CONCRETE ENGINEERS' HANDBOOK

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PREFACE

We have great pleasure in bringing out the third and revised edition of this Handbook. A word of apology is due to our readers as several months have passed since the last edition was sold out and circumstances beyond our control delayed the publication of this revised edition.

The Handbook will be found useful by overseers and contractors whose theoretical background of reinforced concrete design is limited but who nevertheless are called upon sometimes to design minor concrete structures. It will also find a place on the bookshelf of the junior engineer, and such other engineers whose main careers are spent in other branches of civil engineering such as drainage, irrigation, or water supply, but who are sometimes entrusted with the design and construction of a concrete structure, in which case it would be too much to expect them to remember the long formulae for design of R. C. structures.

Most of the present day concrete work in India is based on the recommendations of the Indian Standards Institution and the tables, charts, etc., in this book are mostly in conformity with stresses and modular ratios suggested by the Institution. Charts and tables are also given for the requirements of the Bombay Municipal Corporation whose bye-laws are slightly different from those of the I. S. I. Code no. 456-1957.

Before concluding this preface it would not be out of place to say a word or two about the most important and much discussed problem of the design of concrete mixes. This aspect of concrete engineering is practically new to the vast majority of Indian engineers who so far were working on the basis of arbitrary mixes found suitable in practice. A method of rationally designing concrete mixes has been given in this Handbook and we trust Indian engineers will make extensive use of it

henceforth, and let us have the reports of their findings. It should be noted that certain modifications and additions have been made in this method given in the first edition in order to make them more useful and practical.

Thanks are due to Mr. N. H. Mohile, B.E., M.I.E. (India), M.I.Struct.E (Lond.), of this Association whose efforts are mostly responsible in bringing out this Handbook.

The book is published with a sincere hope that it will fulfil the long felt need for a concise reference book on the design and technology of concrete.

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CONCRETE ENGINEERS' HANDBOOK

CHAPTER 1

MATERIALS

1.1 Portland Cement.

1.1.1 DEFINITION.

Portland cement is defined as a product obtained by intimately mixing together calcareous and argillaceous and/or other silica, alumina, or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resulting clinker. After burning no material other than gypsum or air entraining agents is added.

1.1.2 VARIOUS KINDS OF CEMENT (OTHER THAN ORDINARY CEMENT).

1.1.2.1 Rapid Hardening (also called High Early Strength Cement).

(a) *Materials used for manufacture* : Same as ordinary cement but more carefully prepared and carrying higher lime content.

(b) *Burning operations* : At a temperature higher than that of ordinary cement.

(c) *Grinding :* Finer than ordinary.

(d) *Setting properties* : Same as ordinary type.

(e) *Hardening properties* : Attains in 7 days the strength of 28 days old normal cement and so saves cost of moulds, etc., by about 30 per cent.

1.1.2.2. For other properties see page 8.

1.1.2.3 White Cement and Coloured Cement.

(NOTE.—White cement "Silvicrete" is now made in India by A.C.C. Ltd.)

(a) *Materials used for manufacture* : Pure limestone free from any iron content.

(b) *Strength, etc.* : Up to B.S.S. or I.S.S., but slightly less than normal cement.

Coloured cement is made by mixing white cement with inorganic colours about 5 to 10% at the time of grinding.

1.1.2.4 Aluminous (also called High Alumina) Cement.

[Not made in India. Imported brands are : *Ciment Fondu* Lightning (U.K.), Lumnite (U.S.A.) etc.]

(a) *Manufacture* : Mixture of bauxite and lime is heated to fusion at high temperature.

(b) *Setting :* Initial — Between 2 and 6 hours. Final — Within 2 hours of initial set.

(c) *Hardening* : Very rapid. Final strength developed within 24 hours.

(d) *Special qualities* : Immune from attacks of sea-water, sulphate bearing waters, frost, etc. Forms excellent refractory concrete stable up to 1500°C.

Precautions : Contamination with ordinary cement to be avoided. Other properties see Table on page 8.

1.1.2.5 Portland Blast Furnace Slag Cement.

(a) *Manufacture* : Clinker of normal Portland cement is ground with 65 to 25% of granulated slag.

(b) *Properties* : Same as ordinary cement; advantageous for marine structure and massive structures e.g. dams, and in sulphate-bearing soils.

For other properties see page 8.

1.1.2.6 Masonry Cement.

(a) *Manufacture* : Ordinary Portland cement is mixed with hydrated lime or calcium or aluminium stearate or paraffin oil.

(b) *Properties* : Gives more workable and plastic mortar and hence more suitable for masonry and plaster works.

1.1.2.7 Low Heat Cement.

(a) *Properties* : Less heat is evolved during setting. Hence more suitable for large mass concrete works, where heat of hydration does not dissipate easily and so cracks the concrete after cooling. It however hardens a little slowly.

For other properties see page 8.

1.1.2.8 Air Entraining Cement.

(a) *Manufacture* : Rosin and Vinsol resin or vegetable fats and oils such as tallow and olive oil and other fatty acids such as stearic and oleic acids are ground with ordinary cement.

(b) *Properties* : Development of microscopic air bubbles while setting forms minute voids in the concrete and increases

its resistance against freezing, and scaling action of salts like calcium chloride, etc. Three to five per cent air trapped in the concrete in the form of tiny individual bubbles improves the workability of the concrete, permitting a reduction in the water cement ratio, reduces shrinkage and improves durability, etc.

1.1.2.9 Pozzolanic or Silica Cement.

(a) *Manufacture* : Ordinary cement clinker and pozzolana (about 30%) are ground together. The pozzolana may be natural such as diatomaceous earth or pumice, or artificial such as burnt clay.

(b) *Properties* : The pozzolana reacts with free lime in the concrete which otherwise is affected by corrosive water. Addition of pozzolana also improves such qualities of the concrete as water-tightness and fire resistance. The concrete is also of low heat type.

1.1.2.10 Modified Cement.

Gives lower heat of hydration than normal cement and has improved resistance to sulphates.

1.1.2.11 Extra Rapid Hardening Cement.

Has a rapid initial set that may vary according to temperature from 5 to 30 minutes and its hardening rate is considerably faster than that for rapid hardening Portland cement. This cement is intended to allow concreting to proceed in cold weather. It is also used when very high early strength is required. Mixing and placing operations should be speeded up so that the concrete is placed before initial set takes place and preferably within 15 minutes. Shrinkage may be a little greater than when ordinary cement is used.

1.1.2.12 Water-repellent Portland Cement.

Is mainly used in renderings to check moisture penetration. When used in concrete it is most important to control the composition of the mix and the mixing time very carefully or too much air may be entrained and the strength of the concrete reduced.

1.1.2.13 Waterproof Portland Cement.

Is not subject to air-entrainment and therefore needs no precautions during mixing apart from the care always required in making good concrete. Concrete made with it has

rather more resistance to penetration by water and some oils than has concrete made with ordinary Portland cement.

1.1.2.14 Sulphate-resisting Cement.

Is specially designed to resist attack by mineral sulphates in soils and ground waters (up to 0.1 per cent sulphur trioxide in ground waters and up to 0.5 per cent sulphur trioxide in subsoil. It is essential that concrete used in situations where sulphates are present be dense and well made.

1.1.2.15 Super-sulphated Cement.

Resists attack by the highest concentration of sulphates normally found in ground waters and soils, and by peaty acids and vegetable oils. It also stands up to some acids and oily liquids. Its early strength is similar to that of Portland blast furnace cement (B.S. 146), but it has higher strength from three days onwards. It is also a low-heat cement.

Concrete mixes are similar to those for ordinary Portland cement, but should not be leaner than 1 : 6, and over-sanding should particularly be avoided. For rendering or mortar 1 : 2 or 1 : 2½ is recommended. Surfaces of freshly laid concrete should be kept moist for three days or a powdery finish will result.

1.1.3 STORAGE.

All possible precautions for keeping moisture away are necessary. The storage shed should have a pucca floor raised at least 6 inches from ground, with air-tight doors and windows. Bulk storage is preferable for longer interval. Fig. 1-1 gives a design of an ideal godown.

Reduction of Strength in Storage.

The following reduction may be expected at 28 days:—

After storage of 3 months 20% minimum.
After storage of 6 months 30% minimum.
After storage of 1 year 40% minimum.
After storage of 2 years 50% minimum.

1.1.4 STANDARD SPECIFICATIONS.

Summary of specifications controlling the manufacture of various cements, used in India is given on page 8.

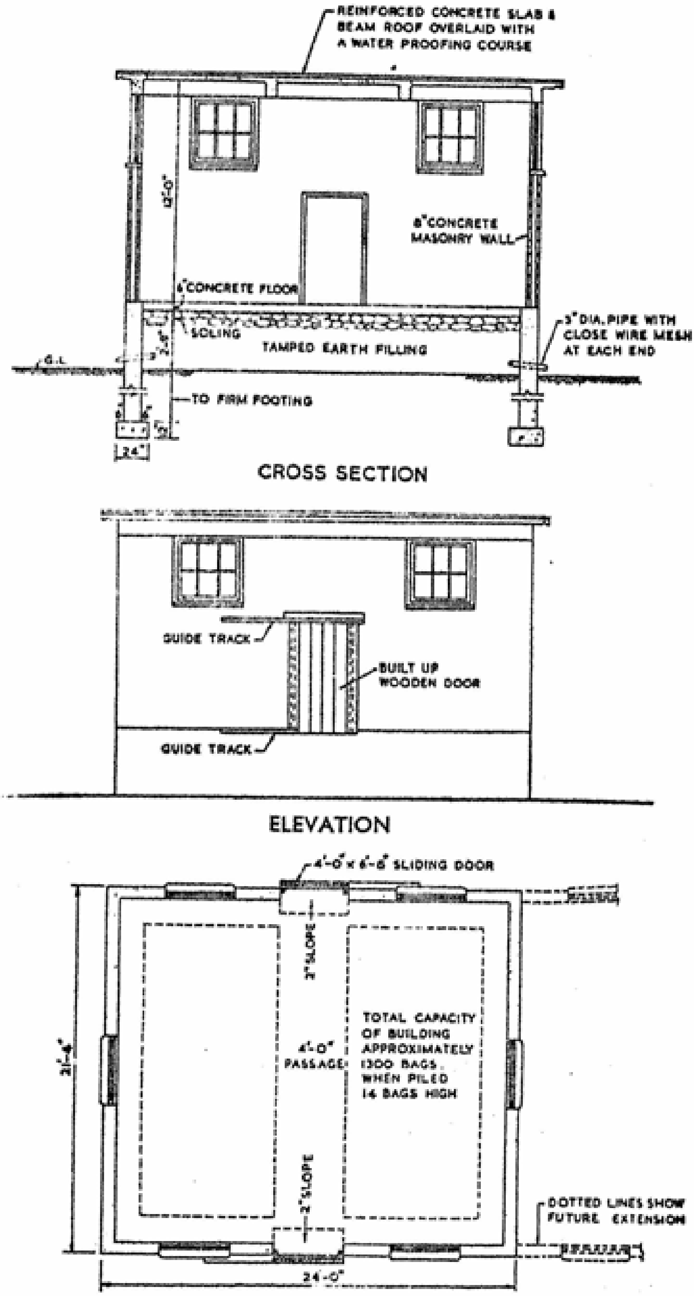


Fig. 1-1 Suggested building for storing 65 tons of Portland cement

PROPERTIES OF CEMENTS

Type of Cement		Ordinary Portland Cement	Rapid-hardening Portland Cement (1)	Portland Blastfurnace Cement	Low-heat Portland Cement	High Alumina Cement
Standard *		I. S. 269 (1958)	I. S. 269 (1958)	I. S. 455 (1953)	I. S. 269 (1958)	B. S. No. 915 (1947)
Fineness (3)	Maximum Residue By weight on I.S. Test Sieve No. 9	10 per cent	5 per cent	10 per cent	--	8 per cent
	Minimum Specific Surface Sq. cm per gm (A.P. method)	2250	3250	2250	3200	2250
Minimum Tensile Strength(2) kg/cm²	1 day 3 days 7 days	— 20 25	20 30 —	— 20 30	— — —	— — —
Minimum Compressive Strength (2) kg/cm²	1 day 3 days 7 days 28 days	— 115 175 —	115 210 — —	— 115 175 —	— 70 115 265	400 420 — —
Setting times (Hours)	Initial Final	Not less than ½ Not more than 10			* 1 †10	2 to 6 †2 after Initial set
Soundness (Le Chatelier)	Expansion	Not more than 10 mm.				†1 mm.
Heat of hydration	7 days 28 Days	None specified			Cals. per GM † 65 † 75	None specified
Chemical composition	S = SiO_2 A = Al_2O_3 F = Fe_2O_3 C = CaO	$\frac{C - 0.7S}{2.8S + 1.2A + 0.65F}$ *0.66 †1.02 $\frac{A}{F}$ *0.66		Blastfurnace Slag †65% (Cement clinker to comply with I. S. No. 269)	C†2.4S+1.2A+0.65F *1.9S+1.2A+0.65F	$\frac{A}{C}$ *0.85 †1.3 A*32%
	Admixture after burning	None (except gypsum or water) or air entraining agents			None (except gypsum and water)	None (except water)
	MgO SO_3	†5 per cent †2.75 per cent		†5%	†5% †2.75%	—
	Insoluble residue	†1.5%				—
	Loss on Ignition	†4 per cent				

Notes : 1. "High Early Strength Cement."
2. Alternative tests. Strength at any age must be greater than strength at earlier ages.
3. Alternative Tests (Except for Low Heat Portland Cement)
* Denotes not less than.
† Denotes not more than.

1.1.5 ADULTERATION.

Field Test for Adulteration.

(a) A sample of doubtful stuff should be burned for about 20 minutes on a steel plate heated by a stove. Adulterated sample changes its colour, while unadulterated cement remains unchanged.

(b) Make small pats, say 2" x 2" x ½" with adulterated and genuine cement. Pats made with doubtful cement can be broken easily with pressure of your fingers.

It is always advisable to send the sample to laboratory for full analysis and tests.

1.1.6 USEFUL MEMORANDA ON CEMENT.

1 jute bag contains 50 kg of cement.
1 ton of Portland cement=20 jute bags=24 cft.
1 barrel of cement in U.S.A. weighs 376 lb
6 barrels of cement make 1 tonne.
1 cft. of cement loosely filled weighs 90 lb
1 cft. of cement tightly packed weighs up to 110 lb in storage structures.

Silvicrete white cement weighs 85 lb per cft.

Rapid hardening cement weighs 75 lb per cft.

Ciment Fondu Aluminous Cement weighs 87 lb per cft.

1 cubic yard of cement=$1\,^1/_{12}$ tons.

1 cubic foot of loose cement neat as cement paste will cover about 10.4 sq. ft. (1 inch thick).

1 cft. of neat cement (90 lb) will cover 2.2 sq. yds. (½" thick).

1 cft. of neat cement (90 lb) will cover 1.9 sq. yds. (⅝" thick).

1 cft. of neat cement (90 lb) will cover 1.7 sq. yds. (¾" thick).

1 cft. of neat cement (90 lb) will cover 1.4 sq. yds. (⅞" thick).

1 cft. of neat cement (90 lb.) will cover 1.1 sq. yds. (1" thick).

1 cft. of loose Portland cement will make :

4.3 cft. of 1 : 2 : 4 concrete.
5.0 cft. of 1 : 2½ : 5 concrete.
5.8 cft. of 1 : 3 : 6 concrete.
7.5 cft. of 1 : 4 : 8 concrete.

1.2 Aggregates.

1.2.1 DEFINITION.

Inert material such as sand, pebbles, gravel, crushed stone, industrial by-products etc., which is mixed with Portland cement and water to produce concrete or mortar is called aggregate.

1.2.2. GENERAL REQUIREMENTS.

Necessary characteristics : The aggregates must be clean, dense, hard, durable, structurally sound, capable of developing good bond with cement, weather-resisting and unaffected by water. Aggregates for road work must have good wearing qualities. When fire-proof construction is needed the aggregates must possess fire-resisting qualities. In case of industrial by-products, blast furnace slag, which is a non-metallic product consisting essentially of silicates and alumino silicates of lime and of other base obtained along with iron in a blast furnace, must not contain more than 40% lime. Cinders must be obtained as a product of high temperature combustion and must not contain more than ½% of sulphur and 1% of sulphates. Similarly coke breeze must be free from sulphur and unburnt coal.

1.2.3 SITE TREATMENT OF AGGREGATES.

Site treatment : This is necessary if the aggregate as supplied is short of requirement as regards cleanliness and grading. Screening can be done by hand or mechanically to adjust the grading. If the material requires cleansing, washing may be resorted to, but precautions against loss of fine material should be taken. A simple arrangement for mechanical washing device is shown diagramatically in Fig. 1-3.

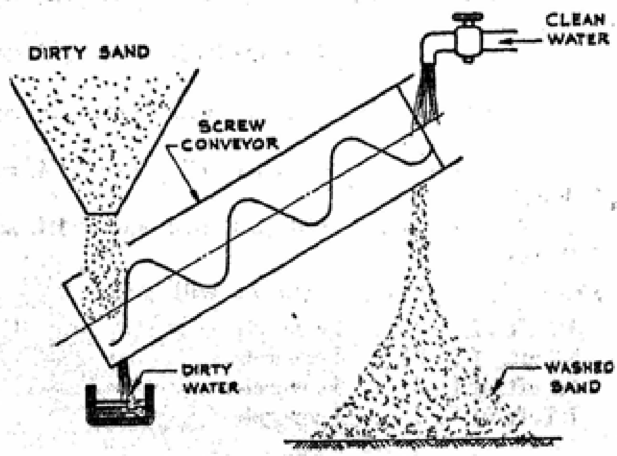
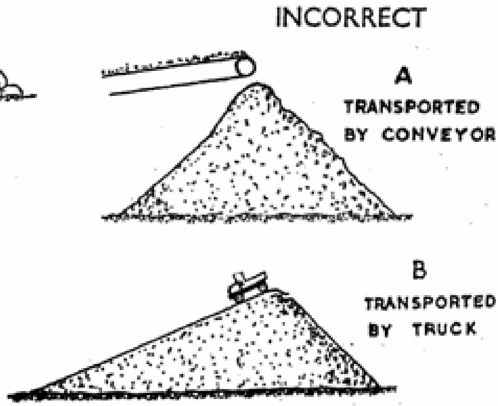


Fig. 1-3

1.2.4 STORAGE OF AGGREGATES.

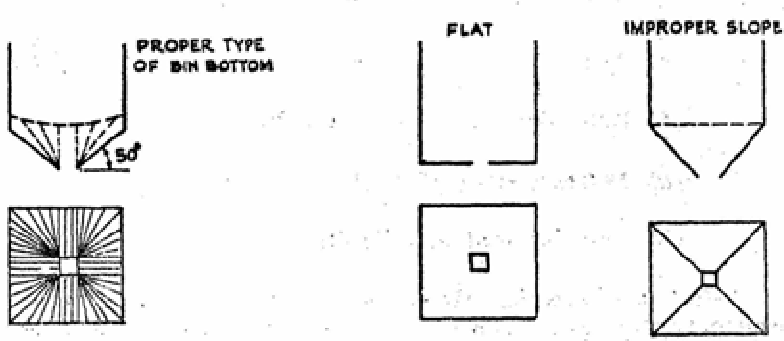
Precautions.—Avoid storing on dusty, muddy or grassy spots. Dumps must be protected from exposure to dust. Old steel sheets or wooden planks may be used as platforms for storage. On large works storage bins may be used. When stored on ground, the bottom layer of aggregates, say 3″ deep, should be rejected. Correct and incorrect methods of handling and storing aggregates are shown diagramatically in Fig. 1-4.

Place aggregates in stock piles in individual units not larger than a truck load and in suitable layers to prevent segregation. [They should not be allowed to run down slopes as shown in B at right].

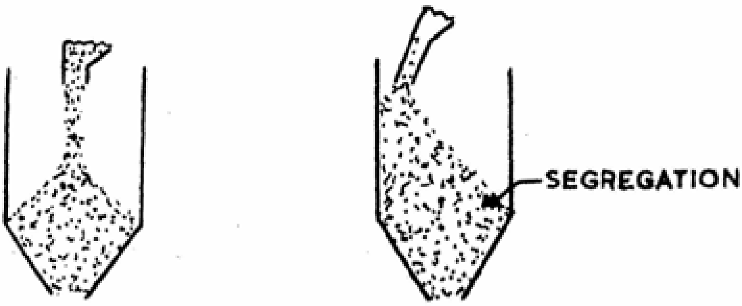


A. Belt Conveyor. B. Truck unloading material at the top of pile and allowing same to run down slope.

Fig. 1-4 (a)



When bins are used for storing aggregates they should have bottoms sloping about 50° in all directions and corners of the bottom should be properly rounded. [Flat or insufficiently sloping bottomed bins are not suitable.]



While filling the bins material should be made to drop in the centre and not against sides to avoid segregation.

Fig. 1-4 (b)

The aggregates should not segregate into various sizes while storing, otherwise there will be serious difference in the quality of concrete produced.

1.2.5 TESTS ON AGGREGATES.

1.2.5.1. Laboratory Tests.

(a) Sieve analysis.

(b) Determination of clay, silt and dust.

(c) Determination of organic impurities.

(d) Specific gravity and absorption.

(e) Aggregate crushing test.

(f) Bulk density or unit weight.

(g) Determination of voids.

(h) Test for coal and lignite.

Selection of sample.—Care is necessary to have a fairly representative sample. A large quantity, say 12 cwts., should be collected by taking one cwt. from different heaps. This should be reduced to required quantity by method of quartering as shown in Fig. 1-5.

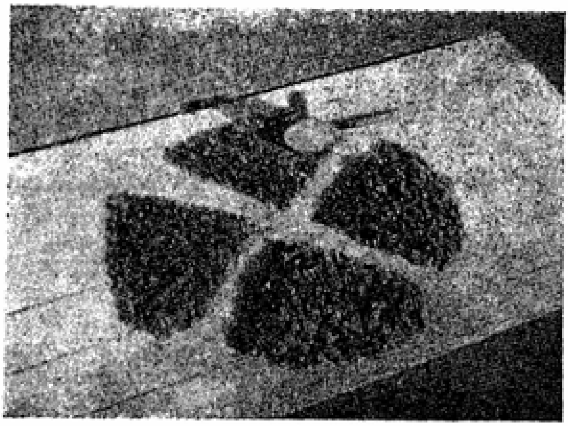


Fig. 1-5. Method of quartering aggregates for sampling.

Minimum quantity.—Different tests require different minimum quantity of aggregates as given below :—

Test	To be supplied to the laboratory	To be tested
Sieve analysis		
2½″ to 1½″ aggregates	1½ cwt.	50 lb
¾″ to ⅜″ aggregates	1 cwt.	20 lb
Fine aggregates	28 lb	1 lb
Determination of clay etc.		
2½″ to 1½″ aggregates	1 cwt.	14 lb
¾″ to ¼″ aggregates	28 lb	1 lb
Fine aggregates	2 lb	1 lb
Specific gravity and absorption		
Coarse aggregates	4 lb	2 lb
Fine aggregates	,,	,,
Aggregate crushing strength		
2″ to ¾″ size	2 cwt	1 cwt.
¾″ to ¼″ size	,,	14 lb
Fine aggregates	,,	2 lb
Bulk density		
Coarse aggregate	2 cwt	75 lb
Fine aggregate	½ cwt	15 lb
Voids test		
Coarse aggregate		500 cc
Fine aggregates		100 cc

(a) *Sieve test:* A known weight of dry aggregates is passed through a set of standard sieves of size 3″, $1\frac{1}{2}$″, $\frac{3}{4}$″, $\frac{3}{8}$″, $\frac{3}{16}$″ in the case of coarse aggregate, and Indian Standard Test Sieves Nos. 240, 120, 60, 30, 15, in case of fine aggregates, and percentage retained is noted.

(b) *Determination of clay, etc.:* A certain fixed quantity of material is sieved through 240 sieve. Material retained on the sieve is washed with sodium oxalate solution of 0.8 grs. per litre strength. This solution is again sieved through No. 240 sieve, and 150 m.l. of this solution taken. This solution is mixed with the material that has passed the No. 240 sieve. A soft rubber pestle is used for mixing the material without causing any attrition. The mixture is kept in a sedimentation tube and after 100 seconds a certain amount is taken in a pipette. This quantity is evaporated in a crucible and weight of residue taken. From this data the percentage of clay, etc., is known.

(c) *Organic impurities:* A 12 oz. medicine bottle is filled to $4\frac{1}{2}$ oz. mark with sand and 3% solution of sodium hydrooxide is added up to 7 oz. mark. The colour of the liquid is compared with standard colour chart.

(d) *Specific gravity:* A certain sample of material properly washed to remove dust is dried in an oven and weighed. The sample is then immersed in distilled water and entrained air from the sample is removed by gentle rodding. The sample is then placed in a wire basket suspended in water and weighed. The weight of saturated sample immersed in water is thus obtained. The specific gravity is calculated from the result.

(e) *Aggregate crushing value:* A weighed quantity of aggregates is placed in a metal cylinder fitted with a plunger. This plunger is subjected to a specified compression and the aggregate is sieved to remove the material crushed by the compression. The weight of the fines formed is expressed as a percentage of the total sample.

(f) *Bulk density:* Weight of material held by a container of unit volume when filled under specified conditions is found out.

(g) *Voids:* A cylindrical metal measure is filled one-third with water and dry aggregate is then added and tamped to exclude air. The process is repeated till the measure is filled to the top and further water added till the measure overflows. The volume of water added gives the volume of voids in the aggregate, from which the required percentage can be calculated.

(h) *Coal and lignite:* This is found by removing the particles by flotation in a liquid with a specific gravity of 2 (made from a mixture of carbon tetrachloride and acetylene tetrabromide).

1.2.5.2. Field Tests.

Sieve analysis is done in the same way as above but all the sieves are not necessary.

Silt test: A glass vessel is filled half with sand, and water is added up to three-fourth height. After shaking vigorously the contents are allowed to settle for one hour. This gives a fair idea about the quantity of silt in the sample.

Organic matter and void tests: Same as laboratory tests.

1.2.5.3 Particle Shape and Surface Texture.

In addition to above, a report on aggregates should also contain information about particle shape and surface texture of the aggregates as per following description :—

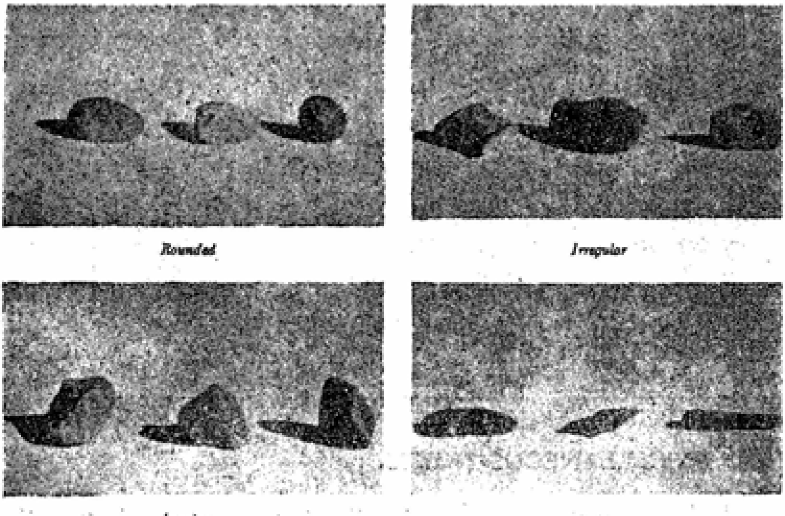


Fig. 1-6. Characteristic specimens of concrete aggregates.

(a) *Particle Shape.*

Classification	Description	Examples.
Rounded	Fully waterworn or completely shaped by attrition.	River gravel, wind blown sand, desert sand etc.
Irregular	Naturally irregular or partly shaped by attrition and having rounded edges.	Pit sand & gravels land or dug flints, cuboid rock etc.
Angular	Having well defined edges.	Crushed rock of all types.
Flaky	Material (usually angular) of which thickness is small relative to width and length.	Crushed rock of all types. Laminated rocks.

(b) *Surface Texture.*

Texture.	Example.
Glassy	Flint, vitrious sand.
Smooth	Slate, marble etc.
Granular	Sandstone, oolite etc.
Crystalline	Fine basalt. Medium dolerite.
Pitted fine slag	Coarse granite, gneiss etc.
Honeycombed porous	Coarse slag, brick, pumice, etc.

1.2.6 MISCELLANEOUS NOTES.

Bulking of sand: The volumetric expansion of sand due to moisture content is called bulking. Finer sands bulk more than coarser varieties. As the moisture increases and the sand

becomes fully saturated, it occupies the same volume as dry sand.

Type of sand	% Moisture by weight	% Bulking by volume.
Fine	5 10 15 20 27	38 32 22 10 0
Medium	5 10 15 20	29 22 12 0
Coarse	5 10 15	18 12 2

1.2.7 USEFUL DATA ON AGGREGATES.

	Weight lb/cft.
Fine and dry river sand (loose)	90
Medium ,, ...	95
Coarse ,, ...	100
Burnt clay ballast	70
Beach or river shingle ¾" to ¼"	100
Gravel—coarse loose, unscreened	115
Broken brick 2" to ¾" guage	80
,, stone ,, ...	100
Stone screening ¾" to ½"	90
Broken granite 2" to ¾"	105
Granite chipping ¼" down	95
Coke breeze 1" down	45
Clinker hard furnace 1" to ¼"	70
Pumice stone	40
Blast furnace slag 1½" to ¾"	90
Honeycomb slag	40

Voids: (Approximate percentage)

Sand (moist and fine)	43
Sand (coarse)	35
Sand (mixed)	38
Sand (dry mixed)	30
Stone screenings	58
Broken stone 1" and under	46
" 2" "	45
" 2½" "	41

Specific Gravity

Trap	2·9
Granite	2·7
Slate	2·7
Gravel	2·66
Sand	2·65
Limestone	2·60
Sandstone	2·40

1.3 Water.

1.3.1 FUNCTION OF WATER

1.3.1.1 Chemical.

Water and various compounds in cement react chemically in the process of setting and hardening of cement. Portland cement contains about 65% of lime. For complete hydration of all the lime in 100 lb of cement about 21 lb of water are required. In setting, complete hydration does not take place : hence about 14 lb of water are sufficient.

1.3.1.2 Physical.

(a) Water distributes the cement evenly so that every particle of stone and sand is coated by it and brought into intimate contact with each other.

(b) Water acts as lubricant and gives workability to the mixture.

1.3.2 FIELD TESTS FOR WATER.

1.3.2.1 Acids.

Can be detected by litmus paper.

1.3.2.2 Sulphates.

Acidify the water with dilute sulphuric acid and then add a little barium chloride solution. Formation of white precipitate indicates presence of sulphates. This should be compared with the local tap water similarly treated.

1.3.2.3 Chlorides.

Acidify water with a little nitric acid and add a few drops of 10% silver nitrate solution. A thick white precipitate indicates chlorides.

1.3.2.4 Carbon dioxide.

Add a few drops of dilute hydrochloric acid. A rapid evolution of CO_2 will then take place.

1.3.3 QUANTITY OF WATER.

(a) *Mixing concrete.*—For exact quantity, detailed information is given in chapter on proportioning of concrete, but for estimating purposes the following figures may be used.

Mix	1 : 3 : 6	1 : 2 : 4	1:1⅔:3⅓	1 : 1½ : 3	1 : 1 : 2
Dry aggregates	7½	6½	6	5½	5
Damp aggregates	6½	6	5½	5	4½

(The above figures give quantity of water in gallons per cwt. of cement.)

(b) *Other purposes.*—For washing aggregates, curing, etc. 75 to 80 gallons may be assumed per 100 cft. of concrete work.

1.3.4 USEFUL DATA.

One cft. of water = 6.23 Imperial gallons.
= 7.48 U.S.A. gallons.
= 62.4 lb (at 60° F.).
One Imperial gallon = 4.55 litres.
= 4 qrts.
= 0.16 cft.
= 1.2 U.S.A. gallon.
One U.S.A. gallon = 0.83 Imperial gallon.
One ton of water = 1 cubic metre.
= 244 Imperial gallons.
= 35.9 cft.
One cft. of sea water = 64.1 lb

1.4 Reinforcement.

1.4.1 STEEL REINFORCEMENT.

Steel reinforcement comprises of :

(a) mild steel rods,
(b) cold drawn mild steel wire,
(c) twisted bars, single or double,
(d) welded fabrics,
(e) expanded steel,
(f) ribbed mesh steel sheets acting as shuttering also, and
(g) R.S. sections such as joists, channels, rails, etc.

1.4.2 GENERAL REQUIREMENTS.

(a) Freedom from surface defects.
(b) Freedom from rust scales, (moderate surface rusting may be permitted).
(c) Freedom from oil, grease or paint ; (lime or cement wash is permissible).

1.4.3 STRUCTURAL REQUIREMENTS AND OTHER PARTICULARS.

(a) M.S. rods
(b) Cold drawn M.S. wire

Material	Size D=Diameter in inches	Minimum Stress Tons/□"		Elongation		Internal radius of cold bend
		Yield	Ultimate	Length	per cent	
Mild Steel	Over 1" ¾" To 1" Below ¾"	Not specified.	25 to 27	4.5D 9D 9D	24 20 16	1.5D D D
Medium Tensile Steel	Over 1" ¾" To 1" Below ¾"	22 23 Do.	37	4.5D 9D 9D	22 18 14	1.5D D D
Cold Drawn Wire	All Sizes	Not Specified	37 to 42	9D	7½	D

(c) *Twisted bars.* (B.S. Standard).

Material	Size D=Diameter in inches	Minimum stress Lbs/□"		Elongation.		Diameter of bend
		Yield	Ultimate	Length	Percent	
Twin Twisted Bars	Over 1" $\frac{7}{8}$" to 1" $\frac{3}{8}$" to $\frac{7}{8}$" Below $\frac{3}{8}$"	54,000	63,000	5.7D 5.7D 11.3D 11.3D	16 16 14 12	3D 2D 2D 2D
Twisted Square Bars	Over $\frac{1}{4}$" $\frac{11}{16}$" to 1" $\frac{3}{8}$" to $\frac{11}{16}$" Below $\frac{3}{8}$"	60,000 Do. Do. 70,000	70,000 Do. Do. 80,000	4.5D 4.5D 9D 9D	16 16 14 12	4.2D 2.8D 2.8D 2.8D

D=Diameter of one round bar or side of square rod before being twisted.

Isteg twisted bars are mild steel bars treated by patent cold twisting and stretching process. The length after twisting is the same as original bars. Faulty rods break in the process of twisting, hence the rods which remain can stand higher stresses being without any defect. Yield point of these rods is at 54,000 lb per square inch. Bond stress of 540 lb per sq. inch and tensile stress of 27,000 lb per sq. inch can be permitted. Hooks, etc., which are required for anchorage can also be omitted and hence there is a saving of 33 per cent in weight of reinforcement.

(d) *Welded fabrics (Plain and twisted steel).*—Several fabrics are available, names of a few being :

1. B.R.C.
2. Maxweld
3. Matobar
4. Twist Steel
5. Spun Groove, etc.

Manufacture of plain fabrics is controlled by B.S.S. 1221.

The fabric is to consist of main wires and cross-wire electrically welded.

The fabric is to be made of hard drawn steel wire complying with B.S.S. 785 and can be made both in oblong and square

mesh. All joints and junctions are to be electrically welded. For twisted steel fabrics, cold twisted steel bars complying with B.S.S. 1144 are to be used. In case of oblong mesh, cross bars may be of plain hard-drawn steel wire complying with B.S.S. 785.

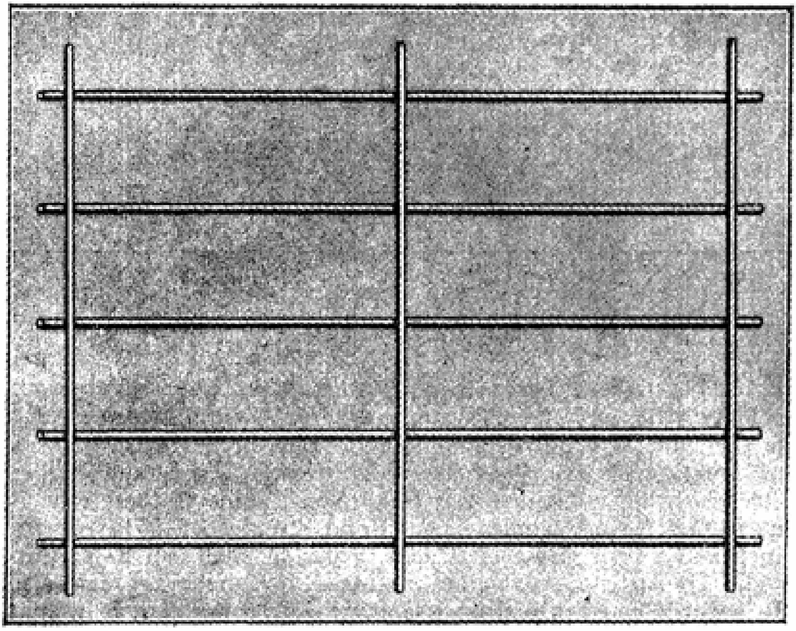


Fig. 1-7 B. R. C. Fabric.

(i) *B.R.C. Fabric:* Made from hard-drawn steel wire and consists of a wire mesh made up of a series of parallel longitudinal wires held at fixed distances apart by means of transverse wires at right angles to longitudinal wires (See Fig. 1-7). A higher working tensile strength of 25,000 lb per sq. inch is recommended by the manufacturers. Properties of standard sizes of B.R.C. Fabric are given in the following table. The fabric is available in sheets 7 ft. wide.

Ref. No. of Fabric	Size of Mesh and or Wire					Weight Lb/□ yd.
	Distance of Longitudinal Wires, Inches	Distance of Cross Wires, Inches	Gauge of Wire (Imperial)		Sectional Area Per Ft. Width Sq. In.	
			Longitudinal	Cross		
1	3	16	4/0	4	.5027	16.35
2	,,	,,	3/0	4	.4347	14.27
3	,,	,,	2/0	6	.3805	12.31
4	,,	,,	1/0	6	.3298	10.76
5	,,	,,	1	6	.2827	9.32
6	3	16	2	7	.2393	7.88
7	,,	,,	3	8	.1995	6.57
8	,,	12	4	9	.1691	5.67
9	,,	,,	5	10	.1412	4.71
10	,,	,,	6	10	.1158	3.94
12	,,	,,	8	12	.0804	2.72
14	,,	,,	10	12	.0515	1.83
65	6	6	5	5	.0706	4.32
610	6	6	10	10	.0257	1.58

(ii) *Maxwell fabrics:* These are also of the same type as B.R.C. and their references Nos. 403, 303, 203, 103, 1, 2, 3, 4, 5B, 6, 8, 10, 56 and 106 correspond approximately with Reference Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 65 and 610 of B.R.C. fabrics.

Fabrics Nos. 3, 4 and 5 are not very common in this country and hence particulars of the same have not been given.

(e) *Expanded steel:* This is made from steel plates and sheets by cutting them and expanding them into diamond-shaped meshes of different sizes. Manufacture is controlled by B.S.S. 1221, Part C, main requirements being :

The blank steel plates shall have ultimate stress between 26 to 32 tons per sq. inch.

The strength of the fabric is

Minimum ultimate tensile stress	75,000 lb per sq. in.	
„ yield stress	50,000 „	„
„ elongation	7½%	

Due to absence of any joints in the mesh work the fabric can be stressed to 20,000 lb per sq. inch in design work.

(f) *Ribbed mesh steel sheets* (*See Fig.* 1-8) : *The* ' V ' shaped ribs give rigidity to the fabrics and the meshwork is so shaped that it retains the wet concrete without appreciable loss of the same through the openings. Only timber joists are required for supporting the fabric at definite intervals depending upon the thickness of slab. This type of reinforcement is very convenient and economical in case of curved surfaces where

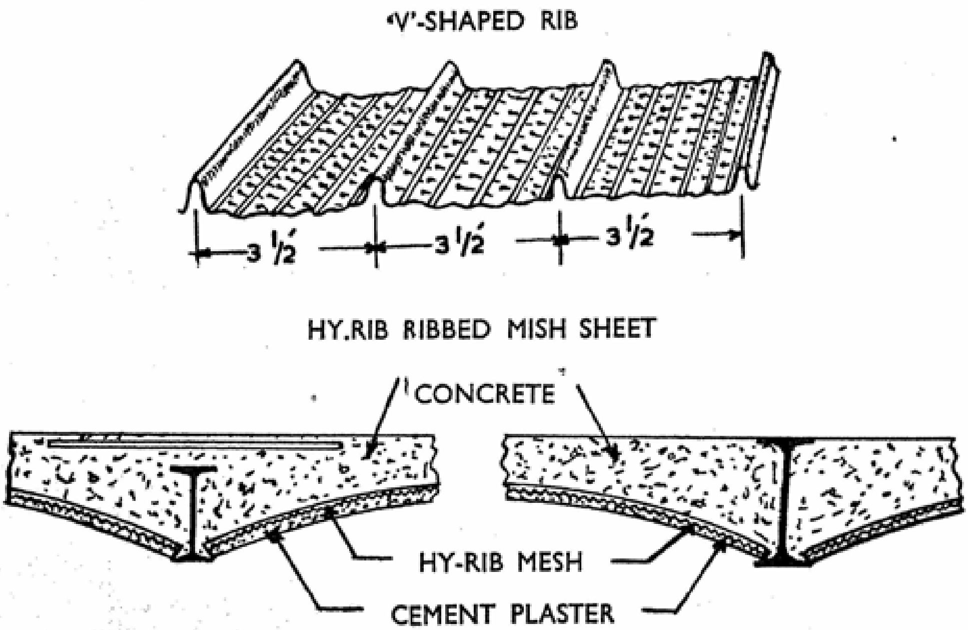


Fig. 1-8

shuttering cost is heavy (see Fig. 1-8). "Hyrib" and "Self-sentering" are two common trade names for such reinforcement available in this country in pre-war days.

1.4.4 AREAS, WEIGHTS, ETC. OF BARS.

Round and Square M.S. Bars.

Weight in pounds per lineal foot. Area in sq. inches and Perimeter in inches.

Diameter or Side in inches	Round: Weight	Round: Area	Round: Perimeter	Round: Lineal feet in 1 cwt.	Square: Weight	Square: Area	Square: Perimeter	Square: Lineal feet in 1 cwt.
3/16	.094	.028	.589	1192	.120	.035	.75	933
1/4	.167	.049	.785	667	.213	.062	1.00	526
5/16	.261	.077	.982	428	.332	.097	1.25	337
3/8	.376	.110	1.178	297	.478	.140	1.50	234
7/16	.511	.150	1.375	218	.651	.191	1.75	172
1/2	.669	.196	1.571	167	.849	.250	2.00	132
9/16	.845	.248	1.767	132	1.076	.316	2.25	104
5/8	1.043	.307	1.963	107	1.328	.390	2.50	84
11/16	1.262	.371	2.160	88	1.607	.472	2.75	70
3/4	1.502	.442	2.336	74	1.912	.562	3.00	59
12/16	1.763	.518	2.553	63	2.245	.660	3.25	50
7/8	2.044	.601	2.749	54	2.653	.765	3.50	43
15/16	2.347	.690	2.945	45	2.988	.879	3.75	37
1	2.670	.785	3.142	42	3.400	1.000	4.00	33
1 1/8	3.380	.994	3.534	33	4.343	1.265	4.50	26
1 1/4	4.172	1.227	3.927	27	5.312	1.562	5.00	22
1 3/8	5.049	1.484	4.320	22	6.428	1.820	5.50	17.5
1 1/2	6.008	1.767	4.713	18.5	6.650	2.250	6.00	15.6
2	10.68	3.141	6.283	10.5	13.60	4.000	8.00	8.2

Areas per foot width for various spacings.

Spacing	Diameter of bars. 3/16"	1/4"	5/16"	3/8"	7/16"	1/2"	5/8"	3/4"	7/8"	1"
3"	0.110	0.196	0.307	0.442	0.601	0.785	1.227	1.767	2.405	3.142
3½"	0.095	0.168	0.263	0.379	0.515	0.673	1.052	1.515	2.060	2.690
4"	0.083	0.147	0.230	0.331	0.451	0.589	0.930	1.325	1.804	2.356
4½"	0.074	0.131	0.205	0.295	0.401	0.524	0.818	1.178	1.604	2.090
5"	0.066	0.118	0.184	0.265	0.361	0.471	0.736	1.060	1.443	1.885
5½"	0.060	0.107	0.167	0.241	0.328	0.428	0.669	0.964	1.312	1.714
6"	0.055	0.098	0.153	0.221	0.301	0.393	0.614	0.884	1.203	1.571
6½"	0.051	0.091	0.142	0.204	0.278	0.365	0.566	0.816	1.110	1.450
7"	0.047	0.084	0.131	0.189	0.258	0.337	0.526	0.797	1.031	1.346
7½"	0.044	0.079	0.123	0.177	0.241	0.314	0.491	0.707	0.962	1.257
8"	0.041	0.074	0.115	0.166	0.225	0.295	0.461	0.663	0.902	1.178
8½"	0.039	0.069	0.108	0.156	0.212	0.272	0.433	0,624	0.849	1.109
9"	0.037	0.065	0.102	0.147	0.200	0.262	0.409	0.589	0.802	1.047
9½"	0.035	0.062	0.097	0.140	0.190	0.248	0.388	0.586	0.760	0.992
10"	0.033	0.059	0.092	0.139	0.180	0.236	0.368	0.530	0.722	0.942
10½"	0.032	0.056	0.088	0.126	0.172	0.224	0.351	0.505	0.687	0.898
11"	0.030	0.054	0.084	0.120	0.164	0.214	0.335	0.482	0.656	0.857
12"	0.028	0.049	0.077	0.110	0.150	0.196	0.307	0.442	0.501	0.785
15"	0.022	0.039	0.061	0.088	0.120	0.157	0.245	0.359	0.481	0.628
18"	0.018	0.032	0.051	0.074	0.100	0.131	0.205	0.295	0.401	0.524
24"	0.014	0.025	0.038	0.055	0.075	0.098	0.153	0.221	0.301	0.393

Areas for given Numbers (sq. in.)														
	Diameter of Bars													
Nos.	3/16″	1/4″	5/16″	3/8″	7/16″	1/2″	5/8″	3/4″	7/8″	1″	1⅛″	1¼″	1⅜″	1½″
1	0.028	0.049	0.077	0.110	0.150	0.196	0.307	0.442	0.601	0.785	0.994	1.227	1.484	1.767
2	0.055	0.098	0.153	0.221	0.301	0.393	0.614	0.884	1.203	1.571	1.988	2.45	2.97	3.53
3	0.082	0.147	0.230	0.331	0.451	0.589	0.920	1.325	1.804	2.36	2.98	3.68	4.45	5.30
4	0.110	0.196	0.307	0.442	0.601	0.785	1.227	1.767	2.41	3.14	3.98	4.91	5.94	7.00
5	0.138	0.245	0.384	0.552	0.752	0.982	1.534	2.21	3.01	3.93	4.97	6.14	7.42	8.84
6	0.165	0.295	0.460	0.663	0.902	1.178	1.841	2.65	3.61	4.71	5.96	7.36	8.91	10.60
7	0.193	0.344	0.537	0.773	1.052	1.374	2.15	3.09	4.21	5.50	6.96	8.59	10.39	12.37
8	0.221	0.393	0.614	0.884	1.202	1.571	2.45	3.53	4.81	6.28	7.95	9.82	11.88	14.14
9	0.248	0.442	0.690	0.994	1.353	1.767	2.76	3.98	5.41	7.07	8.95	11.04	13.36	15.90
10	0.276	0.491	0.767	1.104	1.503	1.963	3.07	4.42	6.01	7.85	9.94	12.27	14.85	17.67
11	0.304	0.540	0.844	1.215	1.654	2.16	3.37	4.86	6.61	8.64	10.93	13.50	16.33	19.44
12	0.331	0.589	0.920	1.325	1.804	2.36	3.68	5.30	7.22	9.42	11.93	14.73	17.82	21.21
13	0.359	0.638	0.997	1.436	1.954	2.55	3.99	5.74	7.82	10.21	12.92	15.95	19.30	22.97
14	0.387	0.687	1.074	1.547	2.10	2.75	4.30	6.19	8.42	11.00	13.92	17.18	20.79	24.74
15	0.414	0.736	1.151	1.657	2.25	2.95	4.60	6.63	9.02	11.78	14.91	18.41	22.27	26.51
16	0.442	0.785	1.227	1.768	2.41	3.14	4.91	7.07	9.62	12.57	15.90	19.64	23.76	28.27
17	0.469	0.836	1.304	1.878	2.56	3.34	5.22	7.51	10.22	13.56	16.90	20.86	25.24	30.04
18	0.497	0.884	1.381	1.989	2.71	3.53	5.52	7.95	10.82	14.14	17.89	22.09	26.73	31.81
19	0.525	0.933	1.457	2.10	2.86	3.73	5.83	8.39	11.43	14.92	18.89	23.32	28.21	33.57
20	0.552	0.982	1.534	2.21	3.01	3.93	6.14	8.84	12.03	15.71	19.88	24.54	29.70	35.34

Spacing	Weight per sq. yard for various spacings (lb.)													
	Diameter of bars													
	3/16"	1/4"	5/16"	3/8"	7/16"	1/2"	5/8"	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"	1 1/2"
2½"	4.06	7.23	11.27	16.24	22.08	28.86	45.06	64.88	88.50	115.34	146.02	180.23	218.12	260.00
3"	3.39	6.02	9.41	13.53	18.40	24.04	37.60	54.07	73.70	96.12	121.68	150.19	181.60	216.28
3½"	2.90	5.15	8.07	11.60	15.72	20.61	32.20	40.40	63.60	82.39	104.30	128.73	155.80	185.39
4"	2.54	4.51	7.07	10.15	13.80	18.03	28.16	40.55	55.40	72.00	91.26	112.64	136.32	162.22
4½"	2.26	4.01	6.27	9.02	12.26	16.03	25.03	36.10	49.20	64.08	81.20	100.13	121.21	144.20
5"	2.03	3.61	5.64	8.12	11.01	14.42	22.52	32.50	44.20	57.67	73.20	90.09	109.05	129.77
5½"	1.85	3.28	5.13	7.38	10.01	13.12	20.50	29.51	40.25	52.59	66.50	81.99	99.25	117.20
6"	1.69	3.01	4.71	6.76	9.20	12.02	18.77	27.02	36.84	48.10	60.84	75.09	90.87	108.14
6½"	1.56	2.78	4.34	6.25	8.49	11.09	17.32	24.95	34.67	44.40	56.25	69.48	83.89	99.82
7"	1.45	2.58	4.03	5.80	7.85	10.31	16.09	23.17	31.68	41.20	52.20	64.37	77.89	92.89
7½"	1.35	2.41	3.77	5.41	7.36	9.62	15.02	21.63	29.50	38.50	48.80	60.08	72.71	86.80
8"	1.27	2.26	3.52	5.07	6.90	9.02	14.08	20.31	27.70	36.10	45.53	56.30	68.16	81.25
8½"	1.19	2.12	3.32	4.78	6.50	8.49	13.25	19.06	26.07	33.97	43.05	53.10	64.15	76.60
9"	1.13	2.00	3.14	4.51	6.14	8.02	12.51	18.02	24.53	32.08	40.60	50.06	60.56	72.30
9½"	1.07	1.90	2.97	4.27	5.79	7.59	11.86	17.05	23.28	30.38	38.60	47.42	57.39	68.50
10"	1.02	1.80	2.82	4.06	5.51	7.22	11.26	16.22	22.08	28.80	36.58	45.06	54.52	64.88
11"	0.92	1.64	2.57	3.69	5.02	6.56	10.24	14.74	20.07	26.22	33.30	40.96	49.57	58.90
12"	0.85	1.50	2.36	3.38	4.60	6.02	9.39	13.52	18.41	24.00	30.42	37.54	45.44	54.07
15"	0.68	1.20	1.88	2.71	3.68	4.81	7.54	10.82	14.72	19.20	24.38	30.10	36.35	43.26
18"	0.56	1.00	1.37	2.26	3.06	4.01	6.26	9.01	12.26	16.02	20.28	25.04	30.29	36.05

CHAPTER 2

PROPORTIONING OF CONCRETE

CONTENTS

CHAPTER 2

PROPORTIONING OF CONCRETE

2.1 Definition of Terms.

2.1.1 INTRODUCTION.

Concrete is a mixture of cement, water and aggregates, which consolidates into a hard mass due to chemical reaction between cement and water. Each of the four ingredients has its separate function. Coarse aggregates act as filler. Fine aggregates fill in the voids in the coarse aggregates and cement and water form the binder. The science of proportioning of concrete is therefore mainly concentrated on the principle of obtaining a durable and strong concrete at the most economical rate. It is obvious that a properly designed concrete mix for certain requirements of strength should have the minimum possible cement content to make the mix economical.

2.1.2 WATER-CEMENT RATIO.

It is the ratio of weight or volume of water used for mixing (correction of absorption by aggregates should be made), to weight or volume of cement in the concrete mixture. It may also be expressed as so many gallons of water per cwt. of cement Since volume of cement is a variable term depending upon the manner in which a volumetric measure is filled, it is now common to express the water cement ratio on weight basis. Prof. D. Abrams discovered that the strength of concrete is solely governed by the amount of water used in making the concrete and is independent of the ratio of cement to aggregates provided the concrete is workable. The results of thousands of experiments carried out by him with various cement aggregate ratios are shown in Fig. 2-1 from which it will be noted that mixes varying from neat cement to **1** : 15 give the same strength. The equation of the curve is :—

$$S=\frac{A}{Bx} \text{ or } \log S=\log A-x\log B$$

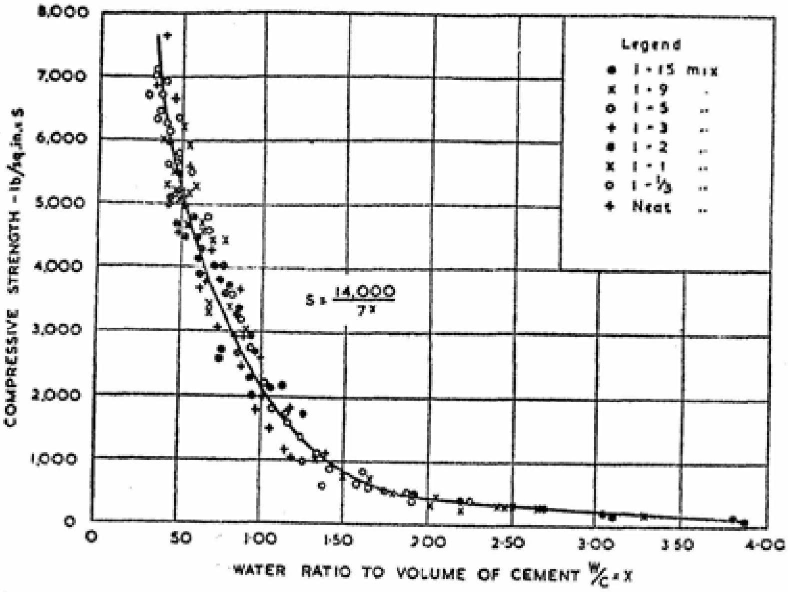
S=compressive strength in lb./sq. inch.

$$x=\frac{\text{Volume of mixing water}}{\text{Volume of cement}}$$

(**Note.**—1 cft. of cement is assumed to weigh 94 lb)

A and *B* are constants depending upon age of concrete, quality of cement and aggregates, climatic conditions, mixing, etc.

For washed and graded gravel, and for workable mix mixed in a machine for one minute, the values of *A* and *B* are : $A = 14000$ and $B = 9$ for 28 days strength (for special control $B = 7$).



Note:—Lean and rich mixtures give same strength for same w/c ratio. The figures represent cylinder strengths, which are three-fourths the corresponding cube strengths approximately.

Fig. 2-1

It should be noted that though the water cement ratio law holds good universally the values of the constants *A* and *B* may vary according to the quality of cement, aggregates, etc. The values of compressive strength as given in curve in Fig. 2-1 are low, compared to present day values, as there is considerable progress in the manufacture of cement. The following values should therefore be used. Where the magnitude of the job permits the values of the constants should be found by actual experiments.

Water-Cement Ratio			Crushing Strength lb./□" @ 7 days	Remarks
Gals/cwt.	By wt.	By volume		
4	.36	.52	5600	mix too
4½	.40	.58	4950	dry for
5	.45	.64	4300	hand com-
5½	.49	.71	3750	paction
6	.54	.77	3250	mix work-
6½	.58	.83	2850	able for
7	.63	.90	2400	hand com-
7½	.67	.96	2120	paction
8	.71	1.03	1850	
8½	.76	1.10	1670	wet mix
9	.80	1.16	1500	

(Note.—The figures are for cube test.)
(One cwt. of cement=1.25 cft.)

2.1.3 WORKABILITY.

It has been defined in the simplest form as ease with which concrete can be mixed, handled, transported and placed. Workability will therefore vary according to the type of mould that is being used for the concrete structure under construction, and the obstruction to the free flow of concrete caused by the spacing and nature of the reinforcement. Rational measure of workability is therefore not easy. A more scientific definition of workability would therefore be that property of concrete which determines the amount of useful internal work required to produce full compaction.

Measurement of Workability.

(a) *Slump test* is very widely used in practice. Sometimes, however, accurate results are not possible by this test due to distorted slumps as shown in figure below. (Fig. 2-2.)

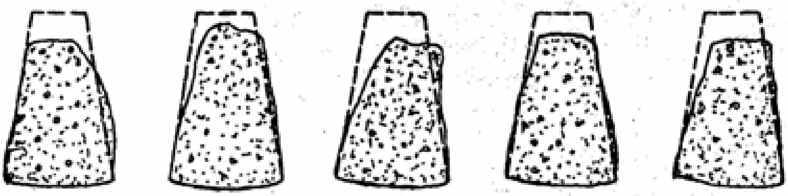


Fig. 2-2. Distorted slump.

(b) *Compacting factor test.*—It is a better test and depends on the definition of workability on basis of internal work as mentioned above. The apparatus used consists of two inverted cone hoppers and a cylindrical container (vide Fig. 2-3).

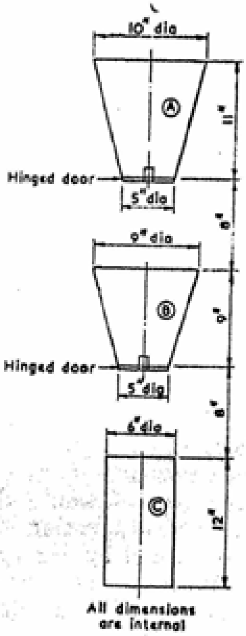


Fig. 2-3

A is filled fully with representative sample of concrete. The hinged door at bottom is opened and concrete falls into B. The hinged door of B is then opened and concrete falls into C from which surplus concrete is struck off with steel floats. The contents of C are then weighed, the weight being say W. C is again filled with the same sample, in 2 inch layers, the concrete being compacted by heavy ramming or vibration, and then weighed, weight being say w. The compacting factor is then W/w.

2.2 Essential Requirements of Concrete.

These are:—

(a) Strength.
(b) Durability.
(c) Resistance to wear.
(d) Water-tightness.
(e) Compactness.
(f) Workability.
(g) Economy.

(a) *Strength.*—The capacity to withstand without injury the stresses developed when being used as a structural material.

(b) *Durability.*—The property of resisting the chemical and physical destructive actions, such as—

(i) Leaching due to lime contents in the cement being dissolved by pure and distilled waters.

(ii) Expansion and contraction resulting from temperature and alternate drying and wetting.

(iii) Freezing and thawing of water sucked in small crevices by capillary action.

(iv) Disintegration by alkaline, acidic or saline waters.

(c) *Resistence to wear.*—Especially in case of pavements and roads.

(d) *Water-tightness.*—Obstructing through passage of water after initial absorption takes place.

(e) *Compactness.*—Is the proportion between the volume of concrete produced and the absolute volume of the aggregates and cement used.

(f) *Workability.*—Ease with which concrete can be handled, transported and placed.

(g) *Economy.*—Is effected by using local aggregates with minimum amount of cement and designing the mix properly to get the specified strength.

2.3 Proportioning of Concrete.

There are various methods of proportioning as given below.

2.3.1 ARBITRARY PROPORTIONS.

The proportions of cement, sand and coarse aggregates are specified as 1 : 2 : 4 ; 1 : 3 : 6, etc., mostly by volume.

2.3.2 SIMPLE VOIDS METHOD.

Voids in the coarse aggregates are to be filled in by the sand and voids in sand are to be filled in by cement paste. Ten per cent extra sand and 15 per cent extra cement paste are provided to allow for additional voids created by wedging action of sand particles on the coarse aggregates and that of cement particles on the sand.

Example.—Design a concrete mix if coarse aggregates and sand have 43% and 32% voids respectively.

Sand required for 100 cft. of coarse aggregate
$= 43 + .43 \times 10 = 47.3$ cft.

Cement paste required
$= (47.3 \times .32) + (47.3 \times .32 \times .15) = 17.406$ cft.

$\therefore$ Dry cement required $= 17.406 \times 1.2 = 20.9$ cft.
$= 20.9$ cft.

$\therefore$ Proportions of cement : sand : coarse aggregate
$= 20.9 : 47.3 : 100$
$= 1 : 2.31 : 4.9$

2.3.3 FINENESS MODULUS METHOD.

2.3.3.1 Object.

The arbitrary mix method described in para 2.3.1 has certain drawbacks, as the exact strength of the arbitrary mix is not known and such mixes are usually uneconomical. It is, therefore, necessary to specify concrete of a stipulated strength, and to work out an economical mix by some rational method. The following paras explain in a simple manner the convenient methods which may be adopted with advantage.

2.3.3.2 Variables in Design of Concrete Mix.

The variables in the design of a mix are :

(a) Water-cement ratio.

(b) Cement content for a unit quantity of concrete.

(c) Workability, grading of aggregates, and proportions of fine and coarse aggregates.

2.3.3.3 Data required for Designing a Concrete Mix.

It is necessary to ascertain the following data before designing a satisfactory concrete mix.

The safe compressive strength of concrete to which a structure is designed is specified and the workability required is also given. As use has to be made of available aggregate, the grading of both coarse and fine aggregates, their weights, their bulking percentage and the water content must be known. These can be easily determined.

2.3.3.4 Relation between the Minimum and Average Crushing Strength.

Table 1 gives the estimated relation between the minimum and average crushing strength of works cubes for different conditions.

This serves as a guide for determining the average strength on which the mix design is to be based when the minimum strength is specified.

2.3.3.5 Water-Cement Ratio.

Table 2 gives the relation between the crushing strength and water-cement ratio for fully compacted concrete using ordinary Portland cement. The water-cement ratio is determined for the average strength.

2.3.3.6 Workability and Slump.

The degrees of workability for various requirements are given in Table 3, and knowing the conditions of work, the required slump is determined from this table.

2.3.3.7 Weight of Cement per 100 cft. of Concrete.

The quantity of cement per 100 cft. of concrete may be determined from Table 4 in which the total quantity of water per 100 cft. of concrete is given. These values divided by the water-cement ratio give the required quantity of cement.

2.3.3.8 Absolute Volumes of Water, Cement and Mixed Aggregates.

The quantity of water and of cement per 100 cft. of concrete being found, the absolute volumes of these two are obtained by dividing the weights by their absolute specific gravities. The absolute volume of mixed aggregate is then 100 minus absolute volumes of water and cement. The absolute specific gravities for cement, fine and coarse aggregates may be taken as 3.15, 2.65 and 2.8 respectively.

2.3.3.9 Determination of Fineness Modulii of Fine and Coarse Aggregates and Calculation of the Proportions of Fine and Coarse Aggregates.

The proportions of coarse and fine aggregates to produce optimum workability is obtained through Fineness Modulus. The fineness modulii of the coarse and of the fine aggregates are determined separately by ascertaining the percentage retained on each of the I.S. sieves.

$$15—30—60—120—240—\tfrac{3}{16}''—3/8''—\tfrac{3}{4}''—1\tfrac{1}{2}''—3''$$

The sum of the percentages retained divided by 100 gives the F.M. Suitable F.M. for mixed aggregates are given in Fig. 2-4 (a) & (b).

The percentage of fine aggregate is obtained from $\frac{F_c—F_m}{F_c—F_f} \times 100$.

Values of F_c and F_f i.e. the F.M. of coarse and fine aggregates respectively, are determined as above and the value of F_m, the F.M. for mixed aggregate, is taken from charts in Fig. 2-4.

2.3.3.10 Absolute Volumes and Weights of Fine and Coarse Aggregates.

Once the proportions of coarse and fine aggregates are determined as explained, the absolute volumes of these aggre-

gates are obtained from these proportions. The weights of the aggregates are determined by multiplying the absolute volumes by absolute specific gravity and the weight of water.

2.3.3.11 Determination of Nominal Mix.

The nominal mix is obtained by dividing the weights of the various components by the weight of cement.

2.3.3.12 Quantity of Mixing Water Required.

In order to determine the quantity of mixing water required per 100 cft. of concrete, the free moisture in the aggregates has to be taken into account ; the free moisture being obtained by multiplying the percentage of water in each aggregate by the weight required for 100 cft. of concrete. This free moisture is to be deducted from the total quantity of mixing water as determined in para 2.3.3.8.

2.3.3.13 Field Mix by Weight.

The field mix by weight is obtained by taking into consideration the free moisture in the aggregates in the nominal mix.

2.3.3.14 Field Mix by Volume.

It is often convenient to prepare a concrete mix by volume, and in such a case, bulking of the aggregates has to be taken into consideration. Bulking is the increase in volume of aggregates due to the presence of water. The method of correction for this item is shown in the example.

2.3.3.15 Quantity of Mixing Water Required per Bag of Cement.

The mixing water required after allowing for the free moisture in the aggregates is easily obtained by dividing the mixing water as obtained in para 2.3.3.12 by the number of bags of cement required per 100 cft. of concrete as determined in para 2.3.3.7.

Table 1

Estimated relation between the minimum and average crushing strengths of works cubes for different works conditions.

Conditions	Minimum strength as percentage of average strength.
Very good control with weigh-batching, constant supervision, etc.	75
Fair control	60
Poor control	40

Table 2

Relation between cube crushing strength and water-cement ratio by weight for fully compacted concrete (ordinary Portland cement).

Water-cement ratio by weight	Cube crushing strength p.s.i. 7 days	28 days
0.35	5,700	7,500
0.40	5,000	6,700
0.45	4,300	6,000
0.50	3,600	5,300
0.55	3,100	4,600
0.60	2,600	4,000
0.65	2,200	3,500
0.70	1,900	3,100
0.75	1,600	2,800
0.80	1,500	2,500

NOTES: 1. Cylinder strength may be taken as 3/4 of cube strength.
2. Strengths at 3 months and 1 year are approximately 25% and 67% greater than the strength at 28 days.

Table 3

Degrees of workability for various requirements.

Degree of workability	Slump in inches	Use for which concrete is suitable.
"Very Low"	0 to 1	Vibrated concrete in roads or other large sections.
"Low"	1 to 2	Mass concrete foundation without vibration. Simple reinforced sections with vibration.
"Medium"	2 to 4	For normal reinforced work without vibration and heavily reinforced sections with vibration.
"High"	4 to 7	For sections with congested reinforcement. Not normally suitable for vibration.

Table 4.

Water content per 100 cft. of concrete for 3″ slump.

Max. size of coarse aggregate	½″	¾″	1″	1½″	2″	3″
Water in lb.						
(a) for rounded coarse aggregate	1241	1149	1111	1037	982	926
(b) for angular coarse aggregate	1333	1241	1204	1122	1074	1019

For each 1″ increase or decrease in slump, increase or decrease the water content by 3 percent.

Fineness modulii of mixed aggregates for different maximum size of aggregates are given by chart in Fig. 2-4, for 3″-4″ and 6″-7″ slump.

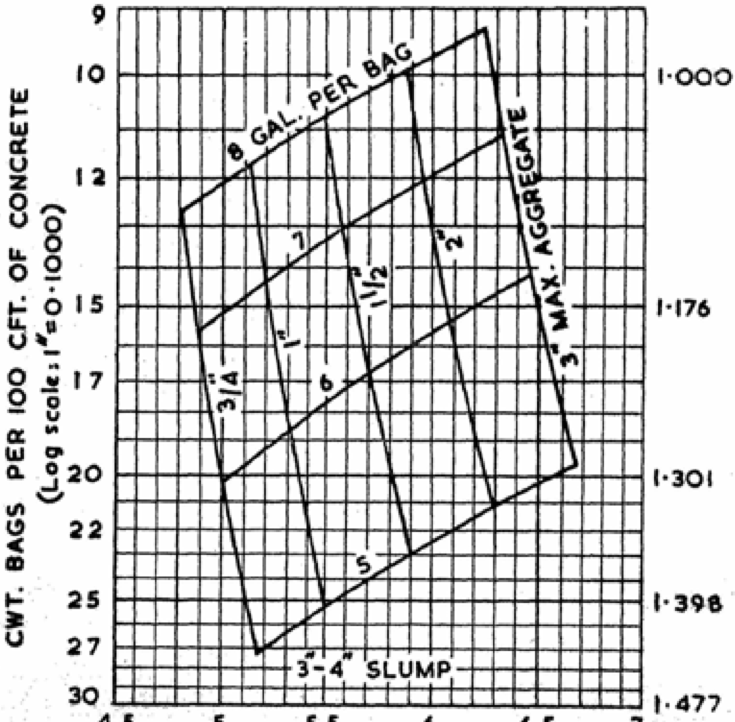


Fig. 2-4 (a)
FINENESS MODULUS OF MIXED AGGREGATES.

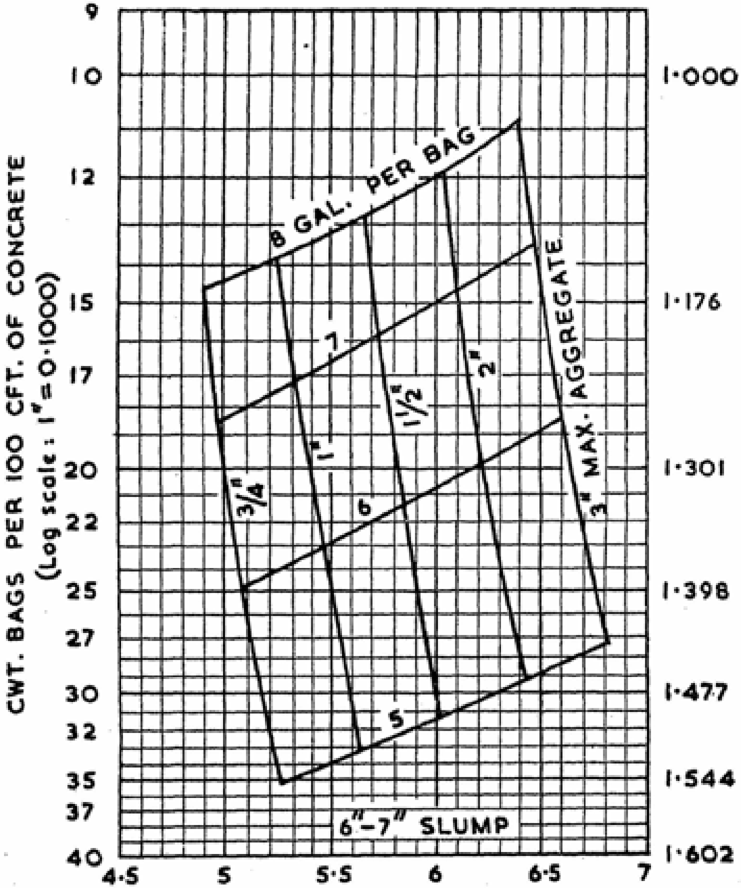


Fig. 2-4 (b)
FINENESS MODULUS OF MIXED AGGREGATE

EXAMPLE

(Paragraph numbers in this example are identical with the paragraph numbers in the text of section 2.3.3.)

