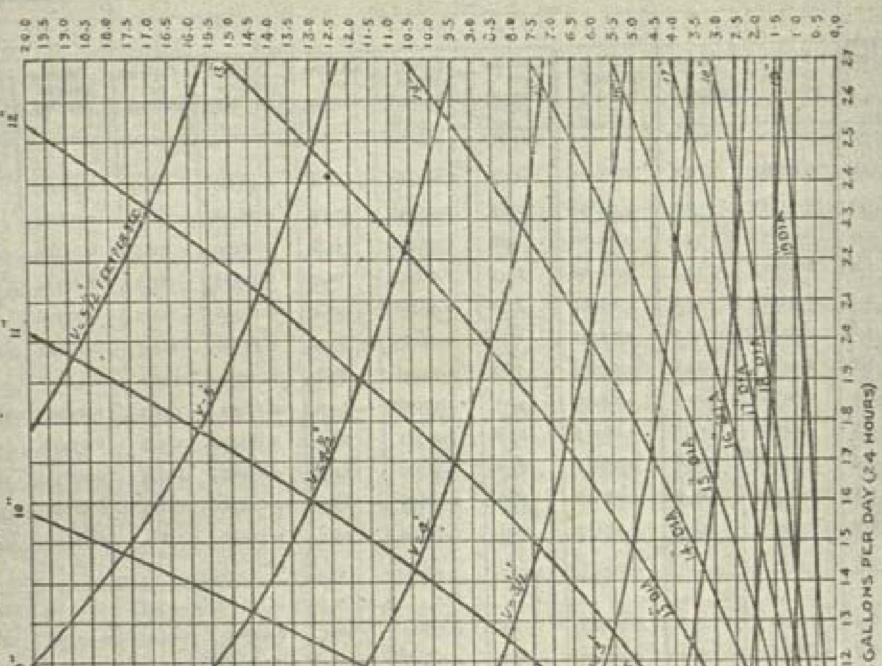
The following table is based on Hazen and William's formula, $v = 118 \cdot 62\ r^{0.63}\ s^{0.54}$.

PLATE CXVIII-A

DISCHARGE CURVES FOR INCRUSTED CAST IRON PIPES.

(BASED ON HAZEN & WILLIAMS FORMULA $V = C R^{0.63} S^{0.54} \times 1.318$ WHERE C=90)

(SEE TABLE CLVII)



G., P.S., F., Poona. 1960.

To face page 426

TABLE

SHOWING HEAD LOST IN 1,000 (INCRUSTED PIPES) AS PER HAZEN AND WILLIAM'S

Diameters

Slope per 1,000	3″		4″		5″		6″		7″	
	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute
0.5	0.00904	6.3	0.01928	13.4	0.034467	24.1	0.05597	38.9	0.08376	58.2
1.0	0.01315	9.1	0.02804	19.5	0.05041	35.0	0.08138	56.5	0.12179	84.6
1.5	0.01637	11.4	0.03489	24.2	0.06275	43.6	0.10130	70.3	0.15160	105.3
2.0	0.01912	13.3	0.04086	28.3	0.07329	50.9	0.11833	82.2	0.17710	122.9
2.5	0.02157	15.0	0.04493	31.2	0.08268	57.4	0.13348	92.7	0.19976	138.7
3.0	0.02380	16.5	0.05073	35.2	0.09123	63.4	0.14729	102.3	0.22043	153.1
3.5	0.02587	18.0	0.05514	38.3	0.09916	68.8	0.16011	111.2	0.23956	106.3
4.0	0.02780	19.3	0.05926	41.1	0.10658	74.0	0.17204	119.5	0.25747	187.7
4.5	0.02962	20.6	0.06315	43.8	0.11357	78.9	0.18334	127.3	0.27438	190.5
5.0	0.03136	21.8	0.06685	46.4	0.12022	83.5	0.19403	134.8	0.29051	201.7
5.5	0.03302	22.9	0.07038	48.9	0.12656	87.9	0.20432	141.0	0.30578	212.35
6.0	0.03461	24.0	0.07377	51.3	0.13266	92.1	0.21415	148.7	0.32049	222.5
6.5	0.03613	25.1	0.07702	53.5	0.13840	96.1	0.22361	155.2	0.33465	232.4
7.0	0.03761	26.1	0.08023	55.7	0.14417	100.1	0.22274	161.6	0.34832	241.8
7.5	0.3904	27.1	0.08321	57.8	0.14965	104.0	0.24160	167.8	0.36154	251.1
8.0	0.04042	28.1	0.08616	59.8	0.15495	107.6	0.25014	173.7	0.37436	259.9
8.5	0.04177	29.0	0.08904	61.8	0.16011	111.2	0.25847	179.5	0.38682	268.6
9.0	0.04308	29.9	0.09182	63.8	0.16513	114.7	0.26657	185.1	0.39894	277.0
9.5	0.04435	30.8	0.09454	65.7	0.17003	118.1	0.27447	190.6	0.41076	285.3
10.0	0.04560	31.7	0.09720	67.5	0.17479	121.8	0.28218	195.0	0.42229	293.3
10.5	0.04682	32.5	0.09980	69.3	0.17946	124.6	0.28971	201.2	0.43357	301.1
11.0	0.04801	33.3	0.10234	71.1	0.18403	127.8	0.29708	206.3	0.44460	308.8
11.5	0.04916	34.1	0.10482	72.8	0.18850	130.9	0.30430	211.3	0.45540	316.3
12.0	0.05032	34.9	0.10726	74.5	0.19288	133.9	0.31137	216.2	0.46599	323.6
12.5	0.05144	35.7	0.10965	76.1	0.19718	136.9	0.31831	221.1	0.47637	330.8
13.0	0.05254	36.5	0.11200	77.8	0.20140	139.9	0.32513	225.8	0.48657	337.9
13.5	0.05362	37.2	0.11430	79.4	0.20555	142.7	0.33182	230.4	0.49659	544.9
14.0	0.05469	38.0	0.11657	80.5	0.20962	145.6	0.33840	235.0	0.50644	351.7
14.5	0.05573	38.7	0.11880	82.5	0.21363	148.4	0.34458	239.5	0.51613	358.4
15.0	0.05676	39.4	0.12100	84.0	0.21758	151.1	0.35125	243.9	0.52566	365.0
15.5	0.05788	40.1	0.12316	85.5	0.22147	153.8	0.35752	248.3	0.53505	371.6
16.0	0.05878	40.8	0.12529	87.0	0.22530	156.5	0.36371	252.6	0.54430	378.0
16.5	0.05976	41.5	0.12739	88.8	0.22907	159.1	0.36980	256.8	0.55342	384.3
17.0	0.06073	42.2	0.12946	89.9	0.23280	161.7	0.37581	261.0	0.56247	390.6

CCXII.

FORMULA $V = Cr^{0.63} \times S^{0.54} \times 0.001^{-0.04}$, WITH C = 90 FOR INCRUSTED PIPES

of pipes.

8″		9″		10″		11″		12″	
Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute
0.11932	82.0	0.16263	112.9	0.21455	148.9	0.27566	191.4	0.34656	240.6
0.17349	120.5	0.23646	164.2	0.31195	216.6	0.40080	278.3	0.50390	349.8
0.21595	149.9	0.29435	204.4	0.38831	269.7	0.49890	346.4	0.62724	435.5
0.25224	175.2	0.34381	238.7	0.45357	314.9	0.58275	404.7	0.73266	508.8
0.28455	197.6	0.38784	269.4	0.51165	355.3	0.65737	456.4	0.82648	573.8
0.31399	218.0	0.42797	297.2	0.56458	392.0	0.72539	503.7	6.91199	633.3
0.34124	237.0	0.46512	322.9	0.61359	426.1	0.78836	547.4	0.99115	688.2
0.36675	254.7	0.49990	347.1	0.65947	458.0	0.84730	588.3	1.06526	739.8
0.39085	271.4	0.53273	369.9	0.70278	487.9	0.90298	627.0	1.13609	788.3
0.41372	287.3	0.56391	391.5	0.74392	516.5	0.95580	663.7	1.20169	834.5
0.43560	320.5	0.59370	412.3	0.78321	543.9	1.00630	698.8	1.26515	878.4
0.45653	317.1	0.62225	432.1	0.82089	570.1	1.05500	732.6	1.32601	920.6
0.47669	331.0	0.64975	451.1	0.85715	595.3	1.10129	764.7	1.38458	961.4
0.49615	344.5	0.67627	469.6	0.89215	619.4	1.14624	796.0	1.44111	1001.0
0.51499	357.6	0.70194	487.4	0.92600	643.0	1.18976	826.2	1.49579	1039.0
0.53325	370.3	0.72684	504.7	0.95885	665.9	1.23195	855.5	1.54937	1076.0
0.55100	382.6	0.75102	521.5	0.99077	688.0	1.27295	884.1	1.60041	1,111
0.56827	394.6	0.77456	537.9	1.02182	709.6	1.31300	911.8	1.65059	1,146
0.58511	403.3	0.79751	553.8	1.05209	730.7	1.35174	938.7	1.69948	1,180
0.60154	417.7	0.81991	569.4	1.08164	751.1	1.38971	965.1	1.74721	1,213
0.61760	428.9	0.84180	584.6	1.11052	771.2	1.42681	990.8	1.79385	1,246
0.63331	439.8	0.86322	599.1	1.13877	790.8	1.46311	1.016	1.83948	1,277
0.64870	450.5	0.88419	614.0	1.16644	810.0	1.49865	1.041	1.88417	1,308
0.66378	460.9	0.90474	628.3	1.19355	828.9	1.53349	1,065	1.92798	1,339
0.67857	471.2	0.92491	642.3	1.22016	847.3	1.56767	1,089	1.97095	1,369
0.69310	481.3	0.94471	656.0	1.24627	765.5	1.60123	1,112	2.01314	1,398
0.70737	491.2	0.96416	669.6	1.27193	883.3	1.63420	1,135	2.05459	1,427
0.72140	501.0	0.98328	682.8	1.29716	900.8	1.66661	1,157	2.09534	1,455
0.73520	510.5	1.00209	695.8	1.32197	918.0	1.69849	1,180	2.13542	1,483
0.74878	520.0	1.02060	708.8	1.34640	935.0	1.72987	1,201	2.17487	1,510
0.76216	529.3	1.03886	721.4	1.37045	951.7	1.76077	1,223	2.21373	1,537
0.77534	538.4	1.05680	733.9	1.39415	968.2	1.79122	1,244	2.25201	1,564
0.78833	547.4	1.07451	746.2	1.41751	984.4	1.82123	1,265	2.28974	1,590
0.80114	556.3	1.09197	758.3	1.44054	1,000.4	1.85083	1,285	2.32695	1,616

TABLE

Slope per 1,000	3″		4″		5″		6″		7″	
	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute
17.5	0.06169	42.8	0.13150	91.3	0.23647	164.2	0.38174	265.2	0.57129	396.7
18.0	0.06264	43.5	0.13351	92.7	0.24009	166.7	0.38759	269.2	0.58005	402.8
18.5	0.06357	44.1	0.13550	94.1	0.24367	169.2	0.39336	273.2	0.58869	408.8
19.0	0.06449	44.8	0.13747	95.5	0.24721	171.7	0.39907	277.1	0.59723	414.7
19.5	0.06540	45.4	0.13941	96.8	0.25070	174.1	0.40471	281.0	0.60567	420.6
20.0	0.06630	46.0	0.14133	98.1	0.25415	176.5	0.41028	284.9	0.61400	426.4

Slope per 1,000	13″		14″		15″		16″		17″	
	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute
0.5	0.42475	297.0	0.51967	360.8	0.62325	432.8	0.73856	512.9	0.86623	601.5
1.0	0.62193	431.8	0.75559	524.7	0.90620	629.2	1.07385	745.7	1.25950	874.6
1.5	0.77416	537.5	0.94053	653.1	1.12801	783.2	1.33709	928.5	1.56776	1,089
2.0	0.90427	627.9	1.09861	762.8	1.31757	914.9	1.56135	1,084	1.83125	1,272
2.5	1.02007	708.2	1.23931	860.6	1.48631	1,032	1.76129	1,223	2.06609	1,435
3.0	1.12561	781.6	1.36751	949.5	1.64006	1,139	1.94352	1,350	2.27948	1,583
3.5	1.23320	889.4	1.48622	1.032	1.78307	1,238	2.11224	1,467	2.47735	1,720
4.0	1.31479	913.1	1.59734	1,109	1.91573	1,330	2.27016	1,577	2.66259	1,840
4.5	1.40099	972.9	1.70300	1,182	2.04158	1,418	2.41923	1,680	2.83743	1,970
5.0	1.48315	1,030	1.80186	1,253	2.16106	1,501	2.56087	1,778	3.00357	2,086
5.5	1.56145	1,084	1.89707	1,317	2.27609	1,580	2.69612	1,872	3.16221	2,196
6.0	1.63661	1,136	1.98833	1,380	2.38465	1,656	2.82583	1,962	3.31431	2,302
6.5	1.70890	1,187	2.07614	1,442	2.48999	1,729	2.95064	2,049	3.46070	2,403
7.0	1.77900	1,235	2.16090	1,501	2.59165	1,800	3.07111	2,133	3.60199	2,501
7.5	1.84621	1,282	2.24195	1,557	2.69003	1,868	3.18769	2,214	3.73873	2,596
8.0	1.91162	1,327	2.32249	1,613	2.78583	1,934	3.30080	2,292	3.87132	2,688
8.5	1.97528	1,372	2.39980	1,666	2.87812	1,999	3.41051	2,368	4.00015	2,778
9.0	2.03809	1,415	2.47495	1,719	2.96834	2,061	3.51751	2,443	4.12559	2,863
9.5	2.09756	1,457	2.54770	1,769	3.05630	2,122	3.62172	2,515	4.24777	2,950
10.0	2.15649	1,498	2.61990	1,819	3.14217	2,182	3.72343	2,586	4.36709	3,033

CCXII—*cont.*

8″		9″		10″		11″		12″	
Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute
0.81378	565.1	1.10920	770.3	1.46327	1016.2	1.88003	1,306	2.36366	1,641
0.82625	573.8	1.12620	882.1	1.48570	1031.7	1.90885	·1,326	2.39989	1,667
0.83856	582.3	1.14298	793.7	1.50784	1047.1	1.93729	1,345	2.43565	1,691
0.85072	590.8	1.15956	805.3	1.52971	1062.3	1.96539	1,365	2.47098	1,716
0.86274	599.1	1.17594	816.6	1.55132	1077.3	1.99315	1,384	2.50588	1,740
0.87462	607.4	1.19212	827.9	1.57267	1092.0	2.02059	1.403	2,54038	1,764

18″		20″		21″		22″		23″	
Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute
1.00668	699	1.33037	923.9	1.51002	1,049	1.70721	1,186	2.14534	1,490
1.46371	1,016	1.93431	1,343	2.19552	1,525	2.48224	1,724	3.26629	2,268
1,82200	1,265	2.40778	1,672	2.73292	1,898	3.08982	2,151	3.88280	2,696
2.12901	1,478	2.81244	1,953	3.26658	2,268	3.60911	2,506	4.53534	3,149
2.10077	1,667	3.17260	2,203	3.60100	2,501	4.07128	2,827	5.11613	3.553
2.64910	1,840	3.50084	2,448	3.97359	2,759	4.49251	3.120	5.64546	3.920
2.87905	1,999	3.80473	2,642	4.31851	2,999	4.88248	3.391	6.13550	2,461
3.09431	2,140	4.08921	2,840	4.64140	3,223	5.24754	3,644	6.59426	4.579
3 29752	2,290	4.35775	3,026	4.94620	3,425	5.59215	3,883	7.02730	4,880
3.49059	2,424	4.61287	3,203	5.23577	3,636	5.91953	4,110	7.43869	5,166
3.67493	2,552	4.85650	3,373	5.51230	3,828	6.23217	4.328	7.83158	5.439
3.85171	2,675	5.09013	3.535	5.77747	4,012	6.53199	4.536	8.20834	5,700
4.02184	2,793	5.31497	3,691	5.03271	4,189	6.82051	4.736	8.57051	5.952
4.18609	2,007	5.53197	3,842	6.27900	4,360	7.09899	4,930	8.91264	6,189
4.34497	3,017	5.74196	3,967	6.51739	4.526	7.36846	5,117	9.25948	6,430
4.49909	3,124	5.94560	4,129	6,74848	4,686	7.62978	5,298	9.58790	6,658
4.64873	3,228	6.14346	4,266	6.97306	4,842	7.88369	5,475	9.90695	6,880
4.79450	3.329	6.33064	4,400	7.19164	4,994	8.13082	5,646	10.21740	7,094
4.93665	3,428	6,52376	4.530	7.40468	5,142	8.37171	5,814	10.52011	7,306
5.07520	3,524	6.70698	4,658	7.61267	5,287	8.60683	5,977	10.81568	7,511

TABLE

TABLE SHOWING DISCHARGES OF PIPES OF SMALL DIAMETERS (SERVICE PIPES) HAZEN

Slope		$\frac{1}{4}$"		$\frac{1}{2}$"		$\frac{3}{4}$"		1"	
per 100	per 1,000	Millon gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute
1" or 0.083' ..	0.83'	0.000017	0.0119	0.00010	0.0681	0.00060	0.2452	0.00067	0.4626
3" or 0.25' ..	2.50	0.000031	0.0216	0.00021	0.1484	0.00064	0.4448	0.00121	0.8391
6" or 0.50' ..	5.0	0.000045	0.0314	0.00031	0.2158	0.00093	0.6467	0.00175	1.219
9" or 0.75' ..	7.5	0.000056	0.0392	0.00039	0.2686	0.00116	0.8050	0.00219	1.518
1'	10.0	0.000066	0.0457	0.00045	0.3116	0.00135	0.9403	0.00255	1.773
5' ..	50.0	0.00016	0.1091	0.00108	0.7482	0.00323	2.2423	0.00609	4.2303
10	100.0	0.00023	0.1586	0.00157	1.0878	0.00469	3.2602	0.00886	6.1508
15	150.0	0.00028	0.1974	0.00195	1.3541	0.00584	4.0572	0.01102	7.6563
20	200.0	0.00033	0.2306	0.00228	1.5816	0.00683	4.7403	0.01288	8.9440
25	250.0	0.00037	0.2601	0.00257	1.7874	0.00770	5.3473	0.01451	10.0800
30	300.0	0.00041	0.2870	0.00283	1.9688	0.00850	5.9006	0.01002	11.1280
35	350.0	0.00045	0.3119	0.00308	2.1387	0.00923	6.4128	0.01742	12.0984
40	400.0	0.00048	0.3352	0.00331	2.2996	0.00992	6.8922	0.01872	13.0030
45	450.0	0.00051	0.3573	0.00353	2.4506	0.01058	7.3448	0.01995	13.8569
50	500.0	0.00054	0.3782	0.00374	2.5941	0.01119	7.7749	0.02112	14.6681

CCXIII.

AND WILLIAM'S FORMULA $V = Cr.^{0.63} \times S^{0.54} \times 0.001^{-0.04}$ WHERE $C = 90$.

1¼"		1½"		1¾"		2"		2½"	
Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute	Million gallons per day	Gallons per minute
0.00118	0.8221	0.00178	1.2490	0.00280	1.9412	0.00408	2.8346	0.00721	5.0603
0.00215	1.4943	0.00326	2.2610	0.00507	3.5209	0.00738	5.1313	0.01293	8.9759
0.00312	2.1677	0.00473	3.2874	0.00737	5.1193	0.01072	7.4608	0.01901	13.2018
0.00389	2.6983	0.00589	4.0921	0.00918	6.3724	0.01336	9.2766	0.02366	16.4332
0.00454	3.1518	0.00688	4.7798	0.01072	7.4434	0.01562	10.8479	0.27650	19.1951
0.01082	7.5160	0.01640	11.39	0.02556	17.7506	0.03725	25.8695	0.06592	45.7757
0.01574	10.9284	0.02386	16.57	0.03716	25.8089	0.05556	37.6135	0.09584	66.5566
0.01959	13.6034	0.02971	20.63	0.04626	32.1262	0.06742	46.8202	0.11930	82.8477
0.02287	15.8897	0.03278	24.0973	0.05404	37.5255	0.07875	54.6890	0.13919	96.6600
0.02581	17.9245	0.09914	27.1831	0.06096	42.3309	0.08884	61.6924	0.15720	109.1640
0.02848	19.7790	0.04319	29.9956	0.06728	46.7192	0.9803	68.0753	0.17346	120.4582
0.03095	21.4959	0.04694	32.5970	0.07310	50.7652	0.10654	73.9845	0.18852	130.9145
0.03327	23.1031	0.05045	35.0368	0.07857	54.5610	0.11450	79.5162	0 20261	140.7029
0.03545	24.6203	0.05377	37.3176	0.08373	58.1440	0.12202	84.7381	0.21492	149.9428
0.03753	26.0617	0.05692	39.5265	0.08857	61.5480	0.12950	89.6891	0.22856	158.7212

WELL-SINKING.

General.

1. **Design.**—The design of wells depends on the character of the soil through which the well is sunk. In the Deccan, where the majority of wells are sunk through soil, hard muram and rock, it is not the custom to use curbs, but to build the steining of the well on a ledge formed in the hard soil through which the well is sunk after the excavation of the well is complete. In Gujarat and other parts, where the wells are sunk through alluvium or sandy soils to a considerable depth, excavation is carried on in the ordinary way till water level is reached, at which point the curb is placed, the steining is built up, and the well sunk to such a further distance as may be necessary by excavation from the inside of the well. Where wells are sunk through laterite, the soil becomes softer as the water level is reached, where the stuff is almost a semi-liquid "shadu" or white clay. In such a position also it is necessary to use curbs, and do further sinking as above. The specifications given below, which apply principally to such wells, must not be considered as generally applicable to wells in the Deccan, where undersinking is not employed. Paragraphs 5 and 7, page31, should not, therefore, be considered as applicable to wells in the Deccan.

2. **Site.**—The greatest care should be exercised in the selection of the site for wells required for the purpose of water-supply. All sites should be considered with reference to the abundance of their probable water-supply and to their freedom from the possibility of pollution. Wells should never be sunk in positions where they are liable to contamination by the infiltration of water from land which is fouled in any way, and, in all cases, such infiltration of surface water should be prevented as far as possible. Consequently, wells, if situated near a village, should, if possible, be constructed above the village, so that surface drainage from the village may not have a chance of entering the well.

Step wells should be abandoned in favour of draw wells.

3. **Construction of steining.**—The sides of the well should be lined with masonry or brickwotk to prevent the loose soil from falling into the well, such masonry or brickwork being made as water-tight as possible to prevent infiltration. For this purpose it is advisable when filling up the excavation to back the lining with some impermeable material, such as puddle, for 8 to 10 feet from the surface. Iron linings are frequently now used in England instead of brickwork for this purpose.

4. **Platform.**—As there will be a considerable quantity of water spilt round a well which should not be allowed to percolate back into the soil and so into the well, the lining or steining should be raised at least two feet above ground level and the well should be surrounded by a masonry platform, sloping from the well and provided with a gutter all round to collect the waste water, which may be led away by proper gutter either to cattle trough or to a clump of trees planted not closer than 20 yards from the well, or to some suitable natural water course.

5. In order to prevent the contamination of the water by dust, leaves and other impurities it is better to cover the well ; but for small village wells this has generally to be omitted on the score of expense.

Specification No. 182.

1. **Rate.**—The rates, when the work is executed by contract, to include all necessary plant and tools in any way required for the execution of the work.

2. **Protection during construction.**—Wells to be fenced round during execution of the work ; and if near a public thoroughfare lights and watchman to be provided by the contractor without extra charge.

3. **Excavation.**—Where wells are constructed on a curb with brickwork of stone steinings, the excavation to be carried down to water level before the curb is laid and steining built up.

Where no curbs are used, the excavation shall be completed and the steining shall be commenced at such a level as may be directed by the Executive Engineer, the foundation being such that there will be no danger of disintegration subsequently taking place below the level of the steining. Above the commencement of the steining the finished diameter of the well to be 2 feet greater than below it.

4. **Thickness of steining.**—The steining shall be of the following thickness :—

	Brick work	*Stone masonry*
Wells 10 feet and under	$13\frac{1}{2}$ inches ..	12 inches.
From 10--33 feet	18 inches ..	15 inches.

and for every additional 7 feet depth, increase the thickness by 3 inches.

Where wells are excavated in hard ground and no lining is required, steining should be provided for a depth of at least 6 feet to prevent pollution from surface washings.

5. **Curbs.**—Wooden curbs shall be made of babul, tamarind, jamba or other wood approved by the Executive Engineer and shall be made of 2 thicknesses of wood for wells 6 feet in diameter and under, and of 3 thicknesses for larger wells, strongly dove-tailed and dowelled together and secured by iron bolts, as ordered by the Executive Engineer. When the rings cannot be made of one piece across the width, the concentric rings shall break joints ; the upper and lower courses to be alternately one-third and two-thirds of the whole width. The steining will be sunk to such further depth as the Executive Engineer may direct.

When ordered by the Executive Engineer, the curb will be secured to the masonry by iron holding-down bolts, over the upper end of whch an iron bond plate shall be passed and secured by nails. In undersinking wells great care shall be taken to keep the steining truly vertical ; for this purpose, three plumb lines shall be kept suspended round the inside of the steining.

6. **Removal of bad work.**—If the steining splits during the sinking within six months after completion and in the opinion of the Executive Engineer, be unsound, the contractor shall be bound to dismantle the whole or part, according to circumstances and reconstruct it without charge ; and if the falling in of the sides of the excavation from insufficient shoring, or any other cause due to negligence of the contractor, render it necessary in the opinion of the Executive Engineer, the contractor shall be bound to sink an entirely new well without charge.

7. **Special conditions.**—It occasionally happens that the sinking of steining cannot progress on account of the interposition of a bed of kankar or hard soil, below which a sufficient supply of water would be found. In this case it may be necessary to " underpin " the curb. But if the soil is very

firm or the curb rest on a bed of block kankar, it will be in the option of the Executive Engineer not to carry the steining through, but merely to pierce the bed with a shaft of less diameter than the diameter of the well. These and other exceptional matters will be subjects of special agreement according to the circumstances.

8. **Masonry.**—The masonry shall consist of rabble masonry, with a facing on the inner side of khandkies dressed backtrue and square for 3 inches from the face on beds and joints.

Through stones to be placed 5 feet apart in each course, care being taken not to place the through stones of successive courses one above the other.

The face work to be as for coursed rubble, 1st sort, except as described above.

The backing may be of uncoursed rubble, well bonded to the face work.

Joints on face to be ½ inch only.

Mortar to be made from good hydraulic lime and clean sand.

In the case where curbs are not used, the lower course to consist entirely of through stones which will be measured with the rest of the masonry and paid for at a general rate.

9. **Puddling.**—The space between the excavation and the back of the steining to be filled with a good clay puddle for a depth of at least 8 to 10 feet, or to the bottom of the steining, whichever is less, the average thickness of this puddle being at least 3 feet.

Parapet.—The top of the well, above ground, must be finished with a parapet 15″ thick and 3′ high with the required number of openings for water-drawing arrangements. These openings should be 2′ 6″ wide and the lower part of the openings should be filled with a 6″ curbing, rising one foot above the platform level.

10. **Payment.**—Excavation will be paid for per 100 cubic feet inclusive or exclusive of the removing of the water as may be agreed upon.

11. **Arrangements for drawing water.**—All wells shall be provided with proper arrangements for drawing water.

12. **Platform.**—All wells should be provided with a platform above ground level, about 5 feet wide and sloping outwards. The water from this platform shall be conveyed by a small drain to a distance of 20 to 30 feet from the well.

In front of the parapet openings for water-drawing arrangements the platform should be at least 10′ × 10′ with at least 6″ thick curbing at the edges and raised 3″ above the paving.

13. The platform should be constructed after one monsoon has passed over the filling below it and behind the steining so that no settlement may take place later on.

TESTING YIELD OF WELLS

General.—There are two ways of testing the yield ; one is the pumping test and the other, recuperation test.

Pumping test.—In the pumping test the water level in the well is depressed below the normal to a safe maximum working head and the yield at this depressed level is measured by the quantity that can be bailed out by mots or pumped out in a given time so as to maintain this level constant. This

operation is the more difficult of the two to undertake as it involves steady pumping at a fixed level and the accurate measurement of the discharge from the pumps and reliable data are not likely to be obtained. The yield should be tested at the driest times of the year and enquiries should be made locally regarding the lowest known water level.

2. **Recuperation test.**—Under recuperation test the water surface in the well is depressed to any desired level below the normal and from this level it is allowed to refill to its normal level, the time of refilling being carefully noted and the contents of the space thus refilled worked out accurately. In this test the rate of filling is rapid for greater heads of depression and is slower as the water level is reaching its normal level.

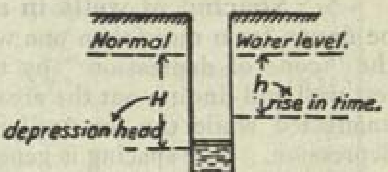
3. **Wells in sand and alluvium.**—There are often practical difficulties, as stated above, in carrying out a pumping test on a well, and more reliable results may be obtained by means of recuperation tests in the case of wells in sand and alluvium. The sub-soil is expected to yield uniformly all over the exposed surface and the depression heads play an important part. It is also easier to note the timings and gauges.

The following formula should be used for the recuperation test :—

$$\frac{K}{A} = \frac{1}{t} \log \frac{H}{h} \times 2{\cdot}303 \qquad \text{I}$$

in which K is a constant, and is called the specific capacity of the well, and denotes the yield of the well, in cubic feet per hour under a head of one foot.

A = area of the well in square feet.
H = head of depression in feet.
h = rise of water to a level in feet below normal water level during the observation period,
t = time in hours of observation.



$\frac{K}{A}$ is the yield in cubic feet per hour, per square foot of area of the well under a head of 1 foot.

The value of $\frac{K}{A}$ is constant as long as the velocity of the inflow does not exceed the " critical velocity ", below which limit the surrounding soil is not disturbed.

Velocity of inflow, V, in feet per hour at which water rises in the well at any head, h, is given by the formula

$$V = \frac{K}{A} h \qquad \text{II}$$

and the yield Y in cubic feet per hour at any head, h, of the well is given by the formula

$$Y = AV = Kh \qquad \text{III}$$

The results of several tests should be plotted in a curve with $\frac{h}{K}$ as ordinates (downwards) and t as absissae. If the value of $\frac{K}{A}$ is not constant, it is an indication that the critical velocity has been exceeded. The maximum yield will be obtained from a well when it is worked continuously without exceeding the critical velocity.

4. The following table gives the general conditions obtaining in wells in different strata :—

Strata (1)	Safe head of depression (2)	Yield per hour per sq. ft. (3)	Value of $\frac{K}{A}$ (4)
Wells in fine sand ..	5 to 7 feet ..	16 gallons, or 2·5 c.ft.	$\frac{1}{2}$
Wells in coarse sand ..	..	..	1
Wells in clay	..	..	$\frac{1}{4}$

In designing, a factor of safety of 2 to 4 is taken, but in practice this sometimes reaches a figure of 10. Detailed information on this subject may be had from the Punjab Public Works Department paper 63 of 1909.

Yield curves for wells in coarse and fine sand, obtained from actual pumping trials, are given in plate CXIX. The value of $\frac{K}{A}$ for Nasik well works out to 0·38, in coarse sand ; while the value for fine sand in Sind works out to 0·27. The actual cone of depression for a well in Sind in fine sand is also given in plate CXX.

5. **Spacing of wells in sand and alluvium.**—When the supply is to be drawn from more than one well, observations should be taken to determine the " cone of depression " by taking test holes at known distances from the test well and finding out the area beyond which the normal water surface is left unaffected while the test well is being drawn upon under various heads of depression. The spacing is generally beyond 200 to 600 feet, the exact distance being decided from observations.

6. **Yield test observations.**—These should be recorded in a suitable statement, from which could be worked the specific capacity of the well under test. If water is bailed out by mots or tins their correct capacity for the quantity actually bailed out per each trip should be noted.

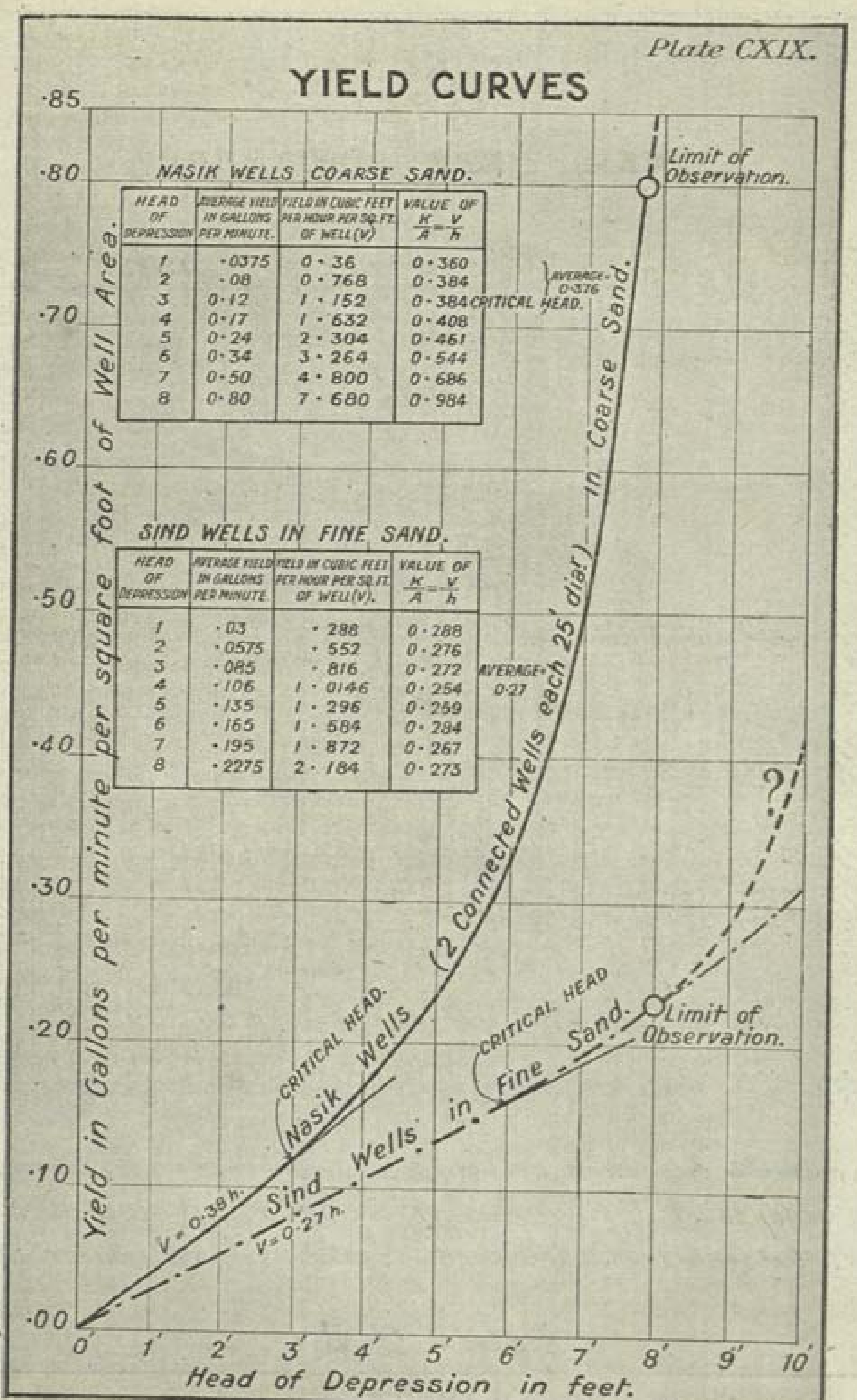
If water is pumped out by machinery, the pumped water should be measured by weir discharge method. Conclusions should be drawn over tests repeated over at least a week in the hot weather.

7. **Recuperation test observations.**—These observations should be recorded in a suitable statement as above. The observations are to extend not for uniform period of time but for uniform rises of level say for every 3″ of height till the normal water surface is restored. Conclusions should be drawn as above from a number of tests extending over a week at least.

If there are wells in the neighbourhood which get affected by these tests, their observations should also be simultaneously recorded and allowed for in determining the specific capacity of the test well.

8. **Wells in trap or granite, etc.**—Infiltration in wells in trap or granite or similar more or less solid strata is not uniform and conclusions have to be drawn from pumping tests as stated in paragraph 1. Generally the supply in these wells is received from underground springs.

Plate CXIX.



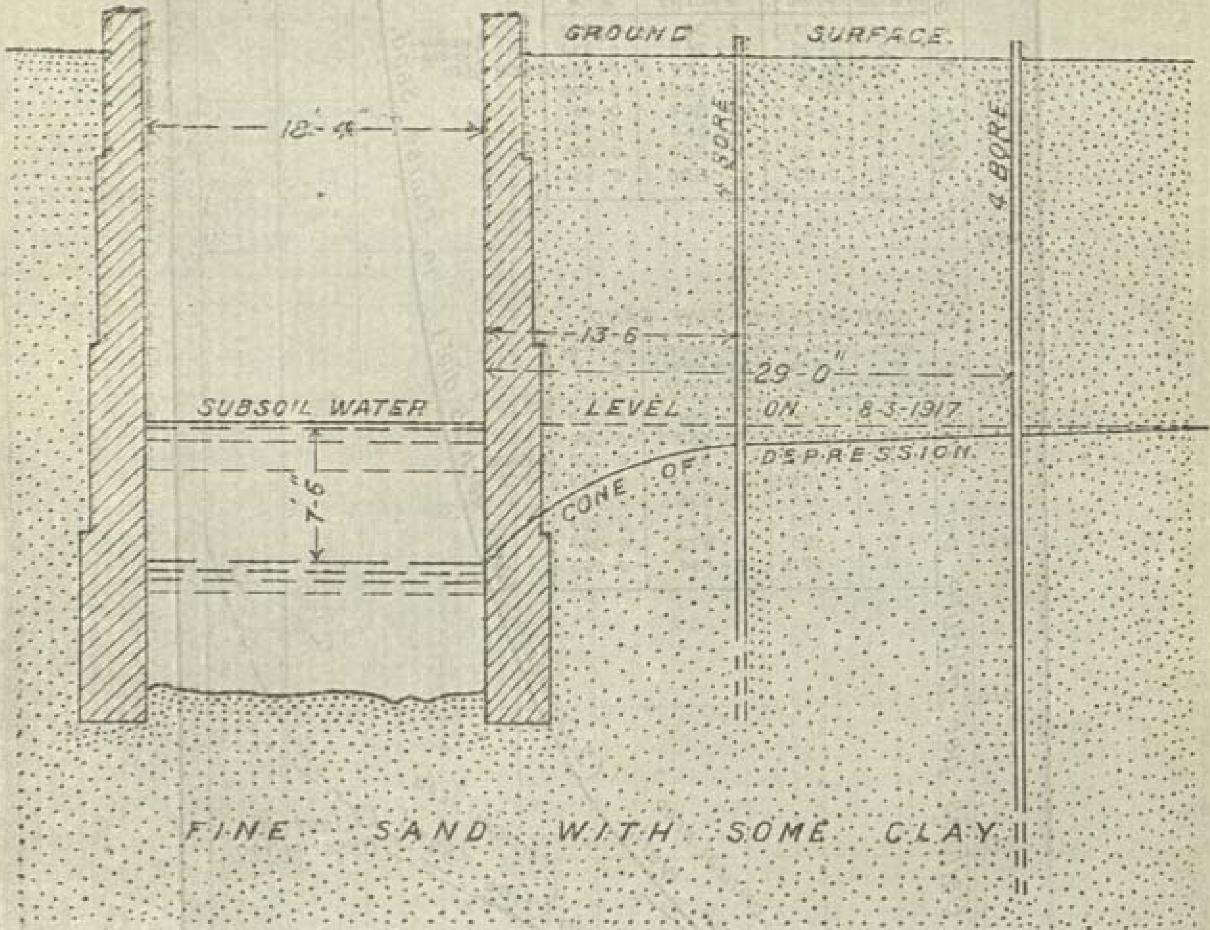
NASIK WELLS COARSE SAND.

HEAD OF DEPRESSION	AVERAGE YIELD IN GALLONS PER MINUTE.	YIELD IN CUBIC FEET PER HOUR PER SQ. FT. OF WELL (V)	VALUE OF $\frac{K}{A} = \frac{V}{h}$	
1	·0375	0 · 36	0 · 360	AVERAGE = 0·376
2	·08	0 · 768	0 · 384	
3	0 · 12	1 · 152	0 · 384	CRITICAL HEAD.
4	0 · 17	1 · 632	0 · 408	
5	0 · 24	2 · 304	0 · 461	
6	0 · 34	3 · 264	0 · 544	
7	0 · 50	4 · 800	0 · 686	
8	0 · 80	7 · 680	0 · 984	

SIND WELLS IN FINE SAND.

HEAD OF DEPRESSION	AVERAGE YIELD IN GALLONS PER MINUTE.	YIELD IN CUBIC FEET PER HOUR PER SQ. FT. OF WELL (V).	VALUE OF $\frac{K}{A} = \frac{V}{h}$	
1	·03	·288	0 · 288	
2	·0575	·552	0 · 276	
3	·085	·816	0 · 272	AVERAGE = 0·27
4	·106	1 · 0146	0 · 254	
5	·135	1 · 296	0 · 259	
6	·165	1 · 584	0 · 284	
7	·195	1 · 872	0 · 267	
8	·2275	2 · 184	0 · 273	

J-1136—26-A.



NOTE: *Water levels were recorded for six intermediate heads of depression. The bores were carried to a depth of five feet below the lining pipe which was free from sand at the time of observation.*

Plate CXX.

9. **Tube wells in sand or alluvium.**—In the experiments carried out in the Punjab on the yield of percolation wells, it was found that with ordinary fine sand, the head of depression must not exceed 5 feet. That is the critical head which must not be increased, or the sand will come up, and be drawn into the pumps. If a strainer tube well is put down, which has tremendously fine spaces between the strainer wires, the sand cannot get through and pumping can be carried on with a very much greater head of depression. Ashford's tube wells can be worked with practically any head of depression, and he gives a case where he actually goes up to 26 feet.

Comparing the yield of one 4½ inch diameter tube strainer well with that of percolation wells, it is found that one single tube of 4½ inches diameter gives the same quantity of water as three ordinary wells each 12 feet in diameter and at considerably less cost.

The cost of an Ashford tube well per foot run is, 10-inch diameter, Rs. 21 to 24-8 and 5-inch diameter, Rs. 12 to 14. The cost of the outer tube, which can of course be used again, is Rs. 16-8 to 19-4 per foot for 13-inch tubes and Rs. 4-14 to 5-11 per foot for 7-inch tubes ; these rates apply to " cressed and swelled " tubing, which is suitable for the purpose. The cost of sinking varies from a few annas to Rs. 5-4 per foot depending on the nature of the soil.

SPRING WELLS

1. Granitoid and basaltic rocks constitute the main varieties of igneous rocks met with in the Bombay Presidency. The body of the rock is impervious unless the rock is deeply decomposed. Consequently the prospect of obtaining large supplies of water would be discouraging were it not for the fact that these rocks are usually traversed by strong joints and fissures and sometime faulted. If such joints can be located and the well sunk sufficiently deep, enormous supplies of water are occasionally procurable. On the other hand, if the ground water level of the district has not been ascertained, it is quite possible that such a joint may drain the water from a well which is being deepened, and in the process has struck a joint above the level of the ground water. In such a case it is best to go on down to the ground water level.

2. Among the basaltic lavas of the Deccan it is usually necessary to go through the thickness of the overlying lava to the next flow below. As these flows vary in thickness from 40 to 100 feet, and are separated by a greater or less thickness of soft intertrappean material or the decomposed surface of the underlying lava flow, it should not be difficult, to determine when the next lower flow is being approached. If a well is going to be successful it should encounter water in the sinking operations below this horizon. Most wells in trap seldom exceed 50 feet in depth.

3. Slates are somewhat better than shales owing to their jointed condition. Marbles are also more reliable than limestones, as they are traversed by numerous fissures. Quartzites, unless heavily shattered, are disappointing for water-supply. The gneisses and schists are usually very discouraging unless deeply weathered. The rate of infiltration in these rocks is slow, and wells in such rocks, if heavily drawn upon, take a considerable time to refill. The channel of inflow is usually along the planes of foliation, and if these are vertical the supply to a well is possibly from a belt of rock the width of the well. To increase the capacity of such wells, it is often necessary to drive galleries from the bottom of the wells in directions across the planes of foliation. If the foliation planes are inclined, greater width of infiltration may be attained be deepening the well or in driving a gallery across the planes of foliation.

ARTESIAN CONDITIONS

(PLATE CXXI)

1. There are all kinds of peculiar cases where artesian conditions become possible, but in every case the following fundamental conditions are essential:—the presence of a porous bed into which water can freely percolate ; the intercalation of this porous bed between an underlying and an overlying impervious stratum so that the water of the porous bed is imprisoned : and a difference of height between the place at which the water enters the porous bed and a point below at which this porous bed is to be tapped by a boring. These conditions are shown in Figs. 1 and 2. When the water bearing stratum is filled, springs occur at C, and the height of these springs marks the standing level of the ground water.

Fig. 1 shows a true basin in section. A true basin will give the above type of section across any direction.

2. In such basins, if they are of large extent and have wide out-crops of porous rock underlaid by impervious beds, artesian conditions may be anticipated. If the out-crops of the porous rock are at a higher level than the central valley, borings will tap water which will flow out at the surface of the ground (Fig. 2, boring B). If the valley is above the height of the out-crops, water will rise up in the bore-hole but will not overflow. (Fig. 2, boring A.).

3. The quantity of water depends on the thickness of the porous rock, its extent and porosity. The pressure will depend on the freedom with which the underground water can percolate through the pore-spaces of the porous rock, and the difference in height between the out-crop or point of intake and the depth at which the water is tapped. A heavily fissured rock, if involved in a structural synclinal fold or through, may contain large quantities of water under pressure.

Figs. 3 and 4 also represent geological structures which are favourable for meeting with underground water-supply.

COST OF PUMPING PLANT

1. The pump horse-power required for a plant is found thus—

$$\text{P.H.P.} = \frac{W \times (H+F)}{33{,}000}$$

where W=weight of water lifted per minute in lbs., equivalent to the flow in gallons per minute multiplied by 10.

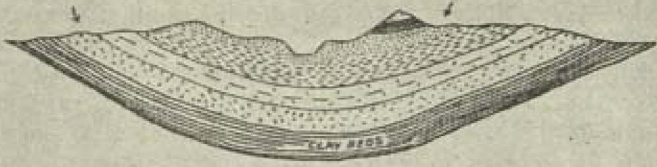
H=height to which water is raised in feet, equivalent to the difference in level between the strainer on the suction pipe and the high water level in the reservoir.

F=frictional head in suction pipe and rising main, together with the small loses at bends, elbows, etc.

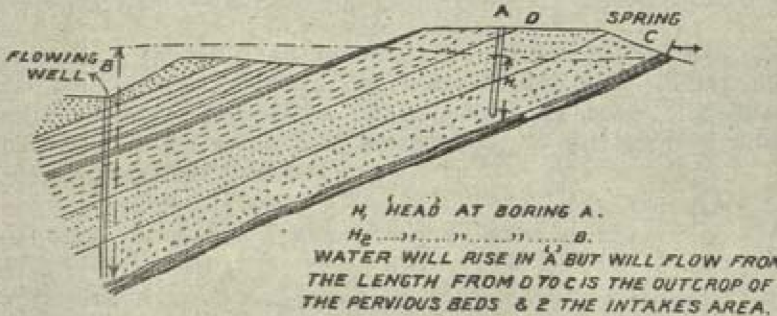
The P.H.P. will vary between 55 to 80 per cent of the brake horse-power depending on the type of pump used, and the B.H.P. will amount to about 80 per cent of the indicated horse-power.

In every case two pumping sets, each capable of doing the whole work, should be allowed for.

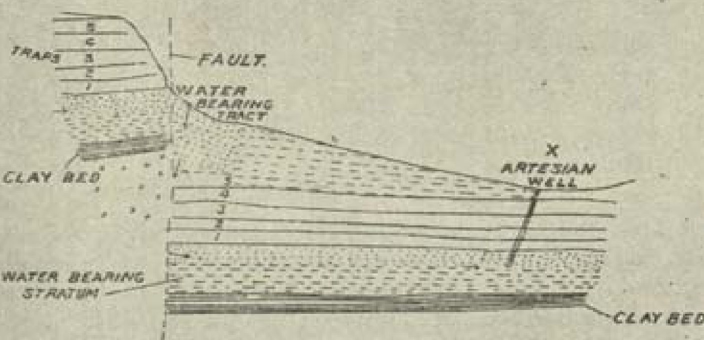
UNDERGROUND STRUCTURES FAVOURABLE FOR YIELDING ARTESIAN SUPPLIES.



1



2



3

4

Alluvial deposits form the greater part of Gujerat, especially in the portion North of the Mahi river. These deposits usually consist of layers of sand, sand mixed with clay, and clay, and the interposed sand layers form a large underground reservoir of water, which can be tapped at comparatively small cost. One of the first borings (and the most westerly), was made at Kharaghoda lying in a sandy waste on the borders of the Rann of Cutch. Salt is manufactured at this place from brine, which is obtained only a few feet below the surface. An ordinary well was out of the question, but a tube well 8″ dia. met with a good supply at a depth of 316 feet, yielding ·576 million gallons per day. Another boring at Viramgam, 8″ diam, was carried to a depth of 776 feet and yields ·324 million gallons per day. Numerous other tube wells have been provided in different parts, with discharges varying from 14,400 gallons per day to 64,800 gallons per day, depths, varying from 273 feet to 1,951 feet and tubes varying from 14″ to 6″. Some yielded no water, as the bores at Broach and Dhandhuka, others such as the bores at Dholera and Ghogha yielded unpotable water, but the majority yielded a supply aggregating to about 5¼ million gallons per day.

Many of the spinning and weaving mills at Ahmedabad have their own tube wells, tapping subartesian water at depths varying from 240 feet to 538 feet, and supplies varying from 12,000 to 30,000 gallons per day. The Ahmedabad Municipality has supplemented its water-supply to the outlying suburbs by putting down similar tube wells.

The initial cost of the installation may be taken at—

Rs.				H. P.
3,000 per P. H. P. for small plants above			..	5
2,250 per P. H. P. for plant about			..	10
1,500	Do.	do.	..	20
1,125	Do.	do.	..	40
900	Do.	do.	..	80

The working expenses per P. H. P. hour may be taken roughly at annas 12 for small plants of 10 H. P. and under ; 6 annas for medium size plants working 8 hours a day ; and 1½ annas for large plants working continuously. The figures include all charges for staff, coal, oil, etc., but nothing for repairs, depreciation and interest on capital outlay.

2. The most economical combination of pumping plant and rising main requires consideration. The diameters of rising main with a velocity between 1 and 3 feet per second should be taken and the friction calculated. Roughly find the cost of the main and the plant for each size of main. Then work out the annual cost made up of the working expenses *plus* 10½ per cent on the cost of the plant and 7½ per cent on the cost of the pipes, for depreciation, repairs and interest on capital outlay.

RATE ABSTRACT

STATEMENT OF RATES OF C. I. PIPES CLASS B. BRITISH STANDARD

Internal bore of pipe in inches	Thick-ness in inches	External diamr.	Length clear in feet	Weight of each pipe	Cost of pipe at Rs. 12 per cwt. C.I.F. Bombay	Carriage by rail from Bombay to Poona Re. 1 per cwt.	Carriage from Railway station to depot As. 4 per cwt.	Total cost at depot of each pipe
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
				Cwt. qr. lb.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.
3	·38	3·76	9	1 0 17	13 13 2	1 2 5	0 4 8	15 4 3
4	·39	4·80	9	1 2 4	18 6 10	1 8 7	0 6 2	20 5 7
5	·41	5·90	9	2 0 4	24 7 0	2 0 7	0 8 2	26 15 5
6	·43	6·98	9	2 2 6	30 10 3	2 8 10	0 10 3	33 13 4
7	·45	8·06	9	3 0 9	36 15 5	3 1 3	0 12 4	40 13 0
8	·47	9·14	9	3 2 24	44 9 2	3 11 5	0 14 10	49 3 5
9	·49	10·22	9	4 1 9	51 15 5	4 5 3	1 1 4	57 6 0
10	·52	11·26	12	6 2 2	78 3 5	6 8 3	1 10 1	86 5 9
12	·57	13·14	12	8 1 6	99 10 3	8 4 10	2 1 3	110 0 4
14	·61	15·22	12	10 1 15	124 9 8	10 6 1	2 9 6	137 9 3
15	·63	16·26	12	11 1 21	137 4 0	11 7 0	2 13 9	151 8 9
16	·65	17·30	12	12 2 7	150 12 0	12 9 0	3 2 3	166 7 3
18	·69	19·38	12	15 0 5	180 8 7	15 0 9	3 12 2	199 5 6
20	·73	21·46	12	17 2 11	211 2 10	17 9 3	4 6 5	233 2 6
21	·75	22·50	12	18 3 25	227 10 10	19 0 0	4 12 0	251 6 10
22	·77	23·54	12	20 2 8	246 13 9	20 9 2	5 2 3	272 9 2
24	·80	25·60	12	23 1 0	279 0 0	23 4 0	5 13 0	308 1 0
26	·83	27·66	12	26 0 4	312 6 10	26 0 7	6 8 2	344 15 7
27	·85	28·70	12	27 2 13	331 6 3	27 9 10	6 14 6	365 14 7
28	·86	29·72	12	28 3 20	347 2 3	28 14 10	7 3 9	383 4 10
30	·89	31·78	12	31 3 26	383 12 7	31 15 9	7 15 11	423 12 3
32	·92	33·84	12	35 0 16	421 11 5	35 2 3	8 12 7	465 10 3
33	·94	34·88	12	37 0 5	447 8 7	37 0 9	9 4 2	493 13 6
36	·98	37·96	12	42 0 4	504 6 10	42 0 7	10 8 2	556 15 7

No. 135

SPECIFICATIONS PER FOOT LAID.

Cost of pipes per foot run (10)	Cost of specials per foot run (11)	Total cost of pipes per foot run (12)	Cost of laying pipes per foot run			Depth 3′ above pipe Cost of excavation per foot run	Total cost of pipe per foot laid	Quantity of materials per joint	
			Labour (13)	Material (14)	Total (15)			Lead lb.	Aloe lb.
Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.		
1 11 2	0 2 0	1 13 2	0 3 9	0 3 0	0 6 9	0 8 0	2 11 11	4·25	0·25
2 4 2	0 2 6	2 6 8	0 4 10	0 4 0	0 8 10	0 8 0	3 7 6	5·50	0·38
2 15 11	0 4 0	3 3 11	0 6 0	0 5 0	0 11 0	0 8 0	4 6 11	7·00	0·44
3 12 2	0 5 0	4 1 2	0 7 3	0 5 3	0 12 6	0 8 0	5 5 8	8·00	0·44
4 8 7	0 6 0	4 14 7	0 8 6	0 6 5	0 14 11	0 8 0	6 5 6	9·50	0·50
5 7 6	0 7 6	5 15 0	0 9 8	0 8 0	1 1 8	0 8 0	7 8 8	12·00	0·63
6 6 0	0 9 0	6 15 0	0 10 11	0 8 10	1 3 9	0 8 0	8 10 9	13·50	0·69
7 3 3	0 9 0	7 12 3	0 9 11	0 9 11	1 2 3	0 12 0	9 10 6	14·75	0·75
9 2 8	0 9 0	9 11 8	0 12 0	0 10 3	1 6 3	0 12 0	11 13 11	14·75	1·06
11 12 9	0 9 0	12 5 9	0 13 10	0 12 0	1 9 10	0 12 0	14 10 7	21·50	1·38
12 10 1	0 10 0	13 4 1	0 15 3	0 13 5	1 12 8	0 12 0	15 12 9	23·00	1·50
13 13 11	0 10 0	14 7 11	1 0 0	0 13 7	1 13 7	0 12 0	15 0 11	24·25	1·63
16 9 10	0 12 0	17 5 10	1 6 10	1 1 10	2 8 8	0 12 0	20 10 6	31·50	2·07
19 6 10	0 12 0	20 2 10	1 9 5	1 2 9	2 12 2	1 4 0	24 3 0	34·50	2·25
20 15 3	0 14 0	21 13 3	1 10 9	1 4 0	2 14 9	1 4 0	26 0 0	36·25	2·38
22 11 5	0 14 0	23 9 5	1 12 0	1 5 0	3 1 0	1 4 0	27 14 5	38·25	2·50
25 10 9	1 0 0	26 10 9	1 14 5	1 7 4	3 5 9	1 4 0	31 4 6	41·25	2·66
28 12 0	1 2 0	29 14 0	2 0 0	1 8 3	3 8 3	1 4 0	34 10 3	44·50	2·84
30 7 11	1 4 0	31 11 11	2 2 0	1 9 9	3 11 9	1 4 0	36 10 8	46·75	2·94
31 15 1	1 6 0	33 5 1	2 4 0	1 12 0	4 0 0	1 4 0	38 9 1	50·25	3·06
35 5 0	1 8 0	36 13 0	2 6 6	2 0 0	4 6 6	1 4 0	42 7 6	58·25	3·22
38 14 6	1 10 0	40 8 6	2 8 8	2 2 0	4 10 8	1 8 0	46 11 2	63·00	3·38
41 2 6	1 12 0	42 14 6	2 10 0	2 4 0	4 14 0	1 8 0	49 4 6	65·75	3·63
46 6 8	2 0 0	48 6 8	2 14 0	2 8 0	5 6 0	1 8 0	55 4 8	71·50	4·13

Table No. CCXIV

TABLE SHOWING COST OF MATERIALS FOR JOINING 100′ LENGTH OF C. I. PIPES OF VARIOUS DIAMETERS

Reference to column in 14 Rate-abstract No. 135.

Dia-mr. of pipe	Pipe length of 100′ approx. wt. for calcula-tion of cartage	No. of join-ts in 100′ leng-th	Quan-tity of lead for 100′	Cost at As. 4 a lb.	Quantity of aloe rope for 100 ft.	Cost at As. 12 a lb.	Carriage and carting from depot to trenches at As. 8 per cwt.	Sundries including coal, etc.	Total for 100 ft. length	Rate per foot run
Inches	Cwts.		lbs.	Rs. a. p.	lbs.	Rs. a.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.
3	12	11	47	11 12 0	3	2 4	0 8 0	4 8 0	19 0 0	0 3 0
4	12	11	61	15 4 0	4·25	3 3	0 8 0	7 0 0	25 15 0	0 4 0
5	22	11	77	19 4 0	5	3 12	1 0 0	7 0 0	31 0 0	0 5 0
6	23	11	88	22 0 0	5	3 12	1 4 0	7 0 0	34 0 0	0 5 2
7	33	11	105	26 4 0	5·5	4 2	1 8 0	8 0 0	39 14 0	0 6 5
8	34	11	132	33 0 0	7	5 4	1 12 0	9 0 0	49 0 0	0 8 0
9	44	11	148	37 0 0	7·7	5 13	2 12 0	10 0 0	55 9 0	0 8 10
10	55	9	132	33 0 0	6	4 8	2 12 0	12 0 0	62 4 0	0 9 11
12	72	9	153	38 4 0	10	7 8	3 8 0	14 0 0	63 4 0	0 10 3
14	90	9	193	48 4 0	12·50	9 6	4 8 0	16 0 0	78 2 0	0 12 0
15	99	9	207	52 0 0	13·50	10 2	5 0 0	17 0 0	84 2 0	0 13 5
16	108	9	218	54 8 0	14·75	11 1	5 8 0	18 0 0	89 1 0	0 13 7
18	135	9	283	70 12 0	18·63	14 0	0 8 0	20 0 0	111 4 0	1 1 10
20	153	9	310	77 8 0	20·00	15 0	7 8 0	22 0 0	117 0 0	1 2 9
21	162	9	326	81 8 0	21·50	16 2	8 0 0	23 0 0	128 10 0	1 4 0
22	180	9	344	86 0 0	22·50	16 14	9 0 0	24 0 0	135 14 0	1 5 0
24	207	9	371	92 12 0	24·00	17 4	10 0 0	26 0 0	146 0 0	1 7 4
26	234	9	400	100 0 0	25·56	18 6	11 8 0	28 0 0	157 14 0	1 8 3
27	243	9	420	105 0 0	27·00	19 8	12 0 0	29 0 0	160 8 0	1 9 9
28	252	9	452	113 0 0	27·54	19 14	12 8 0	30 0 0	175 6 0	1 12 0
30	280	9	524	131 0 0	29·00	21 0	14 0 0	31 0 0	197 0 0	2 0 0
32	315	9	567	141 12 0	30·50	22 2	15 8 0	33 0 0	212 6 0	2 2 0
33	333	9	585	146 4 0	32·75	24 9	16 8 0	35 0 0	222 5 0	2 4 0
36	378	9	643	160 12 0	37·25	27 15	18 8 0	38 0 0	245 3 0	2 8 0

Table CCXV

TABLE SHOWING COST OF LABOUR PER FOOT RUN FOR LAYING VARIOUS SIZES OF PIPES

Reference to column 15 in Rate-abstract No. 135.

Diamr. of pipe	Length of pipe	No. of joints in 100′ length	Circumference of one joint	Total circumferential length	Rate per inch of circumferential length	Total for all joints in 100′ length	Cost of labour for jointing per foot of pipe	Remarks
Inches	ft.		Inches	Inches	Rs. a. p.	Rs. a.	Rs. a. p.	
3	9	11	9,50	105	0 3 6	23 0	0 3 9	
4	9	11	12·56	138	0 3 6	30 0	0 4 10	
5	9	11	15·70	173	0 3 6	38 0	0 6 0	
6	9	11	18·85	207	0 3 6	45 0	0 7 3	
7	9	11	22·00	242	0 3 6	53 0	0 8 6	
8	9	11	25·13	277	0 3 6	60 0	0 9 8	
9	9	11	28·27	311	0 3 6	68 0	0 10 11	
10	12	9½	31·41	283	0 3 6	62 0	0 9 11	
12	12	9	37·69	340	0 3 6	74 0	0 12 0	
14	12	9	44·00	396	0 3 6	87 0	0 13 10	
15	12	9	47·12	433	0 3 6	95 0	0 15 3	
16	12	9	50·26	452	0 3 6	99 0	1 0 0	
18	12	9	56·54	509	0 4 6	143 0	1 6 10	
20	12	9	62·83	566	0 4 6	159 0	1 9 5	
21	12	9	66·00	594	0 4 6	167 0	1 10 9	
22	12	9	69·11	622	0 4 6	175 0	1 12 0	
24	12	9	75·39	679	0 4 6	191 0	1 14 5	
26	12	9	81·68	735	0 4 6	206 0	2 0 0	
27	12	9	84·82	764	0 4 6	215 0	2 2 0	
28	12	9	88·00	792	0 4 6	223 0	2 4 0	
30	12	9	94·24	846	0 4 6	241 0	2 6 6	
32	12	9	100·53	905	0 4 6	255 0	2 8 8	
33	12	9	103·67	933	0 4 6	262 0	2 10 0	
36	12	9	113·10	1,018	0 4 6	286 0	2 14 0	

TABLE CCXVI

STATEMENT SHOWING THE COST OF CAST IRON WATER MAINS AT VARYING

Size of cast iron pipe	Weight of C.I. pipes as per British standard specifications			Cost of cast iron pipes per 100			
	Weight of pipe 12′ in length	Weight of pipe 9′ in length	Total weight in cwt. for 100 rg. ft.	Rate per cwt. at Rs. 10	Rate per cwt. at Rs. 11	Rate per cwt. at Rs. 12	Rate per cwt. at Rs. 13
1	2	3	4	5	6	7	8
	Cwt. qr. lb.	Cwt. qr. lb.	Cwt.	Rs. in Dec.	Rs. in Dec.	Rs. in Dec.	Rs. in Dec.
18″	15 0 5	..	125·37	1,253·70	1,379·07	1,504·44	1,629·81
15″	11 1 21	..	95·31	953·10	1,048·41	1,143·72	1,239·03
12″	8 1 6	6 1 20	69·19	691·90	761·09	830·28	899·47
9″	5 2 9	4 1 9	46·50	465·00	511·50	558·00	604·50
6″	3 1 4	2 2 6	27·38	273·80	301·18	328·56	355·94
4″	1 3 26	1 2 4	17·06	170·60	187·66	204·72	221·78
3″	..	1 0 17	12·80	128·00	140·80	153·60	166 40

Note.—The weights of pipes are taken from British Standard

RATES OF CAST IRON FROM RS. 10 TO RS. 22 PER CWT.

running feet from Rs. 10 to Rs. 22 per cwt.

Rate per cwt. at Rs. 14.	Rate per cwt. at Rs. 15.	Rate per cwt. at Rs. 16.	Rate per cwt. at Rs. 17.	Rate per cwt. at Rs. 18.	Rate per cwt. at Rs. 19.	Rate per cwt. at Rs. 20.	Rate per cwt. at Rs. 21.	Rate per cwt. at Rs. 22.
9	10	11	12	13	14	15	16	17
Rs. in Dec.	Rs. in Dec.	Rs. in Dec.	Rs. in Dec.	Rs. in Dec.	Rs. in Dec.	Rs. in Dec.	Rs. in Dec.	Rs. in Dec.
1,755·18	1,880·55	2,005·92	2,131·29	2,256·66	2,382·03	2,507·40	2,632·77	2,758·14
1,334·34	1,429·65	1,524·96	1,620·27	1,715·58	1,810·89	1,906·20	2,001·51	2,096·82
968·66	1,037·85	1,107·04	1,176·23	1,245·42	1,314·61	1,383·80	1,452·99	1,522·18
651·00	697·50	744·00	790·50	837·00	883·50	930·00	976·50	1,023·00
383·32	410·70	438·08	465·46	492·84	520·22	547·60	574·98	602·36
238·84	255·90	272·96	290·02	307·08	324·14	341·20	358·26	375·32
179·20	192·00	204·80	217·60	230·40	243·20	256·00	268·80	281·60

Specifications for mains, class B for a test pressure of 400 feet.

RATE ABSTRACT No. 136

LAYING GALVANIZED WROUGHT IRON PIPING, 1 INCH DIAMETER.

Materials for 100 Rg. ft.	Quantity	Rate	Per	Amount	Labour for 100 Rg. ft.	Number or quantity	Rate	Per	Amount
		Rs. a.		Rs. a.					
W.I. pipes, 1" Rg.ft.	100	..	Ft.	..	Excavating trenches .. C.ft.	100	..	100	..
Carriage ,,		..	Lot.	..	Filling in trenches .. ,,	100	..	100	..
Sundries, oil, etc.	..	..	..	..	Fitters .. No.	$\frac{1}{2}$	..	1 Each	..
					Coolies .. ,,	$1\frac{1}{2}$	..	,,	..
					Watchman .. ,,	$\frac{1}{3}$	..	,,	..
					Sundries ..	..	..	..	..
						Total, labour		..	..
	Total, materials					Total, materials		..	..
					Total for 100 Rg. ft., 1" piping			..	..
						or, for 1 Rg. ft.		..	..

RATE ABSTRACT No. 137

LAYING GALVANIZED WROUGHT IRON PIPING, 2 INCHES DIAMETER

Materials for 100 Rg. ft.	Quantity.	Rate	Per	Amount	Labour for 100 Rg. ft.	Number or quantity	Rate	Per	Amount
		Rs. a.		Rs. a.			Rs. a.		Rs. a.
W. I. pipes, 2" Rg.ft.	100		Ft.	..	Excavating trenches .. C.ft.	100	..	100	..
Carriage ..	..	..	Lot	..	Filling in trenches .. ,,	100		100	..
Sundries, oil, etc.	..	..	..	..	Fitters .. No.	$\frac{1}{2}$	..	Each	..
					Coolies .. ,,	2	..	,,	..
					Watchman .. ,,	$\frac{1}{3}$	..	,,	..
					Sundries ..	..	..	..	..
						Total, labour		..	..
	Total, materials			..		Total, materials		..	..
					Total for 100 Rg. ft., 2" piping			..	..
						or, for 1 Rg. ft.		..	..

RATE ABSTRACT No. 138

WELL SINKING IN ALLUVIAL SOIL

(Kaira district)

1. Excavation in dry soil, *i.e.*, above water level, up to about 50 feet depth. Rs. 5-0-0 per 100 c.ft.
2. Excavation in dry soil for depth of 50 feet to 80 feet. Rs. 8-0-0 per 100 c.ft.
3. Excavation in water .. .. .. Rs. 20 to Rs. 25 per 100 c.ft.

3 days' 'kos' working at Rs. 4 per day ..	Rs. 12-0-0
'Kos' arrangement	Rs. 1-0-0
Excavation and removal	Rs. 8-0-0
Total ..	Rs. 21-0-0.

Note.—For bailing out water in a well of 10″ diameter, the rate of Rs. 300 to Rs. 400 may be put down as an average lump sum for 15 feet depth of water.

4. **Curbing.**—Babul or samda wood curb with necessary iron work such as straps, bolts, nails, etc.—

Wood	Rs. 2-0-0 per c.ft.
Labour	Rs. 1-8-0 ,, ,,
Iron work	Rs. 1-4-0 ,, ,,
Laying in position including ropes, etc.	Rs. 0-8-0 ,, ,,
Total ..	Rs. 5-4-0 ,, ,,

RATE ABSTRACT No. 139

WELL SINKING IN ALLUVIAL SOIL (KAIRA DISTRICT)

Burnt brick and lime masonry in steining.

Materials for 100 c.ft.	Number of quantity	Rate	Per	Amount	Labour for 100 c.ft.	Number	Rate	Per	Amount
		Rs. a.		Rs. a.			Rs. a.		Rs. a.
Bricks 9″ × 4½″ × 2½″ allowing 5% for wastage	1500	..	1,000	..	Brick layers Nos.	6	..	1	..
					Coolies .. ,,	4	..	1	..
					Women .. ,,	7	..	1	..
Lime, slaked c.ft.	25	..	100	..	Grinding lime c.ft.	37½	..	100	..
Sand .. c.ft.	37½	..	100	..	Scaffolding No.		..	Lump	..
Sundries ..					Sundries ..				
	Total, materials			..		Total, labour		..	..
						Total for materials, and labour		..	..
						Per 100 Cubic feet		..	..