3. Data

   3.1 Safe compressive stress—750 lb. per sq. in.

   3.2 Workability—medium

   3.3 Aggregates available

   3.3.1 Coarse aggregates — ¾" gravel (rounded coarse aggregate) with 52% passing ⅜" sieve.

Weight of coarse aggregates	95 lb per cft.
Bulking percentage	2.56
Water content	1%
Specific gravity	2.8.

3.3.2 Fine aggregates % passing

B.S. No. 100 sieve		(15)	4
,, 52	,,	(30)	22
,, 25	,,	(60)	58
,, 14	,,	(120)	76
,, 7	,,	(240)	90
,, 3/16	,,	(480)	100

(Figures in brackets indicate I.S.I. Sieve nos.)

Weight of fine aggregates	105 lb per cft.
Bulking	14.3%
Water content	2%
Sp. gravity	2.65

3.4 Control Fair

4. Average crushing strength $= \frac{750\times 3}{0.6}$ (Refer Table 1)

$= 3{,}750$ p.s.i.

5. Water-cement ratio = 0.62 (Refer Table 2) (i.e. 7 gals/cwt of cement).

6. Slump required = 3″ (Refer Table 3)

7. Determination of the weight of cement per 100 cft. of concrete.

$$\text{Weight of cement per 100 cft. of concrete} = \frac{\text{Total quantity of water per 100 cft. of concrete}}{\text{Water-cement ratio}} \text{ (Refer table 4)}$$

$$= \frac{1149}{0.62}$$

$= 1853$ lb $= 16.6$ bags.

8. Absolute volumes of water, cement and mixed aggregates (*Vide* (c) para 2.3.5)

8.1 Absolute volume of water $= \frac{1149}{62.4} = 18.4$

8.2 Absolute volume of cement $\frac{1853}{3.15\times 62.4} = 9.4$

Absolute volume of water and cement $= 18.4+9.4 = 27.8$ cft.

8.3 Therefore, absolute volume of mixed aggregates $= 100-27.8 = 72.2$ cft.

9. F.M. of fine and coarse aggregates and proportion of fine and coarse aggregates.

9.1 F.M. of coarse aggregate F_c

Sieve	Passing	Retained
3/4"	98%	2%
3/8	52%	48%
3/16	0%	100%
7	0%	100%
14	0%	100%
25	0%	100%
52	0%	100%
100	0%	100%
		650

$$F_c = \frac{650}{100} = 6.50$$

9.2 F.M. of fine aggregate F_f

Sieve	Passing	Retained
100	4%	96%
52	22%	78%
25	58%	42%
14	76%	24%
7	90%	10%
3/16	100%	0%
		250

$$F_f = \frac{250}{100} = 2.50$$

9.3 F.M. of mixed aggregates for ¾" max. size of aggregates, 7 gals of water per bag of cement, 3" to 4" slump and cement content of 16.6 bags per 100 cft. of concrete, 4.90 (Ref. Fig. 2-4a)

9.4 Percentage of fine aggregate=

$$\frac{F_c—F_m}{F_c—F_f} = \frac{6.50—4.90}{6.50—2.50} = \frac{1.6}{4.0} = 40\%$$

9.5 Percentage of coarse aggregate = 100 − 40 = 60%.

10. Absolute volumes and weights of fine and coarse aggregates.

10.1 Absolute volume of fine aggregate=72.2×.40=28.9

10.2 Absolute volume of coarse aggregate=72.2×.60=43.3

10.3 Therefore the weight of fine aggregate per 100 cft. of concrete = 28.9 × 2.65 × 62.4 = 4778 lb

10.4 And weight of coarse aggregate per 100 cft. of concrete= 43.3×2.80×62.4=7567 lb

11. Nominal mix $= \frac{1853}{1853} : \frac{4778}{1853} : \frac{7567}{1853}$

$= 1 : 2.58 : 4.08$

12. Mixing water required per 100 cft. of concrete.

Water content of FA = $4778 \times .02 = 95$ lb

Water content of CA = $7567 \times .01 = 76$ lb

Total water content of FA and CA = 171 lb

Hence mixing water required=1149—171=978 lb=97.8 gallons per 100 cft. of concrete after allowing for moisture in the aggregates.

13. Field mix by weight (taking into consideration weight of water in aggregates)

$$\frac{1853}{1853} : \frac{4778+95}{1853} : \frac{7567+76}{1853}$$

$$1 : 2.63 : 4.13$$

14. Field mix by volume (taking into consideration bulking of materials)

Volume of cement in bags $\frac{1853}{112} = 16.6$ bags

Volume of FA allowing for bulking $= \frac{\text{Wt. of FA per 100 cft. of concrete}}{\text{Wt. of FA per cft.}}$ (1+bulking percentage of FA)

$$= \frac{4778}{105}\left(1 + \frac{14.3}{100}\right) = 52.0 \text{ cft.}$$

Volume of CA after allowing for bulking $= \frac{\text{Wt. of CA per 100 cft. of concrete}}{\text{Wt. of CA per cft.}}$ (1+bulking percentage of CA)

$$= \frac{7567}{95} \times \left(1 + \frac{2.56}{100}\right) = 81.8$$

Field mix by volume is therefore

$$\frac{16.6}{16.6} : \frac{52.0}{16.6} : \frac{81.8}{16.6}$$

1 bag cement: 3.14 cft. sand: 4.93 cft. of coarse aggregate

i.e. 1 : 2.62 : 4.10

This works out to 1 : 2.28 : 4.00 when the aggregates are in the dry state.

15. Quantity of mixing water required per bag of cement after allowing for moisture in the aggregates

$$= \frac{97.8}{16.6} = 5.89 \text{ gallons}$$

The quantity of water required is :

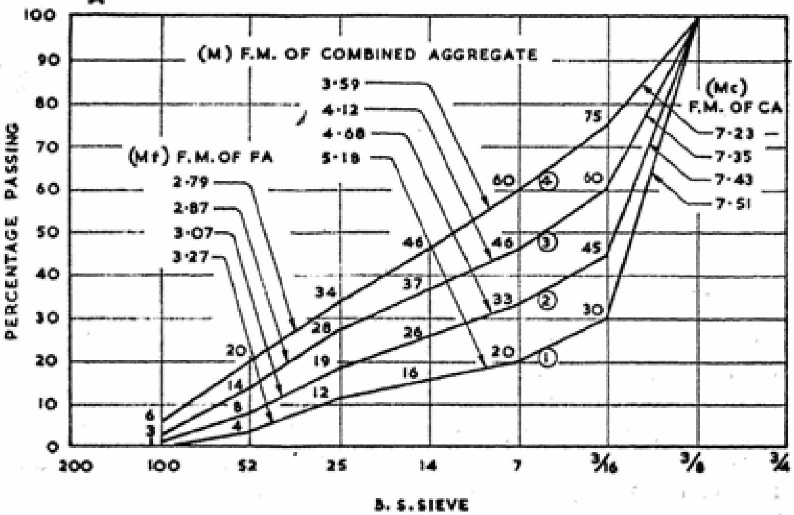
$$= \frac{1149}{16.6} = 6.92 \text{ gallons when the aggregates are in the dry state.}$$

2.3.4 GRADING CURVES METHOD OF PROPORTIONING

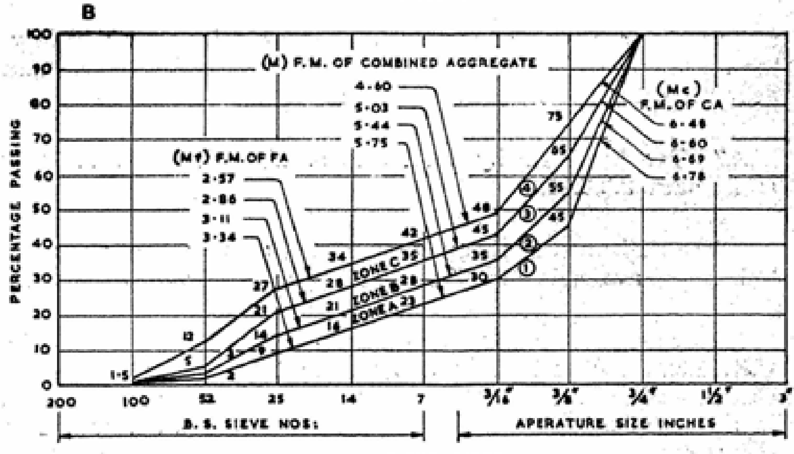
2.3.4.1 In this method, the average crushing strength, water-cement ratio and the degree of workability are determined as in the previous method, use being made of Tables 1, 2 and 3.

2.3.4.2 The aggregate-cement ratio is obtained from Table 6. These ratios are given for ⅜", ¾" and 1½" aggregates and for four different gradings in each case, as depicted in graphs Nos. A, B and C.

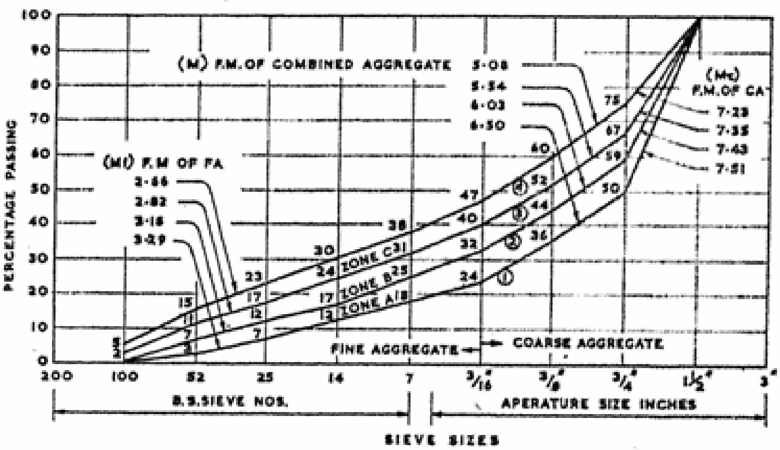
A



B



C



2.3.4.3 Suitable proportions of fine and coarse aggregates are determined from these graphs as illustrated in the second example.

2.3.4.4 The nominal mix is read off from the results obtained in preceding para 2.3.4.3.

2.3.4.5 The field mix by weight is obtained by multiplying the nominal mix proportions by the weight of a bag of cement and adding the weight of free moisture.

2.3.4.6 The quantity of mixing water is obtained by multiplying the water-cement ratio by the weight of a bag of cement and deducting the free moisture in the aggregates.

2.3.4.7 The field mix by volume is obtained in the same way as in para 2.3.3.14.

The limitation of this method is that aggregate-cement ratio Tables are available for ¾″ and 1½″ aggregates only at present.

Table 6 and graphs A and B and C are taken from the U.K. Road Research Laboratory Note No. 4 on "Design of Concrete Mixes", and Tables 1, 2 and 3 are based on data given in the same brochure. Hence B.S. Sieve Nos. are retained in this section.

TABLE No. 6a Aggregate-cement ratio required to give four degrees of workability with different gradings and types of aggregate.

¾ in. Rounded Aggregate.

	Degree of Workability	Very Low				Low				Medium				High			
	Grading of aggregate (Curve No. on Graph B)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Water-cement ratio by weight.	0.35	4.5	4.5	3.5	3.2	3.8	3.6	3.2	3.1	3.1	3.0	2.8	2.7	2.8	2.8	2.6	2.5
	0.40	6.6	6.3	5.3	4.5	5.3	5.1	4.5	4.1	4.2	4.2	3.9	3.7	3.6	3.7	3.5	3.3
	0.45	8.0	7.7	6.7	5.8	6.9	6.6	5.9	5.1	5.3	5.3	5.0	4.5	4.6	4.8	4.5	4.1
	0.50			8.0	7.0	8.2	8.0	7.0	6.0	6.3	6.3	5.9	5.4	5.5	5.7	5.3	4.8
	0.55				8.1			8.2	6.9	7.3	7.3	7.4	6.4	6.3	6.5	6.1	5.5
	0.60								7.7			8.0	7.2		7.2	6.8	6.1
	0.65								8.5				7.8		7.7	7.4	6.6
	0.70															7.9	7.2
	0.75																7.6
	0.80																
	0.85																
	0.90																

TABLE No. 6b ½ in. Irregular gravel aggregate.

Degree of Workability	Very Low				Low				Medium				High			
Grading of aggregate (Curve No. on Graph B)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Water-cement ratio by weight. 0.35	3.7	3.7	3.5	3.0	3.0	3.0	3.0	2.7	2.6	2.6	2.7	2.4	2.4	2.5	2.5	2.2
0.40	4.8	4.7	4.7	4.0	3.9	3.9	3.8	3.5	3.3	3.4	3.5	3.2	3.1	3.2	3.2	2.9
0.45	6.0	5.8	5.7	5.0	4.8	4.8	4.6	4.3	4.0	4.1	4.2	3.9		3.9	3.9	3.5
0.50	7.2	6.8	6.5	5.9	5.5	5.5	5.4	5.0	4.6	4.8	4.8	4.5		4.4	4.4	4.1
0.55	8.3	7.8	7.3	6.7	6.2	6.2	6.0	5.7		5.4	5.4	5.1		4.8	4.9	4.7
0.60	9.4	8.6	8.0	7.4	6.8	6.9	6.7	6.2		6.0	6.0	5.6			5.4	5.2
0.65				8.0	7.4	7.5	7.3	6.8			6.4	6.1			5.8	5.6
0.70					8.0	8.0	7.7	7.4			6.8	6.6			6.2	6.1
0.75								7.9			7.2	7.0			6.6	6.5
0.80											7.5	7.4				7.0
0.85											7.8	7.8				7.4
0.90												8.1				7.7
0.95																8.0
1.00																

TABLE No. 6c ¼ in. Crushed rock aggregate.

Degree of Workability	Very Low				Low				Medium				High			
Grading of aggregate (Curve No. on Graph B)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Water-cement ratio by weight.																
0.35	3.2	3.0	2.9	2.7	2.7	2.7	2.5	2.4	2.4	2.4	2.3	2.2	2.2	2.3	2.1	2.1
0.40	4.5	4.2	3.7	3.5	3.5	3.5	3.2	3.0	3.1	3.1	2.9	2.7	2.9	2.9	2.8	2.6
0.45	5.5	5.0	4.6	4.3	4.3	4.1	3.9	3.7	3.7	3.7	3.4	3.3	3.5	3.5	3.2	3.1
0.50	6.5	5.8	5.4	5.0	5.0	4.9	4.5	4.3	4.2	4.2	3.9	3.8		3.9	3.8	3.5
0.55	7.2	6.6	6.0	5.6	5.7	5.4	5.0	4.8	4.7	4.7	4.5	4.3			4.3	4.0
0.60	7.8	7.2	6.6	6.3	6.3	6.0	5.6	5.3		5.2	4.9	4.8			4.7	4.4
0.65	8.3	7.8	7.2	6.9	6.9	6.5	6.1	5.8		5.7	5.4	5.2			5.1	4.9
0.70	8.7	8.3	7.7	7.5	7.4	7.0	6.5	6.3		6.2	5.8	5.7			5.5	5.3
0.75			8.2	8.0	7.9	7.5	7.0	6.8			6.2	6.1			5.8	5.7
0.80							7.4	7.2			6.6	6.5			6.1	6.0
0.85							7.8	7.6			7.1	6.9			6.4	6.3
0.90											7.5	7.3				6.7
0.95											8.0	7.6				7.0
1.00																7.3

TABLE No. 6d 1½ in. Irregular river gravel aggregate.

Degree of Workability.	Very Low				Low				Medium				High			
Grading of aggregate (Curve No. on Graph C)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Water-cement ratio by weight. 0.35	4.0	3.9	3.5	3.2	3.4	3.3	3.2	2.9	2.9	2.8	2.6	2.5	2.7	2.5	2.3	2.3
0.40	5.3	5.3	4.7	4.3	4.5	4.5	4.2	3.8	3.8	3.8	3.7	3.4	3.5	3.5	3.3	3.1
0.45	6.5	6.5	5.9	5.3	5.6	5.6	5.3	4.8	4.6	4.7	4.6	4.3	4.1	4.4	4.3	4.0
0.50	7.7	7.7	7.1	6.3	6.7	6.6	6.3	5.7	5.4	5.7	5.5	5.1	4.8	5.2	5.1	4.8
0.55			8.1	7.3	7.6	7.6	7.2	6.6	6.2	6.5	6.3	5.8		5.9	6.0	5.5
0.60								7.4	7.0	7.3	7.1	6.6			6.7	6.2
0.65								8.1	7.8	8.1	7.8	7.2			7.3	6.9
0.70												7.9				7.4
0.75																8.0
0.80																

EXAMPLE

(Paragraph numbers in this example are identical with the paragraph numbers in the text of section 2.3.4.)

2.3.4.1 Data.

Safe compressive stress. 750 lb per sq. in.
Workability—Medium.
Aggregates available:

Coarse aggregates	¾" gravel (rounded coarse aggregate) with 40% passing ⅜" sieve.
Weight of C.A.	90 lb per cft.
Bulking percentage	2.56
Water content	1%

Fine aggregates		
% passing	No 100 sieve	2
"	52 "	10
"	25 "	45
"	14 "	67
"	7 "	87
"	$\frac{3}{16}$ "	100

Weight of F.A.	100 lb per cft.
Bulking percentage	14.3
Water content	2%
Control	Fair
Average crushing strength	$= \frac{750 \times 3}{0.6}$ (Refer Table 1)
	=3,750 p.s.i.
Water-cement ratio	=0.62 (Refer Table 2)
Slump required	3" (Refer Table 3)

2.3.4.2 Aggregate-Cement Ratio.

For a medium workability and w/c ratio of 0.62, two different aggregate-cement ratios are obtained from Table 6 as follows, irregular gravel being assumed:

For grading No. 3	....	6.2
" " No. 4	....	5.8

For an economic mix, the aggregate-cement ratio must be as high as possible, i.e., in this case, our grading should approximate to standard grading No. 3 (please refer to graph B).

2.3.4.2 Proportions of Fine and Coarse Aggregates.

The following three trial mixes are prepared :

	Sand	Coarse Aggregate
A	30%	70%
B	35%	65%
C	40%	60%

The sieve analysis of these three mixes is determined and the results are as follows :—

B.S. Sieve	Percentage of material passing sieve		
	Sample containing 30% sand	Sample containing 35% sand	Sample containing 40% sand
No. 100	0.6	0.7	0.7
,, 52	3.0	3.5	4.0
,, 25	13.5	15.75	18.0
,, 14	20.5	23.4	26.8
,, 7	26.0	30.4	34.8
3/16 in.	30.0	36.0	40.0
3/8 in.	58.0	60.0	64.0
3/4 in.	100.0	100.0	100.0

Curves of these gradings are drawn on a tracing paper to the same scale as the optimum grading curves in graph A.

This tracing paper is superimposed on the optimum grading curves to ascertain which of the above three mixes approximates to optimum grading No. 3.

In this case, mix C approximates to optimum grading No. 3, hence, the mix containing 40% sand is suitable.

Hence proportion of sand $= 6.2 \times \frac{40}{100} = 2.48$

and ,, of coarse aggregate $= 6.2 \times \frac{60}{100} = 3.72$

2.3.4.4 Nominal Mix.

Therefore the nominal mix $=$ 1 : 2.48 : 3.72

say $=$ 1 : 2.5 : 3.7

2.3.4.5 Field Mix by Weight.

The quantities of materials required by weight are :

Cement $=112$ lb

Sand $2.5\times112=280$ lb plus weight of free moisture $(.02\times280=5.6)$ $=286$ lb

Gravel $3.7\times112=415$ lb plus weight of free moisture $(.01\times415=4.15)$ $=419$ lb

The field mix by weight is therefore—

$$\frac{112}{112}:\frac{286}{112}:\frac{419}{112} \quad \text{i.e. } 1:2.55:3.74$$

2.3.4.6 Quantity of Mixing Water.

Water $0.62\times112=69.5$—free moisture in sand and coarse aggregate (9.75)

$=59.50$ lb

$=$say 6 gallons

2.3.4.7 Field Mix by Volume.

The quantities of materials required by volume are :

Cement $=1$ bag

Sand $\frac{280}{100}\times1.143$ $=3.2$ cft.

Gravel $\frac{419}{90}\times1.0256$ $=4.75$ cft.

The field mix by volume is therefore 1 bag : 3.2 cft. : 4.75 cft.

2.3.4.8 Remarks.

A slight variation in the mix from the results of the first example may be noted. This is due to the fact that the percentage of sand to gravel by the method of trial and error has been taken as 40 whereas in the first Example, it is calculated to be 40 by the Fineness modulus method.

2.3.5 THE METHOD OF TRIAL MIXES.

(Portland Cement Association, U.S.A.)

In this method also laboratory data on trial concrete mixes made with varying sizes and proportions of aggregates and water content are made use of, in arriving at the proper type of mix for a particular job. Various steps followed in this method are :—

(a) Selection of w/c ratio to get the strength and durability desired.

(b) Selection of slump for desired workability and maximum size of aggregates to be used.

(c) Selection of approximate trial mix for the particular type of aggregates to be used on the job. The total water content and sand to coarse aggregate ratio of this trial mix is used and the exact trial mix for the given aggregates is calculated. If the aggregates as supplied in the field are wet, correction for moisture is made.

(a) W/C RATIOS FOR VARIOUS TYPES OF CONSTRUCTION OR EXPOSURE CONDITIONS

Type or Location of Structure	Severe or Moderate Climate Wide Range of Temperature Hail & Long Freezing Spells					Mild Climate				
	Thin Section		Moderate Section		Heavy Section Mass Concrete	Thin Section		Moderate Section		Heavy Section Mass Concrete
	R.C.C.	Plain	R.C.C.	Plain		R.C.C.	Plain	R.C.C.	Plain	
At the Water Line in Hydraulic Structures Subject to Intermittent Saturation										
In Sea Water	.44	.49	.49	.53	.53	.44	.49	.49	.53	.53
In Fresh Water	.49	.53	.53	.58	.58	.49	.53	.53	.58	.58
Hydraulic Structures away from Water Line but subject to frequent wetting										
By Sea Water	.49	.53	.53	.53	.53	.49	.58	.58	.62	.62
By Fresh Water	.53	.58	.58	.58	.58	.53	.62	.62	.67	.67
Ordinary exposed Structures, Buildings, etc.	.53	.58	.58	.62	.62	.53	.62	.62	.67	.67
Submerged Structures.										
In Sea Water	.53	.58	.58	.62	.62	.53	.58	.58	.62	.62
In Fresh Water	.58	.62	.62	.67	.67	.58	62	.62	.67	.67
Pavement Slabs										
Wearing Slabs	.49	.53				.53	.58			
Base Slabs	.58	.62				.62	.67			

Curves for selecting w/c ratio for particular strength.
(Portland Cement Association's figures.)

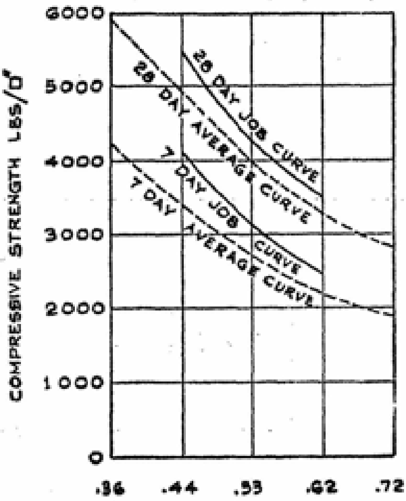


Fig. 2-5

Results of experiments by Indian Railways for compressive strength of Indian cements (Standard Cylinders).

W/c Ratio by weight	.33	.45	.55	.66	.78	.89
Min. Compressive Strength @ 7 days lb/□"	2900	2420	1980	1580	1200	920
Average Comp. Strength @ 7 days lb/□"	3500	3000	2550	2150	1780	1500
Average Comp. Strength @ 28 days taken as 150% Strength @ 7 days	5250	4500	3825	3225	2670	2250

It will be noted that there is slight difference in the figure in the above two as well as those in table in paragraph 2.3.3. Hence the w/c ratio should be selected by judgment for small jobs and for important big jobs actual tests should be made and curves plotted accordingly.

(b) *Slump for particular job* :—To be selected according to nature of work. Maximum size of aggregates to be used will depend on nature of work and should be as per following table :—

Minimum dimension of section in inches	Max. size of aggregate in inches			
	R.C. walls beams & columns.	Unreinforced walls	Heavily reinforced-Slabs.	Lightly reinforced Slabs.
$2\frac{1}{2}$ to 5	$\frac{1}{2}$ to $\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$ to 1	$\frac{3}{4}$ to $1\frac{1}{2}$
6 to 11	$\frac{3}{4}$ to $1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$ to 3
12 to 29	$1\frac{1}{2}$ to 3	3	$1\frac{1}{2}$ to 3	3
30 or more	$1\frac{1}{2}$ to 3	6	3	3 to 6

(c) *Typical trial mixes.*—These are given for medium consistency concrete made with coarse, medium and fine sand and rounded or angular coarse aggregate varying from $\frac{3}{4}''$ maximum size to 2" maximum size. In calculating the quantities of materials it is necessary to use the principle of absolute volume. It is assumed that in, say, 1 cubic yard of compact concrete water occupies all the voids in cement powder. The cement-water paste occupies all the voids in the sand, and mortar of cement and sand in its turn occupies all the voids in the coarse aggregate. Thus the volume of concrete produced by any combination of materials equals the sum of absolute volume of cement and aggregates and the volume of water. The absolute volume of a loose material is the actual total volume of solid matter in all the loose particles and is obtained as follows :—

$$\text{Absolute volume} = \frac{\text{Wt. of loose material}}{\text{Sp. gravity} \times \text{unit wt. of water}}$$

Specific gravities of materials used in concrete are :—

Cement 3.15 ; Sand 2.65 ; Gravel 2.65 ; Trap 2.80 ; Granite 2.70 ; Hard Stone 2.55 ; Lime Stone 2.65 ; and Water 1.0.

SUGGESTED TRIAL MIXES FOR CONCRETE OF MEDIUM CONSISTENCY.

(Slump=3")

FINE SAND. (F.M. 2.2. to 2.6) *Rounded Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of cement	Sand %age of Total	Per Cwt. of Cement		Per Cubic Yard of Concrete				Yield Cubic ft. per Cwt. of Cement
			Sand Lb	Gravel Lb	Water Lb	Cement Cwt	Sand Lb	Gravel Lb	
¾	5	41	200	290	310	6.2	1260	1800	4.35
1	5	36	185	325	300	6.1	1115	1930	4.45
1½	5	32	178	380	280	5.7	1020	2180	4.72
2	5	29	178	430	270	5.4	960	2300	5.05
¾	5½	42	230	320	310	5.6	1310	1810	4.8
1	5½	37	215	362	300	5.4	1170	1985	4.95
1½	5½	33	203	415	280	5.2	1055	2170	5.20
2	5½	30	203	475	270	4.85	985	2320	5.60
¾	6	43	263	345	310	5.2	1360	1800	5.20
1	6	38	245	394	300	5.0	1230	1980	5.35
1½	6	34	232	451	280	4.8	1110	2165	5.65
2	6	31	232	520	270	4.45	1035	2300	6.10
¾	6½	44	292	375	310	4.8	1400	1795	5.65
1	6½	39	275	430	300	4.65	1265	1980	5.85
1½	6½	35	267	495	280	4.38	1170	2160	6.19
2	6½	32	262	560	270	4.10	1080	2300	6.60
¾	7	45	327	400	310	4.45	1460	1775	6.1
1	7	40	304	460	300	4.30	1300	1965	6.3
1½	7	36	292	520	280	4.1	1200	2130	6.5
2	7	33	292	590	270	3.85	1125	2275	7.0
¾	7½	46	361	430	310	4.1	1495	1765	6.6
1	7½	41	332	482	300	4.0	1345	1945	6.7
1½	7½	37	328	560	280	3.8	1240	2115	7.2
2	7½	34	322	625	270	3.6	1160	2260	7.5
¾	8	47	400	334	310	3.85	1540	1750	7.0
1	8	42	370	512	300	3.8	1395	1935	7.2
1½	8	38	357	585	280	3.6	1290	2105	7.5
2	8	38	357	670	270	5.83	1200	2240	8.1

ii FINE SAND (F.M. 2.2 to 2.6) *Angular Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of cement	Sand %age of Total	Per Cwt. of Cement		Per Cubic Yard of Concrete				Yield Cubic ft. per Cwt. of Cement
			Sand Lb	Stone Lb	Water Lb	Cement Cwt	Sand Lb	Stone Lb	
¾	5	46	202	238	335	6.73	1360	1600	4.02
1	5	41	185	268	325	6.55	1210	1755	4.12
1½	5	37	185	310	305	6.22	1150	1925	4.35
2	5	34	185	352	295	5.98	1085	2065	4.60
¾	5½	47	232	262	335	6.13	1420	1605	4.40
1	5½	42	214	298	325	5.96	1280	1775	4.52
1½	5½	38	208	345	309	5.62	1170	1945	4.80
2	5½	35	208	387	295	5.37	1120	2080	5.02
¾	6	48	262	280	335	5.62	1475	1575	4.80
1	6	43	244	321	325	5.46	1330	1755	4.95
1½	6	39	238	369	309	5.20	1240	1920	5.20
2	6	36	238	424	295	4.87	1160	2060	5.55
¾	6½	49	298	304	335	5.2	1520	1580	5.20
1	6½	44	274	345	325	5.04	1380	1740	5.35
1½	6½	40	268	400	309	4.78	1280	1910	5.65
2	6½	37	268	452	295	4.53	1215	2050	5.95
¾	7	50	327	327	335	4.78	1570	1570	5.65
1	7	45	304	369	325	4.70	1430	1735	5.75
1½	7	41	298	428	309	4.45	1325	1910	6.05
2	7	38	298	476	295	4.20	1250	2050	6.42
¾	7½	51	363	345	335	4.45	1615	1540	6.05
1	7½	46	333	393	325	4.36	1460	1715	6.15
1½	7½	42	333	458	309	4.12	1370	1890	6.60
2	7½	39	327	512	295	3.95	1290	2020	6.85
¾	8	52	393	363	335	4.20	1650	1525	6.42
1	8	47	369	417	325	4.12	1520	1715	6.60
1½	8	43	363	482	309	3.86	1405	1865	7.00
2	8	40	363	542	295	3.69	1340	2000	7.32

ii. Medium Sand (F.M. 2.6 to 2.9) *Rounded Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of cement	Sand %age of Total	Per Cwt. of Cement		Per Cubic Yard of Concrete				Yield Cubic ft. per Cwt. of Cement
			Sand Lb	Gravel Lb	Water Lb	Cement Cwt	Sand Lb	Gravel Lb	
¾	5	43	214	280	310	6.2	1330	1740	4.35
1	5	38	196	321	300	6.1	1190	1945	4.45
1½	5	34	190	369	280	5.7	1090	2110	4.72
2	5	31	190	417	270	5.4	1025	2240	5.05
¾	5½	44	244	310	310	5.6	1370	1740	4.80
1	5½	39	226	357	300	5.4	1235	1950	4.95
1½	5½	35	214	405	280	5.2	1115	2115	5.20
2	5½	32	214	464	270	4.9	1045	2260	5.60
¾	6	45	274	333	310	5.2	1425	1735	5.20
1	6	40	256	381	300	5.0	1290	1920	5.35
1½	6	36	244	434	280	4.8	1170	2080	5.65
2	6	33	250	506	270	4.45	1110	2250	6.10
¾	6½	46	310	363	310	4.8	1480	1740	5.65
1	6½	41	292	417	300	4.65	1320	1925	5.85
1½	6½	37	280	476	280	4.38	1220	2080	6.19
2	6½	34	280	542	270	4.10	1150	2230	6.60
¾	7	47	339	387	310	4.45	1510	1725	6.1
1	7	42	321	440	300	4.30	1375	1890	6.3
1½	7	38	310	500	280	4.10	1275	2060	6.5
2	7	35	310	572	270	3.85	1195	2210	7.0
¾	7½	48	381	417	310	4.1	1570	1715	6.6
1	7½	43	352	464	300	4.0	1415	1875	6.7
1½	7½	39	345	542	280	3.75	1305	2050	7.2
2	7½	36	339	607	270	3.6	1225	2190	7.5
¾	8	49	418	434	310	3.85	1610	1680	7.0
1	8	44	387	494	300	3.8	1465	1870	7.2
1½	8	40	374	560	280	3.6	1355	2020	7.5
2	8	37	381	643	270	3.85	1280	2160	8.1

iv. Medium Sand (F.M. 2.6 to 2.9) *Angular Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of cement	Sand %age of Total	Per Cwt. of Cement		Per Cubic Yard of Concrete				Yield Cubic ft. per Cwt. of Cement
			Sand Lb	Stone Lb	Water Lb	Cement Cwt	Sand Lb	Stone Lb	
¾	5	48	208	226	335	6.73	1400	1520	4.02
1	5	43	196	262	325	6.55	1290	1715	4.12
1½	5	39	190	298	305	6.22	1185	1850	4.35
2	5	36	190	345	295	5.98	1120	2030	4.60
¾	5½	49	238	250	335	6.13	1460	1535	4.40
1	5½	44	226	286	325	5.96	1350	1705	4.52
1½	5½	40	333	333	305	5.62	1240	1875	4.80
2	5½	37	375	375	295	5.37	1185	2015	5.02
¾	6	50	274	274	335	5.62	1540	1540	4.80
1	6	45	256	310	325	5.46	1400	1690	4.95
1½	6	41	250	357	305	5.20	1300	1860	5.20
2	6	38	250	411	295	4.87	1220	2000	5.55
¾	6½	51	304	292	335	5.20	1580	1520	5.20
1	6½	46	286	333	325	5.04	1440	1680	5.35
1½	6½	42	280	387	305	4.78	1340	1850	5.65
2	6½	39	280	440	295	4.53	1270	2000	5.95
¾	7	52	339	316	335	4.78	1625	1510	5.65
1	7	47	316	357	325	4.70	1480	1680	5.75
1½	7	43	310	417	305	4.45	1380	1855	6.05
2	7	40	316	470	295	4.20	1325	1975	6.42
¾	7½	53	375	333	335	4.45	1670	1485	6.05
1	7½	48	352	381	325	4.36	1535	1665	6.15
1½	7½	44	352	440	305	4.12	1445	1810	6.60
2	7½	41	345	494	295	3.95	1360	1950	6.85
¾	8	54	411	345	335	4.20	1725	1540	6.42
1	8	49	381	400	325	4.12	1570	1640	6.60
1½	8	45	381	470	305	3.86	1470	1820	7.00
2	8	42	381	524	295	3.69	1410	1935	7.32

v. Coarse Sand (F.M. 2.9 to 3.2) *Rounded Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of cement	Sand %age of Total	Per Cwt. of Cement		Per Cubic Yard of Concrete				Yield Cubic ft. per Cwt. of Cement
			Sand Lb	Stone Lb	Water Lb	Cement Cwt	Sand Lb	Stone Lb	
¾	5	45	220	274	310	6.4	1370	1700	4.35
1	5	40	208	310	300	6.1	1260	1870	4.45
1½	5	36	202	357	280	5.7	1155	2040	4.72
2	5	33	202	405	270	5.4	1090	2175	5.05
¾	5½	46	256	298	310	5.6	1440	1675	4.80
1	5½	41	238	339	300	5.4	1300	1855	4.95
1½	5½	37	226	393	280	5.2	1180	2045	5.20
2	5½	34	232	446	270	4.9	1130	2175	5.60
¾	6	47	286	321	310	5.2	1490	1675	5.20
1	6	42	268	369	300	5.0	1350	1860	5.35
1½	6	38	262	424	280	4.8	1250	2020	5.65
2	6	35	262	488	270	4.45	1165	2170	6.10
¾	6½	48	321	345	310	4.8	1540	1650	5.65
1	6½	43	304	400	300	4.65	1400	1840	5.85
1½	6½	39	298	464	280	4.38	1300	2030	6.19
2	6½	36	298	524	270	4.10	1225	2160	6.60
¾	7	49	357	369	310	4.45	1590	1640	6.1
1	7	44	333	428	300	4.30	1430	1835	6.3
1½	7	40	321	482	280	3.10	1320	1985	6.5
2	7	37	321	554	270	3.85	1240	2140	7.0
¾	7½	50	400	400	310	4.1	1640	1640	6.0
1	7½	45	369	446	300	4.0	1490	1800	6.7
1½	7½	41	363	524	280	3.75	1375	1980	7.2
2	7½	38	357	590	270	3.60	1290	2130	7.5
¾	8	51	435	417	310	3.85	1680	1610	7.0
1	8	46	405	476	300	3.80	1530	1800	7.2
1½	8	42	393	542	280	3.60	1420	1960	7.5
2	8	39	400	625	270	3.85	1340	2100	8.1

vi. COARSE SAND (F.M. 2.9 to 3.2) *Angular Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of cement	Sand %age of Total	Per Cwt. of Cement		Per Cubic Yard of Concrete				Yield Cubic ft. per Cwt. of Cement
			Sand Lb	Stone Lb	Water Lb	Cement Cwt	Sand Lb	Stone Lb	
¾	5	50	220	220	335	6.73	1480	1480	4.02
1	5	45	202	250	325	6.55	1325	1640	4.12
1½	5	41	203	290	305	6.22	1260	1810	4.25
2	5	38	199	328	295	5.98	1190	1960	4.60
¾	5½	51	250	238	335	6.13	1535	1460	4.40
1	5½	46	232	275	325	5.96	1385	1635	4.52
1½	5½	42	232	322	305	5.62	1310	1810	4.80
2	5½	39	232	364	295	5.37	1250	1950	5.02
¾	6	52	280	262	335	5.62	1575	1475	4.8
1	6	47	268	296	325	5.46	1460	1625	4.95
1½	6	43	262	346	305	5.20	1360	1800	5.20
2	6	40	263	398	295	4.87	1280	1940	5.55
¾	6½	53	316	280	335	5.20	1640	1460	5.20
1	6½	48	290	322	325	5.04	1500	1620	5.35
1½	6½	44	294	368	305	4.78	1400	1795	5.65
2	6½	41	298	430	295	4.53	1350	1920	5.95
¾	7	54	350	296	335	4.78	1680	1425	5.65
1	7	49	328	346	325	4.70	1540	1625	5.75
1½	7	45	327	398	305	4.45	1455	1775	6.05
2	7	42	330	452	295	4.20	1400	1900	6.42
¾	7½	55	394	322	335	4.45	1750	1430	6.05
1	7½	50	229	229	325	4.36	1585	1585	6.15
1½	7½	46	366	430	305	4.12	1520	1765	6.60
2	7½	43	362	475	295	3.95	1430	1880	6.85
¾	8	56	423	384	335	4.20	1775	1400	6.42
1	8	51	398	380	325	4.12	1640	1570	6.60
1½	8	47	400	452	305	3.86	1540	1750	7.00
2	8	44	400	506	295	3.69	1475	1870	7.32

Note.—The preceding tables apply to concrete of 3 inches slump and made with natural sand. For concrete with different slump and made with stone sand the following adjustment should be made before using the tables :—

(1) Increase or decrease water content by 3% for each increase or decrease of 1 inch in slump.

(2) For stone sand increase percentage of sand by about 3 and water content by about 15 lb per cubic yard of concrete. For less workable concrete as in pavements decrease percentage of sand by about 3 and water content by 8 lb per cubic yard of concrete.

Example.

An illustrative example will make the procedure clear. A reinforced concrete structure of thin section is to be exposed to fresh water in a severe climate where freezing and thawing takes place. The strength of concrete required is 3,750 lb/sq. in. The coarse aggregate to be used is gravel 1½" downwards carrying free moisture of 1%. The fine aggregate consists of natural sand of fineness modulus 2.5 with free moisture of 3%. The specific gravities of both are 2.65. The slump required for the concrete is 4".

W/c ratio from table on page 54 = .49, i.e., say 5½ gals./cwt.
—do.— graph on page 55 = .55

Take the lower figure of .49.

Approximate trial mix from page 57 is

1 cwt. of cement : 203 lb of sand : 415 lb of gravel.

The percentage of sand will be about 33 and 280 lb of water will be required per cubic yard of concrete.

From these assumptions we shall find out the correct trial mix for 4" slump since the table gives figures for 3" slump. Water required for 4" slump $= 1.03 \times 28.0 = 29.0$ gallons.

Cement required per cubic yard of concrete

$$\frac{29.0}{5.5} = 5.3 \text{ cwt say } 5.4 \text{ bags}$$

% age of sand given in the table is 33

$$\text{absolute volume of cement} = \frac{5.4 \times 110}{3.15 \times 62.3} = 3.07 \text{ cft.}$$

$$\text{volume of water required} = \frac{29.0}{6.23} = 4.70 \text{ cft.}$$

$\therefore$ volume of cement paste $= 7.77$ cft.
$\therefore$ absolute volume of aggregates $= 27 - 7.77 = 19.23$ cft.
$\therefore$ absolute volume of sand $= .33 \times 19.23 = 6.35$ cft.
$\therefore$ wt. of surface dry sand $= 6.35 \times 2.65 \times 62.3$
$= 1048$ lb
absolute volume of gravel $= .67 \times 19.23 = 12.90$ cft.
$\therefore$ weight of surface dry gravel $= 12.90 \times 2.65 \times 62.3$
$= 2130$ lb

and so for each bag of cement (110 lb)

we require, $\frac{1048}{5.4} =$ 195 lb of sand and

$\frac{2130}{5.4} =$ 394 lb of gravel

Since the sand and gravel are wet we must take

$$195 + \frac{3}{100} \times 195 = 195 + 6 = 201 \text{ lb of wet sand}$$

and $$394 + \frac{1}{100} \times 394 = 394 + 4 = 398 \text{ lb of wet gravel}$$

The water to be added to

the mix will be $5.5 - \frac{6+4}{10}$ gallons

$= 4.5$ gallons.

Corrected field mix for trial is

1 bag of cement (110 lb net)

201 lb of sand

398 lb of gravel and

4.50 gallons of water

CHAPTER 3

LOADS, BENDING MOMENTS AND SHEARING FORCES

CONTENTS

CHAPTER 3

LOADS, BENDING MOMENTS AND SHEARING FORCES

3.1 Dead Loads.

(I) WEIGHTS OF MATERIALS:

(a) Bituminous substances:

	lb/cft.
Asphaltum	60 to 80 (240 gallons= 1Ton)
Coal anthracite	97
„ bituminous	84
„ lignite	78
„ peat	47
„ charcoal light	23
„ „ heavy	33
„ coke	75
Graphite	31
Paraffin	56
Petroleum (crude)	55
„ (refined)	50
Pitch	69
Tar bituminous	75

(b) Excavated materials:

Clay dry	63
„ damp plastic	110
Clay and gravel dry	110
Earth dry loose	76
„ „ packed	95
„ moist loose	78
„ „ packed	96
„ mud flowing	108
„ „ packed	115
Riprap	80 to 90
Sand gravel dry loose	90 to 105
„ packed ..	100 to 120
„ wet.. ..	118 to 120

(c) Liquids:

	lb/cft.
Alcohol	49
Acids muriatic	75
,, nitric	94
,, sulphuric	112
Oils vegetable	58
,, mineral	57
Petroleum	55
Gasoline	42
Water fresh	62.4
,, sea	64.0
Ice	57

(d) Minerals and building stones:

Asbestos	153
Barytes	281
Basalt	184
Bauxite	159
Chalk	137
Clay marl	137
Copper ore (pyrites)	262
Dolomite..	181
Granite	175
Hematite	325
Gypsum	159
Hornblende	187
Limestone marble	165
Lead ore (galena)	465
Magnesite	187
Porphyry	172
Pumice	40
Quartz	165
Sandstone	175
Soapstone	169
Lime (ore)	253
Cement	90
Lime (slaked)	36

(e) Metals:

Aluminium	165
Brass	534
Bronze	509

	lb/cft.
Chromium	428
Copper	556
Gold	1205
Iron (pig)	450
,, (wrought)	485
,, (steel)	490
Lead	706
Magnesium	109
Manganese	456
Mercury	848
Nickel	545
Platinum	1330
Silver	656
Tin	459
Tungsten	1180

(f) Timber :

Anjan (Ternimatia Tomentosa)	53-60
Anjan (Hardwickia Binata)	82
Babul (Acacia Arabica)	54
Bambu	71
Cocoanut	57-70
Cedar (white)	22
Deal (yellow)	27
Fir	25-30
Hirda	32
Jambul	47
Kalamb (styphegyne paroifolia)	42
Khair (acacia catechu)	66
Mango	42
Oak (white)	46
Pine (red)	30
Sissue (Tali)	50
Tamarind	79
Teak	41-45
Walnut	38

(g) Solids (miscellaneous) :

Bricks	100
Bakelite	80-120
Carbon	129
Cork	15
Ebony	76

	lb/cft.
Glass (common)	160
Paper	60
Phosphorus	114
Porcelain	150
Resin	67
Rubber	58
Silicon	155
Sulphur	128
Wax	60

(h) Stored material:

Animal food	64
Alum	106
Ashes	40
Bagging (jute)	7
Beans (canned)	43
Boiled oil	59
Books (on shelves)	40
,, bulk	60
Butter	59
Camphor	62
Candles	32
Carpets	12
Celluloid	84-100
,, goods	10
Chains	160
Chocolate	34
Cigarettes (cases)	15
Cloth	30
Cloves bales	20
Cocoanut oil	58
Coffee bags	28-32
,, beans	40
Cotton raw compressed	25-36
,, pressed	17
,, piece goods	25-30
,, seed bags	43
Cutlery cases	37
Drugs cases	26
Dyes	28
Eggs (crates)	22
Fancy goods mixed	12
Files (cases)	56
Flour sacks	40

	lb/cft.
Fruit (dry)	60
Glycerine (drums)	50
Grain barley	39
„ oats	26
„ rye	45
„ maize	47
„ rice bags	50
„ wheat	49
Ground nuts (bags)	39
Hemp	20
Honey	90
Hoisery (cased)	14
Ice	57
Jaggery	56
Jute bales	30
Linen goods	35
Machinery cases	28
Manila ropes	32
Milk	64
„ cases	38
„ powder	23
Oilcake bags	41
Paint aluminium	70
„ bituminous	70
„ red lead	195
„ zinc	150
Paper	60
Perfumery (cases)	28
Rags (baled)	13
Rope	42
Rubber cases	25
„ raw	50
Salt bulk	60
„ bags	45
Silk	25
Silk piece goods	18
Soap (boxed)	57
Soft drinks cases	27
Starch	59
Sugar bags	45-50
Tea chests	22
Tobacco packets	18
Wine bulk	61
Wine bottles in cases	37
Wool bales	20
Woollen piece goods	22

(ii) WEIGHTS OF STRUCTURAL ITEMS:

		lb/cft.
Concrete reinforced	.. ..	144
with 1% steel	.. ..	148
2% ,,	.. ..	151
5% ,,	.. ..	161
Concrete:	plain	140
	with brick aggregate	120
	breeze	70 to 90
	lime	120
	pumice	50 to 55
	sawdust	70
	aerated or cell ..	16

			lb/sft.
Flooring:	cork	1" thick	2
	fibre board	,,	$1\frac{1}{2}$
	granolithic	,,	12
	hardwood $\frac{7}{8}$" in mastic		4
	macadam tar 1" thick		11
	terrazzo	,,	12

		lb/cft.
Masonry:	ashlar	165
	rubble	150
	dry rubble	130
	brick	120

		lb/sft.
Partitions:	9" brickwork ..	90
	3" breeze	24
	2" hollow block ..	9
	3" ,, ..	$12\frac{1}{2}$
	4" ,, ..	15
	G. I. sheets ..	3
	lath & plaster ..	8
Clay tile partitions	3" thick	18

			lb/sft.
Asbestos cement flat sheets		$\frac{1}{4}$" thick	$2\frac{1}{4}$
Plaster:	lime	1" thick	9
	cement	,,	11
	gypsum	,,	7

		lb/sft.
Roofing :	asbestos sheet ¼″ thick	3½
	asbestos sheet roofing complete	10
	bituminous felt ..	1½
	boarding soft wood ¾″ thick	2
	G.I. sheets 24 G ..	1
	,, ,, 18 G ..	2
	G.I. sheet roofing complete with purlins etc. ..	4
	Ruberoid 5 layers ..	1¾
	shingles	1½
	slates 1.5″ thick ..	7
	tiling clay	8½
	,, Mangalore with battens..	14
	,, single country with battens..	14
	,, double country with battens..	24
	thatching 9″ including frame	10
	,, 6″ including frame	6½

3.2 Live Loads.

(a) INDIAN STANDARDS INSTITUTION.

Live loads on floors.

Loading class No.	Types of floors	Minimum live loads	Alternative minimum live loads	
		lb. per sq. ft. of floor area	Slabs lb. uniformly distributed over span per ft. width	Beams lb. uniformly distributed over span
1	2	3	4	5
40a	Floors for residential purposes including dwelling houses.	40	320	2560
40b	Floors of tenements, hospital wards, bed-rooms and private sitting rooms in hostels, and dormitories.	do.	do.	do.
50	Office floors other than entrance halls, floors, of light workrooms. *Note* : The lower value of 50 psf should be taken where separate storage facilities are provided and the high value of 80 psf should be taken where such provisions are lacking.	50-80	400-640	3200 5120
60	Floors of banking halls, office entrance halls and office floors below entrance halls and reading rooms.	60	480	3840

Loading class No.	Types of floors	Minimum live loads	Alternative minimum live loads	
		lb. per sq. ft. of floor area	Slabs lb. uniformly distributed over span per ft. width	Beams lb. uniformly distributed over span
1	2	3	4	5
80	Shop floors used for the display and sale of merchandise; workrooms generally; floors of class rooms in schools, garages for vehicles not exceeding $2\frac{1}{2}$ tons gross weight; places of assembly with fixed seating, churches, chapels, restaurants, circulation space in machinery halls, power stations, etc. where not occupied by plant or equipment.	80	640	5120
100	Floors of warehouses, workshops, factories and other buildings or parts of building of similar category for light weight loads; office floors for storage and filing purposes; places of assembly without fixed seating (public rooms in hotels, dance halls, waiting halls, etc.).	100	800	6400
150	Floors of warehouses, workshop factories and other buildings or parts of building of similar category for medium weight loads; floor of garages for vehicles not exceeding 4 tons gross weight.	150	For garage floors only 1.5 × max. wheel load but not less than 2000 lb. considered to be distributed over a floor area 2′6″ square.	

Loading class No.	Types of floors	Minimum live loads lb. per sq. ft. of floor area	Alternative minimum live loads Slabs lb. uniformly distributed over span per ft. width	Alternative minimum live loads Beams lb uniformly distributed over span
1	2	3	4	5
200	Floors of warehouses, workshops factories, and other bldgs. of similar category for heavy wt. loads, floors of book stores, roofs and pavement lights over basements projecting under the public footpath.	200		
	Stairs, corridors, landings and balconies not liable to overcrowding.			
	For class 40(a) loading.	40		
	For class 40(b) loading.	60		
	In the case of all others.	100		
	Balconies liable to overcrowding.	100		

Live loads on roofs.

Type	Slope	Imposed loads other than wind and snow	Snow loads
Roofs other than sheeted roofs	Flat, sloping or curved with slope upto and including 10°	30 psf measured on plan subject to a minimum of 200 lb. uniformly distributed over any span of one ft. width of the roof slab and 1600 lb uniformly distributed over this span in the case of all beams.	Where snow is encountered additional allowance of 10 lb. per ft. depth of snow measured on plan.
	Sloping or curved roofs from 10° to 30° and including 30°*	15 psf measured on plan or 200 lb. concentrated load.	do.
	Sloping or curved roofs greater than 30°	nil	do.
Sheeted roofs	Flat, sloping or curved	To provide for loads incidental to maintenance all roof coverings (other than glass) and the supporting structure shall be capable of carrying a load of 180 lb. concentrated on an area of 5 in sq. This load is not in addition to wind load and shall be treated as an occasional load.	do.

* For calculating live loads on curved roof divide the curved portion into not less than four parts and determine live loads on each segment appropriate to the scope of the chords of the segments.

(b) BOMBAY MUNICIPAL BUILDING BYELAWS.

Class No.	Type of building or floor or roof	Slabs and other floor construction per sq. ft. of floor area	Beams, columns, piers, walls and foundations per sq. ft. of floor area
1.	Rooms used for residential purposes: hotel bedrooms: hospital rooms and wards: and corridors	70 lb	60 lb
2.	Offices, floors above entrance floor	100 lb	90 lb
3.	Offices, entrance floor and floors below entrance floor: retail shops and garages for private cars of not more than two tons net weight	100 lb	100 lb
4.	Places of worship: schools: reading rooms: art galleries, and similar uses	100 lb	100 lb
5.	Corridors not provided for in class one: stairs and landings: Assembly hall: Drill halls: Dance halls: Gymnasia: Light workshops:. Public spaces in hotels and hospitals: Theatres: Cinema, Restaurants and Grandstands	Loading to be provided for to be ascertained from the Commissioner, but nor less than— 100 lb	100 lb
6.	Workshops and factories: and garages for motor vehicles other than privates cars of not more than two tons net weight	Loading to be provided for to be ascertained from the Commissioner, but not less than— 150 lb	120 lb
7.	Warehouses: book-stores: stationery stores and the like	Loading to be provided for to be ascertained from the Commissioner, but not less than— 200 lb	200 lb
8.	Flat roofs and roofs inclined at an angle with the horizontal of not more than 20 degress	50 lb	40 lb
9.	Any purpose not herein specified:	Loading to be provided for to be ascertained from the Commissioner.	

(c) B. S. CODE.

Class no. and superimposed Load (lb. per square foot)		30	40	50	60	80	100	150	200
Minimum total Load (lb.)	Slabs (per foot width)	240	320	400	480	640	800	—	—
	Beams	1920	2560	3200	3840	5120	6400	—	—

Residential Buildings	Houses : Not more than two stories, one occupant	Class No. 30
	Other (including flats)	,, ,, 40
	Hospital wards : dormitories	,, ,, 40
	Hotels : Bedrooms and private	,, ,, 40
	sitting-rooms public rooms	,, ,, 100
Commercial Buildings	Offices : Entrance floor and below	,, ,, 60
	Above entrance floor	,, ,, 50
	Storage and filing	,, ,, 100
	Banking halls	,, ,, 60
	Retail shops	,, ,, 80
	Book and stationery stores	,, ,, 200
	Warehouses (dependent on loads)	Class Nos. 100 150, or 200
Industrial Buildings	Workshops and factories (dependent on loads)	,, ,, 100 150 or 200
	Workrooms (general)	Class No. 80
	Light workrooms without storage	,, ,, 50
	Power stations and machinery halls circulation space	,, ,, 80
Places of Assembly	School classrooms	,, ,, 60
	Without fixed seating : dance halls	,, ,, 100
	With fixed seating : churches, restaurants	,, ,, 80

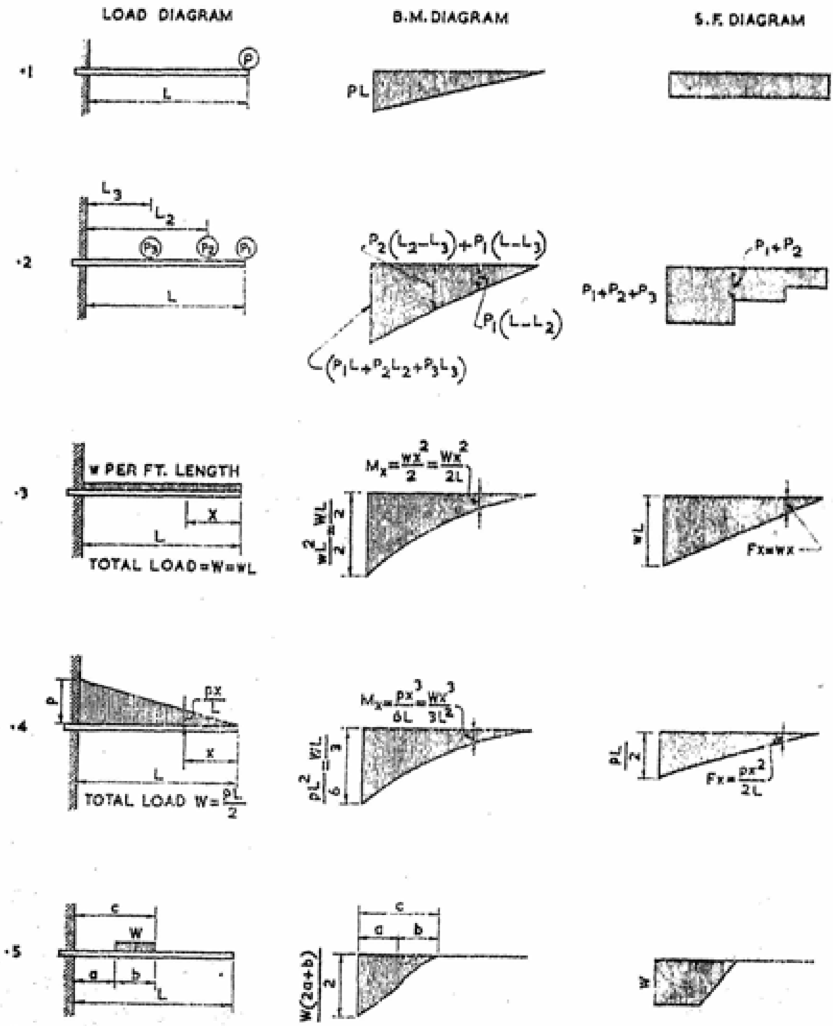
(d) TYPICAL AMERICAN BUILDING CODE.

(Lb. per sq. foot.)

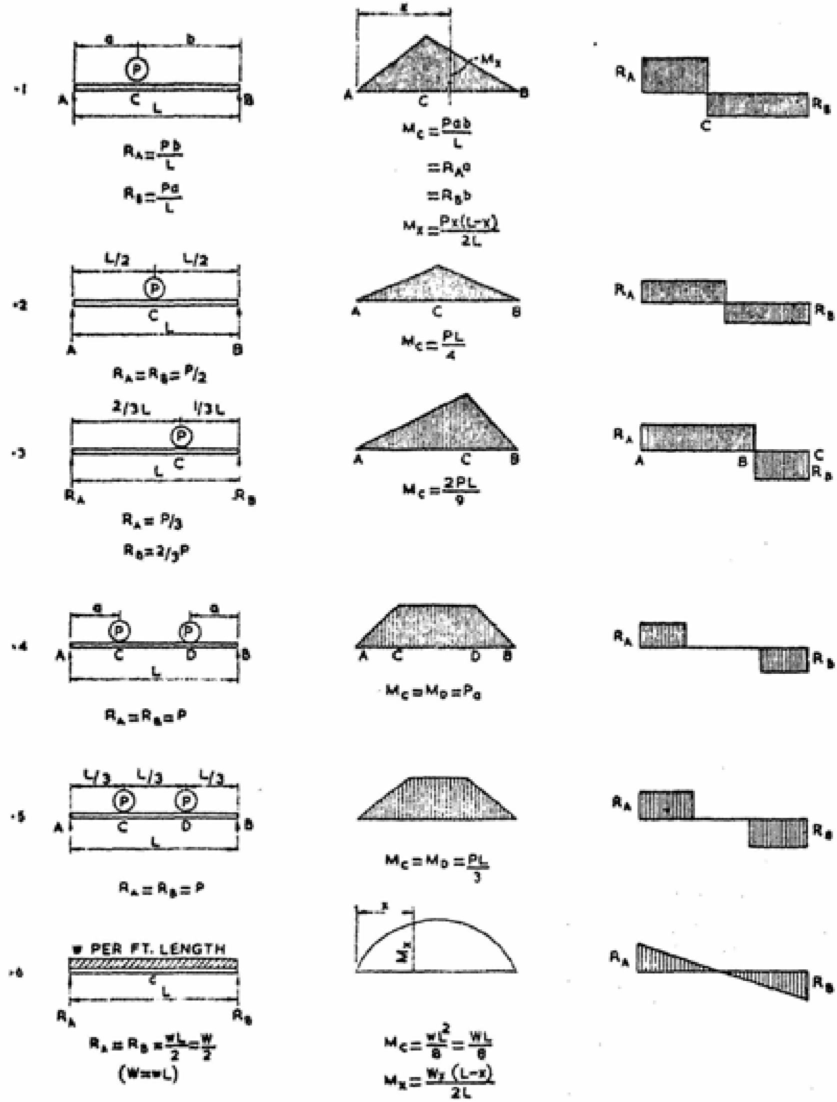
Apartments 40
Auditoriums and theaters :
With fixed seats 50-100
Without fixed seats .. 100
Dwellings 40
Hospitals 40
Hotels :
Rooms 40
Corridors, lobbies, dining rooms 100
Manufacturing buildings :
Light manufacturing .. 75-125
Heavy manufacturing .. 125-200
Office buildings :
Office space 50-60
Corridors, public spaces .. 100-125
Roofs, flat 20-40
School buildings :
Classrooms 40-60
Corridors, public spaces .. 100
Garages :
All types of vehicles .. 100-175
Passenger cars only .. 75-125
Store buildings :
Retail 75-125
Wholesale 100-125
Warehouses :
Light storage 75-150
Heavy storage 200-250

3.3 Diagrams and Formulae for B. Ms. and S. Fs.

3.3.1 CANTILEVERS



3.3.2 SIMPLY SUPPORTED BEAMS



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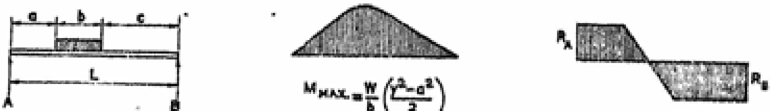


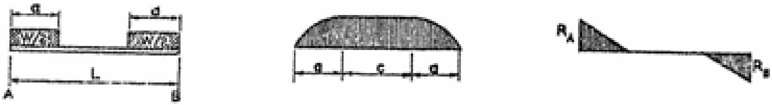
$R_A = \frac{W}{L}\left(\frac{b}{2}+c\right)$

$R_B = \frac{W}{L}\left(\frac{b}{2}+a\right)$

$M_{MAX.} = \frac{W}{b}\left(\frac{y^2-a^2}{2}\right)$

WHERE $y = a + \frac{R_A}{W} b$

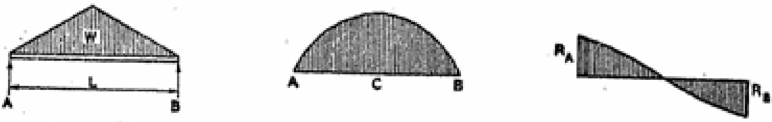
·8



$R_A = W/2 = R_B$

$M_C = \frac{Wa}{4}$

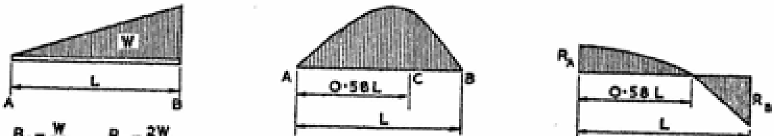
·9



$R_A = R_B = \frac{W}{2}$

$M_C = \frac{WL}{6}$

·10

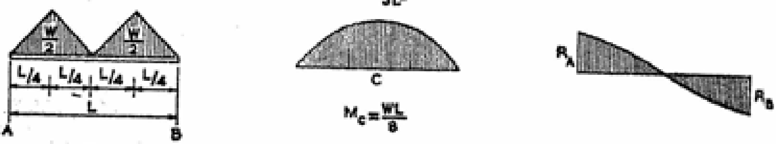


$R_A = \frac{W}{3}$ $R_B = \frac{2W}{3}$

$M_C = \frac{WL}{7 \cdot 8}$

$M_x = \frac{Wx\,(L^2 - x)}{3L^2}$

·11

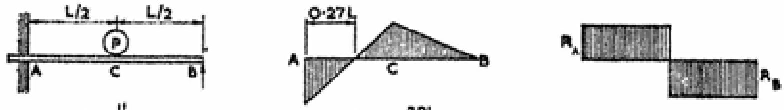


$R_A = \frac{W}{2} = R_B$

$M_C = \frac{WL}{8}$

3.3.3 PROPPED CANTILEVER

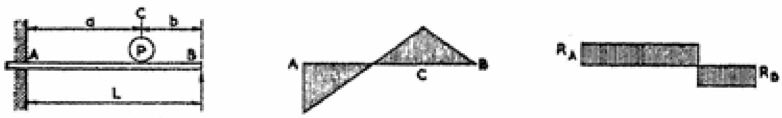
·1



$R_A = \frac{11}{16}P$ $\qquad$ $M_A = -\frac{3PL}{16}$

$R_B = \frac{5}{16}P$ $\qquad$ $M_C = +\frac{PL}{6{\cdot}4}$

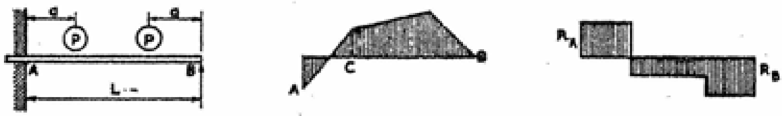
·2



$R_A = \frac{Pb(3L^2 - b^2)}{2L^3}$ $\qquad$ $M_A = -\frac{Pab(L+b)}{2L^3}$

$R_B = \frac{Pa^2(2L+b)}{2L^3}$ $\qquad$ $M_C = +\frac{Pa^2b(2a+3b)}{2L^3}$

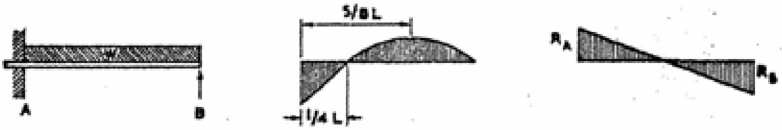
·3



$R_A = \frac{(2L^2 + 3La - 3a^2)P}{2L^2}$ $\qquad$ $M_A = -\frac{3Pa(L-a)}{2L}$

$R_B = \frac{(2L^2 - 3La + 3a^2)P}{2L^2}$ $\qquad$ $M_C = +\frac{Pa(2L^2 - 3La + 3a^2)}{2L^2}$

·4

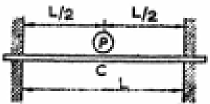


$R_A = 5/8\,W$ $\qquad$ $M_A = -\frac{WL}{8}$

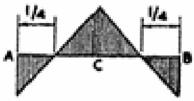
$R_B = 3/8\,W$ $\qquad$ $M_C = +\frac{WL}{14{\cdot}2}$

3.3.4 FIXED END BEAMS

·1

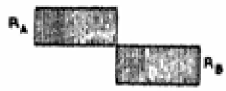


$R_A = R_B = P/2$

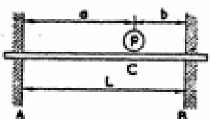


$M_A = M_B = \frac{PL}{8}$

$M_C = \frac{PL}{8}$



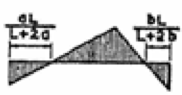
·2



$a > b$

$R_A = \frac{Pb^2(L+2a)}{L^3}$

$R_B = \frac{Pa^2(L+2b)}{L^3}$



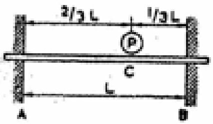
$M_A = \frac{Pab^2}{L^2}$

$M_B = \frac{Pa^2b}{L^2}$

$M_C = \frac{2Pa^2b^2}{L^3}$

$M_{MAX.} = MB$

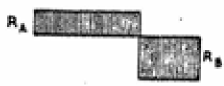
·3



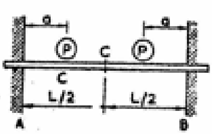
$M_A = \frac{PL}{13{\cdot}5}$

$M_B = \frac{PL}{6{\cdot}75}$

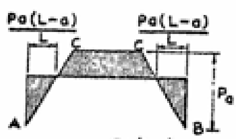
$M_C = \frac{PL}{10{\cdot}2}$



·4

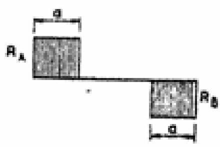


$R_A = R_B = P$

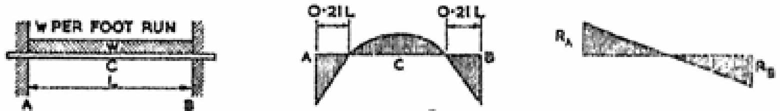


$M_A = M_B = \frac{Pa(L-a)}{L}$

$M_C = \frac{Pa^2}{L}$



·5

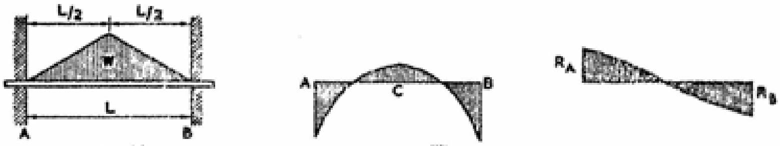


$R_A = \frac{wL}{2} = \frac{W}{2} = R_B$

$M_A = M_B = -\frac{wL^2}{12} = -\frac{WL}{12}$

$+M_C = \frac{wL^2}{24} = +\frac{WL}{24}$

·6

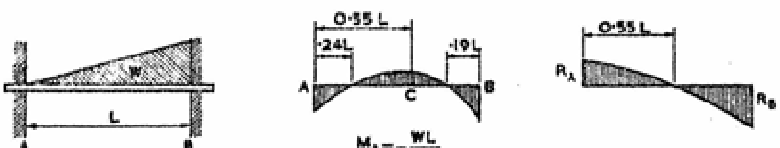


$R_A = R_B = \frac{W}{2}$

$M_A = M_B = -\frac{WL}{9{\cdot}6}$

$M_C = +\frac{WL}{16}$

·7



$R_A = \frac{3W}{10}$

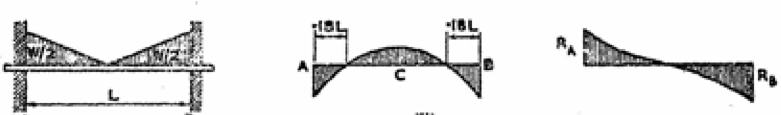
$R_B = \frac{7W}{10}$

$M_A = -\frac{WL}{15}$

$M_B = \frac{WL}{10}$ (MAX.)

$M_C = \frac{WL}{23}$

·8



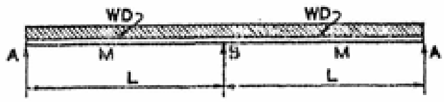
$R_A = R_B = \frac{W}{2}$

$M_A = M_B = \frac{WL}{16}$

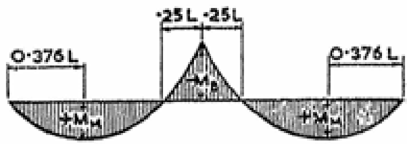
$M_C = +\frac{WL}{48}$

3.3.5 TWO EQUAL SPANS

·1

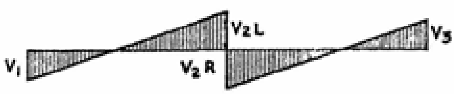


W_D=TOTAL DEAD LOAD ON ONE SPAN



$M_M = +0{\cdot}07\, W_D L$

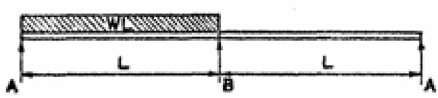
$M_B = -0{\cdot}125\, W_D L$



$V_1 = 3/8\, W_D = V_3$

$V_2L = V_2R = 5/8\, WD$

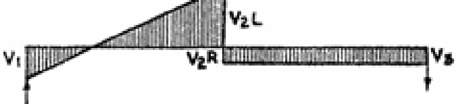
·2



WL=TOTAL LIVE LOAD ON ONE SPAN

$M_M = +0{\cdot}096\, W_L L$

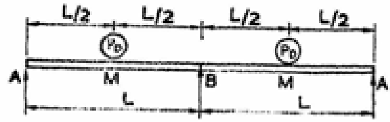
$M_B = -0{\cdot}0625\, W_L L$



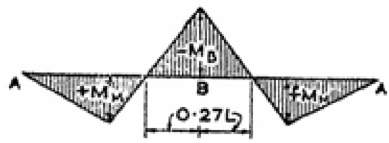
$V_1 = \frac{7}{16} W_L$ $\qquad$ $W_2R = \frac{1}{16} W_L$

$V_3 = \frac{1}{16} W_L$ $\qquad$ $W_2 = \frac{9}{16} W_L$

·3



P_D = CONCENTRATED DEAD LOAD ON CENTRE OF EACH SPAN



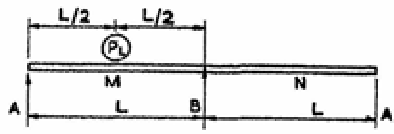
DEAD LOAD MOMENTS

$M_M = +0{\cdot}156 P_D L$ $\quad$ $M_B = -0{\cdot}188 P_D L$

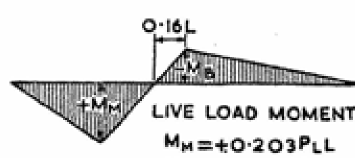
DEAD LOAD SHEARS

$V_1 = 0{\cdot}312 P_D = V_3$ $\quad$ $V_2L = V_2R = 0{\cdot}688 P_D$

·4



P_L = CONCENTRATED LIVE LOAD ON CENTRE OF ONE SPAN

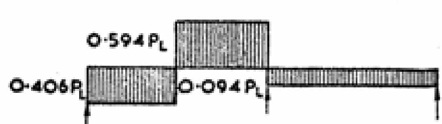


LIVE LOAD MOMENTS

$M_M = +0{\cdot}203 P_L L$

$M_B = -0{\cdot}094 P_L L$

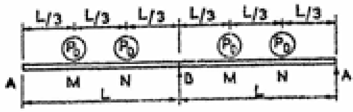
$M_N = +0{\cdot}047 P_L L$



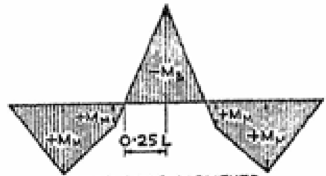
LIVE LOAD SHEAR

$V_1 = 0{\cdot}406 P_L$ $\quad$ $V_2L = 0{\cdot}594 P_L$

$V_3 = -0{\cdot}094 P_L$ $\quad$ $V_2R = 0{\cdot}094 P_L$

·5 

P_D = CONCENTRATED DEAD LOAD AT 3RD POINT OF EACH SPAN

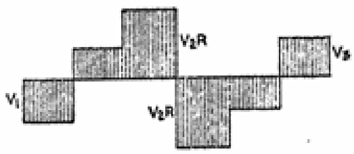


DEAD LOAD MOMENTS

$M_M = 0{\cdot}222\, P_D L$

$M_N = 0{\cdot}111\, P_D L$

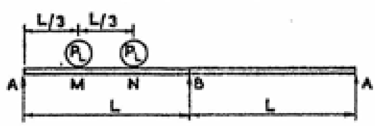
$M_B = -0{\cdot}333\, P_D L$



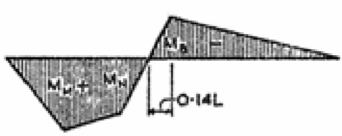
DEAD LOAD SHEARS

$V_1 = V_3 = 0{\cdot}667\, P_D$

$V_2L = V_2R = 1{\cdot}333\, P_D$

·6 

CONCENTRATED LIVE LOADS AT 3RD POINTS OF ONE SPAN ONLY

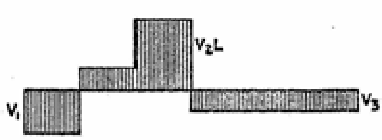


LIVE LOAD MOMENTS

$M_M = 0{\cdot}277\, P_L L$

$M_N = 0{\cdot}222\, P_L L$

$M_B = 0{\cdot}167\, P_L L$



LIVE LOAD SHEAR

$V_1 = 0{\cdot}833\, P_L$

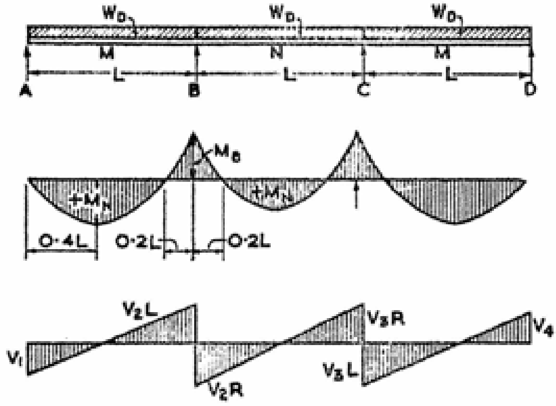
$V_2L = 1{\cdot}167\, P_L$

$V_3 = -0{\cdot}167\, P_L$

3.3.6 THREE EQUAL SPANS

ALL SPANS UNIFORMLY LOADED

·1



W_D=TOTAL DEAD LOAD ON ONE SPAN

DEAD LOAD MOMENTS

$M_M = +0{\cdot}08\,W_D L$

$M_N = +0{\cdot}025\,W_D L$

$M_B = -0{\cdot}1\,W_D L$

DEAD LOAD SHEARS

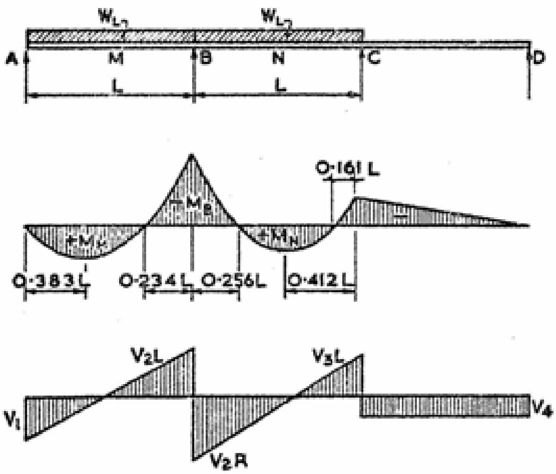
$V_1 = V_4 = 0{\cdot}4\,W_D$

$V_2L = V_3L = 0{\cdot}5\,W_D$

$V_2R = V_3R = 0{\cdot}6\,W_D$

TWO ADJACENT SPANS LOADED

·2



W_L=TOTAL LIVE LOAD ON ONE SPAN

LIVE LOAD MOMENTS

$M_M = +0{\cdot}0735\,W_L L$

$M_N = +0{\cdot}0535\,W_L L$

$M_B = -0{\cdot}117\,W_L L$

$M_C = -0{\cdot}033\,W_L L$

LIVE LOAD SHEARS

$V_1 = 0{\cdot}383\,W_L$

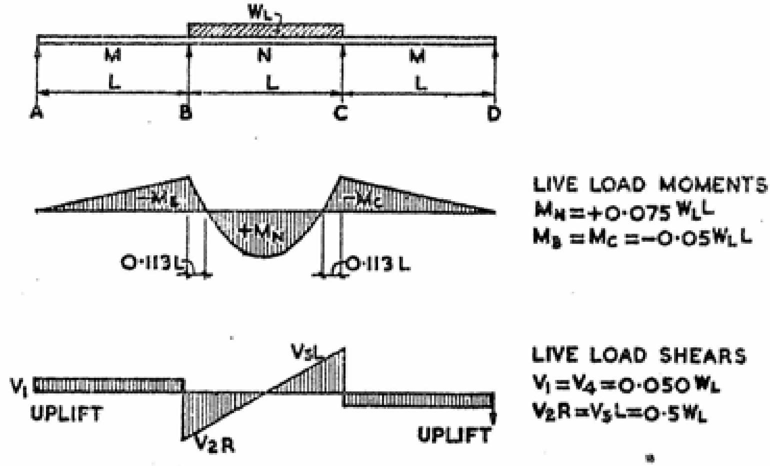
$V_2R = 0{\cdot}617\,W_L$

$V_2L = 0{\cdot}583\,W_L$

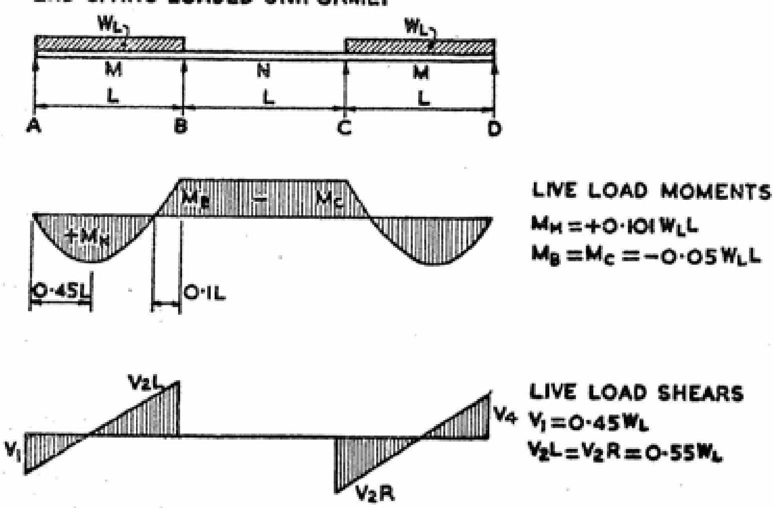
$V_3L = 0{\cdot}417\,W_L$

$V_4 = 0{\cdot}033\,W_L$

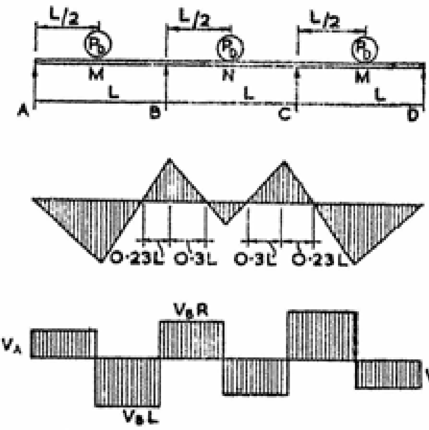
CENTRAL SPAN LOADED UNIFORMLY

·3 

END SPANS LOADED UNIFORMLY

·4 

·5



DEAD LOAD MOMENTS

$M_M = +0{\cdot}175\ P_D L$

$M_B = -0{\cdot}15\ P_D L$

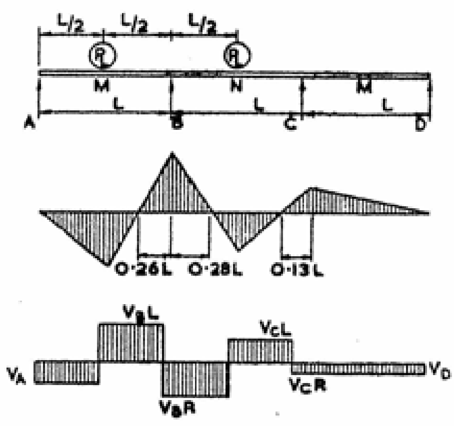
$M_N = +0{\cdot}10\ P_D L$

$V_A = 0{\cdot}35\ P_D = V_D$

$V_B L = 0{\cdot}65\ P_D$

$V_B R = 0{\cdot}50\ P_D$

·6



LIVE LOAD MOMENTS

$M_M = +0{\cdot}162\ P_L L$

$M_N = +0{\cdot}138\ P_L L$

$M_B = -0{\cdot}175\ P_L L$

$M_C = -0{\cdot}05\ P_L L$

$V_A = 0{\cdot}325\ P_L$

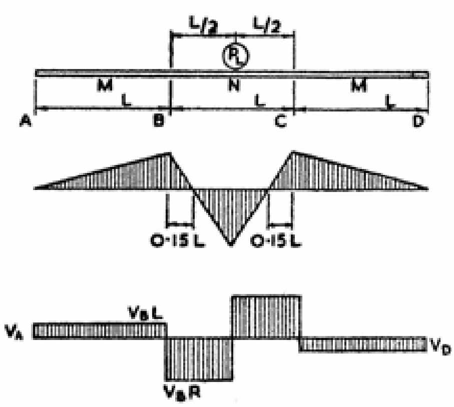
$V_B L = 0{\cdot}675\ P_L$

$V_B R = 0{\cdot}625\ P_L$

$V_C L = 0{\cdot}375\ P_L$

$V_C R = 0{\cdot}05\ P_L = V_D$

·7



$M_B = -0{\cdot}075\ P_L L$

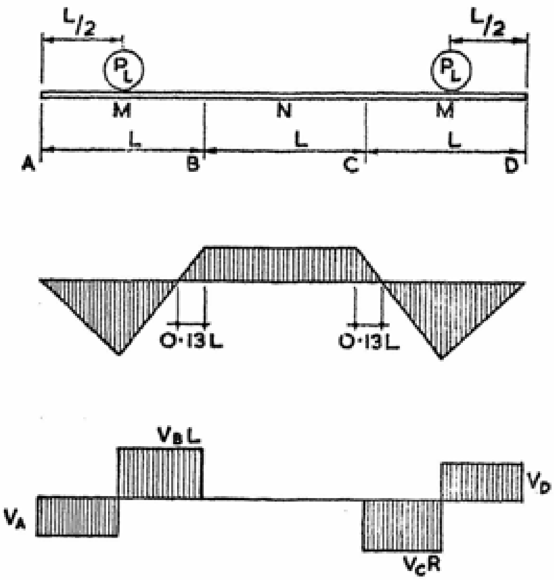
$M_N = +0{\cdot}175\ P_L L$

$V_A = 0{\cdot}075\ P_L L = V_D$

$V_B L = 0{\cdot}075\ P_L = V_C R$

$V_B R = 0{\cdot}5\ P_L = V_C L$

·8



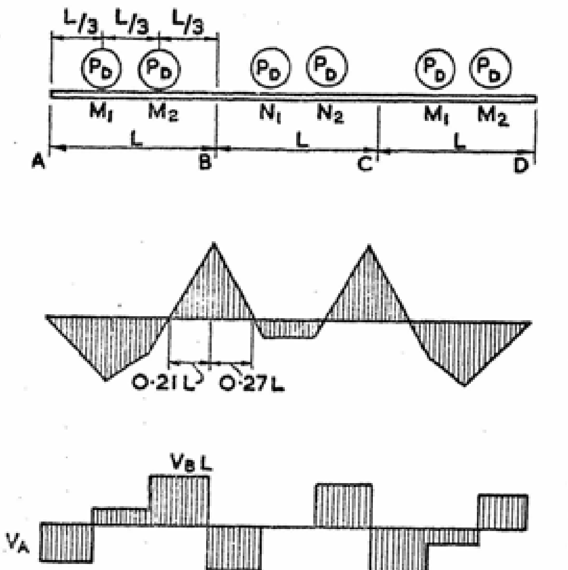
$M_M = +0·212\ P_L L$

$M_B = -0·075\ P_L L$

$V_A = 0·425\ P_L = V_D$

$V_B L = 0·575\ P_L = V_C R$

·9



$M_{M_1} = +0·245\ P_D L$

$M_{M_2} = +0·156\ P_D L$

$M_B = -0·267\ P_D L$

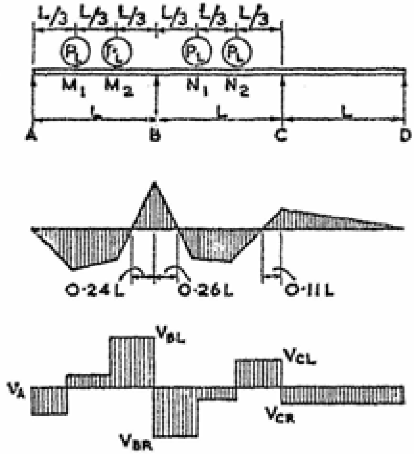
$M_{N_1} = +0·0667\ P_D L$

$V_A = 0·73\ P_D$

$V_B L = 1·27\ P_D$

$V_B R = 1·00\ P_D$

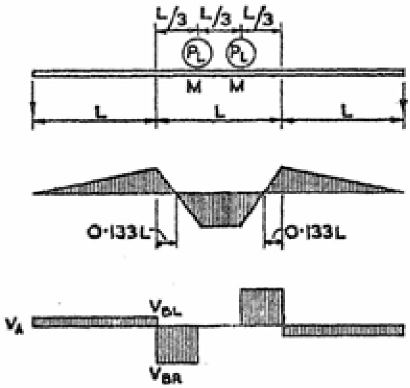
·10



$M_{M1} = +0{\cdot}229\ P_L L$
$M_{M2} = +0{\cdot}126\ P_L L$
$M_B = -0{\cdot}311\ P_L L$
$M_{N1} = +0{\cdot}096\ P_L L$
$M_{N2} = +0{\cdot}170\ P_L L$
$M_C = -0{\cdot}089\ P_L L$

$V_A = 0{\cdot}689\ P_L$
$V_{BL} = 1{\cdot}311\ P_L$
$V_{BR} = 1{\cdot}222\ P_L$
$V_{CL} = 0{\cdot}778\ P_L$
$V_{CR} = 0{\cdot}089\ P_L$

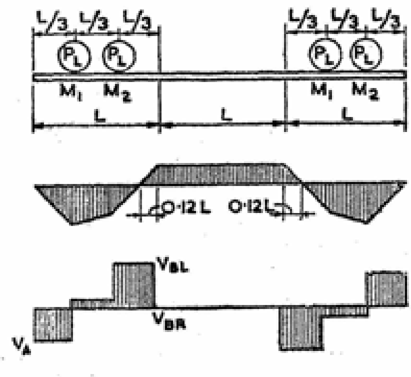
·11



$M_B = -0{\cdot}133\ P_L L$
$M_{M1} = +0{\cdot}2\ P_L L$

$V_A = 0{\cdot}133\ P_L$
$V_{BL} = 0{\cdot}133\ P_L$
$V_{BR} = 1{\cdot}0\ P_L$

·12



$M_{M1} = +0{\cdot}289\ P_L L$
$M_{M2} = +0{\cdot}245\ P_L L$
$M_B = -0{\cdot}133\ P_L L$

$V_A = 0{\cdot}867\ P_L$
$V_{BL} = 1{\cdot}133\ P_L$
$V_{BR} = 0{\cdot}00\ P_L$

3.4 BM CHARTS FOR SLABS AND BEAMS

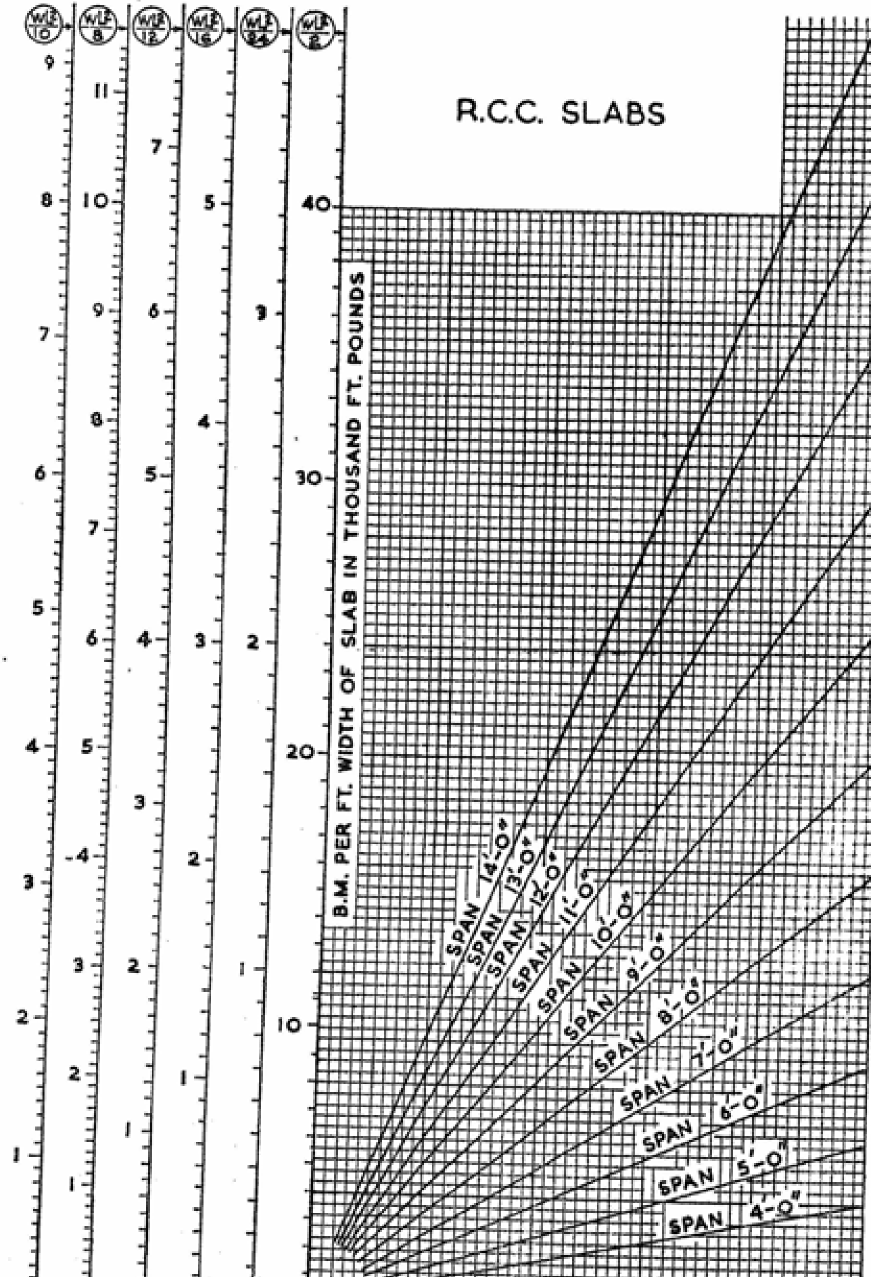


Fig. 3.1 BMs in varying spans of slabs with various loadings.

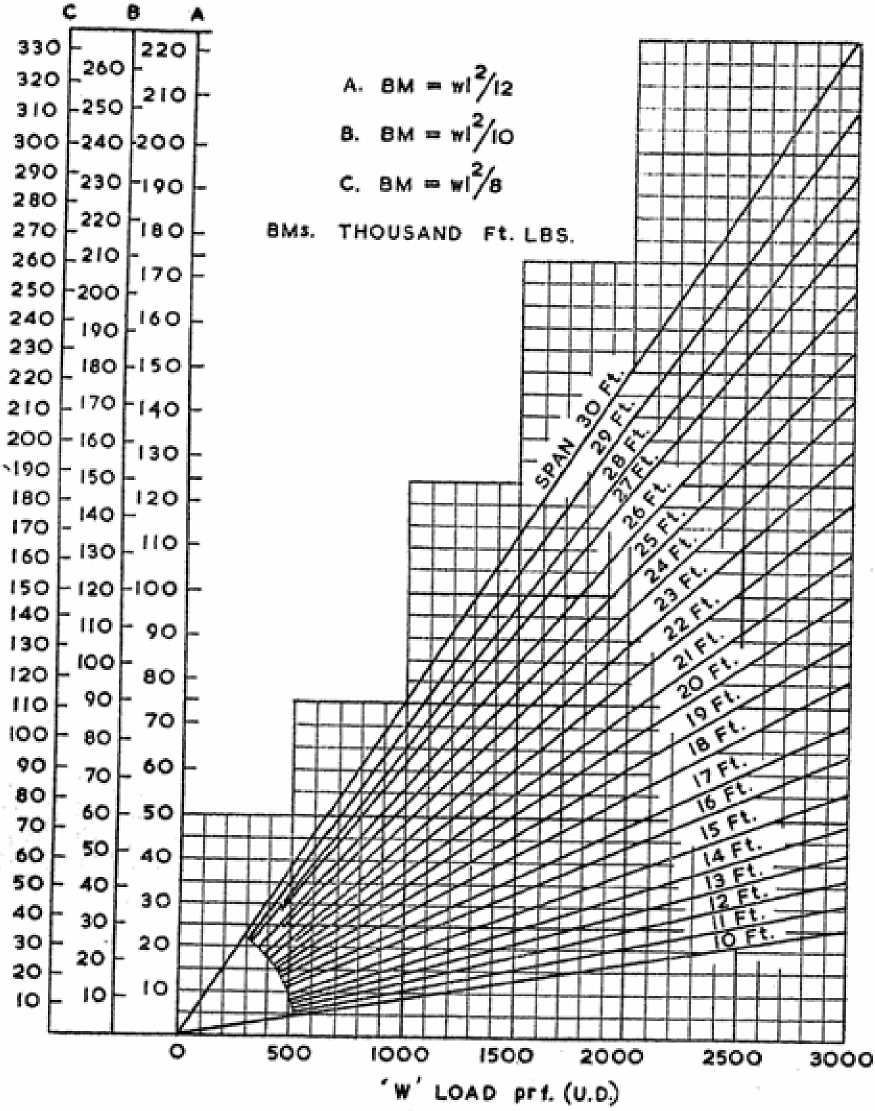


Fig 3.2 BMs in varying spans of beams with various loadings.

TABLE 3-a

Bending moments (in pound feet) for slabs of varying spans with various loadings.

L \ W		40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500
	$wl^2/8$	80	120	160	200	240	280	320	360	400	440	480	520	560	600	640	680	720	760	800	840	880	920	960	1000
4	$wl^2/10$	64	96	128	160	192	224	256	288	320	352	384	416	448	480	512	544	576	608	640	672	704	736	768	800
	$wl^2/12$	53.33	80	106.7	133.3	160	186.7	213.3	240	266.7	293.3	320	346.7	373.3	400	426.7	453.3	480	506.7	533.3	560	586.7	613.3	640	666.7
	$wl^2/8$	125	187.5	250.0	310.5	375	437.5	500	562.5	625	687.5	750	812.5	875	937.5	1000	1062.5	1125	1187.5	1250	1312.5	1375	1437.5	1500	1562.5
5	$wl^2/10$	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250
	$wl^2/12$	83.33	125	166.7	208.3	250	291.7	333.3	575	416.7	458.3	500	541.7	583.3	625	666.7	708.3	750	791.7	833.3	875	916.6	958.3	1000	1041.7
	$wl^2/8$	180	270	360	450	540	630	720	810	900	990	1080	1170	1260	1350	1440	1530	1620	1710	1800	1890	1980	2070	2160	2250
6	$wl^2/10$	144	216	288	360	432	504	576	648	720	792	864	936	1008	1080	1152	1224	1296	1368	1440	1512	1584	1656	1728	1800
	$wl^2/12$	120	180	240	300	360	420	480	540	600	660	720	780	840	900	960	1020	1080	1140	1200	1260	1340	1380	1440	1500
	$wl^2/8$	245	367.5	490	612.5	735	857.5	980	1102.5	1225	1347.5	1470	1592.5	1715	1837.5	1960	2082.5	2205	2327.5	2450	2572.5	2695	2817.5	2940	3062.5
7	$wl^2/10$	196	294	392	490	588	686	784	882	980	1078	1176	1274	1372	1470	1568	1666	1764	1862	1960	2058	2156	2254	2352	2450
	$wl^2/12$	163.2	245	326.6	408.3	490	571.6	653.3	735	816.6	898.3	979.9	1061.6	1143.2	1224.9	1306.6	1388.2	1469.9	1551.6	1633.2	1714.9	1796.5	1878.2	1959.8	2041.5
	$wl^2/8$	320	480	640	800	960	1120	1280	1440	1600	1760	1920	2080	2240	2400	2560	2720	2880	3040	3200	3360	3520	3680	3840	4000
8	$wl^2/10$	256	384	512	640	768	896	1024	1152	1280	1408	1536	1664	1792	1920	2048	2176	2304	2432	2560	2688	2816	2944	3072	3200
	$wl^2/12$	213.33	320	426.6	533.3	640	746.6	853.2	960	1066.6	1173.2	1280	1386.6	1493.2	1600	1706.7	1813.3	1920	2026.6	2133.3	2240	2346.7	2453.3	2559.9	2666.5
	$wl^2/8$	405	607.5	810	1012.5	1215	1417.5	1620	1822.5	2025	2227.5	2430	2632.5	2835	3037.5	3240	3442.5	3341.3	3847.5	4050	4252.5	4455	4657.5	4860	5062.5
9	$wl^2/10$	324	486	648	810	972	1134	1296	1458	1620	1782	1944	2106	2268	2430	2592	2754	2916	3078	3240	3402	3564	3726	3888	4050
	$wl^2/12$	270	405	540	675	810	945	1080	1215	1350	1485	1620	1755	1890	2025	2160	2295	2430	2545	2700	2835	2970	3105	3240	3375
	$wl^2/8$	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250	4500	4750	5000	5250	5500	5750	6000	6250
10	$wl^2/10$	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600	3800	4000	4200	4400	4600	4800	5000
	$wl^2/12$	333.3	500	666.6	833.3	1000	1166.6	1333.3	1500	1666.6	1833	1999.9	2166.6	2333.2	2500	2666.7	2833.3	3000	3166.6	3333	3499.7	3666	3833	3999.6	4166.5
	$wl^2/8$	605	907.5	1210	1512.5	1815.5	2117.5	2420	2722.5	3025	3327.5	3630	3932.5	4235	4537.5	4840	5142.5	5445	5747.5	6050	6352.5	6655	6957.5	7260	7562.5
11	$wl^2/10$	484	726	968	1210	1452	1694	1936	2178	2420	2662	2904	3146	3386	3630	3872	4114	4356	4598	4840	5082	5324	5566	5808	6050
	$wl^2/12$	403.3	605	806.6	1008.3	1210	1411.6	1613.2	1815	2016.6	2218.2	2420	2621.6	2923.2	3025	3226.7	3428.3	3630	3831.6	4033	4234.7	4436.3	4638	4839.6	5041.5
	$wl^2/8$	720	1080	1440	1800	2160	2520	2880	3240	3600	3960	4320	4480	5080	5400	5760	6120	6480	6880	7200	7560	7920	8280	8640	9000
12	$wl^2/10$	576	864	1152	1440	1728	2166	2304	2592	2880	3168	3456	3744	4032	4320	4608	4896	5184	5472	5760	6048	6286	6624	6912	7200
	$wl^2/12$	480	720	960	1200	1440	1680	1920	2160	2400	2640	2880	3120	3360	3600	3840	4080	4320	4560	4800	5040	5280	5520	5760	6000
	$wl^2/8$	845	1267.5	1690	2112.5	2535.0	2957.5	3380	3802.5	4225	4647.5	5070	5492.2	5915.0	6337.5	6760	7182.5	7635	8027.5	8450	8872	9295	9717.5	10140	10562.5
13	$wl^2/10$	676	1014	1352	1690	2028	2366	2704	3042	3380	3718	4056	4394	4732	5070	5408	5746	6084	6322	6760	7098	7436	7774	8112	8450
	$wl^2/12$	563.33	845	1126.7	1408.3	1690	1971.6	2253.3	2535	2816.6	3098.3	3379.9	3661.6	3943.3	4225	4560.7	4788.3	5070	5351.7	5633.3	5915	6196.6	6478.3	6760	7041.5
	$wl^2/8$	976	1464	1952	2440	2928	3416	3904	4392	4880	5368	5856	6344	6832	7320	7808	8296	8784	9272	9760	10248	10736	11224	11712	12200
14	$wl^2/10$	784	1176	1568	1960	2352	2744	3136	3528	3920	4312	4704	5096	5488	5880	6272	6664	7076	7448	7840	8232	8624	9016	9408	9800
	$wl^2/12$	653.3	980	1306.6	1633	1960	2286.6	2613.3	2940	3266.7	3593.3	3920	4246.7	4573.3	4900	5226.6	5555.3	5880	6206.6	6533.3	6860.0	7186.6	7513.3	7840	8166.7

L = SPAN IN FEET   W = LOAD PER SQ. FOOT

TABLE 3-b.

Bending moments for beams of varying spans with various loadings.

$$M = \frac{WL}{12}$$

W \ L	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1000	8333	10083	12000	14083	16333	18750	21333	24083	27000	30083	33333	36750	40333	40083	48000	52083	56333	60750	65333	70083	75000	1000
1100	9466	11166	13200	15491	17999	20625	23466	26481	29700	33091	36667	40425	44366	48491	52800	57291	61966	66825	71866	77091	82500	1100
1200	10000	12100	14400	16900	19600	22500	25600	28900	32400	36100	40000	44100	48400	52900	57600	62500	67600	72900	78400	84100	90000	1200
1300	10833	13108	15600	18308	21233	24375	27733	31308	35100	39108	43333	47775	52433	57308	62400	67708	73233	78975	84933	91108	97500	1300
1400	11666	14116	16800	19716	23266	26250	29866	33716	37800	42116	46667	51450	56466	61716	67200	72916	78866	85050	91466	98116	105000	1400
1500	12500	15125	18000	21125	24500	28125	32000	36125	40500	45125	50000	55125	60500	66125	72000	78095	84500	91125	97900	105125	112500	1500
1600	13333	16133	19200	22533	26133	30000	34133	38533	43200	48133	53333	58800	64533	70533	76800	83333	90133	97200	104533	112133	120000	1600
1700	14166	17141	20400	23941	27766	31875	36266	40941	45900	51141	56666	62475	68566	74941	81600	88541	95766	103275	110866	119141	127500	1700
1800	15000	18150	21600	25350	29400	33750	38400	43349	48600	54150	60000	66150	72600	79350	86400	93750	101400	109350	117600	126150	135000	1800
1900	15833	19158	22800	26758	31033	35625	40533	45758	51300	57158	63333	69825	76633	83758	91200	98958	107033	115425	124133	133158	142500	1900
2000	16666	20166	24000	28166	32333	37500	42666	48166	54000	60166	66667	73500	80667	88166	96000	104166	112667	121500	130667	140166	150000	2000
2100	17500	21249	25200	29574	33966	39375	44800	50574	56700	63174	70000	77175	84700	92574	100800	109374	118300	127575	137200	147174	157500	2100
2200	18333	22183	26400	30983	35600	41250	46933	52983	59400	66183	73334	80850	88734	96983	105600	114583	123934	133650	143734	154183	165000	2200
2300	19166	23191	27600	32391	37233	43125	49066	55391	62100	69191	76667	84525	92767	101391	110400	119791	129567	139725	150267	161191	172500	2300
2400	20000	24199	28800	33740	39200	45000	51200	57800	64800	72200	80000	88200	96800	105800	115200	125000	135200	145800	156800	168200	180000	2400
2500	20833	25208	30000	35208	40500	46875	53333	60208	67500	75208	83333	91875	100834	110208	120000	130208	140834	151875	163234	175208	187500	2500
2600	21666	26216	31200	36618	42133	48750	55466	62616	70200	78216	86667	95550	104867	114616	124800	135416	146467	157950	169867	182216	195000	2600
2700	22500	27224	32400	38024	43766	50625	57600	65024	72000	81224	90000	90225	108900	118704	129600	140624	152100	164025	176200	189224	202500	2700
2800	23333	28233	33600	39433	45399	52500	59733	67432	75600	84233	93334	102900	112934	123433	134400	145832	157734	170100	182934	196233	210000	2800
2900	24166	29241	34800	40841	47033	54375	61866	69841	78300	87241	96667	106575	116967	127841	139200	151041	163367	176175	189467	203241	217500	2900
3000	25000	30250	36000	42250	49000	56250	64000	72250	81000	90250	100000	110250	121000	132250	144000	156250	169000	182250	196000	210250	225000	3000
3100	25833	31333	37200	43658	50633	58125	66133	74650	83700	93258	103333	113905	125033	136658	148800	161458	174633	188325	202533	217258	232500	3100
3200	26667	32267	38400	45067	52266	60000	68267	77067	86400	96267	106667	117600	129067	141067	153600	166667	180267	194400	209067	224267	240000	3200
3300	27500	33275	39600	46475	53900	61875	70400	79475	89100	99275	110000	121275	133100	145475	158400	181875	185900	200475	215600	231275	247500	3300
3400	28333	34283	40800	47883	55533	63750	72533	81883	91800	102283	113333	124950	137133	149882	163200	177083	191533	206550	222133	238283	255000	3400
3500	29167	35292	42000	49292	57167	65625	74667	84290	94500	105292	116667	128625	141167	154292	168000	182292	197167	212625	228567	245292	262500	3500
3600	30000	36300	43200	50700	58800	67500	76800	86700	97200	108300	120000	132300	145200	158700	172800	187500	202800	218700	235200	252300	270000	3600
3700	30833	37308	44400	52108	60433	69375	78933	89108	99900	111308	123333	135975	149233	163108	173600	192708	208433	224775	241533	259308	277500	3700
3800	31667	38317	45600	53517	62066	71250	81067	91516	102600	113317	126667	139650	153267	167517	182400	197916	214067	230850	248267	266317	285000	3800
3900	32500	39325	46800	54925	62700	73125	83200	93925	105300	117325	130000	143325	157300	171925	187200	203125	219700	236925	254800	273325	292500	3900
4000	33333	40333	48000	56333	69332	75000	85333	96332	108000	120333	133333	147000	161333	176333	192000	208332	225334	243000	261333	280333	300000	4000

W = LOAD IN POUNDS PER RFT. B.M. IN FT. POUNDS. L = SPAN IN FEET.

CHAPTER 4

DESIGN OF R.C.C. SLABS

CONTENTS

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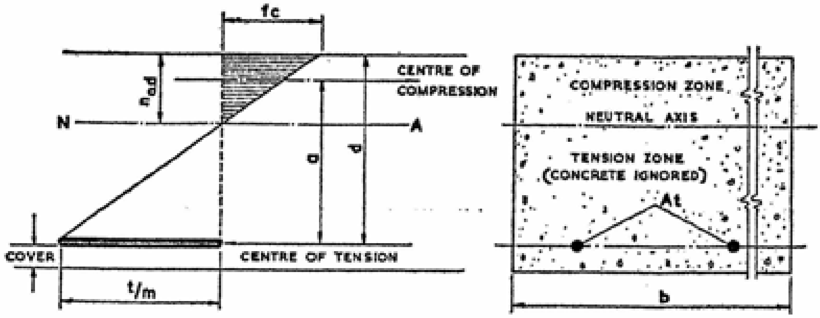
CHAPTER 4

DESIGN OF R.C.C. SLABS

4.1. Design Formulae, Stresses and Constants for Slabs and Rectangular Beams.

4.1.1 NOTATION



fc=permissible compressive unit stress in extreme fibre of concrete. The values adopted in practice for concrete according to different building codes are given in the table in para 4.1.2.1.

t =tensile stress in reinforcement. The values adopted in different building codes are given in table in para 4.1.2.1.

m=modular ratio $\frac{Es}{Ec}$, i.e. $\frac{\text{modulus of elasticity of steel}}{\text{modulus of elasticity of concrete}}$

In most cases, $m = \frac{40{,}000}{3fc}$. In some codes, however, constant value is assumed.

R.M.=Moment of resistance or bending moment in pounds inches.

A_t=Cross-sectional area of reinforcement in tension in sq. inches.

b=breadth of beam or slab in inches.

d=effective depth of beam or slab in inches

n_o=ratio of depth of neutral axis to depth d

a_1=ratio of lever arm of resisting couple to depth d (or j)

a=lever arm or jd

$p = \frac{A_t}{bd}$ = ratio of area of tension steel to effective area of concrete

4.1.2 STRESSES AND DESIGN CONSTANTS.

4.1.2.1 Stresses

	fc	t	m	Ref.
I.S.I. 456/1957 1 : 1 : 2	1150	18000	11.6	(a)
1 : 1½ : 3	950	18000	14	(b)
1 : 2 : 4	750	18000	18	(c)
BOMBAY MUNICIPAL CODE 1 : 1 : 2	950	18000	14	(d)
1 : 1½ : 3	850	18000	16	(e)
1 : 2 : 4	750	18000	18	(f)

Other stresses for which design constants, charts, etc., are given as follows :

	fc	t	m
Ref. (g)	1000	18000	15
Ref. (h)	750	18000	15

4.1.2.2 Constants

.21 Ratio of depth of neutral axis to effective depth.

$$n_o = \frac{mfc}{mfc+t} \text{ or } \frac{1}{1+\frac{t}{mfc}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

n_o=.426 for case a

=.420 „ „ b

=.428 „ „ c

=.420 „ „ d

=.430 „ „ e

=.428 „ „ f

=.450 „ „ g

=.385 „ „ h

The location of the neutral axis is always governed by the stress ratio t/fc and modular ratio m.

The values of n_o for different values of t/fc and m are given in graph No. 4-1.

.22 Ratio of lever arm to effective depth.

$$a_1 = 1 - \frac{n_o}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The values of a_1 for the different codes are as follows :—

a_1 =	.858	for case	a
=	.860	,, ,,	b
=	.857	,, ,,	c
=	.860	,, ,,	d
=	.857	,, ,,	e
=	.857	,, ,,	f
=	.850	,, ,,	g
=	.872	,, ,,	h

.23 Section of reinforcement.

$$A_t = \frac{fc}{t} \times \frac{n_o bd}{2} = pbd \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

or

$$p = \frac{fc}{t} \times \frac{n_o}{2}$$

At= .0134 bd or 1.34% of the effective sectional area of the section for case a

=	.0112 bd or 1.12%	for case	b
=	.0089 bd or .89%	,, ,,	c
=	.0112 bd or 1.12%	,, ,,	d
=	.0102 bd or 1.02%	,, ,,	e
=	.0089 bd or .89%	,, ,,	f
=	.0126 bd or 1.26%	,, ,,	g
=	.0080 bd or .8%	,, ,,	h

(b and d measured in inches)

The percentage of reinforcement depends upon the location of the neutral axis and stress ratio. The value of p is given in graph No. 4-2 for different values of $\frac{t}{fc}$ and m.

.24 Resistance moments.

Measuring b and d in inches,

$$R.M. = t A_t a \quad \ldots\ldots\ldots\ldots (4a)$$
$$= \tfrac{1}{2} f_c n_o a_1 bd^2 \quad \ldots\ldots\ldots\ldots (4b)$$
$$= Qbd^2 \quad \ldots\ldots\ldots\ldots (4c)$$

Q = 210	for case	a	
173.5	,, ,,	b	
137.5	,, ,,	c	
173.5	,, ,,	d	
157.5	,, ,,	e	
137.5	,, ,,	f	
193.0	,, ,,	g	
125.7	,, ,,	h	

Design constants for various values of fc, t and m are given in table No. 4-a on page 119.

Values of R.M. and A_t for slabs of various depths designed for stresses specified by the different codes are given in table 4-b.

The amount of steel as given by formula (3) is the economic amount i.e. both the steel and concrete as stressed to the maximum permitted limits. If steel more than that calculated by formula (3) is used, the steel will be understressed and safe R.M. of the slab will be governed by the concrete. If less steel is used, the concrete will be understressed and the safe R.M. will be governed by steel. The following procedure is necessary to find the safe R.M. of the slab in such cases.

a. Find the neutral axis of the slab by the formula

$$n_o = \sqrt{p^2m^2+2pm} - pm$$

The values of n_o for m=11 to 18 and p=.002 to .02 are plotted in graph No. 4-3.

b. Find lever arm a: j or $a_1 = 1 - \frac{n_o}{3}$

c. Find R.M.

R.M.$=A_t$ ta when steel provided is less than economic

or R.M. $= \frac{fc}{2} n_o jbd^2$ when steel provided is more than economic

In general R.M.$=Qbd^2$

The different values of Q are given in graph No. 4-4 for different values of p and m. R.M.s for various depths of slab reinforced with varying amount of steel are given in charts 4-5 and 4-6.

4.1.3 SUMMARY

NAME	fc psi	t psi	m	n	a	A_t %	Q
I.S.I. 456/1957 1 : 1 : 2	1150	18000	11.6	.426	.858	1.34	210
1 : 1½ : 3	950	do	14	.420	.860	1.12	173.5
1 : 2 : 4	750	do	18	.428	.857	0.89	137.7
BOMBAY MUNICIPAL CODE 1 : 1 : 2	950	do	14	.420	.860	1.12	173.5
1 : 1½ : 3	850	do	16	.430	.857	1.02	157.5
1 : 2 : 4	750	do	18	.428	.857	0.89	137.7
	1000	do	15	.450	.850	1.26	193.0
	750	do	15	.385	.872	0.80	125.7

4.2 Two-way slabs.

R. C. slabs can also be designed to span in two directions. These are then divided into two main classes, viz. (i) those simply supported on four sides and (ii) those restrained on four sides. The latter are again subdivided into seven classes as follows according to different edge conditions :

a) Interior panels.	
b) One edge	Discontinuous
c) Two adjacent edges	-do-
d) Two short edges	-do-
e) Two long edges	-do-
f) Three edges	-do-
g) Four edges	-do-

Design Tables, etc.

In case of (i) simply supported slabs, the tables or charts already given can be used by assuming the load taken by short span, as 50, 59, 68, 74, 79, 84 per cent of the total load, for span ratios of 1.0, 1.1, 1.2, 1.3, and 1.5 respectively. The balance of 50, 41, 32, 26, 21 and 16% is assumed to be taken by the long span. For restrained slabs, the B. M. coefficients and safe loads are given in tables 4-j & 4-k. The B. M.s for both short and long span are given by product of the appropriate coeff, w and square of short span. For example, if this coefficient is x, then the B.M. is xwl_x^2.

4.3 Examples

(1) Charts 4-1 & 4-2 and Table 4-a:

Find R.M. and A_t of a slab where stresses to be adopted are :

fc = 550 lb per sq. inch

t = 16000 „ „ „ „

m = 15

t/fc= 16000/550=29.

$\therefore n_o$ = .34 from chart 4-1.

$\therefore j = 1 - n_o/3 = .887$

$\therefore$ R.M.= $\frac{1}{2} fc \times n_o \times jbd^2 = 550/2 \times .34 \times 887bd^2$

$= 83bd^2$

A_t (from chart 4-2) = .6%

The same values can be obtained directly from table 4-a.

(2) Charts 4-3 to 4-6

Find R.M. of a slab, effective depth 5″ and reinforced with,

(a) .3 sq. inches of steel (5/16″ @ 3″ c.c.)

(b) .6 —do— (7/16″ @ 3½″ c.c.)

and designed for fc=750 psi, t=18000 psi and m=18.

	Case a	*Case b*
	$p = .3 \times 100/60 = .5\%$	$p = .6 \times 100/60 = 1.0\%$
	n_o (chart 4-3)=.342	$n_o = .445$
	$j = 1 - .342/3 = .886$	$j = 1 - .445/3 = .852$
R.M.	$= A_t \times t \times jd$	$fc/2 \times n_o \times j \times bd^2$
	$.3 \times 18000 \times .886 \times 5$in. lb	$750/2 \times .445 \times .852 \times 12 \times 5^2$
	=2000 ft. lb	3540 ft. lb

or (from chart 4-4)

$Q = 80\ bd^2$ inch lb	$Q = 142\ bd^2$
$= 80 \times 25$ ft. lb	$= 142 \times 25$
=2000 ft. lb	=3550 ft. lb

The same values could be obtained direct from chart 4-6.

Chart 4-7 or Table 4-b.

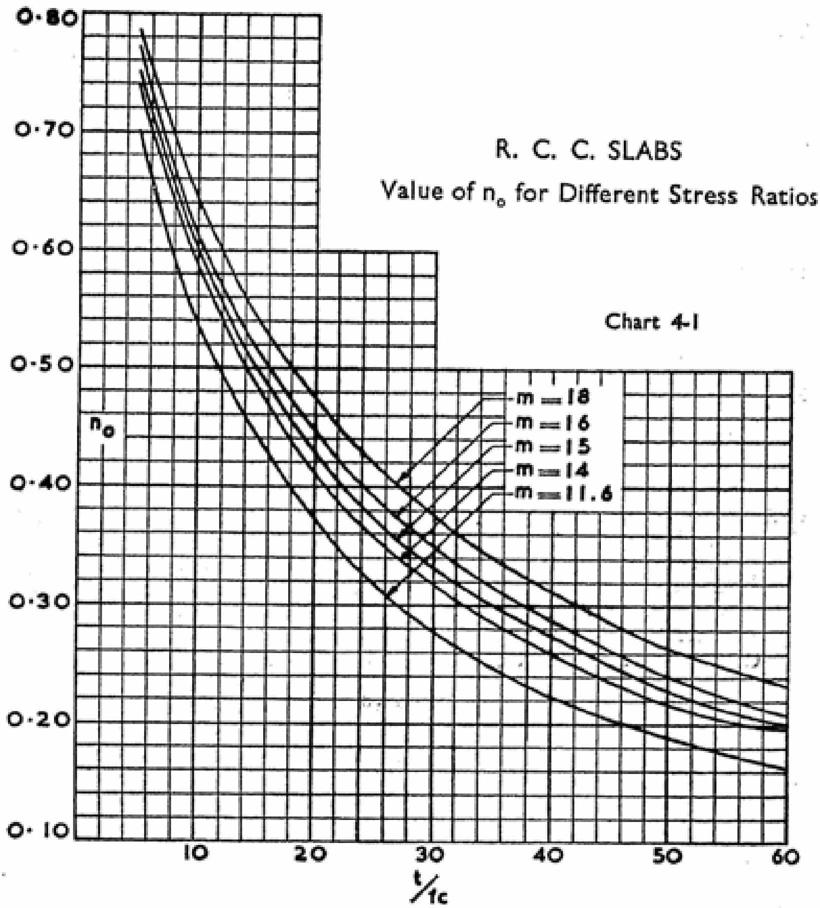
Find R.M. and A_t for a slab (effective depth 6″) designed as per Bombay Municipal Code. 1 : 1½ : 3 mix, refer table 4-b under " e ". R.M.=5660 ft. lb and A_t = .74 sq. inch or refer chart No. 4-7 or 4-4 giving the same result.

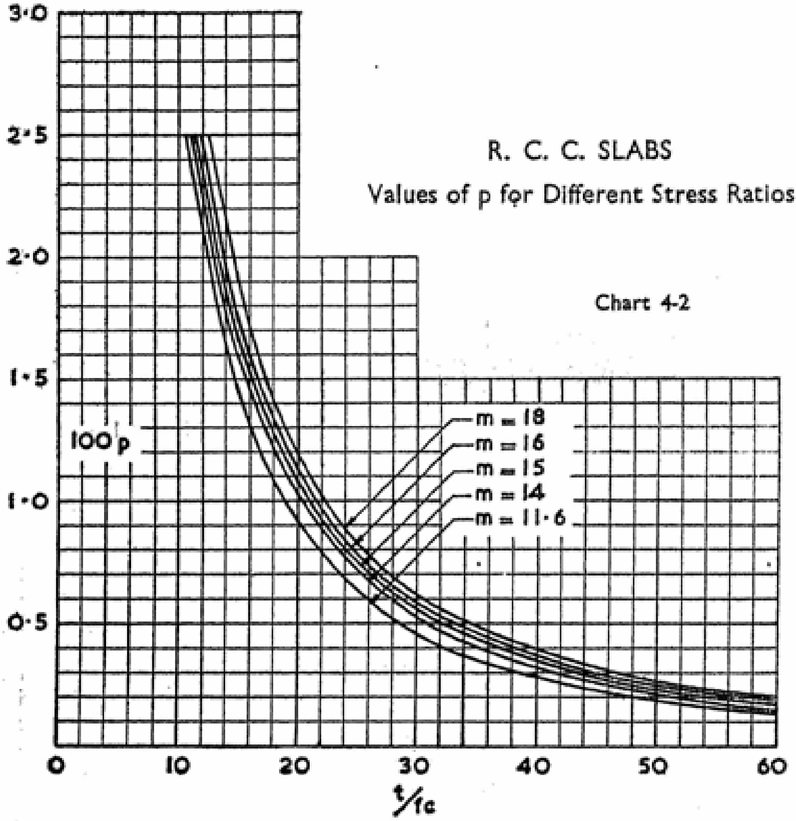
Other Tables and Charts

These are self explanatory giving

(a) safe load per sq. ft.
(b) other structural particulars
(c) quantities of steel and concrete per 100 sft.

for simply supported slabs designed for various values of fc, t and m. For continuous and semi-continuous spans the safe loads may be increased by 50% and 25% respectively.

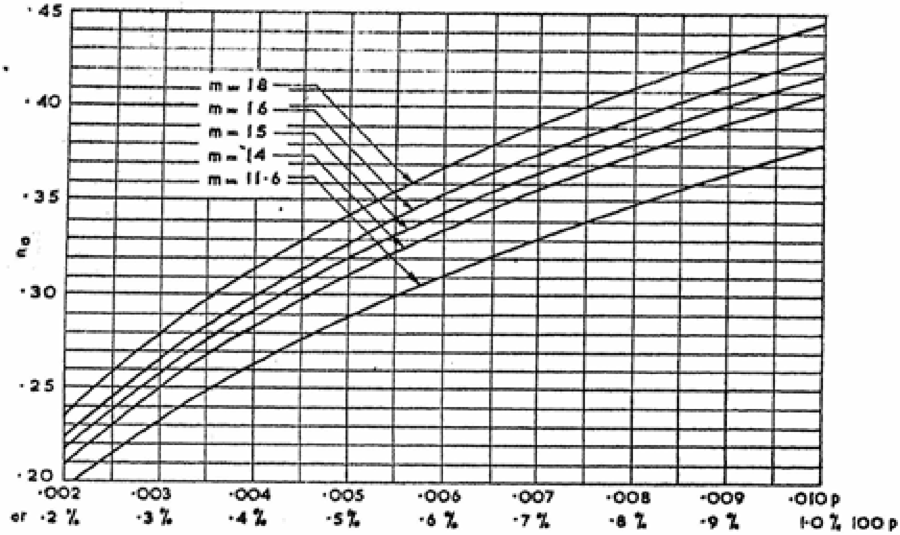


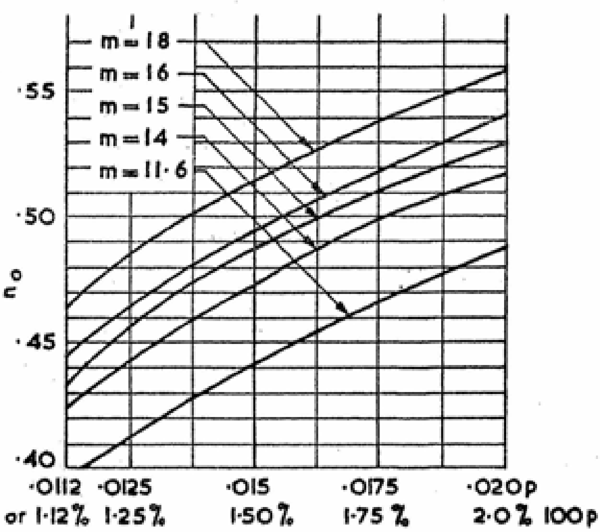

R. C. C. SLABS
Values of p for Different Stress Ratios
Chart 4-2
3·0
2·5
2·0
1·5
1·0
0·5
100p
m = 18
m = 16
m = 15
m = 14
m = 11·6
0
10
20
30
40
50
60
t/fc

R. C. C. SLABS

Values of n_o for Various Percentages of Steel

Chart 4-3

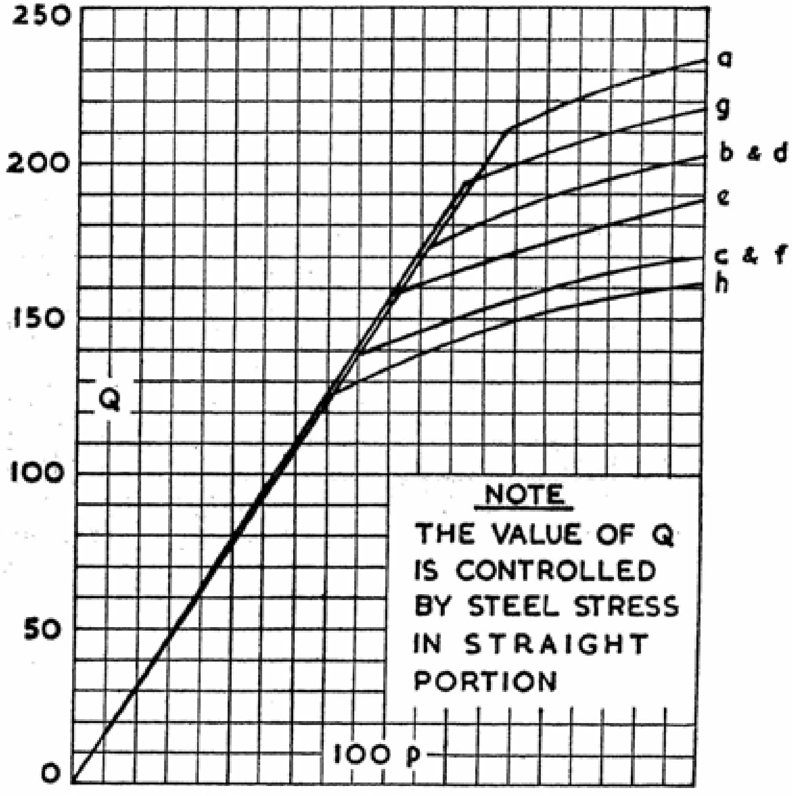


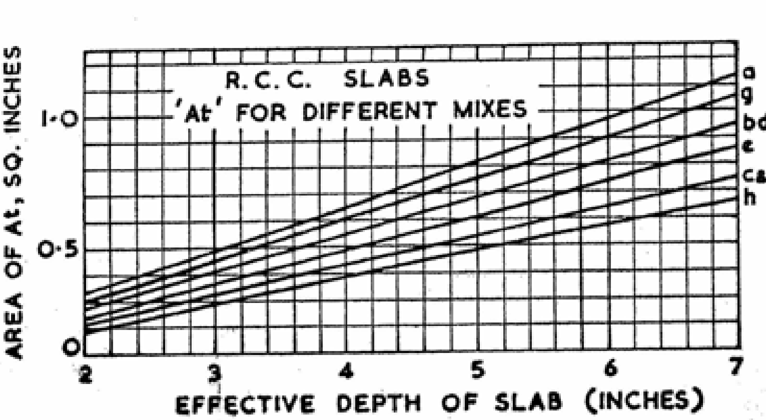


R. C. C. SLABS

Q for Various Percentages of Steel For Different Codes

Chart 4-4





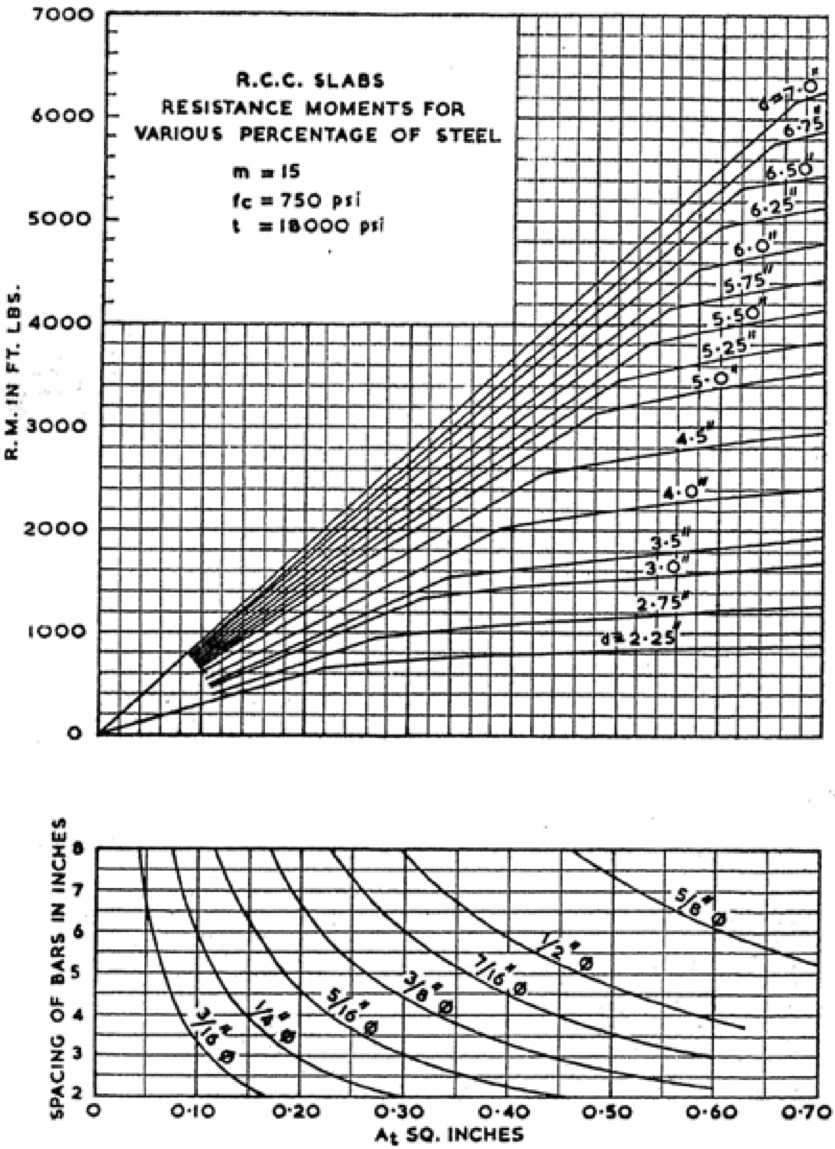

R.C.C. SLABS
RESISTANCE MOMENTS FOR
VARIOUS PERCENTAGE OF STEEL
m = 15
fc = 750 psi
t = 18000 psi
R.M. IN FT. LBS.
7000
6000
5000
4000
3000
2000
1000
0
d=7.0"
6.75"
6.50"
6.25"
6.0"
5.75"
5.50"
5.25"
5.0"
4.5"
4.0"
3.5"
3.0"
2.75"
d=2.25"
SPACING OF BARS IN INCHES
8
7
6
5
4
3
2
3/16" Ø
1/4" Ø
5/16" Ø
3/8" Ø
7/16" Ø
1/2" Ø
5/8" Ø
0
0·10
0·20
0·30
0·40
0·50
0·60
0·70
At SQ. INCHES

Chart 4-5

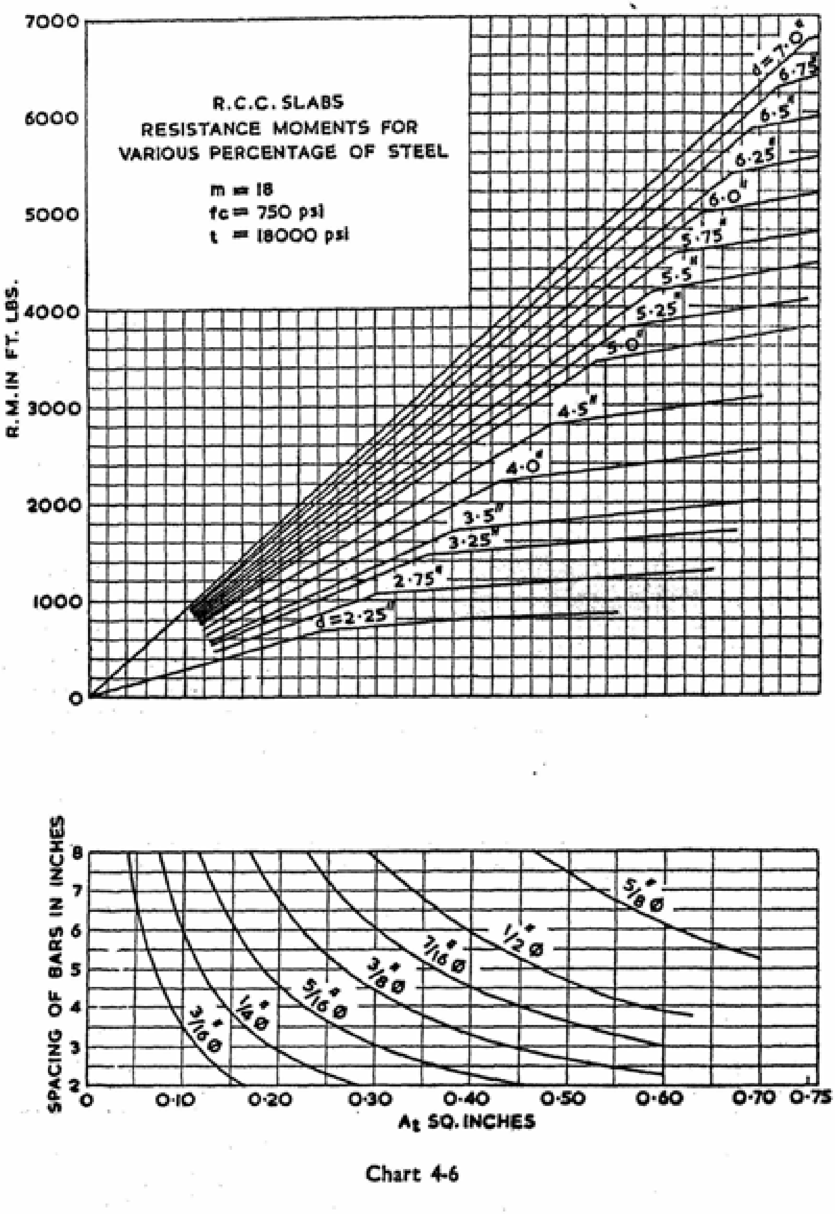

R.C.C. SLABS
RESISTANCE MOMENTS FOR
VARIOUS PERCENTAGE OF STEEL
m = 18
fc = 750 psi
t = 18000 psi
R.M. IN FT. LBS.
7000
6000
5000
4000
3000
2000
1000
0
d = 7.0"
6.75"
6.5"
6.25"
6.0"
5.75"
5.5"
5.25"
5.0"
4.5"
4.0"
3.5"
3.25"
2.75"
d = 2.25"
SPACING OF BARS IN INCHES
8
7
6
5
4
3
2
5/8" Ø
1/2" Ø
7/16" Ø
3/8" Ø
5/16" Ø
1/4" Ø
3/16" Ø
0
0·10
0·20
0·30
0·40
0·50
0·60
0·70
0·75
At SQ. INCHES

Chart 4-6

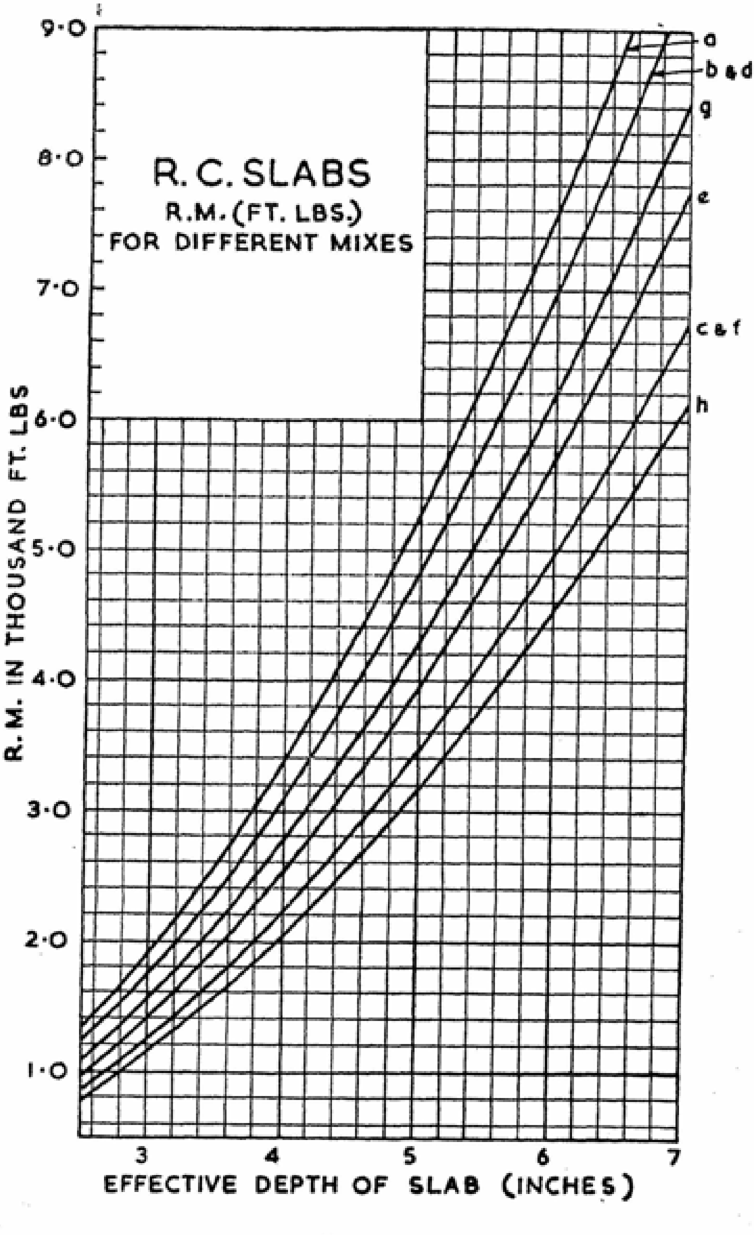

R. C. SLABS
R.M. (FT. LBS.)
FOR DIFFERENT MIXES
R.M. IN THOUSAND FT. LBS
9·0
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
a
b & d
g
e
c & f
h
3
4
5
6
7
EFFECTIVE DEPTH OF SLAB (INCHES)

Chart 4-7

DESIGN OF R.C.C. FLOOR SLAB . STRESSES - $f_c = 750$. $f_t = 18.000$ & $m = 18$.