RATE ABSTRACT No. 140

WELL SINKING IN ROCK

(Panch Mahals)

	Rs.	a.	p.	
1. Excavation in earth and muram near the surface	2	8	0	per 100 c.ft.
2. Excavation in boulders and hard muram ..	10	0	0	,, ,,
3. Excavation in soft rock	15	0	0	,, ,,
4. Excavation in hard rock	30	0	0	,, ,,

Note.—Bailing out water may be included in these rates.

CHAPTER XII.—SANITARY ENGINEERING

DRAINAGE

1. **Need for drains.**—Surface or underground drains are needed in towns and villages for the removal of sewage and sullage and of storm water. Where sullage and storm water have to be dealt with, no night soil, surface drains of V shaped section with segmental inverts are usually most satisfactory ; where night soil has also to be carried, underground stoneware pipes or masonry drains are necessary, these being usually provided of sufficient capacity for the maximum flow of household sewage and sullage, with only a very small quantity of rainfall, surface drains being provided for the latter. The quantity of storm water to be provided for in the case of surface drains is usually between one-quarter inch and one inch per hour, according to the area of the catchment, the nature of the rainfall, and runoff in the locality concerned. It is not advisable to lay any pipe sewer of a less diameter than 8 inches, even though calculations might show that a pipe of much smaller capacity would do all the work required.

2. **Sewers and drains.**—The term drain, when employed in connection with an underground system of sewerage, is usually restricted to the pipe draining a single property ; underground pipes draining more than one property are usually termed sewers. Drains, as thus defined, may, when necessary, be laid around curves, with small inspection chambers at suitable points for cleaning when necessary. Sewers should be laid in straight lines, manholes being constructed at all changes of directions or gradient and at intervals of not more than 300 feet on straight lengths of sewers, for inspection and removal of obstructions. In very crooked and narrow streets and lanes inspection covers merely may be provided, if the distance between manholes is less than 100 feet.

3. **Manholes, disconnecting pits and junction pits.**—These manholes are small masonry chambers on the line of the sewer, providing access to the latter, of sufficient size for a man to work the cleaning rods in a pipe sewer, usually about 5 feet × 3 feet inside, with a shaft about 2 feet 3 inches square and a strong circular iron cover, weighing (frame and cover) not less than $6\frac{1}{2}$ cwts., where exposed to vehicular traffic. Where manholes are to be utilised for ventilation purposes, the covers should be perforated. The manholes, disconnecting pits and junction pits, shall be excavated in each case to the depth required for the foundation below the invert of the drain pipe at the site of the pit. Foundations to be of lime concrete. Walls to be of coursed rubble masonry, third sort, or of brick masonry, second class. Coping over wall to be of cut stone and to be dressed to fit the cast iron frames for covers. Wall to be internally plastered with a $\frac{3}{4}''$ coating of cement and sand (1 to 2), finished with a floating of neat cement. At the bottom of each pit a channel of the full width and depth of the pipe drain is to be constructed of cement concrete plastered with a 1″ coating of cement and sand (1 to 2), laid on while the concrete is still green and finished off with a coat of neat cement. Similar curved channels are to be constructed in the pits to form the junction of branch drains. All channels in pits to be given a gradient of 1 in 30. All cement work to be protected from the rays of the sun and kept watered for 15 days after completion.

Disconnecting pits are to be provided with intercepting sewer trap built into the wall of the pit on the main sewer side. The trap to be carefully set up and levelled ; when fixed the trap to have a drop of $2\frac{1}{2}''$, so as to ensure a cascade action to help to overcome the resistance of the trap.

The seal of the trap to be 3″, each disconnecting pit to be provided with a 2″ cast iron fresh air inlet, with mica valve to head piece, and fixed to an adjacent wall. All pits over 3′ in depth to be provided with wrought iron manhole treads fixed in into one of the side walls at 1′ vertical intervals.

4. **Flushing tanks.**—Where it is not practicable to obtain gradients steep enough to give a self-cleansing velocity of not less than 2½ feet per second, it is necessary to provide chambers or tanks at the head of the sewer, which can be filled with water at intervals in order to flush out the length of sewer below. When possible, tanks which fill and discharge automatically should be provided. The effect of such flushing is only local and gradients giving self-cleansing velocity are always to be preferred.

5. **Ventilation.**—Where adequate ventilation cannot be provided at the manhole cover and at the upper end of the house drains, it is necessary to provide ventilating shats at the upper end of the sewers and at suitable points along their course. The distance between vent shaft and vent shaft should, as a general rule, not exceed 400 feet, and the diameter of the shaft should be not less than 6″. The vent pipes should be fixed, as far as possible, in such positions as would expose them to the sun for as long a period as possible during the day.

6. **Velocity and gradients.**—The following table gives the minimum gradients for sewers and limiting permissible velocities. The minimum gradients are selected to give a self-cleansing velocity of 2½ feet per second or thereabout, in a sewer flowing half full without recourse to flushing, with flushing lower gradients are now accepted as permissible. Every attempt should be made to so design as to attain a velocity of 3 to 3½ feet per second, without flushing :—

TABLE CCXVII.

Diameter of sewer	Minimum gradients		Limiting velocities permissible
4″	1 in 40	..	No limit.
6″	1 in 100	..	10 ft. per second.
7″	1 in 125	..	9 ft. ,, ,,
9″	1 in 185	..	9 ft. ,, ,,
12″	1 in 270	..	8 ft. ,, ,,
15″	1 in 410	..	6 ft. ,, ,,
18″	1 in 600	..	6 ft. ,, ,,
24″	1 in 960	..	6 ft. ,, ,,
30″	1 in 1,300	..	6 ft. ,, ,,

Note.—For 4″ house connections no limiting velocity need be specified. For circular pipe ewers 19″ to 45″ in diameter *minimum* gradient should not be less than 1 in 600, where possible.

7. **Inclination of pipes for special velocities.**—The following table gives the falls required to produce certain velocities in pipes of different sizes when running full or half full, where the coefficient of roughness, N, is equal to ·013:—

TABLE CCXVIII.

Diameter of pipe	Velocity in feet per second						
	2	2½	2¾	3	4	5	6
Inches.	Sine of inclination (1 over :—)						
3 ..	50	32	26	22	12	8	5
4 ..	82	52	43	36	20	13	9
6 ..	155	100	84	70	39	25	17
9 ..	295	190	155	130	75	48	33
12 ..	460	295	245	205	115	75	52
15 ..	640	415	345	290	160	105	73
18 ..	840	540	450	375	210	135	95
24 ..	1,250	820	680	570	325	205	145

8. **Materials.**—For underground drains up to 18″ diameter glazed stoneware pipes are used; for large sizes, concrete pipes or circular or egg-shaped concrete or masonry sewers are employed. Underground drains and sewers are not usually required to stand any considerable internal pressure; where this is necessary as in syphoning under rivers or canals, cast-iron pipes should be used.

9. **Size.**—The sewers and drains shall generally be designed to run from half to two-thirds full, when discharging at the maximum rate of dry weather flow; the latter may be taken as being approximately twice the average dry weather flow, or one-half of the average daily discharge in 6 hours, so that the capacity of the sewer, when running full, will be from 3 to 4 times the average dry weather flow, thus allowing not only for the fluctuation in the hourly rate of the latter, but also for a small quantity of rain water.

Points to be considered in the designing and construction of sewers.

1. Main sewers should be laid out in straight lines and true gradients from point to point with side entrances, manholes, flushing and ventilating arrangements at each principle change of line and gradient.

2. Brick screwers must be formed with bricks moulded to the radii. They should in all cases be set in cement. In no case should any sewer be formed with bricks laid dry and subsequently grouted.

3. If stoneware pipes are used, they must be laid true for line and gradient and jointed with cement.

If the bed is soft they should be laid in concrete. House drains, where they pass below houses (which should be avoided as far as possible) should, in all cases, be bedded in concrete.

4. Tributary sewers should deliver sewage in the direction of the main flow through the manhole by an arrangement of inverts. (See sketch, 1, plate CXXII.)

5. Sewers and drains at junction and curves should have an extra fall to compensate for friction and interruption of flow.

6. Sewers of unequal sectional areas should not join with level inverts. The lesser sewer should have a fall into the main equal to the difference in diameters. Junctions must be made with care, so that the flow in the mains is not impeded.

7. In cases where branch pipe sewers enter the manholes on main pipe sewers, at a higher level than the main sewer, a drop pipe should be used as shown in sketch 2, plate CXXII.

8. House drains should not pass direct from sewers to the inside of houses, but all house drains should end at an outside wall ; or should be cut off from the sewer by an air inlet chamber with trap on sewer side. House drains, sink pipes and soil pipes should well ventilated.

9. Sinks and water closets should be against an outside wall, so that refuse water or soil may be discharged into a ventilated trap and drain outside the main wall.

10. Manholes or lamp-holes should be provided in all straight lengths of sewers at every 100 yards.

SEWAGE DISPOSAL

1. **Disposal on land.**—Sewage and sullage can usually be conveniently and profitably disposed of by broad irrigation on neighbouring land, after allowing the silt and sand carried down the drains to be deposited in a catch pit, and screening out any floating solids.

The sewage from a population of about 150 people can usually be disposed of on one acre of land of average quality ; one acre per 100 persons is the approximate average area of land required allowing a suitable percentage for fallows.

Irrigation or land filtration with crude sewage is, however, objectionable, as the solids choke the surface and prevent the oxidation of the liquid, which is necessary for a good effluent.

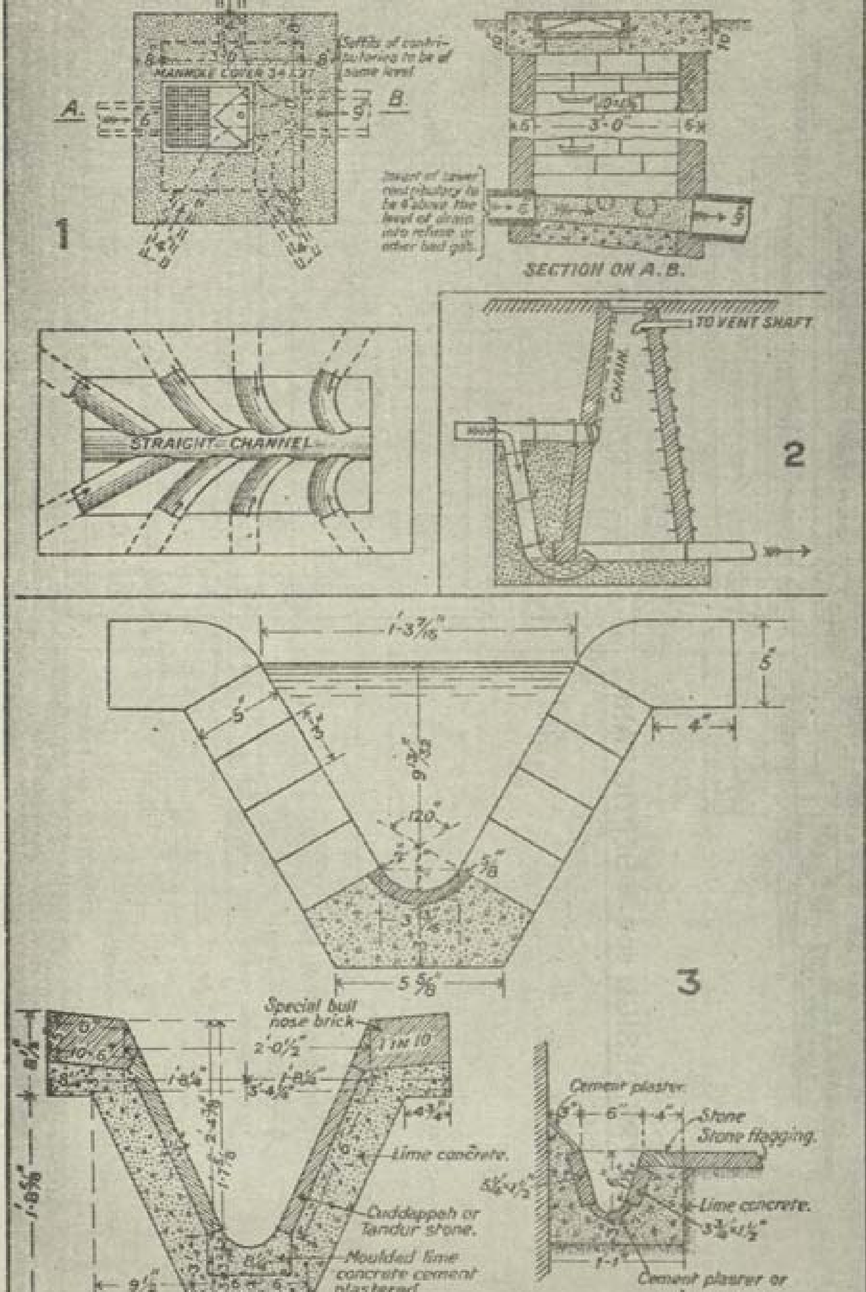
2. **Artificial purification.**—Where suitable land is not available, the desired purification of the liquid can be effected by means of septic tanks and filters, or by the activated sludge process.

Where artificial sewage disposal works are being installed for any area, they should, except under very special circumstances, be designed to treat the whole of the sewage and sullage water of that area.

The process of artificial sewage disposal consists of the separation of the solids, or less bulky part of the sewage, for treatment by burial, and the oxidation of the liquid or more bulky part to such an extent that it is rendered non-putrescible and may be delivered without nuisance or danger, on to land or into a river.

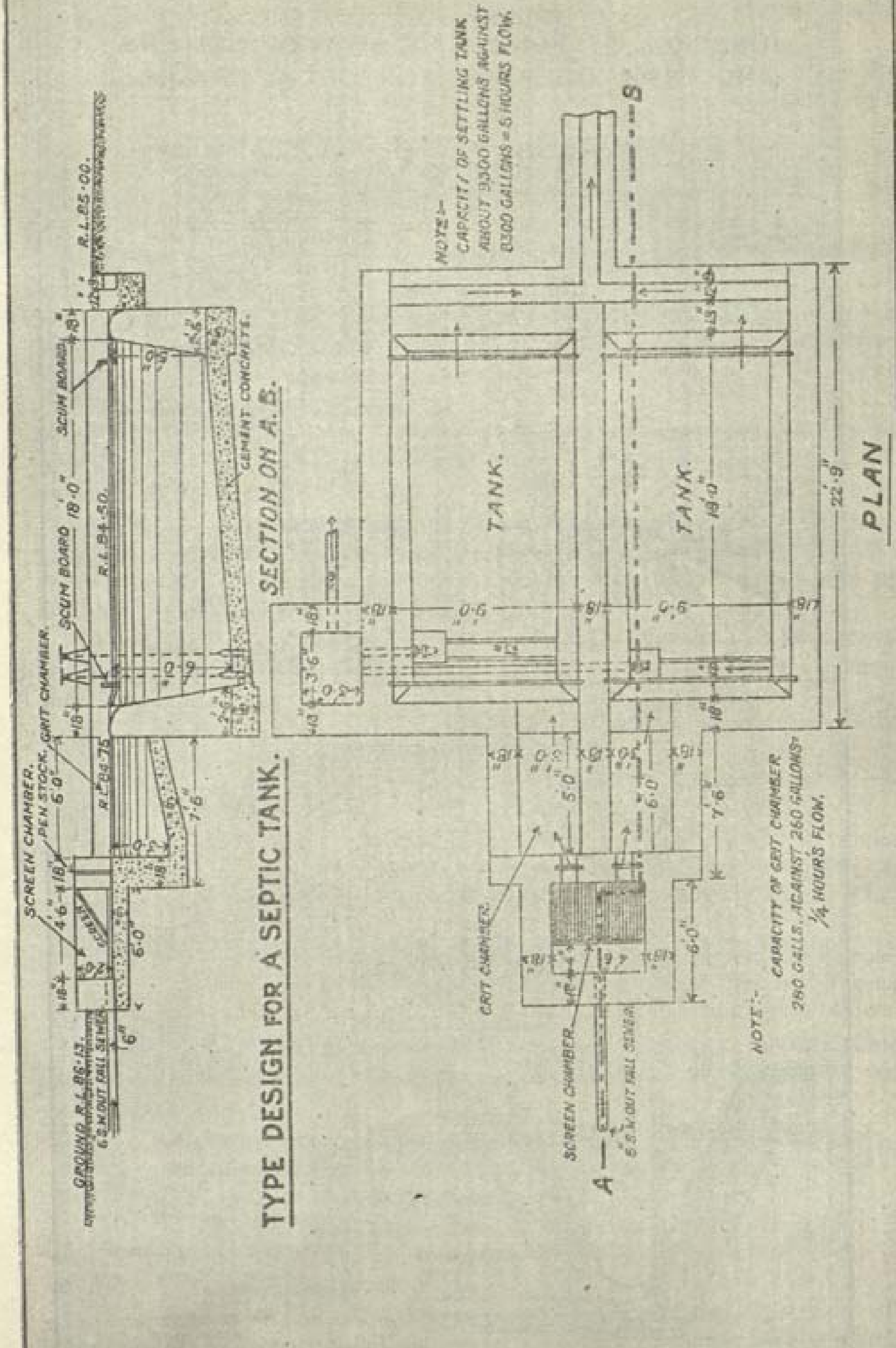
Plate CXXII

JUNCTION OF MAIN & TRIBUTARY SEWERS; AND TYPE DESIGNS FOR OPEN DRAINS.



G. M. P. Poona, 1918.

Plate CXXIII

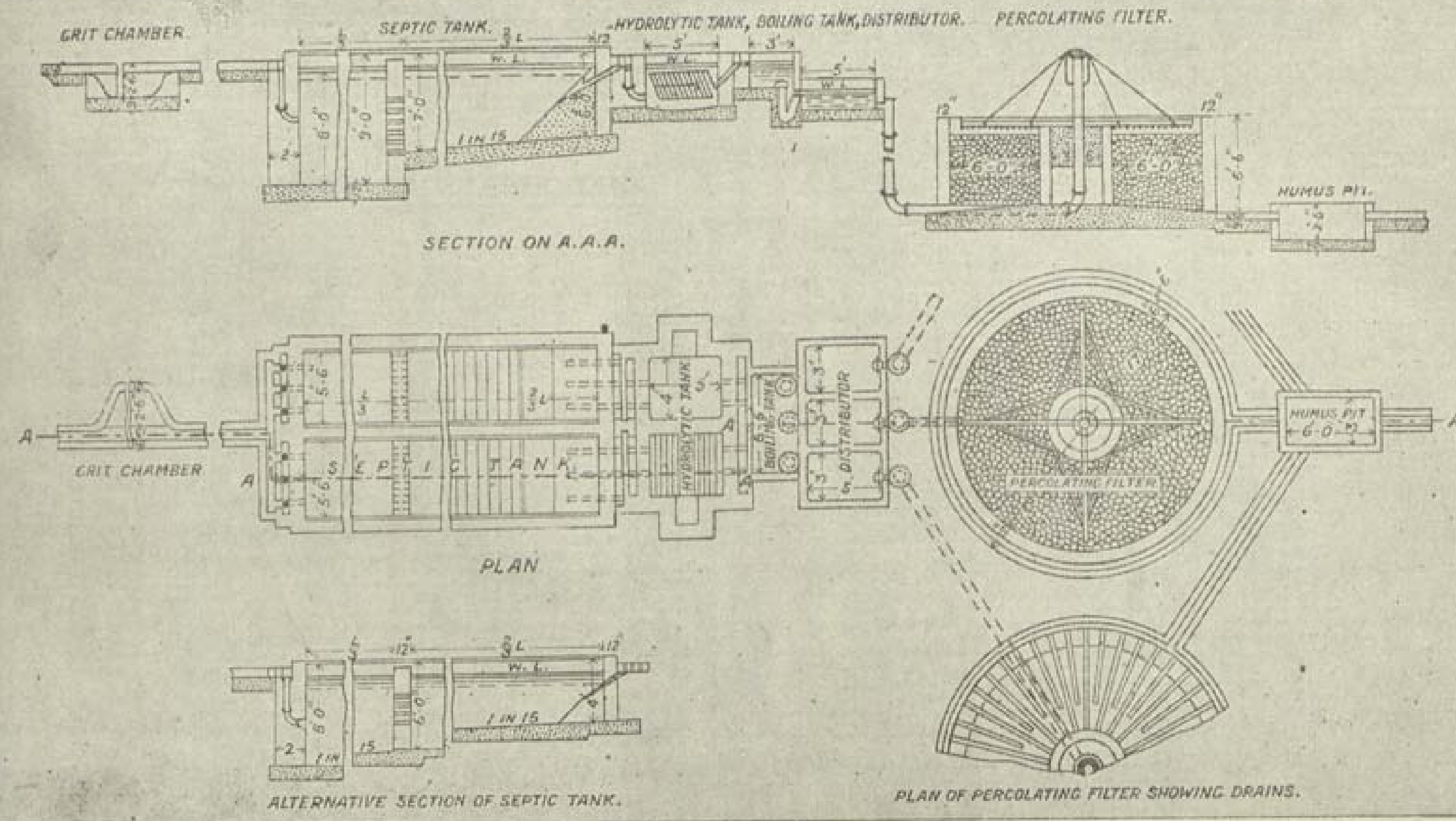


G. PZ. P. Poona, 1959.

To face page 890

Plate CXXIV.

TYPE DESIGN FOR A FILTER.



For this process the minimum dilution compatible with successful working is not known, but, for the present, it may be taken as 5 gallons a head. It is better to add the water at the latrines rather than afterwards.

3. **Grit chamber.**—At the end of the outfall sewer and prior to the septic tank, a grit chamber should be provided to intercept the mineral matter and to obviate the necessity of its removal from the septic tank. Its capacity should be from about 1/48 to 1/24 of the mean daily dry weather flow. It should be designed to catch the heavy mineral matter and to allow the floating foeces to pass on to the septic tank. The mineral matter deposited must be removed daily, and the section should be such as to facilitate this.

Septic tank

4. **Objects.**—A septic tank is constructed in connection with sewage disposal works, where the disposal of crude sewage either on to land or into a river is objectionable. The object of such a tank is to separate the inorganic or mineral solid matter from the liquid and to digest the sludge, as much as possible, by encouraging the growth of *anaerobic* bacteria. It must, therefore, be designed for the efficiency of sedimentation and liquification. The digestion of the sludge will never be perfect since it contains some mineral matter and humus that cannot be further digested. The maximum digestion possible is probably about 30 per cent. of the solid matter in the crude sewage; about 29 per cent. is converted into gas; and about 41 per cent. remains in the tank to be removed as sludge.

5. **Capacity.**—The tank may be designed to give capacities of 1½ day's, 1 day's and ¾ day's average dry weather flow for sewages of strengths of 5 gallons, 12 gallons and 20 gallons a head, respectively. These capacities should be divided between two or more compartments as convenient, to permit of cutting out one, when required for removing the sludge.

6. **Dimensions and bed slopes.**—The ratio of length to breadth of each compartment should be between 3 : 1 and 6 : 1, and it should be divided by a baffle wall in the ratio of about 1 : 2, the inlet chamber being smaller. The inlet chamber should be given a steeper bed slope than the outer chamber, because most of the solid matter settles down in the inlet chamber, and it is necessary that all this should gravitate towards the sludge pipe as quickly as possible. The inlet chamber may have a bed slope of from 1/10 to 1/15, and the outer chamber, 1/18 to 1/25. The interior of the tank must be given a smooth surface with cement plaster. The minimum breadth in the case of very small tanks may be taken as 2½ feet. Suitable depths for septic tanks are shown in plates CXXIII and CXXIV.

7. **Baffle wall.**—The baffle wall should be at 1/3rd of the length of the tank from the inlet. It should be carried to well above the surface. When the inlet compartment is 2′ deeper than the rest of the tank, the lowest two-third of this baffle wall should be perforated as much as possible. Otherwise the middle third only should be perforated. If possible, the perforation should be bell-mouthed at both ends. No other baffle walls are required; but scum boards should be provided at convenient intervals. The last scum board should be about a foot behind the outlet, and it should be 15″ deep.

8. **Inlet and outlet.**—The inflowing sewage should be delivered with as little disturbance of the contents as possible. Open inlets and outlets are better.

9. For the collection of scum, a free board of about 2′—5″ should be allowed between the F. S. L. and the top of the septic tank. Removal of sludge and scum should be attended to as frequently as possible. The sludge pipe should be laid as in the sketch.

10. A type sketch of septic tank without baffle wall is given in plate CXXIII.

11. **Closed or open.**—It is not necessary for the working that the tank should be covered. A permanent roof interferes with the removal of the sludge. To prevent nuisance from flies breeding in the scum a light covering of moveable boards should always be provided.

12. **Storm water.**—In small installations, some storm water may reach the disposal works from open drains. In such cases the storm overflows on the open drains, should be set at such a level, that no more than three times the dry weather flow shall enter the septic tank.

13. **Management.**—When starting a new septic tank, it should first be filled with clean water, and, if possible, a quantity of liquid sludge introduced from a working tank, say enough to cover the bottom of the first compartment to the depth of an inch. The full number of users should not be admitted at once, but the load should be gradually increased, beginning with one-third of the number and increasing to the full number at the end of three months.

For the first six months the depth of the sludge should be tested from time to time with the dipping tube. If the tank is working properly, the sludge should increase rapidly at first and more slowly afterwards. The effluent should also be analysed from time to time, to ascertain the amount of suspended matters and the ratio of free to albuminoid ammonia. In a tank working properly the free ammonia should increase.

When the tank is in full operation, analysis of the effluent should be made at least once a year to ascertain the ratio of free and albuminoid ammonia, preferably before the annual removal of the sludge. Tests to ascertain the amount of suspended matter in the effluent and the depth of sludge should be made every six months, any considerable increase in the former showing that sludging is necessary.

The sludge deposited in the tank must be removed at least once a year, the best digested sludge being removed as far as possible. This is best done by lowering the surface level until sweepers can work in the tank, and removing the sludge with *phawras*. The sludge should never be allowed to accumulate to such an extent as to fill more than one-third of the depth of the inlet compartment. The sludge removed must be buried in shallow trenches about one foot in depth. If the scum becomes too thick the tank should be rested for three or four days when it will be rapidly reduced.

14. **Standard.**—There are two practical standards for the effluent from the septic tank, or from the hydrolysing chamber, *viz.*, the amount of suspended matter and the oxidisability of the effluent. The latter is best shown by the constitution of the effluent from the filters. For the former it may be taken that, with coarse material in the filter, the septic tank effluent should not contain more than 20 parts of suspended matter per 100,000. If this amount is exceeded the best digested sludge should be removed.

15. **Hydrolytic tank.**—One of these should, where the dilution of the sewage is less than 15 gallons per head of population, always be provided to take the septic tank effluent. The capacity should be about 1½ hour's flow and, like the septic tank, it should be divided into two parts to permit of periodical cleaning or renewal. The depth of filtering medium should not be less than 3 feet.

16. **Land irrigation with tank effluent.**—This should not ordinarily be allowed where skilled management is not available. The amount that can be

put on to land varies with the nature of the land. In England the maximum amount are taken to be 30,000 gallons and 3,000 gallons per day per acre for sandy soil and clay, respectively.

Filters

17. **Artificial filtration.**—The object of this part of the process is the elimination of the suspended solids and the oxidation of the liquid to render it non-putrescible.

There are two forms of artificial filters, *viz.*, contact beds and percolating filters. The former are now gradually passing out of use being less efficient and less economical than percolating filters and also requiring more skilled supervision. Their only advantage is that they require less head, and this would be the only reason for using them. But percolating filters can now be designed requiring so little head that the necessity for a contact bed must be very exceptional.

18. **Percolating filters.**—The important points to be borne in mind in the design and working of percolating filters are the uniform distribution of the septic tank effluent over the whole area, and the maintenance of sufficient aeration in the interior of the filter. For the latter object it is necessary, either to allow the suspended matters to pass through the filter, or to remove them from the filtering material, from time to time, when they threaten to impede proper aeration. This aeration is chiefly from the top, side aeration having little effect. With coarse and medium material the suspended matters pass through more or less freely. With fine material they are held up in the body and on the surface of the material. And it is generally better to use coarse or medium material, except perhaps occasionally in large installations where a permanent staff is maintained and skilled supervision is available. Coarse material may be taken to be material of 2½″ diameter or over, and medium material, of diameter from ½″ to 1′

19. **Rate of filtration.**—The rate of filtration which may be allowed, depends on the coarseness of the material used, the amount of suspended matter in the effluent from the septic tank, and the degree of purification required in the filter effluent. For the design of the filter the minimum quantity of filtering material may be taken at four cubic feet of coarse material 2½″ diameter or 8 cubic feet of medium material ½″ to 1″ diameter, per head of population.

These capacities are the smallest that will pass sewage, with an average amount of suspended matter through continuously without clogging. The capacities must be increased where greater purification is desired. With material of intermediate grade, the minimum capacity may be varied proportionately. And where storm water is allowed to enter the septic tank, 50 per cent. should be added to the minimum capacities given above.

20. **Depth of filter.**—For coarse filters, the maximum and minimum depth of filtering material may be taken to be 9 feet and 4 feet, respectively. For filters of medium material the maximum and minimum depths may be taken to be 5 feet and 3 feet, respectively.

21. **Material.**—The material need not be graded, but may be of one size throughout, except that large stuff should be carefully packed in the bottom layer so as to give rapid egress to the suspended matters passing through the filter.

Material with a rough surface is better than that with a smooth surface, and it is important that it should not readily disintegrate. The usual materials in order of merit are: (1) clinker, (2) coke, (3) English coal, (4) broken stone, (5) broken brick.

22. **Base of filter.**—The base of the filter should be of concrete and sloped to the drains and exits. There should be numerous exits and the drains leading to them should be as short as possible. There should be an open channel round the filter collecting the effluent and leading it to the outfall. At a convenient place on this channel there should be a humus pit to eliminate the humus or suspended matter which is still putrescrible.

23. **Walls.**—These are not necessary unless required as a support to the distributing apparatus. Usually rough rubble or wire will suffice to hold up the filtering material. Where walls are provided they need not be perforated but numerous exists must be provided at the bottom.

24. **Distribution.**—There are two efficient methods, suitable to Indian conditions, of distribution for filters of course or medium material, *viz.*, tipping troughs and rotating sprinklers. For small installations, where skilled supervision is not constantly available, the former is preferable, but the troughs must have firm supports. For large installations automatic rotating sprinklers should generally be used, preference being given to those in which the tank effluent is not forced through small perforations in the arms. The mechanism should be as simple as possible so as not to get out of order readily. These sprinklers can now be obtained to work with a small head. Their design may best be left to the manufacturers, details of head available, diameter of filter, and rate of flow required being given to them.

25. **Flushing or dosing tanks.**—These are not required when the distribution is by tipping troughs. With automatic rotating sprinklers they must be provided and syphons are then also necessary. There should be on to each filter, or, with one dosing tank, alternating timed syphons must be used. The design of these also may be left to the manufacturers.

26. **Number of units.**—There must not be less than three filters, to permit of resting and cutting out any one when required. Otherwise the subdivision of the filters will depend on the means of distribution employed and on the levels and area available. Automatic rotating sprinklers can be obtained up to 200 feet diameter.

27. **Management.**—If a new filter is started at the same time as the septic tank which supplies it, the instructions given for starting the latter gradually will ensure that the filter is also started in the proper way. If a new filter is started to work with the effluent from a septic tank in full work, the rate of flow at the commencement should be one-third of that for which the filter is designed, and should be increased gradually to reach its full amount in about 10 days.

In a working filter, the distributing apparatus must be inspected daily, in the case of tipping troughs by the sweeper in charge, and in the case of rotating sprinklers by some one capable of clearing the perforations, if any, and of looking after the mechanism.

On one fixed day of the week, and in the case of coarse filters once in every three weeks, each unit should be thrown out of work for 24 hours. The gelatinous coating of the material will then become granular and fall away, and will be washed through when the filter is again started. Thus if there were three units they would each be thrown out of work on the following Fridays or once in three weeks, two units being always in work.

If there should be any sign of faulty aeration, such as absence of nitrates or excessive absorption of oxygen in the effluent, or visible choking with suspended matter such as humus, the unit should be rested for two or more days as

necessary. And if that should not prove effectual the material must be removed and the filter remade with the same material after washing, or fresh material.

The sediment found in the humus pit must be removed daily and buried.

28. **Standards.**—The filter effluent should not contain more than three parts per 100,000 of suspended matter.

After being filtered through filter paper it should not absorb more than 0·5 parts per 100,000, by weight, of dissolved oxygen in 24 hours, or 1 part by weight in 48 hours, or 1·5 parts by weight in 5 days.

It should contain a large proportion of nitrates and a small proportion of nitrites.

29. **Supervision.**—The duties of the sweeper in charge will be as follows: Every day he will—

(*a*) keep all channels free from obstruction,
(*b*) remove the detritus from the detritus pit,
(*c*) remove the sludge from the sludge pit in the hydrolysing chamber,
(*d*) see that the syphon discharging arrangements and the distributing apparatus are working properly, put them right, when necessary, if he can, or otherwise report to the Executive Engineer's staff,
(*e*) clear the sediment from the humus pit,
(*f*) bury at once all detritus, sludge or humus, removed by him, in trenches not more than one foot deep. Once a week he will throw out of work one of the filter units bringing it again into work on the following day. And he will report to the Executive Engineer's staff any defect in the working of the installations which may come to his notice.

SULLAGE AND STORM WATER SURFACE DRAINS.

1. Surface drains are often constructed with square bottom and of uniform section; the result being that at the time of the minimum flow the velocity is insufficient and silt deposit takes place, and if it is not properly attended to, the drain gets choked up. Therefore, in designing the section of an open drain, the minimum as well as the maximum discharge must be considered, and a self-cleansing velocity for the minimum discharge must be secured.

2. **Preliminary calculation.**—Every surface drain will be expected to carry all the sullage water and a large portion of the storm water. Therefore the quantity of sullage water (which will be equal to the water supply per head per day) from a particular section should be first considered, and the section of the invert portion should be so designed as to carry away in 6 hours 50 per cent. of the average daily supply, without leaving any deposit as far as possible. Next, the area which will be drained by the particular section of the drain should be found out, and a suitable run-off depending on the intensity of the rainfall at the place, and also the nature of the premises, should be assumed and the quantity of the storm water to be passed down should be calculated and added to the quantity of sullage previously found out; and a complete section with the invert as already fixed should be designed.

N. B.—A run off ¼″ to 1″ per hour may be taken according to the rainfall at the place.

3. In determining the size of a drain attention should be paid to securing a self-cleansing velocity, *i.e.*, the minimum velocity obtained for any section should

not be less than 3 feet per second. Though strictly speaking surface drains should not be covered in, in most towns it is absolutely impossible to avoid covered drains. The aim should, however, be to reduce the length of covered drains, as far as possible, because the covered portions generally harbour rats and they are often neglected.

The following rule regarding the length of covered drains will be useful :—

> When the gutter covered is level with the road surface at the edge of the gutter, no covered length should exceed 3 feet. No covering to a gutter should be permitted within 4 feet of the next covering. The minimum clearance between the gutter covering and the invert level of the gutter should be one foot.

4. The inside of the gutter is generally rendered with cement on the invert; but this rendering is damaged by the rough scraper generally used by the sweepers while cleaning. The repairs in such places are often neglected. It will, therefore, be always advisable to have the invert of glazed stoneware pipes. The type sections recommended for surface drains are of the rounded V type, plate CXXII. This shape is suitable because the area of the section decreases in proportion to the decrease of the discharge, and a uniform velocity is generally maintained.

5. For further details, see "Surface Drainage", by H.A. Gubbay, A.M.I.C.E.

STONEWARE PIPES

Specification No. 183.

1. Stoneware pipes shall be of best quality stoneware or fireclay, salt-glazed, thoroughly burnt throughout the whole thickness, of a close and even texture, free from air blows, fire blisters, cracks and other imperfections, and the surfaces, external and internal, shall be smooth and perfectly glazed.

2. A piece of stoneware pipe, about 2 inches square from any part of the pipe, shall not absorb, after 48 hours' immersion in water, more than 4 per cent. of its own dry weight of water.

3. The stoneware pipe shall be capable of resisting a bursting pressure of 30 lbs. per square inch, without showing signs of leakage.

4. The breaking weight of the stoneware pipe shall not be less than 1,700 lbs., applied by means of a lever or otherwise to the centre of a flat board of hard wood of the same length as the pipe, laid along the top of the pipe throughout its length, exclusive of the socket. The pipe, when subjected to this test, should be supported on a similar flat board underneath, the socket overhanging, and a layer of felt being laid between the pipe and the boards.

5. The thickness of the stoneware pipes shall not be less than one-twelfth of the internal diameter and of the fireclay pipes not less than one-tenth, and shall be uniform throughout the body of the pipe. The socket shall be made in one piece with the pipe. The cross section of the pipes at right angles to the axis shall be circle and the ends square to the axis. The pipes to be used for straight drains shall be straight longitudinally and those used for curved drains shall be segments of a circle in plan, and when laid and jointed in position shall form a drain free from any obstruction.

6. The depth of the socket should not be less than 1½ inches for all pipes under 9 inches in diameter, 2 inches for 9-inch and 12-inch pipes, and 2½ inches form all sizes over 12 inches. The internal diameter of the socket should be

sufficiently large to allow a joint of ¼-inch all round the outside of the pipe intended to enter it, so that a caulking of tarred gasket may be inserted.

7. To test the freedom, of the material of which the pipe is made, from lime, pulverize a small piece of the pipe, weigh and boil in hydrochloric acid; subsequently wash on a filter and dry, noting any loss in weight. If there is no loss in weight, then the material may be considered free from lime.

8, Stock sizes should only be used, with 4″ minimum diameter and 24″ maximum diameter.

Note—Fireclay pipes, though less brittle than stonepare pipes, are not considered, thicknes for thickness as strong or as durable as the latter. They also usaually possess greater absorptive power ranging from 4 to 6 per cent, of their weight.

9. The following tables give the details of the diamensions of glazed stoneware pipes :—

COMPARATIVE TABLES OF STANDARDS.

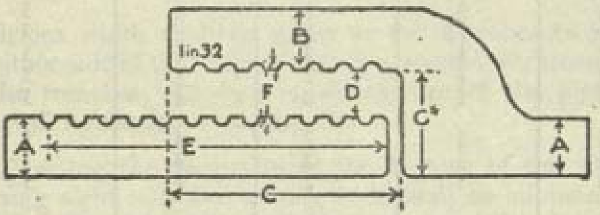


TABLE CCXIX.

BRITISH STANDARD SALT-GLAZED WARE PIPES

1	2	3	4	5	6	7
Int. dia. of pipe	Minimum mean thickness of barrel A	Minimum mean thickness of socket B	Minimum internal depth of socket C	Minimum jointing space D	Length of grooving on spigot E—12C.	Minimum depth of grooving F
ins.	ins.	ins.	ins.	in.	ins.	in.
3	7/16	7/16	2	3/16	3	1/16
4	½	½	2	¼	3	1/16
5	9/16	9/16	2¼	5/16	3⅜	1/16
6	⅝	⅝	2¼	5/16	3⅜	1/16
7	11/16	11/16	2¼	5/16	3⅜	1/16
8	11/16	11/16	2½	⅜	3¾	1/16
9	¾	¾	2½	⅜	3¾	1/16
10	13/16	13/16	2¾	⅜	4⅛	1/16
12	1	1	2¾	⅜	4⅛	1/16
13	1 1/16	1 1/16	3	½	4½	1/16
14	1 3/16	1 3/16	3	½	4½	1/16
15	1¼	1¼	3	½	4½	1/16
18	1½	1½	3	½	4½	1/16
21	1⅝	1⅝	3¼	½	4⅞	1/16
24	1¾	1¾	3½	¾	5¼	1/16
27	1⅞	1⅞	3½	¾	5¼	1/16
30	2	2	3½	¾	5¼	1/16
36	2½	2½	3½	1	5¼	1/16

TABLE CCXX.

RANEEGUNGE OR JUBBULPORE STANDARD SALT-GLAZED WARE PIPES

1	2	3	4	5	6	7
Int. dia. of pipe	Minimum mean thickness of barrel A	Minimum mean thickness of socket B	Minimum internal depth of socket C	Minimum jointing space D	Length of grooving on spigot E = 1½C.	Minimum depth of grooving F
ins.	ins.	ins.	ins.	in.	ins.	in.
3	7/16	7/16	1¾	5/16	3	1/16
4	½	½	1¾	3/8	3	1/16
5	11/16	11/16	1½	7/16	3	1/16
6	5/8	5/8	2	½	3	1/16
7	¾	¾	2	½	3	1/16
8	7/8	7/8	2	½	3	1/16
9	7/8	7/8	2	½	3	1/16
10	7/8	7/8	2	½	3	1/16
12	1	1	2	½	3	1/16
..	..	..	..	..	..	..
..	..	..	..	..	..	..
15	1¼	1¼	2¼	½	3¼	1/16
18	1½	1½	2½	½	3½	1/16
21	1⅝	1⅝	2½	¾	3½	1/16
24	1½	1½	2½	¾	4½	1/16
..	..	..	..	..	..	..
..	..	..	..	..	..	..
..	..	..	..	..	..	..

TABLE CCXXI.

USEFUL PARTICULARS ABOUT PIPES IN CALCULATING FREIGHTS, STOWAGE, ETC.

All pipes are 2 feet long when laid in place.

Interior diameter of pipes in inches ..	2	3	4	6	8	9	12	15	18	21	24
Approximate weight of each pipe in pounds ..	8¾	15	20½	32	44	64	100	130	180	200	260

The pipes can be stowed inside one another when different sizes are required.

SEWER CONSTRUCTION

Specification No. 184.

1. The sewer shall be to the alignment and gradients shown on the plans and sections. The socket ends of pipes shall always face upstream of sewage flow.

2. The sewers shall run in perfectly straight lines between manholes, as shown on plans.

3. The excavation of the trench for a pipe sewer shall be commenced at the downstream end of the sewer and be continued up the gradient.

4. The length of trench to be opened at one time shall depend on its depth and the nature of the sewer and of the ground, and shall usually be so regulated as to enable the excavation to be completed about one day in advance of the pipe laying.

5. Sufficient width shall be given to the trenches to allow a space of 6" to 9" on either side of the body of the pipe, so that workmen can walk saddle-wise along the trenches, one foot on either side of the pipes. The bottom of the trench will be flat from side to side.

6. In obtaining the formation of the bottom of the trenches the usual method of using sight rails and boning rods shall be adopted during the hole of the process. The sight rails shall be fixed at suitable intervals, which may not be more than 50 feet apart, before the excavation is begun. The excavation shall be boned in, at least once in every 6 feet, the foot of the boning rod being set on a block of wood of the exact thickness of the material of the pipes.

7. Under each socket, a spud of earth shall be taken out, into which the socket drops, so that the belly of the pipe beds firmly on the ground. This also will give the jointer more room to make the cement fillet joints properly.

8. When laying pipe sewers in rock, it will be necessary to support the pipes along the whole of their length by being packed with sand or other suitable fine material which will fill in the spaces that will exist between the underside of the pipes and the uneven surfuce of the rock.

In soft or bad ground, in a trench over 15 feet deep or in a very shallow trench under heavy traffic, where the depth of invert below ground surface does not exceed 4 feet, a bed of concrete 6 inches thick shall first be laid, and the pipes subsequently surrounded with 6" of concrete.

9. When trenches are deep and in bad ground, their sides shall be supported by suitable timbering.

10. Near heavy or important buildings, the sides of the trenches when not in rock, shall be closely and securely timbered, and if any settlement of the buildings is to be anticipated, the timbering shall be left in the ground after being measured and recorded.

11. The trenches shall not be filled in until the joints have been tested and the alignment examined and passed by the Engineer in charge.

12. The utmost care shall be taken in refilling the trenches so that no damage may be done to the sewers. The first foot of filling material, immediately over and round every sewer, shall consist of the finest selected material, and unless of fine soft material, shall be lowered into the trench by pails or skips. No lump shall be put round the sewer or thrown into the trenches until the sewer has been protected in the manner described above. The remainder of the filling material shall be put in layers not exceeding 6 inches at a time.

13. In excavating trenches, the road metalling, pavement, turf, etc., forming the surface covering shall be placed on one side and preserved for reinstatement, while the sub-soil shall be kept on the opposite side of the trench. The trench shall be filled up and thoroughly consolidated before the top material is replaced. Live fences, trees, etc., shall be tunnelled under.

14. As each trench is filled, the surplus earth shalll at once be removed after making a suitable allowance for settlement and the surface properly restored.

15. The trench shall be kept free from water or sewage.

16. All pipes and water mains, etc., met with in the course of excavation shall be carefully protected and supported. Mains are usually hung from timbers placed across the top of the trench. All water service pipes shall cross the sewer trench at a higher level than the sewer.

17. The alignment and gradient of each pipe shall be checked by means of boning rod and sight rail, and the regularity of the invert tested by means of a straight edge.

18. **Preparation of pipes.**—The pipes before being laid shall be thoroughly cleaned specially at the inside of the pipes. Cracked pipes shall altogether be rejected, whether at the socket or in the body.

19. All the pipe joints shall be caulked with tarred-gasket in one length for each joint, and sufficiently long to entirely surround the spigot end of the pipe ; the gasket to be driven, as far as possible, into the joint by means of a suitable instrument. After the joint has been thoroughly cleaned and moistened, neat cement is to be forced into it until the whole space around the spigot, between it and the socket, is full, the cement being splayed off to form a neat fillet round the pipe.

Note.—The cement may require to be previously air-slaked, so that there may be no risk of cracking the pipe sockets.

20. Y-junction pipes for house connections shall be inserted where required, the branch being canted up above the horizontal at the angle corresponding to the gradient of the house connection.

21. After an interval of several days has been allowed for the joints to set and before filling the trench, the joints of pipes and drains shall be proved watertight by filling the pipes with water to the level of 6 feet above the top of the highest pipe in the length to be tested, closing the ends of the sections and maintaining this water level for the period of one hour, or such further time as may be directed.

The water test is made by inserting a plug at the lower end of each length and a right-angled bend at the top, brought into position and made tight with

clay. After the air bubbles have escaped after first filling, water is again added to completely fill the pipe. If the water level does not fall more than ½ an inch in a length of 300 feet, the joints may be regarded as satisfactory.

PLUMBING WORK

Drawings, etc.

General floor plans and elevations shall be prepared showing the positions of the fixtures and the arrangement of all plumbing work. The scale for these plans shall be one-fourth of an inch to the foot where possible and never smaller than one-eighth of an inch to the foot.

Details, wherever required, showing the plumbing work in plan, elevation or section shall be shown on a larger scale, as one-half inch to the foot, or one inch to the foot.

The work to be done shall be accurately described in a typewritten or printed specification.

On the completion of the work these plans shall be corrected, if necessary, or redrawn so as to show clearly all work as executed. In the case of a hospital or public building they shall be framed and hung in the office. Otherwise they shall be filed for reference.

House drainage and sanitary fittings.

MATERIAL

Specification No. 185

1. **Cast iron pipes and fittings.**—All cast iron pipes and fittings shall be truly cylindrical, of the clear internal diameter specified, of a uniform thickness smooth and with strong and deep sockets free from flaws, air bubbles, cracks, sand-holes and other defects. They shall not be brittle but shall allow of ready cutting, chipping or drilling.

2. For underground use the thickness and weight of cast-iron pipes shall not be less than those shown in the following table :—

Internal dismeter	Thickness of metal not less than	Weight per 6 ft. length (including socket and beaded spigot or flanges, the socket not than ⅜″ thick) not less than
		lb.
3″	5/16′	110
4″	3/8″	160
5″	3/8″	190
6″	3/8″	230

3. Where used aboveground the thickness and weight shall be :—

Internal diameter	Thickness of metal not less than	Weight per 6 ft length (including socket and beaded spigot or flanges, the socket not less than ¼" thick) not less than
		lb.
3½"	3/16"	48
4"	3/16"	54
5"	¼"	69
6"	¼"	84

4. All cast-iron pipes and fittings shall be treated with two coats of Angus Smith's composition or the Bower-Barff process or Macfarlaine's glass enamel or other approved means of preventing oxidation before being used.

5. **Wrought iron and steel-pipes.**—Wrought iron or steel pipes shall not be used for carrying the discharge from water-closets, urinals or slop sinks.

All wrought iron and steel pipes shall be of the best quality, with heavy shoulders and smooth interior water-way screw-jointed and either galvanized or otherwise suitably coated. The weight shall not beless than the following :—

1½" pipe	.. ..	2·68 lb. per foot.
2" ,,	.. ..	3·61 ,,
3" ,,	.. ..	7·54 ,,
4" ,,	.. ..	10·66 ,,
5" ,,	.. ..	14·50 ,,
6" ,,	.. ..	18·76 ,,

The threads of traps and fittings shall be tapped so as to give a uniform fall to the branches of one-fourth inch to the foot for pipes four inches or larger in size, and of one-half inch for smaller sizes.

In the wards and work-rooms of hospitals all pipes of iron or steel shall either be porcelain or vitreous enamelled or shall be left rough and receive, after fitting, two coats of approved enamel paint.

6. **Brass pipe.**—All brass pipe shall be thoroughly annealed seamless drawn brass tubing of standard iron pipe gauge. Its weight shall average as follows :—

1½" pipe	.. ..	2·84 lb. per foot.
2" ,,	.. ..	3·82 ,,
3" ,,	.. ..	7·92 ,,
4" ,,	.. ..	11·29 ,,

7. **Brass soldering ferrules or flanged thimbles.**—All soldering ferrules shall be of heavy cast or drawn brass or else of brass pipe of iron pipe size.

8. **Brass flange and sockets.**—For the connection of all stoneware water-closets with the soil pipe extra heavy brass flanged pipes or socketed pipes, as necessary, shall be used.

9. **Brass clean-outs.**—All clean-outs in the drainage system shall be closed with brass (not iron) screw caps. All brass screw caps shall be extra heavy and not less than 1/8" thick, and shall have a flange of not less than 3/16" in thickness. Each screw cap shall have a solid square or hexagonal nut not less than 1" high, with a minimum diameter of 1½". The body of the clean-hot ferrule shall at least equal in weight and thickness the caulking ferrule for the same size of pipe. The engaging parts of the screw cap shall not have less than six threads and shall be of iron pipe size and tapered.

10. **Brass floor flanges.**—Where specified extra heavy brass floor flanges shall be used.

11. **Copper flashings.**—Copper flashings and copper tubing for the inside connections of rain water down pipes shall be seamless drawn tubing, not less than 18 gauge.

12. **Lead pipe.**—Soil waste, and vent pipes. Lead pipe shall be used only for short branch soil, waste or vent connections. All such lead pipe shall be the best quality drawn pipe and shall weigh not less than—

1¼" pipe	2½ lb. per foot.
1½" "	3 "
2" "	5 "
3" "	6 "
3½" "	6·5 "
4" "	7·4 "
5" "	9·2 "
6" "	11 "

13. **Lead flashings.**—Sheet lead for flashings shall be of at least 6 lb weight per square foot.

14. **Traps.**—Lead traps shall be of the same weight and thickness as specified for lead pipes.

Brass traps shall be of heavy brass and made particularly smooth on the inside. They shall have all waste and vent connections screwed.

Stoneware traps shall be used for water-closets, urinals and slop sinks.

Iron traps shall correspond in weight to the extra heavy cast-iron pipes specified. The iron traps for house drains shall be provided with two clean-out openings closed with brass screw caps at least 2" in diameter. Cast iron trap standards may be used for slop sinks if procelain lined or enamelled on the inside. They shall be provided with a 2" brass screw cap inside of trap.

15. **Flushing pipes.**—Flush pipes connecting the flushing cisterns with the water-closet, urinal and slop sink bowls may be of heavy drawn brass tubing, iron pipe size. They shall have brass ground union couplings, brass hold-fasts and (for water-closets) rubber buffers or specially made porcelain enamel or vitreous enamel pipes may be used. Neither lead nor galvanized iron flush pipes shall be used without special permission. The size of flush pipes shall be as follows :—

Height of cistern above pan ..	—	2'	4'	8'	12'
Diameter of flush pipe		2½'	2"	1½"	1¼"
Diameter of flush valve		2"	1½"	1½"	1¼"

For urinals the diameter of the flush valve shall be ⅛" smaller.

16. **Escutcheons.**—Escutcheons of sheet or cast brass, tinned or plated shall be used on all pipes which cross or pass through floors, walls, ceilings or partitions.

17. **Pipe supports.**—Supports for iron soil, waste and vent pipes shall be heavy galvanized, improved pipe hangers fastened to the walls with expansion bolts or hung from iron beams by means of pipe clamps.

Brass pipes shall be supported in brass pipe hangers or pipe hold fasts.

Pipe supports shall be secured to brick and stone walls or to marble-work, by expansion bolts, and to wood-work by large size lag screws.

No ordinary soil-pipe hooks shall be used for fastening or supporting pipes.

Vertical lead pipes where permitted shall be supported by metal tacks screwed to wood-work. Horizontal lead pipes shall be continuoulsy supported on boards and fastened by brass strips or hold-fasts, and not with hooks or nails.

18. **Wood-work.**—Exposed wood-work in connection with plumbing work shall be of well seasoned, kiln-dried, close jointed, cabinet finished wood-work.

Water-closet seats shall be strongly made and well framed guaranteed not to warp or crack or open in the joints, and shall have a highly polished surface.

Note.—Wood-work must receive proper attention by keeping it well varnished or polished so as not to expose the grain to water.

19. **Marble.**—Marble shall not be used for floor drains, or in urinals for patients or the public or in kitchen, scullery or pantry sinks in any position in which it is liable to absorb urine or any foul waste. Marble, where specified, shall be first quality blue venied Italian marble, free from stains or defects.

All marble-work shall be sharply moulded and shall be well fitted and perfectly set. All exposed surfaces and edges shall be well polished.

20. **Slate.**—Slate used in connection with plumbing shall be best quality hard slate, of homogeneous texture, free from any green spots or other defects, and shall be polished by rubbing with linseed oil. Thicknesses shall be the same as for marble.

21. **Thickness of marble or slate:**—

Wash basin slabs up to 2′ 9″ long	1½″	finished.
Wash basin slabs up to 5′ „ ..	1½″	Do.
Wash basin slabs longer than 5′ ..	2″	Do.
Backs and ends for basins up to 5′ ..	7/8″	Do.
Backs and ends for longer than 5′ ..	1″	Do.
Aprons	7/8″	Do.
Narrow floor slabs under water closets	1¼″	Do.
Wide floor slabs counter sunk do ..	1½″	Do.
Platforms for urinals	1½″ to 2″	Do.
Do. for spray bath stall ..	2″ to 3″	do. according to pitch.
Drain-boards according to span ..	1½″ to 2″	finished.
Partitions against walls	1″	finished.
Free partitions	1⅛″ to 1½″	Do.

22. **Lead for caulking.**—The lead used for caulking joints of cast iron soil pipes shall be pure soft pig or bar lead free from all impurities.

23. **Work.**—All work shall be executed in a thorough and workman like manner.

24. **Joints.**—Joints in cast-iron pipes and fittings shall be caulked joints, made with a gasket of hemp, or oakum, and molten lead. The amount of lead in each joint shall be not less than the following :—

Weights of lead and gasket for pipe joints

Diameter of pipe	Lead	Gasket
Inches.	Lbs.	Lbs.
2	2·5	0·125
3	3·5	0·170
4	4·5	0·170
6	6·5	0·200
8	9·0	0·200
10	13·0	0·250
12	15·0	0·250
14	18·0	0·375
16	22·0	0·500
18	26·0	0·500
20	33·0	0·625

All joints shall be made perfectly air and watertight.

Joints between iron and vitrified pipe shall be made with pure neat cement mortar.

Joints of wrought iron pipes and fittings shall be screwed joints, with threads of standard gauge. All cut ends of pipe shall have the burr removed. Screw joints shall be made up with a thick paste of white and red lead mixed.

Joints of brass pipes and fittings shall be screw joints. The pipe shall be screwed up to the shoulder of the fitting and in all exposed or plated work no threads must show beyond. No slip joints or couplings in brass pipes, excepting flush pipes shall be permitted. All threads on brass pipes shall be the same as iron pipe threads.

Joints of lead pipes (whether for supply, soil, waste or vent) shall be solder wiped joints.

Joints beween lead and brass shall be wiped joints.

Joints between lead pipe and wrought iron pipe fittings shall be made with heavy brass soldering ferrules, screwed to the iron pipe fittings.

Joints between lead pipe and cast-iron pipes shall be made with heavy brass soldering ferrules or flanged thimbles. The ferrule or thimble will be passed over the end of the lead pipe and securely soldered thereto as at its upper end while at the other end the lead is well dressed over it. It will then be inserted in the socket and caulked with lead in the usual manner.

Where it is required to join lead pipes to the spigot end of iron pipes of fittings, the joints shall be made with brass sockets. The socket shall be caulked to the iron pipe and jointed to the lead pipe by a solder wiped joint.

Where the cast iron pipe or fitting is flanged, heavy brass floor flanges shall be used and bolted to the flange. The floor flange shall be jointed to the lead pipe by a solder wiped joint.

Joints between lead pipes and stoneware traps and pipes shall be made by one of the first two methods specified for jointing lead and cast iron except that the joint between brass and stoneware shall be made with neat cement.

25. **Pipe supports.**—Drainage pipes shall be supported and held in place by the supports specified above.

All pipes shall be so supported that they are held 2″ from the wall to permit of painting, inspection of the joints and cleaning.

Lead pipes shall not be fixed with iron hooks.

Where pipes with ears are used, they should be blocked off at least 1″ from the wall by short pieces of iron pieces.

26. **Manner of running pipes.**—Horizontal drain and waste pipes shall be carried with a minimum fall of ½″ per foot for pipes 4″ diameter and smaller, pipes larger than 4″ shall have a fall of at least ¼″ per foot.

Drain lines shall be laid true to grade and alignment.

Changes in direction shall be made with curved fittings or bends having a long sweep or with Y branches and ⅛ bends. All junctions shall be made with Y branches.

All vertical soil, waste, and vent pipe stacks shall be arranged as direct and straight as possible. They shall stand free from the walls as specified above and at an even distance from the walls.

27. **Traps.**—All traps shall be set perfectly true and level. No fixture shall have more than one trap. The trapped waste from a fixture shall not connect with the inlet or house side of the trap of an adjoining fixture.

28. **Roof joints.**—Where plumber's pipes pass through the roof, water-tight roof joints shall be made round the pipes by means of heavy sheet-copper or sheet-lead flashings with funnels slipped over the pipes.

29. **Floor joints of water-closets and slop-sinks.**—Floor joints of stoneware water-closets having the trap above the floor and of slop-sink trap standards shall be made with brass floor plates. The lead bends connecting the outlets of the fixtures with the soil pipes shall be securely soldered to the brass floor plates, and the fixtures shall be firmly set on the plates, and a plastic composition used to tighten the joint (no rubber washers for floor joints shall be permitted.)

30. **Floor and ceiling joints.**—Wherever plumbers' pipes pass through floors, ceilings, walls, or partitions. the pipes shall be enclosed in short sleeve pipes, where necessary to prevent damage to palster, etc. The holes and air channels shall be properly closed and the pipes provided with escutcheons.

N. B.—In hospitals the floor shall be kept as free from encumbrances as possible. Plumbers pipes shall not be taken through the floors when they can be taken through walls. Fixtures which leave the floors free shall be selected when suitable ones are available.

31. **Arrangements of drainage system—house drains.**—House drains shall connect with the lateral sewers at a point not less than 8 feet outside

the walls of the building. Where the drain passes through the wall, a relieving arch shall be built over it to prevent breakage in case of settlement. House drains shall be of extra heavy cast iron only.

The minimum inclination shall be $\frac{1}{4}''$ per foot; but pipes 4″ and smaller shall have a greater fall, where obtainable.

A sufficient number of brass clean-outs shall be provided, at traps, bends, junctions, etc., to permit of ready access for cleaning. These clean-outs shall be sealed with approved sealing composition when screwed up.

32. **Size of main house drain** shall be 5″ or 6″, according to the number of fixtures connected with it.

33. **House trap and fresh-air inlet.**—If the house drain is specified to be disconnected from the sewer, a suitable intercepting trap shall be provided at least 8′ and as far as possible from the building. Inlets and outlets shall be provided on one of the three methods prescribed in the Bye-laws of the London County Council, as may be specified in each case. The fresh-air inlet shall not be less than 4 inches diameter and its effective area shall be at least equal to the combined sectional area of all the drains ventilated by it at the point. It shall be located at least 15 feet from any window unless specially permitted otherwise in each case.

If, however, the house drain is specified not to be disconnected from the sewer the intercepting trap and the fresh-air inlets specified above shall be omitted. In this case there must be an inlet on the sewer within 300′ of that end of the house drain which is furthest from the sewer.

Soil and waste pipes shall always be extended the full size up to the roof and shall terminate at last 3′ above the eaves. All such pipes smaller than 4″ shall be enlarged from a point below the roof by a suitable increaser.

All soil and waste pipes shall be carried vertically upward as straight as possible. Necessary offsets on the vent extensions shall be made at an angle of at least 45° to the horizontal.

Pipe extensions above the roof shall be left fully open and protected with a copper-wire dome. They shall not be capped with either cowls, return bends, or ventilating caps.

Pipes coming through extension roofs or located below dormer windows shall be carried up to the higher roof whenever they would otherwise open within 25 feet from a window.

Soil and waste pipes shall have proper fittings or branches for the fixture connections.

Fittings, which shall not be used, are the short quarter bends, double hubs, the common offset fittings and bands and saddles.

Waste pipes shall be taken as directly as possible through an external wall of the building and shall discharge in the open air into a channel leading into a trapped gully grating at last 18 inches away.

For the waste from kitchen sinks efficient flushing rim gullies shall be provided.

34. **Size of soil and waste pipes.**—The diameters of soil and waste pipes shall be as follows :—

Soil pipes	4″
Main waste pipes	2″ and 3″

35. **Vent pipes.**—All vertical lines of vent pipes shall be galvanized wrought iron or steel.

If not connected with the extension of the soil pipe above the uppermost fitting they shall be extended above the roof, and if smaller than 4″ increased in diameter in the manner already specified.

All offsets on vent pipe lines shall be made at angles not less than 45° to the horizontal. All vent pipe lines shall, if possible, be drained at the bottom by connection with the soil or waste pipe, or the drain, to prevent rust accumulation. If the vent pipe cannot conveniently be connected with the soil or waste pipe above ground, a rush pocket of suitable design shall be provided at its foot.

The sizes of vent pipes shall be as follows :—

For water-closets	3″
For other fixtures	2″

36. **Branch soil and waste pipes.**—Short branch soil and waste pipes may be of heavy lead ; long lateral pipes shall be of extra heavy cast iron or galvanized wrought iron. Exposed branches at fixtures may be of brass pipe.

The sizes of branch soil and waste pipes shall be as follows :—

	Inches.
For each water-closet	4
For each slop sink	3
Do. urinal	2
Do. spray bath	3
Do. portable bath	3
For bath tubs	2
For kitchen pantry and scullery sinks	2
For laundry tubs	2
For wash basins	1½

Note.—When branch soil and waste pipes receive a number of fiixtures, their sizes may be increased in proportion as specified..

37. **Branch vent pipes.**—Branch vent pipes, where used, shall be of the following sizes :—

For each water-closet or slop sink	2″
For other fixtures	1½″

Note.—When branch vent pipes serve a number of fixtures, their sizes shall be increased in proportion to the number as specified.

When branch vent pipes are connected with soil or waste pipes the connection shall be at a point above the overflow of all connecting fixtures.

Branch vent pipe lines shall be laid, where possible, at an angle of at least 45° to the horizontal.

No soil, waste or vent pipe shall be used to carry roof water. No rain-water pipe shall be used as a soil or waste pipe.

38. **Overflow pipes** shall discharge into the trap between the seal and the fixture or into the open air. In the latter case it shall be finished with a copper or brass hinged flap valve at its outer end.

39. **Traps.**—No trap shall be placed at the foot of any vertical line of soil or waste pipe.

Each fixtures shall be separately tapped.

Masons or cesspool traps, pot, bottle or drum traps, and D traps are not permitted. Traps depending on interior partitions of metal for a seal shall not be used.

40. **Ventilation of traps.**—Wherever the traps under fixtures have only the ordinary water seal of 1½" in depth and are not non-siphoning they shall be protected from siphonage by vent pipes of the sizes specified. Such vent pipe shall be connected with the arm of the trap at a point not less than 3 and not more than 12" from the highest part of the trap and on that side of the water seal which is nearest to the soil pipe.

The connection with the soil pipe shall be made in the direction of the flow in such a manner that the discharge shall not tend to enter the vent pipe.

Non-siphoning traps may be used under basins, tubs and sinks (not slop sinks).

Wherever non-siphoning traps are used vent pipes may be omitted, except where the length of the branch waste pipe exceeds 5 feet before entering the vented line, or where more than one fixture is connected to an unvented branch pipe.

41. **Sizes of traps.**—The sizes of traps for fixtures shall be as follows :—

	Inches.
For water-closets	3½—4
For slop sinks	3
For kitchen or scullery sinks..	2
For wash tubs	2
For urinals	2
For wash basins and pantry sink	1½

42. **Safe wastes.**—Where a lead or other safe is fixed under any sanitary fixture, it shall be provided with a 1¼" diameter galvanized wrought iron screw-jointed waste pipe discharging into the open air and finished with a copper or brass hinged flap valve on the outside.

43. **Floor drains.**—Where floor drains are provided inwards they shall discharge into special waste pipes and the outlet shall be provided with a copper or brass hinged valve on the outside.

Floor channels which are sometimes provided to take the discharge of urinals must be properly trapped and connected with the soil pipe.

44. **Rain-water down pipes.**—If a separate underground drainage system is provided for surface water, the rain-water down pipes shall discharge in the open air over untrapped gullies which shall be provided with silt pits. Otherwise they shall discharge in the open air into surface drains. If these surface drains discharge into the sewers, the connections shall be made by properly trapped and ventilated gullies at a safe distance from inhabited buildings.

Inside rain-water down pipes, where provided, shall be of heavy cast iron specified for soil pipes.

Outside rain-water down pipes may be of a light section of iron, galvanized or not as approved and coated with two coats of approved paint.

FIXTURES

Specification No. 186

1. **Water closets for Europeans.**—Pan, valve and plunger closets, those hopper closets having a whirl flush, latrines and trough closets are prohibited. Washout-closets are not recommended.

Suitable types of closets are syphon jet, syphonic action, and improved wash down, the preference being given in the order named.

2. All closets shall be provided with flushing rims of the same materials and in one piece with the bowls. There shall be no embossing or decoration about any part of the closet. The closet shall be strong and its form shall be such as to have a minimum of fouling surface. A water pool of good depth and ample surface must be provided. The effective depth of seal shall not be less than 2″ and should preferably be more. The trap shall be thoroughly self-cleansing. The closets shall be made of fire-clay, stoneware, vitreous ware, or other non-absorbent material, with porcelain-enamel imperishable leadless or other durable glaze-finish. It shall have no sharp angles but on the contrary rounded corners so that every part can be easily cleaned.

3. For domestic use preference should be given to those closets, which have the trap above the floor and to those in which the connection with the soil pipe is taken direct through the external wall of the building.

In hospitals, pedestal closets shall not, except in special circumstances, be used; the soil pipe shall be taken through the external wall and the floors shall be left free. The supporting brackets shall be porcelain-enamelled or enamel painted and perfectly plain so as to be easily cleaned The corners and angles of the brackets shall, for the same reason, be rounded.

4. No closet shall be enclosed. The seat shall be of hard wood highly polished, hinged and fixed to the closet itself, if possible. In hospitals, the seat shall be non-absorbent and if possible, the front portion of the wooden seat shall be omitted and the bowl so shaped as to substitute porcelain for wood In hospitals for insane patients the closets shall be of a type without wooden seat.

5. All water-closets shall be flushed from special cisterns. The cisterns shall be efficiently covered and without appertures, in order to prevent them from acting as breeding places for mosquitoes.

6. There shall be no unprotected iron in the interior of the cistern whereby rust may be formed and strain the bowls. The cisterns shall be perfectly plain with rounded corners and free from any ornamentation, panelling or moulding. If iron cisterns are used they shall be finished internally with flawless vitreous enamel and externally with the same or two coats of approved enamel paint. Wooden cisterns shall be copperlined internally and the external surface shall either be cabinet finished and polished or be left plain and painted with two coats of approved enamel paint.

7. The flush shall be by pull except in closets for patients where it may be by pull, or seat or door action, or automatic as the officer in charge may direct. The pull may preferably be by a thin rod with as few joints as possible.

8. The overflow pipe from the cistern shall discharge into the open through an external wall. It shall not be connected with a soil or waste pipe.

9. **Water-closets for Indians.**—Water-closets for those who squat may be of two types, *viz*,. those with a pool of water to receive the faces and those without. The objection to the first type is the liability to splash. The second type without water pool is to be preferred where special cisterns for flushing each bowl are employed or where a staff of sweepers is always at hand to clean the bowl if the flush and the ablution water are not sufficient.

10. For public latrines it is specially necessary that the closets should be kept clean, The second type of pan should alone be used.

It is every where desirable and in hospitals essential that the pans should be provided with flushing rims. Automatic syphon flushes are prohibited. Special flushing cisterns should be provided, if possible, for each closet. The best form of automatic flush is by door action.

The pan is best made of stoneware, vitreous ware or other non-absorbent material. Enamelled iron will not usually stand the rough usuage in cleaning. The surface should be finished with a hard durable glaze-finish.

11. The outlet should be placed well back and the pan should be long to prevent the urine from splashing out. A raised shield is useful for this purpose but may be objectionable if the part hidden is not efficiently flushed.

12. The squatting plate, if separate from the pan, should preferably be of non-absorbent material like the pan and similarly finished. It should preferably be in one piece with the pan.

Foot rests are not to be desired unless in one piece with the squatting plate.

13. The whole closet should be embedded in lime concrete faced with $\frac{3}{4}''$ cement plaster rendered with pure cement. The squatting plate should be on floor level and not raised on a platform.

Except where otherwise specified the rules in regard to water-closets for Europeans shall apply.

14. **Urinals.**—Urinals are probably never required in hospitals or elsewhere except in large public buildings. Water-closets are more sanitary and equally convenient.

Suitable urinal fixture for Europeans are the glazed earthenware bowl with or without lip, the latter preferred. The from of fixture having the porcelain trap attached and made in one piece with the bowl is recommended It should be set low, not more than 20 inches from the floor to the top of the front of the bowl.