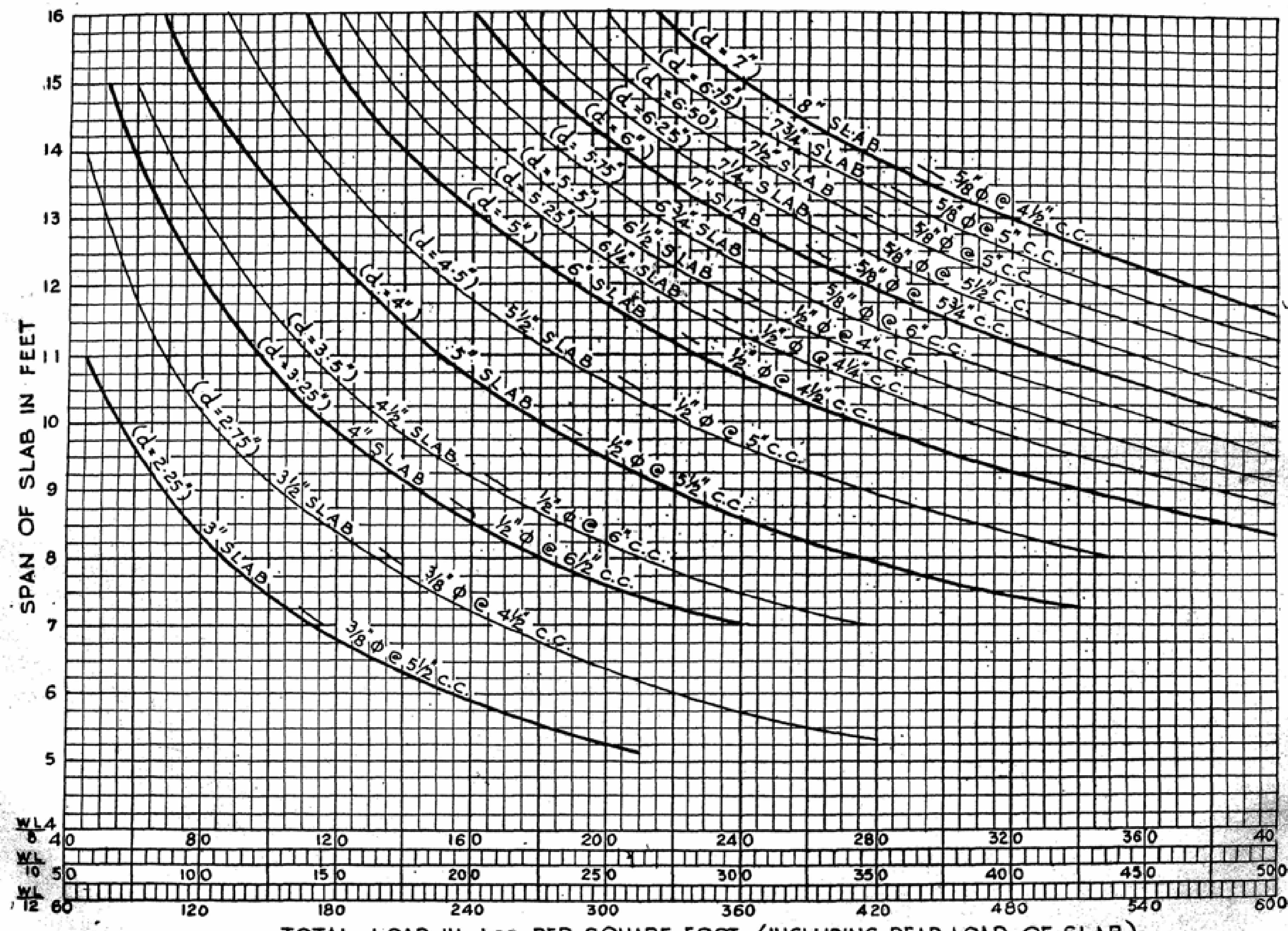


Chart 4-8.

DESIGN OF R.C.C. FLOOR SLAB

STRESSES – $f_c = 750$. $f_t = 18.000$ & $m = 18$.

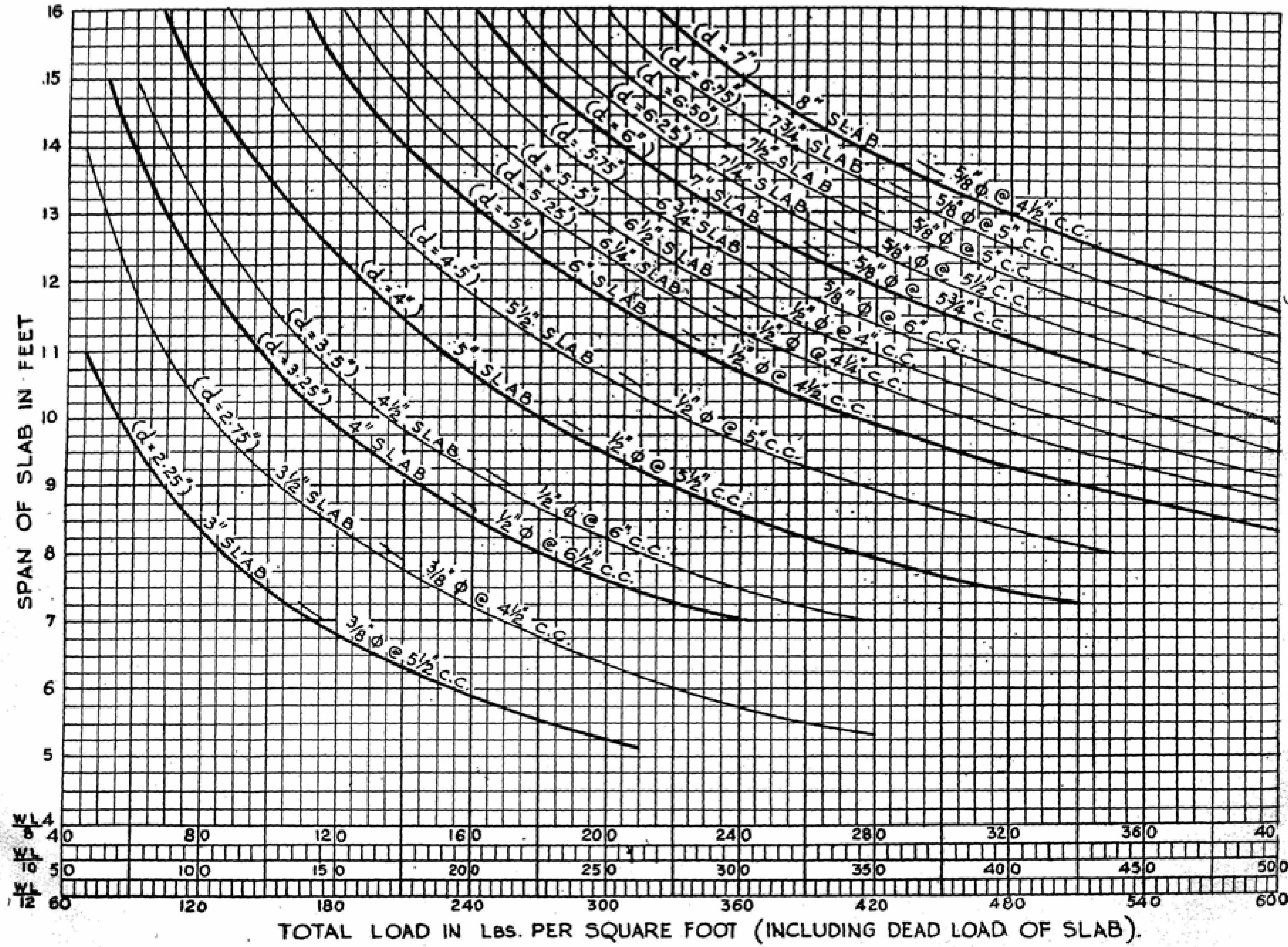


Chart 4-8.

DESIGN OF R. C. FLOOR SLABS

Stresses : fc=950 psi ; t=18000 psi ; m=14

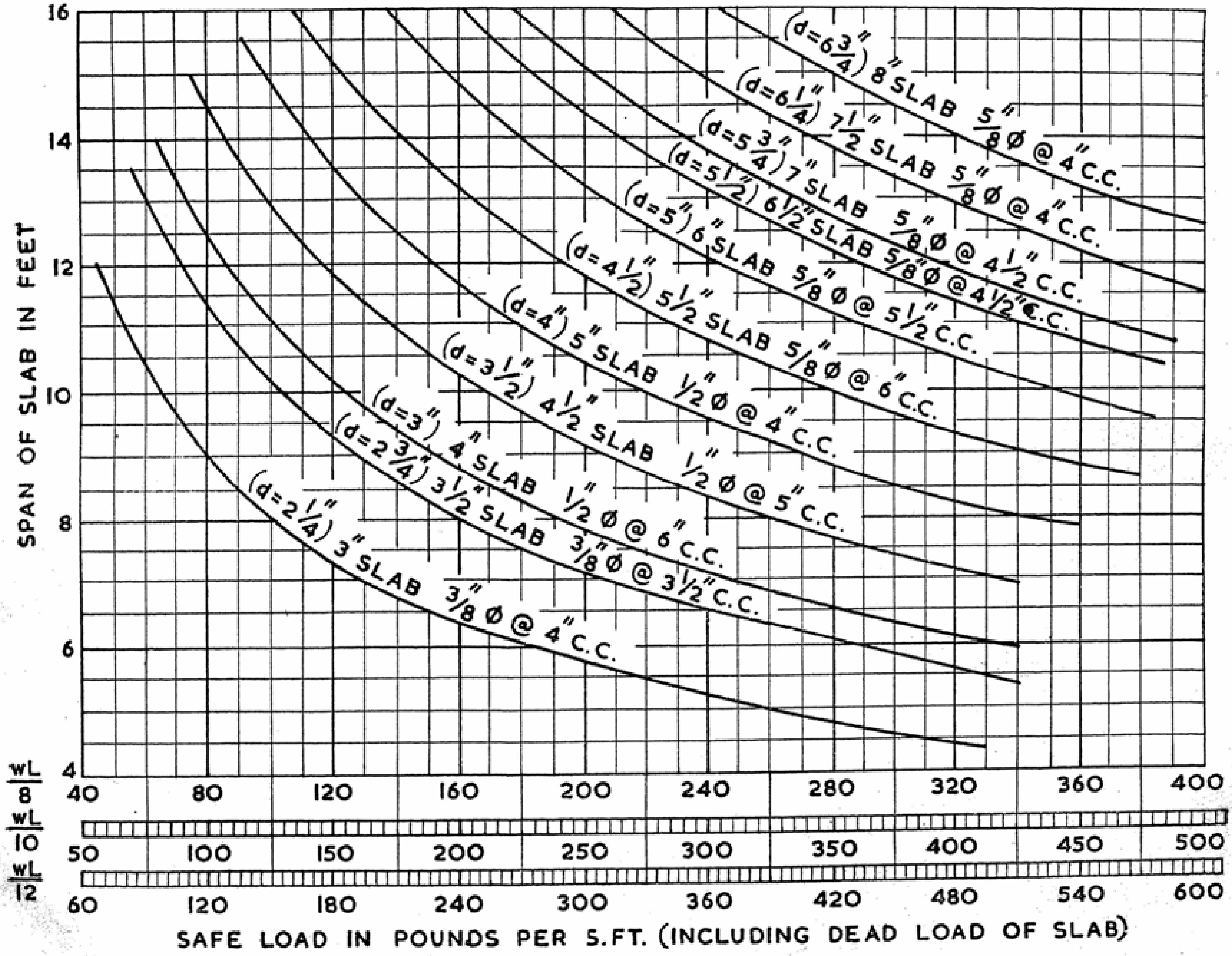


Chart 4-9.

DESIGN OF R. C. FLOOR SLABS

Stresses : fc=850 ; t=18000 psi, m=16

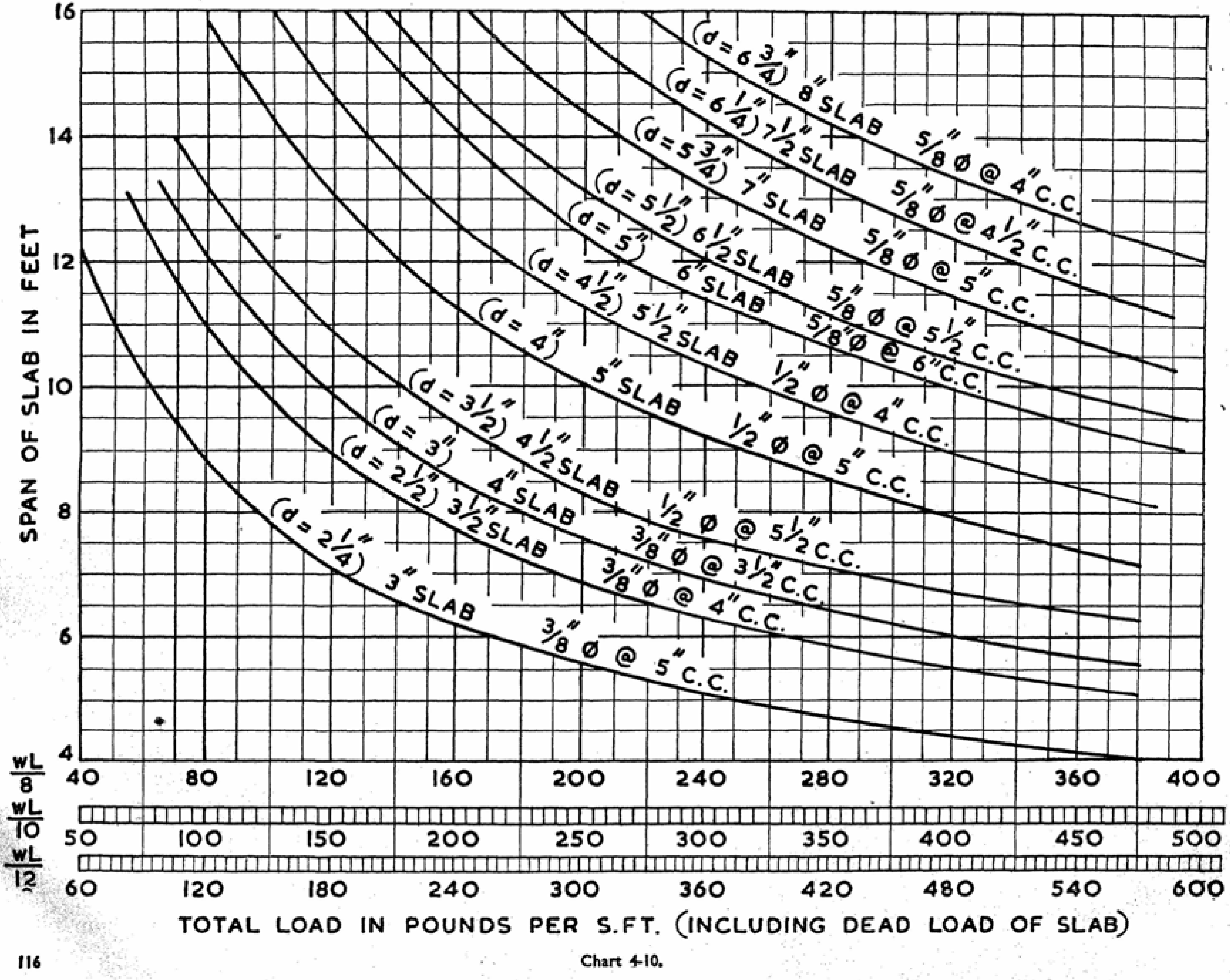


Chart 4-10.

DESIGN OF R.C.C. FLOOR SLAB

STRESSES: C = 750, T = 18,000 & m = 15

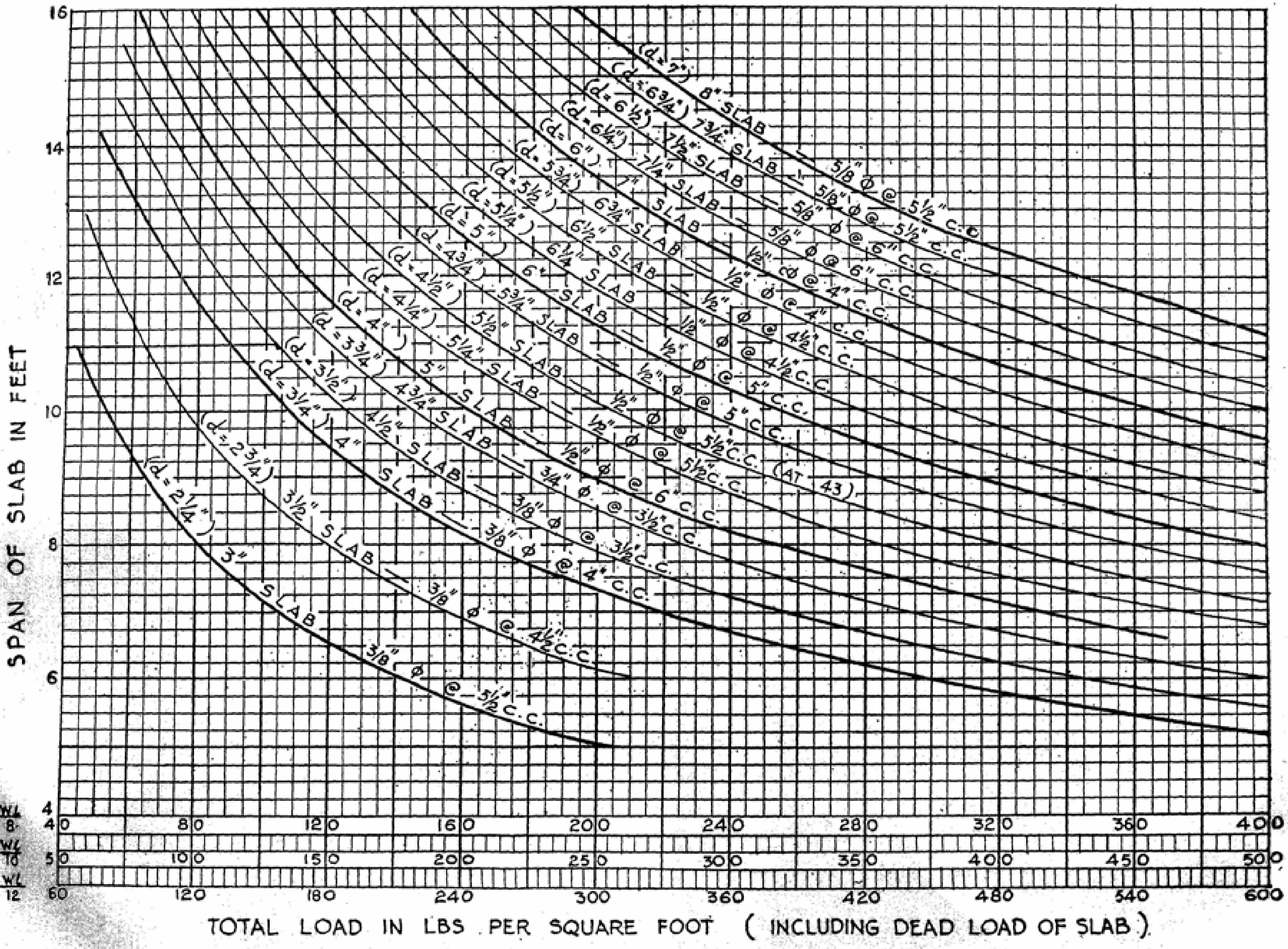


Chart 4-11.

DESIGN OF R.C.C. FLOOR SLABS

STRESSES: $fc = 1{,}000$. $ft = 18{,}000$ & $m = 15$

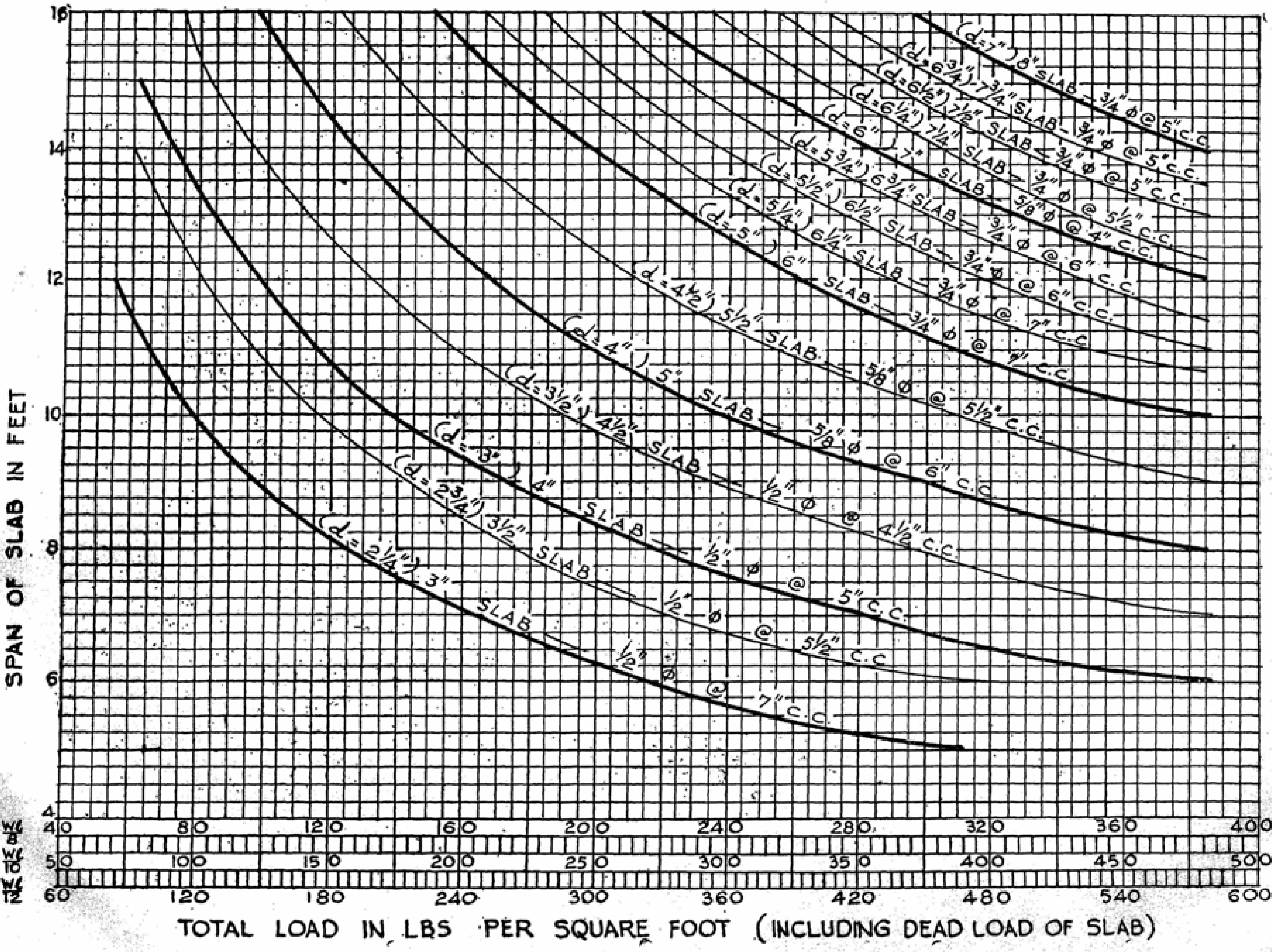


Chart 4-12.

TABLE 4a. Design constants for different values of fc, t and m.

t	fc	m = 15				m = 13				m = 14			
		Q	p	n_o	j	Q	p	n_o	j	Q	p	n_o	j
16000	400	49.6	.0034	.273	.909	55.5	.0039	.310	.897	47.5	.0032	.260	.913
	450	60.2	.0042	.297	.901	66.7	.0048	.335	.888	57.1	.0040	.285	.905
	500	71.3	.0050	.319	.894	79.2	.0056	.360	.880	68.4	.0048	.304	.899
	550	83.0	.0059	.340	.887	91.8	.0066	.383	.872	79.6	.0056	.325	.892
	600	95.0	.0068	.360	.880	104.7	.0076	.403	.866	91.1	.0064	.344	.885
	650	107.5	.0077	.379	.874	117.8	.0086	.422	.859	103.6	.0074	.363	.879
	700	120.4	.0087	.396	.868	131.3	.0096	.440	.853	116.3	.0083	.380	.873
	750	133.5	.0097	.413	.862	145.1	.0107	.456	.848	129.1	.0093	.396	.868
	800	146.9	.0107	.429	.857	159.1	.0118	.472	.843	142.2	.0103	.412	.863
	850	160.6	.0118	.443	.852	174.0	.0130	.489	.837	155.8	.0114	.427	.858
	900	174.5	.0129	.458	.847	188.4	.0141	.503	.832	169.1	.0124	.441	.853
	950	188.6	.0140	.471	.843	203.5	.0154	.517	.828	183.2	.0135	.454	.849
18000	400	45.8	.0028	.250	.917	51.5	.0032	.285	.905	43.7	.0026	.237	.921
	450	55.8	.0034	.273	.909	62.7	.0039	.311	.896	53.2	.0032	.259	.914
	500	66.3	.0041	.294	.902	74.1	.0046	.334	.889	63.5	.0039	.280	.907
	550	77.4	.0048	.314	.895	86.1	.0054	.354	.882	74.1	.0046	.299	.900
	600	88.9	.0056	.333	.889	98.2	.0062	.374	.875	85.4	.0053	.318	.894
	650	100.8	.0063	.351	.883	111.3	.0071	.394	.869	96.8	.0061	.336	.888
	700	113.1	.0072	.368	.877	124.6	.0080	.412	.863	108.9	.0069	.353	.882
	750	125.7	.0080	.385	.872	137.7	.0089	.428	.857	121.2	.0077	.368	.877
	800	138.7	.0089	.400	.867	151.6	.0099	.445	.852	133.9	.0085	.384	.872
	850	151.9	.0098	.415	.862	165.4	.0108	.459	.847	146.9	.0094	.398	.867
	900	165.3	.0107	.429	.857	180.0	.0119	.474	.842	159.9	.0103	.412	.863
	950	179.0	.0117	.442	.853	194.0	.0128	.487	.838	173.3	.0112	.425	.858
	1000	193.0	.0126	.455	.848	208.0	.0139	.500	.833	187.0	.0121	.438	.854
20000	400	42.6	.0023	.231	.923	48.1	.0026	.264	.912	40.2	.0022	.219	.917
	450	52.0	.0028	.252	.916	58.5	.0032	.288	.904	49.8	.0027	.240	.920
	500	62.0	.0034	.273	.909	69.5	.0039	.311	.896	58.2	.0032	.259	.914
	550	72.5	.0040	.292	.903	81.0	.0046	.331	.890	69.3	.0038	.278	.907
	600	83.5	.0047	.310	.897	92.9	.0053	.356	.883	80.2	.0044	.296	.903
	650	94.9	.0053	.328	.891	105.2	.0060	.369	.877	91.1	.0051	.313	.896
	700	106.7	.0060	.344	.885	117.7	.0068	.386	.871	102.4	.0058	.329	.890
	750	118.8	.0068	.360	.880	130.6	.0076	.403	.866	114.2	.0065	.344	.885
	800	131.2	.0075	.375	.875	144.0	.0084	.419	.860	126.3	.0072	.359	.880
	850	144.0	.0083	.389	.870	157.8	.0092	.434	.855	138.8	.0079	.373	.876
	900	157.0	.0091	.403	.866	172.0	.0101	.448	.851	151.7	.0087	.387	.871
	950	170.2	.0099	.416	.861	185.5	.0109	.461	.846	164.5	.0091	.399	.867

t	fc	m = 11.6				m = 16			
		Q	p	n_o	j	Q	p	n_o	j
16000	400	41.4	.0028	.224	.925	51.8	.0036	.286	.905
	450	50.7	.0035	.245	.918	62.6	.0044	.310	.897
	500	60.5	.0042	.266	.911	74.0	.0052	.333	.889
	550	71.8	.0049	.285	.905	86.2	.0061	.355	.882
	600	81.9	.0057	.303	.899	98.4	.0070	.375	.875
	650	93.0	.0065	.320	.893	111.2	.0080	.394	.869
	700	105.0	.0074	.338	.887	124.3	.0090	.411	.863
	750	117.0	.0083	.354	.882	138.0	.0101	.430	.857
	800	130.0	.0093	.368	.877	151.6	.0112	.445	.852
	850	142.0	.0102	.382	.873	165.8	.0123	.461	.846
	900	154.5	.0111	.395	.868	179.5	.0134	.474	.842
	950	167.2	.0121	.408	.864	193.9	.0145	.487	.838
	1000	180.5	.0131	.420	.860	208.5	.0156	.500	.833
18000	400	38.2	.0023	.205	.932	47.8	.0029	.262	.913
	450	46.6	.0028	.224	.925	58.4	.0036	.286	.905
	500	55.8	.0034	.243	.919	69.1	.0043	.308	.897
	550	65.8	.0040	.262	.913	80.4	.0050	.328	.891
	600	75.5	.0046	.278	.907	91.1	.0058	.347	.884
	650	86.5	.0053	.295	.902	104.9	.0066	.366	.878
	700	95.2	.0059	.303	.899	116.8	.0074	.383	.872
	750	108.8	.0068	.326	.891	130.0	.0083	.400	.867
	800	120.5	.0076	.340	.887	143.1	.0092	.415	.862
	850	132.7	.0084	.354	.882	156.5	.0102	.429	.857
	900	145.5	.0092	.368	.877	170.2	.0111	.444	.852
	950	157.7	.0100	.380	.873	184.3	.0121	.459	.847
	1000	170.5	.0109	.392	.869	198.0	.0131	.469	.844
	1050	183.7	.0118	.403	.866	212.0	.0140	.481	.840
	1100	197.0	.0127	.415	.862	226.8	.0157	.495	.835
	1150	210.0	.0136	.426	.858	241.5	.0161	.505	.832
	1200	223.5	.0145	.436	.855	255.4	.0171	.515	.828
20000	400	35.2	.0019	.188	.937	44.6	.0024	.243	.919
	450	43.0	.0023	.206	.931	54.5	.0030	.265	.912
	500	51.8	.0028	.224	.925	64.8	.0036	.286	.905
	550	61.1	.0036	.242	.919	75.4	.0042	.306	.898
	600	70.8	.0039	.258	.914	86.7	.0048	.324	.892
	650	80.4	.0044	.273	.909	98.5	.0055	.342	.886
	700	91.4	.0050	.289	.904	110.6	.0063	.360	.880
	750	102.2	.0057	.303	.899	122.8	.0070	.374	.875
	800	113.6	.0064	.318	.894	136.0	.0078	.391	.870
	850	124.5	.0070	.329	.890	148.8	.0086	.405	.865
	900	136.8	.0077	.344	.885	162.0	.0094	.419	.860
	950	148.6	.0084	.355	.882	175.3	.0102	.431	.856
	1000	161.0	.0092	.368	.877	189.5	.0111	.445	.852
	1050	173.8	.0099	.379	.874	203.9	.0120	.459	.847
	1100	185.9	.0107	.389	.870	216.8	.0129	.467	.844
	1150	199.5	.0115	.400	.867	231.5	.0138	.478	.841
	1200	212.4	.0123	.410	.863	246.0	.0147	.490	.831

TABLE 4-b.

RM and A_t for R.C.C. slabs of various depths for different mixes

Mix	a		b & d		c & f		e		g		h	
d Inches	RM (ft. lbs.)	A_t (sq. ins.)	R. M.	A_t	R. M.	A_t	R. M.	A_t	R. M.	A_t	R. M.	A_t
2.25	1030	.37	831	.31	699	.24	764	.27	977	.34	618	.22
2.75	1590	.45	1295	.37	1044	.29	1190	.34	1459	.42	953	.26
3.25	2220	.53	1760	.44	1457	.35	1660	.39	2038	.49	1350	.31
3.50	2570	.57	2100	.48	1690	.37	1930	.43	2364	.53	1543	.34
4.00	3360	.65	2735	.55	2190	.43	2520	.49	3088	.61	2016	.38
4.50	4258	.73	3480	.61	2800	.48	3190	.55	3907	.68	2540	.43
5.00	5250	.82	4280	.68	3450	.53	3940	.61	4823	.76	3150	.48
5.25	5780	.86	4720	.71	3803	.56	4340	.64	5319	.79	3473	.50
5.50	6357	.90	5190	.75	4175	.59	4760	.67	5838	.83	3812	.53
5.75	6940	.94	5680	.78	4563	.61	5229	.70	6381	.78	4166	.55
6.00	7560	.98	6190	.82	4968	.64	5660	.74	6948	.91	4536	.58
6.25	8220	1.01	6700	.86	5390	.67	6150	.77	7539	.95	4922	.60
6.50	8870	1.06	7250	.88	5830	.69	6650	.80	8154	.98	5324	.62
6.75	9600	1.10	7840	.92	6283	.72	7200	.83	8793	1.02	5740	.65
7.00	10290	1.14	8410	.95	6782	.75	7720	.86	9457	1.06	6174	.67

Table 4-c.

Simply supported slabs (fc = 1150, t = 18000, m = 11.6) (a)

Total depth of Slab (inches)	SAFE LOAD INCLUDING WEIGHT OF SLAB IN PSF. FOR SPAN IN FEET													DETAILS OF SLABS							
														Effective Depth (inches)	Area of Steel/Ft. Sq. Inches.	Cover (inches)	B. M. Ft. Pounds.	REINFORCEMENT (round bars)		QUANTITIES Per 100 sft	
	4	5	6	7	8	9	10	11	12	13	14	15	16					Main	Distribution	Concrete C. Ft.	Steel Cwt
3.0				169	129	102	82	68	58	49	42			2.25	.37	9/16	1030	3/8"@3½"	¼"@8"	25	1.36
3.5				260	199	157	127	105	88	75	65	57		2.75	.45	9/16	1590	3/8"@3"	¼"@7"	29.1	1.57
4.0				310	236	187	151	125	105	89	77	67		3.00	.49	3/4	1890	½"@4½"	¼"@6"	33.3	1.83
4.5				422	321	254	205	170	143	116	104	92	80	3.50	.57	3/4	2570	½"@4"	¼"@5"	37.5	2.11
5.0				550	420	332	268	222	187	152	137	120	104	4.00	.65	3/4	3360	½"@3½"	¼"@5"	41.6	2.36
6.0							420	348	292	248	214	187	164	5.00	.82	11/16	5250	5/8"@4½"	¼"@3½"	50.0	2.95
6.5							462	382	321	266	236	205	180	5.25	.86	15/16	5780	5/8"@4"	¼"@3½"	54.1	3.25
6.75							510	420	352	288	260	226	200	5.50	.90	15/16	6357	¾"@6"	¼"@3½"	56.2	3.15
7.0								446	386	315	283	247	217	5.75	.94	14/16	6942	¾"@5½"	3/8"@8"	58.3	3.38
7.25								500	420	342	309	279	238	6.00	.98	14/16	7560	¾"@5½"	3/8"@8"	60.4	3.38
7.50								545	457	373	336	293	257	6.25	1.01	14/16	8220	¾"@5"	3/8"@7"	62.5	3.76
7.75									486	400	363	316	277	6.50	1.06	14/16	8870	¾"@5"	3/8"@7"	64.5	3.78
8.0										436	392	342	300	6.75	1.10	14/16	9600	¾"@4½"	3/8"@7"	66.6	4.10
8.25										490	420	370	322	7.00	1.14	14/16	10290	¾"@4½"	3/8"@6½"	68.7	4.15

Table 4-d.

Simply supported slabs (fc = 950, t = 18000, m = 14) (b & d)

Total depth of Slab (Inches)	SAFE LOAD INCLUDING WEIGHT OF SLAB PSF SPAN IN FEET													DETAILS OF SLABS							
																		REINFORCEMENT (round bars)		QUANTITIES Per 100 sft	
	4	5	6	7	8	9	10	11	12	13	14	15	16	Effective Depth (Inches)	Area of Steel/Ft. Sq. Inches.	Cover (Inches)	B. M. Ft. Pounds.	Main	Distribution	Concrete C. Ft.	Steel Cwt
3.0	415	260	181	129	101	80	65	53	45					2.25	.31	9/16	881	3/8"@4"	1/4"@10"	25	1.16
3.5		413	287	205	162	128	103	86	72	61	53			2.75	.37	9/16	1295	3/8"@3½"	1/4"@9"	29.1	1.34
4.0			343	245	193	152	123	101	86	73	63	55		3	.41	3/4	1642	1/2"@6"	1/4"@7"	33.3	1.43
4.5				333	262	204	168	138	117	99	86	75	66	3.5	.48	3/4	2100	1/2"@5"	1/4/@6"	37.5	1.71
5.0					340	270	218	179	151	129	111	97	85	4	.55	3/4	2735	1/2"@4"	1/4"@5½"	47.5	2.06
5.5						343	278	228	193	164	142	123	108	4.5	.61	11/16	3480	5/8"@6"	1/4"@5"	45.8	2.20
6.00							350	290	244	207	179	156	137	5	.68	11/16	4280	5/8"@5½"	3/8"@9½"	50.0	2.54
6.25								310	262	224	193	168	148	5.25	.71	11/16	4720	5/8"@5"	3/8"@9½"	54.1	2.63
6.5								342	288	246	212	183	162	5.5	.75	11/16	5190	5/8"@4½"	3/8"@9"	56.2	2.90
7.0									316	269	232	202	178	5.75	.78	15/16	5680	5/8"@4½"	3/8"@8½"	58.3	2.92
7.25									342	292	252	219	193	6.00	.82	15/16	6190	5/8"@4½"	3/8"@8"	60.4	2.95
7.5									371	317	273	237	209	6.25	.86	15/16	6700	5/8"@4"	3/8"@7½"	62.5	2.99
7.75										343	295	257	226	6.50	.88	15/16	7250	5/8"@4"	3/8"@7½"	64.5	2.99
												279	245	6.75	.92	15/16	7880	5/8"@4"	3/8"@7"	66.6	3.34
												298	262	7.00	.95	15/16	8410	5/8"@3½"	3/8"@7"	68.7	3.74

Table 4-e.

Simply supported slabs (fc = 750, t = 18000, m = 18) (c & f)

Total Depth of Slab (inches)	SAFE LOAD (INCLUDING WEIGHT OF SLAB) lb/sft SPAN IN FEET													DETAILS OF SLABS							
														Effective Depth (inches) d	Area of Steel/Ft. A_t	Cover (inches)	Moment of Resistance Foot Lb R.M.	REINFORCEMENT (round bars)		QUANTITIES Per 100 sft.	
	4	5	6	7	8	9	10	11	12	13	14	15	16					Main	Distribution	Concrete C. Ft.	Steel Cwt
3.0			155	114	87	69	56	46						2.25	.240	9/16	699	3/8"@5½"	¼"@10"	25.00	1.03
3.5			231	171	131	104	83	69	58	51	43			2.75	.294	9/16	1044	3/8"@4½"	Do	29.17	1.18
4.0				240	182	144	117	98	81	69	60			3.25	.347	9/16	1457	½"@6½"	¼"@9"	33.33	1.42
4.5				277	211	167	136	114	95	84	69	60		3.50	.374	3/4	1690	½"@6"	¼"@8"	37.50	1.54
5.0					276	218	182	151	127	108	90	78	69	4.00	.427	3/4	2208	½"@5½"	¼"@7"	41.67	1.72
5.5					349	276	228	185	155	132	114	99	88	4.50	.480	3/4	2795	½"@5"	¼"@6"	45.83	1.90
6.0					430	340	276	224	191	163	141	122	110	5.00	.534	3/4	3450	½"@4½"	¼"@5½"	50.00	2.10
6.25					476	376	304	252	212	180	156	135	122	5.25	.560	3/4	3803	½"@4½"	¼"@5"	52.08	2.21
6.5					520	410	332	276	231	195	170	148	133	5.50	.587	3/4	4175	½"@4"	¼"@5"	54.17	2.30
6.75					570	448	364	300	252	216	186	163	146	5.75	.614	3/4	4563	5/8"@6"	¼"@4½"	56.25	2.48
7.0						491	397	329	276	235	204	178	160	6.00	.641	3/4	4968	5/8"@5½"	3/8"@11"	58.33	2.60
7.25							430	356	300	256	220	193	172	6.25	.668	3/4	5390	5/8"@5½"	3/8"@10"	60.42	2.76
7.5							466	386	324	277	238	207	187	6.50	.694	11/16	5830	5/8"@5"	3/8"@9½"	62.50	2.92
7.75							505	416	350	298	257	222	200	6.75	.721	11/16	6283	5/8"@5"	3/8"@9"	64.58	2.97
8.0							540	447	375	320	276	240	216	7.00	.748	11/16	6762	5/8"@4½"	3/8"@9"	66.67	3.22

Table 4-f.

Simply supported slabs (fc=850, t=18,000, m=16)

Total Depth of Slab (Inches)	SAFE LOAD INCLUDING WEIGHT OF SLAB PSF. SPAN IN FEET													DETAILS OF SLABS							
	4	5	6	7	8	9	10	11	12	13	14	15	16	Effective Depth (Inches)	Area of Steel/Ft. Sq. Inches.	Cover (Inches)	B. M. Ft. Pounds.	REINFORCEMENT (round bars) Main	Distribution	QUANTITIES Concrete C. Ft.	Steel Cwt
3.0	382	244	170	121	96	76	61	50	42					2.25	.27	9/16	764	3/8"@10"	1/4"@10"	25	1.62
3.5		380	275	189	149	118	95	79	66	57				2.75	.34	9/16	1190	3/8"@4"	1/4"@9"	29.1	1.20
4.0			320	230	180	142	115	95	80	68				3.00	.37	13/16	1440	3/8"@3½"	1/4"@9"	33.3	1.34
4.5				286	219	174	140	116	97	83	70			3.50	.43	3/4	1750	1/2"@5½"	1/4"@8"	37.5	1.52
5.0					315	250	202	166	140	120	103	90	79	4.00	.49	3/4	2520	1/2"@5"	1/4"@8"	41.5	1.71
5.5						316	255	210	177	151	130	113	100	4.5	.55	3/4	3190	1/2"@4"	1/4@5½"	45.8	2.10
6.0							315	259	219	186	161	140	123	5.0	.61	11/16	3940	5/8"@6"	1/4"@5"	50.0	2.30
6.50							347	285	241	205	175	154	136	5.25	.64	15/16	4340	5/8"@5½"	1/4"@4½"	54.1	2.43
6.75								314	264	226	194	169	149	5.5	.67	15/16	4760	5/8"@5½"	3/8"@9½"	56.2	2.44
7.0								344	290	247	213	186	163	5.75	.70	15/16	5220	5/8"@5"	3/8"@9½"	58.3	2.62
7.25									314	268	231	200	177	6.00	.74	15/16	5660	5/8"@5"	3/8"@9"	60.4	2.65
7.50									340	290	250	218	192	6.25	.77	15/16	6150	5/8"@4½"	3/8"@8½"	62.5	3.00
7.75										314	270	236	208	6.50	.80	15/16	6650	5/8"@4½"	3/8"@8"	64.5	2.95
8.0										340	284	255	224	6.75	.83	15/16	7200	5/8"@4"	3/8"@7½"	66.6	3.28
8.25											315	274	240	7	.86	15/16	7720	5/8"@4"	3/8"@7"	68.7	3.34

Table 4-g.

R.C.C. SLABS

Simply supported slabs (fc = 750, t = 18000, m = 15) (h)

Total Depth of Slab (inches)	SAFE LOAD (INCLUDING WEIGHT OF SLAB) lb/sft SPAN IN FEET													DETAILS OF SLABS							
	4	5	6	7	8	9	10	11	12	13	14	15	16	Effective Depth (inches) d	Area of Steel/Ft. A_t	Cover (inches)	Moment of Resistance Foot Lbs. R.M.	REINFORCEMENT (round bars) Main	Distribution	QUANTITIES Per 100 sft Concrete C. Ft.	Steel Cwt
3.0		204	142	104	80	63	51	42						2.25	.216	9/16	638	3/8"@5½"	¼"@9"	25.00	1.03
3.5			210	155	119	94	76	63	53	45				2.75	.264	9/16	953	,, 4½"	¼"@10"	20.17	1.18
4.0			296	217	167	133	106	87	74	63				3.25	.312	9/16	1350	,, 4"	¼"@12"	33.33	1.25
4.5			343	253	194	153	124	103	86	73	63			3.50	.336	3/4	1543	,, 3½"	¼"@14"	37.50	1.42
5.0					252	196	161	136	112	96	82			4.00	.384	3/4	2016	½"@6"	¼"@15"	41.67	1.46
5.5					320	250	204	168	142	120	102	90	80	4.50	.432	3/4	2550	,, 5½"	¼"@14"	45.83	1.58
6.0					394	310	252	208	176	150	129	112	98	5.00	.480	3/4	3150	,, 5"	¼"@12"	50.00	1.75
6.25					435	345	280	230	195	166	143	127	108	5.25	.504	3/4	3473	,, 4½"	¼"@12"	52.08	1.90
6.5					478	376	305	256	212	180	155	136	119	5.50	.528	3/4	3812	,, 4½"	¼"@12"	54.17	1.90
6.75					520	410	334	275	232	196	170	148	130	5.75	.552	3/4	4166	½"@4"	¼"@11"	56.25	2.12
7.0						448	363	300	251	214	185	161	143	6.00	.576	3/4	4536	½"@4"	¼"@10"	58.33	2.13
7.25						490	396	325	275	234	200	175	154	6.25	.600	3/4	4922	½"@4"	¼"@10"	60.42	2.13
7.5						525	426	350	295	252	217	189	166	6.50	.624	11/16	5324	5/8"@6"	¼"@10"	62.50	2.30
7.75						570	460	380	320	270	235	203	180	6.75	.648	11/16	5740	5/8"@5½"	¼"@9"	64.58	2.55
8.0						610	494	407	342	232	250	219	194	7.00	.672	11/16	6174	5/8"@5½"	¼"@9"	66.67	2.56

Table 4-h.

R.C.C. SLABS

Simply supported slabs (fc = 1000, t = 18,000, m = 15)

Total depth of Slab (inches)	SAFE LOAD (INCLUDING WEIGHT OF SLAB) PSF. SPAN IN FEET													DETAILS OF SLABS							
														Effective Depth (inches)	Area of Steel/Ft. A_t	Cover (inches)	Moment of Resistance Foot Lb B.M.	REINFORCEMENT (round bars)		QUANTITIES Per 100 sft.	
	4	5	6	7	8	9	10	11	12	13	14	15	16					Main	Distribution	Concrete C. Ft.	Steel Cwt.
3.0		313	217	160	122	96	78	65	54					2.25	.340	1/2	976	½"@7"	¼"@12"	25.00	1.30
3.5			325	238	182	144	117	97	81	69	60			2.75	.415	1/2	1460	½"@5½"	„ 12"	29.17	1.60
4.0			387	284	218	172	139	115	97	82	71	62		3.00	.452	3/4	1740	„ 5"	„ 12"	33.33	1.74
4.5				385	295	233	189	156	131	112	96	84	74	3.50	.528	1/2	2360	„@4½"	„ 10"	37.50	1.96
5.0				503	385	304	246	204	171	146	126	110	96	4.00	.604	11/16	3080	⅝"@6"	„ 10"	41.67	2.26
5.5					480	386	313	258	217	185	160	139	122	4.50	.680	11/16	3910	„@5½"	„ 9"	45.83	2.45
6.0						476	386	319	268	228	197	171	150	5.00	.755	5/8	4820	¾"@7"	„ 9"	50.00	2.77
6.25						525	425	351	296	252	217	189	166	5.25	.793	5/8	5310	„@7"	„ 9"	52.08	2.77
6.5						577	467	386	324	276	238	208	183	5.50	.830	5/8	5840	„@6"	„ 7"	54.17	3.26
6.75							510	422	355	302	261	227	200	5.75	.868	5/8	6380	„@6"	„ 7"	56.25	3.26
7.0							555	458	385	328	283	247	217	6.00	.906	11/16	6940	⅝"@4"	„ 7"	58.25	3.38
7.25							603	498	419	357	308	268	235	6.25	.945	5/8	7530	¾"@5½"	„ 6"	60.42	3.57
7.5								540	452	386	333	290	254	6.50	.981	5/8	8150	„@5"	„ 6"	62.50	3.90
7.75								581	489	416	359	313	274	6.75	1.020	5/8	8780	„@5"	„ 6"	64.58	3.90
8.0									525	447	386	335	296	7.00	1.060	5/8	9450	„@5"	„ 6"	66.67	3.90

Table 4-j.

Coefficients for restrained slabs

TYPE OF PANEL AND MOMENTS CONSIDERED	SHORT SPAN α'_x COEFFICIENT								α'_y*
	VALUES OF $\frac{l_y}{l_x}$								
	1·0	1·1	1·2	1·3	1·4	1·5	1·75	2·0 OR MORE	
CASE a INTERIOR PANELS.									
NEGATIVE MOMENT AT CONTINUOUS EDGE	0·033	0·040	0·045	0·050	0·054	0·059	0·071	0·083	0·033
POSITIVE MOMENT AT MID-SPAN	0·025	0·030	0·034	0·038	0·041	0·045	0·053	0·062	0·025
CASE b ONE EDGE DISCONTINUOUS									
NEGATIVE MOMENT AT CONTINUOUS EDGE	0·041	0·047	0·053	0·057	0·061	0·065	0·075	0·085	0·041
POSITIVE MOMENT AT MID-SPAN	0·031	0·035	0·040	0·043	0·046	0·049	0·056	0·064	0·031
CASE c TWO ADJACENT EDGES DISCONTINUOUS									
NEGATIVE MOMENT AT CONTINUOUS EDGE	0·049	0·056	0·062	0·066	0·070	0·073	0·082	0·090	0·049
POSITIVE MOMENT AT MID-SPAN	0·037	0·042	0·047	0·050	0·053	0·055	0·062	0·068	0·037
CASE d TWO SHORT EDGES DISCONTINUOUS									
NEGATIVE MOMENT	0·056	0·061	0·065	0·069	0·071	0·073	0·077	0·080	
POSITIVE MOMENT	0·044	0·046	0·049	0·051	0·053	0·055	0·058	0·060	0·035
CASE e TWO LONG EDGES DISCONTINUOUS									
NEGATIVE MOMENT									0·056
POSITIVE MOMENT	0·035	0·053	0·060	0·065	0·068	0·071	0·077	0·080	0·044
CASE f THREE EDGES DISCONTINUOUS									
NEGATIVE MOMENT AT CONTINUOUS EDGE	0·058	0·065	0·071	0·077	0·081	0·085	0·092	0·098	0·058
POSITIVE MOMENT AT MID-SPAN	0·044	0·049	0·054	0·058	0·061	0·064	0·069	0·074	0·044
CASE g FOUR EDGES DISCONTINUOUS									
POSITIVE MOMENT AT MID-SPAN	0·050	0·057	0·062	0·067	0·071	0·075	0·081	0·083	0·050

*α'_y : LONG SPAN COEFFICIENT FOR ALL SPAN RATIOS

Table 4-k.

Safe loads on restrained slabs of various dimensions

SAFE LOAD PER SFT. EXCLUDING WEIGHT OF SLAB

PANEL $l_y/l_x = 1$

Thickness inches	As short span steel	Edge conditions	10×10	11×11	12×12	13×13	14×14	15×15	16×16	17×17	18×18	A's
4"	0·36 sq.in.	a		325	265	220	184	155	127	108	90	A's = 0·41 SQ.INCH
		b	316	253	200	166	136	112	93	76	63	
		c	257	198	162	131	106	72	69	56	44	A's = 0·41 SQ.INCH
		d	218	172	136	109	86	69	56	43	33	A's = 0·26 SQ.INCH
		e	380	203	248	203	168	145	118	99	77	A's = 0·65 SQ.INCH
		f	209	163	129	105	80	64	51	39	30	A's = 0·41 SQ.INCH
		g	250	198	158	128	102	83	67	54	41	A's = 0·41 SQ.INCH
4½"	0·41 sq.in.	a			358	290	243	205	171	146	123	A's = 0·47 SQ.INCH
		b		334	263	222	183	152	128	106	89	A's = 0·47 SQ.INCH
		c	338	262	215	176	143	115	96	79	64	A's = 0·47 SQ.INCH
		d	289	229	184	148	119	97	80	62	50	A's = 0·30 SQ.INCH
		e			327	269	229	192	160	135	108	A's = 0·75 SQ.INCH
		f	277	220	174	143	116	91	73	59	46	A's = 0·47 SQ.INCH
		g	330	262	212	172	139	116	95	77	63	A's = 0·47 SQ.INCH
5"	0·46 sq.in.	a					328	278	233	201	170	A's = 0·52 SQ.INCH
		b			350	298	248	208	176	148	126	A's = 0·52 SQ.INCH
		c		350	290	239	198	162	136	115	94	A's = 0·52 SQ.INCH
		d		308	249	203	165	137	115	92	75	A's = 0·33 SQ.INCH
		e				358	308	259	218	186	150	A's = 0·82 SQ.INCH
		f		293	238	196	156	129	106	87	71	A's = 0·52 SQ.INCH
		g		351	289	234	191	160	133	111	90	A's = 0·52 SQ.INCH
5½"	0·51 sq.in.	a						340	285	246	210	A's = 0·59 SQ.INCH
		b				363	306	252	218	184	158	A's = 0·59 SQ.INCH
		c			356	293	244	201	170	144	120	A's = 0·59 SQ.INCH
		d			305	249	205	171	144	117	97	A's = 0·37 SQ.INCH
		e					376	318	268	229	186	A's = 0·95 SQ.INCH
		f		358	291	243	193	161	134	111	94	A's = 0·59 SQ.INCH
		g			351	288	236	198	168	139	115	A's = 0·59 SQ.INCH
6"	0·56 sq.in.	a							359	308	267	A's = 0·67 SQ.INCH
		b					380	320	273	233	200	A's = 0·67 SQ.INCH
		c				366	305	252	217	184	155	A's = 0·67 SQ.INCH
		d				312	259	217	185	152	127	A's = 0·42 SQ.INCH
		e							335	288	225	A's = 1·06 SQ.INCH
		f			362	303	243	205	172	143	120	A's = 0·67 SQ.INCH
		g				359	295	250	212	179	149	A's = 0·67 SQ.INCH

PANEL $l_y/l_x = 1\cdot1$

Thickness inches	As short span steel	Edge conditions	10×11	11×12·1	12×13·2	13×14·3	14×15·4	15×16·5	16×17·6	17×18·7	18×19·8	A's
4"	0·36 sq.in.	a	325	260	211	171	141	117	97	80	65	A's = 0·32 SQ.INCH
		b	270	214	172	137	113	91	74	69	49	A's = 0·36 SQ.INCH
		c	218	177	136	109	86	69	55	43	33	A's = 0·36 SQ.INCH
		d	196	154	122	96	76	60	46	35	26	A's = 0·24 SQ.INCH
		e	233	185	147	118	94	76	60	49	39	A's = 0·43 SQ.INCH
		f	181	141	110	86	66	53	40	27	22	A's = 0·36 SQ.INCH
		g	214	166	130	106	97	67	53	41	32	A's = 0·39 SQ.INCH
4½"	0·41 sq.in.	a			277	227	190	159	133	112	93	A's = 0·39 SQ.INCH
		b	354	282	229	185	154	126	103	86	70	A's = 0·41 SQ.INCH
		c	289	236	183	149	120	98	79	63	50	A's = 0·41 SQ.INCH
		d	261	206	165	129	116	85	67	53	42	A's = 0·27 SQ.INCH
		e	308	246	197	160	127	106	86	71	57	A's = 0·50 SQ.INCH
		f	242	189	151	119	94	76	61	43	35	A's = 0·42 SQ.INCH
		g	282	222	184	144	133	95	77	61	48	A's = 0·41 SQ.INCH
5"	0·46 sq.in.	a			372	306	257	216	183	156	130	A's = 0·43 SQ.INCH
		b			308	250	210	174	144	122	103	A's = 0·46 SQ.INCH
		c		317	248	203	168	137	113	92	76	A's = 0·46 SQ.INCH
		d	348	278	224	180	148	120	98	80	68	A's = 0·30 SQ.INCH
		e	390	328	268	218	178	148	119	102	84	A's = 0·55 SQ.INCH
		f	323	256	206	165	132	110	89	66	56	A's = 0·46 SQ.INCH
		g		298	248	198	182	133	109	90	73	A's = 0·46 SQ.INCH
5½"	0·51 sq.in.	a				373	315	266	227	193	163	A's = 0·49 SQ.INCH
		b			376	308	258	215	180	153	129	A's = 0·52 SQ.INCH
		c			306	251	205	171	143	117	97	A's = 0·52 SQ.INCH
		d		341	276	223	184	151	124	102	84	A's = 0·34 SQ.INCH
		e			329	268	224	184	154	128	107	A's = 0·62 SQ.INCH
		f		315	253	205	165	139	113	85	74	A's = 0·52 SQ.INCH
		g			305	243	226	166	137	113	94	A's = 0·52 SQ.INCH
6"	0·56 sq.in.	a					392	333	283	243	206	A's = 0·54 SQ.INCH
		b					325	270	228	194	166	A's = 0·59 SQ.INCH
		c			380	312	259	217	182	151	127	A's = 0·59 SQ.INCH
		d			345	280	233	190	160	133	111	A's = 0·39 SQ.INCH
		e					277	233	195	165	139	A's = 0·71 SQ.INCH
		f		392	317	256	209	177	148	113	98	A's = 0·59 SQ.INCH
		g			380	305	283	211	175	149	124	A's = 0·59 SQ.INCH

PANEL $l_y/l_x = 1\cdot2$

Thickness inches	As short span steel	Edge conditions	10×12	11×13·2	12×14·4	13×15·6	14×16·8	15×18	16×19·2	17×20·4	18×21·6	A's
4"	0·36 sq.in.	a	284	226	183	142	121	99	79	65	53	A's = 0·30 SQ.INCH
		b	233	185	147	118	94	76	60	49	39	A's = 0·32 SQ.INCH
		c	152	150	118	93	71	57	45	33	25	A's = 0·33 SQ.INCH
		d	181	141	111	86	66	46	34	24	18	A's = 0·22 SQ.INCH
		e	200	157	124	98	76	62	48	37	27	A's = 0·38 SQ.INCH
		f	161	125	93	75	57	46	33	22	15	A's = 0·34 SQ.INCH
		g	192	150	116	93	71	58	45	34	24	A's = 0·33 SQ.INCH
4½"	0·41 sq.in.	a	374	299	242	197	164	135	110	93	76	A's = 0·36 SQ.INCH
		b	308	246	197	160	127	106	86	71	57	A's = 0·37 SQ.INCH
		c	254	202	160	128	100	82	65	51	40	A's = 0·37 SQ.INCH
		d	239	188	151	119	94	76	61	47	36	A's = 0·26 SQ.INCH
		e	256	210	168	135	106	87	70	56	43	A's = 0·44 SQ.INCH
		f	216	169	126	108	82	67	50	35	28	A's = 0·39 SQ.INCH
		g	256	202	159	128	100	88	66	51	46	A's = 0·38 SQ.INCH
5"	0·46 sq.in.	a		398	325	267	222	186	154	131	109	A's = 0·38 SQ.INCH
		b	390	328	268	218	178	148	119	102	84	A's = 0·41 SQ.INCH
		c	340	271	218	176	139	117	95	77	62	A's = 0·41 SQ.INCH
		d	323	256	206	166	132	109	89	72	57	A's = 0·28 SQ.INCH
		e	354	282	228	186	148	124	101	83	67	A's = 0·49 SQ.INCH
		f	290	230	176	146	117	97	76	56	47	A's = 0·43 SQ.INCH
		g	341	272	217	176	139	118	96	77	62	A's = 0·42 SQ.INCH
5½"	0·51 sq.in.	a			358	327	273	230	190	163	138	A's = 0·43 SQ.INCH
		b			329	268	224	184	154	127	107	A's = 0·46 SQ.INCH
		c		373	268	218	174	147	121	99	81	A's = 0·47 SQ.INCH
		d		314	254	205	165	137	113	92	74	A's = 0·32 SQ.INCH
		e		346	281	225	184	155	128	106	87	A's = 0·55 SQ.INCH
		f		281	218	183	146	123	97	76	62	A's = 0·49 SQ.INCH
		g		331	267	218	174	148	121	98	80	A's = 0·48 SQ.INCH
6"	0·56 sq.in.	a					342	287	240	208	177	A's = 0·49 SQ.INCH
		b				335	277	233	195	165	139	A's = 0·52
		c			335	273	220	188	155	129	105	A's = 0·53 SQ.INCH
		d			317	259	209	176	145	120	100	A's = 0·36 SQ.INCH
		e			350	287	233	198	165	138	114	A's = 0·62 SQ.INCH
		f			275	230	188	159	128	98	85	A's = 0·55 SQ.INCH
		g			333	273	220	189	155	129	107	A's = 0·54 SQ.INCH

PANEL $l_y/l_x = 1\cdot3$

Thickness inches	As short span steel	Edge conditions	10×13	11×14·3	12×15·6	13×16·9	14×18·2	15×19·5	16×20·8	17×22·1	18×23·4	A's
4"	0·36 sq.in.	a	250	199	158	128	103	84	67	54	43	A's = 0·27 SQ.INCH
		b	212	166	132	105	84	66	52	40	31	A's = 0·29 SQ.INCH
		c	178	138	109	78	66	51	39	29	20	A's = 0·31 SQ.INCH
		d	168	130	102	78	60	47	35	26	17	A's = 0·21 SQ.INCH
		e	222	141	111	86	66	53	40	30	22	A's = 0·35 SQ.INCH
		f	147	112	86	66	49	37	26	17	10	A's = 0·31 SQ.INCH
		g	174	135	106	82	63	49	37	27	19	A's = 0·31 SQ.INCH
4½"	0·41 sq.in.	a	330	264	212	172	141	116	95	77	63	A's = 0·32 SQ.INCH
		b	278	221	177	143	115	93	74	59	46	A's = 0·34 SQ.INCH
		c	238	187	149	109	93	74	58	44	35	A's = 0·35 SQ.INCH
		d	224	176	139	109	85	69	53	42	31	A's = 0·24 SQ.INCH
		e	241	190	150	119	94	76	60	47	36	A's = 0·41 SQ.INCH
		f	194	152	118	93	71	55	42	30	21	A's = 0·36 SQ.INCH
		g	232	182	144	114	89	71	57	44	34	A's = 0·35 SQ.INCH
5"	0·46 sq.in.	a		352	286	234	193	161	135	111	92	A's = 0·34 SQ.INCH
		b	372	298	240	196	161	132	108	88	72	A's = 0·37 SQ.INCH
		c	318	252	203	152	132	107	86	69	55	A's = 0·39 SQ.INCH
		d	300	238	191	152	121	100	80	64	50	A's = 0·27 SQ.INCH
		e	315	262	222	171	138	116	94	77	62	A's = 0·45 SQ.INCH
		f	263	207	163	130	103	83	64	50	38	A's = 0·40 SQ.INCH
		g	291	247	198	158	126	103	84	67	54	A's = 0·37 SQ.INCH
5½"	0·51 sq.in.	a			351	288	238	195	166	139	117	A's = 0·39 SQ.INCH
		b		363	296	243	200	165	136	113	93	A's = 0·42 SQ.INCH
		c		309	250	189	165	135	109	89	73	A's = 0·44 SQ.INCH
		d		291	236	189	151	126	102	82	66	A's = 0·30 SQ.INCH
		e		322	261	212	172	145	120	99	80	A's = 0·57 SQ.INCH
		f		255	203	163	130	105	83	64	52	A's = 0·44 INCH
		g		302	243	198	158	130	107	86	71	A's = 0·44 SQ.INCH
6"	0·56 sq.in.	a				359	299	252	211	179	152	A's = 0·45 SQ.INCH
		b			370	303	251	209	171	142	122	A's = 0·48 SQ.INCH
		c			313	238	209	173	142	118	97	A's = 0·50 SQ.INCH
		d			295	239	193	162	131	109	89	A's = 0·34 SQ.INCH
		e			316	258	210	175	143	120	97	A's = 0·58 SQ.INCH
		f			255	205	168	138	110	89	71	A's = 0·51 SQ.INCH
		g			306	249	201	160	139	114	95	A's = 0·50 SQ.INCH

PANEL $l_y/l_x = 1\cdot4$

Thickness inches	As short span steel	Edge conditions	10×14	11×15·4	12×16·8	13×18·2	14×19·6	15×21	16×22·4	17×23·8	18×25·2	A's
4"	0·36 sq.in.	a	228	179	142	112	92	73	58	42	35	A's = 0·24 SQ.INCH
		b	197	153	120	100	75	59	46	35	26	A's = 0·28 SQ.INCH
		c	164	127	95	77	61	45	32	24	16	A's = 0·29 SQ.INCH
		d	161	126	97	75	58	44	33	23	15	A's = 0·20 SQ.INCH
		e	171	132	104	80	62	48	37	26	18	A's = 0·34 SQ.INCH
		f	134	103	78	69	44	32	22	14	7	A's = 0·29 SQ.INCH
		g	161	124	98	75	56	47	32	23	15	A's = 0·29 SQ.INCH
4½"	0·41 sq.in.	a	301	239	192	152	126	102	83	63	53	A's = 0·29 SQ.INCH
		b	260	203	161	136	104	83	66	53	41	A's = 0·32 SQ.INCH
		c	229	172	136	107	76	66	48	39	29	A's = 0·33 SQ.INCH
		d	216	169	132	106	83	65	50	38	28	A's = 0·23 SQ.INCH
		e	228	179	141	111	87	71	55	42	32	A's = 0·39 SQ.INCH
		f	201	140	109	85	65	49	43	29	17	A's = 0·34 SQ.INCH
		g	216	157	134	105	81	69	50	39	28	A's = 0·43 SQ.INCH
5"	0·46 sq.in.	a		320	258	208	174	143	118	92	80	A's = 0·32 SQ.INCH
		b	348	276	232	188	146	119	97	80	64	A's = 0·35 SQ.INCH
		c	295	233	186	149	122	96	73	62	48	A's = 0·37 SQ.INCH
		d	290	231	182	146	118	94	76	60	47	A's = 0·26 SQ.INCH
		e	312	248	199	161	130	108	88	71	64	A's = 0·43 SQ.INCH
		f	246	192	152	119	95	74	58	44	33	A's = 0·37 SQ.INCH
		g	290	229	185	146	116	100	86	60	46	A's = 0·37 SQ.INCH
5½"	0·51 sq.in.	a			316	258	216	178	149	117	102	A's = 0·36 SQ.INCH
		b		339	273	232	181	149	123	102	83	A's = 0·40 SQ.INCH
		c	361	286	231	185	154	122	93	80	64	A's = 0·42 SQ.INCH
		d	354	283	225	184	148	119	97	78	62	A's = 0·29 SQ.INCH
		e	382	305	246	200	163	135	112	91	75	A's = 0·49 SQ.INCH
		f	301	238	189	151	120	95	76	59	46	A's = 0·43 SQ.INCH
		g	354	281	227	183	145	126	97	78	62	A's = 0·42 SQ.INCH
6"	0·56 sq.in.	a			395	322	272	225	190	152	133	A's = 0·41 SQ.INCH
		b			340	291	230	190	159	131	108	A's = 0·45 SQ.INCH
		c			288	235	195	158	122	102	87	A's = 0·47 SQ.INCH
		d			282	231	189	153	125	104	85	A's = 0·33 SQ.INCH
		e			300	243	195	145	137	111	91	A's = 0·55 SQ.INCH
		f		298	237	192	155	125	102	81	68	A's = 0·48 SQ.INCH
		g		352	285	230	185	162	128	104	83	A's = 0·47 SQ.INCH

PANEL $l_y/l_x = 1\cdot5$

Thickness inches	As short span steel	Edge conditions	10×15	11×16·5	12×18	13×19·5	14×21	15×22·5	16×24	17×25·5	18×27	A's
4"	0·36 sq.in.	a	204	155	127	100	80	63	50	37	28	A's = 0·22 SQ.INCH
		b	181	142	105	87	67	53	40	30	23	A's = 0·26 SQ.INCH
		c	160	118	93	62	54	42	30	21	14	A's = 0·28 SQ.INCH
		d	156	119	93	67	55	42	30	21	13	A's = 0·20 SQ.INCH
		e	158	125	93	75	56	44	33	23	15	A's = 0·33 SQ.INCH
		f	127	96	73	54	39	29	19	12	6	A's = 0·28 SQ.INCH
		g	150	105	89	68	56	49	28	19	12	A's = 0·27 SQ.INCH
4½"	0·41 sq.in.	a	271	207	172	137	111	89	72	57	45	A's = 0·26 SQ.INCH
		b	240	190	142	119	94	76	60	46	35	A's = 0·29 SQ.INCH
		c	214	160	126	100	78	62	48	36	26	A's = 0·32 SQ.INCH
		d	209	161	128	95	79	62	50	38	28	A's = 0·23 SQ.INCH
		e	212	169	128	105	81	65	50	38	28	A's = 0·37 SQ.INCH
		f	171	131	102	78	59	45	35	23	17	A's = 0·33 SQ.INCH
		g	201	156	123	96	80	58	45	33	23	A's = 0·37 SQ.INCH
5"	0·46 sq.in.	a	362	280	233	188	154	126	104	84	68	A's = 0·29 SQ.INCH
		b	323	258	196	166	133	110	89	71	57	A's = 0·33 SQ.INCH
		c	288	218	167	141	111	100	72	56	44	A's = 0·35 SQ.INCH
		d	280	218	176	133	113	91	72	56	44	A's = 0·25 SQ.INCH
		e	285	229	176	147	116	95	76	60	47	A's = 0·41 SQ.INCH
		f	233	180	143	112	87	68	56	45	31	A's = 0·36 SQ.INCH
		g	271	213	170	135	116	86	68	53	41	A's = 0·35 SQ.INCH
5½"	0·51 sq.in.	a		342	286	233	191	158	131	107	88	A's = 0·33 SQ.INCH
		b		316	241	205	166	138	113	91	75	A's = 0·37 SQ.INCH
		c		269	218	176	140	118	92	73	59	A's = 0·40 SQ.INCH
		d		271	218	166	143	115	92	74	59	A's = 0·29 SQ.INC
		e		283	228	184	145	121	97	78	63	A's = 0·47 SQ.INCH
		f		223	178	141	111	89	71	51	42	A's = 0·41 SQ.INCH
		g		263	211	168	144	109	88	70	60	A's = 0·39 SQ.INCH
6"	0·56 sq.in.	a			387	291	242	200	168	140	116	A's = 0·38 SQ.INCH
		b			303	260	211	176	143	114	100	A's = 0·42 SQ.INCH
		c		336	275	222	179	149	121	98	80	A's = 0·45 INCH
		d		338	275	212	182	159	122	98	80	A's = 0·32 INCH
		e		352	275	230	185	157	126	104	85	A's = 0·53 SQ.INCH
		f		280	225	180	142	117	94	75	60	A's = 0·47 SQ.INCH
		g		328	264	213	184	143	116	94	77	A's = 0·47 SQ.INCH

CHAPTER 5

RECTANGULAR BEAMS

CONTENTS

CHAPTER 5

RECTANGULAR BEAMS

5.1 Beams with Tension Reinforcement.

The same formulae as those for slabs apply to the design of rectangular beams. However, in the case of slabs, the concrete area is generally sufficient to meet the shear stresses, while in case of rectangular beams provision for shear stresses will have to be made by means of bent-up bars and stirrups.