Stalls for urinals shall be of non-absorbent materials such as slate or hammer glass or some vitreous ware. Marble stalls shall not be used for fixtures in urinals. The platforms of stalls shall not be provided with drip or waste pipe (They should be mopped up frequently). The width of the stall shall not be less than 2′-6″. The stalls should not touch the ground but should be supported on cast iron brackets fixed about 2′-3″ above the platform.

The flushing of urinals shall be by special automatic syphon flushing tanks.

15. **Slop-sinks for hospital.**—Slop-sinks shall be strong and durable of yellow or white glazed fire-clay. They shall be provided with flushing rim and overhead flushing cisterns. The form of sink which has in addition to

the flushing rim an upward jet arrangement for washing bed pans, urine bottles etc., is recommended. Hot and cold water taps shall be provided. The flushing cisterns shall be finished as specified for ward water-closets, and shall be arranged with a chain and pull flush, on else with combination of pull and automatic flush.

Sinks for drawing water shall be roll rim porcelain sinks with porcelain or slate back and with metal guard in front to prevent damage to the glazed rim.

Cocks placed over sinks shall be fixed at such a height that the mouth of the cock shall be 16" from the floor of the sink.

16. **Baths for hospitals.**—Baths for patients shall be solid porcelain ware, or of best quality enamelled iron with roll rim, and shall not be fixed to the floor. They shall be so set as to stand everywhere entirely free from the walls at such a distance from the walls at the foot or sides as to enable the attendant to pass round them. Each bath shall be supplied with hot and cold water taps with detachable handles or keys accessible only to the attendants. A combination nozzle suitable for attaching a rubber hose and hand spray or better one of the anti-scald pattern valves should be supplied.

Portable baths shall be provided for each ward and shall be of enamelled iron set on wheels. These baths shall have a large waste outlet with gate valve. Hot and cold water supplies for filling the portable baths shall be arranged and shall be extra large to save time in filling.

17. **Lavatories.**—The outlets should be of the same size as the waste pipe and trap. Concealed overflows, which cannot be cleaned, are objectionable and preference should be given to those basins in which the overflow is accessible and can be cleaned such as the stand pipe overflow basin or those basins in which there is a large weir overflow provided in the porcelain which can be readily cleaned. The basin should be kept entirely open and accessible underneath. Solid porcelain lavatories are recommended in preference to marble washstands as being non-absorbent and not easily stained and the objectionable plaster of Paris joint is done away with.

Wash basins for patients shall be either of enamelled iron or of glazed fire clay, stone ware, or otherwise non-absorbent material. The bowls shall be plain bowls with chain and plug waste and overflow pipe or else with a gate valve on the waste pipe in place of the plug. All basins shall be supplied with hot and cold water through approved type of taps ; combination faucets in which it is impossible to turn on the hot water first, may also be used.

Wash basins for operating rooms shall be of glazed white fire clay, the slab and bowl being moulded in one piece, or else of annealed glass the slab and bowl being both of glass, but in separate pieces. Such basins shall always have hot and cold supplies and shall preferably be supplied through a single spout or nozzle discharging either hot or cold or mixed water as a stream or spray at will. The valves on the hot and cold supplies may be operated by foot or pedal action or by knee action or by elbow action ; of these elbow action is the simplest and therefore to be recommended.

18. **Kitchen, pantry, scullery and lavatory sinks.**—These sinks shall be either of plain or galvanized cast iron or else of strong glazed earthenware. Wooden sinks are prohibited. Sinks shall be provided with drain boards which may be of wood or slate and supported on galvanized iron frames or cantilever brackets Marble drain boards shall not be used.

19. **Grease traps.**—Dish washing sinks shall be provided with grease traps. Grease traps shall be preferably set outside the building. If attached to the sink they shall be so arranged that they can be readily cleaned.

20. **Floor Channels.**—Lavatories, sinks and other fixtures in operation rooms, in the rooms subsidiary to operation rooms, in labour wards, and in *post-mortem* rooms shall discharge by untrapped wastes into floor channels.

It is desirable also that lavatories, sinks, baths and other similar fixtures in connection with wards or outpatient departments should similarly discharged by untrapped wastes into floor channels.

All such floor channels shall, on section, be semicircular and 3" radius. A fall of 3/16" in 1' shall be given to all such channels. The floor material shall be benched over the top of the channels on both sides.

When several fixtures discharge into one channel the shoe of the highest down pipe shall be 3"-4" from the invert line and the shoe of the next fixture at least 1" from the invert line.

The head of the floor channel shall be rounded and shall be approximately 10" from the shoe of down pipe of the highest fixture.

All floor channels shall ordinarily be placed vertically underneath the waste from the fitting to be served. If for any reason this be impossible, a down pipe with suitable offset shall be obtained from the manufacturer. In no case shall lead wastes be fitted to lavatories discharging into floor channels.

All lavatories etc., which discharge into open channels, shall be fixed at the height designed by the manufacturer. If any a alteration in height be needed in the case of any fitting a new down pipe of the requisite length and shape must be obtained from manufacturer.

21. **Bedpan arrangements.**—In every room containing a bedpan sink shall be provided a bedpan safe which shall take the form of a cupboard of suitable size occupying the whole thickness of the wall. The front of the cupboard, which shall be in the room, shall consist of a metal or metal lined door fitting as lighly as possible. The back of the cupboard which shall be open to the outside air shall be formed of wire gauze or webbing sufficiently small to exclude flies etc., The inside of such cupboard shall be lined with glazed tiles or with other impervious material. It shall have shelves of glass, slate, galvanized iron or other impervious material placed at suitable distance from one another. If possible the safe shall be placed in a north wall of the sanitary annex, if placed in a wall facing in any other direction it should have, in addition to the gauze or webbing, either a bonnet or louvres to exclude the rays of the sun. All metal work should be painted with enamel paint.

Shelves of impervious material should also be provided in the bedpan room for clean bedpans unless the safe is large enough to store both clean bedpans and those reserved for clinical inspection.

22. **Anti-malarial measures.**—All traps, tanks, etc., in connection with sanitary fixtures, sewerage, or water supply shall, as for as possible, be protected so that they may not form breeding grounds for mosquitoes. This is of special importance in the case of hospital.

Every tank for water supply shall be provided with a mosquito proof cover of a pattern to be approved by the Sanitary Engineer.

All flush tanks shall either have mosquito proof covers or be enclosed in wire gauze or webbing.

Where wastes discharge into an open channel outside the building, the channel shall be so constructed that it together with the ends of the wastes and gully is convered with a framework of mosquito proof wire gauze properly supported.

The wire webbing shall be galvanized iron wire webbing, about 16 wires to the lineal inch.

23. **Number of fixtures.**—It is desirable to provide—

One ward water-closet to each 12 patients.
One slop sink to each ward.
One portable bath to each ward on floor.
One or two fixed baths to each ward.
One wash basin to each 5 or 10 patients.
One lavatory to each 10 or 15 employees.
One water-closet to each 15 employees.

24. **Arrangement of fixtures.**—All plumbing fixtures shall be arranged entirely in an open manner without any enclosing wood-work. All parts of each fixture shall be kept fully exposed and accessible for cleaning , inspection and repairs.

In the wards and work rooms of hospitals all fixtures and their supports shall be designed so as to offer as little lodgment as possible for dust; scroll work decoration and all unnecessary performations shall be omitted and preference shall be given to fixtures so designed as to be easily accessible for cleaning. All wood and metal work shall, except where otherwise specified, be finished with good enamel paint which have a perfectly smooth and polish surface; the flours shall be kept as free as possible, by the adoption of fixtures supported from the wall and not on the floor; where such fixtures are unavoidably fixed to the floor they shall be affixed by brass floor flanges, etc., or in some other approved manner, but so that no crevices shall be left to collect dust or dirt; joints made with plaster of Paris or cement shall be made as small as possible and flush with the pieces joined; exposed surfaces of cement or plaster of Paris shall, where possible, be painted with enamel paint; vertical lines of piping shall be set truly vertical; lead piping of any kind whether exposed or covered up shall be avoided as much as possible.

25. **General.**—All sanitary fittings shall be placed truely and correctly on their brackets or cantilevers ; where the bracket is in several parts these should be firmly fixed together with bolts or otherwise and fitted into the walls as a whole.

All sanitary fixtures in a hospital, if not actually built into the wall, shall be carried 2″ clear of the wall.

In attaching brass cocks, or other similar fixture, to a wall lined with glazed tiles, the wooden block to carry the fixture shall be embedded in the wall in the proper situation and tiles placed over it. Holes shall then be drilled through the tiles into the wooden block in appropriate place for the necessary screws. Good quality brass screws shall be used for fixing brass work fittings. The heads of such screws should be flush with the surface of the wall attachment of the fixture.

26. **Interiors of wards and other work-rooms in hospitals.**—The floors, walls and ceilings shall consist, as far as possible, of non-absorbent materials. Tiles marble, slate, or stone slab shall be set with a perfectly even

surface. Plaster, if used, shall be hard and with an even surface and finished with enamel paint.

Walls of operation rooms and annexes shall be lined to a height of about 6′ and wards to a height of 3′ with glazed brick or glazed tiles with permanent glaze, or marble slate, polished Shahabad or Tandur stone or Portland cement as above. The angles between the floor and walls and between wall and wall, the angles of door and window openings and the angles between the frames of the same and the jambs and sill shall be rounded to a radius of 3″ and (to the same height from floor as above stated) in the interior of the ward or room. The sills shall be sloped down at an angle of about 45° to the horizontal into the ward or room.

The ceiling shall be plain and finished with enamel paint. Open roofs are not permitted and there shall be no bars or ledges which can serve as perches for birds.

27. **Doors for partitions.**—Where not otherwise specified all doors for partitions shall be light and short flap doors, not reaching lower than 10″ from the floor and not more than 5′ high. In the case of Indian water-closets the bottom of the dorrs shall be 3″ from the floor.

WATER SUPPLY

Specification No. 187.

1. **Materials—Lead supply pipes.**—Ordinarily lead pipes shall not be used for supply pipes except with special approval. When specially permitted the minimum weight shall be as follows:—

$\frac{1}{2}$″ pipes	$2\frac{1}{2}$ lb. per foot.
$\frac{3}{4}$″ „	$3\frac{1}{2}$ „
1″ „	$4\frac{1}{2}$ „
$1\frac{1}{4}$″ „	$5\frac{3}{4}$ „
$1\frac{1}{2}$″ „	7 „

2. **Valves.**—All valves on supply lines shall be best quality, heavy, straight water-way, steam metal gate valves. Valves larger than 2″ shall be of best quality iron, brass line.

Wheel handles on valves shall be detachable and made of brass.

Glob valves shall not be used on water supply lines.

All valves placed below floors shall be provided with cast iron boxes and covers so as to be accessible.

Valves on steam supplies shall be best quality soft-seat steam-glob valves with wood handles.

All valves on supply and ditributing lines, on risers and on branches, shall be provided with tinned brass tags securely attached to the valves. These tags shall be either numbered or stampped with letters. For each building triplicate typewritten or printed lists shall be prepared, giving the location, description and use of every valve either by numbers or letters, arranged for each reference. One copy shall be kept in the office of the building.

3. **Check valves.**—Check valves shall be of the best quality steam meta of the horizontal or swing pattern.

4. **Stop-cocks and compression stops.**—Ordinary ground key stop-cocks shall not be used.

All the supplies to fixtures and flushing cisterns, compression stops or else gate valves shall be used.

5. **Sill cocks.**—Steam metal or brass sill cocks for use in washing or flushing tile floors which have floor drains shall be best quality brass or steam metal, wheel handle cocks with hose nozzle.

6. **Taps.**—Taps for basins, tubs and sinks shall be best quality heavy compression or self-closing taps. They shall be either of polished steam metal or of nickelplated brass or of white metal. Hot water taps for ward fixtures of hospitals for the insane shall be arranged with detachable key handles for use by the attendants only.

7. **Supply pipes.**—All supply pipes shall be best quality, welded, galvanized wrought iron pipes. Lead pipes shall not be used for ward fixtures.

Tinned and annealed brass pipes shall not be used for the main supply system and risers and branches except in special cases.

8. **Air chambers.**—Air chambers of suitable size and dimensions shall be placed vertically on the ends of the hot and cold supply to fixtures to prevent water hammer in the pipes.

9. **Fire stand-pipes.**—Where specified all buildings shall be equipped with inside fire stand-pipes. Each building shall have from one to three lines, depending upon its size, with outlets on each floor.

The diameter of the stand-pipes shall be from 3″ to 4″ ; the material shall be extra heavy galvanized screw jointed wrought iron pipe.

The branches for inside fire-valves shall be 1½ inches and in hospitals, the out-lets shall be placed about 6½ feet from the floor line, out of reach of the patients.

10. **Fire valves.**—Fire valves shall be extra heavy brass or steam-metal fire valves of the full waterway or gate pattern. The size of fire valves for use on the fire stand-pipes shall be 1½ inches.

11. **Fire hose.**—The fire hose for inside use shall be best quality unlined linen fire hose, warranted not to leak and to stand a pressure of 400 lb. per square inch. The inside diameter of all fire hose for inside use shall be 1½″.

All inside fire hose shall be supported on hose racks in covered glass fronted boxes fixed to the walls. At each hose rack or fire valve a hose spanner shall be provided. The fire hose shall have standard couplings. At each hose rack or fire valve a brass fire nozzle shall be provided, at least 15 inches long, smooth on the inside, of standard pattern, and with either 1″ or 1⅜″ nozzle opening.

12. **Workmanship in general—joints—pipe supports—manner of running pipes—floor, wall and ceiling joints—finish.**—For these and materials generally the rules specified under house drainage shall apply.

13. **Water supply to fixtures.**—All plumbing fixtures except water-closets and urinals shall be provided with both hot and cold water.

All water supply pipes shall be kept outside of walls, partitions and floors, and be exposed to view and accessible.

The arrangement of service and distributing lines shall be as direct and compact as possible. Unnecessary duplication of supply pipes shall be avoided.

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All horizontal lines shall be so arranged that they will not cross or have any depressions. In hospitals they shall, where possible, be kept within reach so that they may be easily cleaned. Hot and cold water pipes shall not touch each other but shall be kept at least 3″ apart. The main hot water pipes shall a out of reach of patients. All branch supplies to fixtures shall be provided with air chambers with arrangements for recharging them: for this reason taps should not be fixed at the end of pipes where this can be avoided but should be taken from the side of the pipe and the pipe suitably continued so as to form a small air chamber. All branches shall have shut off valves so that any branch may be cut off for repairs without affecting the supply of the others.

All lines of supply pipes shall be so graded that they may be readily and completely emptied. Where two or more pipes run in the same direction they shall be fixed truly parallel. A sufficient number of supports shall be fixed to prevent vibration. All hot water lines shall have return circulation pipes.

14. Where the water is supplied on the intermittent system, house storage tanks must be provided. These tanks shall be made of wood or reinforced concrete or steel. Steel should be painted with approved leadless paint. Galvanized iron or lead lined tanks shall not be used. The tank should be covered and ventilated. The overflow should be on to the roof or into the open air. Emptying pipes must be provided. The drinking water should not be taken from these tanks but from special taps, served by direct pressure from the mains, of which one or more should be provided, as specified. For hospital all drinking water should be filtered. The most satisfactory filter is the Pasteur Chamberland and this must be cleaned at intervals as required.

TESTS OF PLUMBING WORKS

Specification No. 188

1. **Tests of materials.**—All material used in the work shall, as far as possible, be tested by the manufacturer before shipment.

2. **Test of rough work.**—All iron drain, soil, waste and vent pipes, including branches, lead bends and socket thimble and ferrule joints shall be tested by closing, before any fixtures are set, all openings and filling the entire system with water.

3. **Test of supply pipes.**—All supply pipes shall be tested by a strong hydraulic pump, under atleast 100 lb, per square inch water pressure.

Note.—Neither the smoke test nor the peppermint test shall be accepted in lieu of the water test. No painting of the lumbing work shall be done until it has passed the water-test.

4. **Test of filters.**—All water filters shall be tested as to their capacity and efficiency.

5. **Test of hot-water.**—The apparatus for the supply of hot water shall be tested as to its capacity and proper working.

6. **Test of hot-water circulation.**—The circulation of hot water in the entire system shall be tested.

7. **Final test of plumbing system.**—Upon completion the entire work shall be tested by turning on the water at all fixtures and supply lines and regulating all flushing cisterns and ball-cocks.

The correct lettering or numbering of the brass tags on the cocks and valves shall be tested by comparing with the lists and plans.

The supply of water, both hot and cold, at all fixtures shall be properly tested.

All water-closets and urinals shall be tested, after installation, as to their flushing efficiently and operating properly and noiselessly.

8. **Acceptance of work and guarantee.**—All work shall be accepted only after all the above tests have been made and satisfactorily passed. In each case the contractor shall give a written guarantee that he will hold himself resposible for his work, and will make good any defect discovered, for the space of one year, provided such defects are due to imperfections in material or workmanship, or both.

INSTRUCTIONS FOR THE PREPARATION OF DRAINAGE PROJECTS

1. **The general plan.**—For the design of a drainage scheme it is necessary to have a map drawn to such a scale as will enable the levels of existing roads drains, and the positions of public and other important buildings to be shown without undue crowding.

The smallest scale to which such a plan can be drawn with clearness is 330 feet to 1 inch. The scale generally used is 200 feet to 1 inch.

As a rule, an existing plan of the municipality will be avaiable, and it will be sufficient to use such a plan as a basis to work on, and to bring it up to date by the addition of new roads, buildings and municipal boudaries.

Should there be no existing plan to work on, a traverse survey wil have to be made.

The position of all important or public buildings should be shown, as well as all roads and existing pucca and kutcha drains. The portions of the municipality which are thickly populated, sparsely populated, and rural respectively should be marked.

2. **Levelling.**—In the preliminary levelling operations it is generally found most convenient to split up the municipal area into three or for divisions and to run circuits of fly-levels round each of them, fixing permanent bench marks at intervals of about a ½ mile. These permanent bench marks will be found useful during the detailed levelling operations. The permissible error is ·05 feet per mile.

3. **Detail levelling.**—When taking detail levels, readings on the staff should be taken to hundredths of a foot :—

(1) At the summits and lowest points and at intervals of 200 feet along the centres of all roads.

(2) At intervals of 100 feet on the beds of all pucca drains and 200 feet for the more important earthen drains.

(3) At intervals of every 400 feet (should the ground allow of it) readings should be taken at 200 feet and 400 feet to the right and left of the line of section and at right angles to it.

(4) When observing the level of the centres of roads, should the ground level, at the roadside, differ by more than 9 inches from the level of the centre of the road, the ground level on both sides should be observed.

(5) The level of the floor of every culvert should be taken as well as the width of the opening, the height to springing level, the road or formation level, and the rail level in the cases of railway culverts, the form of roadway support (either arched or flat) and the actual condition of the structure. It is desirable to make sketch of every culvert giving dimensions of every part.

(6) All existing drainage lines or channels should be carefully surveyed and levelled over and cross sections taken, showing bed and top widths and height to ground, should the channel be well defined.

(7) The highest flood level and the ordinary flood and bed levels of all streams, nallas, tanks, swamps, etc., met with should be ascertained from authoritative sources and noted in the level book.

(8) The slope at which the sides of earthern drains stand should be observed and noted. Trial pits should be taken where possible.

(9) With a view to the disposal of house sullage, a very important part of any drainage scheme, it is necessary to obtain the level of plinths and court-yards of detached houses as well as that of drains leading to cess-pits attached to houses. In dense bazar areas general levels of the area should be taken dividing it up into suitable groups.

(10) The surveyor should not be content with examining the fronts of the houses ; it is generally at the back of the houses that the sullage nuisance makes itself evident.

A note should be made of the existing method for disposal of sullage.

At the same time as the detail levelling operations are in progress, the surveyor should chain along the centre line of roads, carefully noting the position of the points of intersections with the centre lines of other roads as well as the road widths, and also the width of roadside land in order to estimate the area of land (if any) to be acquired. Complicated crossings of roads are best shown by dimensioned hand sketches shown in the level book. The levels should now be plotted on the general plan, the road levels being shown in red, the ground levels in burnt sienna, and the bed levels of drains in blue.

4. **Contours.**—The general plan is now ready for contouring. The contour lines should generally be not less than ½″ nor more than 3″ apart on a 330 feet to the inch plan, but no hard and fast rule is possible, as this depends on the nature of the country being surveyed. The contour lines should be dotted lines.

All elevations should be marked.

The watersheds or block boundaries will be apparent from the contours, and the surveyors will be in a position to roughly fix the direction of flow of the drains, and the position of the outfalls.

Try to run the main drains along the valley lines, and at right angles to the contours, with subsidiaries flowing along the contour lines.

The arrangements of the main drains and outfalls, being a matter of great importance, needs careful examination by the Executive Engineer. It is important that the next stage of preparation should not be proceeded with until he has scrutinized and approved the proposed arrangement.

5. **Index plan.**—This plan is prepared by tracing from the general plan. It shows the boundaries of the drainage blocks and the lines of proposed drains. In the case of roadside drains the operation resolves itself into tracing the road boundaries.

Culverts which are necessitated by a drain crossing a road, are shown by line drawn across the road.

The starting point of any drain should be shown by a dot, and the direction of flow of the drains given by arrow marks.

No levels are to be shown on this plan.

Every drain should be given a number, commencing the numbering from the outfall upwards.

6. **Area plan.**—This plan shows the area served by each drain. It is a tracing of the general plan showing the watershed lines or block boundaries and the roads.

The areas should be noted in acres to two places of decimals.

7. **Longitudinal sections.**—These are to be plotted from the level books. It is most convenient to plot drain by drain and not road by road.

8. **Scale.**—The horizontal scale should, wherever possible, be the same as that to which the general plan is plotted. The vertical scale of 10 feet to the inch is convenient, except in hilly country when a smaller scale may be necessary.

9. The following items are to be shown on the longitudinal section :—

(1) Road levels.

(2) Ground levels and bed levels of existing drains.

(3) Water level of proposed drains.

(4) Invert levels of proposed drains.

(5) Datum level accurately described.

(6) Gradients of proposed drains.

(7) Numb and type of section of proposed drains.

(8) Referen etters against any points requiring identification, corrrespo g to reference letters given on the index plan.

(9) Continuou hainage of drain.

(10) Drain num rs corresponding with the index plan.

(11) The position of culverts.

(12) At the junction points of drains a reference is to be made to the number water level, and level of the invert of the drain which receives or is received.

(13) A reference should be made at any special point, for instance, at a fall or overflow chamber stating the number of sheet on which the enlarged drawing of the work at the special point is shown.

(14) The widths of roadside land should be noted.

(15) The top widths of drains, *i.e.*, the width of the land the drains occupy, including the slopes in cases where the sides are to be ramped.

10. **Statements.**—Tabular statements are to be compiled drain by drain to determine the sizes of the drains required to carry off the discharges from the different areas.

They should show :—

(1) The number of the drain and the block in which it is situated.

(2) The name and side of the road along which the drain runs.

(3) The number of sheet upon which the longitudinal section is shown.

(4) The reference to the longitudinal section by chainage.

(5) The reference to the index plan by letters.

(6) The additional and total areas to be drained in acres.

(7) The length of drain in feet.

(8) The grade, 1 in—
(9) The number and type of section of drain or culvert.
(10) The required discharge in cusecs.
(11) The full discharge of the drain in cusecs.
(12) The maximum velocity at the required discharge.
(13) The velocity flowing $\frac{1}{3}$rd, (or any other fraction determined upon) full.
(14) The cusecs of flushing water required to produce a velocity of $2\frac{1}{2}$ feet per second.
(15) A column of remarks.

11. **Estimates.**—From the statement forms, an abstract should be made of the total lengths of the various types of drains and culverts. The cost of the various types of drains and culverts per foot run should then be determined. The final estimate should be made out, block by block, for drains, flushing works, outfall works, special works, and land acquisition.

The cost of the whole scheme is shown by adding up the cost of all the blocks plus a percentage to allow for engineering supervision and contingencies.

SANITATION

1. **Requirements of healthy sites for buildings.**—These are dryness, warmth, light and air, and, as a rule, dryness and warmth go together, as do light and air. The site should be moderately elevated, with the ground falling way from it on all sides and not so shut in by trees, etc., as to impede the free circulation of air and the access of sunlight round and over it.

2. **The dryness of a site.**—Is mainly dependant upon the facility with which rain can pass off or through the soil, and the distance from the surface of the sub-soil water. Flat and nonporous land, or land which, though porous, has an impervious stratum immediately underneath, must be damp, and therefore not desirable as a building site.

3. **Suitability of soils.**—Impermeable rocks, as regards dryness, are healthy, as the water readily runs off them, but in country districts the difficulty of obtaining water in many cases militates against such sites. The best soil is gravel or sand. Chalk soil is dry and healthy ; so is sandstone, provided it is of considerable depth and uninterrupted by clay.

4. **Clay and marl.**—But especially the former, are damp, and unless thoroughly drained are not desirable for building sites. Damp surroundings are likely to cause phthisis and other lung diseases, as well as rheumatism, neuralgia, and throat affections.

5. **Marshy land.**—And all soils which contain much vegetation or animal matter are unhealthy.

6. **Made soils.**—Or artificial sites prepared by shooting rubbish and other objectionable matter into pits, ought to be shunned, owing to the amount of organic matter they are likely to contain, which will exist in a state of putrefaction for years, and render the air surrounding the house impure. If, however, there is no other available site for necessary buildings, than such a made soil, it should be carefully drained, and the whole of the ground covered by the buildings carefully protected by an air proof basement of concrete.

7. **The ground air.**—*i.e.*, the air which is intermixed with the soil from its surface down to the level of the sub-soil or ground water—is continually being discharged into the atmosphere, owing among other causes, to its displacement by the rainfall. This is the reason why it is important that the soil on which houses are built should, as far as possible, be free from vegetable and animal matter. To the presence of such decaying matter certain diseases are attributed ; hence the importance of guarding against any risk of pollution of the ground surrounding houses as well as their sites.

8. **Selection of site.**—In selecting a site for a building, preference must be given to one which is dry, and if there is no alternative to building on a damp site, it is imperative that it should first be drained. Attention should, in the first instance, be paid to encouraging the natural drainage, by removing obstructions that may, exist to the free flow of the nallas and water courses in the neighbourhood, and thus lowering the sub-soil water level. Then, artificial surface drains should, if found necessary, be constructed to facilitate rapid removal of rain water.

9. **Sub-soil drainage.**—The principal source of moisture in soil is rain, but it may arise from other causes, such as springs or excessive water supply and wastage of the same. It is only when the sub-soil water is in excess and becomes stagnant and is close within 10 feet of the surface of the ground, that it becomes dangerous to health.

Clay is a soil which is very retentive of moisture, and one cubic foot of moist dry clay will absorb about one gallon of water. To get rid of superfluous water, sub-soil drainage is often necessary on sanitary grounds. Sub-soil drains should not be less than four feet below ground level. The sub-soil drainage system should be graded with a fall of 1 in 100 to 1 in 200 to a point where a connection can be made with the nearest surface water drain.

Plate CXXV, figures 1, 2 and 3 show some typical sub-soil drains.

10. **Distance between sub-soil drains.**—Under similar conditions the apart should be in inverse proportion to the rainfall.

The maximum distance apart in clay soils should be 27 feet, and in bad cases the distance may have to be 21 to 24 feet apart. In strong loam 30 feet apart and in light soils 40 ft. In gravelly soils drains may be laid at greater intervals than 40 ft., but they should then be deeper than 4 ft.

11. **Position of wells.**—The position of a well which supplies water for omestic purposes must be guarded against pollution.

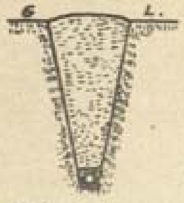
Plate CXXV, fig. 4 gives a section, in which GH is the 'line of saturation' or level to which water rises, O being a well. Under ordinary circumstances the upper surface of the water would lie along GH, and borings or levels of water in a number of surrounding wells, would show that this had a slope in some direction, this slope depending upon the head required to force the water forward through the state.

If water be withdrawn from the well, while pumping is going on, the level of the water inside the well will sink to some point EF, such that the rate of flow of water into the well due to this depression will be equal to the rate at which the water is being pumped out.

As the level sinks, the water converges towards the well from the water bearing region on all sides. It thus moves in ever narrowing circles, and therefore with an ever increasing velocity. Hence the gradient of the line

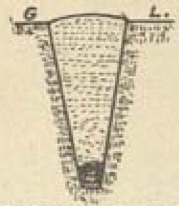
Plate CXXV.

SUBSOIL DRAINS; & CONE OF EXHAUSTION.



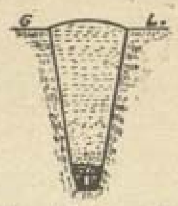
Tyle Drain covered with stones.

FIG 1



Rough stone Drain large stone at bottom smaller as it gets higher

FIG 2.



Rough stone Drain covered with stones.

FIG 3.

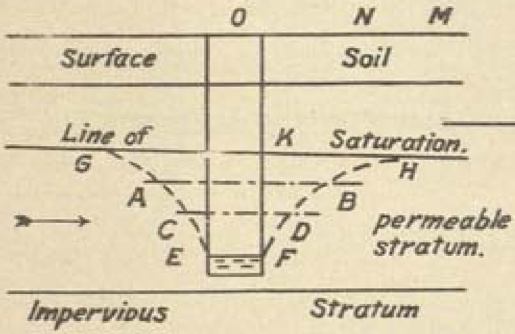
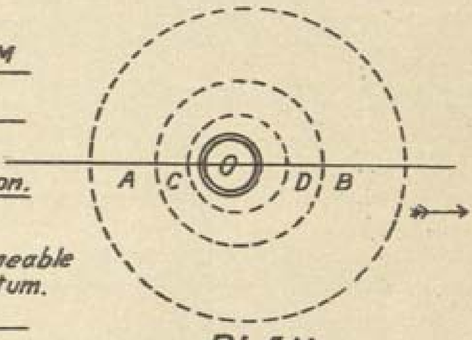


FIG 4.



PLAN

Diagram illustrating effect on the drainage cone of a well (a) of broadening it (b) of driving out lateral adits and (c) of deepening it.

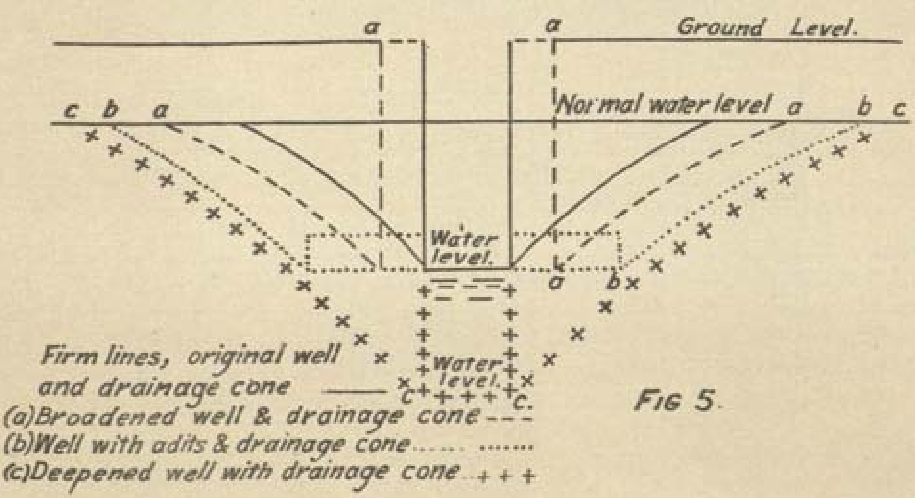


FIG 5.

ECB and FDH which represent the altered position of the line of saturation, will get steeper as these lines approach the well. Water is more or less completely withdrawn from an area roughly in the shape of an inverted cone. This is known as the cone of exhaustion, and if any source of pollution exist within this area, either above or below the well (as at N) it will affect the water drawn from the well. Pollution below the well, but outside of this area as at M, would not sensibly affect the water. Any pollution on the upstream side would affect the water, whether inside the area or not. Careful study should be made in selecting a site for such a well.

The distance, at which the artificial gradient brought about by the pumping will be apparent, depends on the nature of the material and the depth to which the water is pumped (Plate CXXV, Fig. 5). In sand the gradient may be on the a verage from 1 in 50 to 1 in 20, and in chalk as steep as 1 in 10 ; in sand-stone, lime stone, etc., the water generally runs in fissures, hence the gradient is less steep. A gradient of 1 in 10 would mean that the effect of pumping from the well would be perceptible at a distance from the well ten times as great as the difference between the sub-soil water level and the level of the water in the well

12. **Essentials of a good well**—The following are the essentials of good well :—

(1) It should be sunk in good soil.

(2) It should be lined with some impervious material, and the water should come only from the bottom.

(3) The surrounding area at the top should be so sloped as to allow water to drain off readily.

(4) It should be provided with either a pump or a bucket and chain or rope, and no other vessel should be allowed for drawing up water, as with different buckets the water is liable to pollution.

(5) It should have a parapet about 3 feet high, and a platform of cement about 5 feet all round the opening with a proper slope.

(6) The top of every well should have a suitable covering, with openings for ventilation.

(7) All hollows and foul tanks near about, should be filled up and adjoining trees cut down.

(8) No washing of clothes or bathing should be allowed on a well used for drinking purposes.

(9) It should be at a considerable distance from cess pools, privies and other collections of filth, grave-yards, etc.

13. **Aspect or orientation of building.**—Face bungalows north or N. by east in the Deccan or Guzerat and S. by W. in Sind. A west-faced bungalow in the Deccan where the site selected requires such a position, necessitates a deep verandah or the shade of large trees to protect it from the evening sun, and driving rain. In a bungalow with the principal living verandah on the south and the offices on the north , the verandah will be hot and sunny, especially when the sun is low, and it is also open to driving rain.

In Guzerat certain bungalows are faced south-west with a view to catch the breeze that blows in summer from that direction. The comfort of a breeze is

considered to outweigh the inconvenience of occasional and light driving rain into the verandah.

On the west coast a westerly aspect, facing the sea-breeze, is the best. To protect against heavy rains, monsoon tatties are fixed every year on the south and west, during the monsoon.

The prospect from the windows of sitting rooms should be good and pleasing. Herbage around a dwelling is healthy, but rank vegetation is bad.

14. **Prevention of dampness in buildings,** plate CXXVI.—In addition to the great importance of a dry building for sanitary reasons, it is also most necessary for good construction ; dampness in the masonry causes efflorescence and soon communicates itself to the woodwork and causes rot.

The walls of a building are liable to be charged with moisture—

(1) By wet rising in them from the damp earth.
(2) By rain falling upon the exterior of the walls.
(3) By water from the roofs or leaking gutters soaking into the tops of the walls.

Of these evils the first may be prevented by attention to surface and sub-soil drainage and if necessary, by the construction of dry areas or "air drains", and by the introduction of damp proof courses ; the second may be counteracted by impervious outer coatings, *e.g.*, of cement plaster or paint or by the use of hollow walls ; and the third is avoided by the use of projecting eaves with proper gutters, or where parapet walls are used, by an upper damp proof course.

In some cases, to avoid the expense of air drains, the outer surface of the portion of the wall below ground is rendered with cement, asphalted, or covered with a layer of slates or flagstones attached to the wall. Fig. 2.

Substitutes for properly built air-drains may be cheaply formed by placing flagstones in an inclined position against the outside of the wall to be protected.

Wide or open areas allow a freer circulation of air, exclude damp more thoroughly by cutting off direct contact of the wall with the wet soil, and are, on the whole, superior to air-drains. Fig. 5.

15. **Horizontal damp-proof course.**—The damp proof course should be above the surface of the external ground, and at the level of the under surface of the floor concrete. Fig. 1.

The damp proof course may be of glazed pottery slabs built into the wall. The joints between the slabs must be left empty, or the damp will rise through them.

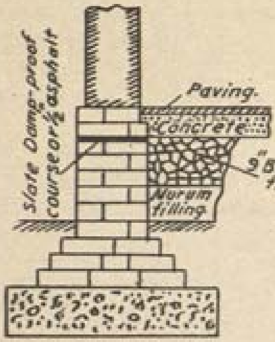
A layer of tough asphalt about ¾ inch thick is often used instead. A layer of well burnt bricks soaked in hot tar and pitch, answers to some extent, as a damp proof course, for cheaper class of buildings.

In buildings finished with a parapet wall, a damp proof course should be inserted just above the flashing of the gutter, so as to prevent the wet which falls upon the top of the parapet from soaking down into the woodwork of the roof and into the walls below.

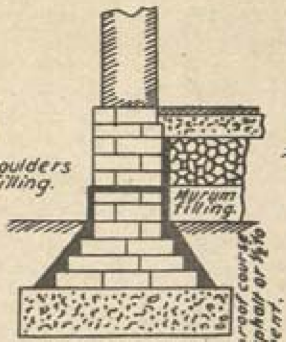
Arches over vaults are frequently rendered all over the extrados with asphal or cement to prevent the penetration of wet.

16. **Vertical damp-proof course.**—The wet may be kept out of the interior of the wall made of inferior bricks or porous stones like laterite, by

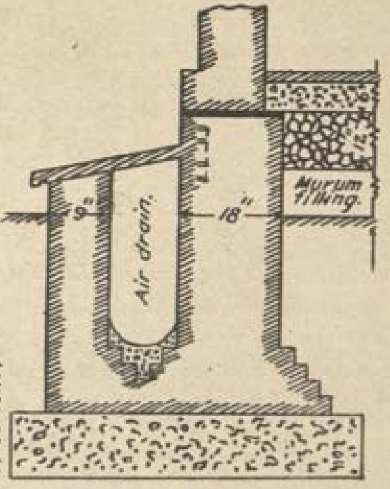
DAMP-PROOF COURSES.



1.

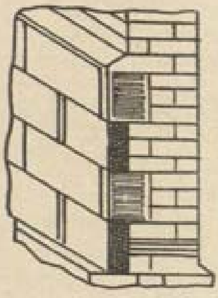


2.



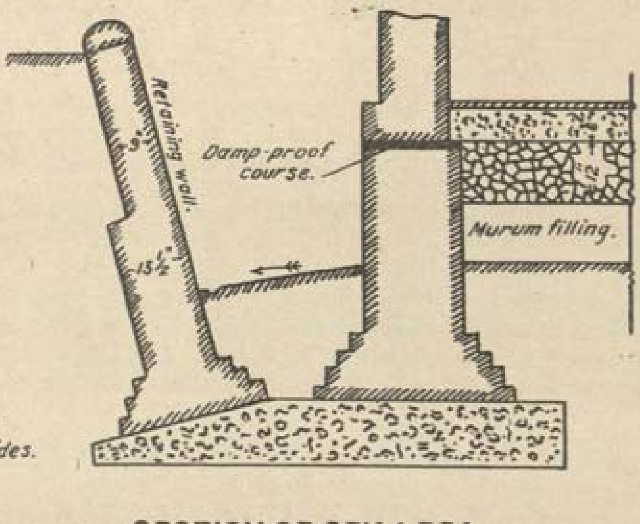
AIR DRAIN.

3.



Vitrified stone ware facing to prevent damp from the sides.

4.



SECTION OF DRY AREA.

5.

rendering the exterior surface with pure cement ¼" thick or cement plaster (1 cement, 1 sand) ⅜" to ½" thick, after raking out the joints or with glazed tiles set in cement (fig. 4) or with a mixture of pitch and tar.

Where the subsoil water is near the ground surface, and cannot be lowered by underground drainage, owing to the flatness of the ground, or any other cause, the level of the floor of the building should be kept sufficiently high to avoid dampness. The height of the plinth is given by the rule, 6 to 8 feet, according to circumstances, minus the difference of level between the ground and the subsoil water table level.

VENTILATION

1. **Necessity.**—A proper supply of pure air is a necessity to health. A person in a closed room will gradually render the air impure by breathing, that is by drawing the air into the lungs, removing oxygen from it, and exhaling carbon-dioxide (CO_2). Impure air causes headache and sickness, and leads to lowered vitality, with pallor and impaired health. People living in close ill-ventilated rooms, are never vigorous, are always prone to illness, and easily succumb to disease. Impure air must be got rid of from rooms and the object of ventilation is to remove this vitiated air and admit fresh air in its place. Open windows will admit fresh air and allow the escape of impurities. The air inside the room would be kept as pure as that outside ; or very nearly so and a person coming in from the outside air, should not be able to perceive any odour or difference.

2. **Composition of atmospheric air.**—Air contains about—

209·6	oxygen	per 1,000	volumes	of air.
790·0	nitrogen	,,	,,	,,
0·4	carbon dioxide.	,,	,,	,,

with traces of other gases.

3. **Standard of purity of air.**—If CO_2 is increased to 0·6 (*i.e.*, 0·4+0·2) per 1,000 parts by volume, the vitiation becomes perceptible to the senses. No room containing more than this, can be said to be well ventilated.

4. **Cubic space required.**—The *average* amount of CO_2 given off per person is 0·6 c. ft. per hour. Therefore, to keep the room properly ventilated, 3,000 c. ft. of fresh air per person must be introduced each hour. How this can be done depends on the temperature. A feeling of draught is unpleasant, and this happens when the velocity of air becomes about 3 feet per second. As the air of a room, as a general rule, can be renewed three times in an hour without creating a draught, the contents of a room should be 1,000 c. ft. per person, with 100 sq. ft. floor area.

5. **Allowance for lights, etc.**—In addition to human respiration, all illumination, which is due to combustion, adds to the amount of carbonic acid in the air. This must also be allowed for.

An ordinary gas burner, consuming 5 cubic feet of gas per hour, requires 9,000 c. ft. of air, or as much as 3 men.

An oil lamp requires as much as one man.

A candle requires about half as much as a man.

The quantity of moisture in wholesome air should not be less than 40 per cent of saturation.

6. The following table gives the amount of fresh air required per hour for ventilation :—

	C. ft.
Incandescent electric lamp	*Nil.*
Arc electric	*Nil.*
Adult male, very hard at work	9,800
Adult male, ordinary manual work ..	4,750
Adult male, at rest	3,300
Adult female, at rest	3,000
Children at rest	2,000
Average mixed community at rest	3,000
Average mixed community at rest, occupying a building for short periods, such as a theatre	1,500

7. **Space usually allowed.**—In practice this amount is seldom met with, owing to cost, and the possibility of renewal of air a certain number of times in an hour without producing draught.

The following may be taken as the space required per head in buildings :—

Classes of buildings	Cubic space	Floor area
(*a*) Residential houses ..	300 c. ft. per head ..	25—30 sq. ft. per head.
(*b*) Chawls	300 " " " ..	25—30 " "
(*c*) Dormitories	400 to 500 " ..	30—40 " "
(*d*) Factories	250 " " " ..	20—25 " "
(*e*) Schools	144 " " " ..	10—20 " " (according to kind of schools).
(*f*) Hospital wards ..	1,000 " " " ..	80—100 sq.ft. per head
(*g*) Stables	800 to 1,000 " ..	80—100 " "
(*h*) Dog kennels (closed)	95—200 " "	
(*i*) Fowl houses (closed)	4—6 " " "	

Through ventilation should be aimed at, as far as possible, specially so in (*d*), (*e*) and (*f*) classes of buildings. The windows and the ventilators are, therefore, best placed in north and south walls opposite to one another. The above, it should be noted, are the minimum requirements. Too much of fresh air can do no harm.

8. **Importance of floor area.**—In calculating contents, limitation to height is important. Beyond a certain point, increasing the height of a room in preference to floor area, would be of no use. In estimating for ventilation, maximum useful height to be taken in calculation is 10 to 12 feet. There is, however, no objection to a lofty room.

Ventilation may be natural, *i.e.*, by forces set in motion by sun's heat, viz., winds, or artificial, *i.e.*, by extraction or propulsion.

9. **Area of windows and ventilators to be provided for various classes of buildings.**—As a minimum, it should not be less than 1/10th of the floor space. But in the cases of (b), (c), (d), (e) and (f) every effort should be made to increase it to 1/5th of the floor space for obvious reasons. The Bombay Municipal byelaw lays down that for ventilation purposes, the windows should have an aggregate opening equal to not less than one-fourth of the superficial area of that side of the room, which faces an open space. The objects of providing windows and ventilators are two-fold, *viz.*, to get (1) fresh air and (2) light.

The main difficulty met with in practice is, that people, even though provided with sufficient window area and ventilators keep them closed or stuffed thus rendering the adequate provision made for ventilation useless for all practical purposes. This is specially to be noticed during the cold weather and in classes of buildings such as (b), (c) and (d). To prevent this, the windows and ventilators should be made to open into external air and the latter should be permanent fixtures.

10. **Best position for windows and ventilators in various kinds of buildings.**—Where no ventilators are provided, the windows should extend nearly to the ceiling. Their positions will depend to some extent on the orientation of the building. Endeavour should, however, be made to get most of the effective light from the windows in the north wall, as those in the south wall are subsidiary and are chiefly for ventilation. The restorative and recuperation value of light is almost equal to that of fresh air. This should specially be borne in mind for factories, workshops and schools. Full advantage should be taken of sunshine which is of real value in ventilation, as it sets up convective currents and also is a powerful disinfectant. Frequent lime-washings of the walls and ceilings does much to improve the lighting specially so for (b), (c), (d) and (e) classes of buildings.

Ventilators should be fixed as high as possible. The sills of the windows should be about 2′—6″ above the inside floor level.

In the case of residential, travellers', district, inspection and similar bungalows, it is a great convenience to make one set of shutters of windows in upper and lower halves. While the lower halves, when shut, ensure privacy, the upper halves can be kept open, which afford proper ventilation for the rooms.

11. **Steps to keep corrugated iron sheds and similar structures cool.**—(1) The colour of any object exposed to the sun's direct rays has a most important influence on its rate of absorption of heat and is of the greatest importance in questions of ventilation.

The following table gives the absorption by different colours :—

White	100
Pale yellow	102
Strong yellow	140
Light green	155

Turkey red	165
Dark green	168
Light blue	178
Black	208

Therefore, whitewash the outside and the roof of the shed so as to minimise absorption of heat. An excellent lime-wash that will adhere to stone, iron or glass may be made by mixing 10 per cent of any common vegetable oil with the lime while slaking. The lime to be weighed dry. If the oil does not saponify and incorporate with the lime, it must be boiled a little until the oil disappears. Castor oil must not be used.

The oil forms with the lime an insoluble soap, which when once dry, will not wash off with heavy rain. It must be strained and applied in the usual manner.

(2) Provide as many windows as possible in the usual way, if the shed is a closed one.

(3) While the sun is shining, its heat may be used for producing a current of air in a blackened shaft of good conducting material. Fix iron tubes about 5″×5″ square in the ridge extending vertically about 3′ above the ridge, and covered by a cowl to keep out rain.

The shaft should be fixed so as to be well exposed to the sun. For every 100 square feet of room area, about 12 square inches of shaft should be allowed.

Note.—Rooms with terraced roofs can similary be rendered cooler by fixing in the roof number of vertical iron shafts blackwashed and covered with cowls at the upper ends, and fixed projecting above the roofs, so as to be well exposed to the sun.

THE SANITARY AND HYGIENIC REQUIREMENTS FOR THE DESIGNING AND CONSTRUCTION OF SCHOOL BUILDINGS

1. **Selection of sites.**—In the selection of a site the following points should be weighed against considerations of economy, convenience, proximity to houses of parents, etc. The last named consideration is of more importance in the case of girls than of boys :—

(i) A site should not be selected if its natural position is in a hollow or in the neighbourhood of high trees or houses which prevent the free circulation of air and the access of sunlight to the school buildings. Shady trees are, however, of value *in the play-ground*, provided that they do not unduly reduce the space available for play and are not planted so close to the school buildings as to obstruct the entry of light into the class-rooms or, in course of time, to cause damage to the structure.

(ii) Made soils should be avoided and, as far as possible, all soils which are specially retentive of moisture.

(iii) Sufficiency of space is important, and in this connection the possibility of future extension and the necessary of giving subsequent class-rooms the proper orientation should be borne in mind.

(iv) Nallas and tanks in the vicinity are a disadvantage.

(v) The presence of rank vegetation, more especially prickly-pear, is objectionable.

(vi) The neighbourhood of dusty and noisy roads and of shops or factories should, as far as possible, be avoided.

2. All site plans should show the nature of the surroundings, the height of the neighbouring buildings, the north point and the direction of the prevailing wind (see note A).

3. **Orientation of buildings.**—Any room intended for use as a class-room should derive light mainly from the north. This is a very important consideration, and the reasons placing a school with a different orientation should always be stated.

4. Extensions to class-rooms should never be made by adding wings at right angles to the main block but by—

(*a*) a second building parallel to the first and separated from it by an interval equal to at least the height of the taller building, or

(*b*) the addition of a second floor.

5. **Floor space.**—The figures given below must not be considered as representing an ideal standard of requirement for the comfort and health of the scholars. In every country the tendency has been to raise the minimum standard originally adopted ; and it must be remembered that the hotter the atmosphere the greater is the demand for air space.

6. When funds are available, they should be utilised in providing floor space in excess of the following *minimum* requirements :—

For primary schools	10—12 sq. ft. per pupil.
For secondary schools	12—15 ,, ,,
For training colleges and technical school	15—20 ,, ,,

Rooms which are intended to be used for practical work, such as laboratories, drawing-rooms, workshops, etc., should be considered each on its own merits.

7. In a large school it may be possible to design separate class-rooms for the younger and the older children, respectively. On the plans should be shown the maximum number and the average age of the pupils whom each class-room is intended to accommodate.

8. **Composition of floors.**—It is desirable that the floors should be made of a material which will admit of their being washed with water. Stone flagging or something better must be aimed at in rooms where desks or benches can be provided. Where the pupils have to sit on the floor, stone floors need not be insisted on if objected to. At the same time it must be recognized that from the hygienic point of view they are to be preferred and the objection on the score of their coldness can be met by providing mats. But where this is done, the greatest care must be taken to ensure that the mats are kept scrupulous clean.

9. **Seating arrangements.**—The general principles which should govern the construction of desks are set-forth in note B. Where single or dual desks are used, the desks may be arranged most suitably (in relation to the proportions of the room) as shown in the plans marked I, II or III on pages 96 and 97.

10. The alternative to a proper desk is a seat on the floor. When the latter is the rule, it is desirable that each child should have his own mat to sit upon, and he must be made responsible for its cleanliness. For the bigger children the size of the mat should be 3′ × 2′, but for small children 2′ × 1½′ will be sufficient.

11. It is essential to teach children who have to sit on the floor to sit properly. The right leg should be raised so that the right thigh can be used as a desk ; if this be done, it will be impossible for a child to sit with chest and abdomen bent inwards.

12. Forms without backs and desks are objectionable ; the rows of seats in tiers often seen in Guzerat schools should never be adopted.

13. Children should be seated in rows with the main light falling from one side ; they should never face the light. The same remark applies to the teachers also.

14. **Windows.**—Windows serve two purposes—

(*a*) admission of light ;
(*b*) admission of air.

15. It is advisable that most of the effective light should come from windows in the north wall. These windows should be placed at regular distances so as to insure uniformity of light ; and it is important to remember that *the edge of the last window in the north wall* should be behind the last row of pupils, and not more than 3 feet from the west wall.

16. It is laid down in England that the window sill should be not more than 4′ from the ground ; this applies to rooms in which the scholars are seated at desks. When pupils sit on the floor the sills should come to within 2½′ or 3′ of the floor level.

17. The light from north windows should not be masked by sun bonnets or by verandahs except in localities where the sun glare is very great.

18. The windows on the south aspect are subsidiary and are chiefly for ventilation.

19. The whole window area should be one-fifth of the floor area, and one-half of its at least should have a north aspect.

20. Sky-lights properly so-called should never be placed in class-rooms. Where, owing to difficulties of situation, some form of top lighting is unavoidable, the best form is that commonly adopted in factories and machine shops with the light coming in from the north. The Board of Education in England lays down that the class-rooms should not be passage rooms from one part of the building to another, nor from the school room to the play-ground ; consequently doors into class-rooms should open from a verandah. The door to each class-room should as a rule be placed at the teacher's end. The verandah, if correct orientation be given, should always be on the south aspect.

21. **Height of walls.**—The minimum height of the walls should be 12′ from floor to the underside of tie beam. The height of the room must depend on the floor space, and when the latter exceeds 600 sq. ft., the height must be at least 14′.

22. **Ventilation.**—Unless there are windows reaching to the top of the wall and capable of being opened, ventiltors are necessary near the top of the wall on both north and south aspects. These ventilators should be regularly distributed in the same way as the windows. For each pupil 48 square inches of open ventilator should be provided.

23. **Size of class-room.**—There are two main types of shool, one in which the shool room is the principal room, and the other in which there are a number of class-rooms designed in accordance with the number and ages of the pupils. In the first case the Board of Education has laid down that no school-room should be designed for more than 100 children and that a smaller sized room than this is desirable. This recommendation is based on considerations concerned with the health of the pupils with special reference to their eyesight, voices and hearing. It is difficult to light efficiently any portion of a class-room which is more than 24′ from the window wall. The length of a school-room must depend on three factors :—

(*a*) the use made of maps, diagrams and black-board ;
(*b*) the carrying power of the voice ;
(*c*) the acuteness of normal hearing.

The eye of the young child is not adapted for near work and, therefore as much use as possible should be made of the black-board, etc. It is important to see that all writing on the diagrams, etc., is of such a size that the normal child's eye can from the furthermost portion of the room decipher it without the strain of accommodation. The maximum length of the room, therefore, must depend on the size of type in the diagrams, maps, etc., used for instruction. The eye is a delicate organ and can be damaged *irretrievably* by inattention to this point. But the voice and ear are not injuriously affected by school routine; the carrying power of the voice and the range of normal hearing influence the value of oral instruction, and are, therefore, educational rather than sanitary matters,

24. It is important that no class-room should be more than 24′ in width unless there are special means for cross lighting. The length of a room must depend on the number of classes to be held in it. In the case of a school divided into a number of class-rooms, the dimensions of any room should not exceed 24′×25′, that is, an approximate square. As it is recognised that a squre is the best area for teaching purposes the length of a class-room in a one-roomed school should be approximately some multiple of the width.

In the case of class-rooms for 60 or more pupils a length of 30′ along the axis of illumination is allowable.

25. **Roofs.**—The roof should, as far as possible, be impervious to heat.

26. **Sanitary arrangements.**—In sewered towns where it is possible to instal water closets, it should be remembered that no water closet should be within the shool building. Every water closet should be disconnected completely from the school building.

27. Hand-served latrines should be used only when sweepers are available and there is some one on the school staff with sufficient interest in the health of the children to supervise the condition of the latrines.

28. When used these latrines should not be placed nearer than 40 feet to any school building. They should be so situated that the prevailing wind will not blow from them in the direction of the school.

29. The number of seats should be on the following scale :—

	Girls	Boys
Under 30 children	2	1
" 50 "	3	2
" 70 "	4	2
" 100 "	5	3
" 150 "	6	3
" 200 "	8	4
" 300 "	12	5
" 500 "	20	8

30. For boys urinals at the rate of 4 per cent are necessary in addition.

31. Separate provision for teachers is necessary.

32. Each closet must be at least 2′—6″ and need not be more than 3′ in width. In depth 4′ should be the minimum. More room should be allowed to older childern and teachers.

33. The floor of the latrines must be of some impervious material which can be washed down and is not disintegrated by urine, etc. The walls of the closets must be of a smooth non-absorbent substance which must extend to at least 3′ above the seats or squatting plates.

34. Unglazed bricks should not be used for latrines ; they are absorbent and may become highly offensive.

35. Corrugated iron is frequently employed and is not objectionable if properly attended to. The usual practice is to give it an annual coating of tar ; in such cases the surface is usually not cleaned between the application of the coats, and the result is very insanitary.

36. All latrines require very careful attention ; five minutes' supervision daily will result in a perfectly sweet latrine but unless the pans are oiled daily and the walls about once a week, the latrines will be fly reservoirs and extremely offensive.

37. The doors of latrines should be three-fourths doors only—short of both floor and roof. As a screen for latrines a fenestratd brick wall or a sheet of corrugated iron is generally used.

38. Urinals must be of impermeable material.

Hostels.

39. **Sleeping Rooms.**—In the case of single rooms or cubicles the minimum floor space should be 96 square feet. Each room or cubicle should be ventilated and lit independently.

40. Rooms for the accommodation of three or four should provide 65 square feet of floor space per head, and those for five or more pupils a minimum of 60 square feet per head. Sleeping rooms, each measuring $16\frac{1}{2}' \times 16'$ and intended for the accommodation of four pupils, have proved very convenient and economical in design.

41. **Bathing arrangements.**—Special arrangements are necessary, the simplest being an open masonry platform situated at some distance from any well. Wherever possible efficient arrangements for privacy and for protection from the sun, wind and rain should be made.

42. The existence of cook-houses, bath-rooms, etc., necessitates careful attention to surface drainage and provision for the removal or disposal of sullage water.

43. **Latrines and urinals.**—The scale of latrine accommodation should be double that prescribed in rule 29 for day schools. Urinals should be in the same proportion as for day schools. Special portable urinals for night use are necessary, one for 25 boarders.

They must be placed in convenient places for night use and removed for cleaning during the day.

44. **Sick-room accommodation.**—For small rooms intended for less than four patients the floor space should be at the rate of 100—120 square feet per head. For larger wards designed for ten or more the floor space may be reduced to 60 square feet per head, provided that a window or door is placed between each pair of beds.

45. The general design of the rooms depends on the object in view, that is to say, whether it is intended to take in only ordinary cases or whether infectious cases also are to be treated. In the latter case small rooms for one or two patients with separate bath rooms are necessary.

46. The amount of sick-room accommodation must depend on local circumstances, *i.e.*, whether or not there is a civil hospital or an infectious diseases hospital in the vicinity. From 3 to 6 per cent of the total number of scholars is the usual provision.

47. **Open air schools.**—In England open air schools are intended for the education of weekly and tuberculous children. In India the proposal for such schools arises from motives of economy in construction. An open air school for ordinary purposes is hygienically as far short of a properly built school as it is in advance of many of the buildings used to-day for schools in villages. An open air school should be considered therefore as a step towards a permanent school and the following points should be borne in mind :—

(*a*) The site must be large, airy and well drained. The vicinity of dusty roads is very objectionable.

(*b*) The long axis of the building must run east and west, and shutters for closing in the south aspec are necessary.

(*c*) The floor must be of muram.

(*d*) The roof must be heat proof as far as is possible.

(*e*) Walls or shutters on the east and west aspect are necessary, so that scholars and teachers need not face the light.

Note A.

A revised list of points on which the sanitary authorities require definite information to be submitted to them, either in the plans and estimates or in an accompanying letter, to enable them to pass an opinion on the plans and estimates for educational buildings :—

1. Plan of the site in addition to plans of buildings to be erected or altered.

2. North point on all plans.

3. Direction of the prevailing winds.

4. Sanitary condition of the surroundings, including the height of the neighbouring buildings, and proximity of any tank.

5. Position of latrines and urinals in relation to other buildings . (When latrines and urinals are not provided, the reason for omitting them, *e.g.*, want of sweepers, should be stated).

6. Type of latrines and urinals to be erected.

7. The use each room is to be put to.

8. The number of students to be accommodated in each room, whether dining, sleeping, recreation, class or other room.

9. Position of doors and windows.

10. Number and position of any ventilators in walls or roof. (Ventilators should not be combined with windows, but placed as high up as possible).

11. Dimensions of rooms.

12. Maximum age of the students to be accommodated or taught in each room.

13. Dimensions of the area to be used as a playground. (If no playground is provided, the reason for omitting should be given).

In the case of rooms to be used for teaching—

14. Position of seats for students.

15. Position of teacher's desk.

In the case of hostels—

16. Bathing arrangements.

17. Surface drainage and method of disposal of waste water.

18. Source of water-supply.

19. If sick-room accommodation is provided, it should be stated whether for ordinary or for infectious diseases.

Note B.

1. The seat should not be so high as to prevent the child resting its feet upon the floor, or on a footboard, and if the latter, the knees should not be elevated.

2. Assuming a child to be sitting upright in his seat and the arms to be hanging freely down, the edge of the desk next the body should be about an inch higher than the level of the elbows in the case of boys, and from $1\frac{1}{2}$ to $1\frac{3}{4}$ inches in the case of girls.

(If the desk be higher than this, there is a tendency for the boy to be twisted and for one shoulder to be raised above the other, with the consequen risk of lateral curvature of the spine).

3. A line dropped from the edge of the desk ought to strike the edge of the seat or a point an inch or two within it.

(This arrangement obliges the child to assume an upright position, which is best for the eyes and the spine).

4. No seat should be without a back, and the top of this should be one inch lower than the edge of the desk in the case of boys and one inch higher than the edge of the desk in the case of girls.

(In schools which are graded, great inequalities will be found in the size of the sholars in each room, to meet which it is desirable to provide three sizes of desks. In schools of mixed ages there should be a large number of sizes).

5. The desk must not be flat. It should slightly incline towards the child.

6. The seat should not be flat, but saddle-shaped. Change of position will be desirable.

7. The desks must be easy of access, yet compactly arranged. The angle of vision for the teacher should be not more than 45°.

Height and dimensions.

(1) The sloping part of the top should be not less than 12 inches in width.

(2) The inclination should be about 2 inches, and the slope should be about 1 in 10.

(3) The flat portion of the desk with the groove should be from 3 to $3\frac{1}{2}$ inches in width.

(4) The proper height allows the forearm of the seated child to rest horizontally upon the desk without discomfort :—

(*a*) Youngest children ..	20″ to 25″	to the middle of the slope.
(*b*) Intermediate children ..	22″ to 26″	do.
(*c*) Oldest scholars ..	30″ to 36″	do.

The seat should be $16\frac{1}{2}$ inches high.

(5) The back rail should be not more than 7 inches for younger children, and not more than 10 inches for the elder ones.

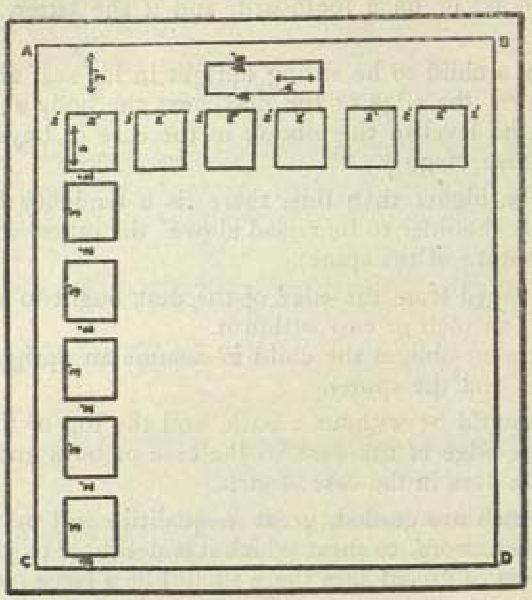
(6) The minimum space for each child should be 20 inches ; 22 inches would be better.

(7) The width of the gangway should be 18 inches at least.

(8) The seats should be 8 inches wide.

PLAN I.

SINGLE DESKS



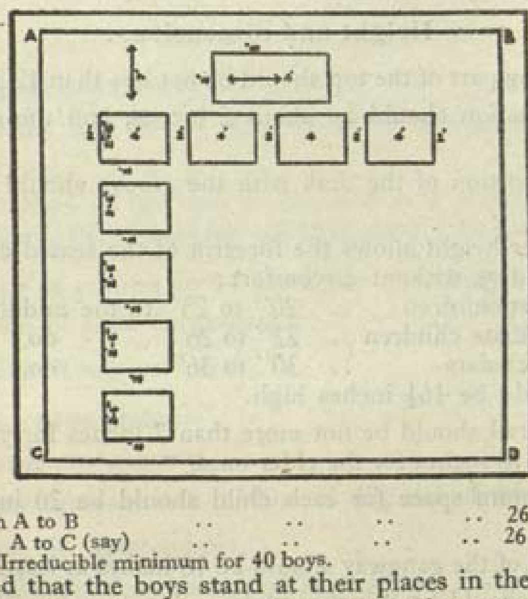
From A to B	26 feet.
,, A to C	26 feet.

Irreducible minimum for 36 days.

Dimensions of desks are taken from the single desk in use, but their depth might be reduced somewhat,

PLAN II.

DUAL DESKS WITH MOVEABLE SEATS



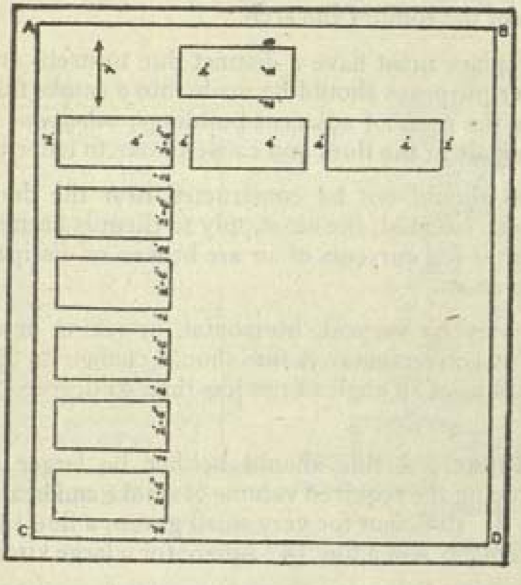
From A to B	26 feet.
,, A to C (say)	26 feet.

Irreducible minimum for 40 boys.

It is assumed that the boys stand at their places in the desks, not in the gangways. As an alternative, the desk could also be arranged on a front of three, as in plan III.

PLAN III.

DUAL DESKS WITH FIXED SEALS.



A to B	24 feet
A to C (say)	24 feet

Irreducible minimum for 34 boys

Boys stand in the gangways.

DOMESTIC CHIMNEYS.

1. **Fireplace.**—A fireplace is formed by building out jambs from the walls, or by a projection on the back of the wall, and turning an arch over the opening, upon which is erected the chimney breast to contain the flue.

2. **Construction and support.**—The jambs or projection should be carefully built upon solid foundations. The jambs should be 14″ in width. Fireplaces, in a house of more than one story, usually stand one over the other, the flues from the lower rooms being carried to one side or the other, in the jambs of the fireplaces above. The fireplace arches are turned in 9″ brick-work, in cement mortar.

3. **Size of opening for ordinary grates.**—The depth should not be less than 14 inches, and need not be more than 18″ for ordinary grates. The width of fireplace openings vary from 18″ to 27″ for small rooms, to 42″ and upwards for large rooms. The height of a fireplace should be 3 feet 3 inches for ordinary grates.

4. **Size of opening for kitcheners.**—The depth of a kitchener opening should be 27″, and the back, 9″ thick. The breast above the mantel-shelf may be set back sufficiently to contain the flue.

5. **Smoke prevention.**—To prevent smoking, pockets, where eddying currents of cold air can form, should be avoided. The filling on either side of the

stove should be built solid, as in plate CXXVII. The flue of its proper size, should be formed immediately at the back of the fireplace arch, and directly over the fire. After ascending vertically for a short distance, it may then be bent as required. The lip of the flue at the back should be about 2″ to 3″ above the level of the crown of the soffit of the arch.

6. Every fireplace must have a distinct flue to itself, and no openings for ventilation or other purposes should be made into a smoke flue. Flues must be carried well above the roofs of adjacent buildings, otherwise the wind will beat down the ascending air in the flues and cause smoke to enter the building.

7. Fireplaces should not be constructed near the doors and principal windows, as when so situated, the air supply to them is keener and draughts are more apparent than if the currents of air are broken or dissipated by travelling a distance across the room.

8. **Flues.**—May be vertical, horizontal, or raking or combination of all types in one flue, as convenient. A flue should change its direction by gradual curves and inclinations at an angle of not less than 45 degrees, otherwise soot will accumulate.

9. **Size of Flues.**—A flue should neither be larger or smaller than is necessary for conveying the required volume of smoke and heated air. Generally, a flue 9″ square is sufficient for very small grates, a flue 14″ × 9″ will suffice for an ordinary fireplace, and a flue 14″ square for a large kitchen range.

10. **Lining.**—This is to provide against the chance of bad joints in brick-work, with the attendant fault of cooling the flue by drawing in cold air, and the danger of setting fire to adjoining woodwork. The cheapest method is to render the inside of a flue with lime and hair mortar, which is greatly improved by a liberal admixture of cowdung.

11. **House chimney shafts and stacks.**—Chimneys above roofs should be carried at least 3 feet above adjacent ridges. This should be built of the same materials as the walls, and should be 9″ thick throughout.

12. **Caution.**—For the proper working of the fireplaces and chimneys it is imperative that the fresh air ducts should be quite free from chokage.

COOK ROOM OR BATH ROOM DRAINS.

The drainage water from cook rooms or bath rooms should always be conducted away from a house into garden nalis, or where there is no garden, to a small pit round which shrubs or plantations are planted, and should not be allowed to accumulate against the walls of the building. A type design for a convenient form of drain and pit is given in plate CXXIX.

Specification No. 189.

1. The outlet from the cook room or bath room should be by a three inch pipe with its outer end at least six inches from the wall.

2. Water from this pipe should fall into a small trap 9″ × 9″ inside dimensions, and 4″ deep, connecting with (*a*) a cement plastered drain 4″ × 4″ or (*b*) with a half round stoneware pipe 6″ in diameter. The drain to be laid at not less than a 1 in 15 slope.

TYPE DESIGN FOR A FIRE PLACE

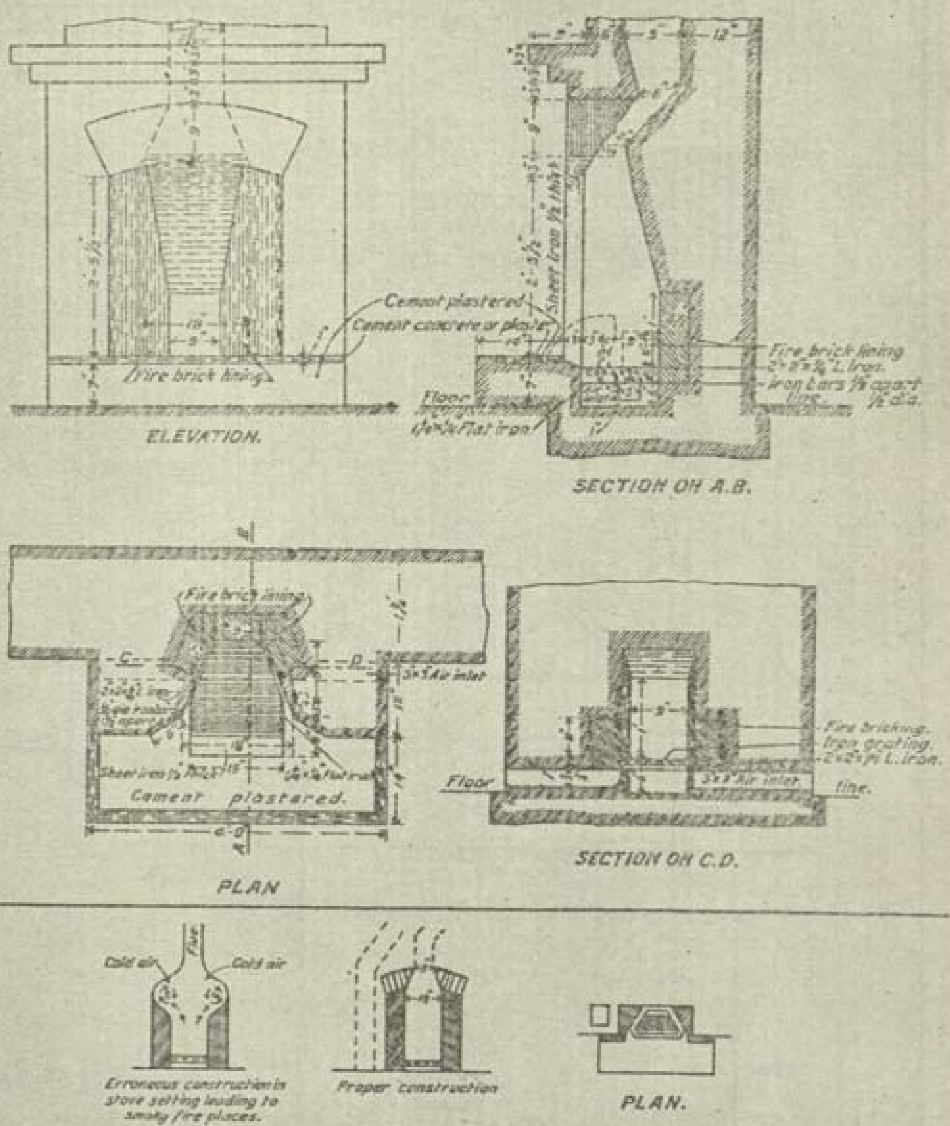


Plate CXXVIII

CORNER FIRE PLACE & CHIMNEY.

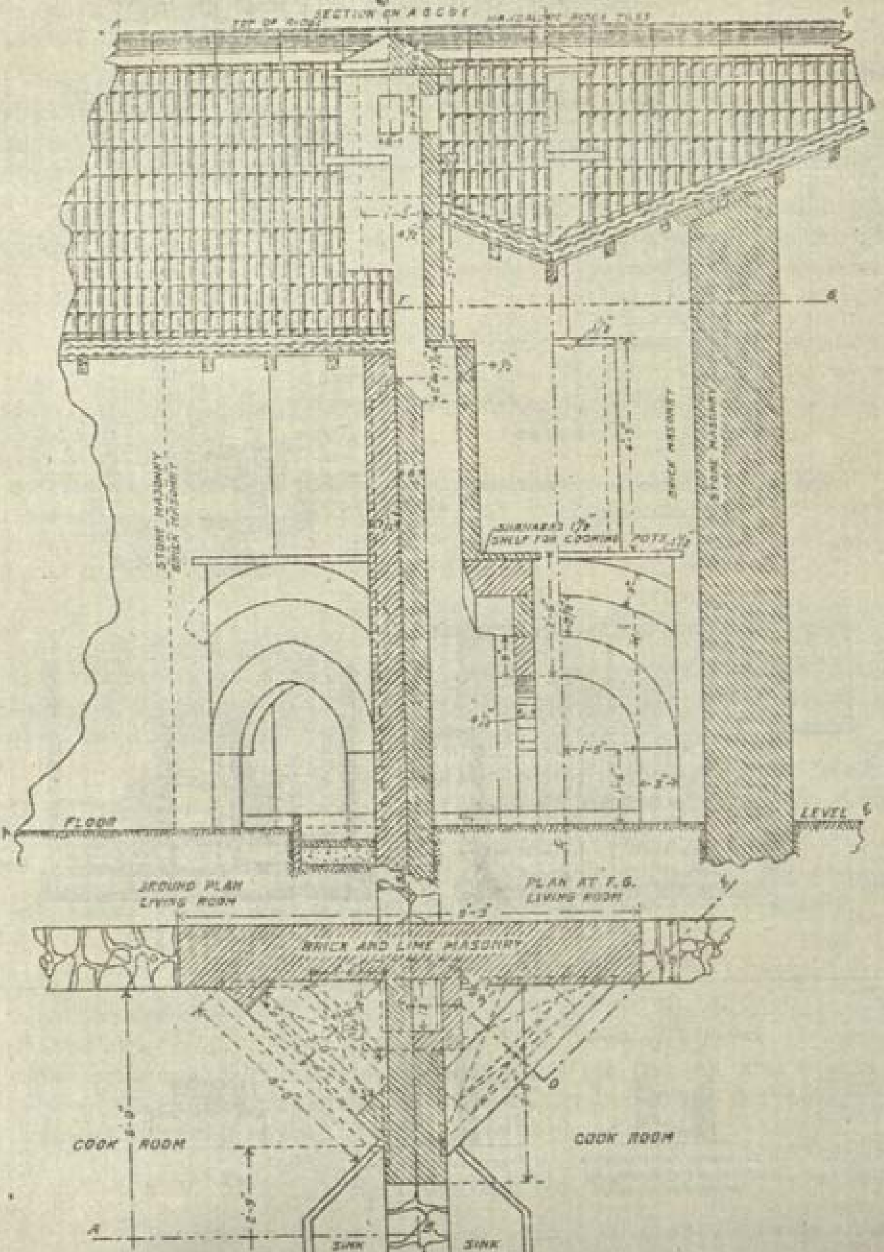
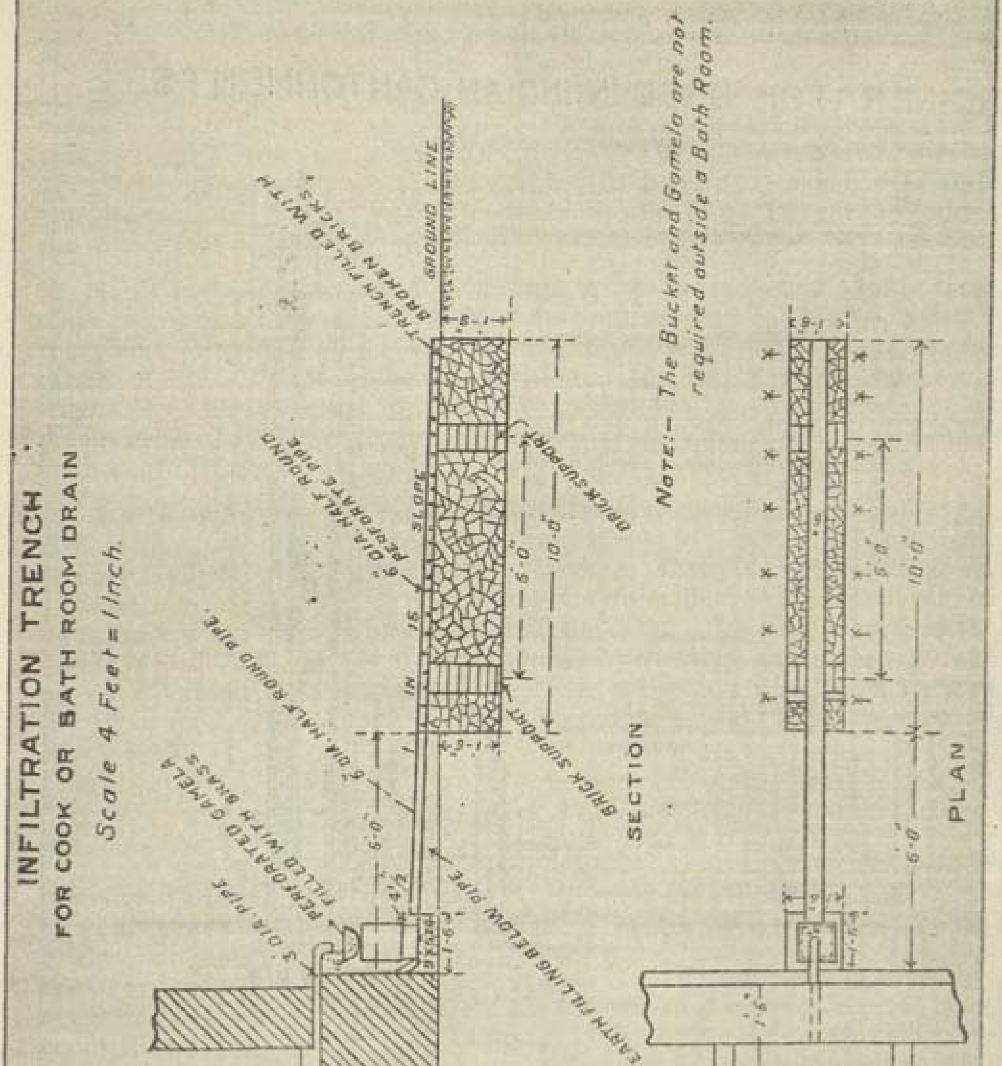


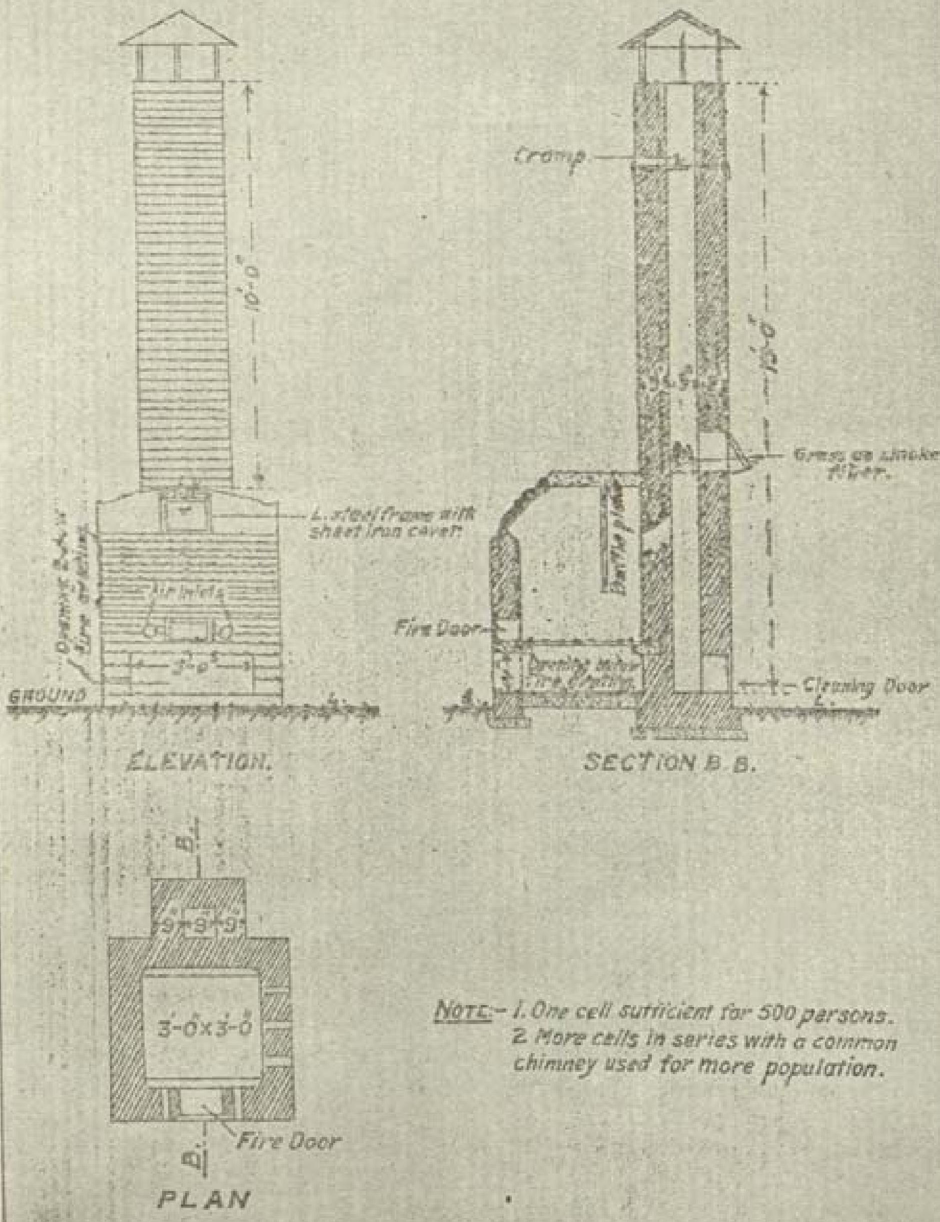
Plate CXXIX



INFILTRATION TRENCH
FOR COOK OR BATH ROOM DRAIN
Scale 4 Feet = 1 Inch.
TRENCH FILLED WITH BROKEN BRICKS.
GROUND LINE
BRICK SUPPORT
6" DIA. HALF ROUND PERFORATE PIPE
SLOPE 1 IN 15
6" DIA. HALF ROUND PIPE.
BRICK SUPPORT
EARTH FILLING BELOW PIPE
PERFORATED GAMELA FILLED WITH BRASS
3" DIA. PIPE
SECTION
Note:- The Bucket and Gamela are not required outside a Bath Room.
PLAN
MORI

Plate CXXX.

INCINERATOR USED IN INDIAN CANTONMENTS.



NOTE:- 1. One cell sufficient for 500 persons.
2. More cells in series with a common chimney used for more population.

3. At a distance of not less than 6′ from the wall of the house, the drain connects with a 6″ diameter half round galvanized iron, zinc or tin pipe, pierced from the outside with conical perforations. This pipe is laid over a trench 6′ or more in length, 18″ wide, and of such a depth (usually 2′ deep) that the water can easily be absorbed by the surrounding earth. There should be a fall away from the inlet of about 3″ from end to end of the trench. The pipe is supported on two dry-brick supports laid 6′ apart in the trench. In the case of clay soil, the trench must be excavated down to a good pervious soil. For larger trenches 15 gallons per square foot per day may be allowed.

4. The trench should be filled in with broken brick, kankar, coal or some other porous material well packed round the brick supports of the pipe, and at a convenient distance from the sides of the pit, plantains, yams, or ornamental grasses or shrubs, should be planted. Should the pipe be in a position where it is accessible to pigs or cattle, it should be surrounded by a stout fence. The porous material in the trench should be taken out every three months, and either be thoroughly dried or renewed.

5. No water from latrines should be allowed to flow into the trench and it is more important that all fat and solid matter should be removed from the water before it is allowed to flow into the perforated pipe. Outside a kitchen, therefore, a bucket or kerosine oil tin, with a perforated bottom, filled with lumps of coke or brick, broken small, should be placed on the top of the trap so that water from the waste pipe will strain through the tin or bucket into the trap, and on the top of the bucket a perforated tin or ghamela filled with grass should be placed to catch any fat or solid. This grass should be changed daily, and the porous material once a week.

INCINERATORS FOR TOWN REFUSE

1. These are contrivances for the final disposal of town or similar refuse by burning. The smaller types are in use in the Indian cantonments, a type design of which is given in plate CXXX. The chamber or cell is constructed of 9″ brickwork masonry 4 or 5 feet high with an iron grating at the height of about 2 feet above ground level. The smoke or gases are led away through a chimney opening, 9″ square, at the back of the cell with which it is connected and taken about 10 feet above its top. The charging is done by hand through a side door nearer to the top of the cell and the burnt clinker and ashes are taken out from the floor beneath the grating. One cell is provided for dealing with refuse from a population of 500. Its cost with chimney would be approximately Rs. 250. The Madras type (Griffith) with 3′ 7″ diameter cell disposes of 300 c.ft. of rubbish daily. Incinerators of smaller type are also used to burn night soil where horse litter or rubbish of inflammable material is available.

2. The larger types are composed of one or more cells, each cell designed to dispose of as much as 8 to 10 tons per 24 hours daily, and utilizing the heat so developed for boiler purposes. These types are generally termed "destructors" from the very high temperatures developed in them. The types best known are (1) Horsefall, (2) Beaman and Deas, (3) Meldrum, (4) Heenan and Froude, (5) Sterling and (6) Baker. The Horsefall type is in use at Colombo and Calcutta. Bombay has a destructor on the Port Trust properties.

3. The quantity of daily refuse varies between ½ to 1 ton per 1,000 population or about 7 cwts. per head per annum. In the wet weather the refuse is about

25 per cent heavier than in the dry and the destructors can deal with about half the quantity of refuse in wet weather as compared with that dealt with in dry weather.

4. The preparation of refuse for burning consists in the separating of heavier matter, by hand picking of incombustible material, and screening for getting rid of dust or earthy material.

SANITATION OF WORKING PARTIES

1. When large gangs of work-people are engaged on works, particular attention must be given by the Officer-in-charge to sanitary requirements, especially in malarious districts or where epidemics prevail. The great requisites for preserving the health of the work-people are (1) proper accommodation, (2) food, (3) water, (4) conservancy. These will necessarily vary according to locality and circumstances, and the following remarks are offered merely to illustrate the general nature of the precautions necessary.

2. **Accommodation.**—Huts of bamboos and grass can be constructed at little expense in most parts of the country, and they will be amply sufficient for the accommodation of the work-people.

3. In erecting them, it is of great importance to select a good site. High ground removed from jungle, but well provided with trees, ought to be chosen wherever it is available. The neighbourhood of rank jungle, grass, or weeds is particularly to be avoided ; newly turned soil is also deleterious, so that camps should not be established close to large cuttings or earth-works.

4. The houses themselves should be raised on an earthen plinth, and with open spaces of at least 10 yards between the different rows. When a good natural site cannot be procured, the drainage should be particularly attended to. Whenever, owing to unavoidable circumstances, the huts occupy a situation in a low, swampy, or otherwise unhealthy situation, the sides should be carefully *leeped* or thinly plastered with mud, so as to exclude the night air, and, in such circumstances, it will also be advisable that the people should sleep on raised cots or *charpoys*.

5. It is very important that there should be no overcrowding; each person should be allowed at least 50 superficial feet, and care should be taken to see that the houses are kept clean and in good order.

6. **Food.**—As regards food, in most parts of India, no difficulty will be experienced in providing a good and sufficient supply. In many cases, no special arrangements will be necessary, as the coolies will be able to draw their supplies from a neighbouring market without difficulty. Where no such facilities exist, it will be advisable to organise a *bazar* and to see that the food provided is proper, both as regards quantity and quality. In this respect, it is of importance also to secure a sufficient variety, and, in addition to the ordinary staple articles of rice, *dal*, *ghi* and condiments, such valuable additions to diet as goats, fowls and vegetables should not be omitted.

7. **Water.**—Good and pure drinking water is of hardly less consequence than good food. Well water is generally to be preferred, as being more free from impurities. The wells should be sunk in such a situation as will prevent their being contaminated by sewage. No washing or bathing should be permitted

near the wells. It will tend to the purity of the supply if one or more labourers are employed to draw water for the rest, pouring it into a trough from which it will pass into iron tanks provided with taps.

If cholera is prevalent, the wells should be frequently disinfected by throwing in a solution of permanganate of potash till the water is slightly tinged with pink.

Where water is drawn from tanks, similar precautions should be adopted as regards the prohibition of washing or bathing in the tank.

8. **Conservancy.**—General cleanliness of the lines and their vicinity should be enforced. As the encampment will probably be constantly moving with the progress of the works, it is not advisable to establish regular latrines; under the circumstances, the trench system is most suitable; every morning one or more fresh trenches should be dug, according to the number of people to be provided for. They should neither be deeper than one foot nor wider than 9″ and should be covered in daily. In selecting a site for these trenches, it is indispensable that they should be removed as far as possible, consistent with convenience, from the water-supply. In large camps, where several trenches have to be dug daily, a difficulty would be found in providing fresh sites for these trenches, if the camp remained for long in the same place. If the weather is dry, it is, however, possible to dig up the old trenches after they have been filled for two months without any risk. The system has no other danger than contamination of the water, and it can be effectively carried out at very little expense.

9. The use of shallow trenches necessitates, however a comparatively large area of land, and the use of more sweepers to prevent the ground in the neighbourhood of the trench being fouled. The Pandharpur system is probably more economical and suitable in spite of the initial expenditure on squatting platform.

A deep trench up to 4′ in depth is dug. The walls of the trench should shelve outwards so that the floor of the trench is 12″ to 18″ wider than it is on ground level. This will only be possible in good muram soils. In friable soils, such as the black cotton, the walls of the trench will have to be vertical, but the width of the trench at ground level should never exceed 2′.

For the use of the latrine, a squatting platform is necessary. This platform is built on a series of poles separated from each other by a space of 2′ 6″. On these poles are nailed a pair of strong wooden planks, smoothed and tarred. The intervals between the planks should be 7″. At every 3′ interval a semicircular notch should be cut in the planks so as to form a hole 10″ in diameter. Foot rests are not essential, but are of course useful.

The length of the poles will depend on the nature of the soil—the more friable the soil, the longer the pole.

For convenience of transference from trench to trench each platform should be limited to 3 or 4 seats.

For privacy a tarred matting may be erected between the seats.

Working of latrines.—Latrine seats should be provided at the rate of 8 to 10 per cent of users.

Latrines are used in the morning and between 4 and 6 p.m. After the morning and evening visit, the sweepers should cover the ordure with cut grass soaked in crude oil. The squatting platform should be cleaned with wet broom and smeared with cloth soaked in crude oil.

When the ordure has reached to within 1 foot of ground level, the squatting platform should be moved to a new trench and the used trench should be filled with earth and well stamped down.

10. **Refuse disposal.**—Disposal of refuse by fire is the only safe proceeding. Raynold's portable incinerator is useful, and costs about Rs. 100. This consists of a light circular frame work of iron with a centre flue. The refuse is placed in the receptacle around the centre flue and is ignited from below. By this method a plentiful supply of air is conveyed to all parts of the burning mass and so effects complete and rapid combustion of the whole.

Plates CXXX, CXXXI and CXXXII give details of masonry incinerators.

11. The precautions noted under these different headings, if carefully attended to, are calculated to secure the health of the people employed. It is now necessary to consider what measures should be adopted in the event of sickness appearing among them.

12. Wherever any large body of coolies is collected together, it will be advisable to appoint a native doctor, and provide a small hospital. In most cases a central establishment will be sufficient for several miles of works. The hospital should be reserved for treating accidents and cases of a trifling nature in which complete recovery maybe soon accepted. As a rule, it will be better to transfer the sick suffering from more severe illness to the neighbouring station, where they can be looked after in the dispensary.

13. These remarks apply more particularly to ordinary cases of sickness. Those diseases, which are liable to become epidemic, require separate attention. Under this head there are only three which require separate attention. They are small-pox, cholera and contagious fever.

16. Small-pox is rarely epidemic among adult natives. On the occurrence of any case, no matter how slight, the patient should be at once removed to a small-pox shed which will form part of the hospital, but will be well removed from the rest. On his becoming convalescent he should be provided with new clothes and sent to his home; on convalescence or death, his clothing and all other infected articles should be destroyed,

15. The occurrence of a case of cholera has a different significance according to the part of the country and the particular time at which it occurs. Under any circumstances, however, the appearance of even one case of the disease should not be lightly thought of. The care taken in the conservancy arrangements should be redoubled; the patient should be isolated, and his discharges disinfected. Cholera pills should be freely distributed, so that cases of diarrhoea may be treated without delay. If the disease becomes epidemic, that portion of the encampment, which has been attached, should be vacated without delay, and if the attack has not been limited to any particular locality, it will be advisable to remove the whole of the people elsewhere. A move of even one or two miles often suffices.

16. In highly malarious localities, where fever of a dangerous type prevails care should be taken that all the party are within doors immediately after sun-down. The huts ought to be shut up at once for the night, no communication with the external atmosphere allowed, and no one permitted to leave for work until the sun has risen. Each member of the gang ought to be given daily, at morning parade, one or two fever pills or such febrifuge as the native doctor may

A SIMPLE INCINERATOR

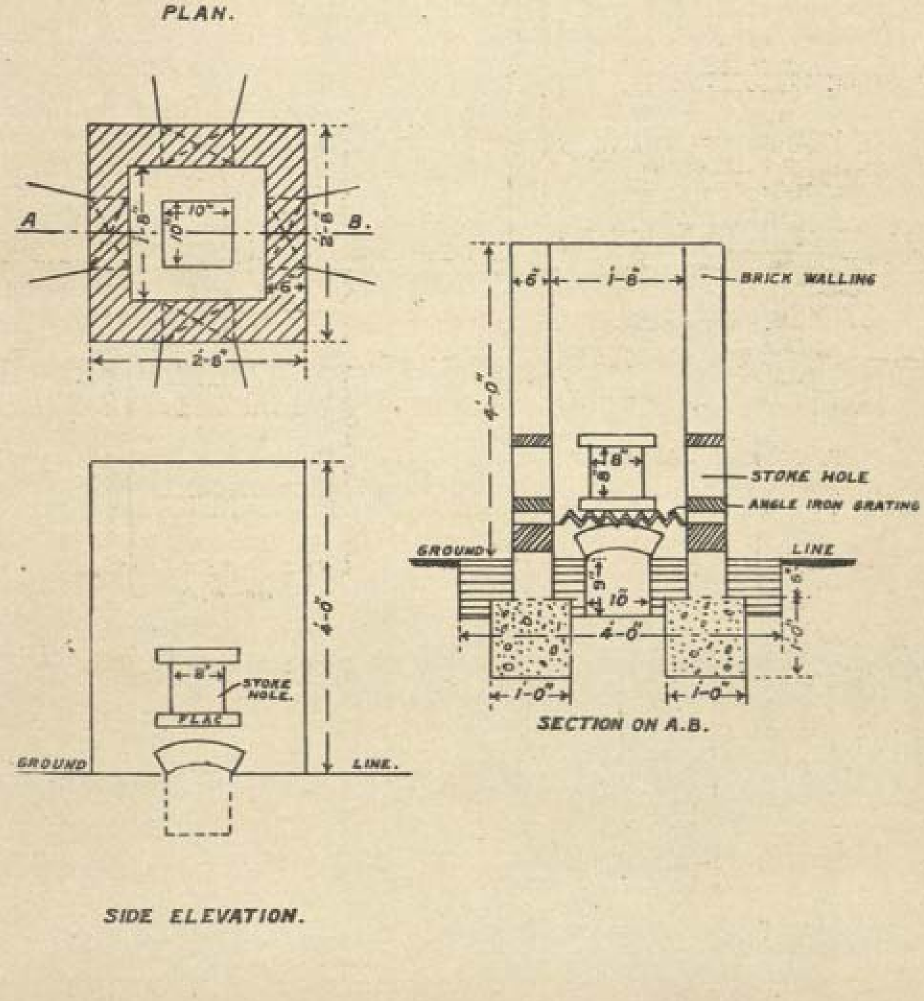


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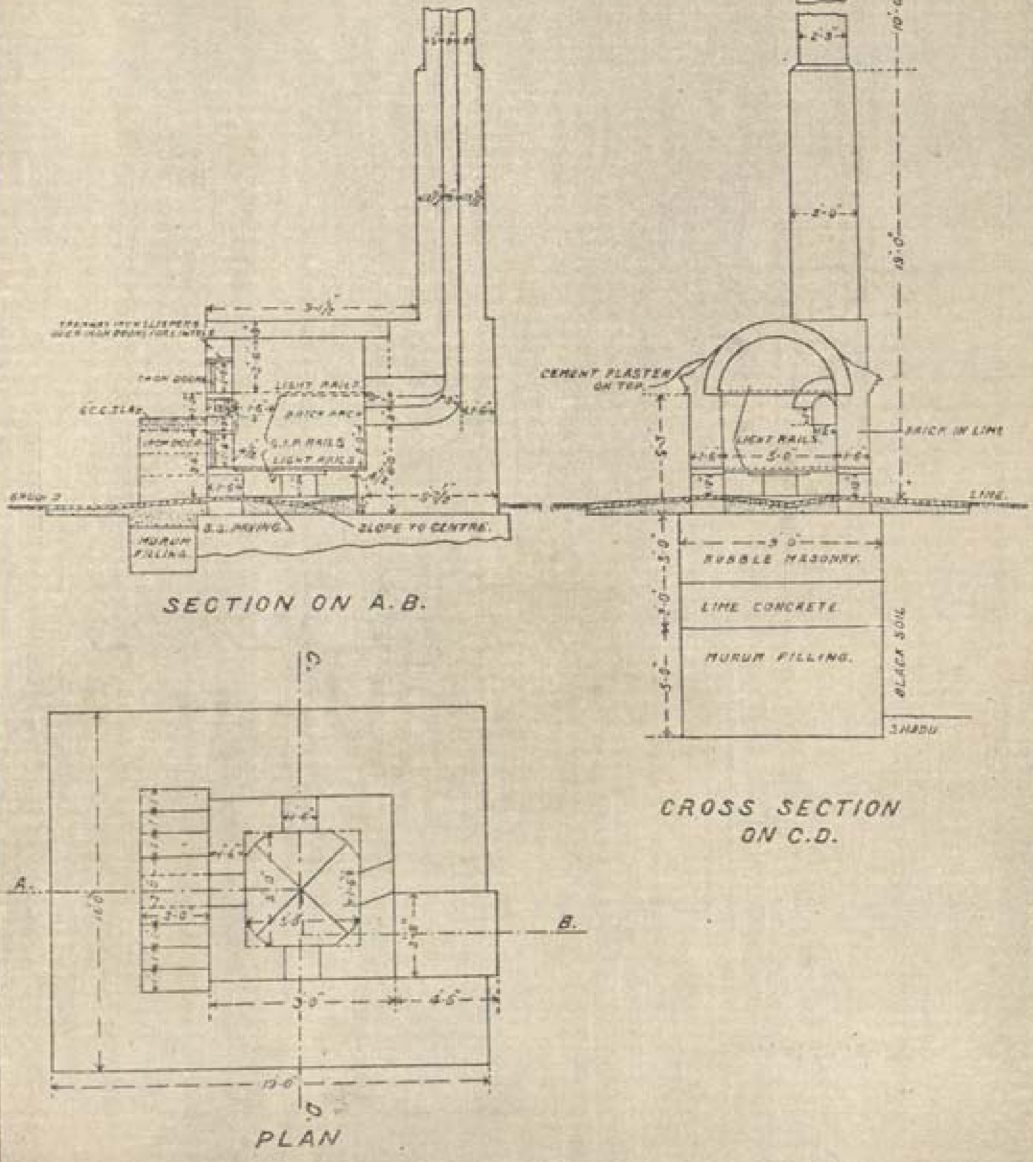
Plate CXXXII

INCINERATOR

NASIK PATTERN



SECTION ON A.B.

CROSS SECTION ON C.D.

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prescribe. Particular care must be taken to prevent the work-people remaining in wet clothes or sleeping on the ground.

17. The question of medical supervision has already been incidentally alluded to. It will be advisable, as has been already stated, that a native doctor, with a small hospital, should be attached to each large gang, or set of gangs of work-people. It is also necessary that he should be under supervision. Whenever circumstances admit of it, the camp should be frequently visited by the Civil Surgeon of the district. Even when distant from his headquarters, it is very desirable that he should pay at least one visit in the month to ascertain that the native doctor is carrying on his duties properly, and also to satisfy himself that the sanitary arrangements are good. A weekly report should be submitted by the native doctor to the Civil Surgeon. He would thus be informed of what was going on, and on the occurrence of any emergency, his services would always be available when called for by the Engineer-in-Charge.

18. **List of labour camps.**—A complete list should be prepared and posted up-to-date from month to month. A copy of this, together with a small scale map showing the positions of these camps, should be forwarded to the Assistant Director of the district concerned.

19. **Registration of births and deaths.**—All vital statistics should be registered separately and the register maintained by the Officer-in-Charge of the camp. A monthly extract should be sent by him to the Mamlatdar concerned.

20. **Notification of epidemic diseases.**—All cases of epidemic diseases, plague, small-pox, cholera, and influenza should be separately registered. Intimation of an outbreak of any of these diseases should be sent to the Assistant Director concerned by wire and daily returns submitted through the Mamlatdars.

21. **Prevention of epidemic diseases** is given in datail in the Manual of Vital Statistics and Public Health, a copy of which may, with advantage, be supplied to the Officer-in-Charge of the camp.

22. It is the duty of the Superintending Engineer to see that the general orders on the subject of health are duly carried out.

23. Any reasonable outlay for such temporary cover as may be needed for work-people, including marking out, clearing and draining of the sites, for employing one or two policemen, hospital establishments, and a small temporary establishment to clean the latrines, may be authorised as forming part of the contingent outlay on the work under execution.

RATE ABSTRACT No. 141

LAYING STONEWARE PIPES, 12 INCHES DIAMETER

Materials for 100 Rg. ft.	Number or quantity.	Rate	Per	Amount	Labour for 100 Rg. ft.	Number or quantity.	Rate	Per	Amount
		Rs. a.		Rs. a.			Rs. a.		Rs. a.
50 pipes, each 2¼ ft. long No.	50	..	Each.	..	Excavating—trenches C.ft.	1,050	..	100	..
Portland cement C.ft.	2·5	..	C.ft.	..	Filling in and consolidating trenches .. ,,	1,050	..	100	..
					Masons .. No.	6	..	Each.	..
Carriage of pipes .. Lbs	..	..	Lot	..					
Hemp or spun yarn. .. ,,	6	..	Lb.	..	Coolies .. ,,	6	..	,,	..
					Watchmen ,,	6	..	,,	..
Sundries	..	..	..	..	Sundries. ..	..	..	..	..
	Total, materials		..	..	Total, labour			..	..
					Total, materials			..	..
					Total for 100 Rg. ft. 12″ piping				..
					Add—for concrete where required .. C.ft.	360	..	100	..
					Total for 100 Rg. ft.			..	..
					or, per Rg. ft.			..	..

RATE ABSTRACT No. 142

LAYING STONEWARE PIPES, 6 INCHES DIAMETER

Materials for 100 Rg. ft.	Number or quantity.	Rate	Per	Amount	Labour for 100 Rg. ft.	Number or quantity.	Rate	Per	Amount
		Rs. a.		Rs. a.			Rs. a.		Rs. a.
50 pipes, each 2¼ ft. long. No.	50	..	Each	..	Excavating trenches .. C.ft.	750	..	100	..
Portland cement .. C.ft.	1·1	..	C.ft.	..	Filling in and consolidating trenches .. ,,	750	..	100	..
					Masons .. No.	4	..	Each	..
Carriage of pipes .. Lbs.	..	..	Lot.	..	Coolies .. ,,	4	..	,,	..
Spun yarn ,,	3	..	Lb.	..	Watchmen ,,	4	..	,,	..
Sundires	..	..	..	..	Sundries. ..	..	..	..	..
	Total, materials		..	..	Total, labour			..	..
					Total, materials			..	..
					Add—for concrete where required .. C.ft.	150	..	100	..
					Total for 100 Rg. ft. piping			..	..
					or, per Rg. ft.			..	..

RATE ABSTRACT No. 143

LAYING STONEWARE PIPES 4 INCHES DIAMETER

Materials for 100 Rg. ft.	Number or quantity.	Rate	Per	Amount	Labour for 100 Rg. ft.	Number or quantity.	Rate	Per	Amount
		Rs. a.		Rs. a.			Rs. a.		Rs. a.
50 pipes, each 2¼ ft. long .. No.	50	..	Each.	..	Excava t - ing trenches .. C.ft.	600	..	100	..
Portland cement.. C.ft.	½	..	C.ft.	..	Filling in and consolidating trenches .. ,,	600	..	100	..
Carriage of pipes ..	..	..	Lot.	..	Masons .. No.	3	..	Each	..
Spun yarn Lbs.	2	..	Lb.	..	Coolies .. ,,	3	..	,,	..
Sundries	..	..	..	..	Watchmen ,,	3	..	,,	..
					Sundries.. ..	..	..	..	..
	Total, materials ..			..	Total, labour ..				..
					Total, materials ..				..
					Add—for concrete where required.. C.ft.	125@			
					Total for 100 Rg. ft. piping ..				..
					or, per Rg. ft. ..				

RATE ABSTRACT No. 144

STATEMENT SHOWING DETAILS OF PROVIDING AND LAYING STONEWARE PIPES (JUBBULPORE MAKE)

Diamr. of pipe in inches	Thickness of pipes in inches	Length of pipe in Feet	Wt. per pipe in lbs.	Cost per pipe F. O. R. Jubbulpore 1921	Allowance for breakage, etc., at 5 per cent	Railway freight including siding and other terminal charges at Rs. 1-2-0 a maund	Carriage to site from station lead up to 2 miles at 0-0-3 per 10 lb.	Total cost per pipe at site of work
				Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.
4″	⅝″	2 ft.	20½	0 12 6	0 0 7	0 4 6	0 0 6	1 2 1
6″	¾″	,,	32	1 0 6	0 0 9	0 7 3	0 0 9	1 9 3
7″	¾″	,,	38	1 6 0	0 1 1	0 8 7	0 0 11	2 0 7]
9″	⅞″	,,	64	2 0 0	0 1 7	0 14 5	0 1 7	3 1 7]
12″	1″	,,	100	3 5 0	0 2 7	1 6 8	0 2 6	5 0 7
15″	1¼″	,,	130	4 12 0	0 4 0	1 13 3	0 3 3	7 0 6
18″	1½″	,,	180	8 4 0	0 6 6	2 8 6	0 4 6	11 7 6

Cost per ft. run	Local cost of single junction including railway freight and carriage	Cost of junction spread over 30 ft.	Cost of laying per ft. run as per attached statement	Cost per ft. run.	Cost with current rates allowing for fluctuations in railway, Labour charges, etc.	Remarks	Diamr. of pipe in inches
Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.	Rs. a. p.		
0 9 0	3 0 0	0 1 6	0 3 0	0 13 6	1 4 0	These rates do not include the cost of excavation and that of concrete where required.	4″
0 12 8	4 0 0	0 2 2	0 4 0	1 2 10	1 8 0		6″
1 0 3	4 8 0	0 2 6	0 4 6	1 7 3	1 12 0		7″
1 8 9	6 0 0	0 3 5	0 6 6	2 2 6	2 4 0		9″
2 8 3	8 0 0	0 4 3	0 7 0	3 3 6	3 8 0		12″
3 8 3	12 0 0	0 6 5	0 10 0	4 8 8	4 12 0		15″
5 11 9	20 8 0	0 10 11	0 11 0	7 1 8	7 8 0		18″

Statement showing details for laying stoneware pipes (Jubbulpore make)

Diamr. of pipe in inches	Length of the pipe in feet	Quantity of cement for 100 R. ft.			Quantity of spun yarn for 100 R. ft.			Sundries for materials	Total cost for material per 100 R. ft.	Masons for jointing for 100 R. ft.		
		C. ft.	Rate	Amount	Lbs.	Rate	Amount			No.	Rate	Amount
			Rs.			Rs. a. p.					Rs. a. p.	0
4″	2′	·50	4	2·00	2	0 12 0	1·50	0·75	4·25	3	2 0 0	6·0
6″	2′	1·14	4	4·56	3	0 12 0	2·25	0·75	7·56	4	2 0 0	8·0
7″	2′	1·28	4	5·12	3½	0 12 0	2·62	0·75	8·49	4	2 0 0	8·0
9″	2′	2·17	4	8·68	4½	0 12 0	3·37	0·87	12·92	6	2 0 0	12·0
12″	2′	2·52	4	10·08	6	0 12 0	4·50	1·00	15·58	6	2 0 0	12·0
15″	2′	5·76	4	23·04	7½	0 12 0	5·62	1·25	29·91	7	2 0 0	14·0
18″	2′	5·89	4	23·56	9	0 12 0	6·75	1·25	31·56	8	2 0 0	16·0

Coolies and women, etc.			Sundries for labour	Testing joints, etc., 10 per cent of cost of labour	Total cost for labour for 100 R. ft.	Total cost for material and labour for 100 R. ft.	Net cost for laying per foot run	Cost to be adopted per R. ft.	Diamr. of pipe in inches
No.	Rate	Amount							
	Annas	Rs.					Rs. a. p.	Rs. a. p.	
6 3	10 5	3·75 0·93	1·00	1·16	12·84	17·00	0 2 9	0 3 0	4″
8 4	10 5	5·00 1·25	1·50	1·57	17·32	24·38	0 4 0	0 4 0	6″
8 4	10 5	5·00 1·25	1·50	1·57	17·32	25·81	0 4 2	0 4 6	7″
12 6	10 5	7·50 1·87	2·00	2·33	25·70	38·62	0 6 2	0 6 6	9″
12 6	10 5	7·50 1·87	2·50	2·38	26·25	41·83	0 6 8	0 7 0	12″
14 7	10 5	8·75 2·19	2·50	2·75	30·19	60·10	0 9 7	0 10 0	15″
16 8	10 5	01·00 2·50	2·75	3·12	34·37	65·93	0 10 6	0 11 0	18″

P. W. D. HANDBOOK

BOMBAY

Volume II
SECTION VIII

MISCELLANEOUS

1949

CHAPTER XIII

Tables of interests, annuities, present values, sinking funds and conversions of units into those of higher or lower values.

TABLE CCXXII

THE AMOUNT OF ONE RUPEE AT COMPOUND INTEREST FOR A TERM OF YEARS

Example.—Rs. 100 bearing interest at 5 per cent will amount to Rs. 265·3 at the end of 20 years.

Interest 2 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value
1	1·029	26	1·673	51	2·745	76	4·504
2	1·040	27	1·707	52	2·800	77	4·594
3	1·061	28	1·741	53	2·856	78	4·686
4	1·082	29	1·776	54	2·913	79	4·780
5	1·104	30	1·811	55	2·972	80	4·875
6	1·126	31	1·848	56	3·031	81	4·973
7	1·149	32	1·885	57	3·092	82	5·072
8	1·172	33	1·922	58	3·154	83	5·174
9	1·195	34	1·961	59	3·217	84	5·277
10	1·219	35	2·000	60	3·281	85	5·383
11	1·243	36	2·040	61	3·347	86	5·491
12	1·268	37	2·081	62	3·414	87	5·600
13	1·294	38	2·122	63	3·482	88	5·712
14	1·319	39	2·165	64	3·551	89	5·827
15	1·346	40	2·208	65	3·623	90	5·943
16	1·373	41	2·252	66	3·695	91	6·062
17	1·400	42	2·297	67	3·679	92	6·183
18	1·428	43	2·343	68	3·844	93	6·307
19	1·457	44	2·390	69	3·921	94	6·433
20	1·486	45	2·438	70	4·000	95	6·562
21	1·516	46	2·487	71	4·080	96	6·693
22	1·546	47	2·536	72	4·161	97	6·827
23	1·577	48	2·587	73	4·244	98	6·963
24	1·608	49	2·639	74	4·329	99	7·103
25	1·641	50	2·692	75	4·416	100	7·245

TABLE CCXXII.—THE AMOUNT OF ONE RUPEE, ETC.—*continued.*

2½ per cent.								3 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value
1	1·025	26	1·900	51	3·523	76	6·532	1	1·030	26	2·157	51	4·515	76	9·454
2	1·051	27	1·948	52	3·611	77	6·695	2	1,061	27	2·221	52	4·651	77	9·738
3	1·077	28	1,996	53	3·701	78	6·862	3	1·093	28	2·288	53	4·790	78	10·030
4	1·104	29	2·046	54	3·794	79	7·034	4	1·126	29	2·357	54	4·934	79	10·331
5	1·131	30	2·098	55	3·889	80	7·210	5	1·159	30	2·427	55	5·082	80	10·641
6	1·160	31	2·150	56	3·986	81	7·390	6	1·194	31	2·500	56	5·235	81	10·960
7	1·189	32	2·204	57	4·086	82	7·575	7	1·230	32	2·575	57	5·392	82	11·289
8	1·218	33	2·259	58	4·188	83	7·764	8	1·267	33	2·652	58	5·553	83	11·628
9	1·249	34	2·315	59	4·292	84	7·958	9	1·305	34	2·732	59	5·720	84	11·976
10	1·280	35	2·373	60	4.400	85	8·157	10	1·344	35	2·814	60	5·802	85	12·336
11	1·312	36	2·433	61	4·510	86	8·361	11	1·384	36	2·898	61	6·068	86	12·706
12	1·345	37	2·493	62	4·623	87	8·570	12	1·426	37	2·985	62	6·250	87	13·087
13	1·379	38	2·556	63	4·738	88	8·784	13	1·469	38	3·075	63	6·438	88	13·480
14	1·413	39	2·620	64	4·857	89	9·004	14	1·513	39	3·167	64	6·631	89	13·884
15	1·448	40	2·685	65	4·978	90	9·229	15	1·558	40	3·262	65	6·830	90	14·300
16	1·485	41	2·752	66	5·102	91	9·460	16	1·605	41	3·360	66	7·035	91	14·729
17	1·522	42	2·821	67	5·230	92	9·696	17	1·653	42	3·461	67	7·246	92	15·171
18	1·560	43	2·892	68	5·361	93	9·938	18	1·702	43	3·565	68	7·463	93	15·627
19	1·599	44	2·964	69	5·495	94	10·187	19	1·754	44	3·671	69	7·687	94	16·095
20	1·639	45	3·038	70	5·632	95	10·442	20	1·806	45	3·782	70	7·918	95	16·578
21	1·680	46	3·114	71	5·773	96	10·703	21	1·860	46	3·895	71	8·155	96	17·076
22	1·722	47	3·192	72	5·917	97	10·970	22	1·916	47	4·012	72	8·400	97	17·588
23	1·765	48	3·271	73	6·065	98	11·244	23	1·974	48	4·132	73	8·652	98	18·115
24	1·809	49	3·353	74	6·217	99	11·526	24	2·033	49	4·256	74	8·912	99	18·659
25	1·854	50	3·437	75	6·372	100	11·814	25	2·094	50	4·384	75	9·179	100	19·219

TABLE CCXXII.—THE AMOUNT OF ONE RUPEE, ETC.—*continued.*

3½ per cent.								4 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value
1	1·035	26	2·446	51	5·780	76	13·660	1	1·040	26	2·772	51	7·391	76	19·703
2	1·071	27	2·532	52	5·983	77	14·139	2	1·082	27	2·883	52	7·687	77	20·491
3	1·100	28	2·620	53	6·192	78	14·633	3	1·125	28	2·999	53	7·994	78	21·311
4	1·148	29	2·712	54	6·409	79	15·146	4	1·170	29	3·119	54	8·314	79	22·163
5	1·188	30	2·807	55	6·633	80	15·676	5	1·217	30	3·243	55	8·646	80	23·050
6	1·229	31	2·905	56	6·865	81	16·224	6	1·265	31	3·373	56	8·992	81	23·972
7	1·272	32	3·007	57	7·106	82	16·792	7	1·316	32	3·508	57	9·352	82	24·931
8	1·317	33	3·112	58	7·354	83	17·380	8	1·369	33	3·648	58	9·726	83	25·928
9	1·363	34	3·221	59	7·612	84	17·988	9	1·423	34	3·794	59	10·115	84	26·965
10	1·411	35	3·334	60	7·878	85	18·618	10	1·480	35	3·946	60	10·520	85	28·044
11	1·460	36	3·450	61	8·154	86	19·269	11	1·539	36	4·104	61	10·940	86	29·165
12	1·511	37	3·571	62	8·439	87	19·944	12	1·601	37	4·268	62	11·378	87	30·332
13	1·564	38	3·696	63	8·735	88	20·642	13	1·665	38	4·439	63	11·833	88	31·545
14	1·619	39	3·825	64	9·040	89	21·364	14	1·732	39	4·616	64	12·306	89	32·807
15	1·675	40	3·959	65	9·357	90	22·112	15	1·801	40	4·801	65	12·799	90	34·119
16	1·734	41	4·098	66	9·684	91	22·886	16	1·873	41	4·993	66	13·311	91	35·484
17	1·795	42	4·241	67	10·023	92	23·687	17	1·948	42	5·193	67	13·843	92	36·903
18	1·857	43	4·390	68	10·374	93	24·516	18	2·026	43	5·400	68	14·397	93	38·380
19	1·923	44	4·543	69	10·737	94	25·374	19	2·107	44	5·617	69	14·973	94	39·915
20	1·990	45	4·702	70	11·113	95	26·362	20	2·191	45	5·841	70	15·572	95	41·511
21	2·059	46	4·867	71	11·502	96	27·182	21	2·279	46	6·075	71	16·194	96	43·172
22	2·132	47	5·037	72	11·904	97	28·133	22	2·370	47	6·318	72	16·842	97	44·899
23	2·206	48	5·214	73	12·321	98	29·118	23	2·465	48	6·571	73	17·561	98	46·695
24	2·283	49	5·396	74	12·752	99	30·157	24	2·563	49	6·833	74	18·217	99	48·562
25	2·363	50	5·585	75	13·199	100	31·191	25	2·666	50	7·107	75	18·945	100	50·505

TABLE CCXXII.—THE AMOUNT OF ONE RUPEE, ETC.—*continued*.

4½ per cent.								5 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value
1	1·045	26	3·141	51	9·439	76	28·369	1	1·050	26	3·556	51	12·041	76	40·774
2	1·092	27	3·282	52	9·864	77	29·645	2	1·103	27	3·733	52	12·643	77	42·813
3	1·141	28	3·430	53	10·308	78	30·979	3	1·158	28	3·920	53	13·275	78	44·954
4	1·193	29	3·584	54	10·772	79	32·373	4	1·216	29	4·116	54	13·939	79	47·201
5	1·246	30	3·745	55	11·256	80	33·830	5	1·276	30	4·322	55	14·636	80	49·561
6	1·302	31	3·914	56	11·763	81	35·352	6	1·340	31	4·538	56	15·367	81	52·040
7	1·361	32	4·090	57	12·292	82	36·943	7	1·407	32	4·765	57	16·136	82	54·641
8	1·422	33	4·274	58	12·845	83	38·606	8	1·477	33	5·003	58	16·943	83	57·374
9	1·486	34	4·466	59	13·423	84	40·343	9	1·551	34	5·253	59	17·790	84	60·242
10	1·553	35	4·667	60	14·027	85	42·158	10	1·629	35	5·156	60	18·679	85	63·254
11	1·623	36	4·877	61	14·659	86	44·056	12	1·710	36	5·792	61	19·613	86	66·417
12	1·696	37	5·097	62	15·318	87	46·038	12	1·796	37	6·081	62	20·594	87	69·738
13	1·772	38	5·326	63	16·008	88	48·110	13	1·886	38	6·385	63	21·623	88	73·225
14	1·852	39	5·566	64	16·728	89	50·275	14	1·980	39	6·705	64	22·705	89	76·886
15	1·935	40	5·816	65	17·481	90	52·537	15	2·079	40	7·040	65	23·840	90	80·730
16	2·022	41	6·078	66	18·267	91	54·901	16	2·183	41	7·392	66	25·032	91	84·767
17	2·113	42	6·352	67	19·089	92	57·372	17	2·292	42	7·762	67	26·283	92	89·005
18	2·208	43	6·637	68	19·948	93	59·954	18	2·407	43	8·150	68	27·598	93	93·455
19	2·308	44	6·936	69	20·846	94	62·651	19	2·527	44	8·557	69	28·978	94	98·128
20	2·412	45	7·248	70	21·784	95	65·471	20	2·653	45	8·985	70	30·426	95	103·035
21	2·520	46	7·574	71	22·764	96	68·417	21	2·786	46	9·434	71	31·948	96	108·186
22	2·634	47	7·915	72	23·789	97	71·496	22	2·925	47	9·906	72	33·545	97	113·596
23	2·752	48	8·271	73	24·859	98	74·713	23	3·072	48	10·401	73	35·222	98	119·276
24	2·876	49	8·644	74	25·978	99	78·075	24	3·225	49	10·921	74	36·984	99	125·239
25	3·005	50	9·033	75	27·147	100	81·589	25	3·386	50	11·467	75	38·833	100	131·501

TABLE CCXXII.—THE AMOUNT OF ONE RUPEE, ETC.—*continued.*

6 per cent.								7 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value
1	1·060	26	4·549	51	19·525	76	83·800	1	1·070	26	5·807	51	31·519	76	171·07
2	1·124	27	4·822	52	20·697	77	88·828	2	1·145	27	6·214	52	33·725	77	183·40
3	1·191	28	5·112	53	21·939	78	94·158	3	1·225	28	6·649	53	36·086	78	195·86
4	1·262	29	5·418	54	23·255	79	99·808	4	1·311	29	7·114	54	38·612	79	209·56
5	1·338	30	5·743	55	24·650	80	105·796	5	1·403	30	7·612	55	41·315	80	224·23
6	1·419	31	6·088	56	26·129	81	112·144	6	1·501	31	8·145	56	44·207	81	239·93
7	1·504	32	6·453	57	27·697	82	118·872	7	1·606	32	8·715	57	47·302	82	256·73
8	1·594	33	6·841	58	29·359	83	126·005	8	1·718	33	9·325	58	50·613	83	274·70
9	1·689	34	7·251	59	31·120	84	133·565	9	1·838	34	9·978	59	54·156	84	293·93
10	1·791	35	7·686	60	32·988	85	141·579	10	1·967	35	10·677	60	57·946	85	314·50
11	1·898	36	8·147	61	34·967	86	150·074	11	2·105	36	11·424	61	62·003	86	336·52
12	2·012	37	8·636	62	37·065	87	159·078	12	2·252	37	12·224	62	66·343	87	360·07
13	2·133	38	9·154	63	39·289	88	168·623	13	2·410	38	13·079	63	70·987	88	385·28
14	2·261	39	9·704	64	41·646	89	178·740	14	2·579	39	13·995	64	75·956	89	412·25
15	2·397	40	10·286	65	44·145	90	189·465	15	2·759	40	14·974	65	81·273	90	441·10
16	2·540	41	10·903	66	46·794	91	200·832	16	2·952	41	16·023	66	86·962	91	471·98
17	2·693	42	11·557	67	49·601	92	212·882	17	3·159	42	17·144	67	93·049	92	505·02
18	2·854	43	12·250	68	52·577	93	225·655	18	3·380	43	18·344	68	99·563	93	540·37
19	3·026	44	12·985	69	55·732	94	239·195	19	3·617	44	19·628	69	106·532	94	578·20
20	3·207	45	13·765	70	59·076	95	253·546	20	3·870	45	21·002	70	113·989	95	618·67
21	3·400	46	14·590	71	62·620	96	268·759	21	4·141	46	22·473	71	121·969	96	661·98
22	3·604	47	15·466	72	66·378	97	284·885	22	4·430	47	24·046	72	130·506	97	708·32
23	3·820	48	16·394	73	70·360	98	301·978	23	4·741	48	25·729	73	139·642	98	757·90
24	4·049	49	17·378	74	74·582	99	320·096	24	5·072	49	27·530	74	149·417	99	810·95
25	4·202	50	18·420	75	79·057	100	339·302	25	5·427	50	29·457	75	158·876	100	867·72

TABLE CCXXII.—THE AMOUNT OF ONE RUPEE, ETC.—*continued*.

8 per cent.								9 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value
1	1·080	26	7·396	51	50·65	76	346·90	1	1·090	26	9·399	51	81·05	76	698·9
2	1·166	27	7·988	52	54·71	77	374·65	2	1·188	27	10·245	52	88·34	77	761·8
3	1·260	28	8·627	53	59·08	78	404·63	3	1·295	28	11·167	53	96·30	78	830·4
4	1·360	29	9·317	54	63·81	79	437·00	4	1·412	29	12·172	54	104·96	79	905·1
5	1·469	30	10·063	55	68·91	80	471·95	5	1·539	30	13·268	55	114·41	80	986·6
6	1·587	31	10·868	56	74·43	81	509·71	6	1·677	31	14·462	56	124·71	81	1075·3
7	1·714	32	11·737	57	80·38	82	550·49	7	1·828	32	15·763	57	135·93	82	1172·1
8	1·851	33	12·676	58	86·81	83	594·53	8	1·993	33	17·182	58	148·16	83	1277·6
9	1·999	34	13·690	59	93·76	84	642·90	9	2·172	34	18·728	59	161·50	84	1392·6
10	2·159	35	14·785	60	101·26	85	693·46	10	2·367	35	20·414	60	176·03	85	1517·9
11	2·332	36	15·968	61	109·36	86	748·93	11	2·580	36	22·251	61	191·87	86	1654·5
12	2·518	37	17·246	62	118·11	87	808·85	12	2·813	37	24·254	62	209·14	87	1803·5
13	2·720	38	18·625	63	127·55	88	873·56	13	3·066	38	26·437	63	227·97	88	1965·8
14	2·937	39	20·115	64	137·76	89	943·44	14	3·342	39	28·816	64	248·48	89	2142·7
15	3·172	40	21·725	65	148·78	90	1018·92	15	3·643	40	31·409	65	270·85	90	2335·5
16	3·426	41	23·462	66	160·68	91	1100·43	16	3·970	41	34·236	66	295·22	91	2545·7
17	3·700	42	25·339	67	173·54	92	1188·46	17	4·328	42	37·318	67	321·79	92	2774·8
18	3·996	43	27·367	68	187·42	93	1283·54	18	4·717	43	40·676	68	350·75	93	3024·6
19	4·316	44	29·556	69	202·41	94	1386·22	19	5·142	44	44·337	69	382·32	94	3296·8
20	4·661	45	31·920	70	218·61	95	1497·12	20	5·604	45	48·327	70	416·73	95	3593·5
21	5·034	46	34·474	71	236·09	96	1616·89	21	6·109	46	52·677	71	454·24	96	3916·9
22	5·437	47	37·232	72	254·98	97	1746·24	22	6·659	47	57·418	72	495·12	97	4269·4
23	5·871	48	40·211	73	275·38	98	1885·94	23	7·258	48	62·585	73	539·68	98	4653·7
24	6·341	49	43·427	74	297·41	99	2036·82	24	7·911	49	68·218	74	588·25	99	5072·5
25	6·848	50	46·902	75	321·20	100	2199·76	25	8·623	50	74·358	75	641·19	100	5529·0

TABLE CCXXII.—THE AMOUNT OF ONE RUPEE ETC.—*continued.*

10 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value
1	1·100	26	11·918	51	129·13	76	1399·1
2	1·210	27	13·110	52	142·04	77	1539·0
3	1·331	28	14·421	53	156·26	78	1692·9
4	1·464	29	15·863	54	171·87	79	1862·2
5	1·611	30	17·449	55	189·06	80	2048·4
6	1·772	31	19·194	56	207·97	81	2253·2
7	1·949	32	21·114	57	228·76	82	2478·6
8	2·144	33	23·225	58	251·64	83	2726·4
9	2·358	34	25·548	59	276·80	84	2999·1
10	2·594	35	28·102	60	304·48	85	3299·0
11	2·853	36	30·913	61	334·93	86	3628·9
12	3·138	37	34·004	62	368·42	87	3991·8
13	3·452	38	37·404	63	405·27	88	4390·9
14	3·797	39	41·145	64	445·79	89	4830·0
15	4·177	40	45·259	65	490·37	90	5315·0
16	4·595	41	49·785	66	539·41	91	5844·3
17	5·054	42	54·764	67	593·35	92	6428·8
18	5·560	43	60·240	68	652·68	93	7071·6
19	6·116	44	66·264	69	717·95	94	7778·8
20	6·727	45	72·890	70	789·75	95	8556·7
21	7·400	46	80·180	71	868·72	96	9412·3
22	8·140	47	88·197	72	955·59	97	10353·6
23	8·954	48	97·017	73	1051·15	98	11388·9
24	9·850	49	106·719	74	1156·27	99	12527·8
25	10·835	50	117·391	75	1271·90	100	13780·6

TABLE CCXXIII

THE AMOUNT OF ONE RUPEE PER ANNUM WITH COMPOUND INTEREST AT THE END OF A TERM OF YEARS

Example.—A yearly sum of Rs. 10 invested at 5 per cent compound interest will accumulate to Rs. 3,306·6 at the end of 20 years.

Interest 2 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value
1	1·000	26	33·671	51	87·271	76	175·208
2	2·020	27	35·344	52	90·016	77	179·712
3	3·060	28	37·051	53	92·817	78	184·306
4	4·122	29	38·792	54	95·673	79	188·992
5	5·204	30	40·568	55	98·587	80	193·772
6	6·308	31	42·379	56	101·558	81	198·647
7	7·434	32	44·227	57	104·589	82	203·620
8	8·583	33	46·112	58	107·681	83	208·693
9	9·755	34	48·034	59	110·835	84	213·867
10	10·950	35	49·994	60	114·052	85	219·144
11	12·169	36	51·994	61	117·333	86	224·527
12	13·412	37	54·034	62	120·679	87	230·017
13	14·680	38	56·115	63	124·093	88	235·618
14	15·974	39	58·237	64	127·575	89	241·330
15	17·293	40	60·402	65	131·126	90	247·157
16	18·639	41	62·610	66	134·749	91	253·100
17	20·012	42	64·862	67	138·444	92	259·162
18	21·412	43	67·159	68	142·213	93	265·345
19	22·841	44	69·503	69	146·057	94	271·652
20	24·297	45	71·893	70	149·978	95	278·085
21	25·783	46	74·331	71	153·977	96	284·047
22	27·299	47	76·817	72	158·057	97	201·340
23	28·845	48	79·354	73	162·218	98	298·166
24	30·422	49	81·941	74	166·463	99	305·130
25	32·030	50	84·579	75	170·792	100	312·232

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TABLE CCXXIII—THE AMOUNT OF ONE RUPEE PER ANNUM, ETC.—*continued.*

2½ per cent.								3 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value
1	1·000	26	36·012	51	100·921	76	221·261	1	1·000	26	38·553	51	117·181	76	281·810
2	2·025	27	37·912	52	104·444	77	227·792	2	2·030	27	40·710	52	121·696	77	291·264
3	3·076	28	39·860	53	108·056	78	234·487	3	3·091	28	42·931	53	126·347	78	301·002
4	4·153	29	41·856	54	111·757	79	241·349	4	4·184	29	45·219	54	131·137	79	311·032
5	5·256	30	43·903	55	115·551	80	248·383	5	5·309	30	47·575	55	136·072	80	321·363
6	6·388	31	46·000	56	119·440	81	255·592	6	6·468	31	50·003	56	141·154	81	332·004
7	7·547	32	48·150	57	123·426	82	262·982	7	7·662	32	52·503	57	146·388	82	342·964
8	8·736	33	50·354	58	127·511	83	270·557	8	8·892	33	55·078	58	151·780	82	354·253
9	9·955	34	52·613	59	131·699	84	278·321	9	10·159	34	57·730	59	157·333	84	365·881
10	11·203	35	54·928	60	135·992	85	286·279	10	11·464	35	60·462	60	163·053	85	377·857
11	12·483	36	57·301	61	140·391	86	294·436	11	12·808	36	63·276	61	168·945	86	390·193
12	13·796	37	59·734	62	144·901	87	302·796	12	14·192	37	66·174	62	175·013	87	402·898
13	15·140	38	62·227	63	149·524	88	311·366	13	15·618	38	69·159	63	181·264	88	415·985
14	16·519	39	64·783	64	154·262	89	320·150	14	17·086	39	72·234	64	187·702	89	429·465
15	17·932	40	67·403	65	159·118	90	329·154	15	18·599	40	75·401	65	194·333	90	443·349
16	19·380	41	70·088	66	164·096	91	338·283	16	20·157	41	78·663	66	201·163	91	457·649
17	20·865	42	72·840	67	169·199	92	347·843	17	21·762	42	82·023	67	208·198	92	472·379
18	22·386	43	75·661	68	174·429	93	357·539	18	23·414	43	85·484	68	215·444	93	487·550
19	23·946	44	78·552	69	179·789	94	367·477	19	25·117	44	89·048	69	222·907	94	503·177
20	25·545	45	81·516	70	185·284	95	377·664	20	26·870	45	92·720	70	230·594	95	519·272
21	27·183	46	84·554	71	190·916	96	388·106	21	28·676	46	96·501	71	238·512	96	535·850
22	28·863	47	87·668	72	196·689	97	398·808	22	30·537	47	100·397	72	246·667	97	552·926
23	30·584	48	90·860	73	202·606	98	409·779	23	32·453	48	104·408	73	255·067	98	570·513
24	32·349	49	94·131	74	208·672	99	421·023	24	34·426	49	108·541	74	263·719	99	588·629
25	34·158	50	97·484	75	214·888	100	432·549	25	36·459	50	112·797	75	272·631	100	607·288

TABLE CCXXIII—THE AMOUNT OF ONE RUPEE, ETC.—*cont.*

3½ per cent.								4 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value
1	1·000	26	41·313	51	136·583	76	361·729	1	1·000	26	44·312	51	159·774	76	467·677
2	2·035	27	43·759	52	142·363	77	375·389	2	2·040	27	47·084	52	167·165	77	487·280
3	3·106	28	46·291	53	148·346	78	389·528	3	3·122	28	49·968	53	174·851	78	507·771
4	4·215	29	48·911	54	154·538	79	404·161	4	4·246	29	52·966	54	182·845	79	529·082
5	5·362	30	51·623	55	160·947	80	419·307	5	5·416	30	56·085	55	191·159	80	551·245
6	6·550	31	54·429	56	167·580	81	434·983	6	6·633	31	59·328	56	199·806	81	574·295
7	7·779	32	57·335	57	174·445	82	451·207	7	7·898	32	62·701	57	208·798	82	598·267
8	9·052	33	60·341	58	181·551	83	467·999	8	9·214	33	66·210	58	218·150	83	623·197
9	10·368	34	63·453	59	188·905	84	485·379	9	10·583	34	69·858	59	227·876	84	649·125
10	11·731	35	66·674	60	196·517	85	503·367	10	12·006	35	73·652	60	237·991	85	676·090
11	13·142	36	70·008	61	204·395	86	521·985	11	13·486	36	77·598	61	248·519	86	704·134
12	14·602	37	73·458	62	212·549	87	541·255	12	15·026	37	81·702	62	259·451	87	733·299
13	16·113	38	77·029	63	220·988	88	561·199	13	16·627	38	85·970	63	270·829	88	763·631
14	17·677	39	80·725	64	220·723	89	581·841	14	18·292	39	90·409	64	282·662	89	795·176
15	19·296	40	84·550	65	238·763	90	603·205	15	20·024	40	95·026	65	294·968	90	827·983
16	20·971	41	88·510	66	248·120	91	625·317	16	21·825	41	99·827	66	307·767	91	862·103
17	22·705	42	92·007	67	257·804	92	648·203	17	23·698	42	104·820	67	321·078	92	897·587
18	24·500	43	96·849	68	267·827	93	671·890	18	25·645	43	110·012	68	334·921	93	934·490
19	26·357	44	101·238	69	278·201	94	696·407	19	27·671	44	115·413	69	349·318	94	972·870
20	28·280	45	105·782	70	288·938	95	721·781	20	29·778	45	121·029	70	364·290	95	1012·785
21	30·269	46	110·484	71	300·051	96	748·043	21	31·969	46	126·871	71	379·862	96	1054·296
22	32·329	47	115·351	72	311·553	97	775·225	22	34·248	47	132·945	72	396·057	97	1097·468
23	34·460	48	120·388	73	323·457	98	803·358	23	36·618	48	139·263	73	412·899	98	1142·367
24	36·667	49	125·602	74	335·778	99	832·475	24	39·083	49	145·834	74	430·415	99	1189·061
25	38·950	50	130·998	75	348·530	100	862·612	25	41·646	50	152·667	75	418·631	100	1237·624

TABLE CCXXIII—THE AMOUNT OF ONE RUPEE PER ANNUM ETC.—*cont.*

4½ per cent.								5 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value
1	1·000	26	47·571	51	187·536	76	608·191	1	1·000	26	51·113	51	220·815	76	795·486
2	2·045	27	50·711	52	196·975	77	636·500	2	2·050	27	54·669	52	232·856	77	836·261
3	3·137	28	53·993	53	206·839	78	666·205	3	3·153	28	58·403	53	245·499	78	879·074
4	4·278	29	57·423	54	217·146	79	697·184	4	4·310	29	62·323	54	258·774	79	924·027
5	5·471	30	61·007	55	227·918	80	729·558	5	5·526	30	66·439	55	272·713	80	971·229
6	6·717	31	64·752	56	239·174	81	763·888	6	6·802	31	70·761	56	287·348	81	1020·790
7	8·019	32	68·666	57	250·937	82	798·740	7	8·142	32	75·299	57	302·716	82	1072·830
8	9·380	33	72·756	58	263·229	83	835·684	8	9·549	33	80·064	58	318·851	83	1127·471
9	10·802	34	77·030	59	276·075	84	874·289	9	11·027	34	85·067	59	335·794	84	1184·845
10	12·288	35	81·497	60	289·498	85	914·632	10	12·578	35	90·320	60	353·584	85	1245·087
11	13·841	36	80·164	61	303·525	86	956·791	11	14·207	36	95·836	61	372·263	86	1308·341
12	15·464	37	91·041	62	318·184	87	1000·846	12	15·917	37	101·628	62	391·876	87	1374·758
13	17·160	38	96·138	63	333·502	88	1046·884	13	17·713	38	107·710	63	412·470	88	1444·496
14	18·932	39	101·464	64	349·510	89	1094·994	14	19·599	39	114·095	64	434·093	89	1517·721
15	20·784	40	107·030	65	366·238	90	1145·269	15	21·579	40	120·800	65	456·798	90	1594·607
16	22·719	41	112·847	66	383·719	91	1197·806	16	23·657	41	127·840	66	480·638	91	1675·338
17	24·742	42	118·925	67	401·986	92	1252·707	17	25·840	42	135·232	67	505·670	92	1760·105
18	26·855	43	125·276	68	421·075	93	1310·079	18	28·132	43	142·993	68	531·953	93	1849·110
19	29·064	44	131·914	69	441·024	94	1370·033	19	30·539	44	151·143	69	559·551	94	1942·565
20	31·371	45	138·850	70	461·870	95	1432·684	20	33·066	45	159·700	70	588·529	95	2040·694
21	33·783	46	146·098	71	483·654	96	1498·155	21	35·719	46	168·685	71	618·956	96	2143·728
22	36·303	47	153·673	72	506·418	97	1566·572	22	38·505	47	178·119	72	650·903	97	2251·915
23	38·937	48	161·588	73	530·207	98	1638·068	23	41·430	48	188·025	73	684·448	98	2365·510
24	41·689	49	169·859	74	555·066	99	1712·781	24	44·502	49	198·427	74	719·670	99	2484·786
25	44·565	50	178·503	75	581·044	100	1790·856	25	47·727	50	209·348	75	756·654	100	2610·025

TABLE CCXXIII—THE AMOUNT OF ONE RUPEE PER ANNUM ETC.—*cont.*

6 per cent.								7 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value
1	1·000	26	59·156	51	308·756	76	1380·006	1	1·000	26	68·676	51	435·986	76	2429·53
2	2·060	27	63·706	52	328·281	77	1463·806	2	2·070	27	74·484	52	467·505	77	2600·60
3	3·184	28	68·528	53	348·978	78	1552·634	3	3·215	28	80·698	53	501·230	78	2783·64
4	4·375	29	73·640	54	370·917	79	1646·792	4	4·440	29	87·347	54	537·316	79	2979·50
5	5·637	30	79·058	55	394·172	80	1746·600	5	5·751	30	94·461	55	575·929	80	3189·06
6	6·975	31	84·802	56	418·822	81	1852·396	6	7·153	31	102·073	56	617·244	81	3413·30
7	8·394	32	90·890	57	444·952	82	1964·540	7	8·654	32	110·218	57	661·451	82	3653·23
8	9·897	33	97·343	58	472·649	83	2083·412	8	10·260	33	118·933	58	708·752	83	3909·95
9	11·491	34	104·184	59	502·008	84	2209·417	9	11·978	34	128·259	59	759·365	84	4184·65
10	13·181	35	111·435	60	533·128	85	2342·982	10	13·816	35	138·237	60	813·520	85	4478·58
11	14·972	36	119·121	61	566·116	86	2484·561	11	15·784	36	148·913	61	871·467	86	4793·08
12	16·870	37	127·268	62	601·083	87	2634·634	12	17·888	37	160·337	62	933·469	87	5129·59
13	18·882	38	135·904	63	638·148	88	2793·712	13	20·141	38	172·561	63	999·812	88	5489·66
14	21·015	39	145·058	64	677·437	89	2962·335	14	22·550	39	185·640	64	1070·799	89	5874·94
15	23·276	40	154·762	65	719·083	90	3141·075	15	25·129	40	199·635	65	1146·755	90	6278·19
16	25·673	41	165·048	66	763·228	91	3330·540	16	27·888	41	214·610	66	1228·028	91	6728·29
17	28·213	42	175·951	67	810·022	92	3531·372	17	30·840	42	230·632	67	1314·900	92	7200·27
18	30·906	43	187·508	68	859·623	93	3744·254	18	33·999	43	247·776	68	1408·039	93	7705·29
19	33·760	44	199·758	69	912·200	94	3969·910	19	37·379	44	266·121	69	1507·602	94	8245·66
20	36·786	45	212·744	70	967·932	95	4209·104	20	40·995	45	285·749	70	1614·134	95	8823·85
21	39·993	46	226·508	71	1027·008	96	4462·651	21	44·865	46	306·752	71	1728·124	96	9442·52
22	43·392	47	241·099	72	1089·629	97	4731·410	22	49·006	47	329·224	72	1850·092	97	10104·50
23	46·996	48	256·565	73	1156·006	98	5016·294	23	53·436	48	353·270	73	1980·599	98	10812·81
24	50·816	49	272·958	74	1226·367	99	5318·272	24	58·177	49	378·990	74	2120·241	99	11570·71
25	54·865	50	290·336	75	1300·940	100	5648·368	25	63·249	50	406·529	75	2269·657	100	12381·66

TABLE CCXXIII—THE AMOUNT OF ONE RUPEE PER ANNUM ETC.—*cont.*

8 per cent.								9 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value	Years	Value
1	1·000	26	79·954	51	620·672	76	4323·76	1	1·000	26	93·32	51	889·44	76	7754·4
2	2·080	27	87·351	52	671·326	77	467·066	2	2·090	27	102·72	52	970·49	77	8453·3
3	3·246	28	95·339	53	726·332	78	5045·32	3	3.278	28	112·97	53	1058·83	78	9215·1
4	4·506	29	103·966	54	785·114	79	5449·94	4	4·573	29	124·14	54	1155·13	79	10045·5
5	5·867	30	113·283	55	848·923	80	5886·94	5	5·985	30	136·31	55	1260·09	80	10690·5
6	7·336	31	123·346	56	917·837	81	6358·89	6	7·523	31	149·58	56	1374·50	81	11937·1
7	8.923	32	134·214	57	992·264	82	6868·60	7	9·200	32	164.04	57	1499·21	82	13012·5
8	10·637	33	145·951	58	1072·645	83	7419·09	8	11·028	33	179·80	58	1635·13	83	14184·6
9	12·488	34	158·627	59	1159·457	84	8013·62	9	13·021	34	196·98	59	1783·30	84	15462·2
10	14·487	35	172·317	60	1253·213	85	8655·71	10	15·193	35	215·71	60	1944·79	85	16854·8
11	16·645	36	187·102	61	1354·470	86	9349·16	11	17·560	36	236·12	61	2120·82	86	18372·7
12	18·977	37	203·070	62	1463·828	87	10098·10	12	20·141	37	258·38	62	2312·70	87	20027·3
13	21·495	38	220·316	63	1581·934	88	10906·94	13	22·953	38	282·63	63	2521·84	88	21830·7
14	24·215	39	238·941	64	1709·489	89	11780·50	14	26·019	39	309·07	64	2749·81	89	23796·5
15	27·152	40	259·057	65	1847·248	90	12723·94	15	29·361	40	337·88	65	2998·29	90	25939·2
16	30·324	41	280·781	66	1996·028	91	13742·85	16	33·003	41	369·29	66	3269·13	91	28274·7
17	33·750	42	304·244	67	2156·710	92	14843·28	17	36·974	42	403·53	67	3564·36	92	30820·4
18	37·450	43	329·583	68	2330·247	93	16031·74	18	41·301	43	440·85	68	3886·15	93	33595·3
19	41·446	44	356·950	69	2517·667	94	17315·28	19	46·018	44	481·52	69	4236·90	94	36619·8
20	45·762	45	386·506	70	2720·080	95	18701·51	20	51·160	45	525·86	70	4619·22	95	39916·6
21	50·423	46	418·426	71	2938·636	96	20198·63	21	56·765	46	574·19	71	5035·95	96	43510·1
22	55·457	47	452·900	72	3174·781	97	21815·52	22	62·873	47	626·86	72	5490·19	97	47427·0
23	60·893	48	490·132	73	3429·764	98	23561·76	23	69·532	48	684·28	73	5985·31	98	51696·5
24	66·765	49	530·343	74	3705·145	99	25447·70	24	76·790	49	746·87	74	6524·98	99	56350·2
25	73·106	50	573·770	75	4002·557	100	27484·52	25	84·701	50	815·08	75	7113·23	100	61422·7

TABLE CCXXIII.—THE AMOUNT OF ONE RUPEE PER ANNUM ETC—*concld.*

10 per cent.							
Years	Value	Years	Value	Years	Value	Years	Value
1	1·000	26	109·18	51	1281·3	76	13980·8
2	2·100	27	121·10	52	1410·4	77	15379·9
3	3·310	28	134·21	53	1552·5	78	16918·9
4	4·641	29	148·63	54	1708·7	79	18611·8
5	6·105	30	164·49	55	1880·6	80	20474·0
6	7·716	31	181·94	56	2069·7	81	22522·4
7	9·487	32	201·14	57	2277·6	82	24775·6
8	11·436	33	222·25	58	2506·4	83	27254·2
9	13·579	34	245·48	59	2758·0	84	29980·6
10	15·937	35	271·02	60	3034·8	85	32979·7
11	18·531	36	299·13	61	3339·3	86	36278·7
12	21·384	37	330·04	62	3674·2	87	39907·5
13	24·523	38	364·04	63	4042·7	88	43899·3
14	27·975	39	401·45	64	4447·9	89	48290·2
15	31·772	40	442·59	65	4893·7	90	53120·2
16	35·950	41	487·85	66	5384·1	91	58433·2
17	40·545	42	537·64	67	5923·5	92	64277·6
18	45·599	43	592·40	68	6516·8	93	70706·3
19	51·159	44	652·64	69	7169·5	94	77778·0
20	57·275	45	718·90	70	7887·5	95	85556·8
21	64·002	46	791·80	71	8677·2	96	94113·4
22	71·403	47	871·97	72	9545·9	97	103525·8
23	79·543	48	960·17	73	10501·5	98	113879·4
24	88·497	49	1057·19	74	11552·7	99	125268·3
25	98·347	50	1163·91	75	12709·0	100	137796·1

TABLE CCXXIV

Present Value of Re. 1 per annum, allowing Interest on Capital at $3\frac{1}{2}$ per cent to 8 per cent. and 10 per cent. and for Redemption of Capital at 3 per cent to 8 per cent.