The charts and tables in this chapter are useful in designing rectangular beams ordinarily employed in practice. Continuous beams in a structure which are treated as T-beams at the centre of the span, act as rectangular beams over supports and the charts can be used for their calculation by placing the required reinforcement at top.

Tables 5a and 5b give R.M. and A_t for rectangular beams for different concrete and steel stresses.

Charts 5-1 & 5-2 also give R.M. and A_t as above.

Tables 5-c and 5-d give safe load per ft. run for rectangular beams as above.

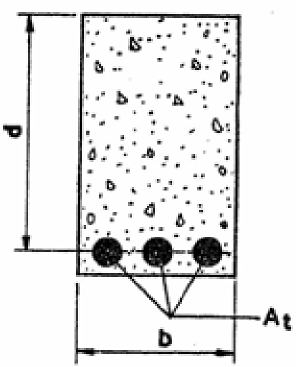


Fig. 5-1. Singly reinforced rectangular beams

5.2 Beams with Tension and Compression Reinforcement.

In practice, beams with compression steel have to be used in the following cases:

(a) T-beams, when continuous, behave as rectangular beams at supports and when singly reinforced require considerable depth to take up the B.M. Steel for compression being

automatically available from the two spans adjacent to a support, a doubly reinforced rectangular beam is more suitable from architectural considerations and practical reasons.

(b) Rectangular beams, lintels, etc. where the depth is necessarily restricted from consideration of headway or other architectural reasons.

(c) Braces, walls of storage reservoirs, etc. where B.M. reverses according to loading conditions.

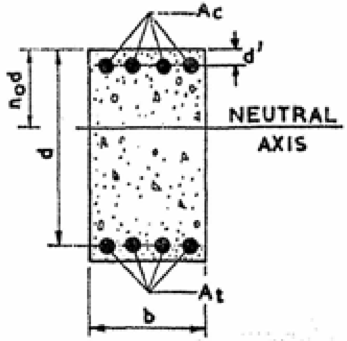


Fig. 5-2. Beam with compression reinforcement

In case of (a) and (c), the following formulae give the amount of A_c and A_t in sq. inches for B.M.=M inch lb.

$$A_c = \frac{M-137bd^2}{Kd} \; ; \qquad A_t = .009 + \frac{M-137bd^2}{18000(d-d^1)}$$

$$\text{where } K = \frac{t(m-1)\left(1-\frac{d'}{d}\right)\left(n_o-\frac{d'}{d}\right)}{m(1-n_o)}$$

The values of t being 18000 psi, and $n_o=0.43$ when fc=750 psi. The values of K are given as follows :

d'/d	.02	.04	.06	.08	.10	.12	.14	.16	.18	.20
K	11850	11050	10260	9500	8760	8100	7360	6780	6030	5420

In case of (c), it is necessary to provide equal top and bottom steel. In this case, both steel and concrete may not be stressed to the maximum permitted stress. If steel is assumed to be stressed to the maximum permissible limit, the stress in concrete will be below the maximum limit. Alternatively if concrete is fully stressed, steel will be understressed. The following procedure is necessary to find out the R.M. of section reinforced with known amount of A_c and A_t :—

Determine position of neutral axis by the general formula

$$n_o = \sqrt{[mr+(m-1)r']^2+2[mr+(m-1)r'\frac{d'}{d}]} \\ -[mr+(m-1)r']$$

where $r = \frac{At}{bd}$ and $r' = \frac{A_c}{bd}$

Use of table 5a will facilitate the calculation.

$$A = mr + (m-1)\ r' \text{ and } B = mr + (m-1)\ r'\ \frac{d'}{d}$$

$$n_o = \sqrt{A^2 + 2B} - A$$

The figures in vertical columns give the values of B. For values of A and B calculated as above, the required value of n_o can be found from the top horizontal column.

After the position of neutral axis is determined, the R.M. can be found by the following formulae :—

$$\frac{M}{bd^2} = t\frac{n_o}{m(1-n_o)}\left[\frac{n_o}{2}(1-\frac{n_o}{3}) + \frac{A_c}{bd}(1-\frac{p}{d})(n_o-\frac{d'}{d})\frac{m-1}{n_o}\right] = Q$$

or

$$\frac{M}{bd^2} = \frac{fc}{2}n_o\left(1-\frac{n_o}{3}\right) \times \frac{A_c}{bd}\left(1-\frac{d'}{d}\right)\left(n_o-\frac{d'}{d}\right)\frac{(m-1)}{n_o}fc = Q$$

The smaller of the two values of Q calculated by the above formulae is to be adopted. With fc = 750, t = 18000 and $\frac{d'}{d} = 0.1$, the values of Q for different percentages of steel and modular ratios are as follows :

	m = 15	m = 18
$A_c = A_t = 1.0\%$	159	159
$A_c = A_t = 1.5\%$	232	242
$A_c = A_t = 2.0\%$	276	314

The adoption of the above formulae which are rather complicated can be avoided if necessary by finding the moment of inertia of the beam as illustrated in example (2).

5.3 Steel Beam Theory

A beam having equal steel at top and bottom can be treated as a steel beam and its strength may be calculated on the assumption that the concrete area can be neglected as far as bending is concerned.

In this case $RM = t \times A_t\ (d-d') = 18000\ A_t\ (d-d')$

This method however should be used with caution as at higher percentage of steel, the strength by this theory is much more than that obtained by application of standard theory. Hence this method should not be used where p is more than 3%.

5.4 Charts, Tables Etc. for Design.

Table 5a. Position of neutral axis for beams with tension and compression reinforcement.

A	λ_o x																									
	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70
0.05	.030	.035	.041	.047	.053																					
0.06	.032	.037	.043	.049	.056	.063																				
0.07	.034	.040	.046	.052	.059	.066	.074																			
0.08	.036	.042	.048	.055	.062	.069	.077	.086																		
0.09	.038	.044	.050	.057	.064	.072	.080	.088	.097																	
0.10	.040	.046	.053	.060	.067	.075	.083	.092	.101																	
0.11	.042	.048	.055	.062	.070	.078	.086	.095	.104	.114																
0.12	.044	.051	.058	.065	.073	.081	.090	.099	.108	.118	.128															
0.13	.046	.053	.060	.068	.076	.084	.093	.102	.112	.122	.132															
0.14	.048	.055	.062	.070	.078	.087	.096	.105	.115	.125	.136	.147														
0.15	.050	.057	.065	.073	.081	.090	.099	.109	.119	.129	.140	.151														
0.16	.052	.059	.067	.075	.084	.093	.102	.112	.122	.133	.144	.155	.167													
0.17	.054	.062	.070	.078	.087	.096	.106	.116	.126	.137	.148	.160	.172													
0.18	.056	.064	.072	.081	.090	.099	.109	.119	.130	.141	.152	.164	.176	.189												
0.19	.058	.066	.074	.083	.092	.102	.112	.122	.133	.144	.156	.168	.180	.193												
0.20	.060	.068	.077	.086	.095	.105	.115	.126	.137	.148	.160	.172	.185	.198	.211											
0.21	.062	.070	.079	.088	.098	.108	.118	.129	.140	.152	.164	.176	.189	.202	.216											
0.22	.064	.073	.082	.091	.101	.111	.122	.133	.144	.156	.168	.181	.194	.207	.221											
0.23	.066	.075	.084	.094	.104	.114	.125	.136	.148	.160	.172	.185	.198	.212	.226	.240										
0.24	.068	.077	.086	.096	.106	.117	.128	.139	.151	.163	.176	.189	.202	.216	.230	.245										
0.25	.070	.079	.089	.099	.109	.120	.131	.143	.155	.167	.180	.193	.207	.221	.235	.250										
0.26	.072	.081	.091	.101	.112	.123	.134	.146	.158	.171	.184	.197	.211	.225	.240	.255	.270									
0.27	.074	.084	.094	.104	.115	.126	.138	.150	.162	.175	.188	.202	.216	.230	.245	.260	.276									
0.28	.076	.086	.096	.107	.118	.129	.141	.153	.166	.179	.192	.206	.220	.235	.250	.265	.281									
0.29	.078	.088	.098	.109	.120	.132	.144	.156	.169	.182	.196	.210	.224	.239	.254	.270	.286	.302								
0.30	.080	.090	.101	.112	.123	.135	.147	.160	.173	.186	.200	.214	.229	.244	.259	.275	.291	.308								
0.31	.082	.092	.103	.114	.126	.138	.150	.163	.176	.190	.204	.218	.233	.248	.264	.280	.296	.313								
0.32	.084	.095	.106	.117	.129	.141	.154	.167	.180	.194	.208	.223	.238	.253	.269	.285	.302	.319	.336							
0.33	.086	.097	.108	.120	.132	.144	.157	.170	.184	.198	.212	.227	.242	.258	.274	.290	.307	.324	.342							
0.34	.088	.099	.110	.122	.134	.147	.160	.173	.187	.201	.216	.231	.246	.262	.278	.295	.312	.329	.347							
0.35	.090	.101	.113	.125	.137	.150	.163	.177	.191	.205	.220	.235	.251	.267	.283	.300	.317	.335	.353							
0.36	.092	.103	.115	.127	.140	.153	.166	.180	.194	.209	.224	.239	.255	.271	.288	.305	.322	.340	.358	.377						
0.37	.094	.106	.118	.130	.143	.156	.170	.184	.198	.213	.228	.244	.260	.276	.293	.310	.328	.346	.364	.383						
0.38	.096	.108	.120	.133	.146	.159	.173	.187	.202	.217	.232	.248	.264	.281	.298	.315	.333	.351	.370	.389						
0.39	.098	.110	.122	.135	.148	.162	.176	.190	.205	.220	.236	.252	.268	.285	.302	.320	.338	.356	.375	.394						
0.40	.100	.112	.125	.138	.151	.165	.179	.194	.209	.224	.240	.256	.273	.290	.307	.325	.343	.362	.381	.400						
0.41	.102	.114	.127	.140	.154	.168	.182	.197	.212	.228	.244	.260	.277	.294	.312	.330	.348	.367	.386	.406	.426					
0.42	.104	.117	.130	.143	.157	.171	.186	.201	.216	.232	.248	.265	.282	.299	.317	.335	.354	.373	.392	.412	.432					
0.43	.106	.119	.132	.146	.160	.174	.189	.204	.220	.236	.252	.269	.286	.304	.322	.340	.359	.378	.398	.418	.438					
0.44	.108	.121	.134	.148	.162	.177	.192	.207	.223	.239	.256	.273	.290	.308	.326	.345	.364	.383	.403	.423	.444					
0.45	.110	.123	.137	.151	.165	.180	.195	.211	.227	.243	.260	.277	.295	.313	.331	.350	.369	.389	.409	.429	.450					
0.46	.112	.125	.139	.153	.168	.183	.198	.214	.230	.247	.264	.281	.299	.317	.336	.355	.374	.394	.414	.435	.456	.477				
0.47	.114	.128	.142	.156	.171	.186	.202	.218	.234	.251	.268	.286	.304	.322	.341	.360	.380	.400	.420	.441	.462	.484				
0.48	.116	.130	.144	.159	.174	.189	.205	.221	.238	.255	.272	.290	.308	.327	.346	.365	.385	.405	.426	.447	.468	.490				
0.49	.118	.132	.146	.161	.176	.192	.208	.224	.241	.258	.276	.294	.312	.331	.350	.370	.390	.410	.431	.452	.474	.496				
0.50	.120	.134	.149	.164	.179	.195	.211	.228	.245	.262	.280	.298	.317	.336	.355	.375	.395	.416	.437	.458	.480	.502				
0.51	.122	.136	.151	.166	.182	.198	.214	.231	.248	.266	.284	.302	.321	.340	.360	.380	.400	.421	.442	.464	.486	.508	.531			
0.52	.124	.139	.154	.169	.185	.201	.218	.235	.232	.270	.288	.307	.326	.345	.365	.385	.406	.427	.448	.470	.592	.515	.538			
0.53	.126	.141	.156	.172	.188	.204	.221	.238	.256	.274	.292	.311	.330	.350	.370	.390	.411	.432	.454	.476	.498	.521	.544			
0.54	.128	.143	.158	.174	.190	.207	.224	.241	.259	.277	.296	.315	.334	.354	.374	.395	.416	.437	.459	.481	.504	.527	.550			
0.55	.130	.145	.161	.177	.193	.210	.227	.245	.263	.281	.300	.319	.339	.359	.379	.400	.421	.443	.465	.487	.510	.533	.557			
0.56	.132	.147	.163	.179	.196	.213	.230	.248	.266	.285	.304	.323	.343	.363	.384	.405	.426	.448	.470	.493	.516	.539	.563			
0.57	.134	.150	.166	.182	.199	.216	.234	.252	.270	.289	.308	.328	.348	.368	.389	.410	.432	.454	.476	.499	.522	.546	.570			
0.58	.136	.152	.168	.185	.202	.219	.237	.255	.274	.293	.312	.332	.352	.373	.394	.415	.437	.459	.482	.505	.528	.552	.576	.601		
0.59	.138	.154	.170	.187	.204	.222	.240	.258	.277	.296	.316	.336	.356	.377	.398	.420	.442	.464	.487	.510	.534	.558	.582	.607		
0.60	.140	.156	.173	.190	.207	.225	.243	.262	.281	.300	.320	.340	.361	.382	.403	.425	.447	.470	.493	.516	.540	.564	.589	.614		
0.61	.142	.158	.175	.192	.210	.228	.246	.265	.284	.304	.324	.344	.365	.386	.408	.430	.452	.475	.498	.522	.546	.570	.595	.620		
0.62	.144	.161	.178	.195	.213	.231	.250	.269	.288	.308	.328	.349	.370	.391	.413	.435	.458	.481	.504	.528	.552	.577	.602	.627		
0.63	.146	.163	.180	.198	.216	.234	.253	.272	.292	.312	.332	.353	.374	.396	.418	.440	.463	.486	.510	.534	.558	.583	.608	.634		
0.64	.148	.165	.182	.200	.218	.237	.256	.275	.295	.315	.336	.357	.378	.400	.422	.445	.468	.491	.515	.539	.564	.589	.614	.640		
0.65	.150	.167	.185	.203	.221	.240	.259	.279	.299	.319	.340	.361	.383	.405	.427	.450	.473	.497	.521	.545	.570	.595	.621	.647	.673	
0.66	.152	.169	.187	.205	.224	.243	.262	.282	.302	.323	.344	.365	.387	.409	.432	.455	.478	.502	.526	.551	.576	.601	.627	.653	.680	
0.67	.154	.172	.190	.208	.227	.246	.266	.286	.306	.327	.348	.370	.392	.414	.437	.460	.484	.508	.532	.557	.582	.608	.634	.660	.687	
0.68	.156	.174	.192	.211	.230	.249	.269	.289	.310	.331	.352	.374	.396	.419	.442	.465	.489	.513	.538	.563	.588	.614	.640	.667	.691	
0.69	.158	.176	.194	.213	.232	.252	.272	.292	.313	.334	.356	.378	.400	.423	.446	.470	.494	.518	.543	.568	.594	.620	.646	.673	.700	
0.70	.160	.178	.197	.216	.235	.255	.275	.296	.317	.338	.360	.382	.405	.428	.451	.475	.499	.524	.549	.574	.600	.626	.653	.680	.707	
0.71	.162	.180	.199	.218	.238	.258	.278	.299	.320	.342	.364	.386	.409	.432	.456	.480	.504	.529	.554	.580	.606	.632	.659	.686	.714	
0.72	.164	.183	.202	.221	.241	.261	.282	.303	.324	.346	.368	.391	.414	.437	.461	.485	.510	.535	.560	.586	.612	.639	.666	.693	.721	
0.73	.166	.185	.204	.224	.244	.264	.285	.306	.328	.350	.372	.395	.418	.442	.466	.490	.515	.540	.566	.592	.618	.645	.672	.700	.728	.756
0.74	.168	.187	.206	.226	.246	.267	.288	.309	.331	.353	.376	.399	.422	.446	.470	.495	.520	.545	.571	.597	.624	.651	.678	.706	.734	.763

Table 5b. Rectangular beams: resistance moments and reinforcement section for various depths and widths.

fc=750, t=18000 and m=18. R.M. in ft. lb

d \ b	6"	8"	9"	10"	12"	14"	15"	16"	18"	20"
6"	2466 .32	3287 .43	3699 .48	4127 .53	4932 .64	5743 .75	6165 .80	6575 .85	7398 .96	8254 1.07
7"	3356 .37	4475 .50	5034 .56	5618 .62	6713 .75	7831 .87	8391 .94	8950 1.00	10069 1.12	11230 1.25
8"	4384 .43	5845 .57	6576 .64	7338 .71	8768 .85	10229 1.00	10960 1.07	11690 1.14	13152 1.28	14613 1.42
9"	5548 .48	7397 .64	8322 .72	9287 .80	11097 .96	12946 1.12	13871 1.20	14795 1.28	16645 1.44	18474 1.60
10"	6850 .53	9133 .71	10275 .80	11466 .89	13700 1.07	15983 1.25	17125 1.34	18266 1.42	20550 1.60	22833 1.78
11"	8288 .59	11050 .78	12432 .88	13873 .98	16577 1.18	19337 1.37	20721 1.47	22101 1.57	24865 1.76	27627 1.06
12"	9864 .64	13151 .85	14796 .96	16511 1.07	19728 1.28	23015 1.50	24660 1.60	26303 1.71	29592 1.92	32879 2.14
13"	11576 .69	15434 .93	17304 1.04	19377 1.16	23153 1.39	27011 1.62	28941 1.74	30869 1.85	34729 2.08	38587 2.31
14"	13426 .75	17900 1.00	20139 1.12	22473 1.25	26852 1.50	31326 1.74	33565 1.87	35801 2.00	40278 2.24	44752 2.49
15"	15412 .80	20549 1.07	23118 1.20	25798 1.34	30825 1.60	35961 1.87	38531 2.00	41098 2.14	46237 2.40	51374 2.67
16"	17536 .85	23380 1.14	26304 1.28	29352 1.42	35072 1.71	40916 1.99	43840 2.14	46760 2.28	52608 2.56	58452 2.85
17"	19796 .91	26394 1.21	29694 1.36	33136 1.51	39593 1.82	46190 2.12	49391 2.27	52788 2.42	59389 2.72	65980 3.03
18"	22194 .96	29590 1.28	33291 1.41	37140 1.60	44388 1.92	51784 2.24	55485 2.40	59181 2.56	66485 2.88	74298 3.20
19"	24728 1.02	32970 1.35	37092 1.52	41392 1.69	49457 2.03	57698 2.37	61821 2.54	65900 2.71	74077 3.04	82784 3.38
20"	27400 1.07	36532 1.42	41100 1.6	45864 1.78	54800 2.14	63932 2.40	68500 2.67	73064 2.85	82200 3.20	91728 3.56
21"	30208 1.12	40276 1.50	45312 1.68	50565 1.87	60417 2.24	70486 2.62	75521 2.80	80553 2.99	90625 3.36	101130 3.74
22"	33154 1.17	44203 1.57	49731 1.76	55405 1.96	66308 2.35	77357 2.74	82885 2.94	88407 3.13	99462 3.52	110511 3.92
23"	36242 1.23	48313 1.64	54354 1.84	60400 2.05	72473 2.46	84550 2.87	90591 3.07	96627 3.28	108709 3.69	120786 4.09
24"	39456 1.28	52606 1.71	59184 1.92	65757 2.14	78912 2.56	92062 2.99	98640 3.21	105212 3.42	118368 3.85	131518 4.27
25"	42812 1.34	57081 1.78	64218 2.00	71662 2.23	85625 2.67	99893 3.12	107031 3.34	114162 3.56	128437 4.01	142706 4.45
26"	46306 1.39	61730 1.85	69459 2.08	77510 2.31	92612 2.78	108045 3.24	115765 3.47	123478 3.70	138918 4.17	154351 4.63
27"	49936 1.44	66579 1.92	74904 2.16	83587 2.40	99873 2.88	116516 3.36	124841 3.61	133159 3.85	149809 4.33	166452 4.81
28"	53704 1.50	71602 1.99	80556 2.24	89893 2.49	107408 2.99	125306 3.49	134560 3.74	143205 3.99	161112 4.49	179010 4.98
29"	57608 1.55	76801 2.07	86412 2.32	96429 2.58	115217 3.10	134417 3.61	144024 3.87	153617 4.13	172825 4.65	192025 5.16
30"	61650 1.60	82197 2.14	92475 2.40	103194 2.67	123300 3.20	143847 3.74	154125 4.01	164394 4.27	184950 4.81	205497 5.34
31"	65828 1.66	87768 2.21	98742 2.48	110188 2.76	131657 3.31	153596 3.86	164571 4.14	175536 4.41	197485 4.97	219425 5.52
32"	70144 1.71	93521 2.28	105216 2.56	117411 2.85	140288 3.42	163665 3.99	175702 4.27	187043 4.56	210432 5.13	233809 5.70
33"	74596 1.76	99458 2.35	111894 2.64	124884 2.94	149193 3.52	174054 4.11	186491 4.41	198196 4.70	223789 5.29	248651 5.87
34"	79186 1.82	105577 2.42	118779 2.72	132546 3.03	158372 3.63	184763 4.24	197965 4.54	211154 4.84	237558 5.45	263949 6.05

Table 5-c Rectangular beams: resistance moments and reinforcement section for various depths and widths.

fc=750 t=18000 m=15. R.M. in ft. lb.

d \ b	6″	8″	9″	10″	12″	14″	15″	16″	18″	20″
6″	2268 .288	3024 .384	3402 .432	3780 .480	4536 .576	5292 .67	5670 .72	6048 .77	6804 .86	7560 .96
7″	3087 .336	4116 .448	4630 .504	5145 .560	6174 .672	7203 .78	7717 .84	8232 .90	9261 1.01	10290 1.12
8″	4032 .384	5376 .512	6048 .576	6720 .640	8064 .768	9408 .90	10080 .96	10752 1.02	12096 1.15	13440 1.28
9″	5103 .432	6804 .576	7654 .648	8505 .720	10206 .864	11907 1.01	12757 1.08	13608 1.15	15309 1.30	17010 1.44
10″	6300 .480	8400 .640	9450 .720	10500 .800	12600 .960	14700 1.12	15750 1.20	16800 1.28	18900 1.44	21000 1.60
11″	7623 .528	10164 .704	11434 .792	12705 .880	15246 1.056	15187 1.23	19057 1.32	20328 1.41	22869 1.58	25410 1.76
12″	9072 .576	12096 .768	13608 .864	15120 .960	18144 1.152	21168 1.34	22680 1.44	24192 1.54	27216 1.73	30240 1.92
13″	10647 .624	14196 .832	15970 .936	17745 1.04	21294 1.248	24843 1.46	26617 1.56	28392 1.66	31941 1.87	35490 2.08
14″	12348 .672	16464 .896	18522 1.00	20580 1.12	24696 1.34	28812 1.57	30870 1.68	32928 1.79	37044 2.05	41160 2.24
15″	14175 .72	18900 .96	21262 1.08	23625 1.20	28350 1.44	33075 1.68	35437 1.80	37800 1.92	42525 2.16	47250 2.40
16″	16128 .77	21504 1.02	24192 1.15	26880 1.28	32256 1.54	37632 1.79	40320 1.92	43008 2.05	48384 2.30	53760 2.56
17″	18207 .82	24276 1.09	27310 1.22	30345 1.36	36414 1.63	42483 1.90	45517 2.04	48552 2.18	54621 2.45	60690 2.72
18″	20402 .86	27216 1.15	30618 1.30	34020 1.44	40824 1.73	47628 2.02	51030 2.16	54432 2.3	61236 2.59	68040 2.88
19″	22743 .91	30324 1.22	34114 1.37	37905 1.52	45486 1.82	53067 2.13	56857 2.28	60648 2.43	68229 2.74	75810 3.04
20″	25200 .96	33600 1.28	37800 1.44	42000 1.60	50400 1.92	58800 2.24	63000 2.40	67200 2.56	75600 2.88	84000 3.20
21″	27783 1.01	37044 1.34	41674 1.51	46305 1.68	55566 2.02	64827 2.35	69457 2.52	74088 2.69	83349 3.02	92610 3.36
22″	30492 1.056	40656 1.41	45738 1.58	50820 1.76	60984 2.11	71148 2.46	76230 2.64	81312 2.82	91476 3.17	101640 3.52
23″	33327 1.10	44436 1.47	49990 1.66	55542 1.84	66654 2.21	77763 2.58	83317 2.76	88872 2.94	99981 3.31	111090 3.68
24″	36288 1.15	48384 1.54	54432 1.73	60480 1.92	72576 2.3	84672 2.69	90720 2.88	96768 3.07	108864 3.46	120960 3.84
25″	39375 1.20	52500 1.60	59062 1.80	65625 2.00	78750 2.40	91875 2.8	98437 3.00	105000 3.20	118125 3.60	131250 4.00
26″	42588 1.24	56784 1.67	63882 1.87	70980 2.08	85176 2.50	99372 2.91	106470 3.12	113568 3.33	127764 3.74	141960 4.16
27″	45927 1.30	61236 1.73	68890 1.94	76545 2.16	91854 2.59	107163 3.02	114817 3.24	122472 3.46	137781 3.89	153090 4.32
28″	49392 1.34	65856 1.79	74088 2.02	82320 2.24	98784 2.67	115248 3.14	123480 3.36	131712 3.58	148176 4.03	164640 4.48
29″	52983 1.39	70644 1.86	79474 2.09	88305 2.32	105966 2.78	123627 3.25	132457 3.48	141288 3.71	158949 4.18	176610 4.64
30″	56700 1.44	75600 1.92	85050 2.16	94500 2.40	113400 2.88	132300 3.36	141750 3.60	151200 3.84	170100 4.32	189000 4.80
31″	60543 1.49	80724 1.98	90814 2.23	100905 2.48	121086 2.98	141267 3.47	151357 3.73	161448 3.97	181629 4.46	200810 4.96
32″	64512 1.54	86016 2.05	96768 2.30	107520 2.56	129024 3.07	150528 3.58	161280 3.84	172032 4.10	193536 4.61	215040 5.12
33″	68603 1.58	91476 2.11	102910 2.38	114345 2.64	137214 3.17	160083 3.70	171570 3.96	182952 4.22	205821 4.75	228690 5.28
34″	72828 1.63	97104 2.18	109242 2.45	121380 2.72	145656 3.26	169932 3.81	182070 4.08	194208 4.35	218484 4.90	242760 5.44

Table 5-d Rectangular beams: Safe uniformly distributed load including weight of beam lb/rft.

fc=750 psi, t=18,000 psi, m=18

Size b x d	B.M. Ft. Lb	A_t Sq. in.	Effective Span in Feet 6	7	8	9	10	12	14	16	18	20
8"× 8"	5850	0.57	1300	956	731	578	468	325	238	182	142	117
8"×10"	9260	0.71	2160	1520	1160	912	740	515	375	288	225	185
8"×12"	13200	0.85	2930	2158	1650	1305	1052	735	540	412	326	264
8"×14"	18200	1.00	4050	2970	2275	1800	1455	1010	742	569	450	364
8"×16"	23400	1.14	5200	3810	2920	2320	1860	1300	940	730	577	467
8"×18"	29500	1.28	6550	4800	3680	2910	2358	1680	1200	920	728	590
8"×20"	36500	1.42			4560	3600	2920	2030	1500	1145	905	734
8"×22"	44200	1.57			5530	4360	3540	2460	1800	1380	1090	885
8"×24"	52600	1.71				5200	4200	2940	2140	1646	1300	1050
8"×26"	62000	1.85					4950	3440	2530	1960	1560	1240
10"×10"	11400	0.87	2530	1860	1425	1125	910	634	465	356	282	238
10"×12"	16450	1.04	3660	2680	2060	1625	1315	915	672	515	406	328
10"×14"	22380	1.22	4970	3650	2800	2200	1780	1240	915	700	562	446
10"×16"	29300	1.39	6500	4780	3660	2890	2340	1625	1195	923	724	585
18"×18"	37000	1.57		6040	4620	3650	2960	2050	1510	1150	915	740
10"×20"	45700	1.78			5700	4500	3660	2535	1860	1425	1125	914
10"×22"	55000	1.90			6860	5430	4400	3060	2240	1720	1350	1100
10"×24"	65700	2.08				6500	5250	3650	2680	2050	1620	1310
10"×26"	77000	2.26					6150	4270	3140	2400	1960	1540
10"×28"	89500	2.44						4960	3650	2800	2210	1790
12"×12"	23800	1.25	5300	3880	2880	2350	1900	1320	970	745	587	476
12"×14"	26800	1.46	5950	4370	3350	2650	2140	1490	1090	840	660	535
12"×16"	34800	1.68	7740	5700	4350	3440	2780	1930	1420	1805	860	695
12"×18"	44500	1.88		7260	5550	4400	3560	2470	1815	1390	1100	890
12"×20"	54700	2.09			6850	5410	4380	3040	2230	1710	1350	1095
12"×22"	66000	2.30				6510	5270	3660	2680	2060	1625	1315
12"×24"	79000	2.50					6310	4380	3220	2460	1945	1575
12"×26"	92600	2.70						5140	3780	2880	2280	1850
12"×28"	107000	2.94						5950	4370	3350	2640	2140
12"×30"	123400	3.14						6850	5040	3850	3040	2460

Note: To the left of the stepped line shear intensity exceeds 75 psi

Table 5-c. Rectangular beams: Safe uniformly distributed load including weight of beam, lb/rft

fc=750 psi, t=18000 psi, m=15

Size b×d	R.M. Ft. Lb	At Sq. in.	Effective Span in Feet									
			6	7	8	9	10	12	14	16	18	20
8"× 8"	5376	.51	1195	880	672	532	430	295	219	168	133	107
8"×10"	8400	.64	1870	1370	1050	830	672	466	343	262	207	168
8"×12"	12096	.77	2680	1970	1512	1195	970	670	494	378	298	242
8"×14"	16464	.90	3660	2690	2058	1630	1322	915	675	515	407	329
8"×16"	21504	1.02	4770	3500	2688	2120	1730	1190	877	672	530	430
8"×18"	27216	1.15	6050	4430	3402	2690	2180	1510	1110	850	670	544
8"×20"	33600	1.28			4200	3320	2690	1865	1370	1050	830	672
8"×22"	38976	1.41			4820	3850	3120	2160	1580	1240	962	730
8"×24"	48384	1.54				4750	3870	2680	1980	1510	1190	968
8"×26"	56784	1.66					4550	3150	2320	1780	1400	1135
10"×10"	10500	.8	2330	1710	1310	1035	840	584	428	318	259	210
10"×12"	15120	.96	3360	2400	1800	1490	1210	840	617	472	373	302
10"×14"	20580	1.12	4570	3300	2560	2150	1645	1140	837	643	509	412
10"×16"	26880	1.28	6000	4400	3360	2660	2150	1500	1100	810	667	538
10"×18"	34020	1.44		5500	4250	3360	2720	1900	1390	1062	840	680
10"×20"	42000	1.60			5250	4150	3360	2340	1720	1310	1038	840
10"×22"	50820	1.76			6350	5020	4050	2820	2070	1585	1255	1016
10"×24"	60480	1.92				5070	4840	3360	2470	1885	1490	1210
10"×26"	20085	2.08					5670	3940	2900	2205	1755	1419
10"×28"	82300	2.24						4580	3360	2570	2035	1656
12"×12"	18148	1.15	4020	2960	2270	1790	1450	1008	740	566	447	363
12"×14"	24696	1.34	5420	4020	3087	2430	1970	1370	1000	770	610	494
12"×16"	32256	1.54	7160	5260	4032	3190	2580	1790	1321	1005	795	645
12"×18"	40824	1.73		6670	5103	4030	3260	2260	1660	1275	1005	816
12"×20"	50400	1.92			6300	4970	4300	2790	2050	1575	1240	1008
12"×22"	60984	2.11				6000	4870	3370	2470	1900	1500	1220
12"×24"	72576	2.30					5800	4010	2950	2270	1790	1451
12"×26"	85176	2.40						4720	3470	2660	2100	1704
12"×28"	98784	2.69						5470	4010	3090	2430	1975
12"×30"	113400	2.88						6300	4620	3540	2800	2227

Note :—Shear intensity more than 75 psi. to left of stepped line.

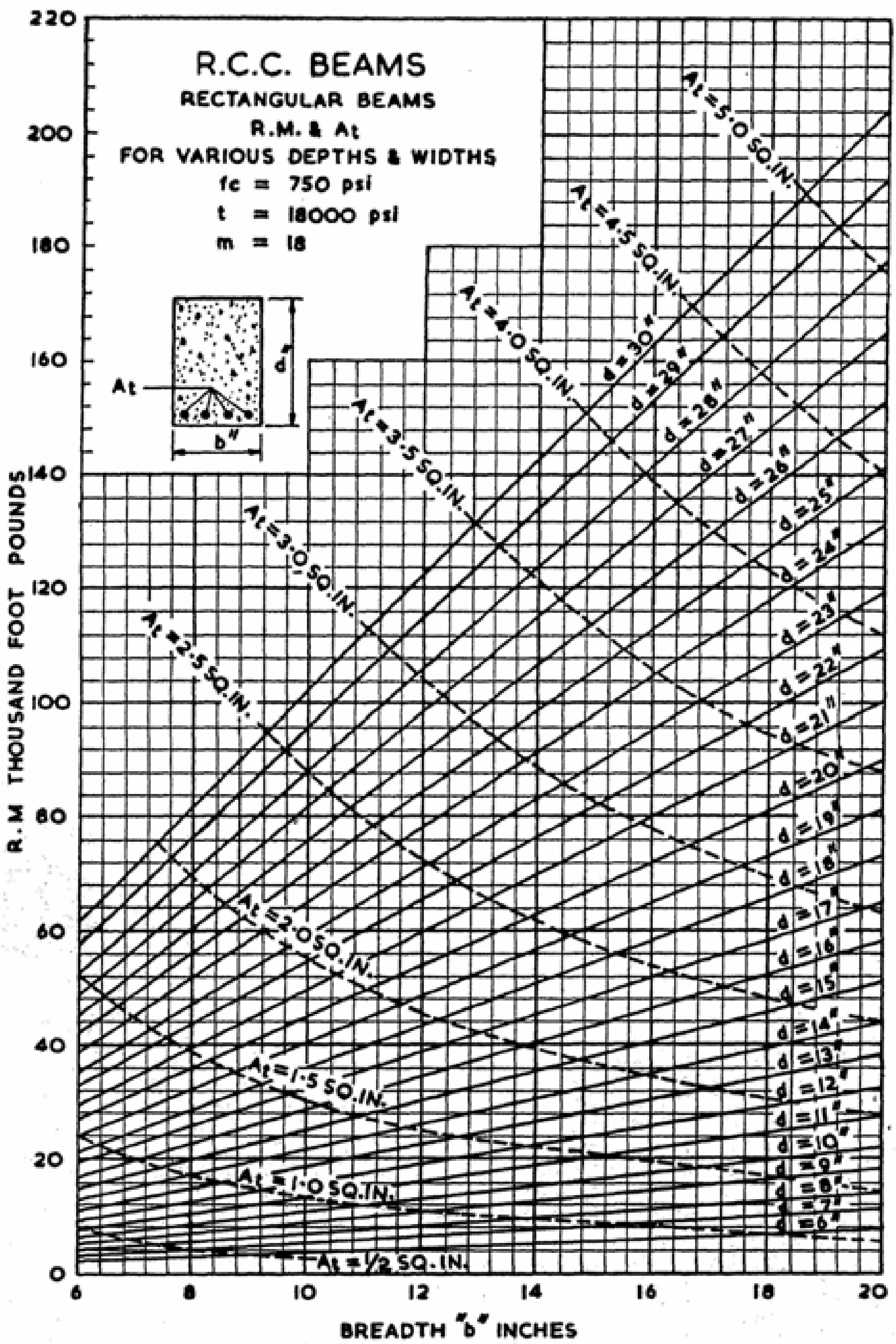

R.C.C. BEAMS
RECTANGULAR BEAMS
R.M. & At
FOR VARIOUS DEPTHS & WIDTHS
fc = 750 psi
t = 18000 psi
m = 18
At
d"
b"
R.M THOUSAND FOOT POUNDS
BREADTH "b" INCHES
At = 5·0 SQ.IN.
At = 4·5 SQ.IN.
At = 4·0 SQ.IN.
At = 3·5 SQ.IN.
At = 3·0 SQ.IN.
At = 2·5 SQ.IN.
At = 2·0 SQ.IN.
At = 1·5 SQ.IN.
At = 1·0 SQ.IN.
At = 1/2 SQ.IN.
d = 30"
d = 29"
d = 28"
d = 27"
d = 26"
d = 25"
d = 24"
d = 23"
d = 22"
d = 21"
d = 20"
d = 19"
d = 18"
d = 17"
d = 16"
d = 15"
d = 14"
d = 13"
d = 12"
d = 11"
d = 10"
d = 9"
d = 8"
d = 7"
d = 6"

Chart 5-1

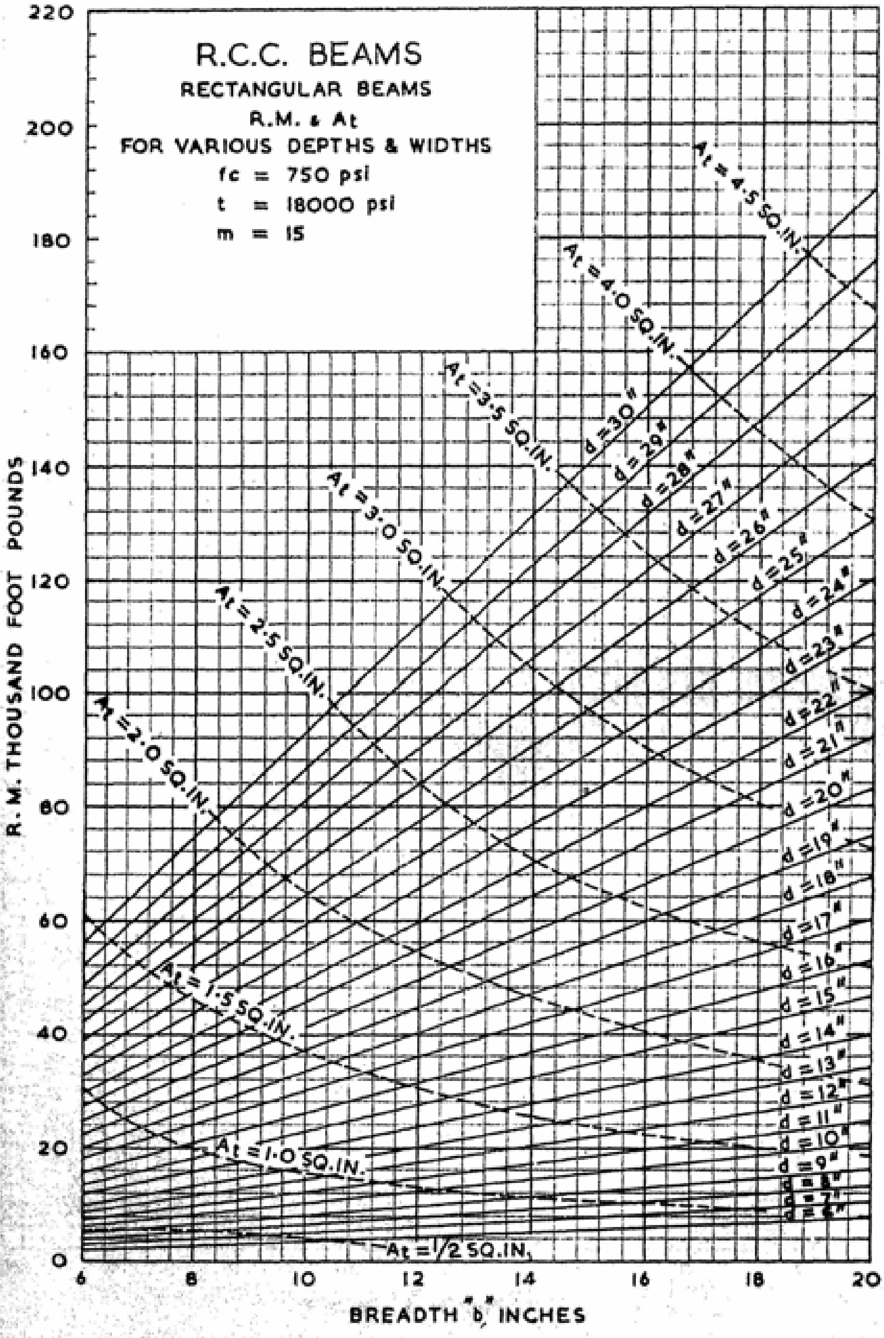

R.C.C. BEAMS
RECTANGULAR BEAMS
R.M. & At
FOR VARIOUS DEPTHS & WIDTHS
fc = 750 psi
t = 18000 psi
m = 15
R. M. THOUSAND FOOT POUNDS
BREADTH "b" INCHES
At = 4·5 SQ.IN.
At = 4·0 SQ.IN.
At = 3·5 SQ.IN.
At = 3·0 SQ.IN.
At = 2·5 SQ.IN.
At = 2·0 SQ.IN.
At = 1·5 SQ.IN.
At = 1·0 SQ.IN.
At = 1/2 SQ.IN.
d = 30"
d = 29"
d = 28"
d = 27"
d = 26"
d = 25"
d = 24"
d = 23"
d = 22"
d = 21"
d = 20"
d = 19"
d = 18"
d = 17"
d = 16"
d = 15"
d = 14"
d = 13"
d = 12"
d = 11"
d = 10"
d = 9"
d = 8"
d = 7"
d = 6"
0
20
40
60
80
100
120
140
160
180
200
220
6
8
10
12
14
16
18
20

Chart 5-2

5.5 Examples.

Example 1 :

A beam 12″×20″ (effective d) is subjected to a BM of 10,00,000 in lb. Find the compressive and tensile reinforcement if d′/d=.10

R. M. of above beam from table No. 5b = 54,800 ft. lb. = 6,57,600 inch lb. and value of constant K for given d′/d =8760

$$\therefore\ A_c = \frac{10,00,000-657600}{K\times 20} = \frac{342400}{8760\times 20} = 1.97 \text{ sq. in.}$$

$$A_t = .009bd + \frac{342400}{18000\times 18} = 2.16+1.05 = 3.21 \text{ sq. in.}$$

Example 2 :

Find the safe B. M. for a beam 12″ wide and 22″ effective depth having 1.7 sq. in. as compressive reinforcement and 2.25 sq. in. as tensile reinforcement. The centre of compression reinforcement is at 2″ from top (m=15).

$$r = \frac{2.25}{22\times 12}$$

$$r' = \frac{1.7}{22\times 12}$$

$$\therefore\ mr = 15\times\frac{2.25}{264} = .128$$

$$(m-1)r' = 14\times\frac{1.7}{264} = .087$$

$$(m-1)r' \times\frac{d_1}{d} = \frac{2}{22} \times .087 = .008$$

∴ from Table no. 5a for A = .128+.087 = .215 and B = .128+.008 = .136, n_o=.35

Hence $n_o d$=.35×22=7.7 inches.

∴ I of the beam $=12\times 7.7^3\times 1/3$ (concrete in compression)
$+14\times 1.7\times 5.7^2$ (steel in compression)
$+15\times 2.25\times (22-7.7)^2$ (steel in tension)
=1824+772+6860=9456 inch units.

$$M = \frac{I}{y_1}\ fc = \frac{9456\times 750}{7.7} = 920000 \text{ in lb}$$

$$\text{or}\quad M = \frac{I}{y_2}\ \frac{t}{m} = \frac{9456\times 18000}{14.3\times 15} = 792000 \text{ in. lb}$$

(y_1 and y_2 are distances of top and bottom from neutral axis)

∴ Safe BM = 792000 inch lb.

NOTES.

CHAPTER 6

T-BEAMS AND L-BEAMS

CONTENTS

CHAPTER 6

T-BEAMS AND L-BEAMS

6.1 General.

In practice in case of T-beams, the thickness of the flange d_s is the same as the thickness of slab already calculated to span

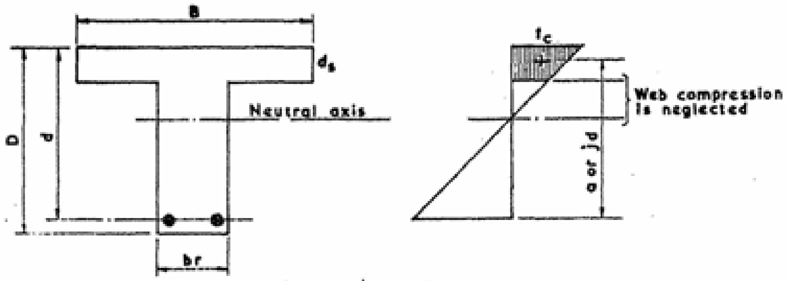


Fig 6-1

between the beams. The width of the slab (B) which is supposed to act as the top flange of the beam cannot be determined theoretically but is assumed as follows :

	I.S.I. Code, or Bombay Municipal Code.
T-beam	$\frac{\text{effective span}}{3}$ or Distance between the centres of ribs or $12d_s+br$
L-beam	$\frac{\text{effective span}}{6}$ or $\frac{1}{2}$ clear distance between ribs$+b_r$ or $4d_s+b_r$

6.2 Practical Design.

The practical procedure followed and formulae used in design of T-beams are described below.

The values of d_s and B are known; the value of d the effective depth is assumed from practical and economical or architectural considerations. For smaller values of d the amount of tension steel is more; for bigger values of d it is less. The most suitable value of d will therefore depend upon the relative cost of steel and concrete and the following formula is sometimes used to find it approximately:

$$d=\sqrt{\frac{rM}{tb_r}}+\frac{d_s}{2}$$

M=B.M. in inch lb

$$r=\frac{\text{cost of 4.38 cwt of steel}}{\text{cost of 1 cft of concrete}}$$

When the value of d is assumed, the value of lever arm also requires to be assumed by judgment. This value will vary from $d-\frac{d_s}{2}$ to $d-\frac{d_s}{3}$. In the case of a thin slab and deep beam, the value will be nearer to $d-\frac{d_s}{2}$ and in the case of a thick slab and shallow beam the value will be nearer to $d-\frac{d_s}{3}$.

Since slabs in buildings are rarely thicker than 6" we may say for practical purposes that the value of lever arm is say upto .95d for deep beams and .89d for comparatively shallow beams. On these assumptions the amount of tensile steel A_t can be found from chart 6-1.

Value of lever arm given by $d-\frac{d_s}{2}$ errs on the safe side and gives slightly more steel.

If further accuracy is required, charts Nos. 6-2 and 6-3, and table 6-a or formulae on the next page may be used, as follows:—

Find the value of $Q=\frac{M}{Bd^2}$ and ratio d_s/d. Find from chart 6-2 or 6-3 the value of fc for the above values of Q and d_s/d. From chart 6-4 find the location of neutral axis for the particular, value of fc and the table 6-a will give the factor j for the particular value of n_o and d_s/d.

The maximum B.M. which a particular beam can take without causing excessive fc is shown by the dotted lines in charts 6-1. Thus for a T-beam with d=20" and B=52", the B.M. should not exceed 2140000 inch lb in chart 6-1. Otherwise fc will be more than permitted and compression steel will be required.

6.3 Design Formulae.

Alternatively the following formulae can be used for calculations of properties of T-beams when approximate values of d and A_t are found from the chart No. 6-1 and the value of B is taken in conformity with code regulations.

(1) Position of neutral axis $n_o d = \dfrac{\dfrac{Bd_s^2}{2} + mA_t d}{Bd_s + mA_t}$

$$n_o = \frac{1}{1+(t/mfc)}$$

(2) Value of lever arm $a = jd = d - \dfrac{d_s}{2} + \dfrac{d_s^2}{6(2n_o d - d_s)}$

(3) Moment of resistance $= QBd^2$

$$= fc\left(1 - \frac{d_s}{2n_o d}\right) Bad_s \quad \text{on concrete}$$

$$= tA_t\, a \quad \text{on steel}$$

(Charts Nos. 6-2, 6-3 and table 6-a are based on the above formulae and are drawn on basis of t = 18000 psi and m = 18 and/or 15)

Table 6-a. Lever arm factor for various ratios of slab depth to effective depth.

n_o \ d_s/d	·06	·08	·10	·12	·14	·16	·18	·20	·22	·24	·26	·28	·30	·32	·34	·36	·38	·40
·20	·97	·96	·96	·95	·94	·94	·93	·93										
·25	·97	·96	·95	·95	·94	·93	·93	·92	·92	·92								
·30	·97	·96	·95	·94	·94	·93	·92	·92	·91	·91	·90	·90	·90					
·35	·97	·96	·95	·94	·94	·93	·92	·91	·91	·90	·90	·89	·89	·89	·88			
·40	·97	·96	·95	·94	·93	·93	·92	·91	·90	·90	·89	·89	·88	·88	·87	·87	·87	·87
·45	·97	·96	·95	·94	·93	·93	·92	·91	·90	·89	·89	·88	·88	·87	·87	·86	·86	·85
·50	·97	·96	·95	·94	·93	·93	·92	·91	·90	·89	·89	·88	·87	·87	·86	·85	·85	·84
·55	·97	·96	·95	·94	·93	·92	·92	·91	·90	·89	·88	·88	·87	·86	·85	·85	·84	·84
·60	·97	·96	·95	·94	·93	·92	·92	·91	·90	·89	·88	·87	·87	·86	·85	·85	·84	·83

6.4 Standard T-Beams.

The table 6-b give particulars of simply supported T-beams carrying uniformly distributed load of 1000 to 3000 lb per running foot. These tables should be used for preliminary designs and estimates.

Notation in Table 6-b:

D = Overall depth of beam in inches

b_r = Thickness of web in inches

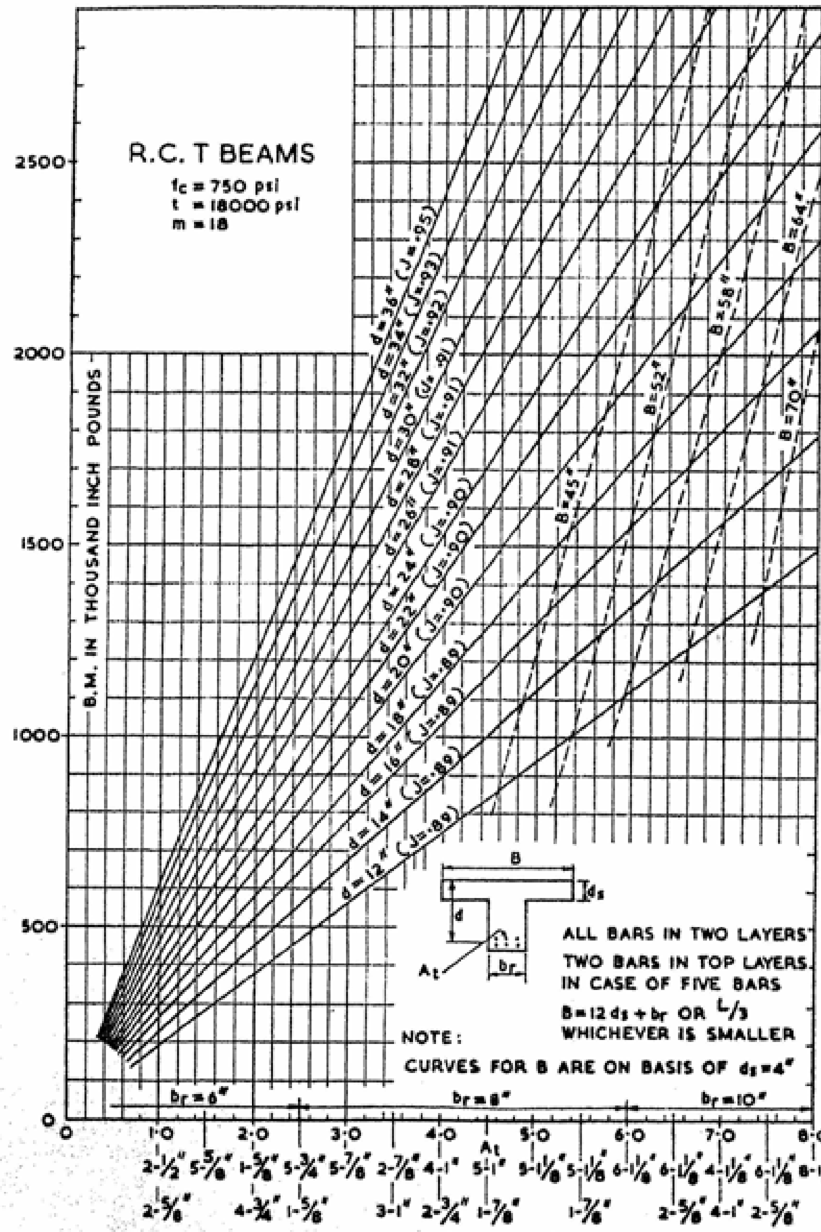

R.C. T BEAMS
fc = 750 psi
t = 18000 psi
m = 18
B.M. IN THOUSAND INCH POUNDS
2500
2000
1500
1000
500
0
d=36" (J=.95)
d=34" (J=.93)
d=32" (J=.92)
d=30" (J=.91)
d=28" (J=.91)
d=26" (J=.91)
d=24" (J=.90)
d=22" (J=.90)
d=20" (J=.90)
d=18" (J=.89)
d=16" (J=.89)
d=14" (J=.89)
d=12" (J=.89)
B=45"
B=52"
B=58"
B=64"
B=70"
B
ds
d
At
br
ALL BARS IN TWO LAYERS
TWO BARS IN TOP LAYERS
IN CASE OF FIVE BARS
B=12 ds + br OR L/3
WHICHEVER IS SMALLER
NOTE:
CURVES FOR B ARE ON BASIS OF ds=4"
br=6"
br=8"
br=10"
0
1·0
2·0
3·0
4·0
5·0
6·0
7·0
8·0
At
2-1/2" 5-5/8" 1-5/8" 5-3/4" 5-7/8" 2-7/8" 4-1" 5-1" 5-1/8" 5-1/8 6-1/8" 6-1/8" 4-1/8" 6-1/8" 8-1/8"
2-5/8" 4-3/4" 1-5/8" 3-1" 2-3/4" 1-7/8" 1-7/8" 2-5/8" 4-1" 2-5/8"

Chart 6-1

d_s=Minimum thickness of flange in inches necessary to keep compression below 750 psi as permitted by regulations.

a, b, c, d=main steel bars (a and c are in pairs) as shown in sketch on page 157.

K=distance in feet in which shear intensity exceeds 75 psi

n_1=number of stirrups in portion AB (vide example)
n_2 —Do— BC
n_3 —Do— CD
n_4 —Do— DE (where K exceeds AD)

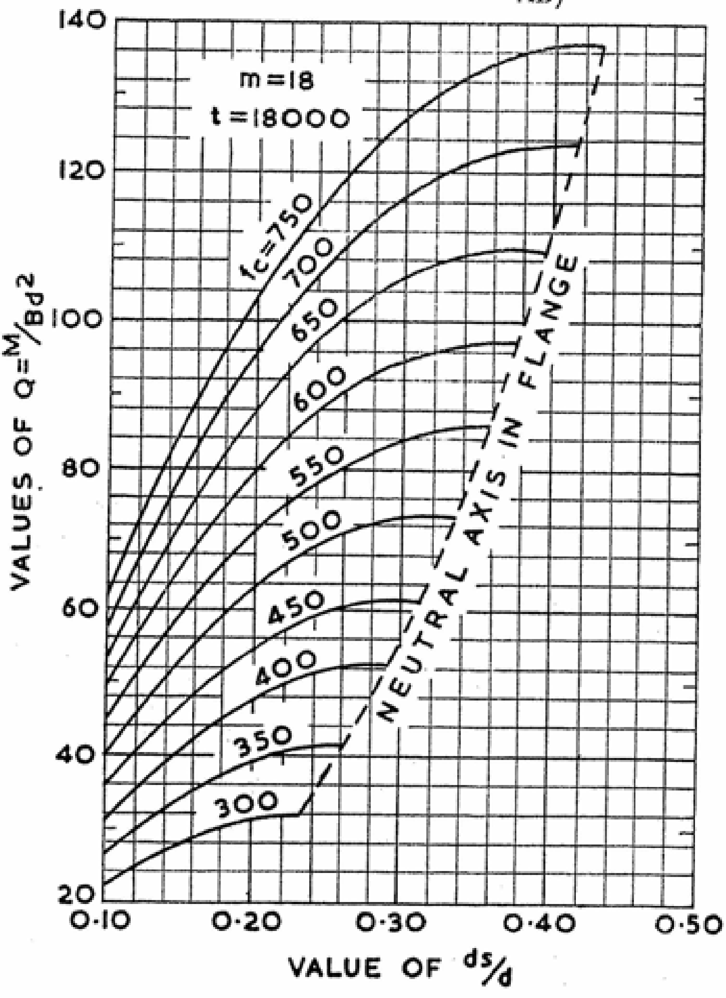


Chart 6-2

6.4 Standard T–beams

Table 6-b. Cross-section and reinforcement for T–beams for different loadings

fc=750 psi ; ft=18000 psi ; m=18

Span=8′–0″ (effective). load=lb/rft uniform including wt. of beam

Load	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600
SECTION (vide Table 6-c)	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_2	B_2	B_3	B_3	B_3
Main Steel sq. inches	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.53	1.53	1.90	1.67	1.9	1.9
a	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$
b	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$
c					$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$
d														
No. of $\frac{1}{4}$″ strps	9	9	9	9	9	9	9	9	9	9	9	9	9	9
n_1	1		1	1	1	1	1	1	1	1	1	1	1	1
n_2						1	1	1	1	1	1	1	1	1
n_3														
n_4														
K				.25	.7	1.0	1.3	1.5	1.7	1.8	1.8	1.2	1.3	1.5
Concrete cft	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	5.1	5.1	7.7	7.7	7.7
Main Steel lb	33	37	40	40	44	48	52	55	65	65	69	74	78	78
Stirrups lb	10	10	10	10	10	12	12	12	12	12	12	12	12	12

Span=10′–0″ (effective).

SECTION (vide Table 6-c)	B_1	B_1	B_1	B_1	B_2	B_2	B_2	B_2	B_3	B_3	B_3	B_3	B_3	B_3
Main Steel sq. inches	.8	1.2	1.22	1.31	1.5	1.67	1.9	2.1	1.9	1.94	2.1	2.21	2.3	2.53
a	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$
b	$\frac{1}{2}$		$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$
c		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$
d														
No. of $\frac{1}{4}$″ strps	10	10	10	10	11	11	13	13	13	13	13	15	15	15
n_1	1	1	1	1	1	1	1	1	1	2	1	1	1	1
n_2					1	1	2	2	2	1	2	2	2	2
n_3												1	1	1
n_4														
K			0.7	1.50	1.50	1.80	2.0	2.3	1.5	1.8	2.0	2.2	2.3	2.5
Concrete cft	5.5	5.5	5.5	5.5	6.3	6.3	6.3	6.3	9.4	9.4	9.4	9.4	9.4	9.4
Main Steel lb	44	58	63	67	75	80	88	101	89	96	102	108	114	121
Stirrups. lb	11	11	11	11	12	12	14	14	14	14	14	16	16	16

Span=12′-0″ (effective) load=lb/rft uniform including wt. of beam.

Load	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600
SECTION (vide Table 6-c)	B_2	B_2	B_2	B_2	B_2	B_2	B_3	B_3	B_3	B_3	B_3	B_4	B_4	B_4
Main Steel sq. inches	1.2	1.43	1.67	1.94	2.21	2.3	2.21	2.3	2.68	2.84	3.0	2.68	2.84	3.0
a	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$
b	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
c	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$
d														
No of ¼″ strps	14	14	14	14	14	14	14	14	14	18	20	20	18	20
n_1	1	1	1	1	1	1	1	1	1	1	1	2	1	2
n_2	1	1	1	1	1	1	1	1	1	2	2	2	2	2
n_3										1	2	1	1	1
n_4														
K		.4	1.0	1.5	2.2	2.6	1.0	2.2	2.5	2.8	3.0	2.4	2.5	2.8
Concrete cft	7.4	7.4	7.4	7.4	7.4	7.4	11.0	11.0	11.0	11.0	11.0	14.0	14.0	14.0
Main Steel lb	73	84	96	111	127	132	121	130	143	153	160	152	162	170
Stirrups lb	15	15	15	15	15	15	15	15	15	19	21	30	27	30

Span=14′—0″ (effective).

SECTION (vide Table 6-c)	B_2	B_2	B_2	B_2	B_3	B_3	B_3	B_3	B_3	B_4	B_4	B_4	B_5	B_5
Main Steel sq. inches	1.67	1.94	2.3	2.68	2.53	2.84	3.00	3.13	3.60	3.13	3.28	3.60	3.28	3.44
a	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$
b	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
c	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$
d								$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$
No. of ¼″ strps	16	16	16	16	16	18	18	24	24	20	24	24	29	31
n_1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
n_2	1	1	1	1	1	2	2	2	2	2	2	2	2	2
n_3								1	1	1	1	1	1	2
n_4								2	2		2	2	1	1
K		1.4	2.2	2.8	2.0	2.5	2.9	3.3	3.5	3.0	3.2	3.5	2.4	2.7
Concrete cft	8.6	8.6	8.6	8.6	12.7	12.7	12.7	12.7	12.7	16.1	16.1	16.1	17.8	17.8
Main Steel lb	107	123	146	163	160	170	176	210	230	200	204	226	221	231
Stirrups lb	17	17	17	17	18	20	20	26	26	25	30	30	50	53

Span=16′–0″ (effective). load=lb/rft uniform including wt. of beam.

Load	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600
SECTION (vide Table 6-c)	B_2	B_2	B_2	B_2	B_2	B_2	B_3	B_3	B_3	B_4	B_4	B_4	B_4	B_4
Main Steel sq. inches	1.0	2.21	2.53	2.84	3.31	3.6	3.13	3.6	3.98	3.7	4.02	4.02	4.34	4.53
a	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	1	1	1	1	1	1
b	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	1	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	1
c	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	1	1	1	1
d					$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$
No. of $\frac{3}{8}$″ strps.	17	17	17	19	20	20	20	20	24	19	24	24	29	30
n_1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
n_2	1	1	1	2	2	2	2	2	2	2	3	3	4	4
n_3				1	1	1	2	2	2	2	3	3	3	3
n_4									2					1
K		0.5	1.7	2.5	3.2	3.5	2.7	3.2	4.0	2.4	2.8	3.2	3.4	3.7
Concrete cft	15.0	15.0	15.0	15.0	15.0	15.0	18.0	18.0	18.0	27	27	27	27	27
Main Steel lb	127	154	174	204	230	254	230	250	284	271	290	290	310	323
Stirrups lb	18	18	18	20	22	22	25	25	30	30	38	38	47	48

Span=18′—0″ (effective.)

SECTION (vide Table 6-c)	B_2	B_2	B_2	B_2	B_2	B_3	B_3	B_3	B_4	B_4	B_4	B_4
Main Steel sq. inches	2.3	2.84	3.13	3.6	4.0	4.0	4.16	4.53	4.34	4.53	4.72	5.14
a	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	1	1	1	1	1	1	1	$1\frac{1}{8}$
b	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	1	$\frac{7}{8}$	1	$\frac{7}{8}$	$\frac{7}{8}$	1	1	1
c	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	1	1	1	1	1
d			$\frac{3}{4}$	$\frac{7}{8}$	1	$\frac{7}{8}$	$\frac{7}{8}$	1	$\frac{7}{8}$	$\frac{7}{8}$	1	1
No of $\frac{3}{8}$″ strps.	19	19	20	20	20	23	24	26	24	26	28	28
n_1	1	1	1	1	1	1	1	1	1	1	2	2
n_2	1	1	1	1	1	2	2	3	3	2	3	3
n_3			1	1	1	2	2	2	2	3	2	2
n_4				1	1		1	2				
K		1.5	2.3	3.4	4.0	3.3	3.8	4.2	3	3.5	3.8	4.2
Concrete cft	16	16	16	16	16	20.5	20.5	20.5	29.5	29.5	29.5	29.5
Main Steel lb	188	223	243	277	309	309	323	350	348	359	372	400
Stirrups lb	21	21	22	22	22	30	30	33	33	35	38	38

Span=20′—0″ (effective). load=lb/rft uniform including wt. of beam.

Load	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
SECTION (vide Table 6-c)	B_3	B_3	B_3	B_4	B_5	B_5	B_5	B_6	B_6	B_6
Main Steel sq. inches	2.88	3.28	4.00	4.53	4.16	4.72	5.14	4.72	5.14	5.57
a	$\frac{7}{8}$	$\frac{7}{8}$	1	1	1	1	$1\frac{1}{8}$	1	$1\frac{1}{8}$	1
b	$\frac{3}{4}$	$\frac{7}{8}$	1	1	1	1	1	1	1	$1\frac{1}{8}$
c	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	1	$\frac{7}{8}$	1	1	1	1	$1\frac{1}{8}$
d		$\frac{7}{8}$	1	$\frac{7}{8}$	$\frac{7}{8}$	1	1	1	1	$1\frac{1}{8}$
No. of $\frac{3}{8}$″ strps	21	21	21	23	24	25	26	24	26	27
n_1	1	1	1	1	1	1	1	1	1	1
n_2	1	1	1	1	2	2	2	2	2	2
n_3				1	1	2	2	2	2	2
n_4				2		1	2		2	2
K	1.3	2.5	3.6	4.4	3.6	4.2	4.7	3.4	4.1	4.3
Concrete cft	17.0	17.0	17.0	17.0	22.3	22.3	22.3	29.5	29.5	29.5
Main Steel lb	247	272	327	371	346	391	425	397	431	467
Stirrups lb	23	23	23	25	30	32	33	41	45	46

NOTE: Bearing for beams assumed = D—1 inches.
Quantities should be considered approximate, and are given on basis of total length of beam = Effective span plus (D—1) inches and $d_s = 4$″. Quantity of concrete is for web only. Steel includes anchor bars also. 10 to 15 % added extra for hooks, bends wastage, laps, etc.

Table 6-c. Details of T-beams used in Table 6-b.

	B_1	B_2	B_3	B_4	B_5	B_6
D	13	13	16	16	19	22
br	8	9	10	10	10	12
ds	3	3	3	4	3	3

See Fig. 6.1

All dimensions in inches.

a, b, c and d indicate reinforcement bars, a and c being in pairs.

6.5 Illustrative Examples.

Design a simply supported T-beam to carry a load of 1,600 lb per rft. The effective span is 20 ft. and the thickness of floor slab is 4" (assume fc=750, t=18000 psi and m=18)

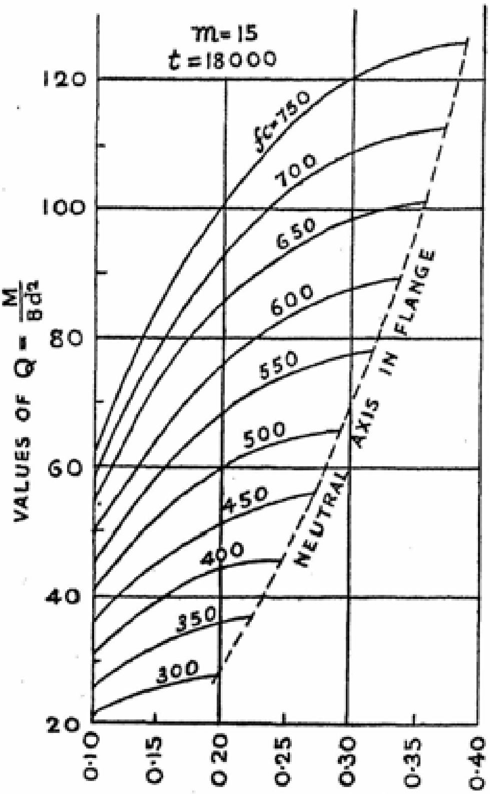


Chart 6-3

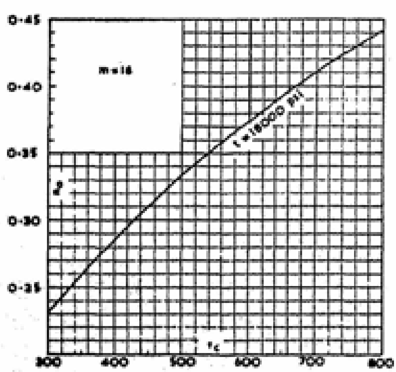


Chart 6-4

$$M = wl^2/8 = \frac{1600 \times 20 \times 20}{8}$$

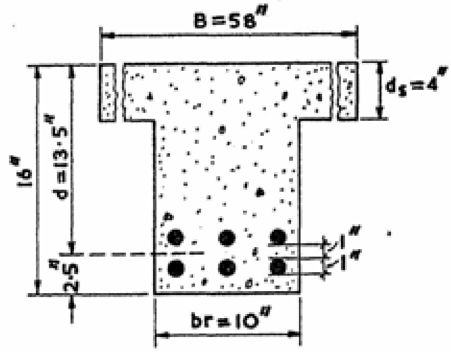
$$= 80{,}000 \text{ ft lb or } 960{,}000 \text{ in lb}$$

From practical considerations and relative cost of concrete and steel it is presumed that section as per sketch is appropriate

$$B = \frac{20 \times 12}{3} = 80'' \text{ or } (12 \times 4) + 10 = 58''$$

Assume B=58″

Effective depth=16—2.5″ (for cover etc. vide sketch)
=13.5″



(a) Approximate and safe design.

lever arm $= d - d_s/2 = 13.5 - 2 = 11.5$ inches

$$\therefore A_t = \frac{960{,}000}{18000 \times 11.5} = 4.63 \text{ square inches}$$

Check stress in concrete :

Total tension $= 4.63 \times 18000 =$ Total compression
$= fc \times 58 \times 4$

$\therefore$ fc = 360 psi average and the maximum will be less than double this value i.e., less than 720 psi while permissible stress is 750 psi.

(b) Accurate design by using charts.

$$t = 18000 \text{ psi} \quad d_s/d = \frac{4}{13.5} = .296$$

$$QBd^2 = Q \times 58 \times 13.5^2 = 960{,}000$$

$\therefore Q = 91.2$

Refer to chart 6-2 — $fc = 580$ psi which is safe

„ 6-4 — $n_o = 0.367$ (say .37)

„ to table 6-a — $j = 0.88$

$$\therefore A_t = \frac{960{,}000}{18000 \times .88 \times 13.5} = 4.5 \text{ square inches.}$$

(c) Accurate design by formulae.

$$fc\ (1 - \frac{d_s}{2n_o d})\ B\ d_s = t\ A_t \quad \ldots\ldots\ldots\ldots \quad \text{(formula 3)}$$

$$\text{i.e. } fc\ (1 - \frac{4}{2 \times 13.5 n_o})\ 58 \times 4 = 18000\ A_t \quad \ldots\ldots\ldots\ldots \quad \text{(a)}$$

$$\text{Also } n_o d = \frac{\frac{Bd_s^2}{2} + mA_t d}{Bd_s \times mA_t} \quad \ldots\ldots\ldots\ldots \quad \text{(formula 1)}$$

$$\text{i.e. } 13.5\ n_o = \frac{58 \times 16/2 + 18 \times 13.5\ A_t}{(58 \times 4) + 18\ A_t} \quad \ldots\ldots\ldots\ldots \quad \text{(b)}$$

$$\text{and } n_o = \frac{1}{1 + \frac{t}{mfc}} \quad \ldots\ldots\ldots\ldots \quad \text{(formula 1)}$$

$$\text{i.e. } n_o = \frac{1}{1 + 1000/fc} \quad \ldots\ldots\ldots\ldots \quad \text{(c)}$$

The above 3 equations (a), (b) and (c) have three unknowns n_o, A_t and fc and can be solved.

The solution can be simplified by trial and error method by assuming probable value of A_t and finding out n_o from (b). This value of n_o is then substituted in equation (a) and the value of fc is found. The correctness of these values is checked by examining if equation (c) is satisfied. Thus in this example we assume, $A_t = 4.5$ sq. inches, and substituting it in (b) we get $n_o = .368$. Substituting this value in (a)we get $fc = 578$ psi.

The assumption is correct since n_o=.368 and fc=578 psi satisfy equation (c).

In actual design work, all this is not required since the charts and tables simplify the procedure altogether.

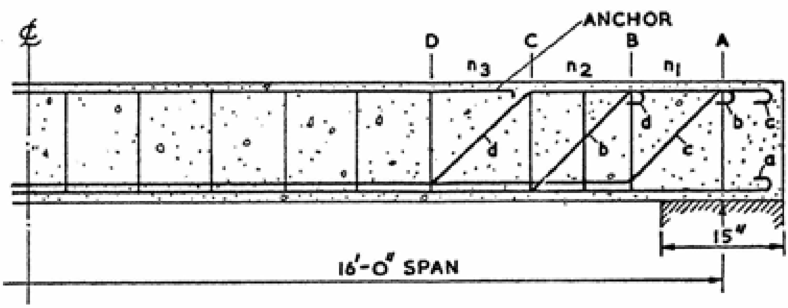
Example on use of standard tables

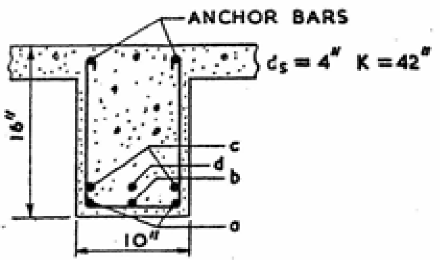
Find the approximate size and other details and quantities of materials required for a T beam 16′ effective span, carrying a load of 2,000 lb per rft.

The tables give section B_8 16″×10″ reinforced with 6 nos. 7/8ϕ bars and 20 nos. 3/8ϕ stirrups. The approximate quantity of concrete is 14.3 cft, whilst 254 lb of main rods and 22 lb of stirrups are required.

The spacing of stirrups and bending of bars is as shown in the sketch. In all 20 stirrups are required 1 in portion AB, 2 in portion BC, 1 in portion CD. One stirrup is provided at the centre of bearing, i.e., at point A. The balance of 10 stirrups is provided in the remaining portion.

In some beams where stirrups are indicated against n_4 they are provided in the portion of beam between point D and end of distance K.





NOTES.

CHAPTER 7

SHEAR

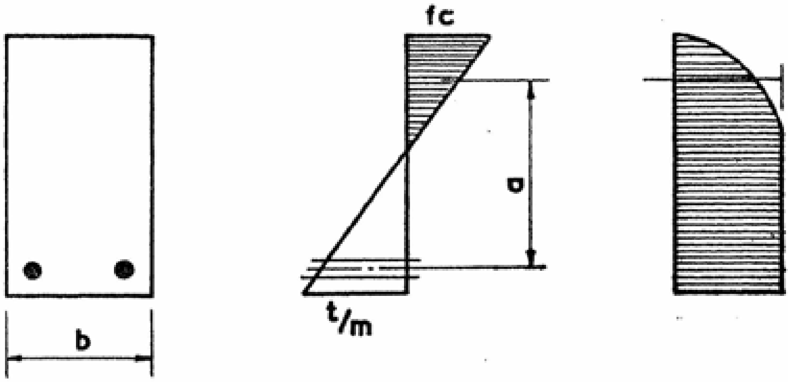
CONTENTS

CHAPTER 7

SHEAR

7.1 General

The shear intensity can be considered as uniform over the area ba of a concrete beam.



Distribution of shear stress

The shear stress therefore is $\frac{S}{ab}$ lb/sq inch, where S is the vertical shear in lb, b and d are breadth and depth of beam in inches, respectively.

This stress must not exceed $\frac{fc}{10}$ otherwise separate shear reinforcement is necessary. If the intensity exceeds $\frac{3fc}{10}$ it is necessary to enlarge the section of the beam.

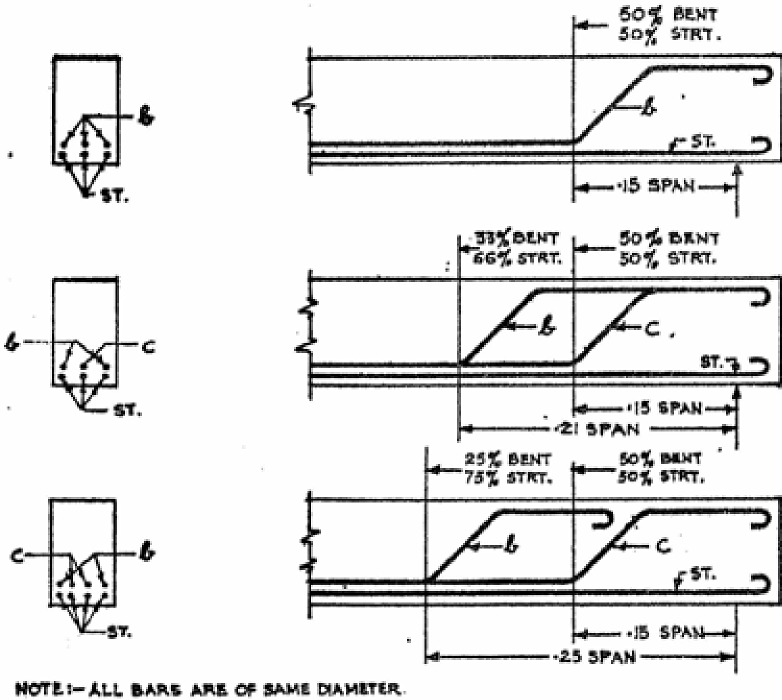
Provision for shear is made generally by:

(a) Inclined bars.

(b) Vertical stirrups.

(a) In ordinary practice special inclined bars are not provided but bars which form the tensile reinforcement are bent up to take shear in such portions of the beam where due to reduction of the bending moment they are no longer necessary for the tensile stress. The points where tensile bars can be bent up are found by drawing the B.M. diagram to scale, on which the tensile value of each bar is sketched to scale.

The following sketches give the location of the point at which part of the tensile steel can be bent up, in case of uniformly distributed load on a simply supported beam.



Bending of bars for shear

7.2 Tables and Charts.

The shearing resistance of inclined bars is given in Table 7-a. The distance from supports of an uniformly loaded simply supported beam, for which shear steel is required for a particular shear intensity at support, is given in Table 7-c.

(b) If the vertical binders are spaced at a distance p, there will be jd/p number of binders in a length equal to the lever arm of the beam. Then the shear resistance in this portion which is $\frac{Atjd}{p}$ equals the shear S (A is the area of both the vertical arms of stirrup). The values of $\frac{At}{p}$ for different sizes and spacings of stirrups are given in Table 7b.

Table 7a

Shear resistance of inclined bars

Diameter of Bar	$t_s = 18000$ lb/sq. in.	
	$\theta = 45°$	$\theta = 30°$
1/2″	2500	1750
5/8″	3900	2750
3/4″	5600	3900
7/8″	7650	5400
1″	10000	7050
1⅛″	12650	8950
1¼″	15600	11050
1⅜″	18900	13350
1½″	22500	15900

θ is angle of inclination of bar from horizontal.

Table 7b

Shear resistance of stirrups at various spacings

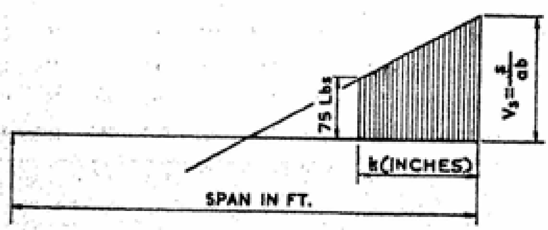
Stirrup size	Values of S/jd i.e. At/p												t = 18000 lb/sq. in.	
	Spacing, Inches													
	2″	3″	4″	4½″	5″	6″	7″	7½″	8″	9″	12″	15″	18″	24″
1/4″	882	587	441	391	355	294	252	235	221	196	147	117	98	74
5/16″	1386	924	693	616	554	462	396	370	347	308	231	183	154	115
3/8″	1980	1320	990	880	792	660	566	528	495	440	330	264	220	165
1/2″	3580	2350	1765	1567	1412	1175	1008	940	883	784	588	472	392	294

Table 7c

Distance from support requiring shear reinforcement (for safe shear at 75 lb/sq. in.)

(Note:—Figures tabulated give value of "k" in inches)

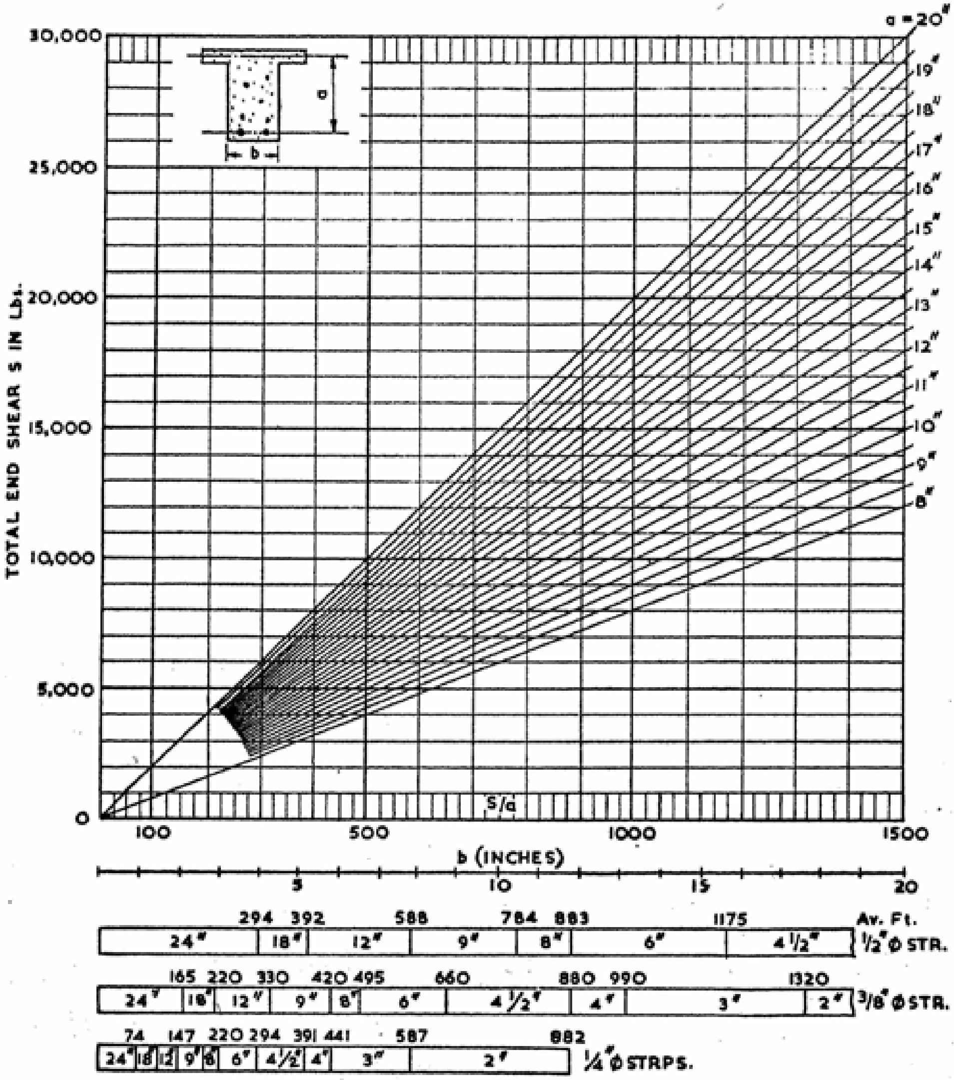
Vs. \ Sp.	10′	11′	12′	13′	13′	15′	16′	17′	18′	19′	20′	21′	22′	23′	24′
200	37.5	41.2	45	48.7	52.5	56.2	60	63.7	67.5	71.2	75	78.8	82.5	86.2	90
195	36.9	40.6	44.3	48	51.7	55.4	59	62.8	66.5	70.2	74	77.6	81.3	85	88.7
190	36.32	40	43.5	47.2	50.8	54.4	58	61.7	65.2	69	72.5	76.2	79.8	83.5	87
185	35.7	39.3	42.8	46.4	50	53.6	57.2	60.8	64.3	68	71.5	75	78.6	82.2	85.8
180	35	38.5	42	45.5	49	52.5	56	59.5	63	66.5	70	73.5	77	80.6	84
175	34.3	37.7	41.2	44.6	48	51.5	54.8	58.3	61.7	65.2	68.6	72	75.5	79	82.4
170	33.5	37	40.3	43.6	47	50.3	53.7	57	60.4	63.8	67.2	70.5	74	77.2	80.7
165	32.7	36	39.3	42.5	45.8	49	52.3	55.6	59	62.2	65.5	68.7	72	75.3	78.6
160	31.9	35.1	38.3	41.5	44.7	47.8	51.1	54.2	57.5	60.7	63.8	67	70.3	73.5	76.7
155	31	34.1	37.2	40.3	43.4	46.5	49.7	52.7	56.6	59	62	65.2	68.2	71.4	74.5
150	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72
145	29	31.9	34.8	37.7	40.6	43.5	46.5	49.4	52.2	55.2	58	61	64.9	66.8	69.7
140	27.9	30.7	33.5	36.3	39.1	41.9	44.7	47.5	50.2	53	56	58.7	61.5	64.2	67
135	26.7	29.4	32	34.7	37.4	40	42.8	45.6	48.1	50.7	53.4	56.1	58.8	61.4	64.1
130	25.4	27.8	30.5	33	35.6	38.1	40.7	43.2	45.7	48.2	50.9	53.4	56	58 5	61
125	24	25.4	28.8	31.2	33.6	36	38.4	40.8	43.2	45.7	48	50.5	52.8	55.2	57.7
120	22.5	24.8	27	29.3	31.5	33.8	36	38.3	40.5	42.7	45	47.3	49.3	51.8	54
115	20.1	22.1	24.1	26.1	28.2	30.2	32.2	34.2	36.2	38.2	40.2	42.2	44.2	46.2	48.2
110	19	20.9	22.8	24.7	26.6	28.5	30.4	32.3	34.2	36.1	38	40	41.8	43.7	45.6
105	17.2	18.9	20.6	22.4	24.1	25.8	27.5	29.3	31	32.7	34.4	36.1	37.9	39.6	41.3
100	15	16.5	18	19.5	21	22.5	24	25.5	27	28.5	30	31.5	33	34.5	36
95	12.6	13.8	15.1	16.4	17.6	18.9	20.4	21.4	22.7	23.9	25.2	26.5	27.7	29	30.2
90	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
85	7	7.7	8.4	9.1	9.8	10.5	11.2	11.9	14.4	15.2	16	16.8	17.6	18.4	19.6
80	3.8	4.1	4.5	4.9	5.3	5.6	6	6.4	6.8	7.2	7.5	7.9	8.2	8.7	9
75						—	N	I	L	—					



Sp.—Span in feet.

Chart 7-1. Spacing of Stirrups for Beams

R. C. C. BEAMS. STIRRUP SPACING CHART.



7.3 Example.

Find the shear reinforcement for a beam of breadth = 10″ effective depth 20″, span 20 ft. with a load of 2,600 prf including self load.

Total end shear = 26000 lb

a = .86 × 20 = 17.2

Two 1″ dia. bars @ 45° take 20,000 lb (Table 7a.)

∴ Balance = 6,000 lb

$$\frac{S}{a} = \frac{6000}{17.2} = 349$$

Hence 3/8″ stirrups required at 9″ c.c.

or ½″ stirrups required 18″ c.c.

(from Chart 7-1 or Table No. 7b.)

The above spacing works only in such portion of span where bent up bars are available. For the remaining span the spacing and size of stirrups is found out as follows: Shear taken by concrete, is calculated thus:—

Draw vertical line at b = 10″ in chart to meet oblique line a = 17.5 and read 13,000 lb on vertical scale. This gives shear taken by concrete. Also mark D on the chart on horizontal line giving S/a by drawing a horizontal line from 26000 to meet line a = 17.5 and projecting the point of intersection down to get point D (vide figure on page 167).

Thus portion AD of the span requires shear reinforcement either in the form of stirrups or bent bars.

$$\frac{S}{ab} = \frac{26000}{17.2 \times 10} = 151$$

Hence, from Table 7 C the length AD or k is 60″. The bent up bars @ 45° cover distance equal to 'a' i.e., 17.2″. Hence 43″ require full shear to be provided by stirrups. The distance between A to D in the Chart is 29.5 divisions. Thus one division indicates $\frac{60}{29.5}$ or say 2 inches.

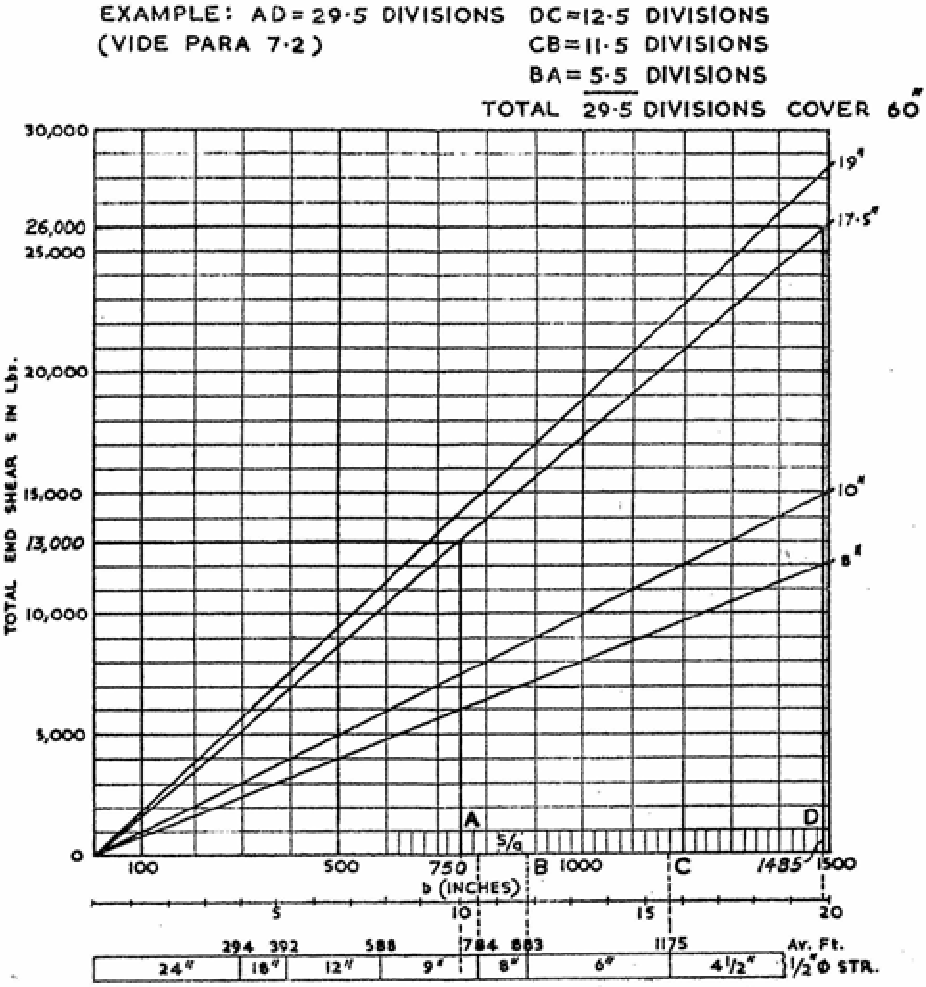
Hence provision for shear in the beam under investigation would be as follows :

From support to 17.2,″ two 1″ dia. bars @ 45° plus ½ inch stirrups @ 18″ c.c.

From D to C a distance of 25 in., 1/2″ dia. stirrups @ 4-1/2″ c.c. (only in portion not covered by bent bars.)

From C to B a distance of 23″, ½″ dia. stirrups @ 6″ c.c.

From B to A a distance of 12″, ½″ dia. stirrups @ 8″ c.c.


EXAMPLE: AD = 29·5 DIVISIONS DC = 12·5 DIVISIONS
(VIDE PARA 7·2) CB = 11·5 DIVISIONS
BA = 5·5 DIVISIONS
TOTAL 29·5 DIVISIONS COVER 60"
TOTAL END SHEAR S IN Lbs.
30,000
26,000
25,000
20,000
15,000
13,000
10,000
5,000
0
19"
17·5"
10"
8"
A
B
C
D
5/a
100
500
750
1000
1485
1500
b (INCHES)
5
10
15
20
294
392
588
784
883
1175
Av. Ft.
24"
18"
12"
9"
8"
6"
4 1/2"
1/2" Ø STR.

NOTES

CHAPTER 8

COLUMNS

CONTENTS

CHAPTER 8

COLUMNS

8.1 General Formulae.

The general formula for the design of columns loaded with axial loads is

$$P = \left\{\begin{array}{l}\text{the load carried by}\\ \text{a short column}\end{array}\right\} = \begin{array}{l}\text{concrete stress} \times \text{concrete area}\\ + \text{steel stress} \times \text{steel area}\end{array}$$

(a) *Concrete area* is assumed as follows :—

Bombay Municipal Byelaws, d^2 : Core area (shown hatched in Fig 8-1 less area of steel, A_v.)

I.S.I. Code, D^2 : Gross cross sectional area—area of steel—area of champhers.

(b) *Steel area* is the area of longitudinal bars only.

(c) *Concrete stress* and modular ratios. (Stress in lb per sq. inch)

I.S.I.	1 : 2 : 4 mix	600 psi	
	1 : 1½ : 3 „	760 „	
	1 : 1 : 2	920 „	
Bombay Municipal Byelaws	1 : 2 : 4	600 „;	m = 18
	1 : 1½ : 3	680 „	16
	1 : 1 : 2	780 „	14

(d) *Steel stress*

I.S.I.	18000 psi
Bombay Municipal Byelaws	m × concrete stress.
For helical binders	13500 psi.

In case of columns with helical binding, only core area is to be considered.

Value of safe loading in different types of columns calculated on above principles are given in Chart Nos. 8-1, 8-2, 8-3 and 8-4 and Table Nos. 8-a and 8-b.

8.2 Details of Columns

These are shown diagramatically in Figs. 8-1 and 8-2.

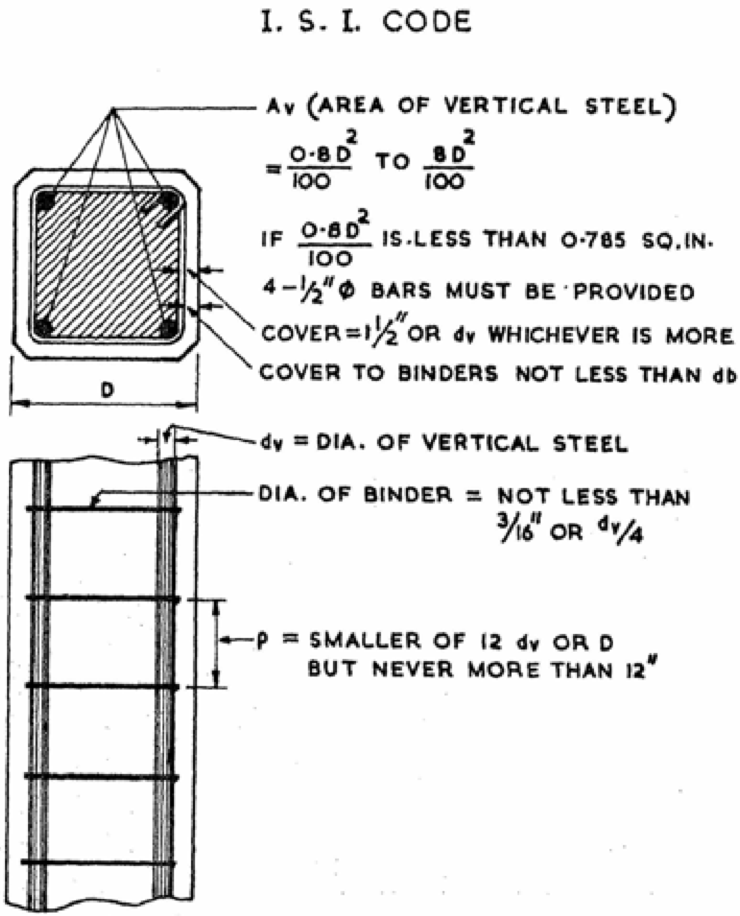
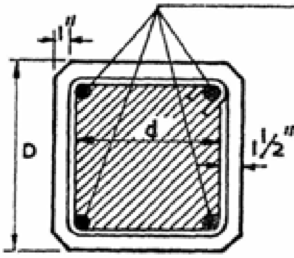
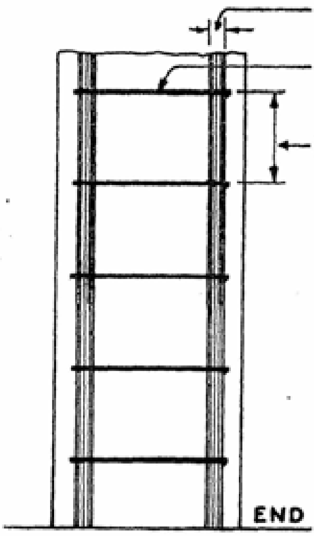


Fig. 8-1

It should be noted that where it is necessary to splice the longitudinal reinforcement the rods must be lapped in contact with one another, the length of the lap being not less than 24 bar diameters.

BOMBAY MUNICIPAL REGULATIONS





BOMBAY MUNICIPAL CODE

(a) VOLUME OF STIRRUPS NOT LESS THAN 0·4% OF GROSS VOLUME OF COLUMN

(b) MIN. DIA. OF STIRRUPS 3/16" OR $d_v/4$ FOR 12" PITCH

(c) PITCH : NOT MORE THAN 12"
: NOT LESS THAN 6"
: NOT TO EXCEED LEAST SIDE OF COL.
: NOT TO EXCEED 12 d_v

Fig. 8-2

8.3 Effect of Slenderness of Columns on Safe Load P.

I.S.I., and Bombay Municipal Codes.

Rectangular and round columns v/d	Any column v/g	Safe load allowed
15	50	1.0 × P
18	60	0.9 × P
21	70	0.8 × P
24	80	0.7 × P
27	90	0.6 × P
30	100	0.5 × P
33	110	0.4 × P
36	120	0.3 × P
39	130	0.2 × P
42	140	0.1 × P
45	150	Nil

Note :—v is the effective column length, d is the least lateral dimension of the column, and g is the least radius of gyration. d and g are taken on gross section basis, except in case of helically bound columns where g is taken on core basis.

Relation between effective length and actual length.

	Type of Column	Effective Column Length
Column of one storey.	(i) Both ends adequately restrained in position and direction.	0.75 of the actual column length.
	(ii) Both ends adequately restrained in position but not in direction.	The actual column length.
	(iii) Both ends adequately restrained in position but one end restrained in direction	0.85 of the actual column length.
	(iv) One end adequately restrained in position and direction and imperfectly restrained in both position and direction at the other end.	A value intermediate between the actual column length and twice that length, depending upon the efficiency of the imperfect restraint.
Columns continuing through two or more storeys.	(i) Both ends adequately restrained in position and direction.	0.75 of the distance from floor level to floor level.
	(ii) Both ends adequately restrained in position and imperfectly restrained in direction at one or both ends.	A value intermediate between 0.75 and 1.00 of the distance from floor level to floor (or roof) level depending upon the efficiency of the directional restraint.
	(iii) One end adequately restrained in position and direction and imperfectly restrained in both position and direction at the other end.	A value intermediate between the distance from floor level to floor (or roof) level and twice that distance depending upon the efficiency of imperfect restraint.

In the Table on p. 175, the actual length is measured between upper surfaces of two floors affording lateral support or the clear distance between supports plus the lateral dimension of the column.

8.4 Helical Binding of Columns.

The safe stress on concrete is the same as given in para 8.1 above but additional load of $2t_bA_b$ (i.e. 27000 A_b lb, t_b being 13500 lb for both codes) can be allowed on the column. However the safe load on the column is to be calculated on core area basis and not on gross area basis.

Thus $P=P_c+P_T+P_B$

where, P_c=load carried by concrete in core

P_T=load carried by vertical steel

P_B=additional load due to helical binding

$=2t_bA_b=27000\ A_b$

A_b= volume of helical binding per unit length of column.

The pitch of helicals should not be more than 3" or 1/6 of core diameter whichever is less. For practical reasons not more than ½" ϕ bars and not less than 3/16" dia. bars should be used for forming the helical binding. The values of P_B for different column sizes and arrangement of helical windings can be found from Chart 8-1.

8.5 Estimates of Formwork for Columns.

Tables 8-4 and 8-5 would be found useful for quick estimates of quantity of concrete in columns of various sizes and shapes. Their use is self explanatory.

8.6 Tables and Charts for Commonly Used Columns

Table 8-1. Square Columns (I.S.I. Code 1:2:4 Mix)

Ref.	D Inches	d Inches	A_v Nos.	A_v Dia. Inches	Stirrups Pitch Inches	Stirrups Dia. Inches	Safe Load Tons	Concrete C.ft. in 10′ height	Steel Lb./10′ ht. Main	Steel Lb./10′ ht. Stirrups
C1	6	3	4	½	6	¼	15.7	2.85	28.00	3.66
C2a	8	5	4	½	6	¼	22.2	4.25	28.00	6.10
C2b	8	5	4	⅝	7½	¼	26.6	4.25	43.68	4.88
C3a	9	6	4	½	6	¼	27.7	5.48	28.00	7.32
C3b	9	6	4	⅝	7½	¼	31.4	5.48	43.70	5.86
C3c	9	6	4	¾	9	¼	35.3	5.48	63.00	4.76
C4a	10	7	4	½	6	¼	32.8	6.75	28.00	8.55
C4b	10	7	4	⅝	7½	¼	36.2	6.75	43.68	6.84
C4c	10	7	4	¾	9	¼	40.4	6.75	63.00	5.55
C4d	10	7	4	⅞	10½	¼	45.4	6.75	85.86	4.71
C4e	10	7	4	1	12	¼	51.1	6.75	114.81	8.28
C5a	12	9	4	⅝	7½	¼	48.0	9.86	43.68	8.80
C5b	12	9	4	¾	9	¼	52.6	9.86	63.00	7.50
C5c	12	9	4	⅞	10½	¼	57.4	9.86	85.86	6.05
C5d	12	9	4	1	12	¼	63.0	9.86	114.81	5.50
C5e	12	9	8	⅞	10½	¼	76.0	9.86	171.36	6.05
C6a	14	11	4	¾	9	¼	66.2	13.55	63.00	8.74
C6b	14	11	4	⅞	10½	¼	71.2	13.55	85.86	7.40
C6c	14	11	4	1	12	¼	76.7	13.55	114.81	6.71
C7a	15	12	4	⅞	10½	¼	79.4	15.50	85.68	8.06
C7b	15	12	4	1	12	¼	84.5	15.50	114.81	7.34
C7c	15	12	4	1⅛	12	⅜	91.3	15.50	148.72	15.15
C8a	16	13	4	⅞	10½	¼	87.2	17.40	85.68	7.92
C8b	16	13	4	1	12	⅜	93.0	17.40	114.81	17.90
C8c	16	13	4	1⅛	12	⅜	99.6	17.40	148.00	17.90
C8d	16	13	8	1	12	⅜	117.0	17.40	229.62	17.90
C9a	18	15	4	1	12	⅜	111.0	22.10	114.81	20.62
C9b	18	15	4	1⅛	12	⅜	117.8	22.10	148.72	20.62
C10a	20	17	4	1⅛	12	⅜	138.2	27.60	148.72	23.33
C10b	20	17	8	1	12	⅜	156.5	27.60	229.62	23.33
C10c	20	17	8	1¼	12	⅜	169.2	27.60	206.00	23.33
C11a	21	18	8	1¼	12	⅜	180.2	30.30	206.00	24.80
C11b	21	18	8	1½	12	⅜	194.2	30.30	367.00	24.80

Table 8-2. Square Columns (Bombay Municipal Byelaws 1:2:4 Mix)

Ref. No.	D Inches	d * Inches	A_v		Stirrups		Safe Load Tons	Concrete C.ft. in 10' height	Steel Lb./10'ht.	
			Nos.	Dia. Inches	Pitch Inches	Dia. Inches			Main	Stirrups
C1	8	5	4	½	6	¼	10.25	4.25	28.00	9.6
C2	9	6	4	½	6	¼	13.21	5.48	28.00	9.31
C3a	10	7	4	½	6	¼	16.70	6.75	28.00	15.3
C3b	10	7	4	⅝	7½	¼	18.72	6.75	43.70	15.3
C4a	12	9	4	⅝	6	¼	27.05	9.86	43.70	18.5
C4b	12	9	4	¾	6	¼	29.70	9.86	63.00	18.5
C4c	12	9	4	⅞	10½	¼	32.60	9.86	85.86	18.5
C5a	14	11	4	⅝	7½	⅜	38.0	13.55	43.70	27.0
C5b	14	11	4	¾	9	⅜	40.5	13.55	63.00	27.0
C5c	14	11	4	⅞	9	⅜	43.5	13.55	85.86	27.0
C5d	14	11	4	1	9	⅜	46.70	13.55	114.81	27.0
C6a	15	12	4	¾	9	⅜	46.70	15.50	63.00	32.6
C6b	15	12	4	⅞	9	⅜	49.5	15.50	85.86	32.6
C6c	15	12	4	1	9	⅜	53.00	15.50	114.81	32.6
C7a	16	13	4	¾	9	⅜	53.4	17.40	63.00	58.6
C7b	16	13	4	⅞	9	⅜	56.1	17.40	85.86	58.6
C7c	16	13	4	1	9	⅜	59.6	17.40	114.81	58.6
C7d	16	13	4	1⅛	9	⅜	63.5	17.40	148.72	58.6
C8a	18	15	4	⅞	8	⅜	71.2	22.10	85.86	54.4
C8b	18	15	4	1	8	⅜	74.6	22.10	114.81	54.4
C8c	18	15	4	1⅛	8	⅜	78.5	22.10	148.72	54.4
C8d	18	15	8	⅞	8	⅜	82.1	22.10	171.36	54.4
C9a	20	17	4	1	7½	⅜	91.8	27.60	114.81	60.7
C9b	20	17	4	1⅛	7½	⅜	95.6	27.60	148.72	60.7
C9c	20	18	8	⅞	7½	⅜	99.4	27.60	171.36	60.7
C9d	20	17	8	1	7½	⅜	106.0	27.60	229.62	60.7
C10a	22	19	4	1⅛	7	⅜	115	33.30	148.72	76.5
C10b	22	19	8	⅞	7	⅜	118.8	33.30	171.36	76.5
C10c	22	19	8	1	7	⅜	125.3	33.30	229.62	91.5
C10d	22	19	8	1⅛	7	⅜	133.0	33.30	297.44	91.5
C11a	24	21	4	1¼	7	⅜	140.5	39.86	183.50	105.9
C11b	24	21	4–4	⅞–1	7	⅜	143.5	39.86	171.36	105.9
C11c	24	21	8	1	7	⅜	146.50	39.86	229.62	105.9
C11d	24	21	8	1⅛	7	⅜	154.5	39.86	297.44	105.9

Table 8-3. Square Columns (I.S.I. Code, Different Mixes)

Size (in)	Longitudinal Steel			Load carried by longitudinal bars at 18,000 lb. per sq. in.	Load carried by the Column Tons		
	Bars No.	Bars Dia.	Area (Sq. in.)	Tons	1 : 2 : 4 600 p.s.i.	1 : 1½ : 3 760 p.s.i.	1 : 1 : 2 920 p.s.i.
8	4	½	0.79	6.3	21.7	27.3	31.3
	4	1	3.14	25.3	41.0	45.4	49.5
	4	1¼	4.91	39.5	54.8	59.0	63.0
9	4	½	0.79	6.3	27.1	33.0	38.4
	4	1	3.14	25.3	45.5	51.5	56.4
	8	1	6.28	50.5	69.9	75.2	80.3
10	4	⅝	1.23	9.9	35.8	42.9	49.6
	4	1⅛	3.98	32.0	57.2	64.0	70.5
	8	1⅛	7.95	64.0	88.1	95.3	100.9
11	4	⅝	1.23	9.9	41.3	40.9	58.8
	4	1¼	4.91	39.5	70.6	78.2	87.6
	4	1¾	9.62	77.3	106.5	112.8	123.2
12	4	⅝	1.23	9.9	48.5	57.6	67.6
	4	1⅜	5.94	47.5	85.9	93.5	103.2
	8	1¼	9.82	78.5	114.8	123.2	132.7
13	4	¾	1.77	14.2	58.4	70.7	82.2
	8	1	6.28	50.5	93.5	104.9	116.7
	10	1¼	12.27	100.5	142.1	172.8	184.0
14	4	¾	1.77	14.2	65.7	79.3	93.1
	8	1	6.28	50.5	110.8	113.9	127.6
	8	1½	14.14	113.5	161.7	174.2	187.3
15	6	⅝	1.84	13.9	73	88.7	104.3
	8	1¼	9.82	78.5	135.4	150.7	165.7
	12	1⅜	17.82	143.0	197.8	212.4	226.9
16	4	⅞	2.41	19.4	87.3	104.9	122.6
	8	1⅜	11.88	95.5	157.6	187.8	194.8
	8	1¾	19.24	154.5	215.1	234.3	250.8
17	4	⅞	2.41	19.4	95.4	116.9	136.6
	8	1⅜	11.88	95.5	169.0	188.9	208.8
	12	1½	21.21	170.5	241.5	260.6	280.0

Table 8-3 (Continued)

Size (in)	Longitudinal Steel			Load carried by longitudinal bars at 18,000 lb. per sq. in.	Load carried by the Column Tons		
	Bars No.	Bars Dia.	Area (Sq. in.)	Tons	1:2:4 600 p.s.i.	1:1½:3 760 p.s.i.	1:1:2 920 p.s.i.
	4	1	3.14	25.3	110.8	134.6	156.2
18	8	1½	14.14	112.6	194.7	216.6	238.4
	8	2	25.13	202.0	281.6	302.7	323.9
	4	1	3.14	25.3	120.9	145.8	171.4
19	12	1¼	14.73	118.1	210.6	236.6	259.6
	12	1¾	28.86	233.0	291.7	344.7	368.6
	8	¾	3.53	28.3	133.8	162.4	190.0
20	12	1⅜	17.82	143.0	244.7	272.9	296.7
	10	2	31.42	233.0	350.7	377.3	402.3
	8	¾	3.53	28.3	145.0	176.4	206.0
21	8	1¾	19.24	154.2	266.7	297.0	327.5
	10	2	31.42	252.0	361.3	390.7	420.0
	8	⅞	4.81	38.8	166.8	200.5	271.9
22	12	1½	21.21	170.5	294.1	327.2	456.4
	12	2	37.70	303.5	422.2	453.5	565.7

Table 8-4 Sectional Areas and Perimeters of Columns per Foot Height

Dia. or Side	Area	Perimeter.	Area	Perimeter.	Area	Perimeter.	Area	Perimeter.
8"	.35	2.09	.37	2.21	.39	2.31	.44	2.67
10"	.55	2.62	.58	2.75	.60	2.88	.69	3.33
12"	.79	3.14	.83	3.33	.87	3.97	1.00	4.00
14"	1.07	3.67	1.13	3.88	1.18	4.03	1.37	4.67
16"	1.40	4.19	1.47	4.42	1.54	4.62	1.78	5.33
18"	1.77	4.72	1.87	4.96	1.05	5.19	2.25	6.00
20"	2.18	5.24	2.30	5.50	2.41	5.78	2.78	6.67
22"	2.63	5.76	2.78	6.08	2.90	6.35	3.35	7.33
24"	3.14	6.28	3.31	6.62	3.46	6.94	4.00	8.00
26"	3.69	6.81	3.89	7.17	4.06	7.50	4.71	8.67
28"	4.27	7.34	4.51	7.80	4.72	8.06	5.43	9.33
30"	4.91	7.86	5.18	8.25	5.41	8.66	6.25	10.00
32"	5.58	8.39	5.89	8.83	6.15	9.22	7.13	10.67
34"	6.31	8.90	6.63	9.38	6.94	9.78	8.00	11.33
36"	7.06	9.43	7.45	9.92	7.78	10.40	9.00	12.00
SHAPE	ROUND		OCTAGONAL		HEXAGONAL		SQUARE	

Note: Cross—sectional areas are in sq. ft. and perimeters in linear feet.

Table 8-5. Sectional Areas of Rectangular Columns in Square Feet.

SIDES	10"	12"	14"	16"	18"	20"	22"	24"	26"	28"	30"	32"	34"	36"
8"	.55	.67	.78	.89	1.00	1.11	1.22	1.34	1.45	1.56	1.67	1.78	1.89	2.01
10"	.69	.83	.97	1.11	1.25	1.39	1.53	1.67	1.80	1.94	2.08	2.22	2.35	2.49
12"	.83	1.00	1.17	1.33	1.50	1.67	1.83	2.00	2.17	2.33	2.50	2.67	2.83	3.00
14"	.97	1.17	1.37	1.56	1.75	1.95	2.14	2.34	2.53	2.72	2.92	3.12	3.30	3.51
16"	1.11	1.33	1.56	1.78	2.00	2.23	2.45	2.66	2.90	3.11	3.34	3.56	3.78	4.00
18"	1.25	1.50	1.76	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50
20"	1.39	1.67	1.95	2.23	2.50	2.78	3.05	3.33	3.62	3.89	4.17	4.43	4.72	5.01
22"	1.53	1.83	2.14	2.44	2.75	3.05	3.25	3.66	3.97	4.27	4.58	4.89	5.18	5.49
24"	1.67	2.00	2.34	2.66	3.00	3.33	3.66	4.00	4.34	4.66	5.00	5.33	5.66	6.00

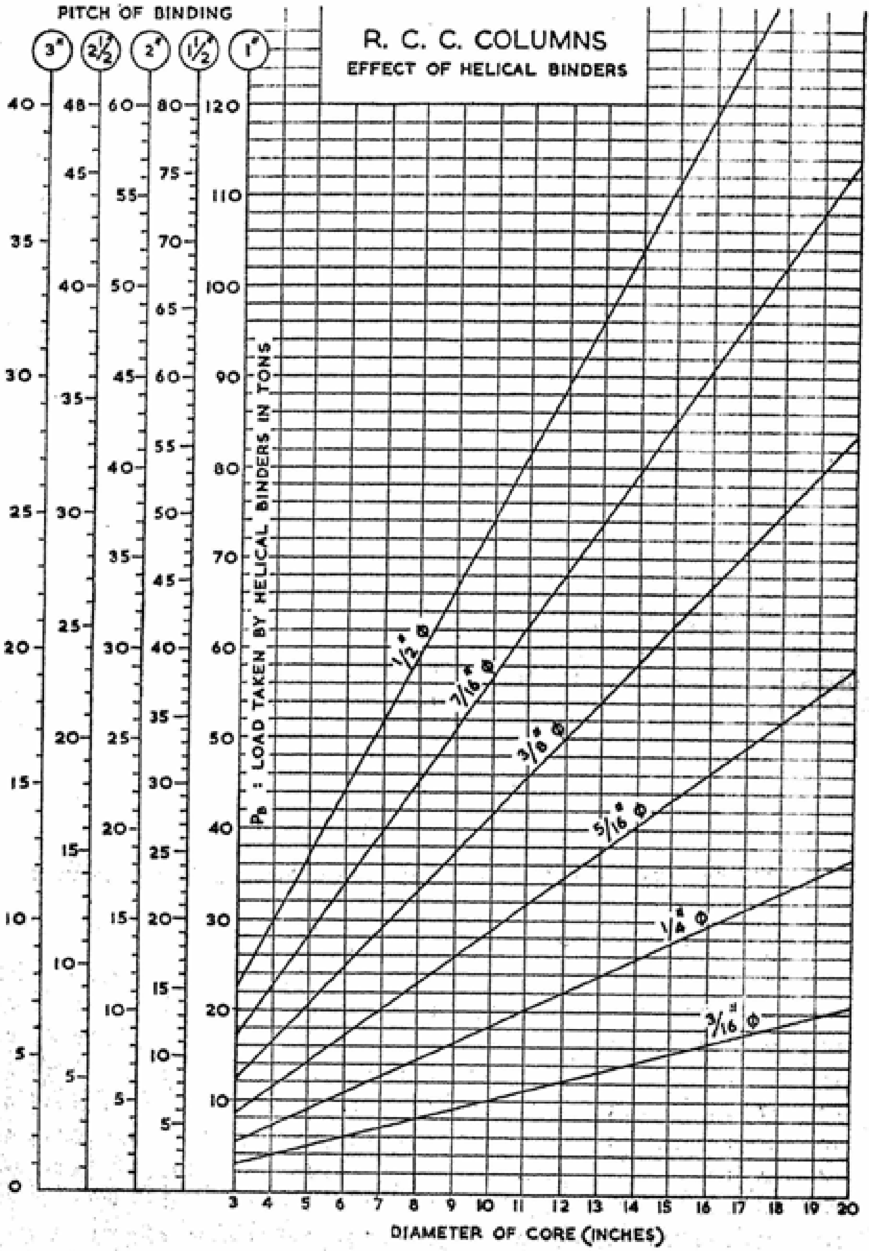


Chart 8-1 Columns with helical binders

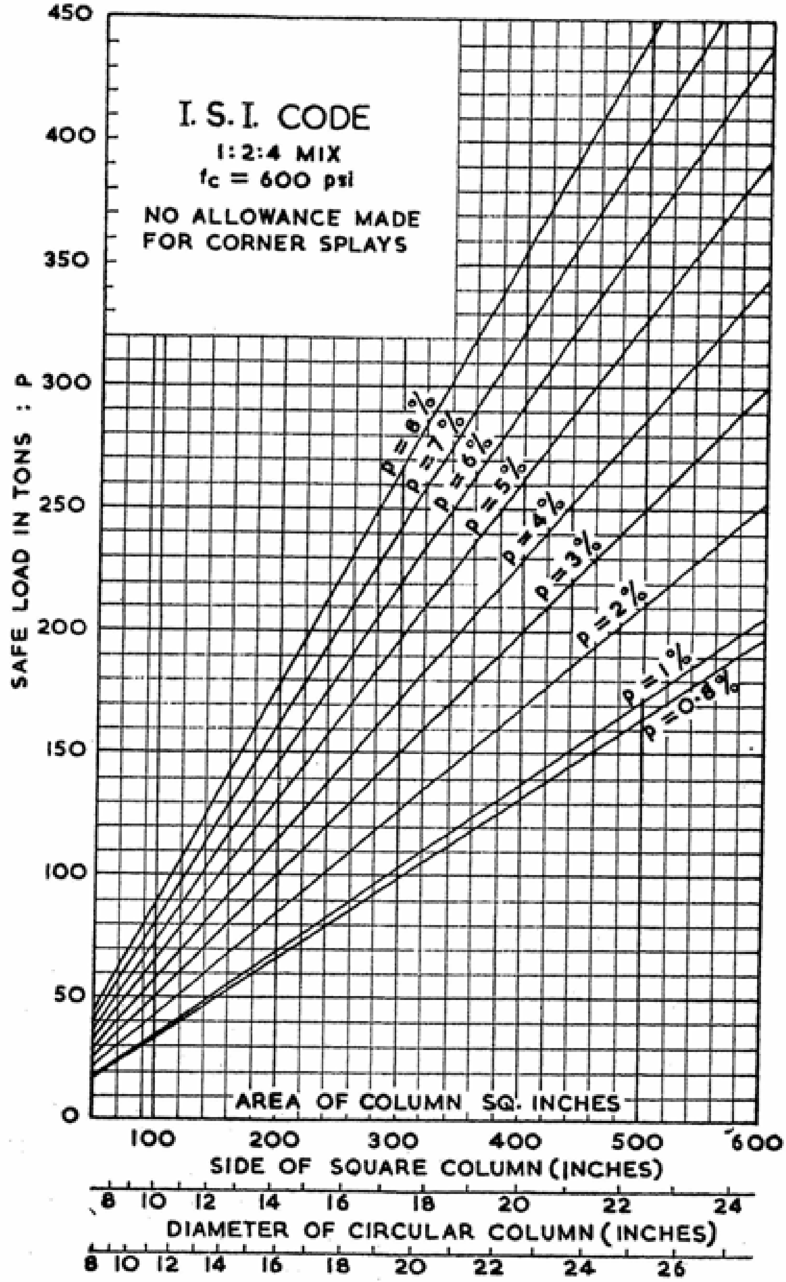


Chart 8-2. Safe loads on 1 : 2 : 4 concrete columns with different percentages of reinforcement

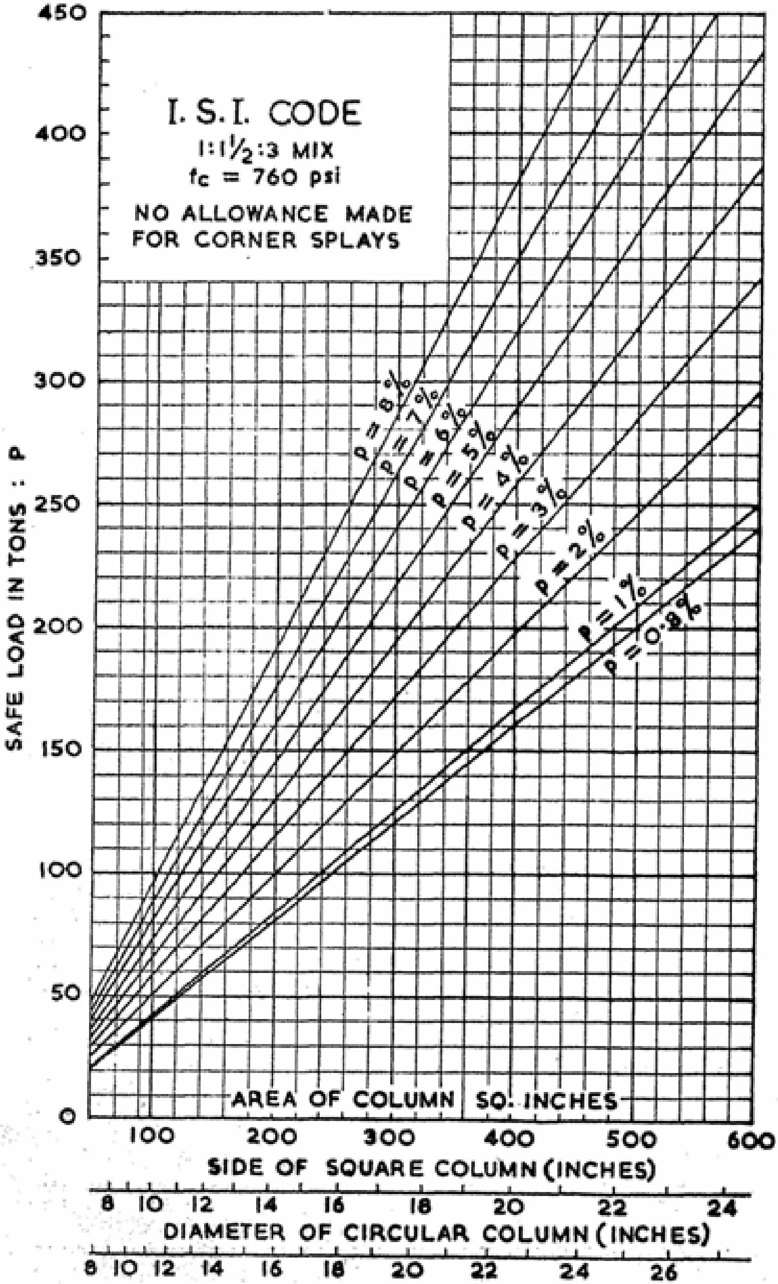


Chart 8-3. Safe loads on 1 : 1½ : 3 diameter columns with different percentages of reinforcement

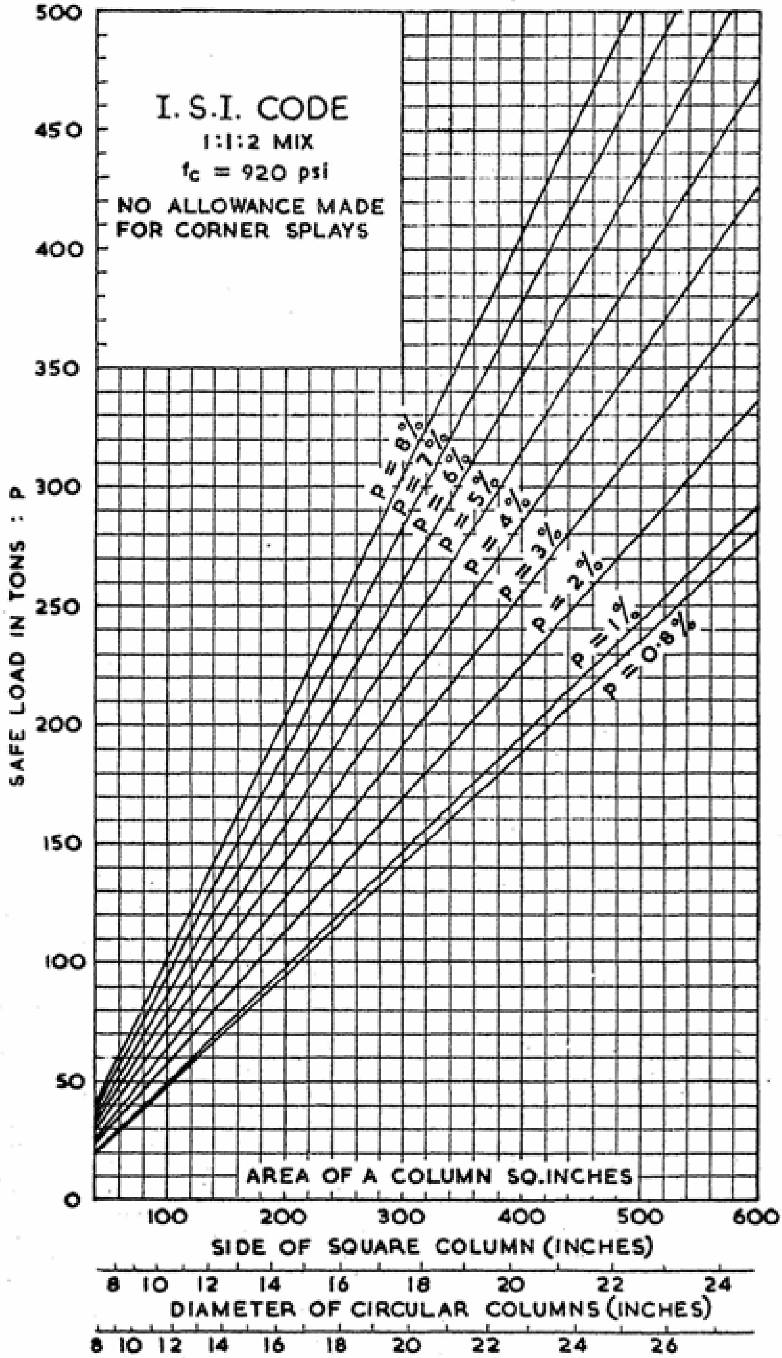


Chart 8-4. Safe loads on 1 : 1 : 2 concrete columns with different percentages of reinforcement

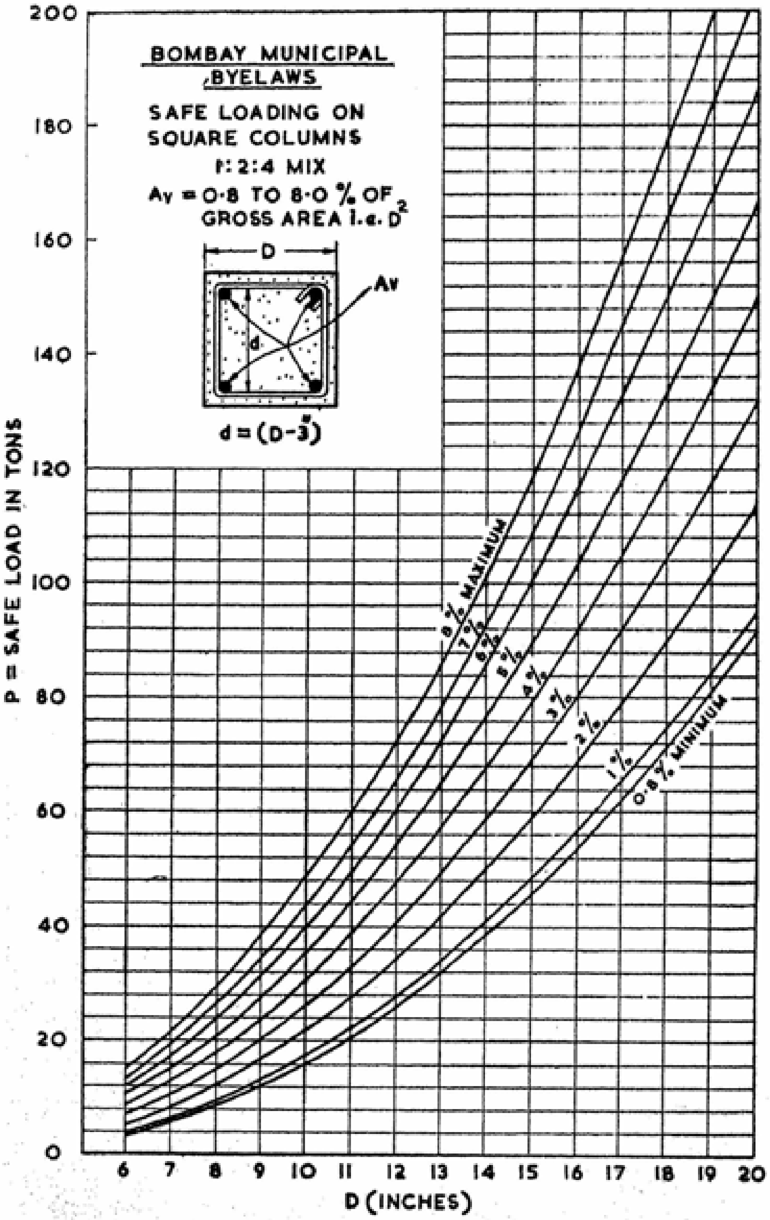


Chart 8-5. Safe loads on 1 : 2 : 4 concrete columns with different percentages of steel in accordance with Bombay Municipal Byelaws

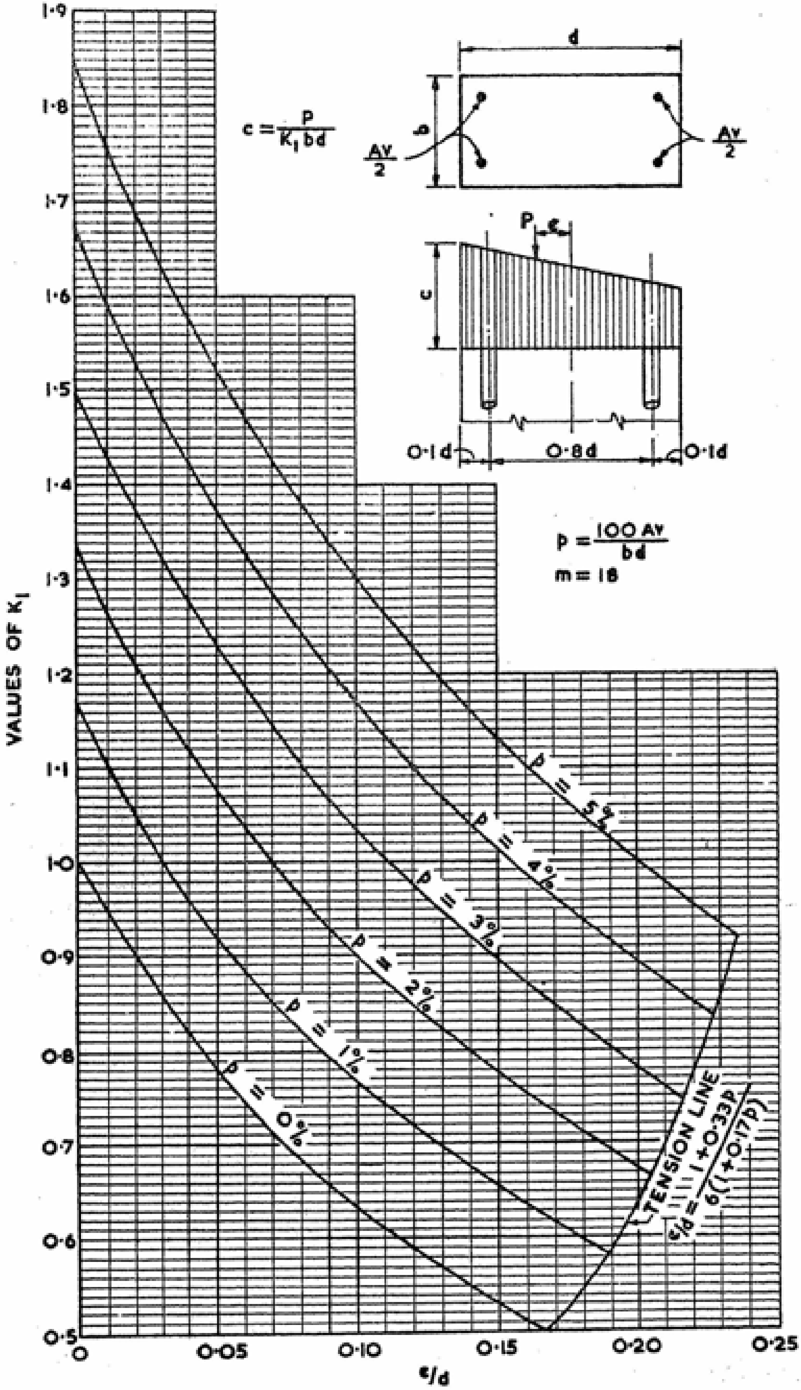


Chart 8-6. Columns with eccentric loads — design factors for sections under compression

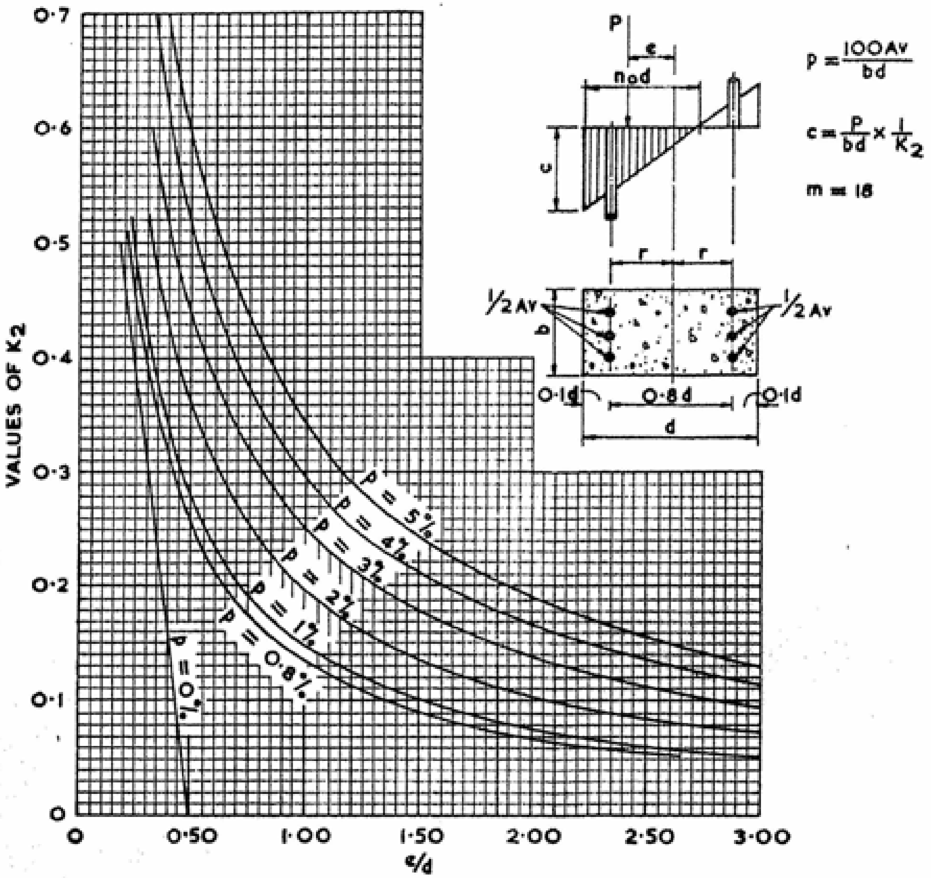


Chart 8-7. Columns with eccentric loads — design factors for sections partly under compression and partly under tension

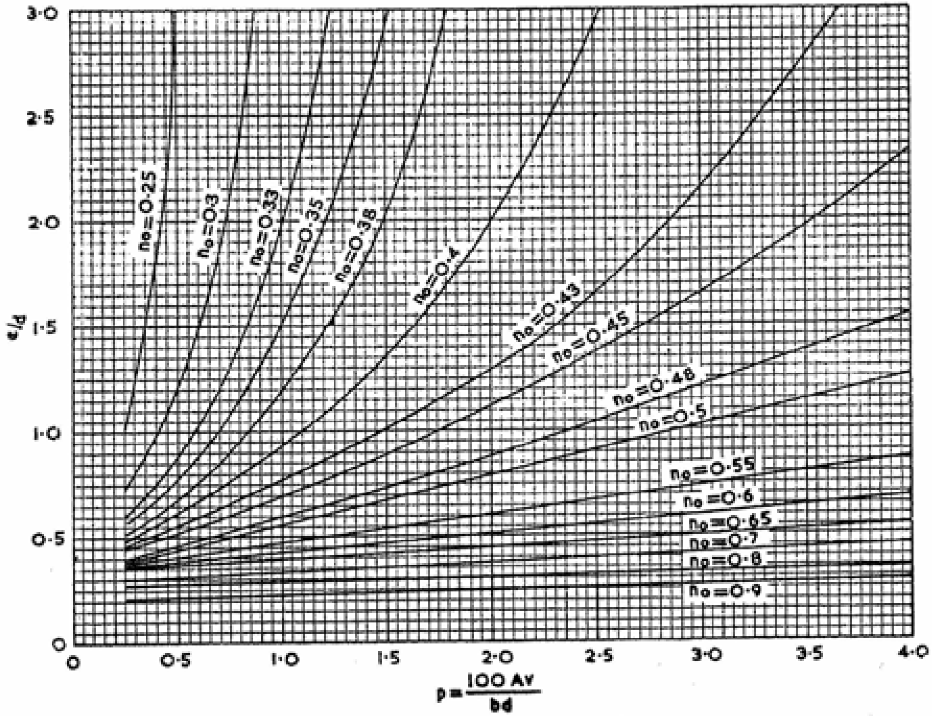


Chart 8-8. Columns with eccentric loads — location of neutral axis.