Example.—The present value of an annuity of Rs. 10 per annum for 20 years at 6 per cent replacing capital by investment at 3 per cent is—

		Rs.
Present value of Re. 1 per annum	=	10·286
Present value of Rs. 10	$=10 \times 10{\cdot}286=$	102·86

TABLE CCXXIV.

Present Value of Re. 1 Per Annum.

ALLOWING INTEREST ON CAPITAL AT $3\frac{1}{2}\%$

	And for Redemption of Capital at										
Years	3%	3½%	Years	3%	3½%	Years	3%	3½%	Years	3%	3½%
1	·966	·966	26	16·410	16·890	51	22·971	23·629	76	25·941	26·480
2	1·895	1·900	27	16·789	17·285	52	23·139	23·796	77	26·019	26·551
3	2·789	2·802	28	17·155	17·667	53	23·302	23·957	78	26·095	26·619
4	3·649	3·673	29	17·509	18·036	54	23·460	24·113	79	26·168	26·685
5	4·477	4·515	30	17·851	18·392	55	23·613	24·264	80	26·239	26·749
6	5·274	5·329	31	18·182	18·736	56	23·762	24·410	81	26·307	26·810
7	6.042	6·115	32	18·503	19·069	57	23·906	24·550	82	26·374	26·870
8	6·782	6·874	33	18·813	19·390	58	24·045	24·686	83	26·439	26·928
9	7·494	7·608	34	19·112	19·701	59	24·180	24·818	84	26·502	26·983
10	8·181	8·317	35	19·403	20·001	60	24·311	24·945	85	26·563	27·037
11	8·843	9·002	36	19·684	20·290	61	24·438	25·067	86	26·622	27·089
12	9·482	9·663	37	19·955	20·571	62	24·562	25·186	87	26·679	27·139
13	10·098	10·303	38	20·219	20·841	63	24·681	25·300	88	26·735	27·187
14	10·692	10·921	39	20·473	21·102	64	24·797	25·411	89	26·789	27·234
15	11·266	11·517	40	20·720	21·355	65	24·909	25·518	90	26·842	27·279
16	11·819	12·094	41	20·959	21·599	66	25·018	25·621	91	26·893	27·323
17	12·353	12·651	42	21·190	21·835	67	25·124	25·721	92	26·942	27·365
18	12·869	13·190	43	21·414	22·063	68	25·226	25·817	93	26·990	27·406
19	13·367	13·710	44	21·631	22·283	69	25·325	25·910	94	27·036	27·445
20	13·847	14·212	45	21·841	22·495	70	25·422	26·000	95	27·081	27·484
21	14·312	14·698	46	22·045	22·701	71	25·515	26·087	96	27·125	27·520
22	14·761	15·167	47	22·242	22·899	72	25·606	26·171	97	27·168	27·556
23	15·194	15·620	48	22·433	23·091	73	25·693	26·253	98	27·209	27·590
24	15·613	16·058	49	22·618	23·277	74	25·779	26·331	99	27·249	27·623
25	16·018	16·482	50	22·797	23·456	75	25·861	26·407	100	27·288	27·655
									PERP·	28·571	28·571

TABLE CCXXIV—*contd.*

Present Value of Re. 1 Per Annum.

ALLOWING INTEREST ON CAPITAL AT 4%

Years	And for Redemption of Capital at 3%	3½%	4%	Years	Years	3%	3½%	4%	Years
1	·962	·962	·962	1	26	15·166	15·575	15·983	26
2	1·878	1·882	1·886	2	27	15·488	15·910	16·330	27
3	2·751	2·763	2·775	3	28	15·799	16·233	16·663	28
4	3·584	3·607	3·630	4	29	16·099	16·544	16·984	29
5	4·379	4·415	4·452	5	30	16·388	16·843	17·292	30
6	5·139	5·190	5·242	6	31	16·667	17·131	17·588	31
7	5·865	5·933	6·002	7	32	16·936	17·409	17·874	32
8	6·559	6·646	6·733	8	33	17·195	17·676	18·148	33
9	7·224	7·329	7·435	9	34	17·445	17·934	18·411	34
10	7·860	7·985	8·111	10	35	17·687	18·182	18·665	35
11	8·469	8·614	8·760	11	36	17·920	18·422	18·908	36
12	9·053	9·218	9·385	12	37	18·145	18·652	19·143	37
13	9·613	9·798	9·986	13	38	18·362	18·874	19·368	38
14	10·150	10·355	10·563	14	39	18·572	19·088	19·584	39
15	10·665	10·890	11·118	15	40	18·775	19.295	19·793	40
16	11·159	11·404	11·652	16	41	18·971	19·494	19·993	41
17	11·634	11·899	12·166	17	42	19·160	19·686	20 186	42
18	12·091	12·374	12·659	18	43	19·343	19·871	20·371	43
19	12·529	12·830	13·134	19	44	19·520	20·049	20·549	44
20	12·951	13·269	13·590	20	45	19·691	20·221	20·720	45
21	13·356	13·692	14·029	21	46	19·856	20·387	20·885	46
22	13·746	14·098	14·451	22	47	20·016	20·547	21·043	47
23	14·122	14·489	14·857	23	48	20·170	20·701	21·193	48
24	14·483	14·865	15·247	24	49	20·320	20·850	21·341	49
25	14·831	15·227	15·622	25	50	20·464	20·994	21·482	50

TABLE CCXXIV—*contd.*

Present Value of Re. 1 Per Annum.

ALLOWING INTEREST ON CAPITAL AT 4%

Years	And for Redemption of Capital at			Years	Years				Years
	3%	3½%	4%			3%	3½%	4%	
51	20·604	21·132	21·617	51	76	22·963	23·384	23·731	76
52	20·739	21·266	21·748	52	77	23·024	23·439	23·780	77
53	20·870	21·394	21·873	53	78	23·083	23·492	23·827	78
54	20·997	21·519	21·993	54	79	23·140	23·544	23·872	79
55	21·120	21·639	22·109	55	80	23·196	23·593	23·915	80
56	21·238	21·755	22·220	56	81	23·249	23·641	28·957	81
57	21·353	21·866	22·327	57	82	23·301	23·638	23·997	82
58	21·465	21·974	22·430	58	83	23·352	23·732	24·036	83
59	21·572	22·078	22·528	59	84	23·401	23·775	24·073	84
60	21·676	22·179	22·623	60	85	23·440	23·817	24·109	85
61	21·777	22·275	22·715	61	86	23·495	23·857	24·143	86
62	21·875	22·369	22·803	62	87	23·539	23·896	24·176	87
63	21·970	22·459	22·887	63	88	23·583	23·934	24·207	88
64	22·062	22·546	22·969	64	89	23·625	23·970	24·238	89
65	22·150	22·630	23·047	65	90	23·666	24·005	24·267	90
66	22·237	22·712	23·122	66	91	23·705	23·039	24·295	91
67	22·320	22·790	23·194	67	92	23·743	24·072	24·323	92
68	22·401	22·866	23·264	68	93	23·781	24·103	24·349	93
69	22·479	22·939	23·330	69	94	23·817	24·134	24·374	94
70	22·555	23·009	23·395	70	95	23·852	24·163	24·398	95
71	22·628	23·077	23·456	71	96	23·886	24·192	24·421	96
72	22·699	23·143	23·516	72	97	23·919	24·219	24·443	97
73	22·768	23·206	23·573	73	98	23·950	24·245	24·465	98
74	22·835	23·268	23·628	74	99	23·981	24·271	24·485	99
75	22·900	23·327	23·680	75	100	24·012	24·296	24·505	100
					PERP·	25·000	25·000	25·000	PERP

TABLE CCXXIV—*contd.*

Present Value of Re. 1 Per Annum.

ALLOWING INTEREST ON CAPITAL AT 4½%

Years	And for Redemption of Capital at 3%	3½%	4%	4½%	Years	Years	3%	3½%	4%	4½%	Years
1	·957	·957	·957	·957	1	26	14·097	14·450	14·800	15·147	26
2	1.860	1·864	1·868	1·873	2	27	14·375	14·738	15·097	15·451	27
3	2·713	2·725	2·737	2·749	3	28	14·643	15·014	15·382	15·743	28
4	3·521	3·543	3·565	3·588	4	29	14·900	15·280	15·654	16·022	29
5	4·285	4·320	4·355	4·390	5	30	15·147	15·535	15·916	16·289	30
6	5·010	5·059	5·108	5·168	6	31	15·385	15·780	16·167	16·544	31
7	5·698	5·762	5·827	5·893	7	32	15·614	16·015	16·407	16·789	32
8	6·351	6·432	6·513	6·596	8	33	15·834	16·241	16·638	17·023	33
9	6·972	7·070	7·169	7·269	9	34	16·046	16·458	16·859	17·247	34
10	7·563	7·678	7·795	7·913	10	35	16·250	16·667	17·071	17·461	35
11	8·125	8·258	8·393	8·529	11	36	16·446	16·868	17·275	17·666	36
12	8·661	8·812	8·964	9·119	12	37	16·636	17·061	17·470	17·862	37
13	9·172	9·340	9·511	9·683	13	38	16·818	17·247	17·658	18·050	38
14	9·659	9·845	10·033	10·223	14	39	16·994	17·425	17·938	18·230	39
15	10·125	10·328	10·533	10·740	15	40	17·164	17·597	18·010	18·402	40
16	10·570	10·789	11·011	11·234	16	41	17·327	17·763	18·176	18·566	41
17	10·995	11·231	11·468	11·707	17	42	17·485	17·922	18·335	18·724	42
18	11·401	11·653	11·906	12·160	18	43	17·637	18·075	18·488	18·874	43
19	11·791	12·057	12·325	12·593	19	44	17·794	18·222	18·634	19·618	44
20	12·163	12·444	12·726	13·008	20	45	17·926	18·364	18·775	19·156	45
21	12·520	12·815	13·110	13·405	21	46	18·063	18·501	18·910	19·288	46
22	12·862	13·170	13·477	13·748	22	47	18·195	18·633	19·040	19·415	47
23	13·190	13·510	13·830	14·148	23	48	18·322	18·759	19·164	19·536	48
24	13·505	13·836	14·167	14·495	24	49	18·446	18·882	19·284	19·651	49
25	13·807	14·149	14·490	14·828	25	50	18·555	18·999	19·399	19·762	50

TABLE CCXXIV—*contd.*

Present Value of Re. 1 Per Annum.

ALLOWING INTEREST ON CAPITAL AT 4½%

Years	And for Redemption of Capital at										
	3%	3½%	4%	4½%	Years	Years	3%	3½%	4%	4½%	Years
51	18·680	19·113	19·509	19·868	51	76	20·598	20·936	21·214	21·439	76
52	18·791	19·222	19·615	19·969	52	77	29·647	20·980	21·253	21·473	77
53	18·898	19·327	19·716	20·066	53	78	20·694	21·023	21·290	21·505	78
54	19·002	19·428	19·814	20·159	54	79	20·746	21·064	21·326	21·536	79
55	19·103	19·526	19·908	20·248	55	80	20·785	21·104	21·361	21·565	80
56	19·200	19·620	19·998	20·333	56	81	20·838	21·142	21·394	21·594	81
57	19·293	19·711	20·085	20·411	57	82	20·870	21·179	21·621	21·621	82
58	19·384	19·799	20·168	20·492	58	83	20·911	21·215	21·457	21·647	83
59	19·472	19·883	20·248	20·567	59	84	20·950	21·249	21·487	21·671	84
60	19·557	19·965	20·324	20·638	60	85	20·988	21·283	21·515	21·695	85
61	19·639	20·043	20·398	20·706	61	86	21·025	21·315	21·542	21·718	86
62	19·718	20·119	20·469	20·772	62	87	21·061	21·346	21·569	21·740	87
63	19·795	20·192	20·537	20·834	63	88	21·095	21·376	21·594	21·760	88
64	19·870	20·262	20·603	20·894	64	89	21·129	21·405	21·618	21·780	89
65	19·942	20·330	20·665	20·951	65	90	21·162	21·433	21·641	21·799	90
66	20·012	20·396	20·726	21·006	66	91	21·193	21·460	21·664	21·817	91
67	20·079	20·459	20·784	21·058	67	92	21·224	21·486	21·685	21·835	92
68	20·144	20·520	20·840	21·108	68	93	21·254	21·511	21·706	21·852	93
69	20·208	20·578	20·893	21·156	69	94	21·282	21·535	21·726	21·868	94
70	20·269	20·635	20·945	21·202	70	95	21·310	21·558	21·745	21·883	95
71	20·328	20·690	20·994	21·246	71	96	21·337	21·581	21·763	21·897	96
72	20·386	20·743	21·042	21·288	72	97	21·364	21·603	21·781	21·911	97
73	20·441	20·794	21·087	21·328	73	98	21·389	21·624	21·798	21·925	98
74	20·495	20·843	21·131	21·367	74	99	21·414	21·644	21·815	21·938	99
75	20·547	20·890	21·173	21·404	75	100	21·438	21·664	21·830	21·950	100
						PERP.	22·222	22·222	22·222	22·222	PERP.

TABLE CCXXIV—*contd.*

Present Value of Re. 1 Per Annum.

ALLOWING INTEREST ON CAPITAL AT 5%

Yrs.	And for Redemption of Capital at												
	3%	3½%	4%	4½%	5%	Yrs.	Yrs.	3%	3½%	4%	4½%	5%	Yrs
1	·952	·952	·952	·952	·952	1	26	13·169	13·476	13·780	14·081	14·375	26
2	1·843	1·847	1·851	1·855	1·859	2	27	13·411	13·726	14·037	14·343	14·643	27
3	2·677	2·689	2·700	2·712	2·723	3	28	13·644	13·966	14·283	14·594	14·898	28
4	3·400	3·481	3·503	3·524	3·546	4	29	13·867	14·195	14·518	14·835	15·141	29
5	4·195	4·229	4·262	4·296	4·329	5	30	14·081	14·415	14·743	15·063	15·372	30
6	4·888	4·934	4·981	5·028	5·076	6	31	14·286	14·626	14·958	15·281	15·593	31
7	5·540	5·601	5·662	5·724	5·786	7	32	14·483	14·828	15·163	15·489	15·803	32
8	6·155	6·231	6·308	6·385	6·463	8	33	14·672	15·021	15·360	15·688	16·003	33
9	6·737	6·828	6·921	7·014	7·108	9	34	14·854	15·207	15·540	15·878	16·193	34
10	7·287	7·394	7·502	7·612	7·722	10	35	15·029	15·385	15·729	16·059	16·374	35
11	7·808	7 931	8·055	8·180	8·306	11	36	15·197	15·556	15·902	16·232	16·547	36
12	8·301	8·440	8·580	8·721	8·863	12	37	15·358	15·720	16·067	16·398	16·711	37
13	8·770	8·924	9·079	9·236	9·394	13	38	15·514	15·878	16·225	16·566	16·868	38
14	9·214	9·383	9·554	9 726	9·899	14	39	15·663	16·029	16·377	16·707	17·017	39
15	9·637	9·821	10·006	10·193	10·380	15	40	15·807	16·174	16·523	16·851	17·150	40
16	10·039	10·237	10·436	10·638	10·838	16	41	15·946	16·314	16·662	16·989	17·294	41
17	10·422	10·633	10·846	11·061	11·274	17	42	16·079	15·448	16·795	17·121	17·423	42
18	10·786	11·011	11·237	11·464	11·690	18	43	16·208	16·577	16·923	17·247	17·546	43
19	11·134	11·371	11·609	11·857	12·085	19	44	16·332	16·701	17·046	17·367	17·663	44
20	11·466	11·715	11·964	12·213	12·462	20	45	16·451	16·820	17·164	17·482	17·774	45
21	11·782	12·043	12·303	12·563	12·821	21	46	16·567	16·934	17·277	17·592	17·880	46
22	12·085	12 356	12·626	12·897	13·163	22	47	16·678	17·045	17·385	17·697	17·981	47
23	12·374	12·655	12 935	13·319	13·489	23	48	16·785	17·151	17·488	17·797	18,077	48
24	12·651	12·941	13·230	13·515	13·799	24	49	16·888	17·253	17·588	17·893	18·169	49
25	12·915	13·215	13·511	13·805	14·094	25	50	16·988	17·351	17·683	17·985	18·256	50

TABLE CCXXIV—*contd.*

Present Value of Re. 1 Per Annum

ALLOWING INTEREST ON CAPITAL AT 5%

Yrs.	And for Redemption of Capital at												
	3%	3½%	4%	4½%	5%	Yrs.	Yrs.	3	3½%	4%	4½%	5%	Yrs.
51	17.084	17.445	17.775	18.073	18.339	51	76	18.675	18.952	19.180	19.363	19.509	76
52	17.177	17.536	17 863	18.156	18.418	52	77	18.715	18.988	19.211	19.391	19.533	77
53	17.267	17.624	17.947	18.237	18.493	53	78	18.754	19 023	19.242	19.417	19.555	78
54	17.353	17.08	18.028	18.313	13.565	54	79	18.972	19.057	19 272	19.442	19.576	79
55	17.437	17.789	18.106	18.386	18.633	55	80	18.828	19.089	19.300	19 466	19.596	80
56	17.518	17.868	18.180	18.457	18.699	56	81	18.864	19.121	19.327	19.489	19.616	81
57	17.596	17.943	18.252	18.524	18.761	57	82	18.898	19.151	19.353	19.511	19.634	82
58	17.671	18.015	18.320	18.588	18.820	58	83	18.931	19.180	19.378	19.532	19.651	83
59	17.744	18 085	18.386	18.649	18.876	59	84	18.963	19.209	19.402	19.553	19.668	84
60	17.815	18.153	18.450	18.708	18.929	60	85	18.995	19.236	19.425	19.572	19.684	85
61	17,883	18.217	18.510	18.764	18.980	61	86	19.025	19.262	19.448	19.591	19.699	86
62	17.949	18.280	18.569	18.817	19.029	62	87	19.054	19.287	19.469	19.608	19.713	87
63	18.013	18.340	18.625	18.868	19.075	63	88	19.083	19.312	19.490	19 625	19.727	88
64	18.074	18.398	18.678	18.918	19.119	64	89	19.110	19.335	19.509	19.641	19 740	89
65	18 134	18.454	18.730	18.964	19.161	65	90	19.137	19.358	19.528	19.657	19.752	90
66	18.191	18.508	18.780	19.009	19.201	66	91	19.163	19.380	19.547	19.672	19.764	91
67	18.247	18.580	18.827	19.052	19.239	67	92	19.188	19.401	19.564	19.686	19.775	92
68	18.301	18.610	18.873	19.093	19.275	68	93	19.212	19.422	19.581	19.699	19.786	93
69	18.353	18.659	18.917	19.132	19.310	69	94	19.235	19.442	19.597	19.712	19.796	94
70	18.404	18.705	18.959	19.170	19.343	70	95	19.258	19.461	19.613	19.725	19.806	95
71	18.453	18.750	19.000	19.206	19.374	71	96	19.280	19.479	19.628	19.736	19.815	96
72	18.500	18.794	19.039	19.240	19.404	72	97	19.302	19.497	19.642	19.748	19.824	97
73	18.546	18.835	19.076	19.273	19.432	73	98	19.323	19.514	19.656	19.759	19. 832	98
74	18.590	18.876	19.112	19.304	19.459	74	90	19.343	19.531	19.669	19.769	19.840	99
75	18.633	18.915	19.146	19.335	19.485	75	100	19.362	19.547	19.682	19.779	19.848	100
							Perp	20.000	20.000	20.000	20.000	20.000	perp

TABLE CCXXIV—*contd.*

PRESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 5½%

And for Redemption of Capital at

Years	3%	3½%	4%	4½%	5%	5½%	Years	Years	3%	3½%	4%	4½%	5%	5½%	Years
1	·948	·948	·948	·948	·948	·948	1	26	12·355	12·625	12·892	13·154	13·411	13·662	26
2	1.826	1·830	1·834	1·838	1·842	1·846	2	27	12·568	12·845	13·117	13·383	13·644	13·898	27
3	2·642	2.653	2·664	2·675	2·687	2·698	3	28	12·772	13·054	13·331	13·602	13·865	14·121	28
4	3·401	3·422	3·442	3·463	3·484	3·505	4	29	12·968	13·255	13·535	13·809	14·075	14·333	29
5	4·109	4·141	4·173	4·205	4·238	4·270	5	30	13·155	13·446	13·731	14·007	14·275	14·534	30
6	4·771	4·815	8·460	4·905	4·950	4·996	6	31	13·334	13·629	13·917	14·196	14·465	14·724	31
7	5·391	5·448	5·506	5·565	5·624	5·683	7	32	13·505	13·804	14·095	14·375	14·646	14·904	32
8	5·972	6·043	6·115	6·188	6·261	6·335	8	33	13·669	13·972	14·265	14·547	14·817	15·075	33
9	6·517	6·603	6·689	6·776	6·864	6·952	9	34	13·827	14·132	14·427	14·710	14·979	15·237	34
10	7·031	7·131	7·231	7·333	7·435	7·538	10	35	13·978	14·286	14·582	14·865	15·135	15·391	35
11	7·514	7·628	7·743	7·859	7·975	8·093	11	36	14·124	14·433	14·730	15·014	15·282	15·536	36
12	7·971	8·098	8·227	8·357	8·487	8·619	12	37	14·263	14·574	14·872	15·155	15·423	15·674	37
13	8·401	8·543	8·685	8·828	8·972	9·117	13	38	14·397	14·710	15·008	15·290	15·556	15·805	38
14	8·809	8·963	9·118	9·275	9·432	9·590	14	39	14·526	14·839	15·138	15·419	15·683	15·929	39
15	9·194	9·361	9·295	9·698	9·868	10·038	15	40	14·649	14·964	15·262	15·542	15·803	16·046	40
16	9·559	9·739	9·919	10·099	10·281	10·462	16	41	14·768	15·083	15·381	15·659	15·918	16·157	41
17	9·906	10·097	10·288	10·480	10·672	10·865	17	42	14·883	15·198	15·494	15·771	16·027	16·263	42
18	10·235	10·437	10·639	10·842	11·044	11·246	18	43	14·993	15·308	15·603	15·878	16·131	16·363	43
19	10·546	10·760	10·972	11·185	11·397	11·608	19	44	15·099	15·414	15·707	15·979	16·230	16·458	44
20	10·844	11·067	11·289	11·511	11·731	11·950	20	45	15·201	15·515	15·807	16·077	16·323	16·548	45
21	11·127	11·359	11·590	11·820	12·040	12·275	21	46	15·299	15·613	15·903	16·169	16·413	16·633	46
22	11·396	11·637	11·877	12·114	12·351	12·583	22	47	15·394	15·706	15·994	16·258	16·498	16·714	47
23	11·653	11·902	12·149	12·394	12·636	12·875	23	48	15·485	15·796	16·082	16·343	16·579	16·790	48
24	11·898	12·155	12·409	12·660	12·908	13·152	24	49	15·573	15·883	16·166	16·424	16·656	16·863	49
25	12·132	12·396	12·656	12·913	13·166	13·414	25	50	15·658	15·966	16·247	16·501	16·729	16·932	50

TABLE CCXXIV

PRESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 5½ per cent.

And for Redemption of Capital at

Years	3%	3½%	4%	4½%	5%	5½%	Years	Years	3%	3½%	4%	4½%	5%	5½%	Years
51	15·740	16·046	16·324	16·575	16·799	16·997	51	76	17·080	17·312	17·502	17·654	17·776	17·871	76
52	15·818	16·123	16·398	16·645	16·865	17·058	52	77	17·114	17·342	17·528	17·677	17·795	17·887	77
53	15·895	16·197	16·460	16·713	16·928	17·117	53	78	17·146	17·371	17·553	17·699	17·813	17·903	78
54	15·968	16·268	16·537	16·777	16·988	17·173	54	79	17·178	17·399	17·578	17·720	17·831	17·917	79
55	16·039	16·336	16·603	16·838	17·045	17·225	55	80	17·208	17·426	17·601	17·740	17·848	17·931	80
56	16·107	16·402	16·665	16·897	17·100	17·275	56	81	17·238	17·452	17·624	17·759	17·860	17·944	81
57	16·173	16·466	16·725	16·953	17·152	17·322	57	82	17·266	17·478	17·646	17·777	17·879	17·956	82
58	16·237	16·527	16·783	17·007	17·201	17·363	58	83	17·294	17·502	17·666	17·795	17·893	17·968	83
59	16·298	16·585	16·838	17·058	17·248	17·410	59	84	17·321	17·525	17·686	17·811	17·907	17·979	84
60	16·358	16·642	16·891	17·107	17·293	17·450	60	81	17·347	17·548	17·706	17·824	17·920	17·990	85
61	16·415	16·697	16·942	17·154	17·335	17·488	61	86	17·372	17·570	17·724	17·843	17·933	18·000	86
62	16·471	16·740	16·991	17·199	17·376	17·524	62	87	17·397	17·591	17·741	17·857	17·945	18·009	87
63	16·524	16·800	17·038	17·242	17·414	17·558	63	88	17·420	17·611	17·759	17·872	17·956	18·018	88
64	16·576	16·848	17·083	17·283	17·451	17·591	64	89	17·443	17·631	17·775	17·885	17·967	18·027	89
65	16·626	16·895	17·126	17·322	17·485	17·622	65	90	17·466	17·650	17·791	17·898	17·977	17·035	90
66	16·675	16·940	17·168	17·359	17·519	17·651	66	91	17·487	17·668	17·806	17·910	17·987	18·043	91
67	16·722	16·984	17·207	17·395	17·551	17·679	67	92	17·508	17·686	17·821	17·922	17·996	18·050	92
68	17·767	17·026	17·246	17·429	17·581	17·705	68	93	17·528	17·708	17·835	17·933	18·005	18·057	93
69	16·811	17·066	17·282	17·462	17·610	17·730	69	94	17·548	17·719	17·848	17·944	18·013	18·063	94
70	16·853	17·105	17·317	17·493	17·637	17·753	70	95	17·567	17·735	17·861	17·954	18·021	18·069	95
71	16·894	17·143	17·351	17·523	17·663	17·776	71	96	17·585	17·750	17·874	17·964	18·029	18·075	96
72	16·934	17·179	17·384	17·552	17·688	17·797	72	97	17·603	17·765	17·886	17·975	18·036	18·081	97
73	16·972	17·214	17·415	17·579	17·711	17·817	73	98	17·620	17·779	17·897	17·982	18·043	18·086	98
74	17·009	17·248	17·445	17·605	17·734	17·836	74	99	17·637	17·793	17·908	17·991	18·050	18·091	99
75	17·045	17·280	17·474	17·630	17·755	17·854	75	100	17·653	17·806	17·919	17·909	18·056	18·096	100
								PERP·	18·182	18·182	18·182	18·182	18·182	18·182	PERP·

TABLE CCXXIV—*contd.*

PRESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 6 per cent

And for Redemption of Capital at

Yrs.	3%	3½%	4%	4½%	5%	5½%	6%	Yrs.	Yrs.	3%	3½%	4%	4½%	5%	5½%	6%	Yrs.
1	·943	·943	·943	·943	·943	·943	·943	1	26	11·636	11·876	12·111	12·342	12·568	12·780	13·003	26
2	1·810	1·814	1·818	1·822	1·825	1·829	1·833	2	27	11·825	12·070	12·309	12·544	12·773	12·995	13·211	27
3	2·607	2·618	2·629	2·640	2 651	2·662	2·673	3	28	12·006	12·255	12·498	12·735	12 966	13·190	13·406	28
4	3·344	3·364	3·384	3·404	3·425	3·445	3·465	4	29	12·178	12·341	12·677	12·917	13·150	13·375	13·591	29
5	4·027	4·057	4·088	4·119	4·150	4·881	4·212	5	30	12·343	12·599	12·848	13·090	13·324	13·540	13·765	30
6	4·660	4·702	4·745	4·787	4·830	4·874	4·917	6	31	12·500	12·760	13·011	13·255	13·489	13·714	13·929	31
7	5·249	5·304	5·350	5·414	5·470	5·526	5·582	7	32	12·651	12·913	13·167	13·411	13·646	13·870	14·084	32
8	5·799	5·866	5·934	6·002	6·071	6·140	6·210	8	33	12·795	13·060	13·315	13·560	13·795	14·018	14·230	33
9	6·312	6·392	6·473	6·554	6·636	6·719	6·802	9	34	12·933	13·200	13·456	13·702	13·935	14·158	14·368	34
10	6·792	6·885	6·979	7·073	7·168	7·264	7·360	10	35	13·065	13·334	13·591	13·837	14·070	14·291	14·498	35
11	7·242	7·348	7 454	7·562	7·669	7·778	7·887	11	36	13·192	13·462	13·720	13·965	14·197	14·416	14·621	36
12	7 665	7·783	7·902	8·021	8·109	8·262	8·384	12	37	13·314	13·585	13·843	14·088	14·318	14·535	14·737	37
13	8·063	8·193	8·323	8·455	8·587	8·720	8·853	13	38	13·430	13·702	13·060	14·204	14·433	14·647	14·846	38
14	8·437	8·578	8·721	8·864	8·007	9·151	9·295	14	30	13·542	13·814	14·072	14·315	14·542	14·754	14·949	39
15	8·790	8·943	9·096	9 249	9·404	9·558	9·712	15	40	13·650	13·922	14·180	14·421	14·646	14·854	15·046	40
16	9·123	9·286	9·450	9·614	9·778	9·942	10·106	16	41	13·753	14·026	14·282	14·522	14·744	14·950	15·138	41
17	9·438	9·611	9·785	9·958	10·132	10·305	10·477	17	42	13·852	14·125	14·380	14·618	14·838	15·040	15·225	42
18	9·736	9·919	10·102	10·284	10·466	10·647	10·828	18	43	13·947	14·220	14·474	14·710	14·927	15·125	15·306	43
19	10·019	10·210	10·402	10·592	10·782	10·971	11·158	19	44	14·039	14·311	14·564	14·797	15·011	15·206	15·383	44
20	10·286	10·486	10·686	10·884	11·081	11·277	11·470	20	45	14·127	14·398	14·649	14·881	15·092	15·283	15·455	45
21	10·541	10·748	10·955	11·161	11·364	11·565	11·764	21	46	14·212	14·482	14·731	13·959	15·168	15·356	15·524	46
22	10·782	10 997	11·211	11·423	11·632	11·838	12·042	22	47	14·294	14·563	14·810	15·036	15·241	15·425	15·580	47
23	11·012	11·234	11·454	11·671	11·885	12·096	12·303	23		14·372	14·640	14·885	15·108	15·310	15·490	15·650	48
24	11·230	11·458	11·684	11·907	12·125	12·340	12550	24	40	14·448	14·714	14·957	15·178	15·375	15·552	15·708	49
25	11·438	11·672	11·903	12·130	12·353	12·571	12 783	25	50	14·521	14·786	15·026	15·243	15·438	15·619	15·762	50

TABLE CCXXIV—*contd*

PRESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 6 per cent.

And for Redemption of Capital at

Yrs.	%	3½%	4%	4½%	5%	5½%	6%	Yrs.	Yrs.	3%	3½%	4%	4½%	5%	5½%	6%	Yrs.
51	14·591	14·854	15·092	15·306	15·497	15·665	15·813	51	76	15·736	15·933	16·093	16·222	325	16·405	16·468	76
52	14·659	14·920	15·156	15·366	15·553	15·718	15·863	52	77	15·765	15·958	16·115	16·241	16·341	16·419	16·470	77
53	14·724	14·983	15·216	15·424	15·607	15·768	15·907	53	78	15·792	15·983	16·137	16·260	16·357	16·432	16·490	78
54	14·787	15·044	15·274	15·479	15·658	15·815	15·950	54	79	15·819	16·007	16·158	16·278	16·371	16·444	16·500	79
55	14·848	15·103	15·330	15·531	15·707	15·859	15·991	55	80	15·845	16·030	16·178	16·294	16·385	16·456	16·509	80
56	14·907	15·159	15·383	15·581	15·753	15·901	16·029	56	81	15·870	16·052	16·197	16·311	16·399	16·467	16·518	81
57	14·963	15·213	15·435	15·629	15·797	15·941	16·065	57	82	15·894	16·073	16·215	16·326	16·412	16·477	16·526	82
58	15·018	15·265	15·484	15·675	15·839	15·980	16·099	58	83	15·918	16·094	16·233	16·341	16·424	16·487	16·534	83
59	15·070	15·315	15·531	15·718	15·879	16·015	16·131	59	84	15·941	16·113	16·249	16·355	16·435	16·496	16·542	84
60	15·121	15·364	15·576	15·759	15·916	16·049	16·161	60	85	15·963	16·133	16·266	16·368	16·447	16·505	16·549	85
61	15·170	15·410	15·619	15·799	15·953	16·082	16·190	61	86	15·984	16·151	16·281	16·381	16·457	16·514	16·556	86
62	15·217	15·455	15·661	15·837	15·987	16·112	16·217	62	87	16·005	16·169	16·296	16·394	16·467	16·522	16·562	87
63	15·263	15·498	15·700	15·873	16·019	16·141	16·242	63	88	16·025	16·186	16·311	16·406	16·477	16·529	16·568	88
64	15·307	15·539	15·739	15·908	16·050	16·169	16·266	64	89	16·044	16·203	16·325	16·417	16·486	16·536	16·573	89
65	15·350	15·579	15·775	15·941	16·080	16·195	16·289	65	90	16·063	16·129	26·338	16·428	16·494	16·543	16·579	90
66	15·391	15·618	15·810	15·973	16·108	16·220	16·310	66	91	16·081	16·234	16·351	16·438	16·502	16·550	16·584	91
67	15·431	15·655	15·844	16·003	16·135	16·243	16·331	67	92	16·099	16·249	16·363	16·448	16·510	16·556	16·588	92
68	15·470	15·690	15·877	16·032	16·160	16·265	16·350	68	93	16·116	16·263	16·375	16·457	16·516	16·561	16·593	93
69	15·507	15·725	15·908	16·060	16·185	16·286	16·368	69	94	16·132	16·277	16·386	16·466	16·525	16·567	16·597	94
70	15·543	15·758	15·938	16·086	16·208	16·306	16·385	70	95	16·148	16·291	16·397	16·475	16·532	16·572	16·601	95
71	15·578	15·790	15·966	16·111	16·230	16·325	16·401	71	96	16·164	16·303	16·407	16·483	16·538	16·577	16·605	96
72	15·612	15·820	15·994	16·136	16·251	16·343	16·416	72	97	16·179	16·316	16·417	16·491	16·544	16·582	16·608	97
73	15·644	15·850	16·020	16·159	16·270	16·359	16·430	73	98	16·194	16·328	16·427	16·499	16·550	16·586	16·611	98
74	15·676	15·879	16·045	16·181	16·289	16·376	16·443	74	99	16·208	16·340	16·436	16·506	16·556	16·590	16·615	99
75	15·706	15·906	16·070	16·202	16·307	16·391	16·456	75	100	16·221	16·351	16·445	16·513	16·561	16·594	16·618	100
									perp	16·667	16·667	16·667	16·667	16·667	16·667	16·667	perp

TABLE CCXXIV—*contd*

PRESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 6½ per cent·

And for Redemption f Capital at

Yrs·		3½%	4%	4½%	5%	5½%	6½%	Yrs·	Yrs	3%	3½%	4%	4½%	5%	5½%	6½%	Yrs·
1	39	·939	·939	·939	·939	·939	·939	1	26	10·996	11·210	11·420	11·625	11·825	12·020	12·392	26
2	703	1·797	1·801	1·805	1·809	1·813	1·821	2	27	11·160	11·383	11·596	11·804	12·006	12·202	12·575	27
3	2·574	2·584	2·595	2·606	2·616	2·627	2·648	3	28	11·326	11·547	11·763	11·973	12·177	12·374	12·746	28
4	3·289	3·309	3·328	3·347	3·367	3·386	3·426	4	29	11·479	11·703	11·922	12·134	12·339	12·536	12·907	29
5	3·947	3·976	4·006	4·036	4·065	4·095	4·156	5	30	11·625	11·852	12·073	12·286	12·492	12·689	13·059	30
6	4·554	4·594	4·635	4·676	4·717	4·758	4·841	6	31	11·765	11·994	12·217	12·431	12·637	12·834	13·201	31
7	5·115	5·167	5·219	5·271	5·324	5·377	5·485	7	32	11·898	12·130	12·354	12·569	12·775	12·971	13·334	32
8	5·635	5·699	5·763	5·827	5·892	5·957	6·089	8	33	12·026	12·259	12·484	12·699	12·905	13·100	13·459	33
9	6·119	6·194	6·270	6·346	6·423	6·500	6·656	9	34	12·147	12·382	12·708	12·823	13·028	13·222	13·577	34
10	6·569	6·656	6·744	6·832	6·920	7·009	7·189	10	35	12·264	12·500	12·726	12·942	13·145	13·338	13·687	35
11	6·989	7·088	7·187	7·286	7·386	7·487	7·689	11	36	12·376	12·613	12·839	13·054	13·256	13·447	13·791	36
12	7·382	7·492	7·602	7·712	7·823	7·935	8·159	12	37	12·483	12·721	12·947	13·161	13·362	13·550	13·888	37
13	7·750	7·870	7·991	8·112	8·233	8·355	8·600	13	38	12·585	12·823	13·049	13·262	13·462	13·648	13·979	38
14	8·095	8·226	8·356	8·488	8·619	8·751	9·014	14	39	12·683	12·922	13·147	13·359	13·557	13·740	14·065	39
15	8·420	8·560	8·700	8·841	8·981	9·122	9·403	15	40	12·777	13·016	13·241	13·451	13·647	13·827	14·146	40
16	8·725	8·874	8·024	9·173	9·322	9·471	9·768	16	41	12·868	13·106	13·330	13·539	13·732	13·910	14·221	41
17	9·013	9·171	9·328	(486	9·643	9·800	10·111	17	42	12·955	13·193	13·416	13·622	13·813	13·988	14·292	42
18	9·284	9·450	9·616	9·781	9·946	10·109	10·432	18	43	13·038	13·276	13·497	13·702	13·890	14·062	14·359	43
19	9·541	9·714	9·887	10·060	10·231	10·400	10·735	19	44	13·118	13·355	13·575	13·778	13·963	14·132	14·421	44
20	9·783	9·964	10·144	10·322	10·499	10·675	11·019	20	45	13·195	13·431	13·650	13·850	14·033	14·198	14·480	45
21	10·013	10·200	10·386	10·571	10·753	10·933	11·285	21	46	13·269	13·504	13·721	13·919	14·099	14·261	14·535	46
22	10·230	10·424	10·616	10·805	10·993	11·177	11·535	22	47	13·340	13·574	13·789	13·985	14·161	14·320	14·587	47
23	10·437	10·636	10·833	11·027	11·219	11·407	11·770	23	48	13·409	13·641	13·854	14·047	14·221	14·376	14·636	48
24	10·633	10·837	11·039	11·238	11·432	11·621	11·991	24	49	13·475	13·706	13·917	14·107	14·278	14·429	14·682	49
25	10·819	11·029	11·234	11·437	11·634	11·827	12·108	25	50	13·538	13·768	13·976	14·164	14·331	14·480	14·725	50

TABLE CCXXIV—*contd.*

PRESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 6½ per cent.

And for Redemption of Capital at

Yrs.	3%	3½%	4%	4½%	5%	5½%	6½%	Yrs.	Yrs.	3%	3½%	4%	4½%	5%	5½%	6½%	Yrs.
51	13·599	13·827	14·033	14·218	14·382	14·528	14·765	51	76	14·588	14·757	14·895	15·005	15·093	15·162	15·256	76
52	13·658	13·884	14·088	14·270	14·431	14·573	14·803	52	77	14·613	14·779	14·914	15·022	15·107	15·173	15·264	77
53	13·715	13·939	14·140	14·319	14·477	14·615	14·838	53	78	14·637	14·800	14·932	15·037	15·120	15·184	15·271	78
54	13·760	13·992	14·191	14·367	14·521	14·656	14·872	54	79	14·660	14·820	14·950	15·053	15·133	15·195	15·278	79
55	13·822	14·042	14·239	14·412	14·563	14·694	14·903	55	80	14·682	14·840	14·967	15·067	15·145	15·205	15·285	80
56	13·873	14·091	14·285	14·455	14·603	14·730	14·932	56	81	14·703	14·859	14·983	15·081	15·156	15·214	15·291	81
57	13·922	14·138	14·329	14·496	14·641	14·765	14·960	57	82	14·724	14·877	14·999	15·094	15·167	15·223	15·297	82
58	13·969	14·183	14·371	14·535	14·677	14·797	14·986	58	3	14·744	14·895	15·014	15·106	15·178	15·231	15·302	83
59	14·014	14·226	14·412	14·573	14·711	14·828	15·010	59	84	14·764	14·912	15·028	15·119	15·187	15·239	15·307	84
60	14·058	14·268	14·450	14·608	14·743	14·857	15·033	60	85	14·783	14·928	15·042	15·130	15·197	15·247	15·312	85
61	14·101	14·308	14·488	14·642	14·774	14·885	15·054	61	86	14·801	14·944	15·056	15·141	15·206	15·254	15·316	86
62	14·142	14·346	14·523	14·675	14·803	14·911	15·075	62	87	14·819	14·959	15·068	15·152	15·214	15·261	15·320	87
63	14·181	14·383	14·558	14·706	14·832	14·936	15·094	63	88	14·836	14·974	15·081	15·162	15·223	15·267	15·324	88
64	14·219	14·419	14·590	14·736	14·858	14·959	15·111	64	89	14·853	14·988	15·093	15·172	15·230	15·273	15·328	89
65	14·256	14·453	14·622	14·764	14·883	14·982	15·128	65	90	14·869	15·002	15·104	15·181	15·238	15·279	15·331	90
66	14·292	14·486	14·652	14·702	14·907	15·003	15·144	66	91	14·884	15·015	15·115	15·189	15·245	15·285	15·335	91
67	14·326	14·518	14·681	14·817	14·930	15·023	15·158	67	92	14·899	15·028	15·125	15·198	15·251	15·290	15·338	92
68	14·359	14·549	14·709	14·842	14·952	15·042	15·172	68	93	14·914	15·040	15·135	15·206	15·258	15·295	15·341	93
69	14·391	14·578	14·736	14·866	14·973	15·060	15·186	69	94	14·928	15·052	15·145	15·214	15·264	15·300	15·343	94
70	14·422	14·607	14·761	14·889	14·993	15·077	15·197	70	95	14·942	15·064	15·154	15·221	15·270	15·304	15·346	95
71	14·452	14·634	14·786	14·910	15·011	15·093	15·209	71	96	14·955	15·075	15·163	15·228	15·275	15·308	15·348	96
72	14·481	14·661	14·809	14·931	15·029	15·109	15·219	72	97	14·968	15·085	15·172	15·235	15·280	15·312	15·350	97
73	14·509	14·686	14·832	14·951	15·046	15·123	15·230	73	98	14·981	15·096	15·180	15·241	15·285	15·316	15·352	98
74	14·537	14·711	14·854	14·970	15·063	15·136	15·239	74	99	14·993	15·105	15·188	15·248	15·290	15·320	15·354	99
75	14·563	14·734	14·875	14·988	15·078	15·149	15·248	75	100	15·004	15·115	15·196	15·254	15·294	15·323	15·356	100
									perp	15·385	15·385	15·385	15·385	15·385	15·385	15·385	PERP

TABLE CCXXIV—*contd.*

PRESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 7 per cent.

And for Redemption of Capital at

Yrs	3%	3½%	4%	4½%	5%	5½%	7%	Yrs	Yrs	3%	3½%	4%	4½%	5%	5½%	7%	Yrs
1	·935	·935	·935	·935	·935	·935	·935	1	26	10·423	10·615	10·803	10·986	11·165	11·339	11·826	26
2	1·777	1·781	1·785	1·789	1·793	1·797	1·808	2	27	10·575	10·770	10·960	11·146	11·326	11·501	11·987	27
3	2·541	2·551	2·562	2·572	2·583	2·593	2·624	3	28	10·719	10·917	11·110	11·297	11·478	11·653	12·137	28
4	3·236	3·255	3·273	3·292	3·311	3·330	3·387	4	29	10·856	11·056	11·251	11·410	11·622	11·797	12·278	29
5	3·871	3·899	3·927	3·956	3·984	4·014	4·100	5	30	10·987	11·189	11·386	11·575	11·758	11·932	12·409	30
6	4·452	4·491	4·530	4·569	4·608	4·647	4·767	6	31	11·111	11·316	11·513	11·704	11·886	12·060	12·532	31
7	4·987	5·037	5·086	5·136	5·186	5·237	5·386	7	32	11·230	11·436	11·635	11·826	12·008	12·181	12·647	32
8	5·481	5·541	5·601	5·662	5·723	5·785	5·971	8	33	11·344	11·551	11·750	11·941	12·123	12·205	12·754	33
9	5·937	6·008	6·079	6·151	6·223	6·296	6·515	9	34	11·452	11·660	11·860	12·051	12·232	12·402	12·854	34
10	6·360	6·442	6·524	6·606	6·689	6·772	7·024	10	35	11·555	11·763	11·965	12·155	12·334	12·504	12·948	35
11	6·753	6·845	6·937	7·030	7·123	7·217	7·499	11	36	11·654	11·865	12·065	12·254	12·432	12·600	13·035	36
12	7·119	7·221	7·323	7·426	7·529	7·632	7·943	12	37	11·749	11·960	12·160	12·348	12·525	12·690	13·117	37
13	7·461	7·572	7·684	7·796	7·908	8·020	8·358	13	38	11·840	12·051	12·250	12·438	12·613	12·776	13·193	38
14	7·781	7·901	8·021	8·142	8·263	8·384	8·745	14	39	11·927	12·138	13·336	12·523	12·696	12·857	13·265	39
15	8·080	8·208	8·337	8·466	8·595	8·724	9·108	15	40	12·010	12·221	12·419	12·604	12·775	12·933	13·332	40
16	8·360	8·497	8·634	8·771	8·907	9·043	9·447	16	41	12·090	12·300	12·497	12·680	12·850	13·005	13·394	41
17	8·624	8·769	8·913	9·056	9·200	9·342	9·763	17	42	12·167	12·377	12·572	12·754	12·921	13·074	13·452	42
18	8·872	9·024	9·175	9·325	9·475	9·623	10·059	18	43	12·240	12·449	12·644	12·823	12·988	13·138	13·507	43
19	9·106	9·264	9·422	9·578	9·733	9·886	10·336	19	44	12·311	12·519	12·712	12·890	12·052	13·199	13·558	44
20	9·327	9·491	9·654	9·816	9·976	10·134	10·594	20	45	12·379	12·586	12·778	12·953	13·113	13·257	13·606	45
21	9·535	9·705	9·874	10·040	10·204	10·366	10·836	21	46	12·444	12·650	12·840	13·013	13·170	13·312	13·650	46
22	9·733	9·908	10·081	10·252	10·421	10·585	10·061	22	47	12·506	12·711	12·900	13·071	13·225	13·363	13·692	47
23	9·919	10·099	10·277	10·451	10·623	10·791	11·272	23	48	12·566	12·770	12·957	13·125	13·277	13·412	13·730	48
24	10·096	10·280	10·462	10·640	10·814	10·985	11·460	24	49	12·624	12·827	13·011	13·177	13·326	13·458	13·767	49
25	10·264	10·452	10·637	10·818	10·995	11·167	11·654	25	50	12·680	12·881	13·063	13·227	13·373	13·502	13·801	50

TABLE CCXXIV—*contd.*

PRESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 7 per cent.

And for Redemption of Capital at

Yrs.	3%	3½%	4%	4½%	5%	5½%	7%	Yrs.	Yrs.	3%	3½%	4%	4½%	5%	5½%	7%	Yrs.
51	12·733	12·933	13·113	13·275	13·418	13·544	13·832	51	76	13·596	13·743	13·862	13·958	14·034	14·093	14·202	76
52	12·785	12·983	13·161	13·320	13·460	13·583	13·862	52	77	13·618	13·762	13·879	13·972	14·046	14·103	14·208	77
53	12·835	13·061	13·207	13·363	13·500	13·620	13·890	53	78	13·638	13·780	13·895	13·986	14·057	14·113	14·213	78
54	12·882	13·077	13·250	13·404	13·538	13·655	13·916	54	79	13·658	13·798	13·910	13·999	14·068	14·122	14·218	79
55	12·928	13·121	13·292	13·443	13·575	13·688	13·940	55	80	13·678	13·815	13·925	14·011	14·079	14·130	14·222	80
56	12·973	13·164	13·332	13·481	13·609	13·720	13·963	56	81	1··696	13·831	13·939	14·023	14·088	14·138	14·226	81
57	13·016	13·204	13·371	13·516	13·642	13·750	13·984	57	82	13·714	13·847	13·953	14·035	14·098	14·146	14·230	72
58	13·057	13·244	13·408	13·550	13·673	13·778	14·003	58	83	13732	13·863	13·969	14·046	14·107	14·153	14·234	83
59	13·097	13·281	13·443	13·583	13·703	13·805	14·022	59	84	13·749	13·877	13·978	14·056	14·116	14·160	14·237	84
60	13·135	13·318	13·477	13·614	13·731	13·830	14·039	60	85	13·765	13·891	13·990	14·067	14·124	14·167	14·240	85
61	13·172	13·352	13·509	13·643	13·758	13·854	14·055	61	86	13·781	13·905	14·002	14·076	14·131	14·173	14·234	86
62	13·208	13·386	13·540	13·672	13·783	13·877	14·070	62	87	13·797	13·918	14·013	14·085	14·139	14·179	14·246	87
63	13·242	13·418	13·570	13·699	13·808	13·898	14·084	63	88	13·811	13·931	14·023	14·093	14·146	14·185	14·249	88
64	13·275	13·449	13·598	13·725	13·830	13·918	14·098	64	89	13·826	13·943	14·034	14·102	14·152	14·190	14·251	89
65	13·307	13·479	13·626	13·749	13·853	13·938	14·110	65	90	13·840	13·955	14·043	14·110	14·159	14·195	14·253	90
66	13·338	13·508	13·652	13·773	13·783	13·956	14·121	66	91	13·853	13·967	14·053	14·117	14·165	14·200	14·255	91
67	13·368	13·536	13·677	13·795	13·893	13·973	14·132	67	92	13·866	13·978	14·062	14·125	14·171	14·204	14·257	92
68	13·397	13·562	13·701	13·817	13·912	13·990	14·142	68	93	13·879	13·988	14·071	14·132	14·176	14·208	14·259	93
69	13·425	13·588	13·724	13·837	13·930	14·005	14·152	69	94	13·891	13·999	14·079	14·138	14·181	14·212	14·261	94
70	13·452	13·613	13·747	13·857	13·947	14·020	14·160	70	95	13·903	14·007	14·087	14·145	14·186	14·216	14·263	95
71	13·478	13·636	13·768	13·876	13·963	14·034	14·169	71	96	13·915	14·018	14·095	14·151	14·191	14·220	14·264	96
72	13·504	13·659	13·788	13·894	13·979	14·047	14·176	72	97	13·926	14·027	14·102	14·157	14·196	14·223	14·266	97
73	13·528	13·681	13·808	13·911	13·994	14·059	14·183	73	98	13·937	14·036	14·199	14·162	14·200	14·227	14·267	98
74	13·552	13·703	13·827	13·927	14·008	14·071	14·190	74	99	1 ·947	14·045	14·116	14·168	14·204	14·230	14·268	99
75	13·574	13·723	13·845	13·942	14·021	14·082	14·196	75	100	13·957	14·053	14·123	14·171	14·208	14·233	14·269	100
									perp	14·286	14·286	14·286	14·286	14·286	14·286	41·286	perp

TABLE XXIV—*contd.*

RESENT VALUE OF Re. 1 ER ANNUM—Allowing interest on Capital at 7½%.

And for Redemption of Capital at

Yrs.	3%	3½%	4%	4½%	5%	5½%	7½%	Yrs	Yrs.	3%	3½%	4%	4½%	5%	5½%	7½%	Yrs.
1	·930	·930	·930	·930	·930	·930	·930	1	26	9·907	10·080	10·249	10·414	10·575	10·730	11·299	26
2	1·762	1·766	1·769	1·773	1·777	1·781	1·796	2	27	10·044	10·219	10·391	10·557	10·719	10·975	11·441	27
3	2·509	2·519	2·529	2·540	2·550	2·560	2·601	3	28	10·174	10·352	10·525	10·693	10·855	11·011	11·573	28
4	3·184	3·203	3·221	3·239	3·257	3·276	3·349	4	29	10·297	10·477	10·652	10·821	10·983	11·140	11·696	29
5	3·797	3·824	3·852	3·879	3·907	3·934	4·046	5	30	10·415	10·596	10·772	10·942	11·105	11·261	11·810	30
6	4·355	4·392	4·429	4·462	4·501	4·542	4·694	6	31	10·526	10·710	10·887	11·057	11·219	11·374	11·917	31
7	4·866	4·913	4·960	5·007	5·055	5·103	5·297	7	32	10·633	10·818	10·995	11·165	11·328	11·482	12·015	32
8	5·335	5·392	5·449	5·506	5·564	5·622	5·857	8	33	10·735	10·920	11·098	11·268	11·430	11·583	12·107	33
9	5·766	5·833	5·900	5·967	6·035	6·104	6·379	9	34	10·832	11·018	11·196	11·366	11·527	11·678	12·193	34
10	6·164	6·241	6·317	6·331	6·472	6·550	6·864	10	35	10·924	11·111	11·290	11·459	11·618	11·768	12·273	35
11	6·533	6·618	6·705	6·791	6·878	6·965	7·315	11	36	11·013	11·200	11·378	11·547	11·705	11·853	12·347	36
12	6·875	6·969	7·065	7·160	7·256	7·351	7·735	12	37	11·097	11·285	11·463	11·630	11·787	11·933	12·415	37
13	7·193	7·286	7·400	7·503	7·607	7·711	8·126	13	38	11·178	11·366	11·543	11·709	11·865	12·009	12·479	38
14	7·489	7·600	7·712	7·824	7·935	8·046	8·480	14	39	11·256	11·443	11·620	11·785	11·938	12·080	12·539	39
15	7·766	7·885	8·004	8·128	8·241	8·359	8·827	15	40	11·330	11·517	11·693	11·856	12·008	12·148	12·594	40
16	8·025	8·151	8·277	8·402	8·527	8·652	9·142	16	41	11·401	11·588	11·762	11·924	12·074	12·211	12·646	41
17	8·268	8·400	8·533	8·664	8·795	8·925	9·434	17	42	11·469	11·655	11·829	11·989	12·137	12·272	12·694	42
18	8·498	8·634	8·772	8·910	9·046	9·181	9·706	18	43	11·534	11·720	11·892	12·051	12·196	12·328	12·739	43
19	8·710	8·854	8·998	9·140	9·281	9·421	9·959	19	44	11·597	11·782	11·952	12·100	12·252	12·382	12·780	44
20	8·911	9·061	9·210	9·357	9·502	9·645	10·194	20	45	11·657	11·841	12·010	12·165	12·306	12·433	12·819	45
21	9·102	9·256	9·409	9·560	9·709	9·856	10·413	21	46	11·715	11·898	12·065	12·218	12·357	12·482	18·855	46
22	9·281	9·440	9·597	9·752	9·904	10·053	10·617	22	47	11·770	11·952	12·118	12·269	12·405	12·526	12·888	47
23	9·451	9·614	9·774	9·932	10·087	10·239	10·807	23	48	11·823	12·004	12·168	12·317	12·451	12·569	12·919	48
24	9·611	9·778	9·942	10·102	10·259	10·413	10·983	24	49	11·875	12·054	12·216	12·363	12·494	12·610	12·948	49
25	9·763	9·933	10·100	10·263	10·422	10·577	11·147	25	50	11·924	12·102	12·262	12·407	12·535	12·648	12·779	50

TABLE CCXXIV—*contd.*

ESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 7½%.

	And for Redemption of Capital at						
Yrs.	3%	3½%	4%	4½%	5%	5½%	7½%
51	11·971	12·147	12·306	12·448	12·574	12·685	13·000
52	12·017	12·192	12·348	12·488	12·611	: 719	13·023
53	12·061	12·234	12·389	12·526	12·647	12·752	13·045
54	12·103	12·274	12·427	12·562	12·680	12·782	13·065
55	12·143	12·313	12·464	12·596	12·712	12·811	13·084
56	12·183	12·351	12·499	12·629	12·742	12·839	13·101
57	12·220	12·387	12·533	12·661	12·771	12·865	13·117
58	12·257	12·421	12·565	12·691	12·798	12·890	13·132
59	12·292	12·454	12·596	12·719	12·824	12·913	13·146
60	12·325	12·486	12·626	12·746	12·849	12·935	13·159
61	12·358	12·517	12·654	12·772	12·873	12·956	13·172
62	12·389	12·546	12·682	12·797	12·895	12·976	13·183
63	12·420	12·575	12·708	12·821	12·916	12·995	13·193
64	12·449	12·602	12·733	12·843	12·936	13·013	13·203
65	12·477	12·629	12·757	12·865	12·955	13·030	13·212
66	12·505	12·653	12·780	12·886	12·973	13·046	13·221
67	12·531	12·678	12·802	12·905	12·991	13·061	13·228
68	12·556	12·701	12·823	12·924	13·007	13·075	13·236
69	12·581	12·724	12·843	12·942	13·023	13·089	13·243
70	12·605	12·745	12·863	12·959	13·038	13·101	13·249
71	12·627	12·766	12·881	12·976	13·062	13·114	13·255
72	12·650	12·786	12·899	12·991	13·066	13·125	13·260
73	12·671	12·805	12·916	13·006	13·079	13·136	13·265
74	12·692	12·824	12·933	13·020	13·091	13·146	13·270
75	12·712	12·842	12·940	13·034	13·102	13·156	13·275

Yrs.	3%	3½%	4%	4½%	5%	5½%	7½%	Yrs.
76	12·731	12·859	12·964	13·047	13·114	13·165	13·279	76
77	12·750	12·876	12·978	13·060	13·124	13·174	13·282	77
78	12·768	12·892	12·992	13·072	13·134	13·183	13·286	78
79	12·785	12·908	13·006	13·083	13·144	13·190	13·289	79
80	12·802	12·922	13·018	13·094	13·153	13·198	13·292	80
81	12·819	12·937	13·031	13·104	13·161	13·205	13·295	81
82	12·834	12·951	13·043	13·114	13·170	13·212	13·298	82
83	12·850	12·964	13·054	13·124	13·177	13·218	13·300	83
84	12·865	12·977	13·065	13·133	13·185	13·224	13·303	84
85	12·879	12·989	13·075	13·142	13·192	13·230	13·305	85
86	12·893	13·001	13·086	13·150	13·190	13·235	13·307	86
87	12·906	13·013	13·095	13·158	13·205	13·240	13·309	87
88	12·919	13·024	13·105	13·166	13·211	13·245	13·310	88
89	12·932	13·035	13·113	13·173	13·217	13·249	13·312	89
90	12·944	13·045	13·122	13·180	13·223	13·254	13·313	90
91	12·956	13·055	13·130	13·187	13·228	13258	13·315	91
92	12·967	13·065	13·138	13·193	13·233	13·262	13·316	92
93	12·978	13·074	13·146	13·199	13·238	13·266	13·317	93
94	12·989	13·083	13·153	13·205	13·242	13·269	13·318	94
95	13·000	13·091	13·160	13·210	13·247	13·273	13·319	95
96	13·010	13·100	13·167	13·216	13·251	13·276	13·320	96
97	13·019	13·108	13·173	13·221	13·255	13·279	13·321	97
98	13·029	13·116	13·180	13·226	13·250	13·282	13·322	98
99	13·038	13·123	13·185	13·320	13·262	13·285	13·323	99
100	13·047	13·130	13·191	13·235	13·266	13·287	13·324	100
perp	13·333	13·333	13·333	13·333	13·333	13·333	13·333	perp

TABLE CCXXIV.—*Contd.*

PRESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 8%.