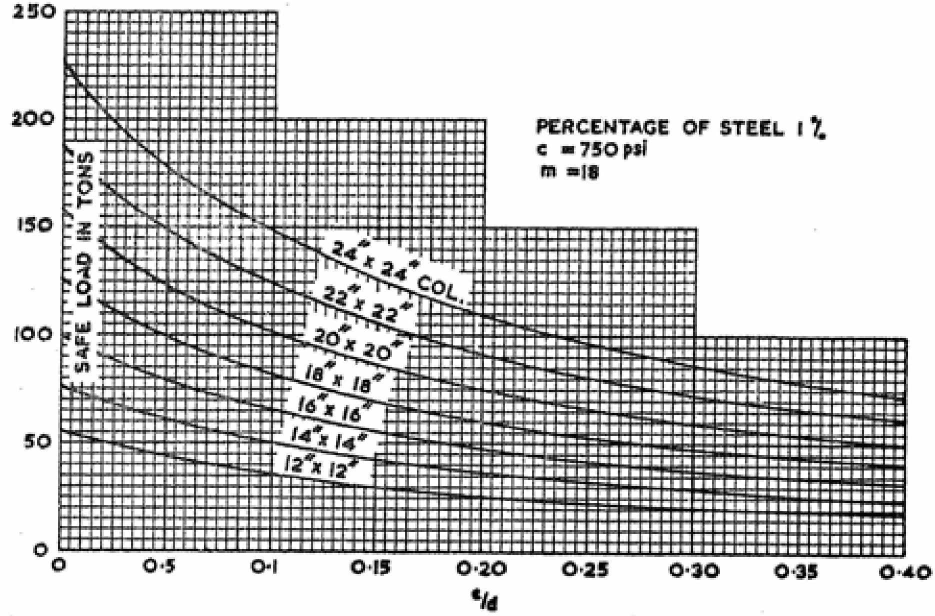


Chart 8-9. Columns with eccentric loads — safe loads with 1% steel

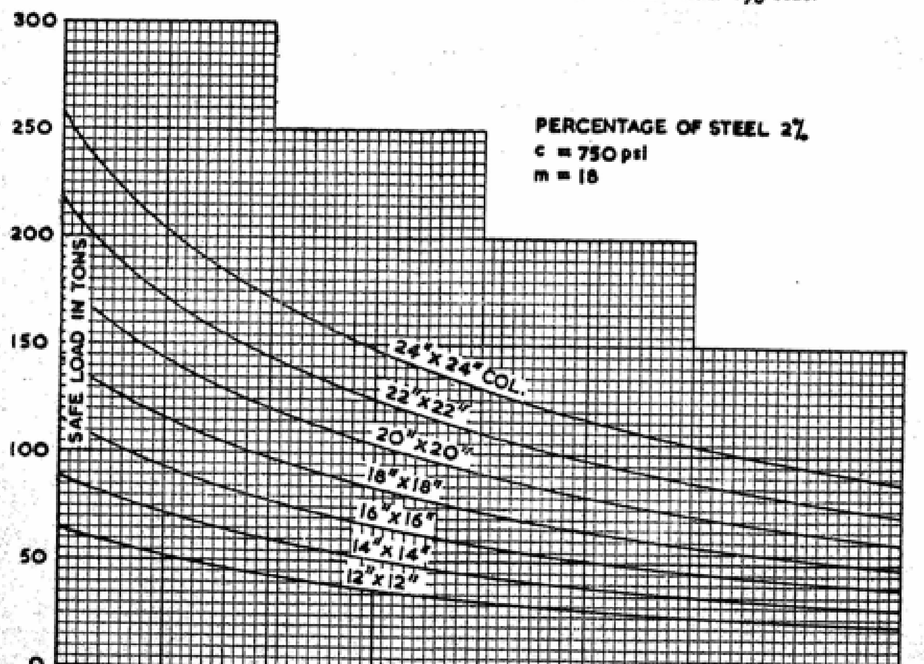


Chart 8-10. Columns with eccentric loads — safe loads with 2% steel

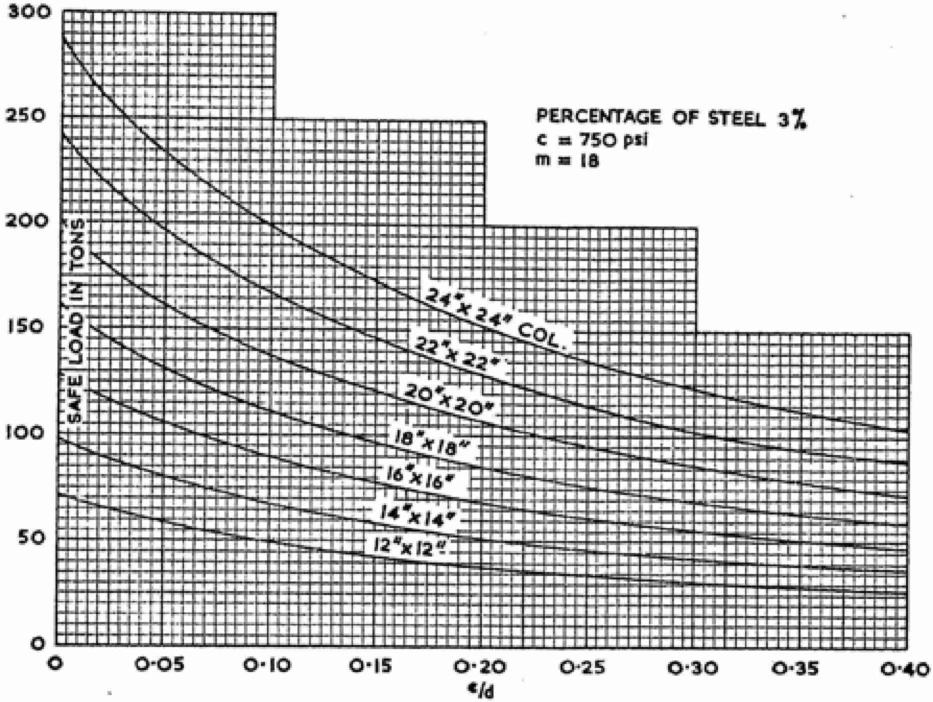


Chart 8-11. Columns with eccentric loads — safe loads with 3% steel.

8.7 Columns with Eccentric Load or Subjected to B.M.

Sometimes columns of a building are not loaded axially but the resultant load is eccentric. Especially in the case of external columns of a building, a portion of the bending moment from the end of the beams is transferred to the columns, and it is necessary to design the column to stand both direct load and B.M.

Eccentrically loaded columns fall under two cases :

(1) Columns where the whole section is under compression.

(2) Columns where only part of the section is under compression whereas the other portion is under tension.

Case (1). In this case the value of e/d is less than

$\frac{1+.33p}{6\,(1+.17p)}$ Thus in the case of columns without steel this value is 1/6 (i.e. the line of load falls within middle third of the section). The stress fc in concrete is given by the formula

$$fc = \frac{P}{bd}\left[\frac{1}{1+.17p} + \frac{e}{d} \times \frac{1}{(.167+.0544p)}\right]$$

$$= \frac{P}{bd}\,\frac{1}{K_1}$$

The value of K_1 can be found from the chart 8–6 for various values of p upto 5% and m=18, $\frac{d}{10}$ being the distance of steel rods from the face of the column.

Case (2). In this case it is necessary to first find out the position of the neutral axis from the formula :

$$n_o^3+3\left(\frac{e}{d}-\frac{1}{2}\right)n_o^2+6mp\frac{e}{d}\,n_o-3mp\left(\frac{2r^2}{d^2}+\frac{e}{d}\right)=0.$$

This being an equation of the third degree is difficult to solve. For solution Chart 8-8 should be used. After finding the neutral axis, the compressive stresses in concrete and tensile stress in steel are given by :

$$fc = \frac{P}{bd} \times \frac{2n_o}{n_o^2+2mpn_o-mp} = \frac{P}{bd} \times \frac{1}{K_2} \quad \ldots\ldots\ldots (a)$$

$$t = mfc\left(\frac{0.9}{n_o} - 1\right) \quad \ldots\ldots\ldots (b)$$

The values of K_2 can be found from Chart 8-7.

Charts 8-9, 8-10 and 8-11 give safe loads on eccentrically loaded columns of different sizes and reinforcement.

8.8 Illustrative Examples.

1. Find suitable reinforcement for a column 16″ × 16″ overall size and supporting a load of 90 tons and to be designed according to stresses for 1 : 2 : 4 concrete specified by I.S.I.

From chart 8-2, use 1.20% vertical steel i.e. $\frac{256}{100} \times 1.20$ $= 3.07$ sq. inches, i.e. 4—1″ ϕ bars.

2. Find safe load on an octagonal column 12″ across flats with a reinforcement of 8-7/8″ ϕ bars and 5/16″ helical bindings at 1″ pitch.

Area of column $= .83 \times 144 = 119.52$ sq. inches (Table 8-4).

Diameter of core

of column $= 12'' - (1\frac{1}{2}'' + 1\frac{1}{2}'') + \left(\frac{5''}{16} + \frac{5''}{16}\right)$

$= 9\frac{5}{8}''$

∴ Area of core $= \pi\,(9\frac{5}{8})^2 \times \frac{1}{4} = 72.76$ sq. in.

∴ Percentage of steel $= \frac{4.81 \times 100}{72.76} = 6.6$

∴ Load carried from Chart 8–2 = 58 tons

Load carried by helical winding from Chart 8-1 = 28 tons

∴ Total load = 86 tons

3. Find safe load on a rectangular column 10″ × 24″, reinforced with eight $\frac{7}{8}$″ ϕ bars made from 1 : 1 : 2 mix. Area of column=240 sq. inches.

$$\text{Percentage of steel} = \frac{4.81 \times 100}{24 \times 10} = 2$$

Safe load from Chart 8-4 by referring to vertical scale is 136 tons.

4. A column is 12″×12″ with 4-7/8 in. bars. It carries a central load of 50,000 lb and a moment 2,50,000 lb inches. Find the stresses in steel and concrete, if m=18.

$$\text{Eccentricity} = \frac{250000}{50,000} = 5 \text{ inches}$$

$$e/d = \frac{5}{12} = 0.42$$

$$\text{Reinforcement} = \frac{2.41}{144} = 1.67\%$$

Interpolating from Chart No. 8-7, K_2 =0.39

$$\therefore \quad fc = \frac{P}{bd} \times \frac{1}{K_2} = \frac{50000}{144} \times \frac{100}{39} = 890 \text{ p.s.i.}$$

From Chart no- 8-8, n_o =0.65

$$\therefore \quad t = mfc \quad (.9/n_o - 1)$$

$$= 18 \times 890\ (1.38 - 1.10) = 6100 \text{ p.s.i.}$$

The column is overstressed as fc is more than 750 p.s.i.

$$\text{If fc is 750, } K_2 = \frac{50000}{750 \times 144} = .465$$

∴ From Chart 8-7, use 2.5% steel

i.e. 2.5 × 1.44 = 3.6 sq. inches (6-7/8 inch bars).

5. Find the safe load for a column 12″×12″ with 2% reinforcement, the load being eccentric by 3 inches.
e/d=3/12=.25

∴ From Chart 8-9 safe load is 24 tons.

CHAPTER 9

COLUMN FOOTINGS

CONTENTS

CHAPTER 9

COLUMN FOOTINGS

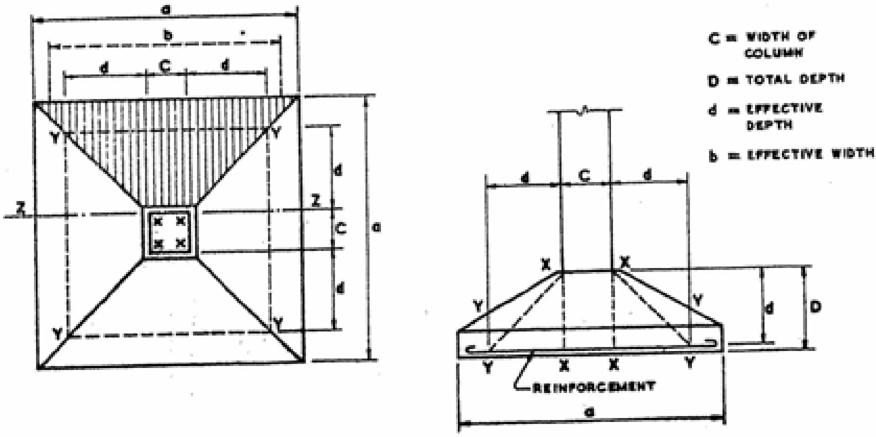
9.1 General.

Footing for a column must be safe against :

(a) Punching shear.

(b) Bending moment and shear due to soil pressure.

In addition, it must be adequately thick to allow proper embedment of the column reinforcement for complete transfer of the column load to the footing. The minimum thickness for the above condition should be 30 times the diameter of the column steel. It is also necessary to check the bond stress in the reinforcement.



(a) *Punching shear :*

The perimeter of the column × depth of footing × safe punching shear = total punching force.

i.e. $4C \times D \times S_p = p\ (a^2 - C^2)$

Safe punching shear is taken as twice the safe ordinary shear viz. 150 lb/sq. inch for 1 : 2 : 4 mix.

(b) *Bending moment :*

$$M = \frac{Wa}{24}\ (2+R)\ (1-R)^2 \text{ inch lb}$$

$$= \frac{Wak}{24} \text{ inch lb}$$

where, W=column load in lb
a=length of the side of the footing in inches.

$$R = \frac{\text{Size of column}}{\text{Size of base}}$$

This moment is at critical section ZZ (face of column) and is caused by soil pressure acting upwards on the hatched portion of the footing.

The values of constant k are given in Chart 9-1 for various values of ratio R. The value of b, the effective breadth of the footing is taken as $C+2d+\frac{1}{2}(a-C-2d)$.

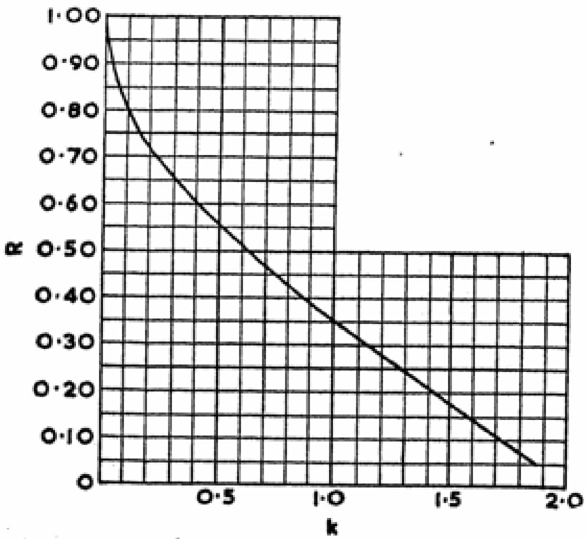


Fig. 8-1

9.2 Illustrative Example

Design a footing for a column for the following conditions :—

W =load on column= 126 tons

C =side of column = 21 inches

p =safe pressure on soil=3 tons/s.ft.= 43.7 lb/sq. in.

S_p =safe punching stress=150 lb./sq. in, m=15

Diameter of column reinforcement=1″.

(a) Size of footing :

Total load on soil $=126$ tons + say 10% wt. of footing
$=140$ tons approximately.

Size of footing $= \sqrt{\frac{140}{3}} = 6.82$ ft. $= 7'\text{-}0''$ say
$=84'' = a$

(b) Depth for safe punching stress

$4C \times d \times S_p = p\,(a^2 - C^2)$

$84 \times d \times 150 = 43.7\,(84^2 - 21^2)$

$\therefore\ d = 23''$

Take total depth of footing as 30″, the column bars being 1″ φ
(The effective depth 'd' may be taken as 27″)

(c) Bending moment.

$R = \frac{21}{84} = .25$, so that $k = 1.27$ from Fig 8-1.

$M = \frac{(126 \times 2240) \times 84}{24} \times 1.27 = 1250000$ inch lb.

Effective width of footing $= C + 2d + \frac{1}{2}(a - c - 2d)$
$= 21 + 54 + \frac{1}{2}(84 - 21 - 54)$
$= 79\frac{1}{2}'' = 80$ inches.

d for B.M. $= \sqrt{\frac{1250000}{126 \times 80}} = 11.5''$

$A_t = \frac{1250000}{18000 \times .87 \times 27} = 3$ sq. inches.

Use 10 Nos. $\frac{5}{8}''$ φ bars both ways.

Diagonal tension

Shear $= 2.56 \left[(a^2 - (C + 2d)^2 \right]$ (on plane yy)

$= 2.56 \left[(7^2 - (1.75 + 4.5)^2 \right] = 25.6$ tons

$\therefore$ Minimum depth required for safe shear @ 75 p.s.i. $\left.\right\} \dfrac{25.6 \times 2240}{4(C+2d) \times 75} = 2.56$ inches

Bond:

$$\text{Shear at column face} = \frac{126}{4} = 31.5 \text{ tons}$$

$$a = .86d = .86 \times 27 = 23.2''$$

$$\text{Sum of perimeter of steel} = 10 \times 1.96 = 19.6$$

$$\text{Local bond stress} = \frac{31.5 \times 2240}{23.2 \times 19.6} = 155 \text{ p.s.i.}$$

If this is to be reduced to 100 p.s.i. use 12—$\frac{3}{4}$ inch dia. bars.

Note :—For calculating punching shear, the value of p should strictly speaking be taken as $\frac{126}{49}$ i.e. 2.56 tsf. or 39.5 p.s.i.

Details of column footing for columns in Chapter 8 are given in Table 9. These can be used for columns, given in both the tables 8-1 and 8-2. The tables are calculated for safe bond stress of 100 p.s.i. Half the number of bars to be provided each way.

9.3 Safe Loads on Foundations.

(a) Wet Clay	..	1 tsf.
(b) Wet Sand	..	2 ,,
(c) Firm Clay	..	2 ,,
(d) Sand and Clay mixed in layers	..	2 ,,
(e) Fine and Dry Sand	..	3 ,,
(f) Hard Dry Clay	..	4 ,,
(g) Coarse Sand	..	4 ,,
(h) Gravel	..	6 ,,
(i) Soft Rock	..	8 ,,
(j) Hardpan	..	10 ,,
(k) Medium Rock	..	15 ,,
(l) Hard Rock	..	40 ,,

9.4 Design Tables.

Table 9

SQUARE FOOTINGS

(fc=750 lb/sq. in, t=18000 lb/sq. in, m=18).

Ref. No. of Column	½ ton/sq. ft.					1 ton/sq. ft.				
	a	D (Inches)	Concrete C.Ft.	Steel Bars	Steel Lb	a	D (Inches)	Concrete C.Ft.	Steel Bars	Steel Lb
C1	6'-3"	15	36	12-½"	50	4'-3"	15	17	8-½"	34
C2a	7'-6"	15	53	18-½"	90	5'-0"	15	24	12-½"	65
C2b	8'-0"	18	66	20-½"	112	5'-6"	18	32	12-½"	72
C3a	8'-0"	15	60	16-½"	136	5'-6"	15	29	10-½"	55
C3b	8'-6"	18	74	16-½"	145	6'-0"	18	38	12-½"	78
C3c	9'-3"	22	99	16-½"	157	6'4"	22	48	10-½"	63
C4a	8'-9"	15	72	20-½"	182	6'-3"	15	37	16-½"	106
C4b	9'-3"	18	88	18-½"	176	6'-6"	18	44	14-½"	98
C4c	9'-9"	22	112	18-½"	186	6'-9"	22	54	14-½"	100
C4d	10'-9"	26	146	18-½"	205	7'-0"	26	63	16-½"	77
C4e	11'-3"	30	177	18-½"	214	7'-3"	30	75	12-½"	94
C5a	10'-9"	18	118	20-½"	322	7'-6"	18	59	18-½"	143
C5b	11'-0"	22	130	18-½"	297	7'-9"	22	71	18-½"	148
C5c	11'-9"	26	179	16-½"	309	8'-0"	26	84	16-½"	136
C5d	12'-6"	30	216	18-½"	337	8'-6"	30	103	16-½"	145
C5e	13'-6"	26	230	20-½"	540	9'-3"	26	111	22-½"	218
C6a	12'-6"	22	179	26-½"	488	8'-8"	22	89	24-½"	217
C6b	13'-3"	26	225	24-½"	467	9'-0"	26	105	22-½"	207
C6c	14'-0"	30	272	24-½"	504	9'-6"	30	128	22-½"	219
C7a	13'-8"	26	240	26-½"	535	9'-6"	26	117	26-½"	256
C7b	14'-9"	30	301	26-½"	576	9'-9"	30	136	24-½"	243
C7c	15'-9"	34	365	28-½"	615	10'-3"	34	163	24-½"	262
C8a						10'-6"	26	131	30-½"	301
C8b						10'-3"	30	150	28-½"	297
C8c						10'-8"	34	179	28-½"	311
C8d						11'-8"	30	187	24-½"	414
C9a						11'-3"	30	191	24-½"	414
C9b						11'-6"	34	207	24-½'	414
C10a						12'-8"	34	154	28-½"	536
C10b						13'-9"	30	268	24-½"	867
C10c						14'-0"	34	305	36-½"	766
C11a						14'-9"	34	238	48-½"	1062
C11b						15'-0"	38	229	48-½"	1080

Sections and reinforcement of footings for soil pressures of ½ and 1 ton/s.ft.

Table 9 (contd.)

SQUARE FOOTINGS

Ref. No. of Column	2 ton/sq. ft.					3 ton/sq. ft.				
	a	D (inches)	Concrete C.Ft.	Steel Bars	Steel Lb	a	D (inches)	Concrete C.Ft.	Steel Bars	Steel Lb
C1	3'-0"	15	9	12-½"	24	2'-8"	15	7	12-½"	21
C2a	3'-6"	15	12	16-½"	39	3'-0"	15	9	16-½"	33
C2b	3'-9"	18	15	16-½"	41	3'-0"	18	10	16-½"	33
C3a	3'-9"	15	14	16-½"	41	3'-3"	15	11	16-½"	36
C3b	4'-3"	18	20	18-½"	51	3'-3"	18	12	18-½"	30
C3c	4'-3"	22	22	18-½"	51	3'-6"	22	16	18-½"	42
C4a	4'-3"	15	18	18-⅝"	81	3'-6"	15	12	18-⅝"	67
C4b	4'-6"	18	21	18-⅝"	86	3'-6"	18	14	18-⅝"	67
C4c	4'-9"	22	27	16-⅝"	81	3'-9"	22	18	16-⅝"	81
C4d	5'-0"	26	34	14-⅝"	75	4'-3"	26	25	14-⅝"	64
C4e	5'-3"	30	41	12-⅝"	68	4'-3"	30	28	12-⅝"	55
C5a	5'-0"	18	27	20-⅝"	105	4'-6"	18	22	20-⅝"	94
C5b	5'-3"	22	34	18-⅝"	100	4'-3"	22	23	18-⅝"	81
C5c	5'-9"	26	45	16-⅝"	98	4'-6"	26	28	16-⅝"	77
C5d	5'-10"	30	50	16-⅝"	98	4'-8"	30	34	16-⅝"	80
C5e	6'-4"	26	53	22-⅝"	146	5'-3"	26	38	22-⅝"	121
C6a	6'-0"	22	44	24⅝"-	150	4'-3"	22	23	24-⅝"	107
C6b	6'-3"	26	52	20-⅝"	131	5'-0"	26	34	20-⅝"	105
C6c	6'-4"	30	59	18-⅝"	120	5'-3"	30	42	18-⅝"	100
C7a	6'-6"	26	57	22-⅝"	150	5'-4"	26	38	22-⅝"	127
C7b	6'-8"	30	66	20-⅝"	140	5'-6"	30	47	20-⅝"	115
C7c	7'-0"	34	79	22-⅝"	161	5'-8"	34	44	22-⅝"	131
C8a	6'-9"	26	62	24-⅝"	168	5'-6"	26	42	24-⅝"	137
C8b	7'-0"	30	72	22-⅝"	161	5'-9"	30	51	22-⅝"	132
C8c	7'-3"	34	86	24-¾"	261	6'-0"	34	61	24-¾"	216
C8d	8'-0"	30	102	24-¾"	288	6'-6"	30	72	24-¾"	234
C9a	7'-9"	30	90	28-¾"	327	6'-3"	30	60	28-¾"	262
C9b	8'-0"	34	105	22-¾"	264	6'-6"	34	70	22-¾"	214
C10a	8'-6"	34	118	24-¾"	306	7'-0"	34	83	24-¾"	252
C10b	9'-3"	30	127	32-¾"	444	7'-6"	30	85	32-¾"	360
C10c	9'-3"	34	140	30-¾"	416	7'-6"	34	94	30-¾"	357
C11a	9'-9"	34	154	32-¾"	468	8'-0"	34	106	32-¾"	384
C11b	10'-3"	38	186	30-¾"	461	8'-3"	38	118	30-¾"	371

Sections and reinforcement of footings for soil pressures of 2 and 3 tons/s.ft.

CHAPTER 10

RETAINING WALLS

CONTENTS

CHAPTER 10

RETAINING WALLS

10.1 Small Retaining Walls.

Small retaining walls upto 15′-0″ are mostly of cantilever type. Retained materials like sand, gravel, earth, etc. exert on the retaining structure, pressure of much the same nature as ordinary fluids. The intensity of this pressure (W_e) depends upon the weight (w), angle of repose (ϕ) and angle of surcharge (α) of the material and is given by the formula :

$$W_e = w \cos\alpha \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}} = wk_1.$$

When there is no surcharge i.e. when $\alpha = 0$, this reduces to

$$W_e = w\,\frac{1 - \sin\phi}{1 + \sin\phi} = wk_1.$$

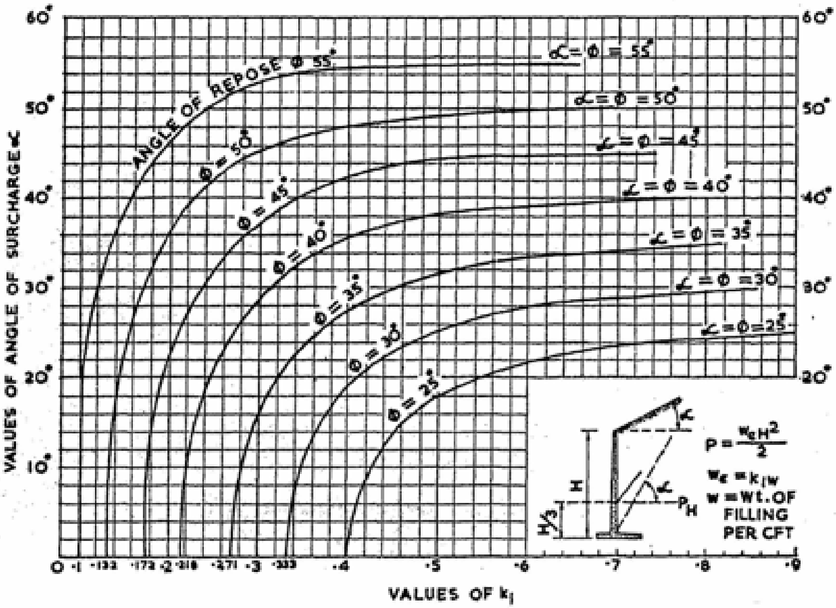


CHART 10-1.

Factors for conversion of weight of soil to horizontal pressures

Chart No. 10-1 gives the values of k for different values of ϕ and α and Table No. 10-1 gives the values w and ϕ for various filling materials.

In case of a cantilevered retaining wall it is necessary to see that :

(a) the stem, heel and toe are adequately reinforced for B.M. and shear

(b) the overturning moment is less than the stabilizing moment

(c) the pressure on the ground is within safe limits

(d) the wall is safe against sliding

Charts 10-2 to 10-6 may be used with advantage for preliminary designs which can subsequently be modified slightly by exact calculations.

10.2 Example.

Find approximate dimensions and reinforcement for a cantilever retaining wall 12′ high over the ground level with level fill weighing 110 lb/c.ft. and with angle of repose of 30°.

W_e, from Chart 10-1 $= .33\times110=37$ lb

Overturning force P (from Chart 10-4) $=$ 4500 for $W_e=40$ and $H=15$; 3400 for $W_e=30$ and $H=15$

$\therefore$ for $W_e=37$ and $H=15$, $P=4150$ lb say

Effective depth of stem (from Chart 10-2) for $H=14'$—$0''$ $=10.8''$

and $A_t=1.18$ sq. inch i.e. $\frac{3}{4}''$ ϕ @ $4\frac{1}{2}''$c.c. For $W_e=37$ (by interpolation) assume $B=.5\times15=7\frac{1}{2}$ ft.

$W=110\times5\times15=8250$ lb

M overturning= 21200 ft. lb (by interpolation) (from Chart 10-4)

Stabilizing M required for a factor of safety of 2

$$=\frac{5}{2}\times W=20500 \text{ lb ft.}$$

Try $B=9'$

Then $W=110\times6\times15=9900$ lb and stabilising moment

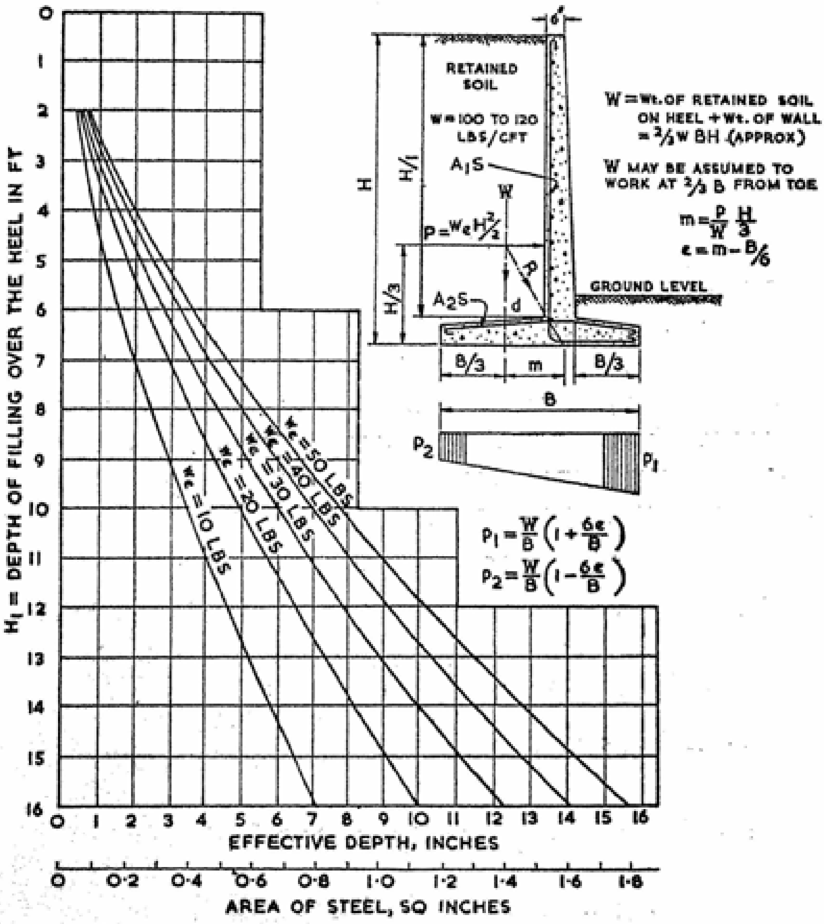
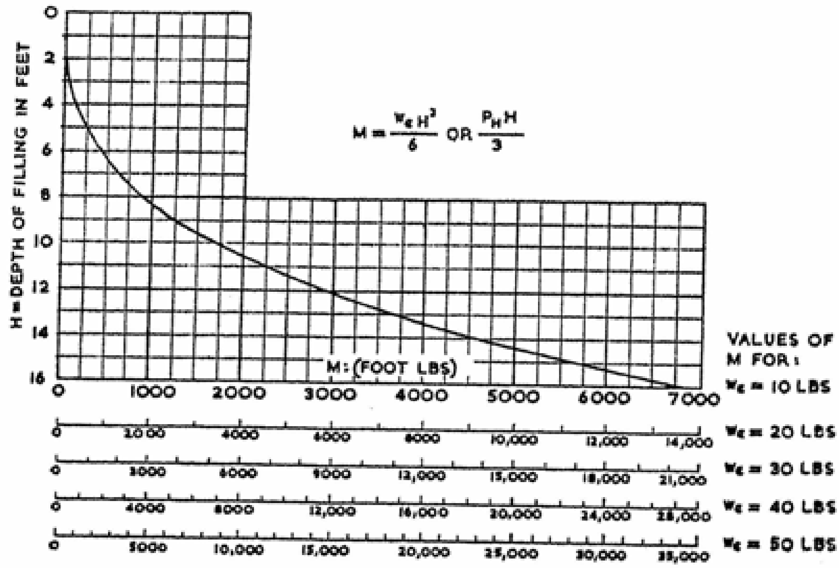


CHART 10-2

Stem thickness for various depths and horizontal pressures

CHART 10-3

BM's for various depths and horizontal pressures



for a factor of safety of 2 = 9900 × 3=29700 ft. lb

Frictional force=μ W=.7×9900=6930 lb, which is more than P.

$$m=\frac{P}{W}\times H/3=\frac{4150}{9900}\times 5=2.1 \text{ ft.}$$

$$e=m-\frac{B}{6}=2.1-\frac{9}{6}=0.6$$

$$p_1=\frac{9900}{9}\left(1+\frac{6\times .6)}{9}\right)=1100\times 1.4=1540 \text{ lb/ft.}$$

$$p_2=\frac{9900}{9}\left(1-\frac{6\times .6}{9}\right)=1100\times .6=660 \text{ lb/ft.}$$

Moment in heel for 15′ height of fill=20800 ft. lb (from Chart 10-5) and 5′ span

$$d=\sqrt{\frac{20800}{137}}=12.2'' \text{ max. say } 15'' \text{ overall.}$$

$$A_t=\frac{20500\times 12}{18000\times .86\times 12.2}=1.33 \text{ sq. in}$$

Moment in toe $= \frac{1540 \times 3^2}{2} = 6900$ ft lb (neglecting small variation of ground pressure).

A_t for $14\frac{1}{2}''$ effective depth of toe $= \frac{6900 \times 12}{18000 \times .86 \times 14.5}$

$= .37$ sq. in. i.e. $\frac{5}{8}''\phi$ @ $10''$

CHART 10-4

Overturning force for various depths and horizontal pressures.

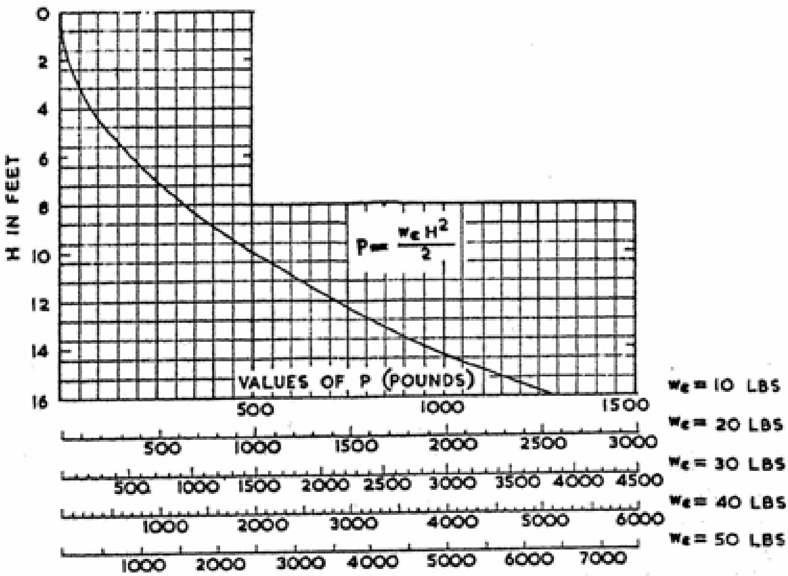


Chart 10-3 gives the bending moment caused in the vertical member of a cantilever retaining wall due to different values of earth pressure and may be used for finding slab reinforcement at different heights, for economy.

From these approximate details accurate calculation in which W includes the weight of wall, and in which the point of application of W etc. is correctly calculated can be carried out, and final details worked out accurately.

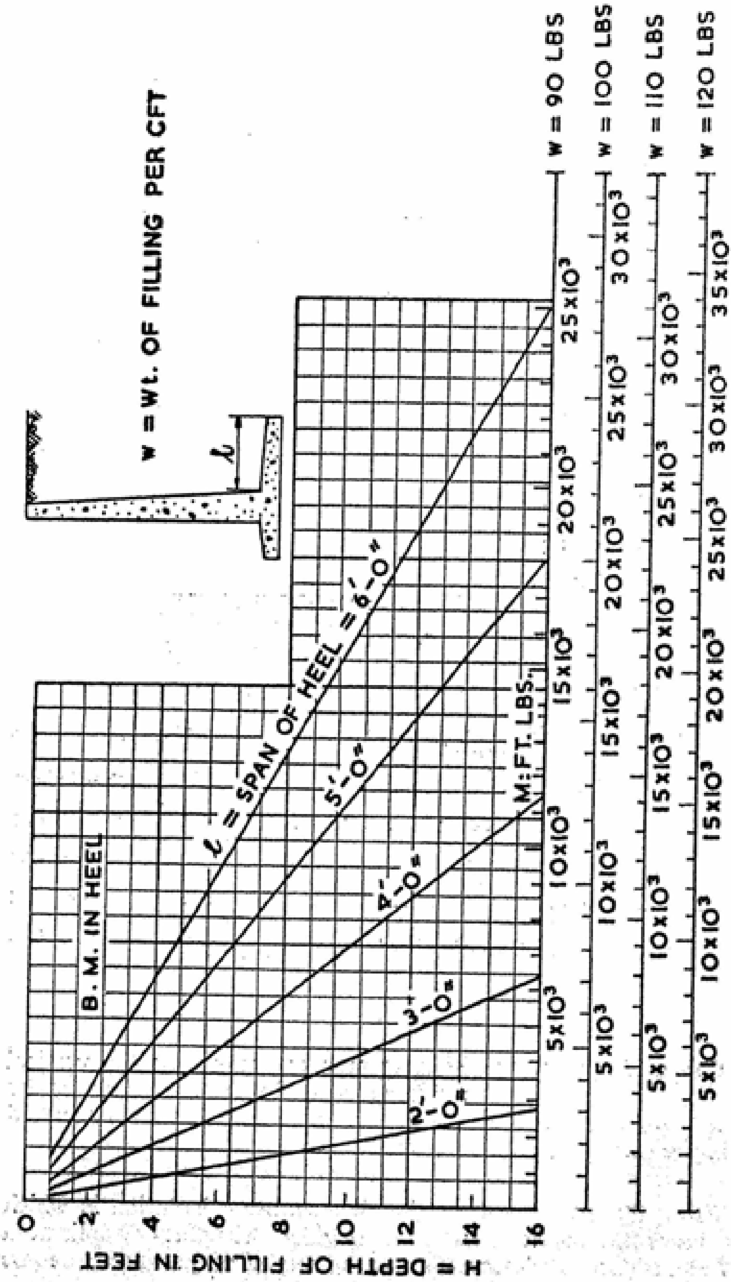


Chart 10-5 B. M. in heel of different widths with varying depths of fill

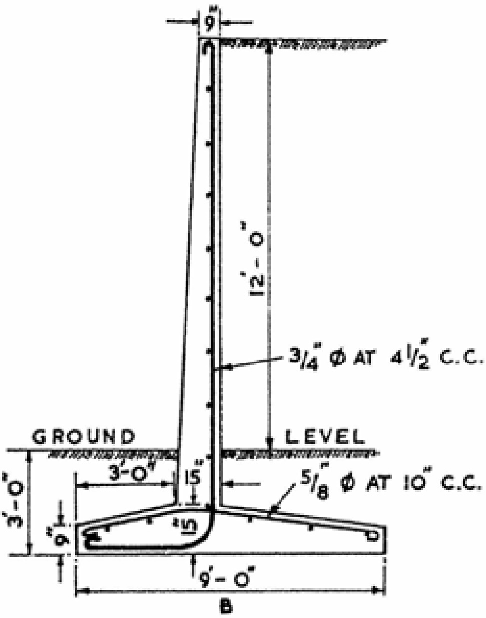


Table 10-1

Weight and angles of repose for various soils

Material	w (lb/cft.)	ϕ (degrees)
Sand dry	90 to 100	30
,, moist	100 to 110	35
,, wet	110 to 125	25
Vegetable earth dry	90 to 100	30
-do- moist	100 to 110	45
-do- wet	110 to 120	15
Gravel	90	40
Rubble stone	100 to 110	45
Gravel and sand	100 to 110	25 to 30
Clay dry	120 to 140	30
,, moist	120 to 160	45
,, wet	120 to 160	15
,, mud	105 to 120	0
Ashes	40	40

NOTES

CHAPTER 11

CIRCULAR TANKS

CONTENTS

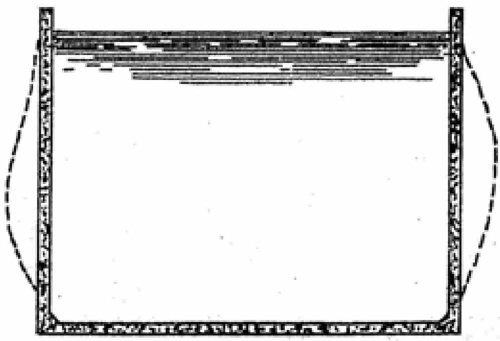
CHAPTER 11

CIRCULAR TANKS

11.1 General

The pressure of water at a depth of h ft. is 62.5 h lb per sq. ft. In the case of a circular tank the tension in the tank walls caused by the water pressure is therefore $\frac{62.5hD}{2}$ lb in a ring one foot high, of diameter D ft. and situated at a mean depth of h ft. below the surface. The cross-sectional area of steel rings to be provided in this strip is $\frac{62.5hD}{2 \times 12000}$ sq. inches.

The walls of all tanks are, however, restrained at the base being monolithic with the floor and the walls assume the shape shown in sketch below when the tank is filled with water.



Deflection of tank walls

In such a case the water pressure at the bottom is entirely resisted by the cantilever action of the vertical wall which is subjected to tensile stress on the inner face. In case of shallow tanks of large diameter, the tendency of the walls is to act more like vertical cantilevers and hoop stresses are small, whereas in cases of deep tanks of small diameter, hoop stresses are more and cantilever action is very small.

The charts on pages 216-218 give

(a) Capacity of tanks in gallons for various heights and diameters (Chart No. 11-1).

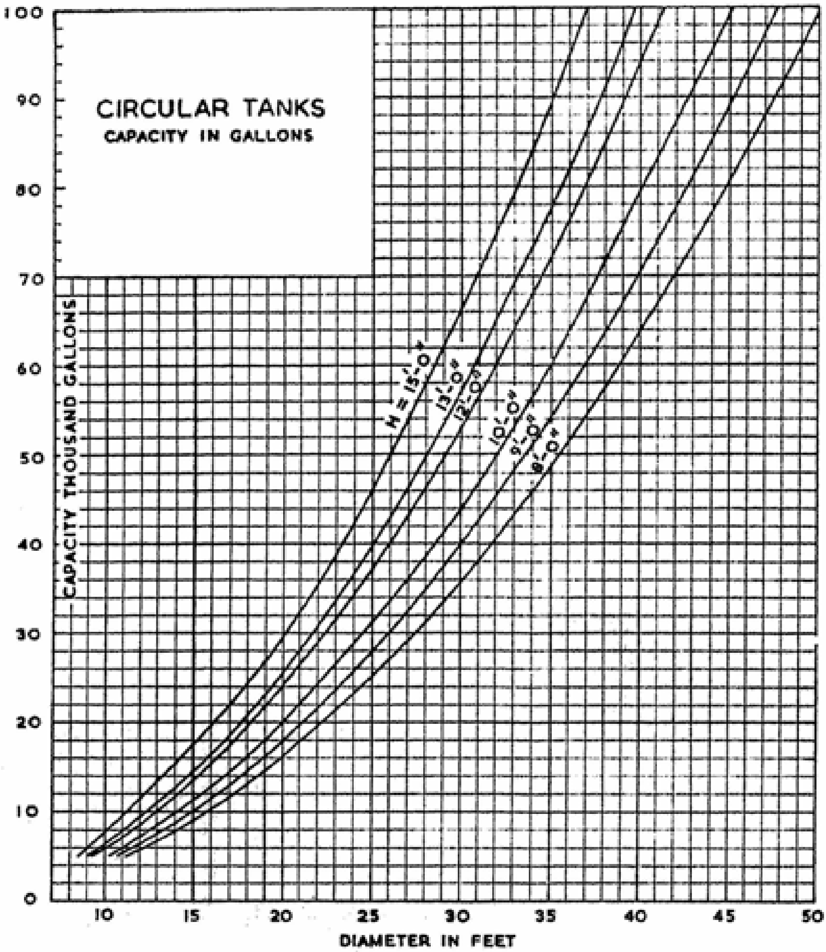


CHART 11-1. Capacity of circular tanks for various diameters and lengths

(b) Position of maximum hoop tension (Chart No. 11-2).

(c) Amount of maximum hoop tension (Chart No. 11-3).

(d) Amount of restraint moment (Chart No. 11-4).

The minimum thickness of wall to avoid cracking due to shrinkage should be 0.0004T inches (T being the maximum hoop tension in lb)

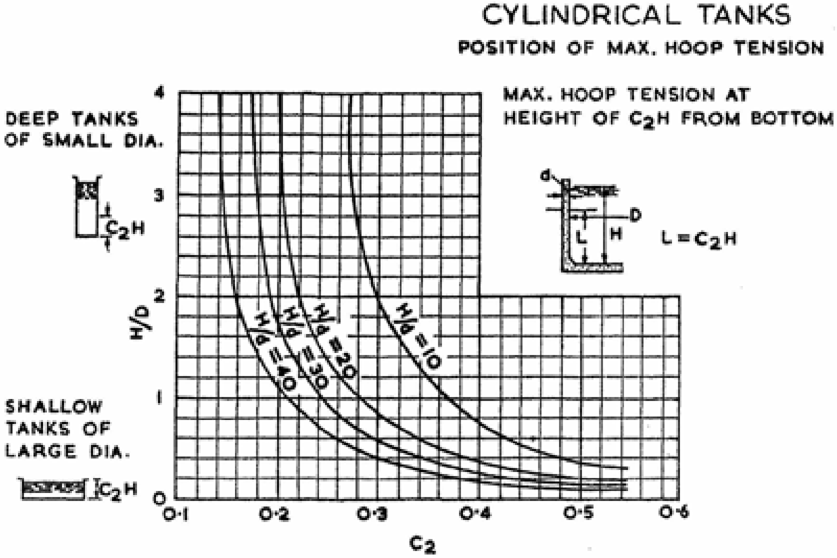


CHART 11-2

Position of maximum hoop tension for various height/diameter and thickness/diameter ratios

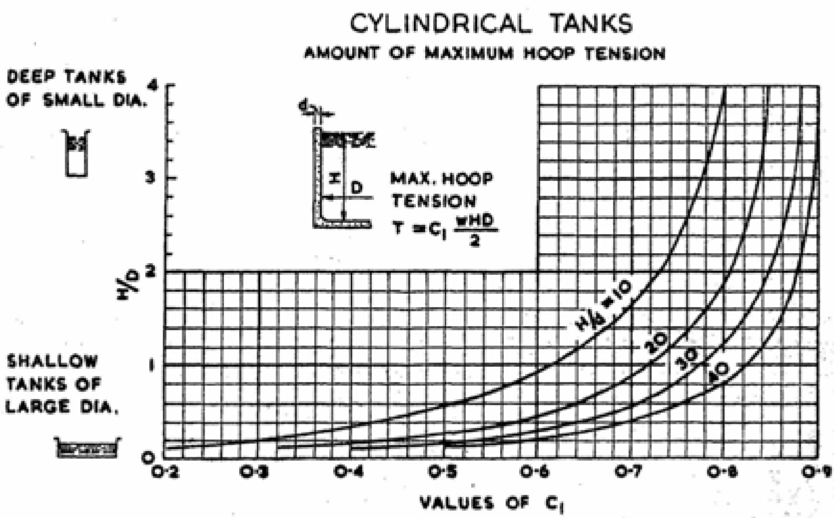


CHART 11-3

Maximum hoop tension for various height/diameter and thickness/diameter ratios

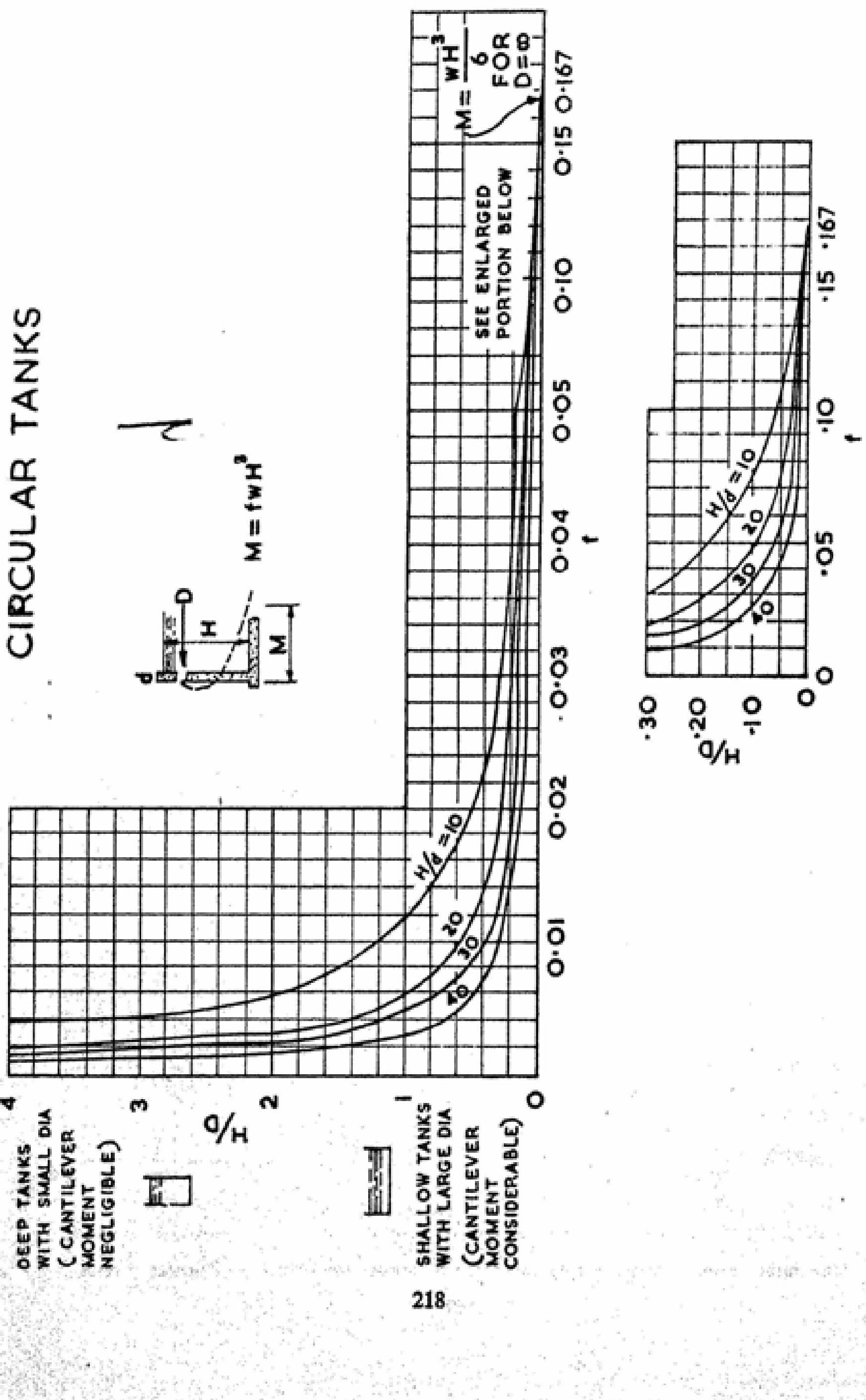


CHART 11-4

Restraint moments for various height/diameter and thickness/diameter ratios

Table 11 gives details of tanks of different capacities and sizes.

Table 11

Ht. of Water ft. / Capacity in Gals.	15					12				
	D Ft	d Inches	L Ft	A_H	A_V	D	d	L	A_H	A_V
100,000	37	10	6.30	.83	.45	40	9	5.64	.68	.38
75,000	32	9	5.55	.80	.33	35.5	8	5.30	.64	.36
50,000	26	8	5.00	.70	.35	29	7	4.6	.58	.31
30,000	20½	7	4.20	.56	.31	22½	7	4.2	.45	.25
10,000	11½	7	3.50	.35	.18	13	6	3.6	.28	.16

Ht. of Water ft. / Capacity in Gals.	10					8				
	D	d	L	A_H	A_V	D	d	L	A_H	A_V
100,000	45	8	5.7	.52	.33	50	7	6.0	.35	.27
75,000	39	7	4.9	.49	.33	43½	7	5.2	.35	.27
50,000	32½	6	4.2	.41	.26	35½	6	3.8	.32	.25
30,000	25	6	3.9	.38	.21	28	6	3.5	.28	.19
10,000	15	6	3.3	.27	.14	16	6	3.2	.19	.12

11.2 Illustrative Example.

Find the stresses in the walls of a circular tank with 10′ depth of water and of diameter 25 ft.

Assuming the thickness d of walls as 6″

$$H/d = \frac{10}{.5} = 20 \quad \text{and} \quad H/D = \frac{10}{25} = .4$$

From charts we have :

(a) position of maximum hoop tension

$L = C_2H = .4 \times 10 = 4$ ft. above base.

(b) Maximum hoop tension

$$T = C_1 \frac{WH}{2} D$$

$= .59 \times 62.5 \times 10/2 \times 25 = 4700$ lb

(c) Restraint Moment

$fWH^3 = 0.014 \times 62.5 \times 10^3$ ft. lb

$= 10{,}500$ inch lb

Minimum $d = 0.0004 \times 4700 \times 1.68$ inches. Provide 6″ for practical purposes.

Reinforcement :

$$A_H \text{ (for hoop tension)} = \frac{4700}{12000} = .39 \text{ sq. in.}$$

Use .6 of above at bottom to allow for fixity between the wall and base.

A_V (for restraint moment)

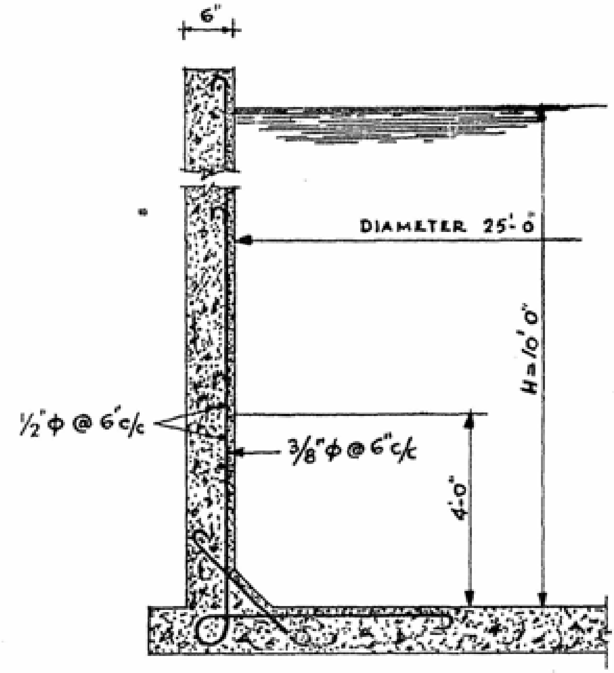
With ½″ ϕ bars and 1″ cover

Effective depth $= 6 - 1.25 = 4.75''$

Lever arm $= .85 \times 4.75''$

$$A_v = \frac{10500}{12,000 \times .85 \times 4.75} = .22 \text{ sq. ins. approximately}$$

Use 3/8" ϕ @ 6" c.c.



Section of tank.

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CHAPTER 12

DIFFERENT KINDS OF CONCRETE

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CHAPTER 12

DIFFERENT KINDS OF CONCRETE

12.1 Prestressed Concrete.

12.1.1 PRINCIPLES OF PRESTRESSED CONCRETE.

The principle of prestressed concrete is to introduce internal stresses in the concrete, of nature opposite to those caused by the design load. Hence when the design load operates, the resultant stresses in the concrete are very low.

12.1.2 ADVANTAGES OF PRESTRESSED CONCRETE.

(a) Economy : spans above 100 ft. are not economical in ordinary R.C. work since so much of concrete is wasted in portion below the neutral axis.

(b) It is possible to use high tensile steel reinforcement which cannot be used in ordinary R.C. because of necessity to limit the width of minute cracks in the tensile zone to .02 inches.

(c) The danger of rusting of reinforcement due to atmospheric action in unfavourable areas is entirely eliminated.

12.1.3 METHODS OF PRESTRESSING.

There are two methods :

(a) Pre-tensioned bonded method.

(b) Post-tensioned bondless method.

In (a) high tensile steel reinforcement is placed in position and stretched with the help of yokes, hydraulic jacks and abutments. The calculated tension is induced in the wires and concrete is filled into the mould of the prestressed concrete member and allowed to set. When the concrete is sufficiently strong, the tension of the wire is released. The steel while contracting induces compression in the concrete, being bonded to the concrete.

In (b) high tensile steel is placed in the moulds of the prestressed concrete member but is prevented from coming in contact with the concrete being encased in sheaths. The prestressing reinforcement consists of cables made of high tensile steel wires, laid in one or more rings round a core. After the concrete is placed and allowed to attain its normal strength, the high tensile wires are stretched by means of special jacks. The wires are then anchored to the two

ends of the beams or structural member by special anchorages. The compression in the concrete is developed through these anchorages instead of through bond between steel and concrete as in method (a).

12.1.4 FUNDAMENTAL CONCEPT.

The prestressing compression being applied eccentrically produces in the section concerned stresses equal to $\frac{F}{A} \pm \frac{F y^1 y}{I}$

These stresses when combined with the tension and compression due to dead and live load bending give the resulting stresses as shown in Fig. 12-1.

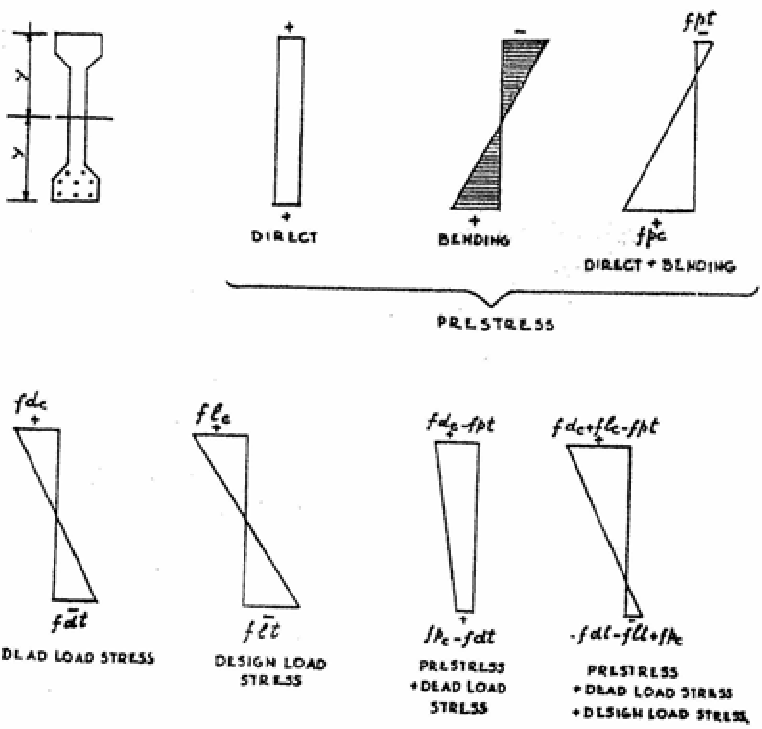

Fig. 12-1

The induced prestressing force is reduced to some extent due to shrinkage of concrete, creep in concrete, plastic flow of steel reinforcement and compression of concrete due to prestressing.

12.1.5 USES OF PRESTRESSED CONCRETE.

Prestressed concrete is being used for various structural items such as bridges, large span roofs, precast roofing joists, railway sleepers, tanks, pressure pipes, etc. etc. The following statements will give some idea about the comparative dimensions and economic possibilities of prestressed concrete.

(1) Prestressed concrete girders *vs* steel joists.

For the same loading

(a) Prestressed concrete girders are twice the weight of joists.

(b) Prestressed concrete girders are one and a half times deeper than steel joists.

(2) R.C.C. *vs* steel girders

Steel in ordinary R.C.C. girders is 10 per cent of that used in steel joists.

(3) Prestressed concrete *vs* R.C.C. girders.

(a) Steel required in prestressed concrete girders is 25% of that required in R.C.C. girders, i.e. $2\frac{1}{2}$% of that required in steel joists.

(b) Concrete in prestressed concrete girders is 50% of that required in ordinary reinforced concrete girders.

12.2 Precast (Prefabricated) Concrete.

Precast (prefabricated) concrete is getting popular day by day.

12.2.1 ADVANTAGES.

(a) Economy in formwork.

(b) Possibility of standardization and employment of machinery for manufacture.

(c) Controlled weather conditions.

(d) Use of experienced and skilled workmen.

(e) Temperature effects in the structure are negligible due to many construction joints.

(f) Defective components can be easily rejected.

12.2.2 DISADVANTAGES.

(a) Repeated handling may break the units.

(b) The problem of connecting various units properly is difficult.

12.2.3 REQUIREMENTS.

Precast concrete units must be strong and at the same time light. It is, therefore, necessary to use lightweight concrete in case of non-structural units. Structural units are made either hollow or flanged or are in prestressed concrete so as to cut down the quantity of concrete. It is also necessary to use special methods of consolidation and curing such as vibration, shocks, spinning, steam or electric curing, etc. The concrete also is very carefully designed and made. Typical sections of structural precast concrete units are shown in Fig. 12-2.

12.2.4 APPLICATIONS.

Precast concrete is used for numerous purposes, the following being only a typical list of most important items:

Floors : Channel beams, hollow beams, T-beams, I-beams, etc.

Foundations :	Sockets for wooden or steel column		
	plates	—do—	
	pedestals	—do—	etc.
	piles	—do—	

Building frames :	Portals, gabled frames, etc.
Building units :	Hollow and solid blocks, lintels, wall panels (hollow or solid), window and door sills, cornices, string courses, chimneys, trusses, roofing tiles, etc.
Bridges :	Bridge girders, slabs, arch voussoirs.
Miscellaneous :	Pipes, transmission line poles, garden furnitures, drains, silos, tanks, railway sleepers, etc.

12.3 Shot Concrete or Gunite.

12.3.1 DEFINITION..

Cement and sand mortar applied by air pressure is commonly called gunite. Actually such concrete is termed Shot-

crete in general and "gunite" is only a trade name for the product of Cement Gun Company.

12.3.2 USES.

Gunite is used for many purposes, the most important being :—

(a) Repairing masonry or concrete structures.

(b) Waterproofing.

(c) Construction of water tanks.

(d) Lining of canals and reservoirs. (Two inches thick gunite is used on brick pitching and three inches on earth slopes.)

(e) Protection of steel from fire, corrosion, etc.

(f) Roof and rib protection in mines.

(g) Walls and roofs etc. of buildings.

12.3.3 PROPERTIES OF GUNITE.

Gunite walls for building are generally 2″ thick and are shot on chicken netting stretched against plywood forms. Roofs of buildings are 2 to 3 inches thick. Gunite is used for r.c. domes also.

Strength @ 28 days—6000 lb/sq. inch average.

Modulus of elasticity—4,670,000 lb/sq. inch.

W/C ratio required—.25 to .30 (by weight).

Density—⅝″ gunite slab could stand 700′ head of water

1½″ gunite slab could stand 1600′ head of water

12.3.4 NOTES ON SPECIFICATIONS FOR GUNITE WORK.

a. Sand should be of fineness modulus 2.4.

The following grading is recommended :

passing No. 480 sieve (I.S.I.)	98—100%
240 „	70— 95%
120 „	60— 85%
60 „	45— 65%
30 „	15— 35%
15 „	0— 5%

Sand should be slightly moist (3 to 8% moisture).

b. Air pressure : 35 lb/sq. inch for 100′ long hose. Increase 5 lb for every additional 50 ft.

c. Water pressure : Should be 15 lb more than the air pressure.

d. Material should be shot at right angles to the surface. Loose sand deposits should be removed. A thin edge should be left at each day's work.

e. The following points to be attended to in case of various works :

Steel encasing : fix 2″ × 2″ mesh wire netting at about ¾″ from the surface. Remove paint, rust, etc. and apply gunite 1 : 3 mix by volume.

Floors : apply 1 : 3 gunite in one coat upto 3½″ thickness. For greater thickness apply in 2 coats the final coat being always more than one inch.

Wall slabs and panels : The thickness to be 1½″ upto 4′ span and 2″ upto 7′ span. The steel fabric reinforcement should not be more than 4″ mesh and the area should be 3% of wall cross-section in each direction.

Waterproofing of walls : Clean and sand-blast the surface and apply ½″ gunite 1 : 3 mix.

12.3.5 DESIGN DATA FOR GUNITE.

Assumptions : Ultimate compressive stress.

1 : 3 mix—4100 lb/sq. inch.
1 : 2½ mix—4800 —do—

fc	t	n_o	j	p	q
1500	20000	.43	.86	.016	276
1800	20000	.47	.84	.021	359
1200	16000	.43	.86	.016	221
1500	16000	.48	.84	.023	305

(Value of modular ratio is 10)

12.4 Lightweight Concrete.

It is frequently used in making precast blocks, etc., to keep down the weight of the units. Research has shown that it is possible to make concrete of low cement content, with excellent workability, sufficient strength and adequate heat insulation, and effect appreciable economy in structural load of a building.

12.4.1 METHODS.

Lightweight concrete is made by

(a) Using light and porous aggregate such as breeze, pumice, etc.

(b) By adding to the cement slurry, containing little or no aggregate, an aerating agent which causes the paste to foam so that the set material contains a certain proportion of air.

12.4.2 LIGHTWEIGHT AGGREGATES.

These are of three types.

(a) Natural : such as pumice, breeze, etc.

(b) By-products : such as blast-furnace slag, coke, breeze, cinders, saw-dust, etc.

(c) Processed aggregates such as
Exfoliated vermiculite—a type of mica expanded by heat.

Sintered diatomite—a processed diatomite with soft chalky particles.

Perlite—an expanded perlite composed of frothy particles.

Expanded clay.

Sintered fly ash—a processed material resulting from the combustion of powered fuel in steam power plants.

12.4.3 AERATED CONCRETE.

Hydrogen gas bubbles are generated in a mix containing lime or cement by incorporation of finely divided aluminium or zinc powder about 0.1% of cement. The cellular structure produced in this way is retained after the cement has set and a lightweight product obtained thereby. Sometimes a foaming agent is used, instead of the metal powder, and the mix is whipped up in a special mixer to a fine foam. The weight of aerated cement is 40 to 60 lb per c.ft.

Properties of Lightweight Concrete

Material	Mix	Wt. Lb/cft.	Compressive strength Lb/sq. in	Transverse strength Lb/sq. in	Shrinkage %	Thermal conductivity
Pumice Concrete ..	1:6	45—70	200—550	100—150	.04—.08	1.4 B.th.U
-do- ..	1:10					1.1
Clinker Concrete ..	1:6	50—105	150—450	75—250	.03—0.20	2.8
-do- ..	1:10					2.3
Foamed Slag Concrete.	1:6	80—95 } 60—95 }	300—500	200—300	0.03—0.05	1.5—2.2
Cellular Concrete ..	1:12	37—60	200—500	100—240	0.05—0.18	1—2
Ballast Concrete ..	1:2:4	140—150	3000—5000	300—600	0.03—0.04	7.0

12.5 Air-entrained Concrete.

It is possible to cause in the concrete the inclusion of millions of microscopic bubbles during the process of mixing by using a small amount of certain chemicals either in the mixing water or in the cement. Each bubble of air is encased in a hard glazed shell formed by the surface active force generated by the chemical reaction. Thus the formation of the usual capillary channels by which the water enters the concrete, is prevented and there is no possibility of disintegration of the concrere by freezing and thawing or by leaching. The air bubbles give additional workability permitting smaller w/c ratio and consequently better strength. The segregation of the concrete is prevented due to reduction of w/c ratio and action of the air bubbles. It is also possible to give a better finish to the concrete and improve the surface texture by preventing sand streaking. Vinsol resin is the most common air-entering agent. Several proprietary air-entraining agents are available in the market.

12.6 Colloidal Concrete or Colcrete.

This is a particular process of making concrete in which stone aggregates which are already laid in position are bound together by cement and sand grout mixed in a special type of mixer. A grout of cement, sand and water mixed in the usual manner is not sufficiently fluid to penetrate between the interstices of the aggregates and produce a dense concrete. Cement particles being very fine are difficult to wet as they cling to each other and are also surrounded by a thin film of air. The surface areas of cement and sand are 80% and 19% respectively of the surface area of all the constituents of concrete. Hence, if these two constituents are efficiently wetted,

it is easy to get proper quality of concrete. The special type of machine for mixing the grout is shown below (Fig. 12-3).

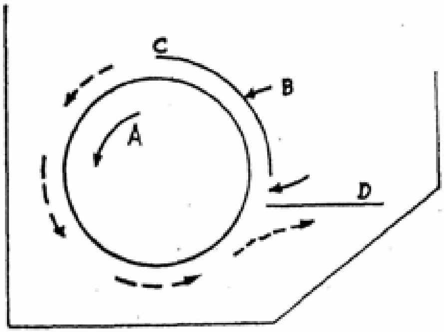

Fig. 12-3.

The roller A about 8″ in diameter rotating anticlockwise at 1200 r.p.m. draws in grout through a volute shaped cavity between the drum and the cowl B. The cowl is hinged at C so that the gap at the end of the volute may be adjusted. A knife-edged plate D nearly touches the roller immediately below the back edge of the cowl and cuts off the liquid and directs it to the back of the tank so that complete mixing is secured. After each mixing the grout is tipped into a sump from where it is removed by a pump. In some machines two stage mixing is done. Cement and water are mixed first and then sand and cement paste subsequently.

Colloidal concrete is very economical as just the required quantity of grout enough to fill in the voids in the coarse aggregate is used. For 1 cubic yard of colloidal concrete only 3 cwt of cement are required as against 5 cwt for usual 1 :2: 4 mix. Colcrete is very useful in road and runway construction.

12.7 Prepacked Concrete.

The principle of this method of making concrete is the same as above, but instead of using mechanical methods of effecting thorough mixture of cement, water and sand, certain chemicals are added to the grout. Cheecol is one such chemical compound.

12.8 Saw Dust Concrete.

Mixture of cement and saw-dust can serve as a useful building material with some limitations. The strength of saw-dust concrete is uncertain and must be determined by tests. How-

ever, it may be taken 10 to 20% the strength of normal concrete. The principal use of saw-dust concrete is as an insulating material and for special purposes. The results of tests on saw-dust concrete are given below :—

Building Research Station U.K.

1 : 2 mix gave 1190 lb/sq. in. @ 7 days

1 : 4 „ 92 „

New Zealand : (with Pinus insignus as aggregates)

1 : 2 mix gave 1190 lb/sq. in.

1 : 4 „ 725 lb/sq. in.

The following results are also experimentally found with pine wood saw-dust.

Mix	Comp. strength @ 7 days ultimate. (lb/sq. in)	Density (lb/cft)
1 : 2	1100	75
1 : 3	500	49
1 : 4	150	41
1 : 6	110	40
1 : 1½ sand : 1½	1300	100

The extractable materials in saw-dust upset the hardening of cement. This can be prevented by using dust from soft woods or by using 20% of the weight of cement of lime or 5% of calcium chloride in the mix. It is advisable to first immerse the saw-dust in boiling water for about 10 minutes and then wash it freely with water. This should be repeated a second time, by mixing 2% ferric sulphate in the boiling water and washing the dust again. Saw-dust concrete absorbs water and hence expands and shrinks on getting wet and dry. This can be prevented by coating the units with water resisting substances and using certain percentage of sand as aggregate.

Consistency of the concrete should be such that the mix compacts itself. The following amounts of water are suggested :

Cement	Saw-dust (slightly damp)	Water
94 lb	1 cft.	5.5 gallons
	2 cft.	5.9 gallons

The finish should be smooth but even, heavy trowelling should not give cement skin on the top.