Yrs.	3%	3½%	4%	4½%	5%	5½%	8%	Yrs.	Yrs.	3%	3½%	4%	4½%	5%	5½%	8%	Yrs.
	And for Redemption of Capital at																
1	·926	·926	·926	·926	·926	·926	·926	1	26	9·439	9·596	9·750	9·899	10·044	10·184	10·810	26
2	1·746	1·750	1·754	1·757	1·761	1·765	1·783	2	27	9·564	9·723	9·878	10·028	10·174	10·314	10·935	27
3	2·478	2·488	2·498	2·508	2·518	2·527	2·577	3	28	9·681	9·842	9·999	10·150	10·296	10·437	11·051	28
4	3·135	3·152	3·170	3·187	3·205	3·223	3·312	4	29	9·793	9·956	10·113	10·265	10·412	10·552	11·158	29
5	3·726	3·753	3·779	3·805	3·832	3·858	3·993	5	30	9·899	10·063	10·222	10·374	10·521	10·660	11·258	30
6	4·263	4·298	4·333	4·369	4·405	4·441	4·623	6	31	10·000	10·165	10·325	10·477	10·623	10·762	11·350	31
7	4·750	4·795	4·840	4·885	4·930	4·976	5·206	7	32	10·096	10·263	10·422	10·575	10·720	10·858	11·435	32
8	5·196	5·250	5·304	5·359	5·414	5·469	5·747	8	33	10·188	10·515	10·515	10·667	10·812	10·949	11·514	33
9	5·604	5·667	5·731	5·795	5·859	5·921	6·247	9	34	10·275	10·443	10·603	10·755	10·899	11·034	11·587	34
10	5·980	6·052	6·124	6·197	6·269	6·342	6·710	10	35	10·358	10·526	10·686	10·838	10·980	11·114	11·655	35
11	6·326	6·406	6·487	6·568	6·640	6·731	7·139	11	36	10·438	10·606	10·766	10·916	11·058	11·190	11·717	36
12	6·646	6·735	6·824	6·912	7·002	7·091	7·536	12	37	10·514	10·682	10·841	10·991	11·131	11·261	11·775	37
13	6·943	7·039	7·136	7·232	7·328	7·425	7·904	13	38	10·587	10·755	10·913	11·062	11·200	11·329	11·820	38
14	7·219	7·322	7·426	7·520	7·632	7·735	8·244	14	39	10·636	10·824	10·982	11·129	11·266	11·392	11·879	39
15	7·476	7·586	7·696	7·806	7·915	8·024	8·559	15	40	10·722	10·890	11·047	11·193	11·328	11·452	11·925	40
16	7·713	7·832	7·948	8·064	8·179	8·293	8·851	16	41	10·786	10·953	11·109	11·253	11·387	11·509	11·967	41
17	7·939	8·062	8·183	8·304	8·425	8·544	9·122	17	42	11·847	11·013	11·168	11·311	11·442	11·562	12·007	42
18	8·149	8·277	8·404	8·530	8·655	8·778	9·372	18	43	10·905	11·071	11·225	11·366	11·495	11·613	12·202	43
19	8·346	8·479	8·610	8·741	8·870	8·997	9·604	19	44	10·961	11·126	11·278	11·418	11·545	11·660	12·077	44
20	8·531	8·668	8·804	8·938	9·071	9·201	9·818	20	45	11·015	11·179	11·330	11·468	11·593	11·705	12·108	45
21	8·705	8·847	8·986	9·124	9·260	9·393	10·017	21	46	11·067	11·230	11·279	11·515	11·638	11·748	12·137	46
22	8·869	9·015	9·158	9·208	9·437	9·572	10·201	22	47	11·116	11·278	11·426	11·560	11·680	11·788	12·164	47
23	9·024	9·173	9·319	9·462	9·603	9·740	10·371	23	48	11·163	11·324	11·470	11·602	11·721	11·826	12·189	48
24	9·170	9·322	9·471	9·617	9·759	9·897	10·529	24	49	11·209	11·369	11·513	11·643	11·759	11·862	12·212	49
25	9·309	9·463	9·614	9·762	9·906	10·045	10·675	25	50	11·253	11·411	11·554	11·682	11·796	11·896	12·233	50

TABLE CCXXIV—*contd*

PRESENT VALUE OF Re. 1 PER ANNUM.—Allowing interest on Capital at 8%.

And for Redemption of Capital at

Yrs.	3%	3½%	4%	4½%	5%	5½%	8%	Yrs.
51	11·295	11·452	11·593	11·719	11·830	11·928	12·253	51
52	11·336	11·491	11·630	11·754	11·863	11·959	12·272	52
53	11·375	11·529	11·666	11·788	11·894	11·987	12·288	53
54	11·412	11·565	11·700	11·820	11·924	11·924	12·304	54
55	11·448	11·599	11·733	11·850	11·952	12·040	12·319	55
56	71·483	11·632	11·764	11·879	11·979	12·065	12·332	56
57	11·517	11·664	11·794	11·907	12·004	12·088	12·344	57
58	11·549	11·695	11·823	11·933	12·028	12·109	12·356	58
59	11·580	11·724	11·850	11·950	12·051	12·130	12·367	59
60	11·610	11·752	11·876	11·983	12·073	12·150	12·377	60
61	11·639	11·780	11·901	12·006	12·094	12·168	12·386	61
62	11·667	11·806	11·925	12·027	12·114	12·186	12·394	62
63	11·694	11·830	11·949	12·048	12·132	12·202	12·402	63
64	11·720	11·855	11·971	12·068	12·150	12·218	12·409	64
65	11·745	11·878	11·992	12·087	12·167	12·233	12·416	65
66	11·769	11·900	12·012	12·106	12·183	12·247	12·422	66
67	11.792	11·922	12·032	12·123	12·198	12·260	12·428	67
68	11.815	11·943	12·050	12·140	12·213	12·273	12·433	68
69	11.836	11·963	12·068	12·155	12·227	12·285	12·438	69
70	11·857	11·982	12·085	12·171	12·240	12·296	12·443	70
71	11·878	12·000	12·102	12·185	12·252	12·307	12·447	71
72	11·897	12·018	12·118	12·199	12·265	12·317	12·451	72
73	11·916	12·035	12·133	13·212	12·276	12·326	12·455	73
74	11·934	12·051	12·147	12·225	12·287	12·336	12·458	74
75	11·962	12·067	12·161	12·237	12·297	12·344	12·461	75

Yrs.	3%	3½%	4%	4½%	5%	5½%	8%	Yrs.
76	11·969	12·082	12·175	12·248	12·307	12·352	12·464	76
77	11·986	12·097	12·187	12·259	12·316	12·360	12·467	77
78	12·002	12·111	12·200	12·270	12·325	12·367	12·469	78
79	12·017	12·125	12·211	12·280	12·333	12·374	12·471	79
80	12·032	12·138	12·223	12·289	12·341	12·381	12·474	80
81	12·046	12·151	12·234	12·299	12·349	12·387	12·475	81
82	12·060	12·163	12·244	12·307	12·356	12·393	12·477	82
83	12·074	12·175	12·254	12·316	12·363	12·399	12·479	83
84	12·087	12·186	12·264	12·324	12·370	12·404	12·481	84
85	12·100	12·197	12·273	12·332	12·376	12·409	12·482	85
86	12·112	12·208	12·282	12·339	12·382	12·414	12·483	86
87	12·124	12·218	12·790	12·346	12·387	12·418	12·485	87
88	12·135	12·228	12·299	12·353	12·393	12·423	12·486	88
89	12·146	12·237	12·307	12·359	12·398	12·427	12·487	89
90	12·157	12·246	12·314	12·365	12·403	12·430	12·488	90
91	12·168	12·255	12·321	12·371	12·407	12·434	12·489	91
92	12·178	12·264	12·328	12·377	12·412	12·437	12·489	92
93	12·188	12·272	12·335	12·382	12·416	12·441	12·490	93
94	12·197	12·280	12·341	12·387	12·420	17·444	12·491	94
95	12·206	12·287	12·348	12·392	12·424	12·447	12·492	95
96	12·215	12·295	12·354	12·396	12·427	12·449	12·492	96
97	12·224	12·302	12·359	12·401	12·431	12·452	12·493	97
98	12·232	12·308	12·365	12·405	12·434	12·455	12·493	98
99	12·240	12·315	12·370	12·409	12·438	12·457	12·494	99
100	12·248	12·321	12·375	12·413	12·440	12·459	12·494	100
perp	12·500	12·500	12·500	12·500	12·500	12·500	12·500	perp

TABLE CCXXIV—*contd.*

Present Value of Re. 1 Per Annum

ALLOWING INTEREST ON CAPITAL AT 10%

And for Redemption of Capital at

Years	5%	Years	5%	Years	5%	Years	5%
1	·909	26	8.364	51	9.567	76	9·876
2	1·701	27	8·454	52	9·588	77	9·882
3	2·397	28	8·538	53	9·609	78	9·887
4	3·012	29	8·617	54	9·628	79	9·893
5	3·559	30	8·692	55	9·646	80	9·898
6	4·048	31	8·762	56	9·664	81	9·903
7	4·488	32	8·828	57	9·680	82	9·908
8	4·885	33	8·890	58	9·696	82	9·912
9	5·244	34	8·948	59	9·711	84	9·916
10	5·571	35	9·003	60	9·725	84	9·920
11	5·869	36	9·055	61	9·738	86	9·924
12	6·142	37	9·104	62	9·751	87	9·928
13	6·392	38	9·150	63	9·763	88	9·931
14	6·621	39	9·194	64	9·775	89	9·935
15	6·833	40	9·235	65	9·786	90	9·938
16	7·029	41	9·275	66	9·796	91	9·941
17	7·210	42	9·311	67	9·806	92	9·944
18	7·378	43	9·346	68	9·815	93	9·946
19	7·533	44	9·379	69	9·824	94	9·949
20	7·678	45	9·411	70	9·833	95	9·951
21	7·813	46	9·440	71	9·841	96	9·954
22	7·938	47	9·468	72	9·849	97	9·756
23	8·056	48	9·495	73	9·856	98	9·958
24	8·165	49	9·520	74	9·863	99	9·960
25	8·268	50	9·544	75	9·870	100	9·962
						perp.	10·000

TABLE CCXXV

Present Value of Re. 1 receivable at the end of a given term at rates of interest ranging from 3 per cent. to 8 per cent.

Example.—The present value of Rs. 100 payable at the end of 15 years reckoning interest at 5 per cent. is—

		Rs.
Present value of Re. 1		= 0·481
	Rs. 100 = 100 × ·481	= 48·1

TABLE CCXXV—*contd.*

Present Value of Re. 1

PAYABLE AT THE END OF A GIVEN TERM

Years	3%	3¼%	3½%	3¾%	Years	Years	3%	3¼%	3½%	3¾%	Years
1	·9709	·9685	·9662	·9639	1	26	·4637	·4354	·4088	·3840	26
2	·9426	·9380	·9335	·9290	2	27	·4502	·4217	·3950	·3701	27
3	·9151	·9085	·9019	·8954	3	28	·4371	·4084	·3817	·3567	28
4	·8885	·8799	·8714	·8631	4	29	·4243	·3955	·3687	·3438	29
5	·8626	·8522	·8420	·8319	5	30	·4120	·3831	·3563	·3314	30
6	·8375	·8254	·8135	·8018	6	31	·4000	·3710	·3442	·3194	31
7	·8131	·7994	·7860	·7728	7	32	·3883	·3594	·3326	·3079	32
8	·7894	·7742	·7594	·7449	8	33	·3770	·3480	·3213	·2968	33
9	·7664	·7499	·7337	·7180	9	34	·3660	·3371	·3105	·2860	34
10	·7441	·7263	·7089	·6920	10	35	·3554	·3265	·3008	·2757	35
11	·7224	·7034	·6849	·6670	11	36	·3450	·3162	·2898	·2657	36
12	·7014	·6813	·6618	·6429	12	37	·3350	·3062	·2800	·2561	37
13	·6810	·6598	·6394	·6197	13	38	·3252	·2966	·2706	·2469	38
14	·6611	·6391	·6178	·5973	14	39	·3158	·2873	·2614	·2379	39
15	·6419	·6189	·5969	·5757	15	40	·3066	·2782	·2526	·2293	40
16	·6232	·5995	·5767	·5549	16	41	·2976	·2695	·2440	·2210	41
17	·6050	·5806	·5572	·5348	17	42	·2890	·2610	·2358	·2131	42
18	·5874	·5623	·5384	·5155	18	43	·2805	·2528	·2278	·2054	43
19	·5703	·5446	·5201	·4969	19	44	·2724	·2448	·2201	·1979	44
20	·5537	·5275	·5026	·4789	20	45	·2644	·2371	·2127	·1908	45
21	·5375	·5109	·4856	·4616	21	46	·2567	·2296	·2055	·1839	46
22	·5219	·4948	·4691	·4449	22	47	·2493	·2224	·1985	·1772	47
23	·5067	·4792	·4533	·4288	23	48	·2420	·2154	·1918	·1708	48
24	·4919	·4641	·4380	·4133	24	49	·2350	·2086	·1853	·1647	49
25	·4776	·4495	·4231	·3984	25	50	·2281	·2021	·1791	·1587	50

TABLE CCXXV—*contd.*

Present Value of Re. 1

PAYABLE AT THE END OF A GIVEN TERM

Years	3%	3¼%	3½%	3¾%	Years	Years	3%	3¼%	3½%	3¾%	Years
51	·2215	·1957	·1730	·1530	51	76	·1058	·0880	·0732	·0609	76
52	·2150	·1895	·1671	·1474	52	77	·1027	·0852	·0707	·0587	77
53	·2088	·1836	·1615	·1421	53	78	·0997	·0825	·0683	·0566	78
54	·2027	·1778	·1560	·1370	54	79	·0968	·0799	·0660	·0546	79
55	·1968	·1722	·1508	·1320	55	80	·0940	·0774	·0638	·0526	80
56	·1910	·1668	·1457	·1273	56	81	·0912	·0750	·0616	·0507	81
57	·1855	·1615	·1407	·1227	57	82	·0886	·0726	·0596	·0489	82
58	·1801	·1564	·1360	1182	58	83	·0860	·0703	·0575	·0471	83
59	·1748	·1515	·1314	·1139	59	84	·0835	·0681	·0556	·0454	84
60	·1697	·1468	·1269	·1098	60	85	·0811	·0660	·0537	·0438	85
61	·1648	·1421	·1226	1059	61	86	·0787	·0639	·0519	·0422	86
62	·1600	·1377	·1185	·1020	62	87	·0764	·0619	·0501	·0406	87
63	·1533	·1333	·1145	·0983	63	8	·0742	·0599	·0484	·0392	88
64	·1508	·1291	·1106	·0948	64	89	·0720	·0580	·0468	·0378	89
65	·1464	·1251	·1069	·0914	65	90	·0699	·0562	·0452	·0364	90
66	·1421	·1211	·1033	·0881	66	91	·0679	·0545	·0437	·0351	91
67	·1380	·1173	·0998	·0849	67	92	·0659	·0527	·0422	·0338	92
68	·1340	·1136	·0964	·0818	68	93	·0640	·0511	·0408	·0326	93
69	·1301	·1100	·0931	·0789	69	94	·0621	·0495	·0394	·0314	94
70	·1263	·1066	·0900	·0760	70	95	·0603	·0479	·0380	·0303	95
71	·1226	·1032	·0869	·0733	71	96	·0586	·0464	·0368	·0292	96
72	·1190	·1000	·0840	·0706	72	97	·0569	·0449	·0355	·0281	97
73	·1156	·0938	·0812	·0681	73	98	·0552	·0435	·0343	·0271	98
74	·1122	·0938	·0784	·0656	74	99	·0537	·0422	·0332	·0261	99
75	·1089	·0908	·0758	·0632	75	100	·0520	·0408	·0321	·0252	100

TABLE CCXXV—*contd.*

Present Value of Re. 1

PAYABLE AT THE END OF A GIVEN TERM

Years	4%	4½%	5%	5½%	Years	Years	4%	4½%	5%	5½%	Years
1	·9615	·9569	·9524	·9479	1	26	·3607	·3184	·2812	·2486	26
2	·9245	·9157	·9070	·8984	2	27	·3468	·3047	·2678	·2356	27
3	·8890	·8763	·8638	·8516	3	28	·3335	·2916	·2551	·2233	28
4	·8548	·8386	·8227	·8072	4	29	·3206	·2790	·2429	·2117	29
5	·8219	·8025	·7835	·7651	5	30	·3083	·2670	·2314	·2006	30
6	·7903	·7679	·7462	·7252	6	31	·2965	·2555	·2203	·1902	31
7	·7599	·7348	·7107	·6874	7	32	·2851	·2445	·2099	·1803	32
8	·7307	·7032	·6768	·6516	8	33	·2741	·2340	·1999	·1709	33
9	·7026	·6729	·5446	·6176	9	34	·2635	·2239	·1903	·1620	34
10	·6758	·6439	·6139	·5854	10	35	·2534	·2142	·1813	·1535	35
11	·6496	·6162	·5847	·5549	11	36	·2437	·2050	·1726	1455	36
12	·6246	·5897	·5568	·5260	12	37	·2343	·1962	·1644	·1379	37
13	·6006	·5643	·5303	·4986	13	38	·2253	·1877	·1566	·1307	38
14	·5775	·5400	·5051	·4726	14	39	·2166	·1797	·1491	·1239	39
15	·5553	·5167	·4810	·4479	15	40	·2083	·1719	·1420	·1175	40
16	·5339	·4945	·4581	·4246	16	41	·2003	·1645	·1353	·1113	41
17	·5134	·4732	·4363	·4024	17	42	·1926	·1574	·1288	·1055	42
18	·4936	·4528	·4155	·3815	18	43	·1852	·1507	·1227	·1000	43
19	·4746	·4333	·3957	·3616	19	44	·1780	·1442	·1169	·0948	44
20	·4564	·4146	·3769	·3427	20	45	·1712	·1380	·1113	·0899	45
21	·4388	·3968	·3589	·3249	21	46	·1646	·1320	·1060	·0852	46
22	·4220	·3797	·3418	·3079	22	47	·1583	·1263	·1009	·0807	47
23	4057	·3633	·3256	·2919	23	48	·1522	·1209	·0961	·0765	48
24	·3901	·3477	·3101	·2766	24	49	·1463	·1157	·0916	·0725	49
25	·3751	·3327	·2953	·2622	25	50	·1407	·1107	·0872	·0688	50

TABLE CCXXV—*contd.*

Present Value of Re. 1.

PAYABLE AT THE END OF A GIVEN TERM.

Years	4%	4½%	5%	5½%	Years	Years	4%	4½%	5%	5½%	Years
51	·1353	·1059	·0830	·0652	51	76	·0507	·0352	·0245	·0171	76
52	·1301	·1014	·0791	·0618	52	77	·0488	·0337	·0233	·0162	77
53	·1251	·0970	·0753	·0586	53	78	·0469	·0323	·0222	0153	78
54	·1203	·0928	·0717	·0555	54	79	·0451	·0309	0212	·0145	79
55	·1157	·0888	·0683	·0526	55	80	·0434	·0295	·0202	·0138	80
56	·1112	·0850	·0651	·0499	56	81	·0417	·0283	·0192	·0131	81
57	·1069	·0813	·0620	·0473	57	82	·0401	·0271	·0185	·0124	82
58	·1028	·0778	·0590	·0448	58	83	·0386	·0259	·0174	·0117	83
59	·0989	·0745	·0562	·0425	59	84	·0371	·0248	·0166	·0111	84
60	·0951	·0713	·0525	·0402	60	85	·0356	·0237	·0158	·0106	85
61	·0914	·0682	·0510	·0381	61	86	·0343	·0227	·0150	·0100	86
62	·0879	·0658	·0485	·0362	62	87	·0330	·0217	·0143	·0095	87
63	·0845	·0625	·0462	·0343	63	88	·0317	·0208	·0136	·0090	88
64	·0812	·0598	·0440	·0325	64	89	·0305	·0199	·0130	·0085	89
65	·0781	0572	·0419	·0308	65	90	·0293	·0190	·0124	·0081	90
66	·0751	·0547	·0399	·0292	66	91	·0282	·0182	·0118	·0076	91
67	·0722	·0524	·0280	·0277	67	92	·0271	·0174	·0112	·0072	92
68	·0694	·0501	·0362	·0262	68	93	·0260	·0167	·0107	·0069	93
69	·0668	·0480	·0345	·0249	69	94	·0250	·0160	·0102	·0065	94
70	·0642	·0459	·0329	·0236	70	95	·0241	·0153	·0097	·0062	95
71	·0617	·0439	·0313	·0223	71	96	·0232	·0146	·0092	·0058	96
72	·0594	·0420	·0298	·0212	72	97	0223	·0140	·0088	·0055	97
73	·0571	·0402	·0284	·0201	73	98	·0214	·0134	·0084	·0053	98
74	·0549	·0385	·0270	·0190	74	90	·0206	·0128	·0080	·0050	99
75	·0528	·0368	·0257	·0180	75	100	·0198	·0122	0076	·0047	100

TABLE CCXXV—*contd.*

Present Value of Re. 1.

PAYABLE AT THE END OF A GIVEN TERM.

Years	6%	6½%	7%	7½%	Years	Years	6%	6½%	7%	7½%	Years
1	·9434	·9390	·9346	·9302	1	26	·2198	·1945	·1722	·1525	26
2	·8900	·8816	·8734	·8653	2	27	·2074	·1826	·1609	·1419	27
3	·8396	·8278	·8163	·8050	3	28	·1956	·1715	·1504	·1320	28
4	·7921	·7773	·7620	·7488	4	29	·1846	·1610	·1406	·1228	29
5	·7472	·7299	·7130	·6965	5	30	·1741	·1512	·1314	·1142	30
6	·7050	·6853	·6663	·6480	6	31	·1642	·1419	·1228	·1062	31
7	·6650	·6435	·6227	·6027	7	32	·1550	·1333	·1147	·0988	32
8	·6274	·6042	·5820	·5607	8	33	·1462	·1251	·1072	·0919	33
9	·5919	·5673	·5439	·5216	9	34	·1379	1175	·1002	·0855	34
10	·5584	·5327	·5083	·4852	10	35	·1301	·1103	·0937	·0796	35
11	·5268	·5002	·4751	·4513	11	36	·1227	·1036	·0875	·0740	36
12	·4970	·4697	·4440	·4198	12	37	·1158	·0973	·0818	·0688	37
13	·4688	·4410	·4150	·3906	13	38	·1092	·0913	·0764	·0640	38
14	·4423	·4141	·3878	·3633	14	39	·1030	·0858	·0714	·0596	39
15	·4173	·3888	·3624	·3380	15	40	·0972	·0805	·0668	·0554	40
16	·3936	·3651	·3387	·3144	16	41	·0917	·0756	·0624	·0515	41
17	·3714	·3428	·3166	·2924	17	42	·0865	·0710	·0583	·0479	42
18	·3503	·3219	·2959	·2720	18	43	·0816	·0666	·0545	·0446	43
19	·3305	·3022	·2765	·2531	19	44	·0770	·0626	·0509	·0415	44
20	·3118	·2838	·2584	·2354	20	45	·0726	·0588	·0476	·0386	45
21	·2941	·2665	·2415	·2190	21	46	·0685	·0552	·0445	·0359	46
22	·2775	·2502	·2257	·2037	22	47	·0646	·0518	·0416	·0334	47
23	·2618	·2349	·2109	·1895	23	48	·0610	·0487	·0389	·0311	48
24	·2470	·2206	·1971	·1763	24	49	·0575	·0457	·0363	·0289	49
25	·2330	·2071	·1842	·1640	25	50	·0543	·0429	·0339	·0269	50

TABLE CCXXV—*contd.*

Present Value of Re. 1.

PAYABLE AT THE END OF A GIVEN TERM.

Years	6%	6½%	7%	7½%	Years	Years	6%	6½%	7%	7½%	Years
51	·0512	·0403	·0317	·0250	51	76	·0119	·0083	·0058	·0041	76
52	·0483	·0378	·0296	·0233	52	77	·0112	·0078	·0055	·0038	77
53	·0456	0355	·0277	·0216	53	78	·0106	·0073	·0051	·0035	78
54	·0430	·0333	·0259	·0201	54	79	·0100	·0069	·0048	·0033	79
55	·0406	·0313	·0242	·0187	55	80	·0094	·0065	·0044	·0031	80
56	·0383	·0294	·0226	·0174	56	81	·0089	·0061	·0042	·0028	81
57	·0361	·0276	·0211	·0162	57	82	·0084	·0057	·0039	·0026	82
58	·0341	·0259	·0197	·0151	58	83	·0079	·0054	·0036	·0025	83
59	·0321	·0243	·0185	·0140	59	84	·0075	·0050	·0034	·0023	84
60	·0303	·0228	0172	·0130	60	85	·0071	·0047	·0032	·0021	85
61	·0286	·0215	·0161	·0121	61	86	·0067	·0044	·0030	·0020	86
62	·0270	·0201	·0151	·0113	62	87	·0063	·0042	·0028	·0018	87
63	·0254	·0189	·0141	·0105	63	88	·0059	·0039	·0026	·0017	88
64	·0240	·0178	·0132	·0098	64	89	·0056	·0037	·0024	·0016	89
65	·0226	·0167	·0123	·0091	65	90	·0053	·0034	·0023	·0015	90
66	·0214	·0157	·0115	·0084	66	91	·0050	·0032	·0021	·0014	91
67	·0202	·0147	·0107	·0079	67	92	·0047	·0030	·0020	·0013	92
68	·0190	0138	·0100	·0073	68	93	·0044	·0029	·0018	·0012	93
69	·0179	·0130	0094	·0068	69	94	·0042	·0027	·0017	·0011	94
70	·0169	·0122	·0088	·0063	70	95	·0039	·0025	·0016	·0010	95
71	·0160	·0114	·0082	·0059	71	96	·0037	·0024	·0015	·0010	96
72	·0150	·0107	·0077	·0055	72	97	·0035	·0022	·0014	·0009	97
73	·0142	·0101	·0072	·0051	73	98	·0033	·0021	·0013	·0008	98
74	·0134	·0095	·0067	·0047	74	99	·0031	·0020	·0012	·0008	99
75	·0126	·0089	·0062	·0044	75	100	·0029	·0018	·0011	·0007	100

TABLE CCXXV—*contd.*

Present Value of Re. 1.

PAYABLE AT THE END OF A GIVEN TERM.

Years	8%	Years	8%	Years	8%	Years	8%
1	·9259	26	·1352	51	·0197	76	·0029
2	·8573	27	·1252	52	·0183	77	·0027
3	·7938	28	·1159	53	·0169	78	·0025
4	·7350	29	·1073	54	·0157	79	·0023
5	·6806	30	·0994	55	·0145	80	·0021
6	·6302	31	·0920	56	·0134	81	·0020
7	·5835	32	·0852	57	·0124	82	·0018
8	·5403	33	·0789	58	·0115	83	·0017
9	·5002	34	·0730	59	·0107	84	·0015
10	·4632	35	·0676	60	·0099	85	·0014
11	·4289	36	·0626	61	·0091	86	·0013
12	·3971	37	·0580	62	·0085	87	·0012
13	·3677	38	·0537	63	·0078	88	·0011
14	·3405	39	·0497	64	·0072	89	·0011
15	·3152	40	·0460	65	·0067	90	·0010
16	·2919	41	·0426	66	·0062	91	·0009
17	·2703	42	·0395	67	·0058	92	·0008
18	·2502	43	·0365	68	·0053	93	·0008
19	2317	44	·0338	69	·0049	94	·0007
20	·2145	45	·0313	70	·0046	95	·0007
21	·1986	46	·0290	71	·0042	96	·0006
22	·1839	47	·0268	72	·0039	97	·0006
23	·1703	48	·0249	73	·0036	98	·0005
24	·1577	49	·0230	74	·0034	99	·0005
25	·1460	50	·0213	75	·0031	100	·4000

TABLE CCXXVI.

Present Value of Re. 1 per annum receivable in perpetuity after a given number of years, at varying rates of interest ranging from 2% to 10%.

Example.—The present value of the reversion to a perpetuity of Rs. 200 per annum after 30 years at 5 per cent. is—

		Rs.
Present value of perpetuity of Re. 1	..	=4·627
Present value of Rs. 200=200×4·627	..	=925·4

TABLE CCXXVI.

Present Value of a Reversion to a Perpetuity.

OF RUPEE 1 PER ANNUM AFTER A GIVEN NUMBER OF YEARS.

After Years	2%	2½%	3%	3½%	After Years	After years	2%	2½%	3%	3½%	After Years
0	50.0000	40.0000	33.3333	28.5714	0	25	30.4765	21.5756	15.9202	12.0899	25
1	49.0196	39.0244	32.3625	27.6052	1	26	29.8790	21.0494	15.4565	11.6811	26
2	48.0584	38.0726	31.4199	26.6717	2	27	29.2931	20.5360	15.0063	11.2861	27
3	47.1161	37.1440	30.5047	25.7698	3	28	28.7187	20.0351	14.5692	10.9044	28
4	46.1923	36.2380	29.6162	24.8983	4	29	28.1556	19.5464	14.1449	10.5357	29
5	45.2865	35.3542	28.7536	24.0564	5	30	27.6035	19.0697	13.7329	10.1794	30
6	44.3986	34.4919	27.9161	23.2429	6	31	27.0623	18.6046	13.3329	9.8351	31
7	43.5280	33.6506	27.1030	22.4569	7	32	26.5317	18.1508	12.9446	9.5026	32
8	42.6745	32.8299	26.3136	21.6975	8	33	26.0114	17.7081	12.5675	9.1812	33
9	41.8378	32.0291	25.5472	20.9637	9	34	25.5014	17.2662	12.2015	8.8707	34
10	41.0174	31.2479	24.8031	20.2548	10	35	25.0014	16.8548	11.8461	8.5708	35
11	40.2131	30.4858	24.0807	19.5699	11	36	24.5112	16.4437	11.5011	8.2809	36
12	39.4247	29.7422	23.3793	18.9081	12	37	24.0305	16.0427	11.1661	8.0009	37
13	38.6516	29.0168	22.6984	18.2687	13	38	23.5594	15.6514	10.8400	7.7303	38
14	37.8937	28.3091	22.0373	17.6509	14	39	23.0974	15.2697	10.5251	7.4689	39
15	37.1507	27.6186	21.3954	17.0540	15	40	22.6445	14.8972	10.2186	7.2164	40
16	36.4223	26.9450	20.7722	16.4773	16	41	22.2005	14.5339	9.9209	6.9723	41
17	35.7081	26.2878	20.1672	15.9201	17	42	21.7652	14.1794	9.6320	6.7365	42
18	35.0080	25.6466	19.5798	15.3817	18	43	21.3384	13.8335	9.3514	6.5087	43
19	34.3215	25.0211	19.0095	14.8616	19	44	20.9200	13.4961	9.0791	6.2886	44
20	33.6486	24.4108	18.4559	14.3590	20	45	20.5098	13.1670	8.8146	6.0760	45
21	32.9888	23.8154	17.9183	13.8734	21	46	20.1077	12.8458	8.5579	5.8705	46
22	32.3419	23.2346	17.3964	13.4043	22	47	19.7134	12.5325	8.3086	5.6720	47
23	31.7078	22.6679	16.8897	12.9510	23	48	19.3269	12.2268	8.0666	5.4802	48
24	31.0861	22.1150	16.3978	12.5131	24	49	18.9479	11.9286	7.8317	5.2949	49

TABLE CCXXVI—*contd.*

Present Value of a Reversion to a Perpetuity.

OF RUPEE 1 PER ANNUM AFTER A GIVEN NUMBER OF YEARS.

After Years	2%	2½%	3%	3½%	After Years	After Years	2%	2½%	3%	3½%	After Years
50	18.5764	11.6377	7.6036	5.1158	50	75	11.3229	6.2773	3.6315	2.1647	75
51	18.2121	11.3538	7.3821	4.9428	51	76	11.1009	6.1242	3.5257	2.0915	76
52	17.8550	11.0769	7.1671	4.7757	52	77	10.8832	5.9748	3.4230	2.0208	77
53	17.5049	10.8067	6.9583	4.6142	53	78	10.6698	5.8291	3.3233	1.9525	78
54	17.1617	10.5432	6.7557	4.4581	54	79	10.4606	5.6869	3.2265	1.8864	79
55	16.8252	10.2660	6.5589	4.3074	55	80	10.2555	5.5482	3.1326	1.8226	80
56	16.4953	10.0351	6.3679	4.1617	56	81	10.0544	5.4129	3.0413	1.7610	81
57	16.1719	9.7904	6.1824	4.0210	57	82	9.8572	5.2808	2.9527	1.7015	82
58	15.8548	9.5516	6.0023	3.8850	58	83	9.6640	5.1520	2.8667	1.6439	83
59	15.5439	9.3186	5.8275	3.7536	59	84	9.4745	5.0264	2.7832	1.5883	84
60	15.2391	9.0013	5.6578	3.6267	60	85	9.2887	4.9038	2.7022	1.5346	85
61	14.9403	8.8696	5.4930	3.5040	61	86	9.1066	4.7842	2.6235	1.4827	86
62	14.6474	8.6533	5.3330	3.3856	62	87	8.9280	4.6675	2.5471	1.4326	87
63	14.3602	8.4422	5.1777	3.2711	63	88	8.7530	4.5536	2.4729	1.3841	88
64	14.0786	8.2363	5.0269	3.1604	64	89	8.5813	4.4426	2.4008	1.3373	89
65	13.8025	8.0354	4.8804	3.0536	65	90	8.4131	4.3342	2.3309	1.2921	90
66	13.5319	7.8394	4.7383	2.9503	66	91	8.2481	4.2285	2.2630	1.2484	91
67	13.2666	7.6482	4.6003	2.8505	67	92	8.0864	4.1254	2.1971	1.2062	92
68	13.0064	7.4617	4.4663	2.7541	68	93	7.9278	4.0248	2.1331	1.1654	93
69	12.7514	7.2797	4.3362	2.6610	69	94	7.7724	3.9266	2.0710	1.1260	94
70	12.5014	7.1021	4.2099	2.5710	70	95	7.6200	3.8308	2.0107	1.0879	95
71	12.2563	6.9289	4.0873	2.4841	71	96	7.4706	3.7374	1.9521	1.0511	96
72	12.0159	6.7599	3.9682	2.4001	72	97	7.3241	3.6462	1.8953	1.0156	97
73	11.7803	6.5950	3.8527	2.3189	73	98	7.1805	3.5573	1.8400	·9812	98
74	11.5493	6.4342	3.7404	2.2405	74	99	7.0397	3.4705	1.7865	·9481	99

TABLE CCXXVI—*contd.*

Present Value of a Reversion to a Perpetuity.

OF RUPEE 1 PER ANNUM AFTER A GIVEN NUMBER OF YEARS.

After Years	4%	4½%	5%	5½%	After Years	After Years	4%	4½%	5%	5½%	After Years
0	25.0000	22.22[illegible]	20.0000	18.1818	0	25	9.3779	7.3940	5.9061	4.7679	25
1	24.0385	21.2653	19.0476	17.2339	1	26	9.0172	7.0756	5.6248	4.5193	26
2	23.1139	20.3495	18.1406	16.3355	2	27	8.6704	6.7709	5.3570	4.2837	27
3	22.2249	19.4733	17.2767	15.4839	3	28	8.3369	6.4793	5.1019	4.0604	28
4	21.3701	18.6347	16.4540	14.6767	4	29	8.0163	6.2003	4.8589	3.8487	29
5	20.5482	17.8322	15.6705	13.9115	5	30	7.7080	5.9333	4.6275	3.6481	30
6	19.7579	17.0643	14.9243	13.1863	6	31	7.4115	5.6778	4.4072	3.4579	31
7	18.9979	16.3295	14.2136	12.4988	7	32	7.1264	5.4333	4.1973	3.2776	32
8	18.2673	15.6263	13.5368	11.8472	8	33	6.8523	5.1994	3.9974	3.1067	33
9	17.5647	14.9534	12.8922	11.2296	9	34	6.5888	4.9755	3.8071	2.9448	34
10	16.8891	14.3095	12.2783	10.6442	10	35	6.3354	4.7612	3.6258	2.7913	35
11	16.2395	13.6933	11.6936	10.0893	11	36	6.0917	4.5562	3.4531	2.6457	36
12	15.6149	13.1036	11.1367	9.5633	12	37	5.8574	4.3600	3.2887	2.5078	37
13	15.0143	12.5394	10.6064	9.0647	13	38	5.6321	4.1722	3.1321	2.3771	38
14	14.4369	11.9994	10.1014	8.5922	14	39	5.4155	3.9926	2.9830	2.2532	39
15	13.8816	11.4827	9.6203	8.1442	15	40	5.2072	3.8206	2.8409	2.1357	40
16	13.3477	10.9882	9.1622	7.7197	16	41	5.0069	3.6561	2.7056	2.0243	41
17	12.8343	10.5150	8.7259	7.3172	17	42	4.8144	3.4987	2.5768	1.9188	42
18	12.3407	10.0622	8.3104	6.9357	18	43	4.6292	3.3480	2.4541	1.8188	43
19	11.8661	9.6289	7.9147	6.5742	19	44	4.4512	3.2038	2.3372	1.7240	44
20	11.4097	9.2143	7.5378	6.2314	20	45	4.2800	3.0659	2.2259	1.6341	45
21	10.9708	8.8175	7.1788	5.9066	21	46	4.1153	2.9338	2.1199	1.5489	46
22	10.5489	8.4378	6.8370	5.5986	22	47	3.9571	2.8075	2.0190	1.4681	47
23	10.1432	8.0744	6.5114	5.3068	23	48	3.8049	2.6866	1.9228	1.3916	48
24	9.7530	7.7267	6.2014	5.0301	24	49	3.6585	2.5709	1.8313	1.3191	49

TABLE CCXXVI—*contd.*

Present Value of a Reversion to a Perpetuity.

OF RUPEE 1 PER ANNUM AFTER A GIVEN NUMBER OF YEARS.

After Years	4%	4½%	5%	5½%	After Years	After Years	4%	4½%	5%	5½%	After Years
50	3.3178	2.4602	1.7441	1.2503	50	75	1.3196	.8186	.5150	.3279	75
51	3.3825	2.3543	1.6610	1.1851	51	76	1.2688	.7833	.4905	.3108	76
52	3.2524	2.2529	1.5819	1.1233	52	77	1.2200	.7496	.4671	.2946	77
53	3.1273	2.1559	1.5066	1.0648	53	78	1.1731	.7173	.4449	.2792	78
54	3.0070	2.0630	1.4348	1.0093	54	79	1.1280	.6864	.4237	.2647	79
55	2.8914	1.9742	1.3665	.9566	55	80	1.0846	.6569	.4035	.2509	80
56	2.7802	1.8892	1.3015	.9068	56	81	1.0429	.6286	.3843	.2378	81
57	2.6732	1.8078	1.2395	.8595	57	82	1.0028	.6015	.3660	.2254	82
58	2.5704	1.7300	1.1805	.8147	58	83	.9642	.5756	.3486	.2136	83
59	2.4716	1.6556	1.1242	.7722	59	84	.9271	.5508	.3320	.2025	84
60	2.3765	1.5842	1.0707	.7320	60	85	.8915	.5271	.3162	.1919	85
61	2.2851	1.5160	1.0197	.6938	61	86	.8572	.5044	.3011	.1819	86
62	2.1972	1.4507	.9712	.6576	62	87	.8242	.4827	.2868	.1724	87
63	2.1127	1.3882	.9249	.6233	63	88	.7925	.4619	.2731	.1635	88
64	2.0314	1.3284	.8809	.5908	64	89	.7620	.4420	.2601	.1549	89
65	1.9533	1.2712	.8389	.5600	65	90	.7327	.4230	.2477	.1469	90
66	1.8782	1.2165	.7990	.5308	66	91	.7045	.4048	.2359	.1392	91
67	1.8059	1.1641	.7609	.5032	67	92	.6774	.3873	.2247	.1319	92
68	1.7365	1.1140	.7247	.4769	68	93	.6514	.3707	.2140	.1251	93
69	1.6697	1.0660	902	.4521	69	94	.6263	.3547	.2038	.1185	94
70	1.6055	1.0201	.6573	.4285	70	95	.6022	.3394	.1941	.1124	95
71	1.5437	.9762	.6260	.4062	71	96	.5791	.3248	.1849	.1065	96
72	1.4844	.9341	.5962	.3850	72	97	.5568	.3108	.1761	.1000	97
73	1.4273	.8939	.5678	.3649	73	98	.5354	.2974	.1677	.0957	98
74	1.3724	.8554	.5408	.3459	74	99	.5148	.2846	.1597	.0907	99

TABLE CCXXVI—*contd.*

Present Value of a Reversion to a Perpetuity.

OF RUPEE 1 PER ANNUM AFTER A GIVEN NUMBER OF YEARS.

After Years	6%	6½%	7%	7½%	After Years	After Years	6%	6½%	7%	7½%	After Years
0	16.6667	15.3846	14.2857	13.3333	0	25	3.8833	3.1867	2.6321	2.1864	25
1	15.7233	14.4456	13.3511	12.4031	1	26	3.6635	2.9922	2.4599	2.0338	26
2	14.8333	13.5640	12.4777	11.5378	2	27	3.4561	2.8096	2.2990	1.8919	27
3	13.9936	12.7361	11.6614	10.7328	3	28	3.2605	2.6381	2.1486	1.7600	28
4	13.2016	11.9588	10.8985	9.9840	4	29	3.0759	2.4771	2.0080	1.6372	29
5	12.4543	11.2289	10.1855	9.2874	5	30	2.9018	2.3259	1.8767	1.5229	30
6	11.7493	10.5436	9.5192	8.6395	6	31	2.7376	2.1840	1.7539	1.4167	31
7	11.0843	9.9001	8.8964	8.0367	7	32	2.5826	2.0507	1.6392	1.3179	32
8	10.4569	9.2959	8.3144	7.4760	8	33	2.4364	1.9255	1.5319	1.2259	33
9	9.8650	8.7285	7.7705	6.9544	9	34	2.2985	1.8080	1.4317	1.1404	34
10	9.3066	8.1958	7.2621	6.4692	10	35	2.1684	1.6977	1.3380	1.0608	35
11	8.7798	7.6956	6.7870	6.0179	11	36	2.0457	1.5940	1.2505	.9868	36
12	8.2828	7.2259	6.3430	5.5981	12	37	1.9299	1.4968	1.1687	.9180	37
13	7.8140	6.7849	5.9281	5.2075	13	38	1.8206	1.4054	1.0922	.8539	38
14	7.3717	6.3708	5.5402	4.8442	14	39	1.7176	1.3196	1.0208	.7943	39
15	6.9544	5.9819	5.1778	4.5062	15	40	1.6204	1.2391	.9540	.7389	40
16	6.5608	5.6168	4.8391	4.1918	16	41	1.5286	1.1635	.8916	.6874	41
17	6.1894	5.2740	4.5225	3.8994	17	42	1.4421	1.0924	.8333	.6394	42
18	5.8391	4.9521	4.2266	3.6273	18	43	1.3605	1.0258	.7787	.5948	43
19	5.5085	4.6499	3.9501	3.3743	19	44	1.2835	.9632	.7278	.5533	44
20	5.1967	4.3661	3.6917	3.1388	20	45	1.2108	.9044	.6802	.5147	45
21	4.9026	4.0996	3.4502	2.9198	21	46	1.1423	.8492	.6357	.4788	46
22	4.6251	3.8494	3.2245	2.7161	22	47	1.0776	.7974	.5941	.4454	47
23	4.3633	3.6145	3.0135	2.5266	23	48	1.0166	.7487	.5552	.4143	48
24	4.1163	3.3939	2.8164	2.3504	24	49	.9591	.7030	.5189	.3854	49

TABLE CCXXVI—*cont.*

Present Value of a Reversion to a Perpetuity

OF RUPEE 1 PER ANNUM AFTER A GIVEN NUMBER OF YEARS

After Years	6%	6½%	7%	7½%	After Years	After Years	6%	6½%	7%	7½%	After Years
50	.9048	.6601	.4850	.3585	50	75	.2108	.1367	.0894	.0588	75
51	.8536	.6198	.4532	.3335	51	76	.1989	.1284	.0835	.0547	76
52	.8053	.5820	.4236	.3102	52	77	.1876	.1205	.0780	.0509	77
53	.7597	.5465	.3959	.2886	53	78	.1770	.1132	.0729	.0473	78
54	.7167	.5131	.3700	.2685	54	79	.1670	.1063	.0682	.0440	79
55	.6761	.4818	.3458	.2497	55	80	.1575	.0998	.0637	.0409	80
56	.6378	.4524	.3231	.2323	56	81	.1486	.0937	.0595	.0381	81
57	.6017	.4248	.3020	.2161	57	82	.1402	.0880	.0556	.0354	82
58	.5677	.3988	.2823	.2010	58	83	.1323	.0826	.0520	.0330	83
59	.5355	.3745	.2638	.1870	59	84	.1248	.0776	.0486	.0307	84
60	.5052	.3516	.2465	.1739	60	85	.1177	.0728	.0454	.0285	85
61	.4766	.3302	.2304	.1618	61	86	.1111	.0684	.0424	.0265	86
62	.4497	.3100	.2153	.1505	62	87	.1048	.0642	.0397	.0247	87
63	.4242	.2911	.2012	.1400	63	88	.0988	.0603	.0371	.0230	88
64	.4002	.2733	.1881	.1303	64	89	.0932	.0566	.0346	.0214	89
65	.3775	.2567	.1758	.1212	65	90	.0880	.0532	.0324	.0199	90
66	.3562	.2410	.1643	.1127	66	91	.0830	.0499	.0303	.0185	91
67	.3360	.2263	.1535	.1048	67	92	.0783	.0469	.0283	.0172	92
68	.3170	.2125	.1435	.0975	68	93	.0739	.0440	.0264	.0160	93
69	.2990	.1995	.1341	.0907	69	94	.0697	.0413	.0247	.0149	94
70	.2821	.1873	.1253	.0844	70	95	.0657	.0388	.0231	.0138	95
71	.2661	.1759	.1171	.0785	71	96	.0620	.0364	.0216	.0129	96
72	.2511	.1652	.1095	.0730	72	97	.0585	.0342	.0202	.0120	97
73	.2369	.1551	.1023	.0679	73	98	.0552	.0321	.0188	.0111	98
74	.2235	.1456	.0956	.0632	74	99	.0521	.0302	.0176	.0104	99

TABLE CCXXVI—*concld.*

PRESENT VALUE OF A REVERSION TO A PERPETUITY—Of Re. 1 per annum after a given number of years.

After Years	8%	After Years	8%	After Years	8%	After Years	8%	After Years	9%	10%	After Years	9%	10%	After Yaers	9%	10%	After Years	9%	10%
0	12.5000							0	11.1111	10.0000	25	1.2885	.9230	50	.1404	.0852	75	.0173	.0079
1	11.5741	26	1.6900	51	.2468	76	.0360	1	10.1937	9.0909	26	1.1821	.8390	51	.1371	.0774	76	.0159	.0071
2	10.7167	27	1.5648	52	.2285	77	.0334	2	9.3520	8.2645	27	1.0845	.7628	52	.1258	.0704	77	.0146	.0065
3	9.9229	28	1.4489	53	.2116	78	.0309	3	8.5798	7.5131	28	.9950	.6934	53	.1154	.0640	78	.0134	.0059
4	9.1879	29	1.3416	54	.1959	79	.0286	4	7.8714	6.8301	29	.9128	.6304	54	.1059	.0582	79	.0123	.0054
5	8.5073	30	1.2422	55	.1814	80	.0265	5	7.2215	6.2092	30	.8375	.5731	55	.0971	.0529	80	.0113	.0049
6	7.8771	31	1.1502	56	.1679	81	.0245	6	6.6252	5.6447	31	.7683	.5210	56	.0891	.0481	81	.0103	.0044
7	7.2936	32	1.0650	57	.1555	82	.0227	7	6.0782	5.1316	32	.7049	.4736	57	.0817	.0437	82	.0095	.0040
8	6.7534	33	.9861	58	.1440	83	.0210	8	5.5763	4.6651	33	.6467	.4306	58	.0750	.0397	83	.0087	.0037
9	6.2531	34	.9131	59	.1333	84	.0195	9	5.1159	4.2410	34	.5933	.3914	59	.0688	.0361	84	.0080	.0033
10	5.7899	35	.8454	60	.1234	85	.0180	10	4.6934	3.8554	35	.5443	.3558	60	.0631	.0328	85	.0973	.0030
11	5.3610	36	.7828	61	.1143	86	.0167	11	4.3059	3.5049	36	4.993	.3235	61	.0579	.0299	86	.0067	.0028
12	4.9639	37	.7248	62	.1058	87	.0154	12	3.9504	3.1863	37	.4581	.2941	62	.0531	.0271	87	.0062	.0025
13	4.5962	38	.6711	63	.0980	88	.0143	13	3.6242	2.8966	38	.4203	.2673	63	.0487	.0247	88	.0056	.0023
14	4.2558	39	.6214	64	.0907	89	.0132	14	3.3250	2.6333	39	.3856	.02430	64	.0447	.0224	89	.0052	.0021
15	3.9405	40	.5754	65	.0840	90	.0123	15	3.0504	2.3939	40	.3537	.2209	65	.0410	.0204	90	.0048	.0019
16	3.6486	41	.5328	66	.0778	91	.0114	16	2.7985	2.1763	41	.3245	.2009	66	.0376	.0185	91	.0044	.0017
17	3.3784	42	.4933	67	.0720	92	.0105	17	2.5675	1.9784	42	.2977	.1826	67	.0345	.0168	92	.0040	.0016
18	3.1281	43	.4568	68	.0667	93	.0097	18	2.3555	1.7986	43	.2732	.1660	68	.0317	.0153	93	.0037	.0014
19	2.8964	44	.4229	69	.0617	94	.0090	19	2.1610	1.6351	44	.2506	.1509	69	.0291	.0139	94	.0034	.0013
20	2.6818	45	.3916	70	.0572	95	.0083	20	1.9826	1.4864	45	.2299	.1372	70	.0267	.0127	95	.0031	.0012
21	2.4832	46	.3626	71	.0529	96	.0077	21	1.8189	1.3513	46	.2109	.1247	71	.0245	.0115	96	.0028	.0011
22	2.2993	47	.3357	72	.0490	97	.0072	22	1.6687	1.2285	47	.1935	.1134	72	.0224	.0105	97	.0026	.0010
23	2.1289	48	.3109	73	.0454	98	.0066	23	1.5309	1.1168	48	.1775	.1031	73	.0206	.0095	98	.0024	.0009
24	1.9712	49	.2878	74	.0420	99	.0061	24	1.4045	1.0153	49	.1629	.0937	74	.0189	.0086	99	.0022	.0008
25	1.8252	50	.2665	75	.0389														

TABLE CCXXVII

Annual Sinking Fund for the redemption of Re. 1 Capital invested at varying rates of interest ranging from 2½ per cent. to 4½ per cent.

Example.—The annual sinking fund for the repayment of loan of Rs. 20,000 within 30 years at 4 per cent. is—

		Rs.
Sinking fund for Re. 1		·0178
" "	Rs. 20,000=20,000 × ·0178	= 356

TABLE CCXXVII

Annual Sinking Fund

FOR THE REDEMPTION OF RUPEE 1 CAPITAL INVESTED

Years	2½%	2¾%	Yrs.	Yrs.	2½%	2¾%	Yrs.	Yrs.	2½%	2¾%	Yrs.	Yrs.	2½%	2¾%	Yrs.
1	1.0000	1.0000	1	26	.0278	.0268	26	51	.0099	.0092	51	76	.0045	.0040	76
2	.4938	.4932	2	27	.0264	.0254	27	52	.0096	.0089	52	77	.0044	.0039	77
3	.3251	.3243	3	28	.0251	.0242	28	53	.0092	.0086	53	78	.0043	.0038	78
4	.2408	.2399	4	29	.0239	.0230	29	54	.0089	.0083	54	79	.0041	.0036	79
5	.1902	.1893	5	30	.0228	.0219	30	55	.0086	.0080	55	80	.0040	.0035	80
6	.1565	.1556	6	31	.0218	.0208	31	56	.0084	.0077	56	81	.0039	.0034	81
7	.1325	1315	7	32	.0208	.0198	32	57	.0081	.0074	57	82	.0038	.0033	82
8	.1145	.1134	8	33	.0198	.0190	33	58	.0078	.0072	58	83	.0037	.0032	83
9	.1004	.0994	9	34	.0190	.0181	34	59	.0076	.0069	59	84	.0036	.0031	84
10	.0892	.0882	10	35	.0182	.0173	35	60	.0073	.0067	60	85	.0035	.0030	85
11	.0801	.0790	11	36	.0174	.0166	36	61	.0071	.0065	61	86	.0034	.0029	86
12	.0725	.0716	12	37	.0167	.0159	37	62	.0069	.0063	62	87	.0033	.0029	87
13	.0660	.0650	13	38	.0161	.0152	38	63	.0067	.0061	63	88	.0032	.0028	88
14	.0605	.0595	14	39	.0154	.0146	39	64	.0065	.0059	64	89	.0031	.0027	89
15	.0558	.0547	15	40	.0148	.0140	40	65	.0063	.0057	65	90	.0030	.0026	90
16	.0516	.0506	16	41	.0143	.0135	41	66	.0061	.0055	66	91	.0029	.0025	91
17	.0479	.0469	17	42	.0137	.0129	42	67	.0059	.0053	67	92	.0029	.0025	92
18	.0447	.0437	18	43	.0132	.0124	43	68	.0057	.0052	68	93	.0028	.0024	93
19	.0418	.0408	19	44	.0127	.0120	44	69	.0056	.0050	69	94	.0027	.0023	94
20	.0391	.0382	20	45	.0123	.0115	45	70	.0054	.0048	70	95	.0026	.0023	95
21	.0368	.0358	21	46	.0118	.0111	46	71	.0052	.0047	71	96	.0026	.0022	96
22	.0346	.0337	22	47	.0114	.0107	47	72	.0051	.0045	72	97	.0025	.0021	97
23	.0327	0317	23	48	.0110	.0103	48	73	.0049	.0044	73	98	.0024	.0021	98
24	.0309	.0300	24	49	.0106	.0099	49	74	.0048	.0043	74	99	.0024	.0020	99
25	.0293	.0283	25	50	.0102	.0095	50	75	.0046	.0041	75	100	.0023	.0019	100

TABLE CCXXVII—*contd.*

Annual Sinking Fund

FOR THE REDEMPTION OF RUPEE 1 CAPITAL INVESTED

Yrs.	3%	3¼%	3½%	3¾%	Yrs.	Yrs.	3%	3¼%	3½%	3¾%	Yrs.
1	1·0000	1·0000	1·0000	1·0000	1	26	·0259	0250	·0242	·0234	26
2	·4926	·4920	·4914	·4908	2	27	·0246	·0237	·0228	·0220	27
3	·3235	·3227	·3219	·3211	3	28	·0233	0·224	·0216	·0208	28
4	·2390	·2381	·2372	·2364	4	29	·0221	·0213	·0204	·0196	29
5	·1883	·1874	·1865	·1855	5	30	·0210	·0202	·0194	·0186	30
6	·1546	·1536	·1527	·1517	6	13	·0200	·0192	·0184	·0176	31
7	·1305	·1295	·1285	·1276	7	32	·0190	·0182	·0174	·0167	32
8	·1124	·1115	·1105	·1095	8	33	·0181	·0173	·0166	·0158	33
9	·0984	·0974	·0964	·0955	9	34	·0173	·0165	·0157	·0150	34
10	·0872	·0862	·0852	·0843	10	35	·0165	·0157	·0150	·0143	35
11	·0781	·0771	·0761	·0751	11	36	·0158	·0150	·0143	·0136	36
12	·0705	·0695	·0685	·0675	12	37	·0151	·0143	·0136	·0129	37
13	·0640	·0630	·0621	·0619	13	38	·0144	·0137	·0130	·0123	38
14	·0585	·0575	·0566	·0556	14	39	·0138	·0131	·0124	·0117	39
15	·0538	·0528	·0518	·0509	15	40	·0133	·0125	·0118	0·111	40
16	·0496	·0486	·0477	·0467	16	41	·0127	0120	·0113	0·10	41
17	·0459	·0450	·0440	·0431	17	42	·0122	·0115	·0108	·0101	42
18	·0427	·0417	·0408	·0399	18	43	·0117	·0110	·0103	·0097	43
19	·0398	·0389	·0379	·0370	19	44	·0112	·0105	·0099	·0092	44
20	·0372	·0363	·0354	·0345	20	45	·0108	·0101	·0094	·0088	45
21	·0349	·0339	·0330	·0321	21	46	·0104	·0097	·0090	·0084	46
22	·0327	·0318	·0309	·0300	22	47	·0100	·0093	·0087	·0081	47
23	·0308	·0299	·0290	·0281	23	48	·0096	·0089	·0083	·0077	48
24	·0290	·0281	·0273	·0264	24	49	·0092	·0086	·0080	·0074	49
25	·0274	·0265	·0257	·0248	25	50	·0089	·0082	·0076	·0071	50

TABLE CCXXVII—*contd.*

Annual Sinking Fund

FOR THE REDEMPTION OF RUPEE 1 CAPITAL INVESTED

Yrs.	3%	3¼%	3½%	3¾%	Yrs.	Yrs.	3%	3¼%	3½%	3¾%	Yrs.
51	·0085	·0079	·0073	·0068	51	76	·0035	·0031	·0028	·0024	76
52	·0082	·0076	·0070	·0065	52	77	·0034	·0030	·0027	·0023	77
53	·0079	·0073	·0067	·0062	53	78	·0033	·0029	·0026	·0022	78
54	·0076	·0070	·0065	·0059	54	79	·0032	·0028	·0025	·0022	79
55	·0073	·0068	·0062	·0057	55	80	·0031	·0027	·0024	·0021	80
56	·0071	·0065	·0060	·0055	56	81	·0030	·0026	·0023	·0020	81
57	·0068	·0063	·0057	·0052	57	82	·0029	·0025	·0022	·0019	82
58	·0066	·0060	·0055	·0050	58	83	·0028	·0024	·0021	·0018	83
59	·0063	·0058	·0053	·0048	59	84	·0027	·0024	·0021	·0018	84
60	·0061	·0056	·0051	·0046	60	85	·0026	·0023	·0020	·0017	85
61	·0059	·0054	·0049	·0044	61	86	·0026	·0022	·0019	·0016	86
62	·0057	·0052	·0047	·0043	62	87	·0025	·0021	·0018	·0016	87
63	·0055	·0050	·0045	·0041	63	88	·0024	·0021	·0018	·0015	88
64	·0053	·0048	·0043	·0039	64	89	·0023	·0020	·0017	·0015	89
65	·0051	·0046	·0042	·0038	65	90	·0022	·0019	·0016	·0014	90
66	·0050	·0045	·0040	·0036	66	91	·0022	·0019	·0016	·0014	91
67	·0048	·0043	·0039	·0035	67	92	·0021	·0018	·0015	·0013	92
68	·0046	·0042	·0037	·0033	68	93	·0020	·0017	·0015	·0013	93
69	·0045	·0040	·0036	·0032	69	94	·0020	·0017	·0014	·0012	94
70	·0043	·0039	·0035	·0031	70	95	·0019	·0016	·0014	·0012	95
71	·0042	·0037	·0033	·0030	71	96	·0019	·0016	·0013	·0011	96
72	·0040	·0036	·0032	·0028	72	97	·0018	·0015	·0013	·0011	97
73	·0039	·0035	·0031	·0027	73	98	·0017	·0015	·0012	·0010	98
74	·0038	·0034	·0030	·0026	74	99	·0017	·0014	·0012	·0010	99
75	·0037	·0032	·0029	·0025	75	100	·0016	·0014	·0011	·0010	100

TABLE CCXXVII—*contd.*

Annual Sinking Fund

FOR THE REDEMPTION OF RUPEE 1 CAPITAL INVESTED

Years	4%	4¼%	4½%	Years	Years	4%	4¼%	4½%	Years
1	1,0000	1,0000	1,0000	1	26	·0226	·0218	·0210	26
2	.4902	·4896	.4890	2	27	.0212	·0205	·0197	27
3	.3204	·3195	·3188	3	28	·0200	·0192	·0185	28
4	.2355	.2346	.2337	4	29	·0189	·0181	·0174	29
5	·1846	·1837	·1828	5	30	·0178	·0171	.0164	30
6	·1507	·1498	·1489	6	31	·0168	·0161	·0154	31
7	·1266	·1256	·1247	7	32	·0159	·0152	·0146	32
8	.1085	·1076	·1066	8	33	.0151	·0144	·0137	33
9	.0945	·0935	·0926	9	34	·0143	·0136	·0130	34
10	.0833	,0823	·0814	10	35	·0136	·0129	·0123	35
11	·0741	·0732	·0722	11	36	·0129	·0122	·0116	36
12	.0665	,0656	·0647	12	37	·0122	·0116	·0110	37
13	·0601	·0592	·0583	13	38	.0116	·0110	·0104	38
14	·0547	·0537	·0528	14	39	·0111	·0104	·0098	39
15	·0499	·0490	·0481	15	40	.0105	.0099	·0093	40
16	·0458	·0449	·0440	16	41	·0100	·0094	·0089	41
17	·0422	·0413	·0404	17	42	·0095	·0089	·0084	42
18	·0390	·0381.	·0372	18	43	·0091	·0085	·0080	43
19	·0361	·0353	·0344	19	44	0087	·0081	·0076	44
20	·0336	·0327	·0319	20	45	·0083	·0077	·0072	45
21	·0313	·0304	·0296	21	46	·0079	·0073	·0068	46
22	·0292	·0284	·0275	22	47	·0075	·0070	·0065	47
23	·0273	·0265	·0257	23	48	·0072	·0066	·0062	48
24	·0256	·0248	·0240	24	49	·0068	·0063	·0059	49
25	·0240	·0232	·0224	25	50	·0065	·0061	·0056	50

TABLE CCXXVII—*contd.*

Annual Sinking Fund

FOR THE REDEMPTION OF RUPEE 1 CAPITAL INVESTED

Years	4%	4¼%	4½%	Years	Years	4%	4¼%	4½%	Years
51	·0062	·0058	·0053	51	76	·0021	·0019	·0016	76
52	·0060	·0055	·0051	52	77	·0020	·0018	·0016	77
53	·0057	·0053	·0048	53	78	·0020	·0017	·0015	78
54	·0054	·0050	·0046	54	79	·0019	·0016	·0014	79
55	·0052	·0048	·0044	55	80	·0018	·0016	·0014	80
56	·0050	·0046	·0042	56	81	·0017	·0015	·0013	81
57	·0048	·0044	·0040	57	82	·0017	·0014	·0012	82
58	·0046	·0042	·0038	58	83	·0016	·0014	·0012	83
59	·0044	·0040	·0036	59	84	·0015	·0013	·0011	84
60	·0042	·0038	·0034	60	85	·0015	·0013	·0011	85
61	·0040	·0036	·0033	61	86	·0014	·0012	·0010	86
62	·0038	·0035	·0031	62	87	·0014	·0012	·0010	87
63	·0037	·0033	·0030	63	88	·0013	·0011	·0009	88
64	·0035	·0032	·0029	64	89	·0012	·0011	·0009	89
65	·0034	·0030	·0027	65	90	·0012	·0010	·0009	90
66	·0032	·0029	·0026	66	91	·0012	·0010	·0008	91
67	·0031	·0028	·0025	67	92	·0011	·0009	·0008	92
68	·0030	·0027	·0024	68	93	·0011	·0009	·0008	93
69	·0029	·0025	·0023	69	94	·0010	·0009	·0007	94
70	·0027	·0024	·0022	70	95	·0010	·0008	·0007	95
71	·0026	·0023	·0021	71	96	·0009	·0008	·0007	96
72	·0025	·0022	·0020	72	97	·0009	·0008	·0006	97
73	·0024	·0021	·0019	73	98	·0009	·0008	·0006	98
74	·0023	·0020	·0018	74	99	·0008	·0007	·0006	99
75	·0022	·0020	·0017	75	100	·0008	·0007	·0005	100

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TABLE CCXXVIII

THE SUM PAYABLE EACH YEAR WHEN IT IS DESIRED TO PAY OFF A LOAN BY EQUAL ANNUAL INSTALMENTS TO INCLUDE INTEREST AND SINKING FUND.

See table for present value of Re. 1 per annum and apply as below :—

Example.—A Municipality has borrowed Rs. 10,000 and desires to pay off the amount—interest and sinking fund by equal annual instalments in thirty years. Interest at 4 per cent sinking fund to be at rate of 3¼ per cent.

Turn up table No. CCXXIV, Page 974.

Y. P. for 30 years at 4 per cent allowing for redemption at 3½ per cent 16·843.

Divide the Rs. 10,000 by this figure and the result is the annual payment, which will have to be made during each of the thirty years, *viz.*, Rs. 593·7.

TABLE CCXXIX

THE NUMBER OF YEARS IN WHICH AN AMOUNT IS DOUBLED BY ACCUMULATION AT SIMPLE AND COMPOUND INTEREST.

Rate per cent	At simple interest	At compound interest	Rate per cent	At simple interest	At compound interest
1	100·00	69·66	3¾	26·67	18·83
1¼	80·00	55·80	4	25·00	17·67
1½	66·67	46·56	4½	22·22	15·75
1¾	57·14	39·95	5	20·00	14·21
2	50·00	35·00	5½	18·18	12·95
2¼	44·44	31·15	6	16·67	11·90
2½	40·00	28·07	6½	15·38	11·01
2¾	36·36	25·55	7	14·29	10·24
3	33·33	23·45	8	12·50	9·01
3¼	30·77	21·67	9	11·11	8·04
3½	28·57	20·15	10	10·00	7·27

Approximately the number of years a sum of money takes to double itself at compound interest is the number 72 divided by the rate per cent (not exceeding 10 per cent).

TABLE CCXXX

CONVERSION OF ANNAS INTO DECIMALS OF ONE GUNTHA

Annas	Gunthas	Annas	Gunthas	Annas	Gunthas	Annas	Gunthas
1	·0625	5	·3125	9	·5625	13	·8125
2	·1250	6	·3750	10	·6250	14	·8750
3	·1875	7	·4375	11	·6875	15	·9375
4	·2500	8	·5000	12	·7500	..	..

TABLE CCXXXI

CONVERSION OF ANNAS INTO DECIMALS OF AN ACRE, OR ACRES INTO DECIMALS OF A SQUARE MILE.

Annas	Acres	Annas	Acres	Annas	Acres	Annas	Acres
1	·0016	5	·0078	9	·0141	13	·0203
2	·0031	6	·0094	10	·0156	14	·0219
3	·0046	7	·0109	11	·0172	15	·0234
4	·0062	8	·0125	12	·0187	..	..

TABLE CCXXXII

CONVERSION OF GUNTHAS INTO DECIMALS OF AN ACRE

Gunthas.	Acres.	Gunthas.	Acres.	Gunthas.	Acres.	Gunthas.	Acres.	Gunthas.	Acres.	Gunthas.	Acres.	Gunthas.	Acres.	Gunthas.	Acres.
1	·025	6	·150	11	·275	16	·400	21	·525	26	·650	31	·775	36	·900
2	·050	7	·175	12	·300	17	·425	22	·550	27	·675	32	·800	37	·925
3	·075	8	·200	13	·325	18	·450	23	·575	28	·700	33	·825	38	·950
4	·100	9	·225	14	·350	19	·475	24	·600	29	·725	34	·850	39	·975
5	·125	10	·250	15	·375	20	·500	25	·625	30	·750	35	·875	..	..

Example.—Ten gunthas and five annas are equivalent to ·250 *plus* ·0078= ·2578 acres.

To turn square yards into decimals of an acre, remember that 1000 square yards=0 2066 acre.

To turn square inches into decimals of a square yard : 100 squrre inches= ·0772 square yard.

CHAPTER XIV—(a) MECHANICAL NOTES AND TABLES

THE STEAM ROAD-ROLLER

1. **General.**—Mechanically propelled transport is to-day rapidly displacing all other forms of vehicular traffic, and the new conditions, which the modern road builder is called upon to meet, render the provision of good roads, capable of standing heavy loads and high speeds, a primary essential. The steam road-roller, simple though it is both in construction and maintenance, plays no mean part in aiding the road builder to meet this demand and enables him to perform work with greater efficiency, in far less time than was previously the case. Steam road-rollers commonly met within Indian service are of standard designs made by reputable British makers. These designs differ but slightly from each other by reason of Regulations framed under an Act of Parliament which govern the dimensions, weights and speeds, permissible for all steam road-rollers used on public streets and highways. The type most frequently met with is a simple single cylinder steam user, burning ordinary coal and easily handled by any intelligent man. Where, however, both fuel and water are scarce and expensive and where better trained drivers are availabe, a standard type of compound cylinder steam user *may* merit consideration. Both types of roller are obtainable in weight values ranging by steps of two, from four to fourteen tons (nominal empty weights). For Indian conditions the boiler should be provided with an extra large or colonial firebox to burn wood or inferior fuel.

2. **Indents.**—Indents for steam road-rollers should convey the following information :—

(1) Specify the weight of roller required.

(2) Specify whether required as a single-cylinder or a side by side compound type. Should be of a reversible horizontal steam engine.

Note.—For ordinary purposes inthe mofussil the single cylinder type is preferabe to a compound engine as it costs less and has fewer moving parts and adjustments to get out of order.

(3) If required for service on gradients of an abnormal character, it should be stated, giving details.

(4) If required with accessories for converting into a traction haulage engine it should be stated. Makers should, however, be asked to state, the maximum load engine will haul and the maximum gradient it to should be expected to give service over, when operating as a traction engine.

(5) If a scarifier is required, the number of types should be stated. Tender should be so constructed as to permit attachment of scarifier by the addition of the necessary fittings, without structural alteration.

The use of scarifiers enables rollers being kept working for longer periods, and progress would be increased.

Note.—Scarifiers should not be fitted to rollers of less than 8 tons.

(6) The conditions of access to locality where delivery is required and whether lifting appliance are available should be stated.

(7) Clearly state that the boiler must comply in every respect with the revised Indian Government Boiler Act.

In addition to these details the indent should give consideration to further points as follows :—

(1) Does the nature of the duty to be imposed demand anything better than the standard C. I. rims, as for example, cast steel ? Ordinarily this expense will not be warranted.

(2) Does the nature of the duty imposed demand the negotiation of sharp curves, or other factors involving undue axle strains ? If so, the extra cost of compensating gears may be justified. For ordinary mofussil work, expensive differential gear is really not required, and considerable saving can be effected by its elimination.

(3) The special awning supplied for protection from direct sun exposure should be included in indent. This awning should completely cover the engine and footplate, and should be made of teakwood covered with canvas, instead of the usual dealwood, which perishes rapidly.

(4) A set of standard tarpaulins for monsoon weather portection should be included in the indent.

(5) If the conditions of service are such as justify the cost of a water lifter with suction hose (26 feet in length) and rose for the purpose of filling the boiler feed tank, the indent should include them.

(6) The indent should *always* include a wash-out pump for boiler and fire-box complete with necessary connections.

(7) The addition of a governor is not quite necessary.

(8) Finally, if the indent conveys a preference for any particular make, it should be borne in mind, that considerable saving may be effected in the cost of future repairs, by giving preference to an engine having all its internal working parts readily accessible and with all parts, subjected to considerable wear, easily removable for either repair or renewal.

All reputable suppliers furnish with the roller a complete set of stoking and maintenance tools covering all ordinary requirements. Upon check, the stock reference numbers should be listed at once.

LOCOMOTIVE NOTES

1. **General.**—These notes are chiefly confined to the plain 0-4-0 and 0-6-0 locomotives common to industrial works and large construction contracts. In making up indents, it should be borne in mind, that the cost of this type of locomotive may, to some extent, be governed by the nature of the duty and length of time for which it is required. For example, there are numerous contract jobs where locomotives are used, which never exceed three years in duration. As a rule, the service to which they are put is very heavy and upon the termination of contract they are worth little more than scrap value. On the other hand, it may be, that the service value of the locomotive to a particular contract outweighs the question of cost altogether, even though the conditions will never allow of its receiving anything like the routine overhaul and repair attention that falls to the lot of the railway locomotive ; in addition to which, it will more often than not, frequently run day in and day out, over long periods of time, owing to the non-provision of reserves. In the case of docks, large works, and canal sidings, it is obviously desirable, that as long a life as possible should be obtained from the purchased article, from which it follows, that money will be saved in the two last mentioned cases, by having specifications for both material and workmanship, as exacting in character as, those which apply to the standard type of railway locomotive. As the working pressure of the boiler will be reduced in the course of time, it is usual

for the locomotive selected, to have at least 25 per cent more power than that required to commence with. Other points to be considered in selection are those which have a bearing upon—

(1) Repair and renewal facilities.

(2) Accessibility for making inspections, washing and cleaning out, repairs and renewals.

Preference should always be given to standared types, so that parts more or less held in stock by local agents can be readily obtained as required. This procedure allows for keeping down to a minimum, the maintenance of expensive stocks of spare parts, etc. The tubes should be either of solid drawn brass, or (where justifiable and money permits) of copper. Boiler mountings and injector arrangements should not be cramped and ample facilities should exist, in particular, for washing out purposes, which will be indicated by the number and position of mud plugs and doors provided on tender drawings. The majority of small locomotives (0-4-0) are of the saddle tank type, owing to its cheaper construction and easier access to gear; for the larger types, side tanks are more advantageous and are, therefore, more usual. Where it is desired that the locomotive should have a long life, with minimum upkeep accounts, it is advisable that the axle boxes and guides should be made of cast steel, as against cast iron.

2. **Indents.**—In the absence of a definite number or name applicable to a known suitable type, indents should include the following detailed information :—

(1) The railway gauge for which the locomotive is required and the weight per yard of rails used.

(2) The radius of the sharpest curve the locomotive will be required to travel over.

(3) The length and gradient of the sharpest incline to be travelled over with the radius of any curve which may exist on it. It should also be stated, whether the locomotive will, as a usual thing, have to start on an incline or not.

(4) The gross load in tons which has to be hauled, with special reference to speeds if necessary.

(5) The longest distance over which it is required to haul the heaviest load without a stop.

(6) The class of fuel to be used.

(7) Give any *special* information, or dimensions, which may be applicable to draw gear, buffers, brakes, overall height or width.

(8) Clearly state that the boiler and its mounfings must comply in every respect to the requirements of the revised Indian Boiler Act, 1923.

Having furnished these details, reputable suppliers will have little difficulty in selecting a locomotive, suitably designed for meeting the requirements of tractive power, boiler power and adhesion, which apply.

3. **Working.**—The remarks made under this head for **steam road rollers** in chapter V apply with greater force to the maintenance of locomotives. Where there are a number of locomotives in constant use, it is necessary to provide a suitable shed for carrying out the necessary cleaning routine inspections, or repairs required. Adjacent to this should be a workshop fitted with

such tools and equipment as is necessary for the carrying out of all minor repairs. Where conditions permit it is advantageous to have all *heavy* overhauls, and repairs carried out at the nearest railway depot available; doing this is conducive to economy, where but a small number of locomotives are in operation. The cleaning of boilers will vary with use and the conditions of feed water. Some definite system of routine which provides for cleanliness throughout, the use of proper oils and grease for lubrication purposes, prompt attention to all wearing adjustments as required, together with frequent inspection, is essential for efficient service at lowest cost and no slip-shod methods should be tolerated, under any circumstances, where the possibilities of neglect or indifference, may endanger life.

NOTES ON THE CARE OF SMALL CONDENSING STEAM ENGINES

1. On first erection an engine should be thoroughly tested and records of the trial kept. No forcing of either the engine or boiler should be allowed during the trial, which should take place under actual working conditions. A similar trial should be carried out after any extensive repairs have been effected or a general overhaul made.

2. The Officer-in-charge should see that the engine and any auxiliarie in the attendant's charge are kept clean and in good working condition.

3. **A maintenance record book** should be kept as distinct from a running log-book in which should be entered up all defects, repairs carried out and examinations made.

4. Slight repairs or adjustments which permit of being promptly carried out, should be so treated and record entry made as may be necessary. Defects likely to cause an accident through continued running should be dealt with immediately and the engine stopped for attention to be given.

5. Before the engine is started, the attendant should carefully inspect all parts likely to work loose during the run and satisfy himself that no trouble exists in connection with the lubrication of cylinders, steam chests and bearings. Authorised lubrication oils only should be allowed and particular attention paid to the oil separator. Hot bearings may arise from dirt in the bearing; improper lubrication or the want of it entirely; or to badly fitting brasses. All auxiliaries should be inspected, likewise the steam and water connections.

6. Leaky slide valves, pistons, glands and joints should be dealt with by routine maintenance and not allowed to continue. When a gland shows signs of leaking, it should receive immediate attention and if it cannot be tightened, should be repacked. When asbestos packing is used, it should be allowed to thoroughly warm through before it is tightened up.

7. Knocking may arise in any bearing or cylinder. If in the latter, the drain cocks should be at once opened, whereupon if due to priming, it will be reduced, if not eliminated. If after this has been done, the knocking still continues, the engine should be stopped in case an obstruction exists in the cylinder. The cylinder cover should be removed, piston examined and if found necessary, clearances also checked.

8. The second operation in starting up (see 5 for the first) is the simple yet highly important one of thoroughly warming up the engine, after which, the supply of condensing water should be opened up and stop valve slowly opened to the working position. The condensing water is now regulated as necessary and the hitherto open cylinder drain cocks closed, speed adjustments made and a final inspection carried out over all.

9. **Examination and repair.**—In carrying out a general examination the engine should be stopped and all parts cleaned. The following points should be given attention.

Cylinder.—Check the amount of wear in the bore and ascertain whether reboring is required. If the cylinder is not to be rebored, any ridges at the ends of the piston travel should be scraped away. The studs should be examined and replaced where necessary to make good joints.

Piston.—The fit of the piston in the cylinder should be tested and also the condition and fit of the piston rings. If any of the latter are renewed, they must be carefully bedded to the cylinder. The piston rod should be gauged for wear and turned down if much worn. The gland and neck-bush may require bushing if they are slack on the rod.

Steam chest.—The port faces may require re-surfacing. The studs require examination and also the joint faces. The slide valve is likely to require facing and the valve spindle may require to be turned down or replaced. The glands are likely to require rebushing.

Crosshead and guides.—The guides should be tested for line with the cylinder and any adjustments made that may be necessary. The slippers may be worn and will require to be metalled or adjusted after these repairs have been done, the piston, crosshead, etc., should be assembled and a check made of the movement from end to end of the stroke in order to see that it is quite free.

Connecting rod.—The brasses will require taking up. Bolts and cotters should be examined. Before bedding the brasses it is as well to see that the gudgeon pin and crank pin are round. The brasses should be finally bedded with the rod in its place. The crank-shaft brasses should be tested for line with the cylinder and any necessary adjustments made before they are finally bedded to the shaft. The crank-shaft should have the journals tested for roundness and if found bad, they must be trued up. Fly-wheel keys should be examined. In bedding brasses it is important to remember that if a brass is allowed to bear on the radius it is sure to run hot. Oil grooves in brasses should be deepened when necessary. Valve gear requires examination for slackness at the joints. If much wear has taken place, the holes for pins must be lapped out and new pins fitted. Eccentric straps must be taken up. The sheaves must be examined for truth and it must be seen that they are tightly keyed to the shaft.

Governor gear.—This must be examined for wear and any worn parts repaired or replaced. There must be no slack in any part of this gear, or ineffective governing will result.

Feed pump.—The feed pump plunger and gland should be examined. The valves and valve seats will probably require trueing up. Feed pump connections must be carefully cleaned.

Steam stop valve.—The valve, spindle and gland require examination. The seat should be trued up and the valve made a good fit on it.

General.—All drain cocks should be ground in. Lubricators and oil ways must be cleaned. In assembling, take special care that nothing is left in the cylinder or ports. See that where split pins are fitted to prevent nuts from working loose, the pins are bearing against the nuts and the ends are opened out. Test the cylinder clearances and adjust the connecting rod as necessary. Set the valves carefully, keeping practically equal leads at each end. Before starting, turn the engine through one complete revolution by hand. As the engine warms up, tighten all steam joints. Run slowly under no load for some time and carefully watch all bearings to see that they are keeping cool and note if the various gears are running quietly. Finally, run up to normal speed and see that the governor is controlling the speed properly. If possible, the load should then be put on and indicator cards taken and examined.

APPENDIX TO BOMBAY BOILER RULES, 1924

General working of boilers

INSTRUCTIONS TO BOILER ATTENDANTS

1. These instructions should be frequently and carefully studied, with a view to keeping in mind the precautions to be observed, and the ordinary procedure to be followed in the safe working of boilers.

2. **Precautions before starting the fires.**—Before starting the fires in a boiler, the attendant should—

(1) see that there is sufficient water in the boiler and that the gauge cocks ;
(2) ease safety valves, or open cock on top of boiler to allow air to escape ; are working freely.
(3) see that the blow-off cock is fully closed and tight ;
(4) see that the safety valves and feed check valve are free and workable ;
(5) see that water is not leaking from any part of the boiler ;
(6) note if the pressure gauge pointer is at zero ;
(7) see that the feed pump is in working order.

He must not rely on the supposition that the water he has previously put in is still in the boiler, as it may have run out without his knowledge through a leak or open cock, nor can he be sure that the gauge glass shows the true water level until he has tested it. This is done in the following manner ; shut off the lower gauge cock and empty the glass by the drain cock ; then shut the drain cock and open the gauge cock ; if everything is in order, the water will then rise in the glass to the same height as before.

3. **Raising steam.**—In getting up steam in all types of boilers the operations should be as gradual as circumstances will allow. Nothing turns a new boiler into an old one sooner than getting up steam too quickly. Forcing the fires when starting work is liable to cause straining of the steams and tubes of the boiler. In the case of large boilers generally, steam should not be got up in less than six hours. Before getting up steam, the water level should be observed, to ensure that water is at the proper height in the glass, the pressure gauge noted, and the safety valves tried to see they are free. The blow-off cock should be examined to see that it is completely shut and tight.

4. Pressure gauge.—The pressure or steam gauge should be kept in order, and be in such a position as to be easily seen by the boiler attendant. There should be a plain mark on it showing the highest pressure allowed for the boiler, and the dail should be kept clean so that the figures may easily be read.

5. Steam pressure.—Ordinarily the safety valve will prevent the steam from rising much above the working pressure, but if the steam gauge shows so rapid an increase of pressure as to indicate danger of exceeding the highest limit, water should be immedi..tely fed into the boiler and the dampers partially closed in order to diminish the effect of the fire. If, however, the water has fallen so low that there is danger of an accident from this cause, the fires should be withdrawn before feeding in water, the safety valves eased, and if the engine is at rest it should be started so as to reduce the pressure.

The safety valves are provided to guard against over—pressure. They should be moved by hand every day so as to prevent them from sticking. If moved only occasionally, they are liable to leak.

The valve can be tested by slowly raising it a little, and when let down, it should close perfectly tight. It should never be opened by a sudden knock or pull. If it does not close tight, turn it on its seat until if fits, or when its construction does not permit this, raise to slowly a few times and let it down again, but on no account must the valve be screwed down further or loaded more than what has been allowed by the Inspector.

Safety valves must never be overloaded, and spring valves should have ferrules or other provision against the valves being screwed down too far. In case of an accident resulting from wilful overloading the culprit might be held criminally responsible at the official inquiry or inquest.

6. Low water safety valves.—If there is a low water safety valve, test it occasionally by lowering the water level to see that the valve begins to blow at, the right point. It should give warning, *before* the water level has sunk too low and before damage can be done. When the boiler is opened, examine the floats and lever and see that they are free and that they give the valve the full rise. With the ordinary type of high-steam and low-water safety valve, the float should be down at its lowest position and the valve full open when the boiler is empty.

7. The water gauges.—These will be kept in best order by frequently blowing through. The cocks are thus kept in good working condition without leaking. Blow through the drain cock at the bottom of the gauge, and shut and open the steam and water coks every few hours. These cocks should be blown through more frequently when the water is dirty. Should either of the passages become choked, or whenever the water in the gauge glass moves sluggisuly the passages must be cleaned. This is best done with a wire. The gauge glass is so arranged that its stop cock connects with the steam space and its bottom cock is below the water line. The water line will ordinarily be near the middle of the glass tube. Always test the glass water gauges thoroughly the first thing in the morning and at the commencement of every shift. This is done by first opening the drain cock and then shutting the upper cock which should give water ; the upper cock should then be opened and the bottom cock closed—which should give steam ; during this test he drain cock should be kept open.

If water and steam do not appear in proper order, then the cocks are choked and the passages should be cleaned. To lessen the risk of breaking the gauge glass, the water cock should always be reopened after the steam cock.

Gauge glasses with a narrow white stripe running the whole length of the glass on the side next the boiler are recommended as they show the water line more clearly, especially when the water is dirty.

The Government boiler regulations require every water gauge glass to be fitted with a guard to prevent injury to the attendants. See that it is always in place, and clean, when there is steam in the boiler.

8. Special note.—It does not follow that there is plenty of water in the boiler because there is plenty of water in the gauge glass. The passage may be choked, and empty gauge glasses are sometimes mistaken for full ones, and explosions have resulted therefrom. Hence the importance of keeping the gauge cocks perfectly tight and clean and of blowing through the test cocks frequently.

A large number of accidents have been due to inoperative water gauges, and to negligence of the attendant in not carefully reading the water level.

9. The blow-off cock.—The blow-off should be used daily if the water is at all dirty or sedimentary, especially with locomotive type and vertical boilers, as their narrow water spaces are liable to get chocked with mud, which soon hardens into a solid mass. The amount of water to be blown out depends on the size of the boiler and can be determined only from experience. When blowing out, the best result is obtained, if the water has been at rest for some time (say before the engine is started) thus giving the sediment time to settle ; if the feed water is clean merely turn the cock round.

10. The scum cock.—When scum cocks are fitted, if the feed water is dirty, a little should be blown off daily ; if the water is clean, merely turn the cock round. Before opening the scum cock see that the water is at the height indicated by the water-level pointer, otherwise the scumming will be ineffective. Water should be blown from the surface through the scum cock when steam is being drawn off, i.e., when the engine or other machinery is working.

11. Manhole and other door joints.—When making such joints the jointing materials should never be of round-sectioned packing. Care must be taken that the spigot of the door is centrally placed in the hole, as many accidents have resulted from packing being blown out between the spigot and side of hole, even when the clearance was only ⅛th of an inch. The nuts must be carefully and evenly tightened. Further tightening should be made during the process of heating up the boiler when raising steam.

12. Steam pipes.—When properly arranged, should give no trouble. Frequently, however, they are so designed as to contain pockets, in which, while out of use, condensed steam accumulates. Such water is exceedingly dangerous and great care should be taken to see that the pipes are properly drained before the stop-valve is opened ; otherwise "water hammer" will take place even with the best, designed steam pipes, and disastrous explosions, causing loss of life and property, may occur.

13. Scale and grease.—Roughly speaking, scale offers a hundred times as much resistance to the passage of heat as does a similar thickness of steel or iron. A half inch furnace plate covered with 1/10th inch scale is as

sufficient a heat retarder as a steel furnace 10 inches thick. Grease is about ten times worse than scale. In a boiler at work, the temperature of a clean furnace plate is only slightly in excess of that of the water in the boiler, but if scale or grease is interposed between the water and the plate, the latter acquires a temperature more nearly approximating that of the flame with which it is in contact. If the fire is fierce (artificial draught) the furnace tube may grow so hot that it elongates considerably. If, in addition, cold air is admitted during each firing, a concertina action of the furnace takes place, which is one of the worst causes of boiler wear and tear.

14. Wear and tear.—Can be reduced and the life of a boiler prolonged, if scale and grease are prevented from accummulating in a boiler. The combind effect of scale or grease and artificial draught are disastrous. Scale or grease also causes waste of fuel.

15. Grease.—A mixture of sedimentary water, soda, and grease produces an adhesive scum. Where this is suspected, the water level should never be lowered below the furnance top, unless the boiler is afterwards entered and this scum cleaned off the furnace plate, before firing again.

16. Scale removal.—The customary method is not a satisfactory one. The boiler is emptied and cooled down by opening all the manholes, and the result is that the scale, which would otherwise be soft, hardens through contact with the air, and requires laborious chipping off.

A very effective, but slower method, is to retain the water in the boiler until cool, and not to run it out until the men are ready to enter the boiler with water hose, brushes and scrapers. The scale will then be soft and easily removable.

If time is a consideration, the cooling can be accelerated by adding cold feed to the hot water in the boiler and slowly running off the cooled water. Another method is to blow off the boiler with the lowest possible pressure (not more than 20 lbs.) and to keep it closed until cold. The scale will then be easily removed.

17. Treatment of feed water.—Many feed waters require soda or other chemicals to arrest corrosion or to change the nature of the scale.

There is no *harmless chemical* which will remove scale or sediment when it has once got into the boiler and the only effective process is to purify the feed water before it enters the boiler. By this means the sediment, and generally, too, the added chemicals, can be deposited in tanks or in filters, and therefore, never goes into the boiler. Excepting when the water obtainable is very good, water-purifying apparatus ought to pay any boiler owner, particularly at those works where three or more boilers are in constant work. Boiler owners, wishing to have definite advice as to the best treatment of their feed water, should have it analysed at some chemical laboratory and ascertain the best treatment in the particular circumstances.

Special attention is drawn to the not infrequent but *very bad* practice of allowing the waste steam from the engine cylinders or pumps to be drained into the boiler feed water tanks. The waste steam from cylinders is always mixed with a certain amount of oily matter, which will be deposited in the feed water tanks and ultimately be pumped into the boiler, with possibly disastrous results, as it will be obvious to every careful boiler attendant that, should the oil be deposited on the furnace crowns, they may become over-heated and collapse.

It should be the first care of the Engineer-in-charge and the Boiler Attendant to see that the feed water is kept as pure as possible. Impure feed water means additional expense on the upkeep of the boiler.

18. Preservation of boilers when not in use.—Steam boilers, when not in use, are liable to deterioration from corrosion, and, unless well cared for and made rust-proof, they may depreciate more repidly than when in use. They should be thoroughly drained and thoroughly dried and all valves, cocks and openings closed so as to exclude moisture. Another plan is to fill the boiler with water to which about 1/100 per cent caustic soda has been added.

NOTES ON THE CARE OF GAS AND OIL ENGINES

1. It is usual for the engine builders to issue printed instructions for the care and working of their engines.• These directions should be hung up in the engine room and carefully observed.

2. Starting.—Before starting, the attendant must carefully examine the engine. All bolts and nuts, pins, cotters, etc., must be properly tightened up, and all split pins properly opened out. Valve springs must be clean and in good order, and all the ignition arrangements must be carefully inspected. If the ignition can be retarded for starting, this should be done. The half-compression cam, if fitted, should be brought into play. The engine must be cleared of all obstructions, and the circulating water valves opened. Care must be taken that the fuel tanks have a proper supply and that the water tanks are filled. Lubricators must be filled and trimmings adjusted. No definite rules can be laid down with regard to starting, as the operations will necessarily vary with the type of engine. With an oil engine care must be taken that the vaporiser is hot enough and not flooded with oil. When a compressed-air starter is fitted, the engine should start on the first impulse. If it does not do this, all the fuel-feed and ignition arrangements should be seen to, and care should be taken not to drop the air pressure in the reservoir too much by attempting to start an engine unless it is certain that it is in perfect order.

3. Running.—After the engine has run up to speed, the load must be put on gradually and adjustment made to the fuel and air supplies as necessary. The water valves must be opened till the jackets become just as hot as the hand can bear when held on them. The lubricators must be examined periodically and filled from time to time. The condition of the bearings requires constant attention. Should a bearing commence to run warm, it must be promptly, attended to. It is a good thing to keep a can of rape or olive oil and use it at once, if any bearing should show a sign of heating.

4. Stopping.—To stop the engine the load must first be removed and then the fuel supply cut off. Should there be a compressed air reservoir for starting, it must be fully charged before the engine is shut down. The water valves must be shut off, the jackets drained if necessary and the engine wiped down while it is warm. The trimmings should be removed from the tubes and put in the oil cups till again required.

5. Notes on working.—The satisfactory working of the engine depends on the following conditions :—

(1) Suitability of fuel and steady fuel supply.
(2) Correct adjustment of mixture.
(3) Correct amount of compression.
(4) Correct timing of valves and of ignition.
(5) Efficient governing.
(6) Good circulation in water jackets.
(7) Good but not excessive lubrication.
(8) General cleanliness of engine.

(1) This may be ensured by a suitable choice of fuel, by seeing that no grit or dirt is introduced with the fuel supply, and that all feed arrangements are clean and valves working properly.

(2) This depends on the adjustment of fuel and air, which must be proportioned to suit the fuel in use.

(3) This can be ensured by keeping the connecting rod of the correct length, and by seeing that there are no leaks at valves, rings, or joints.

(4) The valve timing will depend on the engagement of the gears and on the absence of wear of working parts. The attendant should make no attempt to alter the timing, and, if he suspsects a fault, should at once report it. The ignition on modern engine will probably be electric, and the timing of this should only be carried out by a duly qualified person. The attendant is to remember that his duty is to run with as much spark advance as is practicable without causing back-firing.

(5) The function of the governor is to control the speed of the engine within close limits. If it fails to do this, the gear is to be examined to see that no sticking is taking place. If the gear appears to be quite free and still fails to perform its functions, the matter should be reported. If the engine shows a tendency to race, speed must be at once controlled by hand, and the engine should be stopped as soon as allowable.

(6) All pipes and tanks must be kept clean, and the cyliner jacket must be free from deposit. The circulation should be free enough to prevent the water from boiling, but the jacket should not be allowed to become cool through too much circulation.

(7) The cylinder should not be over-lubricated, although care must be taken that the piston does not get dry. Only approved gas or oil engine cylinder oil may be used to lubricate parts exposed to high temperatures. The lubrication is usually automatic, and does not require any adjustment. With splash lubrication the oil level must be adjusted in strict accordance with instructions. Any over-lubrication will be shown by a dirty exhaust, and will soon cause a deposit in the cylinder and on the piston. This deposit will lead to pre-ignition. If the oil cups are at all deep, cotton wicks should be used in place of worsted. The former will draw off oil from a greater depth, the limit for the latter being about 1¼ in.

(8) The engine should be kept thoroughly clean, and any dust should be avoided in the engine room then the engine is running, as it may get into bearings and cylinders.

6. Ignition.—Trouble may be experienced with ignition from two sources, (*a*) pre-ignition, (*b*) late ignition.

(*a*) This is what is usually known as back-firing, and is at once indicated by a sharp knock in the cylinder. It must be checked at once, or else the engine must be stopped, as it is dangerous in an engine of any size. Its causes are :—

(1) **Ignition too far advanced.**—The ignition should be at once retarded in any case of pre-ignition, if this is possible.

(2) **Deposit in cylinder.**—A deposit may from in the cylinder from excessive lubrication, or from the fuel. This is very liable to cause pre-ignition. The only remedy is to clean the parts affected.

(3) **Too rich a mixture.**—This may cause back-firing. The best thing to do is to reduce the fuel supply and increase the air.

(4) **Defective circulation.**—Allowing the position to get too hot, and so fire the charge before the end of the instroke.

(5) **Excessive compression.**—This applies to Hornsby engines, and must be altered by the method adopted for reducing compression in the particular engine concerned.

(*b*) Late ignition is usually noticed from the failure of the engine to run properly under its load, and is often accompanied by firing in the exhaust pipe or silencer. It may be due to :—

(1) **Ignition too far retarded or faulty.**—The ignition should be as far advanced as practicable. With tube ignition the tube may be too cold or dirty. With electric ignition the plug may be dirty or faulty, or there may not be clean breaking in the circuit. The sparking should be tested and the magneto examined. If the plug is dirty it should be cleaned.

(2) **Too weak mixture.**—This may be due to a change in the quality of producer gas, to a choke in the fuel supply, or by too cold a vaporiser in the case of an oil engine. It should be remembered that an oil engine will not as a rule, run light, unless a lamp is used to heat the vaporiser.

(3) **Insufficient compression.**—This may be due to any joint, valve, or ring failure. These causes are generally evident if the engine is not of an enclosed type.

Any of the above matters may cause the engine to stop. If the trouble is not enough to stop the engine, it will be probably detected by great loss of powers, by intermittent and irregular explosions, or by firing in the exhaust pipe.

7. Water injection.—With some engines a small quantity of water is passed into the clinder just before the expl osion takes place. The amount should be just enough to produce quiet running and to save any violent explosion. Too much water is to be avoided.

8. Knocking.—This may be due to pre-ig nition or to a bearing. Any groaning in the cylinder is due to a broken ring or to want of lubrication. The knock due to a slight back-firing is usually sharper than that due to a bearing. It should, of course, be at once stopped. If a bearing commences to knock, the particular bearing at fault should be identified and attended to when the engine is stopped. Should any sudden knock develop, the engine should be at once stopped, unless the knock is slight and shows no sign of increasing.

9. **Examination and repair.**—It is advisable to carry out an exami nation of the piston, cylinder, and valves of a gas or oil engine after some 200 hours running. The exact length of time that an engine may be allowed to go without this examination will depend on the conditions under which it is worked. At this examination the piston should be drawn and the valves lifted from their seats and examined. The bearing surfaces of the piston rings should be noted, and if there are any signs of a blow-past, the ring at fault should be replaced. The cylinder, piston, valves and valve boxes should be cleaned to remove thoroughly any carbonaceous deposit. The valve seats should be examined and the valves ground in, if necessary.

10. A complete general examination should be periodically carried out when the following points should receive attention :—

(1) **Cylinder.**—Any ridge at the end of the piston stroke should be scraped away, and the bore of the cylinder examined. Any wear should be noted. The valve seats should be examined, and if the seat is too broad it should be faced down. The guides for valve spindles should be bushed, if much wear has taken place. All joint surfaces should be inspected and re-surfaced, if necessary, to make a good joint. The water jacket and the cooling system should be thoroughly cleaned out.

(2) **Piston.**—The rings should be tried in the cylinder and any that show too large an opening at the joint should be replaced If there no studs to prevent the rings from turning, it is a good thing to fit them. The rings must, of course break joint. The piston should be measured for waer. The gudgeon pin and its fixing arrangements should be inspected. Should the gudgeon pin pass through the piston, care is to be taken that there is at least 0·05 in. clearance between the cylinder walls and pin on either side.

(3) **Connecting rod.**—The brasses should be refitted if necessary. Care is to be taken that the original length of rod is maintained, since any alteration will affect the normal compression.

(4) **Main bearings.**—To be examined for wear, tested for line, and re-adjusted, if necessary.

(5) **Crankshaft.**—Journals to be examined, and any scoring removed, if possible. The shaft to be tested for straightness. Fly-wheel keys to be inspected. A useful test for alignment of crankshaft and cylinder is to couple up the connecting rod to the piston and see if the crankpin brasses will swing fair on to the pin at any part of the stroke. Connecting-rod brasses should be finally bedded with the rod and coupled up.

(6) **Camshaft.**—The bearings to be examined and adjusted. Badly worn cams or gear wheels must be replaced. Before stripping the gears, it should be seen that they are properly marked for engagement.

(7) **Valves and valve gears.**—Inspection should be made of all bearings of rocking levers and rollers. The tappets must not be allowed to wear very badly. Valves should be tested for straightness of spindles, and any bent ones rejected. The springs must be good, and any cotters a good fit in their spindles. The valve faces may be ground up, or trued up in the lathe, and then the valves ground to their seats. The width of seat must not be too great. Each valve should have a lift of about one-fifth of its diameter. Should the valve gearing not be marked for engagement, it should be set, so that the exhaust valve opens at about 90 per cent. of the out-stroke. The air valve should open just before the inner dead centre is reached, and close just after the crank reaches the outer dead centre.

(8) **Governor gear.**—This should be carefully examined for wear, and all parts replaced or repaired as soon as much wear shows itself.

(9) **Feed.**—No definite rules can be laid down for the examination of fuel supply parts. Generally, all parts should be very thoroughly cleaned, and any valves ground to the seats. Where there is any spray nozzle, any enlargement of the hole is to be carefully avoided.

(10) **Ignition.**—With tube ignition there should be no necessity for any repair. With electric low-tension ignition the hole in cylinder for rocking arm should be gauged and bushed if much wear has taken place. The rocking arm itself should also be renewed. The leads should be replaced if they are defective and the end connections kept good. As a rule any ignition faults will show themselves when running and wear is the most important consideration at a general examination. If the ignition can be advanced, it should be so set that when it is fully retarded the piston has started on the out-storke. When there is no advance possible it is as well to set the igintion so that the spark passes just when the crank is on the dead centre. With high-tension ignitions the condition of the platinum points and the brushes requires attention.

(11) **Records.**—For all types of engine plant, log records should be maintained. Such records should be designed to clearly show, whether the engine maintenance is being properly kept up, indicate the consumption per B. H. P.—hour of both fuel and lubrication over period covered and also show the extent to which renewals are called for. The cleaning adjustment, or inspecion of pistons, piston rings combustion chamber, valves, crankpins, journals, large and small end connec ing rod brasses, main bearings, water jacket and water pipes, sprayer, strainers, fuel pipes pumps, air receivers, compressors, piping and drains are points to which special attention is called.

NOTES ON THE CARE OF SUCTION GAS PRODUCER PLANTS

1. It should never be overlooked, that the gas from suction plants poisonous, has little smell and, therefore, requires the greatest care to prevent any escape into places where it might be inhaled. All cleaning should be carried out in daylight and under no circumstances should a fire, a naked or atmospheric light be allowed near the plant. Smoking also should be strictly prohibited. Not *less* than two men should be on duty together, either of whom should know what steps to take in case of sudden emergency.

2. Maker's instruction for the running of plants should be strictly followed and as the cleaning arrangements with differing fuel producer gas, are *not* the same, only that fuel (as anthracite or coke) for which the producer is designed, should be used.

3 Many failures to start a plant properly are due to improper fuel combustion. The fuel used should burn uniformly throughout and the gas, when tested, should burn with a perfectly steady flame and show little or no variation incolour.

4. Always turn the fan steadily when gas is being tested. On no account must the fan be stopped.

5. Opening valve at the bottom of hopper at the same time as the outer lid on top of the hopper on the generator is opened is dangerous and *should never be done*.

6. Never open, nor take off any doors from any part of the plant *when the fan is blowing*.

7. Keep the correct supply of water to the scrubber ; if there is too little, dirty gas will be supplied ; if there is too much, the engine will be unable to draw gas properly.

8. The producer should be regularly cleansed out and not less than once weekly. It should be allowed to cool gradually to avoid cracking the firebrick lining. The hydraulic box should be cleaned from dust and mud at least once a month, which also applies to the piping and gas box. The gas box should be drained daily of any accumulation of moisture. Accumulations of mud at the bottom of scrubber should be removed at least every month and when the scrubber is to be emptied, all joints should be opened up and left open for not less than five hours. The operation of emptying should be carefully watched. After cleaning has been done and any joints re-made, all openings form the system should be closed, the pressure blown up with the fan and all joints tested with a lighted candle for air leaks. No air leaks must be allowed and any found must be made good before starting up.

9. Records in either sheet or log-book from which show complete performance, fuel consumption and cleaning attendance, should be carefully maintained as a part of the daily routine.

TABLE CCXXXIII

Specific gravities of various fluids and weights per gallon.

Fluid	Specific gravity	Weight per gallon in lbs.
Water	1·00	10·00
Linseed oil	0·932	9·32
Turpentine	0·865	8·65
Cotton seed oil	0·922	9·22
Olive oil	0·914	9·14
Nut oil	0·920	9·20
Codliver oil	0·930	9·30
Seal oil	0·931	9·31
Sperm oil	0·881	8·81
Whale oil	0·927	9·27
Lard oil and neatsfoot oil	0·916	9·16
Tallow oil	0·915	9·15
Resin oil	0·994	9·94

NOTES ON SHAFTING

The stresses to which shafting is mainly subject are torsion and transverse. The torsional strength or resistance to breaking by twisting is directly proportional to the cube of the diameter. The torsional stiffness which determines the angle through which the shaft is twisted, varies directly as the fourth power of the diameter and inversely as the length. The transverse strength or resistance to bending as a beam is dirctly proportional to the cube of the diameter and inversely proportional to the length between supports or bearings. The transverse stiffness which determines the deflection of the shaft, considered as a beam is directly proportional to the fourth power of the diameter and is inversely proportional to the load and to the cube of the distance between the supports. When purchasing supplies, it should be remembered, that, when properly made, "turned" shafting is preferable to 'cold-rolled".

For *average* conditions the following tables may be of service.

TABLE CCXXXIV

HEAD SHAFTS

Approximate maximum distance apart of bearings

Sizes of shafts for carrying main drive pulleys, etc.

Shaft diameters, in inches	Distance from centre to centre of bearings in feet.				
	4	5	6	8	10
	Diameters of swells in inches				
3	3½	4	4½	..	..
3½	4	4½	5	..	..
4	4½	5	5½	6	..
4½	5	5½	6	6½	
5	5½	6	6½	7	7½
5½	6	6½	7	7½	8
6	..	7	7½	8	8½
7	..	8	8½	9	9½
8	..	..	9½	10	10½
9	..	..	..	10½	11
10	..	..	..	11½	12

TABLE CCXXXV

LINE SHAFTING CARRYING PULLEYS, ETC.

Approximate limit of distance apart of centres of bearings for shafts which do not carry more than an average number of pulleys transmitting normal powers

Dia. of shaft, in inches.	1½	1¾	2	2¼	2½	2¾	3	3½	4	4½	5	5½	6
Revs. per minute	Distance between bearing centres in feet.												
100	7¼	7½	8	8½	9	9½	10	11	11½	12	13	14	15
150	6¾	7¼	7¾	8¼	8¾	9¼	9¾	10¾	11¼	11¾	12¾	13¾	14½
200	6½	7	7½	8	8½	9	9½	10½	11	11½	12¼	13¼	14¼
250	6	6¾	7¼	7¾	8¼	8¾	9¼	10	10½	11	11¾	12½	13½
300	5¾	6½	7	7½	8	8½	8¾	9½	10	10½	11	11¾	12½
350	5¼	6	6¾	7¼	7¾	8	8½	9	9½	9¾	10¼	11	11½
400	5	5¾	6½	7	7½	7¾	8	8½	8¾	9	9½	10	10
500	4½	5½	6¼	6½	7	7½	7¾	8¼	8½	8¾	9¼	9½	10
600	4¼	5¼	6	6¼	6½	7	7¼	8	8¼	8½	9	9¼	9½

TABLE CCXXXVI

TRANSMISSION SHAFTING

(For transmitting power only)

Approximate limit of distance apart of centres of bearings for shafts which do not carry any pulleys, or gears, etc

Dia. of shaft, in inches.	1½	1¾	2	2¼	2½	2¾	3	3½	4	4½	5	5½	6
Revs. per minute	Distance between bearing centres in feet												
100	9	10	11	11½	12	12½	13	14	14½	15	16	17	18
150	8½	9½	10¾	11¼	11¾	12	12½	13½	14	14½	15½	16½	17½
200	8	9	10½	10¾	11¼	11½	12	13	13½	13¾	14¾	15¾	16¾
250	7½	8½	10	10¼	10¾	11	11½	12¼	12¾	13¼	14	15	16
300	7	8	9½	9¾	10	10¼	10¾	11½	12¼	12½	13¼	14	15
350	6¾	7¾	8¾	9	9½	9½	10	10¾	11	11½	12¾	13	13¾
400	6¼	7¼	8	8½	8½	9	9¼	10	10½	10½	11¾	12	12½
500	5¾	6¾	7½	7¾	8	8½	9	9½	9¾	10	10½	11½	11½
600	5¼	6¼	7	7¼	7½	8	8½	9¼	9½	9¾	10	10½	11

To find the H. P. which mild steel shafts of good quality will transmit at various speeds.

(1) *For head shafts which are well supported* :—

Multiply the cube of the diameter of the shaft by the revolutions per minute and divide the product by the constant 100.

(2) *For line shafts well supported, such as obtains in machine shops, etc.*— Multiply the cube of the diameter of the shaft by the revolutions per minute and divide the product by the constant 66⅔ (sixty-six and two-thirds).

(3) *For transmission shafts well supported in bearings and not subject to any transverse strain* :—

Multiply the cube of the diameter of the shaft by the revolutions per minute and divide the product by the constant 50.

CHAINS AND LIFTING TACKLE

1. Accidents caused by the failure of structural parts contained in lifting tackle are not uncommon and quite apart from loss of life or personal injury frequently have a monetary aspect of no mean magnitude. General types of appliances in use, embrace mechanical elements in the form of chains, rings, links, hooks, dogs, shackles, swivels and eyebolts. Examples of common types in use are shown in Figs. 1 to 25, plates CXXXIII and CXXXIV which by no means exhaust the field of selection.

2. With the exception of special types of chain links used for conveyors and elevators, generally made from malleable cast iron, most of the appliances named are usually manufactured from either wrought iron or mild steel. The selection of a suitable quality of materials for the purpose is of the utmost importance, and small users having no means of testing or sampling, must rely entirely on the makers' trade description. Reputable firms supply chains and other tackle of a satisfactory quality, but frequently these items are either purchased from firms whose prices indicate that the materials cannot be of good quality, or through merchants, who have little or no technical knowledge, and naturally sell those goods which yield the greatest profit. The right practice is to invariably indent through the Stores Department for all lifting tackle and when forced through unforeseen circumstances to purchase locally, to purchase *only* material of a definitey reputable character.

3. It is an advantage if the "use" performance of all such tackle is so controlled, so as to permit of records being kept, and various systems of marking appliances are in use having this end in view. Railway, dock, and factory authorities, have long recognised the importance of maintaining records of this nature. They are most useful for reference purposes, when the durability of any particular appliance is in question, and it is desired to know its history during use.

4. Where a large number of appliances are is more or less regular use, the best method of keeping records is by using a card system which affords convenient filing grouped either with reference to the tackle or the department using it.

5. Failures due solely to the reduction of material by wear are not common. The majority of failures can be traced to either a lack of knowledge governing simple mechanical principles, or to a definite disregard for common safeguards. Probably overloading is the most common cause of failure in lifting appliances, and it may originate through either ignorance or carelessness

on the part of workmen. Shock of any kind is another frequent cause of failure, which cannot be too strongly guarded against, as is also the not uncommon habit of using end links, rings or shackles, which do not ride freely upon hooks used with them. The prevention of accidents should invariably be given pre-eminence, and steps should be taken to ensure that periodical inspections are properly carried out.

6. Incidentally, when American lifting appliances marked in tons are used, it must not be overlooked that the U. S. tons should always be interpreted as the short ton of 2,000 pounds. If, therefore, such appliances are worked to the full lifting capacity of British long tons (2,240 pounds) overloading occurs. With appliances marked in metric tons, this again should not be overlooked, since the metric ton is but equivalent to 0·9842 of the British long ton.

7. A good deal is written in text-books with reference to the value of annealing chains, hooks, etc.; it should, however, be realisd that proper annealing can only be carried out by experienced workmen, and then only under proper conditions. In India, the safest course to follow, is to return all lifting appliances suspected of weakness through ageing or stress crystallisation to a head depot, replacing with new tackle. Particular attention should be paid to this question on important works. All such suspected tackle should moreover be so stamped or numbered, that its reissue elsewhere—*as good*—cannot occur.

RENOLD SILENT CHAIN DRIVES

1. *Mounting.*—This should be of a very substantial character, so that there may be no bending or whipping of shafts. Chain wheels should be as near as possible to bearings and, in the case of heavy drives, should have a bearing on each side. Where bearings are fixed on brackets attached to steel girders, or pillars, it is advisable to use pads of felt under them to reduce vibration.

2. *Erection.*—Liner chain—centreguided.—More care should be paid to alignment and parallelism of shafts than is usual in erecting belt drives. The need for accuracy increases, both as the distance between shafts become less, and as the width of the chain becomes greater. Faulty alignment always shorten the life of a chain and, if serious, may rack it to pieces and cause breakage in a few months. The shafts and wheels may be lined up by the usual methods, but with extra care. The chain should then be mounted, a careful inspection made and the drive set in motion. Faulty alignment or lack of parallelism may then be detected by glancing along the back of the chain, a bend in the lines connecting the various links will indicate falsity of running.

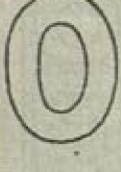


Fig. 1. Oval Link.

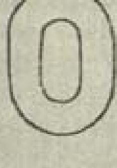


Fig. 2. Straight-sided Link.

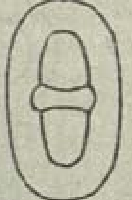


Fig. 3. Stud Link.

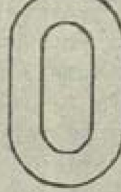


Fig. 4 Long Link.

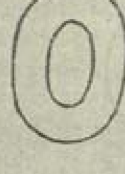


Fig. 5. Weldless Link.

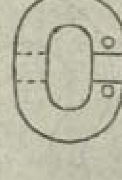


Fig. 6. Split Link.

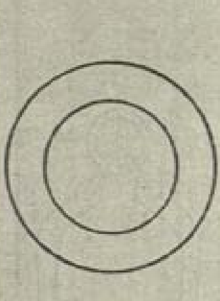


Fig. 7 Ring.

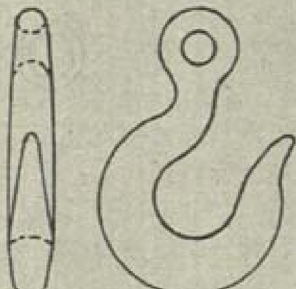


Fig. 8. Sling Hook with rounded Eye.

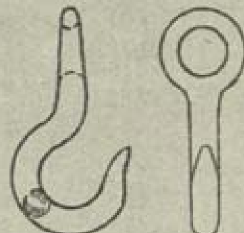


Fig. 9 Cargo Hook.

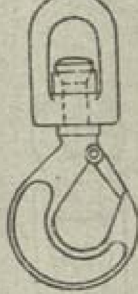


Fig. 10. Swivel Spring Hook.

Fig. 11. Liverpool Hook.

Fig. 12 Burkes safety Hook.

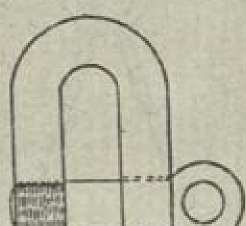


Fig. 13. D Shackle.

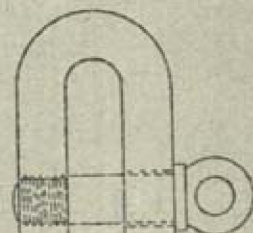


Fig. 14 D Shackle with Collar on Pin.

G. PZ. P. Poona, 1958.

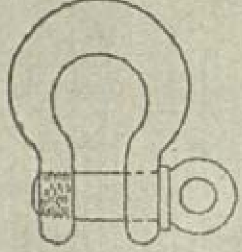


Fig 15.
Bow Shackle

Fig 16.
Plain Eye-Bolt.

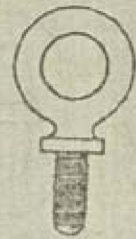


Fig 17
Eye-Bolt with Collar.

Fig 18
Swivel.

Fig 19.
Weldless Swivel.

Fig 22.
Collar Sling

Fig 23
Single Sling.

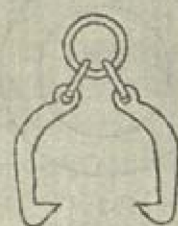


Fig 20
Timber Dogs.

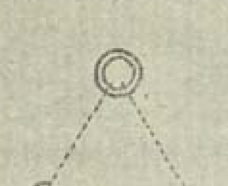


Fig 21
Lead Hooks

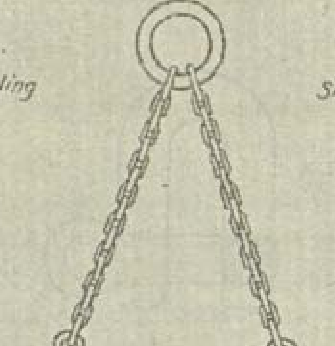


Fig 24
Double Sling

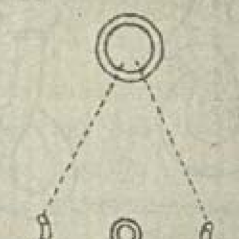


Fig 25
Cotton Hooks

3. After the chain has run for a few days, wear or cutting will be apparent if the alignment has been at all faulty, on the centre guide links. If the wheels are out of line but the shafts are parallel, the centre guide plates will be marked on both sides, but probably more deeply on one side than the other, depending on the relative sizes of the wheels. If the wheels are in line but the shafts are out of parellel, the centre guide plates will only be marked on one side. Prolonged running out of line is very injurious and end play in one or both of the shafts has the same effect as faulty alignment and should consequently be reduced as much as possible. Not more than 1/16″ to 1/8″ is allowable according to length of drive and width of chain. Every chain should be oiled *copiously* immediately after erection and for the first few weeks of running; for cleaning use paraffin or kerosene oil.

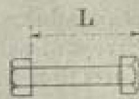
4. *Lubricant.—Never* use a solid lubricant. For gear case lubricant use a good quality light machine oil and for drip iubrication use a fairly heavy macaine or light cylinder oil.

TABLE CCXXXVI-A

Table CLXVII

STEEL HEXAGON BOLTS AND NUTS

Weight of each in lbs.



Length under Head to Point Inches	DIAMETER OF BOLT IN INCHES									
	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
1	·103	·213	..	..	..	..	..	..	..	..
1/4	·110	·227	·385	..	..	..	..	..	..	..
1/2	·118	·241	·407	·637	..	..	..	..	..	..
3/4	·126	·255	·429	·668	1·000	..	..	..	..	..
2	·134	·268	·450	·700	1·031	1·440	..	..	..	..
1/4	·142	·287	·472	·731	1·074	1·496	2·008	..	..	..
1/2	·150	·296	·495	·762	1·116	1·552	2·079	2·727	..	..
3/4	·157	·310	·515	·793	1·160	1·607	2·150	2·910	3·525	..
3	·165	·324	·537	·825	1·202	1·663	2·220	2·900	3·630	4·547
1/4	·173	·338	·560	·856	1·244	1·720	2·290	2·982	3·736	4·672
1/2	·181	·352	·581	·887	1·287	1·774	2·360	3·070	3·841	4·797
3/4	·189	·366	·602	·920	1·330	1·830	2·431	3·156	3·950	4·923
4	·196	·380	·624	·950	1·372	1·885	2·501	3·243	4·051	5·048
1/4	·204	·394	·646	·981	1·415	1·941	2·571	3·330	4·156	5·173
1/2	·212	·408	·658	1·012	1·457	1·997	2·642	3·417	4·261	5·300
3/4	·220	·421	·690	1·044	1·500	2·052	2·712	3·504	4·367	5·423
5	·228	·435	·711	1·075	1·542	2·108	2·783	3·591	4·472	5·550
1/4	..	·450	·733	1·106	1·585	2·164	2·853	3·678	4·577	5·675
1/2	..	·463	·755	1·137	1·627	2·220	2·924	3·765	4·682	5·800
3/4	..	·477	·776	1·170	1·670	2·275	2·995	3·852	4·787	5·925
6	..	·491	·798	1·200	1·713	2·331	3·054	3·939	4·893	6·050
1/2	..	·520	·841	1·263	1·798	2·442	3·205	4·112	5·103	6·300
7	..	·547	·885	1·325	1·883	2·553	3·346	4·285	5·313	6·550
1/2	..	..	·928	1·388	1·968	2·664	3·487	4·460	5·524	6·800
8	..	..	·972	1·450	2·053	2·775	3·628	4·634	5·734	7·050
1/2	..	..	1·015	1·513	2·140	2·887	3·769	4·808	5·944	7·300
9	..	..	1·058	1·576	2·224	3·000	3·910	4·982	6·155	7·550
1/2	..	..	1·102	1·638	2·310	3·110	4·050	5·156	6·365	7·800
10	..	..	1·145	1·700	2·394	3·220	4·190	5·330	6·575	8·050
1/2	..	..	..	1·763	2·480	3·333	4·333	5·505	6·786	8·302
11	..	..	..	1·825	2·564	3·444	4·474	5·617	7·000	8·550
1/2	..	..	..	1·888	2·650	3·554	4·613	5·850	7·206	8·800
12	..	..	..	1·950	2·735	3·666	4·754	6·025	7·417	9·050
For each additional inch in length add	·0313	·0556	·0869	·1252	·1703	·2225	·2817	·3477	·4208	·5007

TABLE CCXXXVI-B

GALVANIZED IRON FITTINGS

Approx. weights in lbs per gross.

HOOK BOLTS.

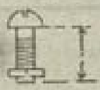
Length	3½"	4"	4½"	5"
5/16" Dia.	18.5	20.5	22.5	25
3/8" Dia.	24	28	32	37.5

ROOFING NAILS.

Length	2½"	3"
1/4" Dia.	5	7

ROOFING SCREWS.

Length	2¼"	2½"	3"	
1/4 Dia.	4.75	5.5	7	



SHEETING BOLTS & NUTS.

Length	1½"	1¼"	3/4"	1/2"
1/4" Dia.	5	4.75	3.75	3.5

SHEETING RIVETS

Length	3/8"	1/2"	5/8"	
1/4" Dia.	2	2.25	2.5	

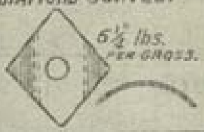
FLAT CIRCULAR WASHERS.

2 lbs per gross.

LIMPET WASHERS. For ¼" dia Bolts.

1½ lbs per gross.

DIAMOND CURVED.



Common allowances for weights of fixings for corrugated sheets are as follows:-

Sheeting Rivets and Washers .... 3¼ lbs per square of 100 feet.
Hook Bolts and Diamond Washers .... 4½ " " " " "
Wood Screws and Diamond Washers for timber purlins. 2½ " " " " "

TABLE CCXXXVII

GAS TUBING

Approximate weights and sizes

Nominal bore inches	Thickness		No. of threads per inch (wh.)	Weight per foot in lbs.
	S. W. G.	Inches		
¾	11	·116	14	1·18
1	10	·128	11	1·79
1¼	9	·144	11	2·52
1½	8	·160	11	2·97
2	8	160	11	4·48

TABLE CCXXXVIII

HOOP IRON

B. W. G.	Width in inches	Weight in lbs. per 100 feet
13	2	63·319
14	1¾	47·153
15	1½	36·375
16	1¼	26·523
17	1⅛	20·840
18	1	16·167
19	⅞	12·000

TABLE CCXXXIX

COMMON C. I. WATER TANK SIZES AND CAPACITIES

Capacity in gallons	Length		Breadth		Depth	
	Feet	Inches	Feet	Inches	Feet	Inches
30	2	0	1	6	1	8
50	2	7	1	7	2	0
80	3	0	2	2	2	0
100	3	0	2	6	2	2
150	3	7	2	5	2	10
200	4	0	2	8	3	0
250	5	0	2	8	3	0
300	6	0	2	8	3	0
400	4	0	4	0	4	0
500	5	0	4	0	4	0
1,000	6	0	6	0	4	6
2,000	8	0	8	0	5	0
2,000	10	0	6	0	5	4

TABLE CCXL

SHEET LEAD

Weight in lbs. per foot superficial	Thickness in inches	Weight in lbs. per foot superficial	Thickness in inches
1	0·017	7	0·118
2	0·034	8	0·135
3	0·051	9	0·152
4	0·068	10	0·169
5	0·085	11	0·186
6	0·101	12	0·205

(b) ELECTRICAL NOTES AND TABLES

International electrical units

1. The international **ohm** is adopted as the legal unit of resistance, which is based upon the ohm equal to 10^9 units of resistance of the C. G. S. system of electromagnetic units and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14·4521 grammes in mass, of a constant cross-sectional area and of the length of 106·245 centimetres.

2. The international **ampere** is adopted as the legal unit of current which is one-tenth of the unit of current of the C. G. S. system of electro-magnetic units and which is represented sufficiently well for practical use, by the unvarying current which, when passed through a solution of nitrate of silver in water, deposits silver at the rate of 0·001118 gramme per second.

3. The international **volt** is adopted as the legal unit of electro-motive force, which is the E. M. F. that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampere, and which is represented sufficiently well for practical use by 1000/1434 of the E. M. F. between the poles or electrodes of the Voltaic cell known as Clark's cell, at a temperature of 14° C.

4. The international **coulomb** is adopted as the legal unit of quantity which is the quantity of electricity transferred by a current of one international ampere in one second.

5. The international **watt** is adopted as the legal unit of power which is equal to 10^7 units of power in the C. G. S. system and which is represented sufficiently well for practical use, by the work done at the rate of one joule per second.

6. The international **joule** is adopted as the legal unit of work, which is 10^7 units of work in the C. G. S. system and which is represented sufficiently well for practical use, by the energy expended in one second by an international watt.

7. The international **farad** is adopted as the legal unit of capacity, which is the capacity of a conductor charged to a potential of one international volt by one international coulomb of electricity.

8. The international **henry** is adopted as the legal unit of induction, which is the induction in the circuit when the E. M. F. induced in this circuit is one international volt, while the inducing current varies at the rate of one ampere per second.

TABLE CCXLI

Name of element considered	Symbol	Practical unit	Symbol	Relation to C.G.S. unit	Relation to other units
Resistance	R.	Ohm.	..	10^9	E/I
Current	I.	Ampere.	A.	10^{-1}	E/R.
Electro-motive force ..	E.	Volt.	V.	10^8	I×R.
Quantity	Q.	Coulomb.	I.	10^{-1}	I×t.
Power	P	Watt.	W.	10^7	E×I or I^2×R.
Work	W.	Joule.	J.	10^7	P×t.
Capacity	C.	Farad.	F.	10^{-9}	..
Self-induction	L.	Henry.	H.	10^9	..

TABLE CCXLII

OTHER UNITS IN COMMON USE.

1.	The Milli-ampere	=0·001 ampere; the micro-ampere= =0·000001 ampere.
2.	The micro-coulomb	=0·000001 coulomb.
3.	The ampere hour	=3·600 coulombs.
4.	The milli-volt	=0·001 volt.
5.	The microhm	=0·000001 ohm.
6.	The megohm	=1,000,000 ohms.
7.	The micro-farad	=0·000001 farad.
8.	The milli-henry	=0·001 henries.
9.	The kilo-volt-ampere	=1,000 volt amperes (alternating).
10.	The kilowatt-hour or kelvin	=3,600,000 joules.

This is the Board of Trade unit of electric energy and is the quantity of energy supplied in one hour, by a current at such a pressure, that the product of volts, amperes and hours=1,000.

TABLE CCXLIII

WIRE GAUGES

The sizes of electrical conductors may be expressed in any of the following terms:—

(*a*) Sectional areas as:—
Equivalent solid wire in square inches.
Equivalent solid wire in square millimetres.
Equivalent solid wire in circular mils.
Equivalent solid wire in Brown and Sharp's American Wire Gauge.

(*b*) Strand composition giving:—
The number of wires and diameter of each in mils.
The number of wires and diameter of each in millimetres.
The number of wires and diameter of each in British Standard Wire Gauge terms.
The number of wires and diameter of each in Brown and Sharp's American Wire Gauge.

(*c*) Weight of conductor as:—
Pounds per mile, or kilogrammes per kilometre.

TABLE CCXLIV

WIRE GAUGE COMPARISON TABLE

British standard gauge		Birmingham wire gauge		B.&S. or American wire gauge	
Gauge No.	Diameter-inches	Gauge No.	Diameter-inches	Gauge No.	Diameter-inches
7/0	0·500	....	....	7/0	0·6513
6/0	0·464	....	....	6/0	·50800
5/0	0·432	5/0	0·500	5/0	0·5165
4/0	0·400	4/0	0·454	4/0	0·4600
3/0	0·372	3/0	0·425	3/0	0·4096
2/0	0·348	2/0	0·380	2/0	0·3648
1/0	0·324	1/0	0·340	1/0	0·3249
1	0·300	1	0·300	1	0·2893
2	0·276	2	0·284	2	0·2576
3	0·252	3	0·259	3	0·2294
4	0·232	4	0·238	4	0·2043
5	0·212	5	0·220	5	0·1819
6	0·192	6	0·203	6	0·1620
7	0·176	7	0·180	7	0·1443
8	0·160	8	0·165	8	0·1285
9	0·144	9	0·148	9	0·1144
10	0·128	10	0·134	10	0·1019
11	0·116	11	0·120	11	0·0907
12	0·104	12	0·109	12	0·0808
13	0·092	13	0·095	13	0·0720
14	0·080	14	0·083	14	0·0641
15	0·072	15	0·072	15	0·0571
16	0·064	16	0·065	16	0·0508
17	0·056	17	0·058	17	0·0453
18	0·048	18	0·049	18	0·0403
19	0·040	19	0·042	19	0·0359
20	0·036	20	0·035	20	0·0320
21	0·032	21	0·032	21	0·0285
22	0·028	22	0·028	22	0·0253
23	0·024	23	0·025	23	0·0226
24	0·022	24	0·022	24	0·0201
25	0·020	25	0·020	25	0·0179
26	0·018	26	0·018	26	0·0159
27	0·0164	27	0·016	27	0·0142
28	0·0148	28	0·014	28	0·0126
29	0·0136	29	0·013	29	0·0113
30	0·0124	30	0·012	30	0·0100
31	0·0116	31	0·010	31	0·0089
32	0·0108	32	0·009	32	0·0080
33	0·0100	33	0·008	33	0·0071
34	0·0092	34	0·007	34	0·0063
35	0·0084	35	0·005	35	0·0056
36	0·0076	36	0·004	36	0·0050
37	0·0068	....	....	37	0·0045
38	0·0060	....	....	38	0·0040
39	0·0052	....	....	39	0·0035
40	0·0048	....	....	40	0·0031
41	0·0044	....	....	41	0·0028
42	0·0040	....	....	42	0·0025
43	0·0036	....	....	43	0·0022
44	0·0032	....	....	44	0·0020
45	0·0028	....	....	45	0·0018
46	0·0024	....	....	....	....
47	0·0020	....	....	....	....
48	0·0016	....	....	....	....
49	0·0012	....	....	....	....
50	0·0010	....	....	....	....

TABLE CCXLW

BRITISH S. W. G. CONDUCTOR AREAS AND WEIGHTS.

Gauge No.	Area (Sq. inch)	Weitht in lbs. per 1,000 yds.	Gauge No.	Area (Sq. inch)	Weight in lbs. per 1,000 yds.
7/0	0·1963	2271·0	23	0·00045239	5·23
6/0	0·1691	1956·0	24	0·00038013	4·396
5/0	0·1466	1695·0	25	0·00031416	3·633
4/0	0·1257	1453·0	26	0·00025446	2·943
3/0	0·1087	1257·0	27	0·00021124	2·443
2/0	0·0951	1100·0	28	0·0001720	1·9895
1/0	0·08245	954·0	29	0·00014527	1·680
1	0·07069	818·0	30	0·00012076	1·3966
2	0·05983	692·0	31	0·00010569	1·2222
3	0·04988	577·0	32	0·000091609	1·0594
4	0·04227	489·0	33	0·00007854	0·9083
5	0·03530	408·2	34	0·000066476	0·7688
6	0·02895	334·8	35	0·000055417	0·6409
7	0·02433	281·4	36	0·000045365	0·5246
8	0·02011	232·5	37	0·000036317	0·420
9	0·01629	188·3	38	0·000028274	0·3270
10	0·01287	148·8	39	0·000021237	0·2456
11	0·01057	122·2	40	0·000018095	0·2093
12	0·008495	98·24	41	0·000015205	0·17585
13	0·006648	76·88	42	0·000012566	0·14533
14	0·005027	58·13	43	0·000010179	0·11772
15	0·004072	47·09	44	0·0000080425	0·09301
16	0·003217	37·20	45	0·0000061575	0·07121
17	0·002463	28·48	46	0·0000045239	0·05232
18	0·001810	20·93	47	0·0000031416	0·03633
19	0·001257	14·53	48	0·0000020106	0·02325
20	0·001018	11·77	49	0·0000011310	0·013079
21	0·0008042	9·301	50	0·0000007854	0·009083
22	0·0006158	7·121	..	..	..

TABLE CCXLVI

REVISED B. E. STANDARDS FOR CONDUCTORS.

Conductors and areas.				
Revised standard		Old standard		
Nominal area in square inches	Number and diameter in inches of wires forming conductor	Number and gauge or diameter in inches of wires forming conductors		Nominal area in square inches
		(S. W. G.)	(Inches)	
0·0010	1-·036	1-20	1-·036	0·0010
0·0015	1-·044	..	..	..
..	..	1-18	1-·048	0·0018
..	..	3-22	3-·028	0·0018
0·0020	3-·029	..	..	..
..	..	7-25	7-·020	0·0022
0·0030	3-·036	3-20	3-·036	0·0030
..	..	7-23	7-·024	0·0031
0·0030	1-·064	1-16	1-·064	0·0032
..	..	7-22	7-·028	0·0042
0·0045	7-·029	..	..	..
..	..	7-21½	7-·030	0·0049
0·0070	7-·036	7-20	7-·036	0·0070
..	..	7-10	7-·040	0·0080
0·0100	7-·044	..	..	..
..	..	7-18	7-·048	0·0125
0·0145	7-·052	..	..	..
..	..	7-17	7-·056	0·0170
0·0225	7-·064	7-16	7-·064	0·0221
0·0300	19-·044	..	..	..
..	..	19-18	19-·048	0·0338
..	..	7-14	7-·080	0·0346
0·0400	19-·052	..	..	..
..	..	19-17	19-·056	0·0459
0·0600	19-·064	19-16	19-·064	0·0600
0·0750	19-·072	19-15	19-·072	0·0750
..	..	19-14	19-·080	0·0937
0·1000	19-·083	..	..	..
0·1200	37-·064	37-16	37-·064	0·1168
..	..	19-13	19-·092	0·1250
0·1500	37-·072	37-15	37-·072	0·1500
..	..	37-14	37-·080	0·1824
0·2000	37-·083	..	37-·083	0·2000
..	..	..	37-·092	0·2500
0·2500	37-·093	..	..	..
0·3000	37-·103	..	..	..
..	..	..	37-·104	0·3000
..	..	..	61-·092	0·4000
0·4000	61-·093	..	..	..
0·5000	61-·103	..	..	..
..	..	..	61-·104	0·5000
..	..	..	61-·112	0·6000
0·6000	91-·093	..	..	..
..	..	..	91-·101	0·7500
0·7500	91-·103	..	..	..
..	..	..	..	1·0000
1·0000	127-·103	..	127-·101	..

TABLE CCXLVII

FLEXIBLE CORD CONDUCTORS AND AREAS.

New sizes.		Old sizes.		
New nominal area.	No. and diameter in inches of wires forming conductor.	No. and gauge or diameter in inches of wires forming conductor.		Old nominal area.
Sq. inch.	Inch.	S. W. G.	Inch.	Sq inch.
..	..	25–40	25–·0048	0·00045
0·0006	14–·0076	14–36	14–·0076	0·0006
0·0006	7–·012	22–38	22–·006	0·0006
0·0006	..	35–40	35–·0048	0·0006
..	..	6–30	6–·0124	0·0007
0·001	23–·0076	23–36	23–·0076	0·001
0·001	11–·012	36–38	36–·006	0·001
..	..	70–40	70–·0048	0·00125
0·0017	40–·0076	..	..	..
0·0017	16·–012	..	..	..
..	..	40–36	40–·0076	0·0018
..	..	64–38	64–·006	0·0018
..	..	136–40	136–·0048	0·0025
0·003	70–·0076	..	..	..
0·003	28–·012	..	..	..
..	..	70–36	70·–0076	0·0032
..	..	114–38	114–·006	0·0032
..	..	90–36	90–·0076	0·004
..	..	225–40	225–·0048	0·004
0·0048	110·–0076	..	..	..
0·0048	44–·012	..	..	..
..	..	110–36	110–·0076	0·005
..	..	178–38	178–·006	0·005
0·007	162–·0076	..	..	..
0·007	65–·012	..	..	..

TABLE CCXLVIII

Current Carrying Capacity of Flexible Cords

Nominal area. (Sq. inch.)	Number and diameter in inches of wires forming conductor.	Current in ampress based on 1919 I. E. E. standard.
0·0006	14/·0076	2·5
0·0006	9/·012	2·5
0·001	23/·0076	4·1
0·001	11/·012	4·1
0·0017	40/·0076	7·0
0·0017	16/·012	7·0
0·003	70/·0076	12·9
0·003	28/·012	12·9
0·0048	110/·0076	19·0
0·0048	44/·012	19·0
0·007	162/·0076	24·0
0·007	65/·012	24·0

TABLE CCXLIX.

Approximate current taken by direct current motors of *average* efficiency.

H. P. of motor.	Current in amperes.				
	Volts. 100.	Volts. 220.	Volts. 440.	Volts. 460.	Volts. 500.
1	9	5	2	2	2
2	18	9	5	4	4
5	41	21	10	10	9
6	49	25	13	12	11
10	79	40	20	19	18
12	95	48	24	23	21
15	119	59	30	29	26
20	154	77	39	37	34
25	193	97	48	46	43
30	231	116	58	56	51
40	308	154	77	74	68
50	377	189	94	90	83
60	452	226	113	108	100
80	590	295	148	141	130
100	737	369	185	176	162
150	1,105	553	277	285	243

TABLE CCL.

The **approximate** current or amperes per phase, for motor (having an efficiency of 90 per cent. and with circuit power fact or of not less than 0·8) on a three-phase system can be ascertained by multiplying the motor B.H.P. by constant shown below for relative voltage.

Terminal volts of motor.	Multiplier.	Terminal volts of motor.	Multiplier.
400	1·5	2,000	0·3
440	1·36	3,000	0·2
500	1·2	6,000	0·1

NOTE.—It should not be overlooked, that the voltage and current of the *rotor* in a plain *slip-ring* induction motor, is independent of the stator. As the rotor current may be much greater than that in the stator from line, it should always be ascertained from suppliers, in order that proper sized cables may be provided.

TABLE CCLI.

APPROXIMATE FUSING CURRENTS.

Current in amperes	Tin wire		Lead wire		Copper wire		Iron wire	
	Dia. in inches.	Approx. S. W. G.	Dia. in inches.	Approx. S. W. G.	Dia. in inches.	Approx. S. W. G.	Dia. in inches.	Approx. S. W. G
1	0·0072	36·0	0·0081	35·0	0·0021	47·0	0·0047	40·0
2	0·0113	31·0	0·0128	30·0	0·0034	43·0	0·0074	36·0
3	0·0149	28·0	0·0168	27·0	0·0044	41·0	0·0097	33·0
4	0·0181	26·0	0·0203	25·0	0·0053	39·0	0·0117	31·0
5	0·0210	25·0	0·0236	23·0	0·0062	38·0	0·0136	29·0
10	0·0334	21·0	0·0375	20·0	0·0098	33·0	0·0216	24·0
15	0·0437	19·0	0·0491	18·0	0·0129	30·0	0·0283	22·0
20	0·0529	17·0	0·0595	17·0	0·0156	28·0	0·0343	20·5
25	0·0614	16·0	0·0690	15·0	0·0181	26·0	0·0398	19·0
30	0·0694	15·0	0·0779	14·0	0·0205	25·0	0·0450	18·5
35	0·0769	14·5	0·0864	13·5	0·0227	24·0	0·0498	18·0
40	0·0840	13·5	0·0944	13·0	0·0248	23·0	0·0545	17·0
45	0·0909	13·0	0·1021	12·0	0·0268	22·5	9·0589	16·5
50	0·0975	12·5	0·1095	11·5	0·0288	22·0	0·0632	16·0
60	0·1101	11·0	0·1237	10·0	0·0325	21·0	0·0714	15·0
70	0·1220	10·0	0·1371	9·5	0·0360	20·0	0·0791	14·0
80	0·1334	9·5	0·1499	8·5	0·0394	19·0	0·0864	13·5
90	0·1443	9·0	0·1621	8·0	0·0426	18·5	0·0935	13·0
100	0·1548	8·5	0·1739	7·0	0·0457	18·0	9·1003	12·0
120	0·1748	7·0	0·1964	6·0	0·0516	17·5	0·1133	11·0
140	0·1937	6·0	0·2176	5·0	0·0572	17·0	0·1255	10·0
160	0·2118	5·0	0·2379	4·0	0·0625	16·0	0·1372	9·5
180	0·2291	4·0	0· 573	3·0	0·0676	15·5	0·1484	9·0
200	0·2457	3·5	0·2760	2·0	0·0725	15·0	0·1592	8·0
250	0·2851	1·5	0·3203	0·0	0·0841	13·5	0·1848	6·5

TABLE CCLII.

Particulars of Light Gauge Conduits.

Exact external diameter ..	·375	·5	·625	·75	·875	1·0	1·25	1·5	2·0
Exact internal diameter ..	·305	·12	·545	·654	·779	·904	1·138	1·372	1·872
Thickness S. W. G. ..	20	19	19	18	18	18	17	16	16
Weight (lbs. per 100 feet) ..	13·5	21	26	38	45	51	74	102	137
Feet per ton ..	16,500	10,600	8,620	5,900	5,000	4,390	3,030	2,190	1,630

TABLE CCLIII.

Particulars of Heavy Gauge Conduits.

Exact internal diameter ..	·388	·497	·606	·731	·856	1·106	1·34	1·816
Threads per inch ..	18	18	16	16	16	16	14	14
Thickness S. W. G. ..	17	16	15	15	15	15	14	13
Weight (lbs. per 100 feet) ..	26	40	54	64	74	94	126	194
Feet per ton ..	8,700	5,600	4,150	3,500	3,030	2,380	1,780	1,160

TABLE CCLIV.

Wiring Capacity of Light Gauge Conduits.

Conduit. External diameter (inches)	Size of conductor.														
(1) ..	1-20	1-18	1-16	3-22	3-20	3-18	7-21½	7-20	7-18	7-16	7-14	19-18	19-16	19-14	16
	Current at 1,000 amps. per square inch.														
(2) ..	1	1·8	3	1·8	3	5	5	7	12	22·2	34	34	60	94	118
	Current according to revised I. E. E. rules.														
(3) ..	..	7·2	12·9	7·2	12·0	20·0	..	24·0	34·0	46·0	60·0	59	83	113	130
Light gauge ⅜ ..	3	2	2	3	2	1	1	1	1	..	..	..	..	..	..
½ ..	6	4	3	4	4	2	2	2	1	1	..	..	..	..	..
⅝ ..	8	6	4	5	5	3	3	3	1	1	1	1	..	..	..
¾ ..	12	8	7	7	7	4	5	4	3	1	1	1	1	..	..
⅞ ..	16	10	8	11	10	5	7	6	4	2	1	1	1	..	..
1 ..	..	..	12	15	13	7	10	9	6	4	2	2	1	1	1
1¼ ..	..	..	..	..	..	..	15	15	9	5	4	4	3	1	1
1½ ..	..	..	..	..	..	..	..	..	..	10	8	8	4	3	1

Note.—The number of the conductors which can be threaded through all sizes of conduit given in this table.

TABLE CCLV

Wiring Capacity of Heavy Gauge Conduits

Conduit. External diameter (inches)	Size of conductor.														
(1)	1-20	1-18	1-16	3-22	3-20	3-18	7-21½	7-20	7-18	7-16	7-14	19-18	19-16	19-14	37-16
	Current at 1,000 amps. per square inch.														
(2)	1	1·8	3	1·8	3	5	5	7	12	22·2	34	34	60	94	118
	Current according to revised I. E. E. rules.														
(3)	..	7·2	12·9	7·2	12·0	20·0	..	24·0	34·0	46·0	60·0	59		113	130
Heavy gauge ½	2	1	1	1	1	1	1	1	..	..	..	..	..	..	..
Heavy gauge ⅝	4	3	2	3	2	1	1	1	..	..	..	..	..	..	..
Heavy gauge ¾	5	3	3	3	3	2	2	1	1	1	..	..	..	..	..
Heavy gauge ⅞	8	5	4	5	4	3	3	2	2	1	..	..	..	..	..
Heavy gauge 1	10	7	6	7	6	4	5	4	3	2	1	1	..	..	..
Heavy gauge 1¼	..	..	9	10	9	6	7	5	4	3	1	1	1	1	..
Heavy gauge 1½	..	..	..	..	..	..	10	10	7	3	2	2	1	1	..
Heavy gauge 2	..	..	..	..	..	..	..	..	..	8	6	6	4	2	1

Note.—For drawing through, take size larger conduit.

ARTIFICIAL RESPIRATION

"Prone Pressure" Method of Resuscitation from Electric Shocks, Drowning or Accidents in Sewer-Cleaning

1. The immediate effect of contact with an electric current of sufficient voltage is a suspension of respiration. The suspended animation may consist merely of a suspension of the respiratory function, or, in the severe shocks of longer contact or higher voltage there may be a suspension of both the heart and respiratory functions.

2. In those occasional cases where the heart action has ceased, there will be no possibility of restoring the respiratory action by the methods of artificial respiration. Yet the artificial respiration should be begun immediately, and should be persisted in, at least until a physician is summoned to ascertain with his stethoscope if the heart is beating. While the heart beats, there is hope. But the heart may be beating in the absence of pulse at the extremities; hence twhen no pulse is felt, the fellow-workmen are not justified in ceasing their efforts at resuscitation.

3. There must be no delay : the efforts must begin the instant the patient is freed from the contact. A piece of dry board, or dry clothing ; a rope, or clothing improvised as a rope, will enable a comrade to rescue him from the circuit. The man nearest to him must know how to perform artificial respiration for him until the rhythm of his respiration is re-established. He must have the oxygen of the air, or his heart will cease beating. There is no time to remove belts and neckties and to open shirt fronts ; this can be done by another during the act of resuscitation.

4. For its simplicity and superior utility, the "prone pressure" method of artificial respiration is to be preferred. The three essentials of this method to be remembered and practised in anticipation of an emergency, are :—

I. The man is laid upon his stomach, face turned to one side, so that the mouth and nose do not touch the ground.

II. The operator kneels, straddling the patient's hips ; or, kneels by either side of the hips, facing the patient's head.

III. The operator places the palms of his hands on the small of back of the patient. He then draws forward and slowly applies, for about three seconds, firm pressure with his elbows straight downwards upon the back. This excites expiration.. He then draws his body back and relaxes pressure, but without removing his hands. This induces inspiration. See sketches.

EXPIRATION INSPIRATION

5. This act should be repeated indefinitely at the rate of about twelve times a minute—the danger is that in the excitement of the occasion, the rate will be too rapid. If the operator is alone with the patient, he can adjust the rate of the artificial respiration by his own deep regular breathing ; if more persons are present, a watch can be used to advantage to regulate the rate. In all cases the efforts at resuscitation should be continued until the arrival of the physician. Any evidence of returning breathing should encourage the operator to continue his efforts. It often requires one-half hour to two hours (in cases of drowning especially, it is advisable to keep at it, for recoveries have resulted after three hours of continuous artificial respiration). The physician can determine if the heart is beating, and whether or not continued efforts at resuscitation would be futile. The victim should have the benefit of the doubt if any exists.

6. An operator can learn to become expert by practising on his friends—and they on him—until he knows what constitutes the essentil in the art of artificial respiration. By this method even a child can operate on an adult and maintain sufficient inflow and outflow of air to supply him with as much air as he would secure, were he able to breathe voluntarily.

7. The prone position of the patient allows the tongue to fall forward, and permits water and mucus to escape from the mouth ; for this reason the "prone pressure" method is the ideal method of resuscitating the drowning, for there is no loss of time in first pressing out the water, as by the old method. Edema of the lungs (accumulaticr of blood-stained serum in the air vessels and bronchloles) sometimes complicates the profound collapse of electric shock ; hence this method is to be preferred, as it allows the blood-stained mucus to flow out.

Furthermore, as an operator can work without exhaustion for an unlimited length of time by this method, there is no need of team work and working in relays, as, for example, with the Silvester-Laborde method.

8. If the operator is alone, the artificial respiration is his chief concern, and offers the only hope for the victim ; if there are others to assist there are measures supplemental to the artificial respiration that may be carried out.

I.—Aromatic spirits of ammonia, on gauze or cotton held over the nose, stimulates the respiratory function—is even more useful than oxygen—yet is valuable only as an adjunct to the other methods.

II.—A dash of cold water in the face.

III.—Spanking the bullocks.

9. Should the respiratory function continue in abeyance, the physician on his arrival may render great assistance by the hypodermic administration of atropine sulphate gr. 1/100 and strychnine sulphate gr. 1/30 which can be repeated at his discretion, or he can stretch the sphincter ani.

10. No liquid should be given by the mouth to a patient in shock, or with suspended activity of the reflex nerve centres from any cause ; if given under these conditions it is more liable to enter the lungs than the stomach.

11. Electrical accidents, as encountered in the industrial applications of electricity may be classified as (1) flash injuries, embracing burns of the eyes and the skin, and (2) contact injuries embracing suspended animation and burns often of a severe character. The even brief consideration of these several types of injuries is not within the scope of the present article, and, as they require the attention of the surgeon, it is understood that the patient for whom artificial respiration has been done, if he be simultaneously burned by the contact, will subsequently need the surgeon's care, as the healing of such electrical burns is in some cases quite tedious.

THE 'EVE' METHOD OF ARTIFICIAL RESPIRATION

This method has been found most successful by the British Navy on persons who have nearly drowned. Wrapped in blankets the victim is laid face downwards on a stretcher with his wrists and ankles lashed to the handles. The stretcher is then placed on a horizontal bar (a barrel toppled over would do equally well) and rocked in a sea-saw fashion, 45° down and up, at the rate of 12 rockings a minute. Full expiration and inspiration are induced by the alternating pressure of the abdominal contents against the diaphragm.

CHAPTER XV—MISCELLANEOUS

KNOTTING AND SPLICING

1. The size of a rope is denoted by its circumference in inches, and tis length is always given in fathoms.

When a rope is passed through a block, it is said to be **rove** ; if one end is made fast, that end is called the **standing part**, the other end the **running end**, and the end of the rope to which the power is applied the **fall.**

In the plates the points of the running ends are shown **whipped**, and the direction in which the power is applied is denoted by an arrow.

In uncoiling a new coil of rope, pass the end which is at the core, through the core to the opposite side and draw it out, when the turns will run out without kinking.

2. **Thumb or overhand knot.**—Grasping the end of the rope with the right hand, and the standing part in the left, pass the end of the rope over the standing part up through the bight thus formed ; haul taut, and the knot is complete. This is the simplest kind of knot and is used to prevent ropes running through blocks when rove, etc. (Fig. 2, plate CXXXV).

3. **Figure of 8 knot.**—Holding the rope as in the last paragraph, pass the end of the rope under, round and over the standing part, then upwards through the bight thus formed. This knot is used where the thumb knot is not sufficiently large (Fig. 3).

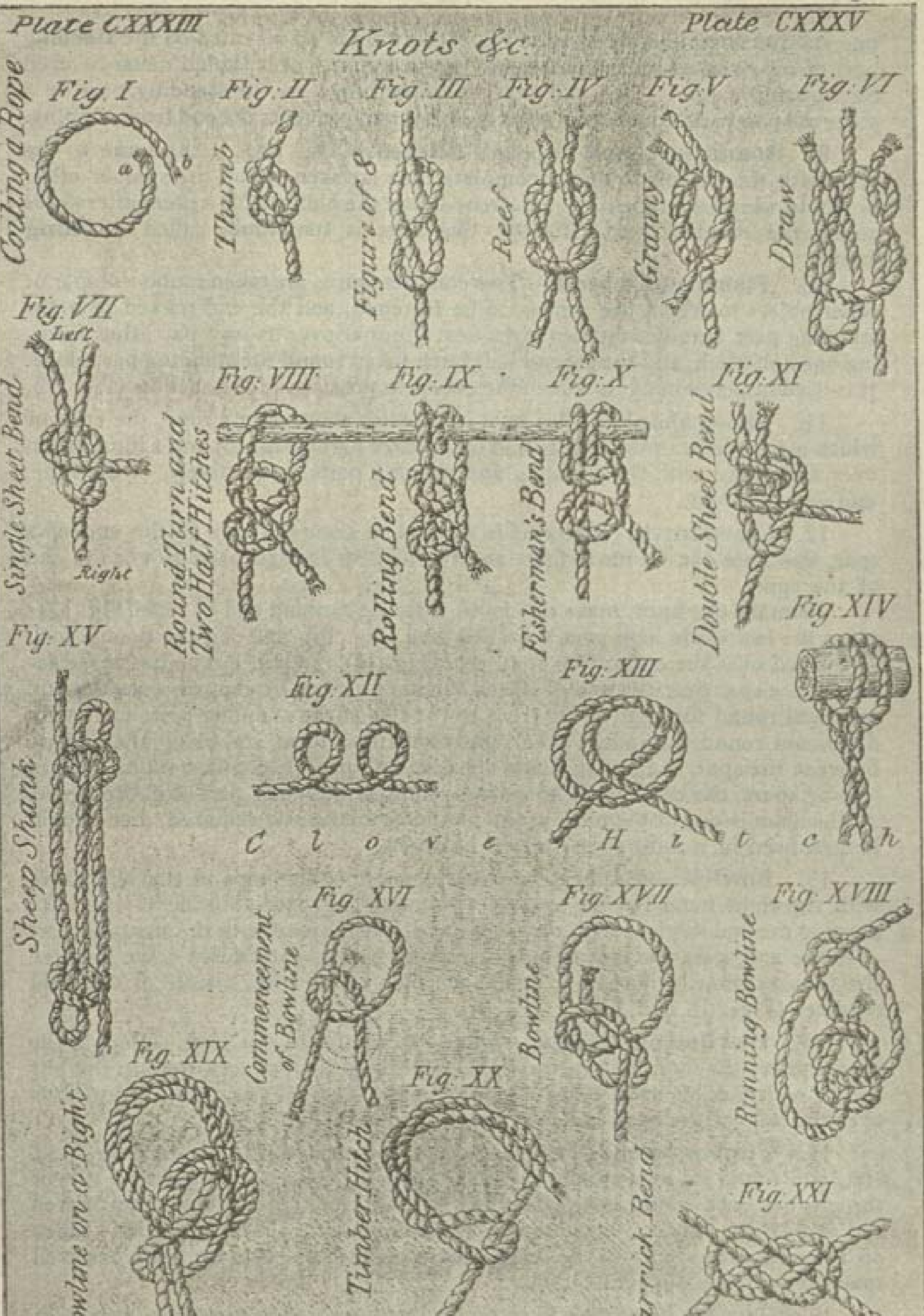
4. **Reef knot.**—Holding one end in each hand, ends to the front, lay the ends of the two ropes to be joined across one another, the left hand rope over the right, and take it once completely round that held in the right hand. Turn the original left hand end back in the direction of and alongside its standing part, and take the original right hand end over the double, up through the loop and haul taut. The standing and running parts of each rope must pass through the loop of the other part in the same direction (Fig. 4): if they pass in the opposite direction, as in Fig. 5, the knot is what is termed a "granny", and cannot be undone when tightened up with the same ease that a reef knot can. A reef knot can be upset, and the ends pulled out, by taking one end of the rope and its standing part and pulling them in opposite directions.

5. **Draw knot.**—This knot is the same as a reef knot, with the exception that a double of the original left hand end is laid alongside its own standing part thus, forming a loop, and the right hand end is taken over the double, and the loop formed by the double as in the above knot (Fig. 6).

6. **Single sheet bend.**—Take a bight or double at the end of one rope, holding it in the left hand, and pass the end of the other rope held in the right hand up through the bight, down on one side under and up over the bight and under its own standing end (Fig. 7). It is used for joining two anchor cables together.

7. **Double sheet bend.**—When greater security is required a **double sheet bend** is used, in which the running end is passed twice round the bight and under its own standing end each time (Fig. 11).

8. **Two half hitches.**—With the end of the rope in the right hand and the standing part in the left, pass the end of the rope round its standing part, and up through the bight, thus forming one half hitch ; two of these alongside of



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one another complete the knot: in Fig. 8 this knot is represented on the standing part of rope passed round, and made fast to a spar, but it should never be used for hoisting a spar. The end may be lashed down to the standing part by a piece of spun yarn, which adds to its security, and prevents the end from slipping.

9. **Round turn and two half hitches.**—This knot is the same as the last, with the exception that a complete turn is taken round the spar or other object to which the rope is to be fastened, and the half hitches taken afterwards round the standing part (Fig. 9); this knot is sometimes called a **rolling bend.**

10. **Fisherman's bend.**—Two complete turns are taken round the spar or other object to which the rope is to be fastened, and the end passed over the standing part, through the two turns next the spar over its own part, thus forming one half hitch, and the second half hitch taken round the standing part alone. It is used in pontooning, to fasten the cables to the rings of the anchors (Fig. 10).

11. **Sheep shank.**—This knot is used for shortening a rope, the ends of which are made fast; the rope is laid up in three parts (Fig. 15) and a hitch taken over each bight with the standing and running parts, respectively, of the rope, and jammed taut.

12. **Clove hitch.**—When it is desired to secure a rope to the end of a spar, this knot can be made first, and the loop so formed passed over the end of the spar.

To make this knot, make two loops with the running end of rope (Fig. 12); place the last made loop over the other one (Fig. 13), and slig the double loop so formed over the end of the spar, etc. (Fig. 14). When a rope has to be secured to a spar over the end of which the knot cannot be slipped, pass the end over and round the spar, bring it up to the left of the standing part, and again down and round the spar, to the right of the first turn, and bring the end up between the spar, the last turn and the standing part (Fig. 14). When used in lashing spars, the end should be twisted round the standing part as in the figure. As this knot is one of the most useful and most frequently required, men should be practised in making it in various positions.

13. **Bowline.**—Holding the standing part of the rope in the left hand, with the right hand lay the end over the standing part pointing to the left; keeping the end in place with the right hand, make a loop with the standing part over the end, pass the end under the standing part, and finally down through the loop previously made and haul taut the end and the double of the knot together (Figs. 16 and 17).

14. **Bowline on a bight.**—Figure 19 illustrates this knot. Double the rope and lay the loop held in the right hand over the two ends held in the left hand; with the left hand make a loop over the doubled end, bring it upwards over the hole of the knot and haul the double taut (Fig. 19).

15. **Timber hitch.**—Pass the end of the rope over and round the spar, etc., and round its own standing part close to the spar. Then twist it two or three times back round itself and haul the fall taut thus jamming the twisted end against the spar. This knot can be easily undone when the strain is taken off the fall, and is found to be really secure for lifting spars, etc., as when well made it will not slip (Fig. 20).

16. **Carrick bend.**—A Carrick bend is used for joining two cables or two ropes to make four guys for the head of a spar. Holding one of the cables to be joined in the left hand, make a loop on the end of it, passing the end under

Plate CXXXVI

Knots & Tackles.

Fig. XXII　Fig XXIII　Fig XXIV　Fig. XXV

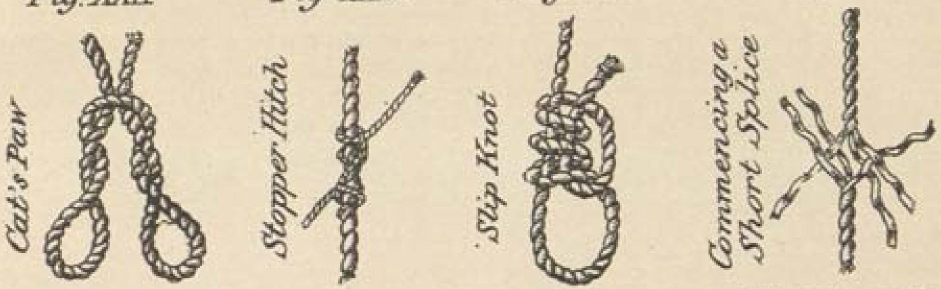
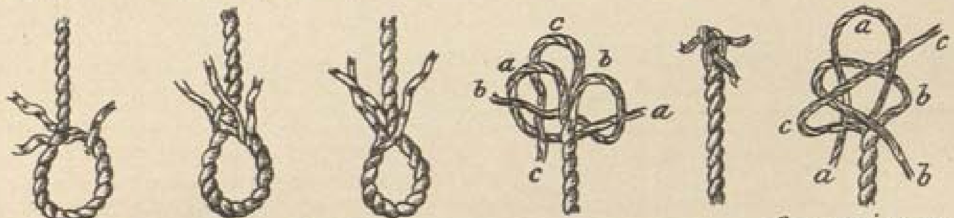


Fig. XXVI　Fig. XXVII. Fig. XXVIII　Fig. XXIX　Fig. XXX　Fig. XXXI



Eye Splice　Wall Knot　Crowning a Wall Knot

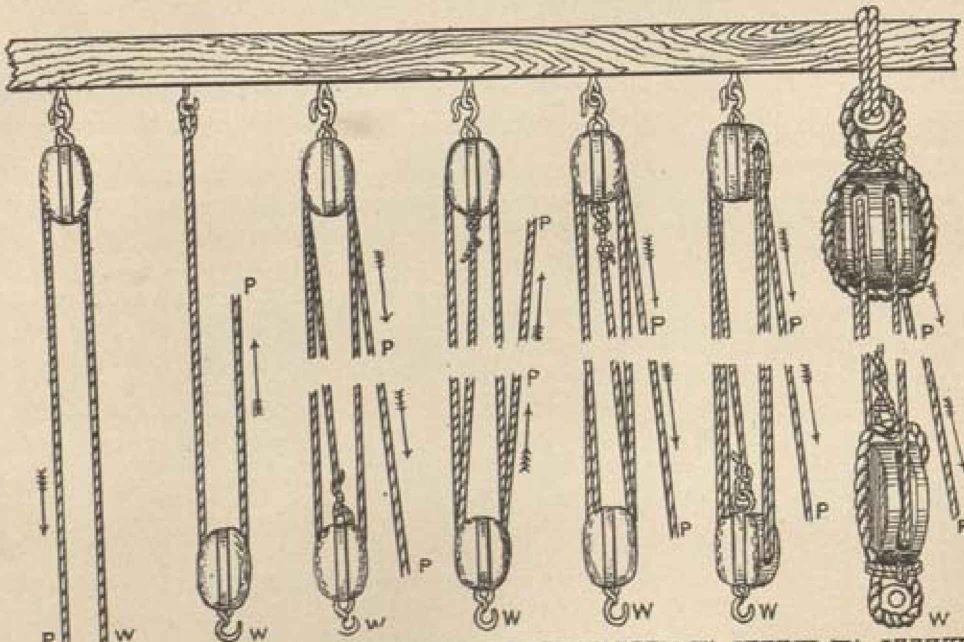


Fig. XXXII. Fig. XXXIII. Fig. XXXIV. Fig. XXV. Fig. XXXVI. Fig. XXXVII. Fig. XXXVIII.

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the standing part away from the person making the knot. With the right hand pass the end of the other cable across the loop under the other end over the other standing part, up through the original loop over its own standing part, and finally down through the loop, and haul taut. If either of the cable (Fig. 21) be traced, it will be seen that it passes alternately over and under each rope that it crosses.

17. **Cat's paw.**—Lay the end over the standing part of a rope, thus forming a bight, and secure the two parts together by a bit of seizing ; then lay hold of the bight with one hand on each side, twisting the hands inwards in opposite direction two or three times ; clasp the two bights together, and hook on the tackle, etc., as required. This knot may be used as a pair of slings for shipping casks, etc. (Fig. 22, plate CXXXVI).

18. **Stopper hitch.**—Take one turn round with the stopper round the sope to be stoppered, and then a second over-riding the turn previously made, in the direction in which the power is applied, and bring the end over its own standing part, and fasten off with two half hitches round the cable, on the opposite side of the standing part of the stopper to that on which the round turns were taken (Fig. 23).

19. **Slip knot or hangman's knot.**—Take a bight on the end of a rope and grasp it in the left hand, the bight towards the right. With the end take four round turns round the double of the bight, working from left to right and pass the end through these four turns next to the standing part and haul taut (Fig. 24).

20. **Wall knot.**—This knot is a neat way of fastening off a rope to prevent its unstranding. Unlay the end of the rope (Fig. 29) and hold it with left hand end upwards. Lay the end of the nearest strand, **a** across the front of the rope end to the right, so as to form a loop to the left. Bring the next strand on the right over and round the end of **a** to the rear of the rope, forming a loop written end to the left ; similarly, pass the end of the third strand over the end of**b**, and round it to the front through the loop in **a**, haul taut each strand and the knot will appear as in Fig. 30. To crown this knot, take the end of the front strand, **a**, pass it over the head of the knot, and down the rear of the rope between the other two strands, leaving a loop at the top of the knot to the front (Fig. 31). Take the next strand to the right **b**, and pass it round the rear of the loop **a**, and over the knot between the loop and the 3rd strand **c**, and down the front of the rope. Pass the 3rd strand **c** over **b**, where it crosses the loop at the head of the knot, and through the loop in **a**, and haul taut.

21. **Blocks.**—For the purpose of changing the directions of ropes, gaining power, etc., blocks are used. They are usually made of wood, and are called single, double, or treble, according to the number of sheaves contained, which being made of metal or hard wood, revolve with but slight friction on a central pin. The block is surrounded by a stop of iron or rope, by means of which it can be lashed or made fast as required ; the sizes of the blocks are usually designated by their length in inches.

22. **Tackles.**—Figures 32 to 38 show the various combinations of blocks most commonly used for forming tackles with falls rove ready for use where **W** is the weight to be moved and **P** the power applied.

Figure 32 shows a single movable block, which gives no increase of power, but merely a change of direction. It is often called a whip, and, for this purpose, a snatch block (*i.e.*, a block with a movable strop to admit a rope without the necessity of passing its end through the block) is often used.

Figure 33 shows a single movable block where **W**=2 **P**.

Figure 34 shows a gun tackle consisting of a fixed double and a movable single block where **W** = 3 **P**.

Figure 35 shows a fixed single and movable double where **W** = 4 **P**.

Figure 36 shows a luff tackle with 2 double blocks, the standing end being attached to the fixed block where **W** = 4 **P**.

Figure 37 shows a gyn tackle with a fixed treble and a movable double block where **W** = 5 **P**.

Figure 38 shows a gun tackle of large blocks with thimbles fitted instead of hooks.

The standing end of the rope is never fixed to the block with the greater number of sheaves ; the weight any system of two blocks will lift is found by multiplying the power by the number of ropes at the movable block including the standing end, if fixed to it. The strops of blocks must be strong enough to withstand the greatest strain, which is equal to the power multiplied by the greatest number of ropes at either block.

To form a pair of temporary shears—

23. The two spars for the shears of equal length are laid alongside each other with their butts together on the ground, the parts below, where the lashing is to be resting on a short spar. A clove hitch is then made round one spar and the lashing taken loosely 8 or 9 times round the two spars above it without riding. A couple of frapping turns are then taken between the spars round the lashing, and finished off with a clove hitch above the round turns on the other spar. It will then appear as in Fig. 1, plate CXXXVII.

The butts of the spars are then opened out, and a sling passed over the fork of the spars to which the block is hooked or lashed. Fore and back guys are then made fast with clove hitches to the tips of the spars, so arranged as to draw their heads together ; when the strain comes on them, foot ropes are secured to the butts of the spars by pickets, and the shears are ready for raising (Fig. 2).

To form a gyn or tripod trestle—

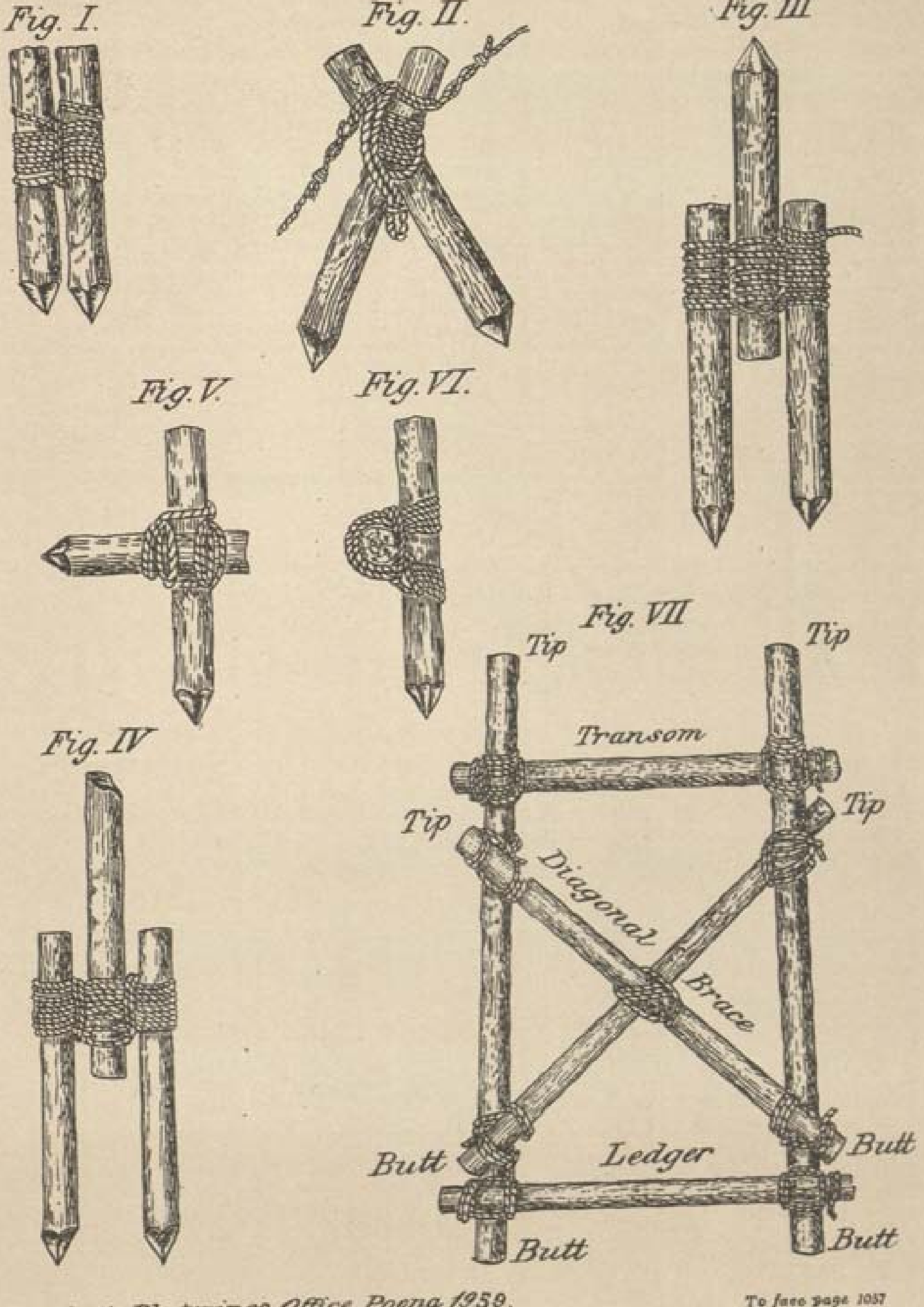
24. The distance from the butts at which the centre of the lashing is to be is marked on each spar. Two of the spars are then laid parallel to each other, rather farther apart than their own diameter, with their tips resting on a piece of skidding and the third spar is laid between them, with its butt in the opposite direction, so that the marks on the three spars may be in line. A clove hitch is then made on one spar, and the lashing taken over and under the spars loosely 8 or 9 times ; the lashing then will appear as in Fig. 3. A couple of frapping turns are then taken between each pair of spars in succession round the lashing and finished off with a clove hitch in one of the spars ; the lashing will then appear as in Fig. 4. A string is then passed over the lashing and the gyn is ready for raising.

To lash a transom to an upright spar—(see Figs. 6 and 7)—

25. In the description the transom is supposed to be in front of the upright. A clove hitch is made round the upright below the position of the transom, the lashing brought under the transom, up in front of it, horizontally behind the upright down in front of the transom and back behind the upright, below the clove hitch, and so on following round, keeping outside of, and not riding over the turns already made. Six turns or more will be required. A couple of frapping turns are then taken between the spars round the lashing,

Plate CXXXVII

—Lashings of Spars.—



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binding the whole firmly together, and the lashings is finished off with clove hitch either round one of the spars on any part of the lashing through which the rope can be passed. The lashing must be well beaten with a handspike or pick handle to tighten it up.

NOTES AND USEFUL RECIPES

1. The cost per cubic foot of buildings erected by the Public Works Department in Bombay and Poona has been as below :—

The measurements are taken as follows :—

Height—from ground line to half way up roof.

Length and breadth—The exterior dimensions of superstructure.

Verandahs—taken as solid.

	Rate per cubic foot Annas
1860—1875	
Victoria Technical Institution	10·00
Mechanics' Institute	11·00
Secretariat	7·33
Public Works Office	7·25
University Hall	9·50
University Library	9·83
Clock Tower	15·66
High Court	5·00
Telegraph Office	4·92
Sailors' Home	4·58
Elphinstone High School	4·66
School of Art	4·25
1875—1900	
Telegraph Building, Poona (two-storeyed)	2·96
Secretariat Offices, Poona (single-storeyed)	2·46
Inspection Bungalow, Khed, in the Poona district (single-storeyed)	2·55
High School for Girls, Poona (double-storeyed)	3·02
Elphinstone College	4·08
Police Magistrate's Court	3·50
Reay Art Workshops, School of Art	3·67
Nurses and Probationers' Quarters, St. George's Hospital	6·17
1900—1906	
Lord Harris Primary School	5·10
Anatomical Rooms, Sir J. J. Hospital	4·93
Commandant and Adjutant's Bungalows	4·50
Currency Buildings, Extension	7·58
Telang Memorial Students' Quarters	3·75
Branch Custom House, Prince's Dock	4·95

LIST OF TYPICAL IMPORTANT BUILDINGS BUILT SINCE 1906 IN THE BOMBAY PRESIDENCY BY THE P. W. D. AND THE RATE PER CUBIC FOOT FOR THE SAME

Names of buildings	Place where situated	Year of construction	Rate per c. ft. Annas	Remarks
	Bombay town and suburbs.			
Houses for 4 officers on Plot No. 2/7239, Malabar Hill, Bombay.	Malabar Hill, Bombay.	1917 to 1910	6·24	
Quarters for the Private and Military Secretaries to H.E. the Governor, Bombay.	Do. ..	1920 to 1921	16·00	
New Small Causes Court at Bombay.	Bombay	1913 to 1922	8·00	
New Customs House, Bombay, main building.	Ballard Pier, Bombay.	1913 to 1922	11·36	
Outhouses			8·00	
Prince of Wales Museum, Bombay.	Fort, Bombay ..	1908 to 1922	10·56	
Royal Institute of Science, Bombay.	Do. ..	1911 to 1923	11·68	
The Honorary Presidency Magistrate's Court, Girgaum.	Girgaum, Bombay	1919 to 1923	20·48	
Pharmacological Laboratory and Stores at Parel.	Parel, Bombay ..	1920 to 1923	11·20	
Central block of six flats ..	Malabar Hill, Bombay.	1921 ..	14·5	
North end block of six flats..	Do. ..	1922 ..	14	
Quarters for 4 European Officers.	Kingsway, Matunga	1922 to 1923	10	One ground and 2 upper floors.
Reinforced cement concrete chawls.	Do. ..	1922 to 1923	9	One ground and 2 upper floors.
	Northern Circle.			
Fireproof building for Registration record.	Thana	1909=10 ..	5·03	
Assistant Collector's bungalow.	Bandra	1917=18 ..	4·09	
Madhavlal Ranchhodlal Science Institute in Gujarat College.	Ahmedabad ..	1915-16 ..	3·25	
King George V Hall in Gujarat College.	Do. ..	1922-23	7	
District Bungalow, Shahibagh.	Do. ..	1921-22 ..	13·5	
Combined Court House at Surat.	Surat	1906-07 ..	3·36	Stoned building with Jack arched flooring.

Names of buildings	Place where situated	Year of construction	Rate per c. ft. Annas	Remarks
	Northern Circle—contd.			
District Judge's Bungalow at Surat.	Surat	1914-15 ..	3·52	Storied building with jack arched flooring.
Office of the District Superintendent of Police at Broach.	Broach	1921--23 ..	6·1	Without any storey.
School house for 250 boys ..	Bhalej, taluka Anand.	1921-22 ..	4·0	
Hostel for the High School at Nadiad.	Nadiad	1910-11 ..	7·5	
Police Lines at Kaira ..	Kaira	1907-8 ..	1·42	
Town Police Lines at Kaira	Do. ..	1919-20 ..	3·83	
	Central Circle			
Yeravda Prison Press (main building).	Poona	1907-08 ..	3·33	Partly single and partly double storeyed.
B. J. Medical School Students' quarters (main buildings).	Do.	1909-10 ..	3·08	Double storeyed
David Sassoon Hospital Septic Ward for maternity.	Do.	1910-11 ..	4·00	Single storeyed.
Jacob Sassoon Hospital (main building).	Do.	1910-11 ..	6·75	Double storeyed.
Central Offices, main block	Do.	1914-15 ..	6·83	Three storeyed.
Bungalow for the Chief Engineer and Joint Secretary to Government main building (Beau Soleil).	Do.	1921-22 ..	7·75	Double storeyed.
Flats (No. 1, Arsenal Road)	Do.	1922-23 ..	8·75	Do.
Bungalow for the Executive Engineer, P. W. D., Ahmednagar.	Ahmednagar ..	1906-07 ..	2·67	
Office of the Executive Engineer, P. W. D., Ahmednagar.	Do.	1906-07 ..	2·67	
Abkari Inspector's bungalow	Shrigonda	1908-09 ..	2·75	
Record Room and Office in the District Judge's Court.	Ahmednagar ..	1908-09 ..	5·75	
Sub-Judge's Court building	Kopargaon ..	1912-13 ..	5·00	
Bungalow for the Assistant Superintendent of Police.	Ahmednagar ..	1922-23 ..	5·38	
School house for 200 boys ..	Parner	1907-08 ..	1·92	
School house for 325 boys..	Rahuri	1918-19 ..	3·21	
New Post and Telegraph Office main building.	Sholapur	1920 ..	6·1	

Names of buildings	Place where situated	Year of construction	Rate per c. ft Annas	Remarks
	Central Circle— contd.			
King Edward Memorial Hospital, proper.	Sholapur	1923 ..	6·75	
Hostel building for the Northcote High School.	Do. ..	1922 ..	3·31	
Revenue buildings	Nasik	1907-08 ..	4·33	Double storeyed
District Superintendent of Police's bungalow.	Do. ..	1908-09 ..	3·17	Do.
Police training school (school building).	Do. ..	1909-10 ..	3·50	Do.
Mamlatdar's kacheri ..	Dindori	1912-13 ..	3·17	Single storeyed.
Nasik High School (main building).	Nasik	1919-20 ..	5·17	Double storeyed.
Mamlatdar's kacheri (main building with side blocks).	Satana	1921-22 ..	4·67	Single storeyed
Assistant Superintendent of Police's bungalow.	Nasik	1921-22 ..	6·92	Do.
Inspection bungalow ..	Trimbak	1921-22 ..	10·17	Do.
Edward VII Technical School, Dhulia.	Dhulia	1916-17 ..	3·36	
Civil Surgeon's bungalow ..	Do.	1916-17 ..	3·09	
Revenue Offices	Jalgaon	1910-11 ..	4·48	Central portion double storeyed and wings single storeyed.
Sheth Govardhandas Sundardas High School.	Do. ..	1914-15 ..	4·34	Do.
Hostel for High School, Satara, main building.	Satara	1913-14 ..	4·33	
Headquarters Police Offices double storeyed.	Do. ..	1913-14 ..	7·08	
Police lines	Vita	1915-16 ..	3·08	
City Police lines	Satara	1919-20 ..	2·58	
Police lines	Tarla	1921-22 ..	5·67	
	Southern Circle.			
Hostel for the High School	Dharwar	1912-13 ..	3·00	
Hostel for the Sardar's High School.	Belgaum	1915-16 ..	3·06	A double storied building.
Revenue Sub-Divisional Office.	Karwar	1915-16 ..	3·65	

Names of buildings	Place where situated	Year of construction	Rate per c. ft. Annas	Remarks
	Southern Circle— concld.			
Bungalow for the Director, Vaccine Institute.	Belgaum	1915-16 ..	3·06	A double storied building.
Office of the District Superintendent of Police.	Karwar	1915-16 ..	5·09	
Executive Engineer's office	.. Do. ..	1915-16 ..	4·06	A double storied building.
Vaccine Depot, main building including engine house and distiling room.	Belgaum	1916-17 ..	3·27	There is an upper storey over the cold chamber area 333 s. ft.
Collector's bungalow ..	Do. ..	1916-17 ..	4·11	A double storied building. The 1st floor is of reinforced concrete.
District Judge's bungalow ..	Bijapur	1917-18 ..	3·62	
Constructing a school house for 2,000 boys.	Harnai	1917-18 ..	3·16	
Mamlatdar's kacheri ..	Honawar	1918-19 ..	4·94	
Distillery, main building ..	Khanapur	1920-21 ..	2·92	

2. The following are the usual size of drawing papers, ferro-prussiate paper and tracing cloth :—

		Size in inches
Paper, drawing,	demy	20 × 15½
Do.	medium	22 × 17
Do.	royal	24 × 19½
Do.	super-royal	27 × 19
Do.	imperial	30½ × 22
Do.	columbier	34 × 23
Do.	atlas	34 × 26
Do.	double elephant	40 × 27
Do.	antiquarian	53 × 31
Do.	extra antiquarian	56 × 38

Ferro-prussiate paper.—Marion's ferro-prussiate paper is 30 inches wide and about 11 yards long.

Tracing cloth.—Sagar's patent vellum tracing cloth is 36 inches wide and contains 24 yards in one roll.

3. **Ferro-typing or blue print.**—The tracing should be clear, with distinct fairly broad lines.

Paper to be sensitized with the following solutions. The solutions will keep when separate, but when mixed are acted on by light, and should be used at once in a dark room.

A.	Citrate of iron and ammonia	100 grains.
	Water	1 oz.
B.	Red prussiate of potash	70 grains.
	Water	1 oz.

Mix qual quantities of solutions A and B, apply to one side of the paper with a sponge, treating the whole surface liberally for about 2 minutes, wipe off the excess of solution with the sponge, taking care not to roughen the surface, and hang the paper up to dry in a dark room.

Printing.—Place the tracing over the prepared side of the paper, and over it a heavy sheet of glass. The whole should rest on a dark piece of cloth. Put out in the sun. From 8 to 10 minutes are generally sufficient for printing.

Fixing.—Wash the print thoroughly in clean water.

Additions and erasures.—A white line may be taken out by going over it with a quill pen or brush dipped in the sensitizing solution, exposing to the sun, and washing as before. Additions or corrections in white, may be made with a quill pen dipped in a solution of 40 grains of carbonate of potash to 1 ounce of water. The corrections so made, must be dried with blotting paper and washed, or the lines will spread and become blurred. Additions are also made with flake-white (water paint).

4. **To purify water for drinking.**—Add to the water to be purified a few drops of permanganate of potash. If the pink colour disappears, there is organic matter present, and the permanganate should be added until the pink colour is permanent. It is best to test a small quantity of water first, and then to add as much as necessary to the day's supply.

The water can afterwards be filtered through clean sand and charcoal with advantage. Permanganate of potash destroys organic matter already in a state of putrefaction instantaneously, but it takes half an hour or more to destroy matter about to putrify.

Alum, *i.e.*, sulphate of alumina, is highly valuable as a purifying agent. It attaches itself to organic animal matter, living germs, etc., and converts them into an insoluble substance like leather. It may be used independently or in combination with permanganate of potash.

Chlorination is more effective and is now generally done to all supplies.

5. **Cleaning saddlery or leather work.**—Beeswax 6 ozs., resin 3 ozs., linseed oil pint ; mix and stir together in a saucepan ; take off fire, add 1 pint Neat's foot oil, ½ pint turpentine and 1 oz. camphor, and pot for use.

6. **Leather preservative or emollient.**—Castor oil is the best known. It does not prevent polish from blacking, and it is said that leather so treated will not be attacked by rats or mice ; or **Dubbing**—2 lbs. black resin, 1 lb. tallow, 1 gallon train oil.

7. **To remove metal screw or bottle stoppers.**—Apply plentifully spirits of turpentine ; this will loosen screws or stoppers almost immediately.

8. **Alloy that expands in cooling:**—

9 parts lead.
2 parts antimony.
1 part bismuth.

9. **Wooden labels, to preserve.**—Soak in a strong solution of sulphate of iron ; when dry, place them in lime water. This causes formation of sulphate of lime and will last for years.

10. **Zinc, to write on.**—Use solution of sulphate of copper (blue vitriol) with a quill pen.

11. **Water-proof mixture.**—For under-water blasting :—

	Per cent
Tallow	5
Rosin	15
Guttapercha	20
Pitch	60

12. **Fumigation.**—Adopt one of the following processes :—

(*a*) With chlorine gas—

	Ounces
Take common salt	4
,, oxide of manganese (in powder).. ..	1
,, sulphuric acid	1
,, water	2

The water and acid to be mixed together and then poured over the ingredients in a delf basin, which should be placed in a pipkin of hot sand.

(*b*) With nitric oxide gas—

	Ounces
Take copper shavings	½
,, nitric acid	1½
,, water	1½

Pour the acid and water upon the copper in a small jar.

(*c*) With sulphurous acid gas—

Burn 2 ozs. of sulphur in a pipkin.

Rooms to be completely emptied and all doors and windows to be closed before commencing fumigation.

The operator will leave the room immediately the process is commenced. At the expiration of from 2 to 3 hours all doors and windows will be thrown open to free ventilation.

13. **To fill cracks in terraced roofs.**—Adopt one of the following processes:—

(*a*) 2 parts linseed oil (raw).
2 parts rosin.
1 part pumice, if obtainable; if not, use fine sand.

Boil oil, pound pumice and mix with pounded rosin; put in these whilst hot and mix till a stock will almost stand upright. (Add rosin if above is not sufficient.) The cracks should not be disturbed or dug out with a trowel, but the liquid mixture poured in and surface smoothed over.

(*b*) 10 parts asphalt.
$2\frac{1}{2}$ parts sand.
$\frac{3}{4}$ part coal tar.

Clean out cracks with a brush and having boiled the materials apply with a small trowel.

(*c*) 12 parts rosin.
8 parts sulphur.
16 parts linseed oil.

Grind the rosin and sulphur fine, mix together, put into the oil and then boil the whole together.

(*d*) To stop fine hair cracks in a new roof the following is often successful:—

Spread over the roof a solution of one part cement, one part cowdung and one part sand. This takes two days to set.

Asphalt emulsions are now procurable, which can be used either for filling in cracks or as a water-proofing membrane over a lèaky surface. In the former case the crack is cleaned out, and filled in with coarse sand and the emulsion is poured in. After it breaks, i.e., changes colour to blue black, the sand is punned in.

As a surface rendering, after cleaning the surface thoroughly, it is put on with a brush, covering the whole surface evenly.

If the terrace is porous, the treatment should be a heavirer one, and somewhat like surface-dressing on a road. The surface after cleaning is covered uniformly by a layer of emulsion, which is gritted, as soon as the emulsion begins to break, and rolled over. A second layer of emulsion is then applied, and covered with sand after it begins to break, and the whole surface finally rolled over.

14. **Cleaning marble**—

2 parts bicarbonate of soda.
1 part powdered pumice stone.
1 part finely pulverized chalk.

Pass through a fine sieve to screen out all particles capable of scratching the marble and sufficient water to form a pasty mass. Rub the marble with it vigorously and then wash with soap and water.

15. **Glaze for ceiling cloths.**—Place 6 lbs. of Paris whiting in a covered vessel with enough cold water to just cover it. Add one quart of double size (made with China glue), mix thoroughly and set in a cool place till it becomes a jelly. Dilute for use. About 1 lb. of the jelly will cover 50 square feet of ceiling.

The Paris whiting may also be substituted by best chalk (finely ground) as well as the China glue by rice size. About ½ lb. of rice should make 1 quart of size.

16. **Lacquered brass, to clean.**—Rub with a soft cloth dipped in stale beer; when the cloth works dry, dip again: this gives a good polish.

17. **Glue.**—To resist moisture, 1 lb. glue melted in 2 quarts of skimmed milk. When strong glue is required, add powdered chalk to common glue.

18. **Marine glue.**—One of India-rubber, 12 mineral naptha or coal tar; heat gently, mix, and add 20 of powdered shellac. Pour out on a slab to cool; when used to be heated to about 250°.

19. **Quick-drying glues.**—

1st.—Break up the glue, dissolve in common whisky or spirit of any sort without heat. Cork tight. It will keep for years.

2nd.—Shellac dissolved in methylated spirits, or French glue in acetic acid.

20. **Liquid glue.**—Mix 4 parts of treacle with 12 parts of water by weight, and add 1 part of quicklime, heat to about 150° Farh., and afterwards macerate for two or three days with frequent agitation. Decant from the undissolved lime, the solution having the consistency of mucilage. Add to the solution ¼ of its weight of glue and 3 per cent of glycerine. This makes a good strong liquid glue.

21. **Glue cements.**—To resist moisture—

1st.—1 glue,
1 black rosin,
¼ red ochre,
} mixed with the least possible quantity of water.

2nd.—4 of glue.
1 of boiled oil by weight.
1 oxide of iron.

22. **Oil cement.**—For laying earthenware pipes—

5 lbs. dry slaked lime,
1 lb. oil by weight.

pounded in a stone mortar with an iron pestle, for 6 hours, to reduce it to a thick paste for use.

23. **Durable cement.**—For steam and water joints. Take 10 lbs. of ground litharge, 4 lbs. ground Paris white, ½ lb. yellow ochre, 2 lbs. red lead, ½ oz. of hemp cut into half-inch lengths. Mix all together in boiled linseed oil to the consistency of very stiff putty. Make the joint in the usual way.

24. **Useful cement.**—For reservoirs, cisterns, etc. Take 90 parts of well-burnt brick (fire-brick is best), 10 parts of litharge, well pulverized and mixed together to the consistency of plaster, with boiled linseed oil. Use in the same way as plaster, previously wetting the parts to be covered with water. In 3 or 4 days the cement will become hard.

25. **Red lead cement.**—For face joints.—

1 oz. white lead,
1 oz. red lead,

mixed with linseed oil to the proper consistency.

26. **Water-proof mastic cement** (Molesworth).—

1 red lead,
4 ground lime,
5 sharp sand mixed with boiled oil,
Or, 1 red lead,
5 whiting,
10 sharp sand mixed with boiled oil.

27. **Rust-joint cement.**—

(*a*) Quick setting—

1 powdered sal-ammoniac (by weight),
2 flour of sulphur,
80 iron borings or filings,

made to a paste with water.

(*b*) Slow setting—

2 sal-ammoniac,
1 flour of sulphur,
200 iron borings or filings.

The latter gives the most satisfactory joint if the joint is not required for immediate use.

28. **Cement for cloth or leather.**—

16 guttapercha cut small,
4 india-rubber,
2 pitch,
1 shellac,
2 linseed oil,

} melt together and mix well.

9. **China and glass cement.**—Equal parts, by weight, of beeswax, sulphur and rosin; melt wax on sand bath, add powdered rosin, and then sulphur till sublimed; then apply to broken pieces also heated on a sand bath.

30. **Water-proof mortar.**—The water-proof mortar is made of 1 part Portland cement and 2 parts of sand. Add ¾ lb. pulverized alum for each cubic foot of sand and mix dry. Then add the proper quantity of water in which has been dissolved ¾ lb. soft soap per gallon of water and mix thoroughly. This mortar is applied as a plaster 1 inch in thickness and is always useful in preventing efflorescence.

31. **To remove putty.**—Paint it with nitric or hydrochloric acid and remove the putty after an hour.

32. **To render glass opaque or frosted.**—Clean the sheet of glass, and if only portions of it are to be frosted, protect the portions not to be frosted by mechanical means in any simple manner. Some flour spar is ground to a fine powder and mixed with concentrated sulphuric acid so as to form a thin paste, and this is rubbed by means of a piece of lead upon the parts to be rendered opaque. This process is known as "etching on glass by hydrofluoric acid".

33. **Removing old paints or varnish.**—Apply a solution composed of—

Soft soap ..	..	..	..	½ part.
Potash ..	..	..	..	1 part.
Quicklime	..	..	..	½ to ⅓ part.

The soap and potash are first dissolved by boiling in water, the lime is then added, and the whole applied while hot with a brush, covering all the paint to be removed with the solution which must be left on 12 to 24 hours, after which the whole of the paint will easily be removed by washing with hot water.

Another method.—

1 part washing soda (caustic soda).
1 part quicklime (**surti** or from roasted stone).

The above should be mixed with cold water, enough to reduce it to the consistency of paint and then applied boiling hot two or three times till the paint is removed. Then wash the material so treated with clean water.

34. **Paint for a black-board.**—Dissolve 1 lb. of shellac in one gallon of methylated spirit (95%) and add ½ lb. of best ivory black, 2½ ounces of finest flour emery and ½ lb. of ultramarine blue. Mix and put in stoppered bottles. Shake well when using.

Dyeing concrete.—

Wax dyes are made by melting beeswax in a container, then adding a little turpentine, and finally the colouring matter, stirring vigorously the while. The mixture is best applied warm. Two or even three coats are sometimes necessary, and a polished surface is obtained by slightly dusting with french chalk, and polishing with a felt pad. The penetration is a quarter inch and more.

For producing various shades of red, a wax mixture from an aniline dye known as fachsine is used.

Wax mixtures invariably give the best results in greens. A wax compound of verdigris, to which gamboge is added, will produce various shades of permanent and pleasing green. If the concrete is warm, and the mixture hot, the penetration can be as great as half an inch and even more.

Various shades of yellow are produced by dissolving gamboge in spirit, the stronger the solution the deeper the shade. The mixture is slightly warmed and applied with a brush. Another method is to dissolve neutral ferric chloride (or iron salt) in spirit, making an 80 per cent. solution and applying warm with a brush. The dye should be allowed to dry for at least 24 hours, and the surface should then be well wetted with clean cold water. A chemical reaction takes place, and a lasting dye, at least ⅛ inch deep is produced.

Cochineal in spirit gives a real by durable scarlet though it is advisable to keep the solution a week before use.

Spirit colours are the most satisfactory for lighter colours. Wax colours are applied after the concrete has dried and been rewarmed to allow the wax dye to penetrate deeply and prove lasting.

35. **Red paint for boundary stones.**—

1 lb. of **shendur** or red oxide of mercury,

½ lb. linseed oil,

⅛ lb. spirits of turpentine,

¼ lb. copal varnish,

2 **tolas** resin.

These quantities are sufficient for about 16 stones.

36. **Solution for coating iron pipes.**—

30 gallons coal tar,

30 lbs. fresh slaked lime,

6 lbs. tallow,

3 lbs. lamp-black,

1½ lbs. resin.

Mix well, boil for 20 minutes, and lay on hot.

37. **Chocolate colour.**—

Oxide of iron (powder)

This colour is supplied in the form of powder and the only preparation necessary is to mix the quantity required with oil and turpentine in the following proportions :—

One cwt. of the powder requires about 8 gallons of thinnings in the proportion of 7 parts of boiled linseed oil to 1 of turpentine. Stir the thinnings and powder together some hours before the paint is required for use. Keep well stirred during use, and see that it is not applied over grease, tar or dirt, observing the same precautions as with ordinary paint. This paint when applied in two coats is very useful for general iron work.

Note.—One cwt. of dry colour mixed with oil, etc., as directed, will cover with one coat on iron work an average area of 500 yards superficial.

Paints for steelwork in bridges.—

The priming coat.—Is usually a coat of non-setting red lead. There is nothing to compare with it for a priming or under coat.

Finishing coat.—For a finishing coat red lead is unsuitable as, it is very soft and easily scratched, bleaches almost white in exposed situations, and oxidises fairly easily forming a chalky deposit.

For a finishing coat either red oxide paint, or paints with aluminium or graphite bases, are found very suitable.

The Corrosion Committee found that for general purposes, red lead paint followed by red oxide paint has few if any superiors.

The aluminium paint is sold as a paste (or as flakes) and is mixed as required with the vehicle and should be used up within a few hours of mixing.

Graphit is sold ready mixed.

Aluminium and graphite paints have great covering capacity.—A gallon of paint covering 1,000 to 1,500 square feet.

Aluminium paint has the additional advantage of being visible in the dark. It does not oxidise and fade as red oxide paint does to a certain extent.

Paints for steelwork under water.—In the Punjab they use for this purpose a mixture called "khanki" mixture (named so after a canal) which is prepared as follows:—

Proportions.—Coal tar 84 lbs. ...
Mineral pitch 10 lbs.
Cement 9 lbs. ...
Kerosene oil 9 lbs.

} The mixture is prepared by heating pitch and coal tar separately, mixing them while hot, and stirring well over a fire, adding cement-sifted gradually the while.

After removal from the fire, Kerosene oil is added, and well stirred in. The mixture is applied hot and hundred weight covers about 2,500 square feet.

Note.—In Bihar a black bitumastic paint finishing coats failed within seven months in one case. The view was held that straight bitumens, dissolved in petroleum spirit, when applied to surfaces exposed to heat and light readily powder. At another place a bituminous paint prepared from a bitumen and coal tar base laid on in 1927, lasted till 1939, and the reason expressed was that in the latter case, the large proportion of non-volatile material acts as a plasticiser, and keeps the paint film together and makes it more elastic.

38. **Varnish for name boards, labels, etc.**—Sandarach 53 parts, mastic 20 parts, camphor 1 part, oil of lavendar 8 parts, Veniee turpentine 4 parts, ether 6 parts, alcohol 40 parts. Macerate for a week or two until the whole is dissolved: This makes a good varnish and gives a colourless, smooth and shining surface, and dries in a few minutes.

39. (*a*) **White and lotion**—

Arsenical:—

	Lbs.	Ozs.
Arsenic	2	4
Dhobi's mud (**khar**)	2	8
Soap, country	2	13
Aloes (œrea)	2	4
Water	4 gallons.	

Pound ingredients fine, mix, boil in half the water in an earthen or iron vessel. Let it cool, then add the rest of the water and boil again. The cost is about Rs. 2 per gallon. Does not stand exposure to rain, being more for inside work Wood if possible to be steeped; but, if applied, a solution will answer.

(*b*) **Copper sulphate** (blue stones or **murchud**).—One lb. dissolved in 4 gallons of water takes two days' steeping per inch of wood. McDougal's sheep dipping composition 1 lb. to 5 gallons.

(*c*) **Avenarium carbolineum** is a good wood preservative and antiseptic oil preparation preventing decay, dry rot, fungus, etc.

It keeps off the white ants and other wood-destroying insects.

Creosote has been fairly satisfactory as a wood preservative, but after some time in exposed situations, the creosote tends to leach out. In houses, creosote treated wood cannot be used as creosote has a strong smell, and besides the wood-work treated cannot be painted or polished.

A new preservative, called Ascu has been developed at the Forest Research Institute, Dehra dun. It is made up of three chemicals proportioned as under:—

One part by weight of $As_2O_5\ 2H_2O$

Three parts by weight of $CuSo_4 \cdot 5H_2O$

Four parts by weight of $K_2\ Cr_2O_7$

It is in powder form, and six parts weight of the powder dissolved in a hundred parts by weight of water gives a solution for ordinary use. The solution is odourless and wood treated with it can be painted, varnished, polished or waxed. Ascu solution can be applied or sprayed on in two coats, or the wood pieces can be soaked in the solution tank, or the wood pieces impregnated with the solution under pressure. The method to be adopted depends on the degree of immunity required and the nature of the wood; the last method being the most effective, and the first the least.

40. **White ants as a pest of trees.—**

(Gondal fluid)

1 part **dikamali** gum resin of (**Gardenia gummifera**).

2 parts asafoetida (**hing**).

2 parts (**gugal**) (**Amyris agalocha**) or 2 parts aloe (or **eliyo**).

2 parts castor oil cake (**Erandika bagda**).

Pound and mix thoroughly, then keep in water about a fortnight till it is thoroughly decomposed into a thickened compound. Add water till the mixture is the consistency of paint. Colouring matter such as red ochre (green) or blue powder should be added to the mixture, so that it can easily be seen what trees have been treated.

The fluid should be applied in a continuous band round the trunk of the tree to a height of about 2 feet from the ground. This part of the trunk must be brushed free of ants and quite cleaned of all mud encrustations. Care must be taken to see that the fluid penetrates into all the crevices of the bark. The effect of an application lasts for at least eight months.

41. **Attacks of beetles.**—To protect bamboos from the attacks of bettles, soak them in water for 5 days, then dry in a shed and soak in Rangoon oil for 48 hours.

42. **Destroying roots and vegetation in masonry.—**

Asafoetida (**hing**).— $\frac{1}{16}$ to $\frac{1}{8}$ tola.

Raw sugar (**gul or jagri**).—$\frac{1}{4}$ to $\frac{1}{2}$ tola,

Unslaked lime (**kali chuna**).=1 tola.

Mix them. The Mixture when applied to roots after removing the plant in the cold weather (about December) has the proparty to destroy vegetable life. Mixture to be applied each time after freshly preparing.

43. **Mixture for welding steel**:—

1 sal-ammoniac.
10 borax.

Pound together and fuse till clear. Allow to cool, and when cold, reduce to powder. Sprinkle over portions to be welded.

44. **To harden steel.**—The article to be made white hot and then thrust into sealing wax (common lac), withdrawn, and then insert again in another part, and so on till cold.

45. **Wash to remove white or yellow blotches (due to efflorescence from mortar or cement facing).**—

It consists of a solution of—

1 part hydrochloric acid.
5 parts water.

This to be applied vigorously with scrubbing brushes, water being constantly played on the work with a hose to prevent the penetration of the acid.

This recipe is of use for removing blotches from floor tiles also.

MEASURES, WEIGHTS, ETC.

(1) Bombay linear measures:—

1 inch = 1 tasu.
24 tasus = 1 gaj.
1½ gajas = 1 yard.

(2) Bombay square measures:—

(a) 1 kathi = 50′ × 10′	= 500 square feet.
(b) 1 anna	= 68 1/16 sq. ft.
16 annas	= 1,089 sq. ft. or 1 **guntha.**
40 **gunthas**	= 1 acre.
43,560 sq. ft.	= 1 acre.
640 acres	= 1 sq. mile.
(c) 1 bigha = 23 gunthas	= 2,783 square yards.
1¾ bighas = **one acre.**	

(3) Bombay measure for lime:—

16¼″ × 16¼″ × 6′ = 0·92 c. ft. = 1 **pharra.**
14·72 c. ft. = 16 **pharras** or 1 **khandi.**

Measures of weight

(1) Indian weights: –

1 tola	= the weight of one rupee.
	= ⅜oz. Troy = 180 grains (British).
5 tolas	= 1 **chatak.**
16 **chataks**	= 1 **ser** = $\frac{2}{235}$ lbs. Avoirdupos.
	= 2½ lbs. Troy.
40 **sers**	= 1 mon or mound.
	= 100 lbs. Troy = 82 $\frac{2}{7}$ lbs. Avoirdupos.

NOTE.—**Pao**=¼ ser.

Panseri or **panch-seri**=5 sers.

Factory maund =⅝cwt.

(2) Bombay weights :—

40 **sers** make 1 maund (28 lbs. Avoirdupois).

20 maunds make 1 **khandi** (560 lbs. Avoirdupois).

Principal measures in the metric system with their English approximate equivalents

(1) Measures of length :—

1 metre { = 39·37 inches ; ∴ 1 inch=25·4 millimetres.
= 1·093 yards ; ∴ 1 yard=0·914 metre. }

1 kilometre = 5 furlongs=⅝ mile.

(2) Measures of capacity :—

1 litre = { 1·7598 pints* ∴ 1 gallon* =4·55 litres.
61·024 cub. in 1 c. ft. =·028 cubic metre. }

Note.—A cylinder 3½ ins. in diameter and 3 ins. high contains one pint ; a cylinder 7 ins. in diameter and 6 ins. high contains one gallon.

Notes on the modus operandi followed in the Presidency district in measuring liquid fuel tanks.

(1) Mean of the levels of the points in the bottom of the tank, vertically below the gauge holes at the top of the tank, is worked out and adopted as the zero point.

Note.—(a) Care should be laken to see that there is a clear plate in the bottom, veritically below the gauge holes, as, should a joint happen to be there, the gauge likely to be read at 3 different levels at different times.

(b) All levels observed by means of a levelling instrument.

(2) The bottom of the tank being irregular, the average level of the entire bottom is worked out, and the capacity of the tank for the depth [*viz.* the difference between the average level and the zero point mentioned in (1) above] thus obtained, is worked out. This capacity is presumed to have been equally distributed between the highest and the lowest point in the bottom of the tank.

Note—The capacitity between the lowest point and the zero point, when the former is below zero is recorded as capasity below zero.

(3) The average diameter and height of the tank is measured by means of a steel tape, separately for each vertical bay for the purpose of calculating the gross capacity of the tank.

Note.—Diameters of the consecutive veritical bays differ owing to the thickness of the plates.

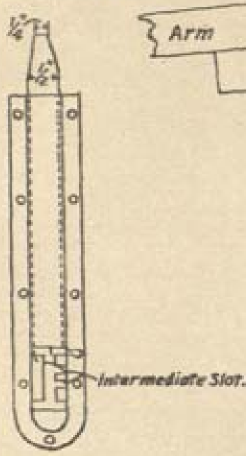
(4) Measurements of the internal fittings, e.g., rivet heads, bolt heads, inlet pipes, floats, ladders, central columns, trusses, angle iron frame work, cover plates, etc., are then measured in detail, nothing the levels with reference to the zero point at which each fitting occurs, and the volume of oil likely to be displaced by these fittings is calculated and deducted from the gross capacity of the layers concerned.

MISCELLANEOUS.

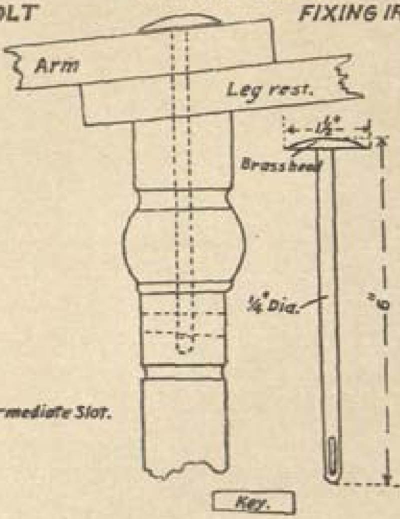
THE NEVER COLLAPSE LEG REST FOR ARM CHAIRS

THE TAPERING BOLT

FIXING IRON BARS IN A WINDOW FRAME WITHOUT REMOVAL.



1



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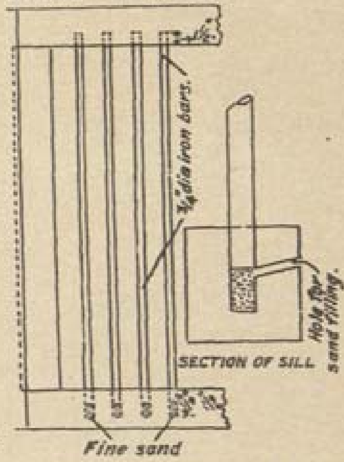
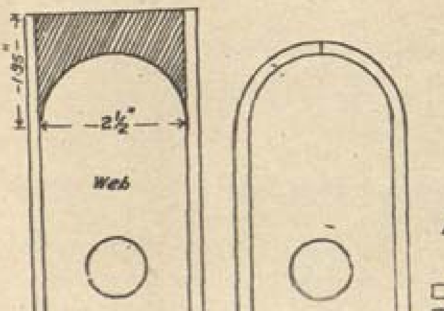


ELEVATION. 3

FINISH OF JOIST USED FOR STANDARDS IN FENCING.

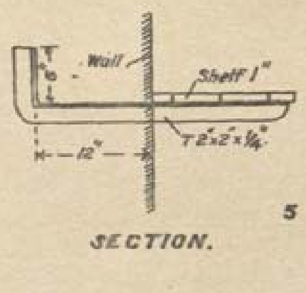
THE IRON SUPPORT FOR SHELVES.



Joist showing hatched portion of web to be cut away.

Top of joist with flanges bent round to meet and form a semicircular finish.

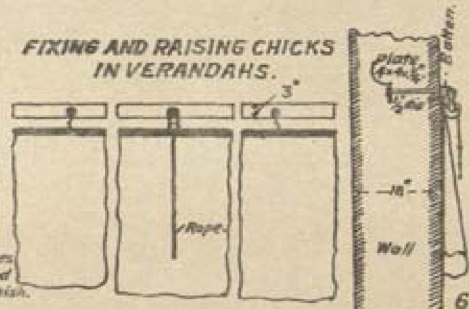
4



5

SECTION.

FIXING AND RAISING CHICKS IN VERANDAHS.



6

ELEVATION. SECTION.

G.P.Z.O. Poona, 1930.

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(5) Tables are then prepared showing the capacity at several heights of the tank, each successive one varying generally by 3″ but sometimes less, where there is considerable variation between the volumes of successive layers.

Electrical units

Derived units

1 megohm	=	1 million ohms.
1 microhm	=	1 millionth of an ohm.
1 milliampere	=	1 thousandth of an ampere.
1 micro-farad	=	1 millionth of a farad.
1 millivolt	=	1 thousandth of a volt.
1 kilowatt	=	1,000 watts = 44,240 ft. = lb. per minute=1·34 horse-power.
1 electrical horse-power	=	746 watt-hours = 33,000 ft.-lb. per minute = 1horse -power.
1 Joule	=	1 watt-second = 0·7373 ft.-lb.
1 B. T. U. (Board of Trade unit)	=	1,000 watt-hours.
	=	1 kilowatt-hour.
	=	1·34 horse-power during one hour.

For commercial purposes electrical energy is charged for in units of 1,000 watt-hours each, generally known as Board of Trade units.

$$1 \text{ B. T. U.} = \frac{1,000}{746} = 1\tfrac{1}{3} \text{ horse-power hours.}$$

1 dyne (the absolute unit of force) is that force which, acting for one second on a weight of 1 gramme on a smooth horizontal plane, will give it velocity of 1, centimetre per second.

1 erg (the absolute unit of work) = 1 centimetre dyne.

10,000,000 ergs = 1 joule = ·7373 foot-lbs.

Currents for working telegraph apparatus are measured in milliamperes. The average strength of a telegraph current is 20 milliamperes.

Currents for electric light and electric power purpoes are measured in amperes.

Insulation resistances are usually measured in megohms.

CREOSOTE FOR THE TREATMENT OF RAILWAY SLEEPERS, TELEGRAPH AND TELEPHONE POLES AND TIMBER GENERALLY

1. **Description.**—The creosote shall be of the best quality and shall be a pure distillate of coal tar and shall be free from any admixture of petroleum or similar oils. It shall be clear and free from all feculent matter.

2. **General characteristics.**—The creosote shall have the following characteristics :—

(*i*) *Fluidity.*—It shall become completely liquid on being slowly warmed to 38° C. with stirring and on cooling down shall remain completely liquid after standing for two hours at 32° C.

(*ii*) *Specific gravity.*—The creosote shall have a specific gravity of not less than 1·0 at 15° C.

(*iii*) *Water content.*—The amount of water in the material shall not be more than 2 per cent when determined in accordance with the British Engineering Standard Association specification No. 144-1921 (Appendix II).

(*iv*) *Insoluble matter.*—The amount of matter insoluble in benzine shall not exceed 1 per cent. by weight.

(*v*) *Free tar acids.*—The amount of tar acids shall not be more than 10 per cent. It will be determined by the method described in Appendix IV of British Engineering Standards Association specification No. 144-1921.

(*vi*) *Distillation.*—The loss by distillation shall be limited to the following values :—

Up to 200° C. not to exceed 5 per cent.
„ 240° C. between 10 per cent and 40 per cent.
„ 260° C. between 20 per cent and 50 per cent.
„ 280° C. between 30 per cent and 60 per cnet.
„ 300° C. between 35 per cent and 70 per cent.
„ 320° C. between 45 per cent and 80 per cent.
„ 340° C. between 60 per cent and 95 per cent.
„ 360° C. between 75 per cent and 100 per cent.

The distillation is to be conducted at the rate of one drop per second, on 250 grammes of oil in a 500 c.c. Hampel flask with the bulb of the thermometer opposite the side tube.

INDEX

(For Vols. I and II)

(1) The following abbreviations have been used in the Index: T. for Table; No. Pl. for Plate No.; Spc. for Specification No.; R. Ab. for Rate Abstract No.; To face p. for To face page.

(2) The figures refer to pages.

(3) Pages 1 to 546 refer to Volume I and pages 547 to 1075 to Volume II.

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GPN—J-1136—DASPWDSB—12-10-60—20,000.