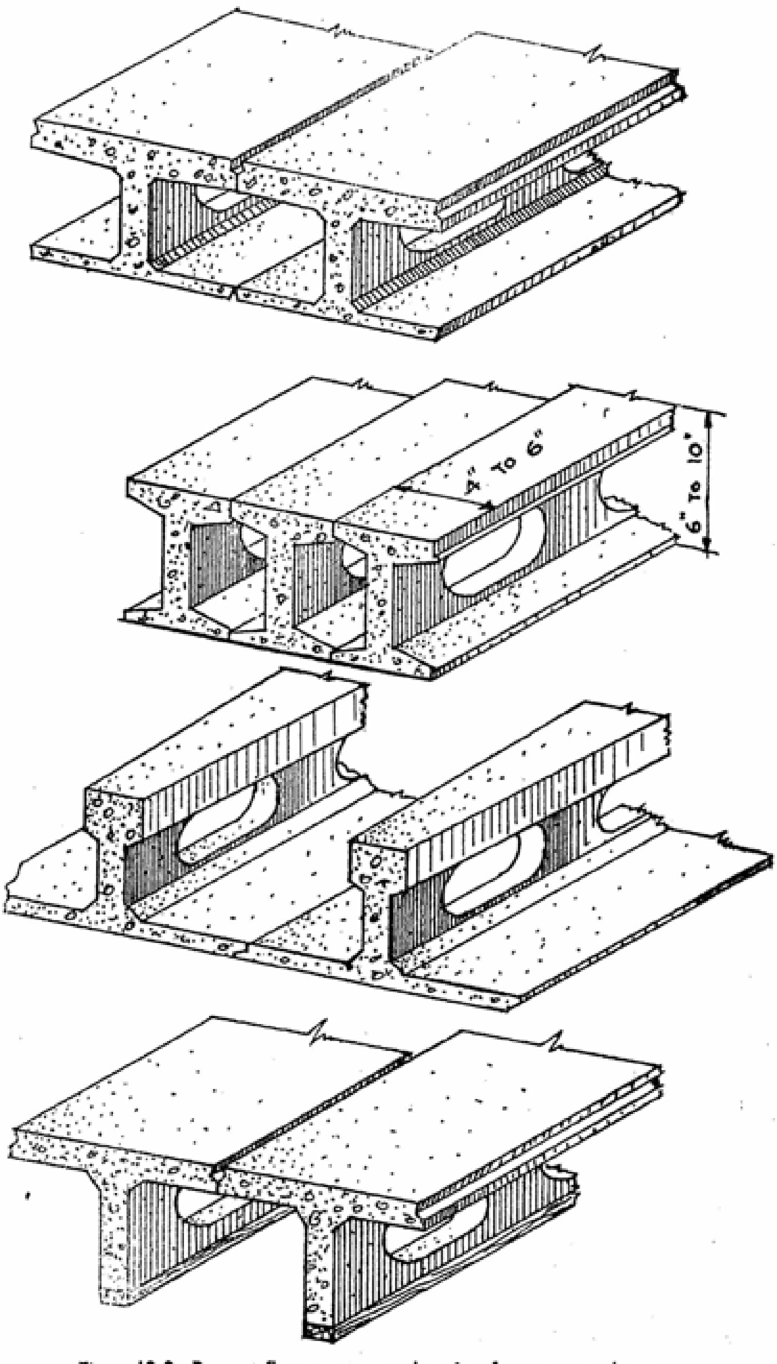

Fig. 12-2. Precast floor systems, showing from top to bottom I-beam, Rapid floor, Rail system and T-section

NOTES

CHAPTER 13

MISCELLANEOUS INFORMATION

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CHAPTER 13

MISCELLANEOUS INFORMATION

13.1 Soil-cement.

1.1 The stabilisation of natural soil, using cement as a stabilising agent, is now a well established form of construction for road bases.

1.2 Soil-cement is an intimate mixture of measured amounts of Portland cement, pulverised soil and water, adequately compacted to a high density to form a hard, stable and durable mass. It has the appearance of very dense soil, and its colour is practically that of the soil used in construction. It is a distinctive structural material with its own characteristics and forms a type between a "flexible" and a "rigid" construction.

1.3 The manner in which cement acts as a binding material in a soil-cement mixture is a matter of speculation. Studies in the soil-cement laboratory of the Portland Cement Association show that each grain of cement picks up a varying number of soil grains, (depending on the grain size of the soil), and as the cement hydrates and crystallises, a new and larger soil grain or agglomeration is produced. As more and more cement is added to a soil, more soil grains lose their identity to become larger soil grains or agglomerations. The agglomeration of cement and soil grains is shown by the tests of soil-cement mixtures of low cement content. These agglomerations can also be thought of as links in a chain. When enough cement has been added to link all agglomerations together enclosing pockets of trapped soil, the mixture becomes a structural material.

13.1.2 ADVANTAGES OF SOIL-CEMENT.

The outstanding advantages of soil stabilisation with cement are cheapness and speed of construction. The process is economical because the soil can frequently be used as it occurs on the site, and even if it has to be imported, it is usually brought from a nearby pit. The same factor is responsible for the large output of work per day. The method of construction is simple and requires only such equipment as is normally available with all road making authorities. The interruption of traffic during the period of construction is a minimum and in most cases the hardened soil-cement can be put under traffic before any surfacing is provided. As a sub-base in the construction of roads and runways, it forms

an integral part of the structure and enables the thickness of base itself, whether of concrete or of other types of construction to be reduced ; it thus gives an economical design for roads and runways which will be required to carry heavy loads. The most important argument in favour of soil-cement is that it is an engineering material that eliminates all guesswork regarding its quality and performance unlike other low-cost paving materials. Specific control tests in the laboratory and in the field assure its success in building strong, durable pavements.

13.1.3 FACTORS AFFECTING SOIL-CEMENT.

The principal factors affecting the quality of soil-cement are soil type, cement content, moisture content, density of compaction and degree of pulverisation in the mixing.

3.1 Soil Type.

There are several systems of soil classification devised to suit the requirements of various types of engineering projects It is considered that of all the systems, the best suited for road and airfield works are the Casagrande Classification System and the United States Public Roads Administration (USPRA) System. It is not possible to give here detailed descriptions and discussions of these systems ; for these the reader is referred to "Soil Mechanics for Road Engineers" published by Her Majesty's Stationery Office, U.K., and other standard works on the subject.

Highly organic soils such as agricultural top soils and peaty soils are quite unsuitable for stabilisation of any kind, but most other soils can be stabilised with cement.

Heavy cohesive soils present difficulties, and before preparing a specification for their treatment, careful laboratory work is required. Often the addition of from 8 to 20 per cent of granular material mixed with pulverised soil will enable this work to be carried out. Lighter clays with liquid limits below 40 per cent have been successfully stabilised without the addition of granular material.

3.2 Cement Content.

The cement content required is determined by means of tests for unconfined compressive strength. The test consists in preparing and testing samples containing different percentages of cement in order to fix the cement content which would be most satisfactory for economy and strength.

The test is usually made with cylindrical specimens of soil-cement which have a height/diameter ratio of 2. The

diameter of the specimens may be 2 in., 4 in., or 6 in., depending on the particle size distribution of the soil. The specimens are cured in a moist atmosphere for a period of seven days and then tested in compression at a rate of 250 lb. per sq. in. per minute, or at a rate of strain of 0.05 in. per minute. A compressive strength of 250 lb./sq. in. after seven days is usually accepted as a satisfactory minimum.

It has been found that the percentage of cement (by weight of dry soil) required to produce suitable soil-cement mixtures normally ranges from 5 to 12 per cent. As it is necessary to have a reasonable proportion of cement to ensure proper distribution in the soil, it is not desirable or practicable to go in for cement contents lower than 5 per cent. In general it may be stated that for purposes of estimating job requirements, a cement content of 8 to 10 per cent may be used.

3.3 Moisture Content.

The effect of moisture content on the quality of soil-cement largely arises from its influence on compaction, for good compaction is necessary to bring the materials to the maximum density for a given effort. The best moisture content for compaction is governed by the soil type and the method of compaction. The water/cement ratio concept as used in concrete work is therefore of little value in soil-cement construction.

The required moisture content is determined by means of the standard moisture-density test carried out on soil-cement mixtures. The moisture density test defines the moisture content at which maximum density is obtained, when the soil is compacted in a standard manner. The degree of compaction obtainable in the test is designed to be comparable with thorough compaction under field conditions. The test consists in dropping a standard rammer a given number of times from a specified height on to a specimen prepared in a standard mould with varying moisture contents. Under a constant force of compaction the density of a soil-cement mixture varies as the moisture content of the mixture varies. With a given amount of compaction there exists for each soil a moisture content termed the optimum moisture content at which a maximum dry density is obtained. If the moisture contents are plotted against the corresponding dry densities, the points will usually form a parabola or a regular type curve the peak of which will indicate the optimum moisture content and the maximum dry density.

3.4 Density.

The density to which the soil-cement mixture should be compacted is also determined by the standard moisture-density test. The density of soil-cement as constructed shall not be below the standard maximum density by more than 5 lb. per cu. ft.

3.5 Degree of Pulverisation in Mixing.

The presence and moisture content of any lumps of clay in the mixture affect the properties of soil-cement mixtures. Investigations carried out by the Portland Cement Association suggest that mixtures containing upto 20 per cent of clay balls which are at about optimum moisture content are not inferior to those possessing no unpulverised lumps. However, if the lumps are initially air dry, they have a very detrimental effect.

13.1.4 CONSTRUCTION.

There are three methods of construction, namely :

1. The Pre-mix Method,
2. The Mix-in-place Method, and
3. The Travelling Plant Method.

All the three have this in common—the soil is pulverised, mixed intimately with the cement and the mixture compacted at the optimum moisture content to the greatest density obtainable.

Whatever method of construction is used, the first step in preparing a site for stabilisation, as with all types of road construction, is to provide suitable drainage. The object of this drainage is to prevent moisture changes in the formation, to intercept any water that may flow towards the road site and to keep the water table at a constant level.

All turf and top soil should be removed and the foundations cleared of stumps, boulders and debris to a depth of about 12 in. The area to be processed should extend one foot beyond the carriageway on both sides. The ground should then be shaped up approximately to its formation level either by hand or by a scraper.

4.1 Pre-mix Method.

In principle the pre-mix method differs little from concrete road construction. After the necessary tests, cement and soil are mixed with the required amount of water in a mechanical mixer. The soil may be that occurring on the site, or if this

is unsuitable for stabilisation, suitable soil may be imported. In gauging the water content, it is desirable to have a little excess of water, especially in dry weather.

Mixing: While the ordinary concrete mixers are satisfactory for granular soils, they are not suitable for the more cohesive types of soil, because the material sticks in the drum. In this case the best results are obtained with double-paddle mixers, pug mills or the roller pan type machines. as, in these, lumps of soil are easily broken up. Whatever type of mixer is used, it must be capable of mixing uniformly and intimately the soil with cement. The mixing time will be longer than that for concrete and will depend largely on the type of soil and the type of mixer. Mixing should continue until the soil-cement mixture is of uniform colour and texture throughout.

Spreading: The mixed materials are spread on the prepared formation and distributed in a uniform loose layer by means of long-handled rakes and shovels. (*N.B.*—Before spreading it is important to check that the subgrade is thoroughly compacted.) It is essential to have templates available to check the height and shape to which the material is spread.

Compaction: The next step is the thorough compaction of the mixture on which depends very largely the success of the whole operation. Suitable plant for compaction is as follows :

(a) **For cohesive soils :** Multi-wheeled pneumatic rollers, smooth-wheeled rollers, and power rammers. The last mentioned are particularly suitable for small areas.

(b) **For granular soils :** Smooth-wheeled rollers, vibrating rollers, pneumatic tyred rollers and vibrating beam tampers.

It is better to use a light roller for initial compaction, since a heavy roller tends to bed into the loose material thereby causing ridges and waviness. Rolling should start at the sides and work towards the centre or, where there is a straight cross fall, from the low side towards the high side. Final rolling should be done with a smooth-wheeled roller. A tandem roller which gives uniform pressure produces the best results.

Rolling should continue until the processed soil no longer shows any yield under the roller and until a uniform close-knit surface is obtained. The complete rolling should not occupy more than an hour.

Curing: On completion of the final compaction, the surface of the soil-cement must be prevented from drying out too rapidly. It should be efficiently cured for a period of seven days by sprinkling water or by covering it with wet sand or wet straw. Traffic should be kept off the processed soil for 7 days.

Construction joints: At the end of each day's work a straight transverse construction joint shall be formed by cutting back into the completed work to form a true, vertical face and by installing a temporary wooden header against it. The portion of the completed work, over which the compaction plant has to run on the next day, should be covered with earth to prevent the surface being damaged.

Surfacing: Soil-cement, while capable of carrying heavy loads, will not be resistant to traffic abrasion and it is therefore necessary to provide a surfacing. The minimum requirement is a double surface dressing of bitumen or tar with chippings. For roads carrying heavy traffic a thicker covering of bitumen or a surfacing of concrete may be provided.

4.2 Mix-in-place Method.

Pulverisation: In the mix-in-place method the ground is first scarified and the soil is pulverised to a fine tilth until at least 80 per cent of it, exclusive of stones, passes the standard 3/16 in. sieve. This work is most effectively done by rotary tillers. However, any other machine, (such as ploughs or disc harrows), capable of achieving the same results in a reasonable number of passes may also be used for the purpose.

During pulverisation stones exceeding 3 in. in diameter should be removed as they interfere with processing and may also damage the tines of the rotary tiller.

The depth to which the soil is pulverised should be such as to permit of subsequent compaction. Thus, if the finished thickness of soil-cement base is to be 6 in. (which is the most usual thickness), the soil should be scarified and pulverised to a depth of 8 in. to 9 in.

On completion of the pulverisation the surface should be again graded to the required crossfall or camber and checks should be made to ensure that there is a uniform depth of pulverised soil.

The soil is now ready for processing, but its moisture content should be determined before this is done. The purpose of this is to make due allowance for the moisture content

already present in the soil at the time of the addition of cement and water.

Spreading cement: The next step in the process is the spreading of cement. Cement can be spread mechanically or by hand. In the first case the cement in bulk is fed from a lorry into a mechanical spreader from which it is spread at an even and controlled rate over the soil.

For hand spreading, the bags of cement are spotted at intervals so as to provide the specified percentage of cement. The area to be covered by each bag of cement can be calculated and marked with strings, tapes or lines. Then each bag is split open and the cement spread uniformly on the surface.

Mixing: After the cement has been spread, it is mixed well with the soil. The mixing is usually done with the same plant as was used for pulverising the soil. It is important that the materials should be thoroughly and intimately mixed together. Several passes of the mixing equipment may be required to ensure this, but the number of passes should be kept to the minimum consistent with uniform mixing. Mixing should continue until the soil-cement is of uniform colour and texture throughout the whole area and to the full depth of treatment.

Adding water: At this stage the moisture content of the mix should again be determined and then the required quantity of water, which should be slightly above the optimum in order to make up for losses due to evaporation, etc., added to it. There should be provision for rapid supply of the water ; to avoid interruptions two tankers should be used for this purpose, one spraying while the other is being filled.

The water should be distributed evenly over the surface. The water distributor should never be allowed to remain stationary over any spot and thus cause flooding, as this would result in a wet soft area, difficult to put right.

It is preferable, but not always practicable, to distribute the water from the sides of the road by means of a spray bar. If the water tank travels over the loose materials, care should be taken to erase the wheel marks when mixing the water into the soil-cement.

After sufficient quantity of water has been added, it should be mixed thoroughly and uniformly to the full depth of treatment.

Final grading: When the mixing is complete, the surface is shaped upto the required contour or crossfall.

Compaction: The operations for compaction as well as for for the remainder of the work such as curing, construction joints, surfacing etc., are carried out in exactly the same way as for the pre-mix method.

4.3 The Travelling Plant Method.

The general principle of the travelling plant method is that the pulverised soil and cement are lifted into a hopper whence they are fed into the mixer (usually of the pugmill type), and water added as necessary. The mixed material is then discharged on to the road and spread with a grader ready for compaction.

The plant required for this method is expensive and therefore must be kept working continuously, if its use is to be economical.

4.4 Comparison of the Three Methods.

.1 Pre-mix Method.

The advantages are :

(i) Accurate proportioning of the mixture.

(ii) Easy control of depth of treatment.

(iii) Concrete mixers can be used.

(iv) Small losses of moisture during mixing and transport of the material.

The disadvantages are :

(i) Relatively small output.

(ii) Material must be compacted as delivered and not as a complete section.

.2 Mix-in-Place Method.

The advantages are :

(i) The plant required is simple, relatively cheap and easily transported.

(ii) The number of machines required can be adjusted to the size of the job.

(iii) The whole processed section is ready for compaction at the same time.

(iv) A large daily output can be maintained.

The disadvantages are :

(i) It is not easy to obtain a uniform thickness of treatment.

(ii) The mixing is not as uniform as in the pre-mix and travelling plant methods.

(iii) Work is susceptible to changes of weather, and once cement has been spread, the work cannot be stopped.

(iv) In hot weather, there may be considerable loss of moisture by evaporation.

.3 Travelling Plant Method.

The advantages are :

(i) Accurate proportioning and control of added water.

(ii) Uniform mixing.

(iii) Short mixing time.

(iv) Uniform thickness of stabilised soil ensured.

(v) Large output per day.

The disadvantages are :

(i) High initial cost of plant.

(ii) Large scale work necessary to run plant economically.

(iii) A minor breakdown in one piece of plant may cause a complete hold up.

13.1.5 CONTROL OF CONSTRUCTION.

During the construction, checks must be made to ensure its success and that the terms of the specification are being followed. The following points, in particular, should be carefully checked.

5.1 Degree of Pulverisation.

Specifications require that the soil should be pulverised until at least 80 per cent of it, exclusive of coarse particles, normally retained, passes the 3/16 in. B.S. sieve. Tests for the degree of pulverisation should be made on samples of soil taken at intervals of about 200 to 300 ft. along the processed area at points distributed across the width of the area.

5.2 Moisture Content.

Normally a moisture content somewhat higher than that determined by laboratory tests should be adopted in the field to compensate for drying out during processing and compaction. Tests for moisture content during construction should be made at the following stages :

(i) On completion of pulverisation, to determine approximately how much water would be needed.

(ii) After mixing soil with the cement to determine precise requirements, and

(iii) immediately after adding and mixing in any additional water, for checking.

5.3 Cement Content.

Inspection of samples obtained with a trowel from the full depth of the layer during processing gives a good indication of the distribution of cement. Such inspections should be made continuously during processing throughout the length and width of the processed area and to the full depth of the loose soil. Uniformity of colour and texture will be the mesure of the even distribution of cement. Where required, however, samples of soil-cement may be analysed periodically to check that the cement content complies with the specifications.

5.4 Dry Density.

The dry density of the compacted soil-cement is a measure of the effectiveness of compaction, and therefore, of the success of the work. The dry density should be checked at intervals for about every 150 sq. yd. of the area processed.

5.5 Thickness of the Processed Layer.

The final thickness should be within $\pm$ 1/2 in. of the specified thickness, and checks to ensure this should be made at all stages during the construction.

It should be noted that the greatest thickness of stabilised soil that can be satisfactorily produced is governed by the thickness which can be fully compacted with the plant used, as well as by the depth of soil which can be efficiently pulverised and mixed. No layer of soil cement should exceed 9 in. in thickness prior to compaction.

5.6 Regularity of Surface.

It is important that a thin carpet should be of uniform thickness when it is superimposed on the stabilised soil, and this will not be possible, if the surface of the stabilised base is itself very irregular, especially where a machine-laid carpet is to be used.

When tested under a 10-ft straight edge there should generally be no differences of level exceeding 1/4 in. in the finished surface of the stabilised soil, but if the thickness of the superimposed carpet exceeds 3/4 in., a tolerance of 3/8 in. may be allowed. If depressions exceeding this figure are disclosed, they may be made up with fine bituminous macadam or fine cold asphalt.

Care must be taken to adhere to the specified levels throughout the length of the road. The maximum tolerance over the whole road surface should not exceed $\pm$ 1 in.

13.2 Asbestos Cement.

Asbestos cement is a combination of asbestos fibres and Portland cement. Asbestos is an infusible, tough and flexible mineral in fibrous form. The fibres are made of extremely minute threads about 1/1000 mm. in diameter. Suitable type of asbestos for asbestos cement products is found in Russia, Canada and South Africa. Neat Portland cement is mixed with about 15% of asbestos fibres in such a way that all fibres are thoroughly coated with fine cement. This composition is kept under great hydraulic pressure until it sets. The asbestos fibres act in the same way as steel reinforcement used in R.C.C. work, but the mixture possesses the great advantage that it is more resilient. It has been proved to possess indefinite durability and great resistance to transverse and tensile stresses. The cement in these products is reinforced in a most effective manner by an intricate network of carefully blended and opened asbestos fibres.

13.3 Cement Grouting.

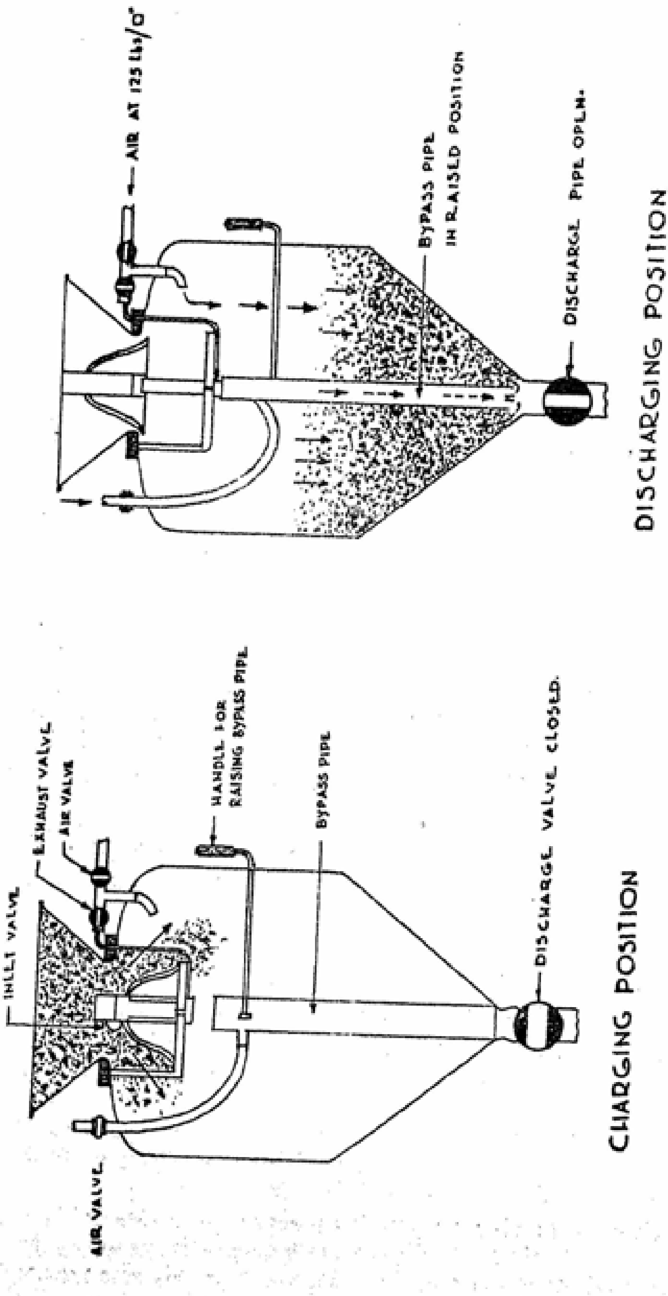
Grouting is usually done under high or occasionally at normal pressure. High pressure grouting is done at pressures above 100 lb./sq. inch. There are various methods of pressure grouting such as

(a) Fluid or pump grouting.

(b) Plastic grouting (air pressure grouting).

(a) Fluid grouting is the older method of grouting. Mixtures with a consistency of soft fluid mud are used for injection and usually neat Portland cement or very rich cement and sand mixtures are employed. Since the amount of water used is excessive, the grout has got very little cementing value. A reciprocating pump is used for this work.

(b) Cement mortar or small aggregate concrete with a slump of 6 to 8 inches is injected by pneumatic pressure by means of special machinery which consists of an air compressor



NOTE:-
WHEN DISCHARGE VALVE & RIGHT HAND SIDE AIR VALVE IS CLOSED AIR FROM LEFT HAND VALVE COMING UP THROUGH THE BYPASS AS SHOWN BY DOTTED ARROWS AGITATED THE MIX.

Fig. 13-1. Grouting Machine

and a grouting chamber as shown in Fig. 13-1. By proper manipulation of the various valves and the by-pass pipe it is possible to charge and discharge the grout and also agitate the grout.

Grouting is used for various purposes, such as:

(a) Soil stabilization.

(b) Solidification of fractured, porous or fissured rock.

(c) Restoration of completed structures by strengthening the foundations.

(d) Sealing of rock strata, gravel or other water-logged ground formations. Preventing contamination of well water from polluted water oozing through porous strata, etc.

(e) Dry pack concrete construction.

(f) Cast-in-place pile work, etc.

13.4 Cement Admixtures.

Admixtures consist of powdered materials or liquids to be added to the concrete during its preparation to improve its quality. Most of these are more or less inert and have an indirect effect on the quality of concrete. Admixtures can be classed as of three types, physical, cementitious and pozzolanic.

13.4.1 PHYSICAL ADMIXTURES.

When water is added to the cement, heavier particles of cement settle down and finer particles and water go to the top. The segregation of cement particles is prevented by these admixtures which help in improving the texture of the concrete.

13.4.2 CEMENTITIOUS ADMIXTURES.

These behave more or less like cement and give a richness to the concrete mixture.

13.4.3 POZZOLANIC ADMIXTURES

Pozzolanic admixtures have no cementing value of their own, but they react with the products of hydration of cement to form compounds adding to the strength of the concrete mixture.

Admixtures commonly used are quicklime, slaked lime, diatomaceous earth, bentonite, glue, and salts acting as dispersing agents.

13.5 Waterproofing of Concrete.

13.5.1 WHY REQUIRED

Portland cement concrete has a high resistance to permeation of water when it is gauged with correct quantity of water. In practice, however, we usually add more water to increase the workability and thus increase the voids space in concrete, making it permeable. In order to get watertight concrete, it is necessary to use clean, well graded, non-porous aggregates with sufficient sand to fill in the voids and correct amount of mixing water.

13.5.2 METHODS OF WATERPROOFING.

(a) Use of internal waterproofers.

(b) Surface treatments.

(a) These consist of materials added to cement or concrete. They are available in form of finely ground inert substances such as chalk, diatomaceous earth, silica, dolomitic lime or talc intended to improve the plasticity of the mix and thereby reduce the voids. These are usually employed in conjunction with substances of hydrophobic character e.g. calcium and aluminium soaps. Liquid waterproofers contain substances capable of reacting with a second solution or with cement to form an insoluble product. Examples of this type of solutions are alkali silicates, calcium chloride, zinc sulphate and ordinary soap. Integral waterproofers generally contain calcium chloride soaps, hydrated lime, etc.

(b) These are asphalt emulsions, iron salamoniac compounds, cement washes, silicate of soda, boiled linseed oil, gelatinous pastes, etc.

13.6 Effects of Acids, Oils and Salts on Concrete.

13.6.1 GENERAL CONSIDERATIONS.

The industrial application of this problem is of great importance in numerous cases where chemicals, oils, and various other industrial liquids are kept in storage in reinforced concrete tanks.

The protective treatments recommended are based, as they must be, on the assumption that the concrete is of a suitable quality, which means a well cured, dense, watertight concrete.

This requires :

(a) Low water-cement ratio, not to exceed 6 gal. of mixing water per bag of cement.

(b) Suitable workability to avoid mixes so harsh and stiff that honeycombing occurs, and those so fluid that water rises to the surface.

(c) Thorough mixing, at least one minute after all materials are in the mixer, or until the mix is uniform.

(d) Proper placing, with spading or vibration to fill all corners and angles of forms without segregation of materials—avoid construction joints.

(e) Adequate curing, protection by leaving forms in place, covering, with wet sand or burlap and sprinkling. Concrete to be kept wet and above 50° F for at least the first week. Not to be subject to hydrostatic pressure during this period.

Many solutions such as brines and salts, which have no chemical effect on concrete, may crystallize upon loss of water. It is especially important that concrete subjected to alternate wetting and drying of such solutions be very dense and nonabsorbent. If the concrete is porous it will absorb the solution. Since the crystals require more space than the liquid, they exert considerable pressure which may be sufficient to break down the concrete. Salt solutions corrode steel more rapidly than plain water. In structures which are to be subjected to frequent wetting and drying by these solutions it may be advisable to provide some surface coating such as sodium silicate, linseed oil or one of the varnishes as an added precaution.

13.6.2 SURFACE TREATMENTS.

Materials are available for almost any degree of protection required on concrete. The more common methods of treatment are indicated in the table on pages 256-261, the numbers in the table corresponding to the following numbered paragraphs in which the necessary instructions are given :

(1) Magnesium Fluosilicate or Zinc Fluosilicate.

The treatment consisits of two or more applications. First, a solution of about 1 lb. of the fluosilicate crystals per gallon of water is used. For subsequent applications about 2 lb. of crystals per gallon of water is used. Large brushes are convenient for applying on vertical surfaces, and mops on horizontal areas. Each application should be allowed to dry ; after the last has dried, the surface should be brushed and

washed with water to remove crystals which have formed. The treatment densifies and hardens the surface by chemical action. Fluosilicates are available through dealers in chemicals.

(2) Sodium Silicate (commonly called water glass).

This is quite viscous and must be diluted with water to obtain penetration, the amount of dilution depending on the quality of the silicate and the density of the concrete. Silicate of about 42.5 deg. Baume gravity diluted in proportions of 1 gal. with 4 gal. of water makes a good solution. It may be applied in two or three or more coats, allowing each coat to dry thoroughly. On horizontal surfaces it may be poured on and then spread evenly with brooms or brushes. Scrubbing each coat with water after it has hardened provides a better condition for application of succeeding coats. For tanks and similar structures progressively stronger solutions are often used for the succeeding coats.

(3) Linseed Oil.

Only boiled linseed oil should be used. Applied hot, it gives better penetration. Two or three coats may be applied, allowing each to dry thoroughly before the next application. The concrete should be well cured and seasoned before the first application. Linseed oil is sometimes applied after the magnesium fluosilicate treatment, providing a good coating over a hardened surface.

(4) Cumar.

Cumar is a synthetic resin soluble in xylol and similar hydrocarbon solvents. A solution consisting of about 6 lb. of Cumar per gallon of xylol with ½ pint boiled linseed oil makes a good coating. Two or more coats should be applied. Concrete should be fairly dry. The cumar should be powdered to aid dissolving. It is available in grades from dark brown to colourless.

(5) Varnishes.

Any varnish can be applied to dry concrete. High grade varnishes of the spar, china-wood oil, or bakelite types give good protection against many substances. Good varnishes may contain natural or synthetic resins. Two or more coats should be applied.

(6) Bituminous or Coal Tar Paints, Tar and Pitches.

These are usually applied in two coats, a thin priming coat to ensure bond and a thicker finish coat. Concrete must be

dry and dust-fee. Finish coat must be carefully applied to ensure continuity and avoid pin holes. Surface should be touched up where necessary.

(7) Bituminous Enamel.

This is suitable protection against relatively strong acids. It does not resist abrasion at high temperatures. Two materials are used, a priming solution and the enamel proper. The priming solution is of thin brushing consistency and should be applied to dry, dust-free concrete, touching up any uncoated spots before applying the enamel. When primer has dried to a slightly tacky state, it is ready for the enamel. The enamel usually consists of a bitumen with a finely powdered siliceous mineral filler. The filler increases the resistance to flowing and sagging at elevated temperatures, and to abrasion. The enamel should be melted and carefully heated until it is fluid enough to brush. The temperature should not exceed 375° F. When fluid it should be mopped on quickly, as it sets and hardens rapidly.

Bituminous paints and enamels are made by a number of companies.

(8) Bituminous Mastic.

This is used chiefly for floors on account of the thickness of the layer which must be applied, but some mastics can be trowelled on vertical surfaces. Some mastics are applied cold. Others must be heated until fluid. The cold mastic consists of two compositions—the priming solution and the body coat or mastic. The primer is brushed on dry, dust-free concrete. When it has dried to a tacky state, a thin layer—about 1/32″ of the mastic is trowelled on. When this has dried, successive 1/32″ coats of the mastic are applied, until the required thickness has been built up. The mastic is similar to the primer but is ground with sufficient asbestos and finely powdered siliceous material fillers to make a very thick, pasty fibrous mass.

The hot mastics are somewhat similar to the mixtures used in sheet asphalt pavements, but contain more asphaltic binder so that when heated to fluid condition, they can be poured and trowelled into place. They are satisfactory only when applied in layers of 1 in. or more in thickness. When ready to lay, the mixture usually consists of about 15 per cent asphaltic binder, 20 per cent finely powdered siliceous mineral filler, and the remainder is sand graded up to ¼ in. maximum size.

Mastics are made by a large number of manufacturers.

(9) Vitrified Brick or Tile.

These are special burnt clay products which are not attacked by acids or alkalies. They must, of course, be laid in mortar which is also resistant against the substance to which they are to be exposed. A bed of the mortar is usually placed between the brick or tile and concrete. Some of the acid-proof cements are melted and poured in the joints. Many manufacturers make acid-proof brick and cement.

(10) Glass.

May be cemented to the concrete.

(11) Lead.

May be cemented to the concrete with an asphaltic paint.

(12) Rubber.

One of the largest rubber companies in U.S.A. contracts to treat tanks and other structures with their "Acid-Seal". The material is not for sale to other contractors.

Table 13-1 Effect of various substances on concrete and their treatment.

Material	Effect on concrete	Surface treatment
ACIDS.		
Acetic	Disintegrates slowly	5, 6, 7
Acid waters	Natural acid waters may erode surface mortar, but usually action then stops	1, 2, 3, 4, 5, 6, 7
Carbolic	Disintegrates slowly	1, 2, 3, 5
Carbonic	Disintegrates slowly	2, 3, 4, 5, 6, 7
Humic	Depends on humus material but may cause slow disintegration	1, 2, 3, 4, 5, 6, 7
Hydrochloric	Disintegrates	8, 9, 10, 11, 12
Hydrofluoric	Disintegrates	8, 9, 11, 12
Lactic	Disintegrates slowly	1, 2, 3, 4, 5, 6, 7
Muriatic	Disintegrates	8, 9, 10, 11, 12
Nitric	Disintegrates	8, 9, 10, 11, 12
Oxalic	None	None
Phosphoric	Attacks surface slowly	1, 2, 3, 4, 5, 6, 7
Sulphuric	Disintegrates	8, 9, 10, 11, 12
Sulphurous	Disintegrates	8, 9, 10, 11, 12
Tannic	Disintegrates slowly	1, 2, 3, 4, 5, 6, 7

Material	Effect on concrete	Surface treatment
SALTS AND ALKALIES		
Carbonates of Ammonia, Potassium, Sodium	Weak solutions and dry salts will not affect concrete. Strong solutions may cause slow disintegration and concrete should be treated	1, 3, 4, 5, 6, 7
Chlorides of Calcium, Potassium, Sodium	None unless concrete is alternately wet and dry with the solution, when it is advisable to treat with	1, 3, 4, 5, 6, 7
Chlorides of Ammonia, Copper, Iron, Magnesium, Mercury, Zinc	Disintegrates slowly	1, 3, 4, 5, 6, 7
Fluorides	None except ammonium fluoride	3, 4, 5, 6, 7
Hydroxides of Ammonia, Potassium, Sodium	None	1, 3, 4, 5, 6, 7
Nitrates of		
Ammonia	Disintegrates	8, 9, 10, 11, 12
Calcium	None	None
Potassium	Disintegrates slowly	1, 3, 4, 5, 6, 7
Sodium	Disintegrates slowly	1, 3, 4, 5, 6, 7
Potassium Permanganate	None	None
Silicates	None	None
Sulphates of Ammonia	Disintegrates	8, 9, 10, 11, 12
Sulphates of Aluminum, Calcium, Cobalt, Copper, Iron, Manganese, Nickel, Potassium, Sodium, Zinc	Disintegrates	1, 3, 4, 5, 6, 7

Material	Effect on concrete	Surface treatment
PETROLEUM OILS		
*Heavy oils below 30° Baume	None	None
*Light oils above 30° Baume	None—Some loss from penetration	1, 2, 3, 5
Benzine Gasoline Kerosene Naphtha	None—Considerable loss from penetration	1, 2, 3, 5
CHEMICALS		
Coal	Great majority of structures show no deterioration. Exceptional cases have been coal, high in pyrites (sulphide of iron) and moisture showing some action but the rate is greatly retarded by deposit of an insoluble film. Action may be stopped by surface treatments	1, 2, 3, 4, 5, 6, 7
Corn syrup	Disintegrates slowly	1, 2, 3, 4, 5, 6, 7
Electrolyte	Depends on liquid. For lead and zinc refining use	7, 8, 9, 10, 12
Formalin	Aqueous solution of formaldehyde disintegrates concrete	9, 10, 11, 12
Fruit juices	Most fruit juices have little if any effect as tartaric acid and citric acid do not appreciably affect concrete. Floors under raisin seeding machines have shown some effect, probably due to poor concrete	1, 2
Glucose	Disintegrates slowly	1, 2, 3, 4, 5, 6, 7
Glycerine	None	None
Honey	None	None
Lye	Same as sodium hydroxide	1, 2, 3, 4, 5, 6, 7
Milk	Sweet milk should have no effect but if allowed to sour the lactic acid will attack	1, 2, 3, 4, 5, 6, 7
Molasses	Does not affect dense, thoroughly cured concrete. Dark, partly refined molasses may attack concrete that is not thoroughly cured. Such concrete may be protected with	2, 5

*Many lubricating and other oils contain some vegetable oils. Concrete exposed to such oils should be protected as for vegetable oils.

Material	Effect on concrete	Surface treatment
Nitre	Same as nitrate of potassium	1, 3, 4, 5, 6, 7
Sal ammoniac	Same as ammonium chloride—causes slow disintegration	1, 3, 4, 5, 6, 7
Sal soda	Same as sodium carbonate	1, 3, 4, 5, 6, 7
Salt petre	Same as nitrate of potassium	1, 3, 4, 5, 6, 7
Sauserkraut	Little, if any, effect, Protect taste with	1, 2
Silage	Attacks concrete slowly	3, 4, 5, 6, 7
Sugar (cane or beet)	No effect on concrete that is thoroughly cured	None.
Sulphite liquor	Attacks concrete slowly	1, 2, 3, 4, 5, 6, 7
Tanning liquor	Depends on liquid. Most of them have no effect. Tanneries using chromium report no effects. If liquor is acid, protect with	1, 2, 3, 4, 5, 6, 7
Vinegar	Disintegrates (see acetic acid)	1, 2, 3, 4, 5, 6, 7
Washing soda	Same as sodium carbonate	1, 3, 4, 5, 6, 7
Whey	The lactic acid will attack concrete	1, 2, 3, 4, 5, 6, 7
Wine	Many wine tanks with no surface coating have given good results but taste of first batch may be affected unless concrete has been given tartaric acid treatment	For fine wines the concrete has been treated with 2 or 3 applications of tartaric acid solution. (1 lb. tartaric acid in 3 pints water.) Sodium silicate is also effective. In a few cases tanks are lined with glass-tile.
Wood pulp	None	None.
Alizarin, Anthracene, Benzol, Carbozol, Cumol, Paraffin, Pitch, Toluol, Xylol	None	None
Carbolineum, Creosote, Cresol, Lysol, Phenol	Disintegrates slowly	1, 2, 3, 5

VEGETABLE OILS

Material	Effect on concrete	Surface treatment
Cotton seed	No action if air is excluded. Slight disintegration if exposed to air	None 1, 2
Rosin	None	None
Almond Castor *China-wood Cocoanut *Linseed Olive Peanut Poppy seed Rope seed Soy-bean Tung Walnut	Disintegrates surface slowly	1, 2
Turpentine	None-Considerable penetration	1, 2

* Applied in thin coats the material quickly oxidizes and has no effect. Results indicated above are for constant exposure to the material in liquid form.

FATS AND FATTY ACIDS (Animal)

Material	Effect on concrete	Surface treatment
Fish oil	Most fish oils attack concrete slightly. Menhaden oil does not	1, 2
Folio to Lard and lard oil Tallow and tallow oil	Disintegrates surface slowly	1, 2

MISCELLANEOUS

Material	Effect on concrete	Surface treatment
Alcohol	None	None
Ammonia water (Am. Hydrozide)	Disintegrates slowly	1, 3, 4, 5, 6, 7
Baking soda	Same as sodium bicarbonate—no effect in weak solutions and dry salts. For strong solutions treat concrete	1, 2, 3, 4, 5, 6, 7
Beer	Beer will cause no progressive disintegration of concrete, but in beer storage and fermenting tanks a special coating is used to guard against contamination of beer	Coating made and applied by a New York Company.
Bleaching powder	Mixtures of calcium chloride and calcium hypochloride do not affect dense concrete	None
Borax, boracic acid, boric acid	No effect	None
Brine (salt)	No effect on dense concrete. Where subject to frequent wetting and drying of brine provide	1, 2, 3, 4, 5, 6, 7
Buttermilk	Same as milk	1, 2, 3, 4, 5, 6, 7
Charged water	Same as carbonic acid—slow attack	1, 2, 3, 4, 5, 6, 7
Caustic Soda	(Sodium hydroxide) Disintegrates	1, 2, 3, 4, 5, 6, 7
Cider	Disintegrates (See acetic acid)	1, 2, 3, 4, 5, 6, 7
Cinders	May cause some disintegration	1, 2, 3, 4, 5, 6, 7

CHAPTER 14

GENERAL DATA, TABLES, ETC.

CONTENTS

CHAPTER 14

GENERAL DATA, TABLES, ETC.

14.1 Crushing Strength of Stones

	Tons/s.ft.
Granite	1000 to 700
Trap	400
Basalt	1000
Sandstone (hard)	600
,, (medium)	400
Limestone (hard)	400
,, (soft)	100
Brick (1st class)	100
Cement concrete 1 : 2 : 4	180

14.2 Strength of Lime Mortars

		3 months Tons/sq.ft.	27 months Tons/sq.ft.
Hydraulic Kankar Lime	1 : 1	71	107
	1 : 1½	66	104
	1 : 2	64	118
	1 : 2½	52	104
	1 : 3	46	85
Fat lime	1 : 2	48	—
—do— Surkhi	2 : 1 : 6	59	—
—do— Blacksoil Surkhi	2 : 1 : 6	49	—

14.3 Safe Permissible Loads on Masonry

		Tons/s.ft.
1.	Brick in mud	1½
2.	Brickbat concrete in lime	2
3.	Stone metal concrete in lime	3 to 3½
4.	Laterite masonry in lime	2
5.	—do— (good quality stone)	3

		Tons/s.ft.
6.	Country brickwork in lime	2 to 3½
7.	1st Class „ „	4 to 5
8.	C. R. Masonry in lime	3.5 to 7
9.	—do— (granite)	5
10.	Country bricks in cement	4 to 6
11.	1st Class bricks —do—	8
12.	Granite ashlar	15
13.	Trap —do—	20
14.	Cement concrete	
	1 : 2 : 4	32
	1 : 3 : 6	25
	1 : 4 : 8	19

14.4 Wind Velocity and Pressure

Nature of wind.	Equivalent velocity miles per hour.	Mean wind pressure lb per sq. foot.
1. Moderate breeze	15	0.67
2. Fresh breeze	21	1.31
3. Strong breeze	27	2.30
4. Strong gale	50	7.70
5. Whole gale	59	10.50
6. Storm	68	14.00

The following approximate values may be adopted for structures not more than 30 ft. high.

Zone 1 : Areas south-west and west of line passing throughout but excluding Hyderabad (Sind), Baroda and Ratnagiri. Areas approximately within 50 miles of the coast line between Masulipatam and Akyab.

Zone 2 : Areas inland of a line running through and including Gwalior, Chitorgarh, Aurangabad, Tirupur, Madura, Trichinopoly, Jalarpet, Cuddapah, Dornakal, Jharsuguda and Allahabad.

Zone 3 : Other parts excluding above.

Wind pressure p =	8 psf	.. for H =	0 to 10 ft.
	12 „	..	10 to 20 ft.
	15 „	..	20 to 30 ft.

Take twice for Zone 1 and ½ for Zone 2.

14.5 Water Velocity and Pressure

$P = 1.8V^2$ for fresh water.

$= 1.85V^2$ for salt water.

where, V=velocity of current in feet/sec.

P=pressure on a plane normal to the current in lb per sq. foot.

14.6 Working Stresses for Timber

Name	Youngs Modu-lus.	Bending (lb per sq. in)			Shear	Compression (lb/sq. in)					
						Parallel to grain			Perpendicular to grain		
		A	B	C		A	B	C	A	B	C
No. 1 Quality.											
Burma Teak ..	1600	2200	2000	1670	125	1700	1580	1230	700	520	420
M. P. Teak ..	1200	1820	1650	1300	120	1380	1280	1000	670	500	400
Yellow Pine ..	1630	1740	1580	1240	120	1350	1250	980	400	300	240
Kail ..	986	950	860	680	110	970	900	700	170	125	100
Deodar ..	1348	1740	1580	1240	100	1370	1270	990	440	330	260
Sal ..	1920	2120	1930	1510	175	1510	1400	1090			
Jarrah ..	1500	2300	2090	1640	—	870	810	630			
No. 2 Quality.											
Burmah Teak ..	1400	1830	1600	1300	115	1380	1230	1000	600	470	380
M. P. Teak ..	1050	1610	1300	1070	110	1120	1000	810	570	450	360
Yellow Pine ..	1420	1450	1240	1020	105	1100	980	800	340	270	220
Kail ..	858	790	680	560	95	790	700	570	140	110	90
Deodar ..	1170	1440	1235	1020	90	1110	990	810	380	295	240
Sal ..	1670	1770	1610	1250	160	1230	1090	890			
Jarrah ..	1300	1910	1640	1350	—	710	630	510			

Note: A Inside location.
B Outside location.
C Wet location.

14.7 Daily Task Work for Artisans and Labourers

(Working day 8½ hours)

(1) Excavation: (5′ lift and 100′ lead)

Earth	75 cft. per man
Soft murum	50 „ „
Average murum	35 „ „
Hard murum	25 „ „
Soft rock	16 „ „
Hard rock	8 „ „

(2) Breaking metal

Trap stone	1½″ size	10 cft. per man
Quartz	-do-	13 „ „
Laterite	-do-	20 „ „
Brick	-do-	50 „ „

(3) Conveying metal on head

Lead 100 ft.	85 cft. per man
200 „	65 „ „
300 „	50 „ „
600 „	33 „ „

(4) Masonry

Ashlar stone	2 cft. one mason and 1 man
Coursed rubble 1st class	9 „ „ „
-do- 2nd „	12½ „ „ „
-do- 3rd „	20 „ „ „
Brick 1st class	17 „ „ „
„ 2nd „	25 „ „ „

(5) Plastering

¾″ thick cement	33 s.ft. one mason and 1 man
Roughcast	90 „ „ „
Pointing	60 „ „ „

(6) Flooring

Flagstone (lâdi)	30 to 40 sq. ft.
Dressed trap stone	5 ,,
Cement concrete	30 ,,

(7) Carpenter

Panelled doors 4′×7′	10 days per piece
Plain planked	4 ,,
Glazed windows	6 ,,
Venetianed windows	14 ,,
Teakwood work (framing)	2 cft.
-do- (joinery)	1 ,,
Woodwork in Mangalore tiled roof	100 sft.
-do- in G.C.I. roof	33 ,,

(8) Precast concrete work (in steel moulds)

Pipes 6″ diameter	12 nos.
Roofing tiles	90 ,,
Hollow blocks (in hand machine)	100 ,, (1 mason and 2 coolies)
Paving flags	30 ,,

(9) Cutting and bending reinforcement

$\frac{1}{4}''\ \phi$ to $\frac{3}{8}''\ \phi$	2 cwts. one fitter
$\frac{1}{2}''\ \phi$	$2\frac{1}{2}$,,
$\frac{5}{8}''\ \phi$ to $2''\ \phi$	4 ,,

(10) Erecting formwork — 20 s.ft.

(11) Finishing

Whitewashing 3 coats	400 s.ft.
Distempering	200 ,,
Cement washing 2 coats	400 ,,

14.8 Properties of Circles, Etc.

Circumference of circle	Dia × 3.1416
Side of an equal square	Dia × .8862
Side of an inscribed square	Dia × .7071
Area of a circle	Dia^2 × .7854
Area of a sector	length of arc × $\frac{1}{2}$ radius
Area of ellipse	.7854 × long axis × short axis
Area of parabola	Base × height × $\frac{2}{3}$
Area of parallelogram	Height × base
Area of trapezium	Sum of parallel sides × H/2

Volume or surfaces.

Lateral surface of a sphere		$4 \pi r^2$
,, ,,	cylinder	$2 \pi rh$
,, ,,	cone	$\pi r \sqrt{h^2 + r^2}$
Contents of a sphere		$\frac{4 \pi r^3}{3}$
do	cone	$\pi r^2 h/3$
do	cylinder	$\pi r^2 h$
do	pyramid	area of base × perpendicular height ÷ 3

Chord of angle A $= \frac{c}{r}$

Versed sine of angle $\frac{1}{2}$A $= \frac{h}{r}$

$$= 1 - \cos\frac{A}{2}$$

Area of circle $= \pi r^2 = .7854d^2$

Circumference of circle $= 2\pi r$

$\pi = 3.141593 \qquad \pi^2 = 9.869604$

Arc length abc = rA (A in radians)

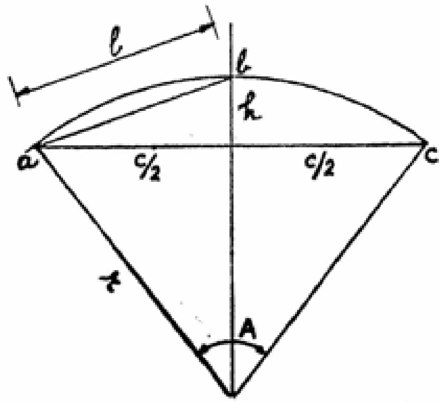
one radian $= 57.296^0$

$$l = \sqrt{h^2 + c^2/_4}$$

$$c = 2\sqrt{2rh - h^2}$$

$$r = \frac{4h^2 + c^2}{8h}$$

$$h = r - \sqrt{r^2 - c^2/_4}$$



I about a diameter $= \frac{\pi d^4}{64} = .0491d^4$

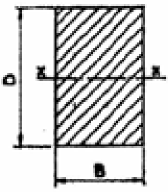
Side of a square having periphery equal to circumference of circle $\frac{r\pi}{2}$

Diameter of a circle circumscribed about a square = side of square × 1.41421.

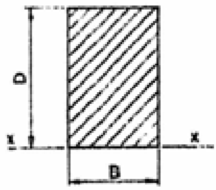
14.9 Areas of Small Circles Advancing by 32nds of an inch

Diameter in inches	Area sq. inches	Diameter in inches	Area sq. inches	Diameter in inches	Area sq. inches	Diameter in inches	Area sq. inches
1/32	.0008	9/32	.0621	17/32	.2217	25/32	.4794
1/16	.0031	5/16	.0767	9/16	.2485	13/16	.5185
3/12	.0069	11/32	.0928	19/32	.2769	27/32	.5591
1/8	.0123	3/8	.1104	5/8	.3068	7/8	.6013
5/32	.0192	13/32	.1296	21/32	.3382	29/32	.6450
3/16	.0276	7/16	.1503	11/16	.3712	15/16	.6903
7/32	.0376	15/32	.1726	23/32	.4057	31/32	.7371
1/4	.0491	1/2	.1963	3/4	.4418	1	.7854

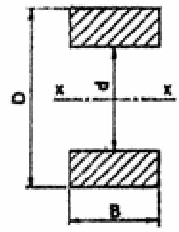
14.10 Moments of Inertia



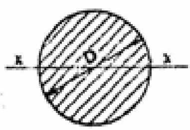
$$I_{xx} = \frac{BD^3}{12}$$



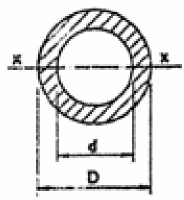
$$I_{xx} = \frac{BD^3}{3}$$



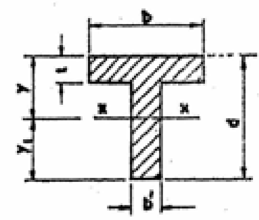
$$I_{xx} = \frac{B(D^3-d^3)}{12}$$



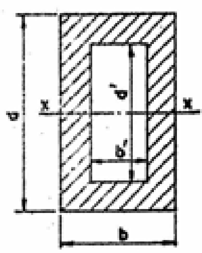
$$I_{xx} = \frac{\pi D^4}{64} = 0{\cdot}0491\ D^4$$



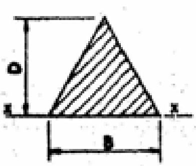
$$I_{yy} = \frac{\pi(D^4-d^4)}{64} = 0{\cdot}0491\,(D^4-d^4)$$



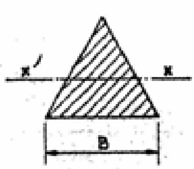
$$I_{xx} = \frac{b'y_1^3 + by^3 - (b-b')(y-t)^3}{3}$$



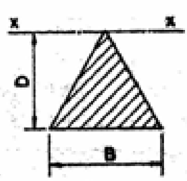
$$I_{xx} = \frac{bd^3 - b'd'^3}{12}$$



$$I_{xx} = \frac{BD^3}{12}$$



$$I_{xx} = \frac{BD^3}{36}$$



$$I_{xx} = \frac{BD^3}{4}$$

14.11 Conversion Factors

Multiply by	To convert	To	
7000	Pounds (avoir)	Grains (troy)	.000143
28.35	Ounces (avoir)	Grammes	.0352
.065	Grains	-do-	15.38
50.8	Cwts.	Kilogrammes	.01968
1016.0	Tons	-do-	.000984
4.546	Gallons	Litres	.22
10	Gallons of water	Pounds	.1
.454	Pounds of water	Litres	.2202
70.3	lb/sq. inch	gms/sq. cm.	.0142
2.3	-do-	Head of water ft.	.434
0.7	-do-	,, M.	1.4285
.068	-do-	atmospheres	14.7
1.575	Tons/sq. inch	Kg/mm^2	.635
4.883	Lbs./sq. ft.	Kg/m^2	.205
.593	Lbs./Cubic yd.	Kg/m^3	1.686
16.02	Lbs./Cubic ft.	Kg/m^3	.0624
.0998	Lbs./gal.	Kg/Litre	10.02
.138	Foot lbs.	Kg meters	7.23
.33	Foot Tons	Tonnes meters	3
1014	H.P.	Force-de-cheval	.9861
746	,,	Watts	.00134
33000	,,	Ft. lb/min	—
76	,,	Kg. m/sec.	.01316
	To obtain	From	Multiply by above

Multiply by	To Convert	To	
44	Watts	Ft. lb/min	.0227
0.1	,,	Kg m/sec.	10
0.252	Heat units	Calories	3.97
14.7	Atmospheres	Lb./Sq. inch	.068
0.70	German candles	English Candles	1.1111
9.55	Carcels	Candles	.1047
.737	Joules	Ft. lbs.	1.357
88	Miles/hour	Ft./min.	.01134
197	meters/sec.	Ft./min.	.00508
1.8	C.H.O.	B.Th.U.	.5555
0.0208	Centipoise	Lb/m² sec.	48
1.488	lbs./ft.	kg/m	0.672
0.496	lbs./yd.	-do-	2.016
3333.33	tons/ft.	-do-	0.0003
1111.11	tons/yd.	-do-	0.0009
0.2818	lb./mile	kg/kilometer	3.548
10.936	tons/sft.	tonnes/meter²	0.0914
1.215	tons/syd.	-do-	0.823
1.329	tons/cu. yd.	tonnes/m³	0.752
0.01426	grains/gallon	gm./litre	70.12
48.905	gallons/sft.	litres/m²	0.0204
25.8	inch/tons	kg/meters	0.0387
0.477	lbs./H.P.	kg per cheval	2.235
0.0916	sft./H.P.	m²/cheval	10.913
0.0279	cft./H.P.	m³/cheval	35.806
2.713	Heat units/H.P.	calories/m²	0.369
	To obtain	From	Multiply by above

14.12 Metric Measures

(1) Length:

Millimeter (mm)			=	.039370 inches
Centimeter	=	10^1 mm	=	.393704 ,,
Decimeter	=	10^2 mm	=	3.937043 ,,
Meter	=	10^3 mm	=	39.370428 ,,
			=	3.281 ft.
Decimeter	=	10^4 mm	=	393.70428 inches
			=	32.80869 ft.
Hectometer	=	10^5 mm	=	328.0869 ft.
Kilometer	=	10^6 mm	=	3280.869 ft.

(2) Area

Square millimeter (mm^2)			=	.001550 sq. inches
Sq. Centimeter	=	10^2 sq. mm	=	.1550 sq. inches
Sq. Decimeter	=	10^4 sq. mm	=	15.5003 sq. inches
Sq. Meter	=	10^6 sq. mm	=	1550.03 sq. inches
			=	10.764 s.ft.
Sq. Kilometer	=	10^{12} sq. mms	} =	10764101 s.ft. or
	=	10^6 sq. meters.		247.11 acres.

(3) Capacity.

Millilitre	=	.0610254 cubic inches.		
Centilitre	=	10 Mililitres	=	.610254 cubic in.
Litre	=	10^3 Mililitres	=	61.0254 cubic in.
Kilolitre	=	35.3156 cubic ft.		

(4) Weight.

Milligramme	=	$\frac{1}{10}$ Centigramme	=	$\frac{1}{10^3}$ gramme
			=	.015432 grains.
Gramme	=		=	0.03527 oz.
Kilogramme	=	10^3 Grammes	=	2.2046 lb
Tonne	=	1000 Kilogrammes	=	.9843 long tons

(5) Volume.

1 cubic centimeter (c.c.)	=	.06103 cubic inches.		
1 cubic meter	=	1,000,000 c.cs	=	35.3156 cubic ft.
			=	1.31 cubic yds.

14.13 Metric Equivalents of Feet and Inches

(figures indicate metres)

Feet → / Inches ↓	0	1	2	3	4	5	6	7	8	9	10	11	12
0	.0	.305	.610	.914	1.219	1.524	1.829	2.133	2.438	2.743	3.048	3.352	3.657
1	.0254	.330	.635	.940	1.244	1.549	1.854	2.158	2.463	2.768	3.073	3.378	3.682
2	.0508	.350	.660	.965	1.269	1.575	1.880	2.184	2.489	2.794	3.099	3.403	3.708
3	.0762	.381	.686	.991	1.295	1.600	1.905	2.209	2.514	2.819	3.124	3.429	3.733
4	.1016	.406	.711	1.016	1.320	1.626	1.931	2.235	2.540	2.844	3.150	3.454	3.759
5	.1270	.432	.737	1.041	1.346	1.651	1.956	2.260	2.565	2.870	3.175	3.479	3.784
6	.1524	.457	.762	1.066	1.371	1.676	1.981	2.285	2.590	2.895	3.200	3.505	3.810
7	.1778	.483	.787	1.092	1.397	1.702	2.007	2.311	2.616	2.921	3.226	3.530	3.835
8	.2032	.508	.813	1.117	1.422	1.727	2.032	2.336	2.641	2.946	3.251	3.555	3.860
9	.2286	.533	.838	1.142	1.448	1.753	2.057	2.362	2.667	2.972	3.276	3.581	3.886
10	.2540	.559	.864	1.168	1.473	1.778	2.083	2.387	2.692	2.997	3.302	3.606	3.911
11	.2794	.584	.889	1.193	1.498	1.803	2.108	2.412	2.717	3.022	3.327	3.623	3.936

INCH EQUIVALENTS OF CENTIMETERS AND MILLIMETERS

	0	1	2	3	4	5	6	7	8	9	10 cms.
m/m 0	.0	.3937	.7874	1.1811	1.5748	1.9685	2.3622	2.7559	3.1495	3.5423	3,9370 inches
1	.0394	.4331	.8268	1.2205	1.6142	2.0079	2.4016	2.7953	3.1890	3.5827	
2	.0787	.4724	.8661	1.2598	1.6536	2.0473	2.4410	2.8347	3.2284	3.6221	
3	.1181	.5118	.9055	1.2992	1.6929	2.0866	2.4803	2.8740	3.2677	3.6614	
4	.1575	.5512	.9449	1.3386	1.7323	2.1260	2.5197	2.9134	3.3071	3.7008	
5	.1968	.5906	.9843	1.3780	1.7717	2.1654	2.5591	2.9528	3.3465	3.7402	
6	.2362	.6299	1.0236	1.4173	1.8110	2.2047	2.5984	2.9922	3.3859	3.7796	
7	.2756	.6693	1.0630	1.4567	1.8504	2.2441	2.6378	3.0315	3.4252	3.8189	
8	.3150	.7087	1.1024	1.4961	1.8898	2.2835	2.6772	3.0709	3.4646	3.8583	
9	.3543	.7480	1.1417	1.5354	1.9291	2.3228	2.7166	3.1103	3.5040	3.8977	

METRIC EQUIVALENTS

(millimetres from inches and sixteenths)

Inch	0	1/16	1	3/16	1/4	5/16	3/8	7/16
0		1.58	3.17	4.76	6.35	7.93	9.52	11.11
1	25.400	26.98	28.47	30.16	31.74	33.33	34.92	36.51
2	50.799	52.38	53.97	55.56	57.14	58.73	60.32	61.91
3	76.199	77.78	79.37	80.96	82.54	84.13	85.72	87.31
4	101.60	103.19	104.77	106.36	107.95	109.54	111.12	112.71
5	127.00	128.59	130.17	131.76	133.35	134.94	136.52	138.11
6	152.40	153.98	155.57	157.16	158.75	160.33	161.92	163.51
7	177.80	179.38	190.97	182.56	184.15	185.73	187.32	188.91
8	203.20	204.78	206.37	207.96	209.55	211.13	212.73	214.31
9	228.60	230.18	231.77	233.36	234.94	236.53	238.12	239.71
10	254.00	255.58	257.17	258.76	260.35	261.93	263.52	265.11
11	279.39	280.98	282.57	284.16	285.74	287.33	288.92	290.51
12	304.79	306.38	307.97	309.56	311.14	312.73	314.32	315.91
13	330.19	331.78	333.37	334.96	336.54	338.13	439.72	341.31
14	355.59	357.18	358.77	360.36	361.94	363.53	365.12	366.71
15	380.99	382.58	384.17	385.76	387.34	388.93	390.52	392.11
16	406.39	407.98	409.57	411.17	412.74	414.33	415.92	417.50
17	431.79	433.38	434.97	436.56	438.14	439.73	441.32	442.90
18	457.19	458.78	460.37	461.96	463.54	465.13	460.72	468.30

METRIC EQUIVALENTS

(millimetres from inches and sixteenths)

Inch	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
0	12.70	14.28	15.87	17.46	19.05	20.63	22.22	23.81
1	38.09	39.68	41.27	42.86	44.44	46.03	47.62	49.21
2	63.49	65.08	66.67	68.26	69.84	71.43	73.02	74.61
3	88.89	90.48	92.07	93.66	95.24	96.83	98.42	100.01
4	114.30	115.89	117.47	119.06	120.65	122.24	123.82	125.41
5	139.70	141.28	142.87	144.46	146.05	147.63	149.22	150.81
6	165.10	166.68	168.27	169.86	171.45	173.03	174.62	176.21
7	190.50	192.08	193.67	195.26	196.85	198.43	200.02	201.61
8	215.90	217.48	219.07	220.66	222.25	223.83	225.42	227.01
9	241.30	242.88	244.47	246.06	247.65	249.23	250.82	252.41
10	266.70	268.28	269.87	271.46	273.05	274.63	276.22	277.81
11	292.10	293.68	295.27	206.86	298.44	300.03	301.62	303.21
12	317.50	319.08	320.67	322.26	323.84	325.43	327.02	328.61
13	342.90	344.48	346.07	347.66	349.24	350.83	352.42	354.01
14	368.30	369.88	371.47	373.06	374.64	376.23	377.82	379.41
15	393.69	395.28	296.87	398.46	400.04	401.63	403.22	404.81
16	419.09	420.68	422.27	423.85	425.44	427.03	428.62	430.20
17	444.49	446.08	447.67	449.25	450.84	452.43	454.02	455.60
18	469.89	471.48	473.07	474.65	476.24	477.83	479.42	481.00

14.14 Table of British Weights Expressed in Indian Weights

English	Indian	English	Indian	English	Indian	English	Indian
Lb 2	Mds.Srs 1	16	21 31	34	925 22	90	2450 0
4	2	18	24 20	36	980 0	92	2504 18
6	3	Tons 1	27 9	38	1034 18	94	2558 36
8	4	2	54 18	40	1088 36	96	2613 13
10	5	3	81 27	42	1143 13	98	2667 31
12	6	4	108 36	44	1197 31	100	2722 0
14	7	5	136 4	46	1252 9	200	5444 18
16	8	6	163 13	48	1306 27	400	10888 36
18	9	7	190 22	50	1361 4	500	13611 4
20	10	8	217 31	52	1415 22	1000	27222 9
22	11	9	245 0	54	1470 0		
24	12	10	272 9	56	1524 18		
26	13	11	299 18	58	1578 36		
Qrts 1	14	12	326 27	60	1633 13		
2	27	13	353 36	62	1687 31		
3	1 1	14	381 4	64	1742 9		
Cwt 1	1 14	15	408 13	66	1796 27		
2	2 29	16	435 22	68	1851 4		
3	4 3	17	462 31	70	1905 22		
4	5 18	18	490 0	72	1960 0		
5	6 32	19	517 9	74	2014 18		
6	8 7	20	544 18	76	2068 36		
7	9 21	22	598 36	78	2123 13		
8	10 36	24	653 13	80	2177 31		
9	12 10	26	707 31	82	2232 9		
10	13 24	28	762 9	84	2286 27		
12	16 13	30	816 27	86	2341 4		
14	19 2	32	871 4	88	2395 22		

100 Mds = 3.673 Tons.

1 Ton = 27.22 Mds.

1 Md. = 82.29 Lb

14.15 Weights and Measures

8 Ruttees	=	1 masha	= 3/175 dr.	Avois
12 mashas	=	1 Tola	= 12/175	,,
5 Tolas	=	1 chattak	= 2 $^{2}/_{35}$ oz	,,
16 chattaks	=	1 seer	= 2 $^{2}/_{35}$ lb	,,
40 seers	=	1 maund	= 82 $^{2}/_{27}$ lb	
4 chattaks	=	20 Tolas	= 2 $^{2}/_{35}$ lb	
4 Paus	=	1 seer		
5 seers	=	1 Pansari		

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16 Drams	=	1 ounce
16 ounces	=	1 pound
14 pounds	=	1 stone
28 pounds	=	1 quarter
112 pounds	=	1 hundredweight (cwt.)
20 cwts.	=	1 Ton.
1 long ton	=	2240 pounds
1 short ton	=	2000 do

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4 inches	=	1 hand
9 inches	=	1 span
12 inches	=	1 foot
3 feet	=	1 yard
5 feet	=	1 pace
6 feet	=	1 fathom
5½ yards	=	1 rod pole
4 poles	=	1 chain
10 chains	=	1 furlong
8 furlongs	=	1 mile (one nautical mile=6080 ft.)
3 miles	=	1 league (1 Knot = 1 nautical mile/hour.)

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144 square inches	=	1 square foot
9 square feet	=	1 square yard
30¼ square yards	=	1 square perch
40 perches	=	1 rood
4 roods	=	1 acre
640 acres	=	1 square mile
an acre	=	4840 sq. yds.

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cubic foot	=	1728 cubic inches
cubic yard	=	27 cubic feet.
stack of wood	=	108 cubic feet.
1 bushel	=	2150.42 cubic inches.
1 ton (shipping)	=	40 cubic feet.
1 British bushel	=	1.2837 c.ft.

CHARTS

TABLES

INDEX

CONCRETE ENGINEERS' HANDBOOK

NOMENCLATURE

a	Part of span of a beam.
a	Lever arm.
a_1	(Vide j).
A_t	Cross-sectional area of tensile reinforcement.
A_b	Volume of helical winding per unit length of column.
A_c	Cross-sectional area of compression reinforcement.
A_H	Horizontal reinforcement for tank walls.
A_v	Vertical reinforcement for columns, tank walls, etc.
B	Width of base of retaining wall.
B	Width of table of T-beam.
b	Breadth of beam or slab (in inches).
b	Part of span of a beam.
b_r	Breadth of web of T-beam.
c_1	Numerical coefficient giving value of maximum hoop tension in a circular tank.
c_2	Numerical coefficient showing place of maximum hoop tension in circular tank.
D	Overall depth of beam in inches.
D	Gross size of a column.
D	Effective depth of footing.
D	Diameter of the tank.
d	Effective depth of a slab or a beam.
d	Diameter or side of core area of a r.c. column.

d	Thickness of the side of a circular tank.
d	Effective diameter of column measured across core in direction of lateral supports.
d_1	Distance of centre of compression steel from top of the beam.
d_s	Depth of flange of T-beam.
d_v	Diameter of vertical bars of a column.
e	The eccentricity of load.
f_c	Compressive unit stress in extreme fibre of concrete
F or FM	Fineness modulus of aggregates.
F_c	Fineness modulus of coarse aggregates.
F_f	Fineness modulus of fine aggregates.
F_m	Fineness modulus of mixed aggregates.
F_x	Shear force at a distance x from a particular support.
g	Least equivalent radius of gyration ascertained on the core area.
H	Height of the retaining wall from foundation.
H_1	Height of the retaining wall measured from top of base.
h	Height of water in a tank.
jd	Lever arm of a section.
j	Ratio of lever arm of resisting couple to depth d.
K	Distance in feet from support in which shear intensity exceeds the safe limit. (Reference T-beam tables).
K	Ditto in inches (Ref. shear tables).
K_1, K_2	Factors used in design of rectangular beams with compression reinforcement.

l	Actual length of a column taken as clear distance between lateral supports.
l_x, l_y	Short and long spans of two-way slab respectively.
M	Bending moment.
M_A M_B etc.	Bending moments at particular points A, B, etc. on a beam.
M_x	Bending moment at any point x on a beam.
m	Modular ratio.
n_o	Neutral axis factor for columns under bending.
$n_1 n_2$ etc.	Number of stirrups in various portions of a T-beam.
P P_1 P_2 P_D	Concentrated loads on beams.
P	Overturning force on retaining wall.
P	Total load on a column.
P_c	Load carried by concrete in core of a column.
P_T	Load carried by vertical steel of a column.
P_B	Load carried by helical binding of a column.
p	Ratio of area of tensile steel to effective area of concrete (vide r).
p	Pitch of links in a column or stirrups in a beam.
psi	Pounds per square inch.
psf	Pounds per square foot.
Q	Qualifier giving value of resisting moment of a section in terms of breadth and depth of a section.
R	Ratio of side of column to side of base.

R_A, R_B	End reaction in a beam.
R.M.	Resisting moment of a section.
r	Ratio of area of tensile steel to effective area of concrete (vide p).
r	Ratio of cost of one cft. of steel to cost of one cft. of concrete.
r_1	Ratio of compressive steel in a section to the effective area of the section $=\frac{A_c}{bd}$.
S	Vertical shear in pounds on a beam.
t	Tensile unit stress in steel.
tsi	tons per square inch.
tsf	tons per square foot.
v	Virtual length of a column.
V_1, V_2	Vertical shears at non-continuous end of beams.
V_2L	Vertical shear at continuous ends of beams.
V_2R	L and R denotes shear at left or right of the support.
V_s	Shear at support of a beam.
W	Total load on one span of a beam.
W_L	Total live load on one span of beam.
W_D	Total dead load on one span of a beam.
w	Load per unit length of a beam.
W_e	Intensity of pressure exerted by a retained granular material.
Z_x, Z_y	B.M. coefficients, two-way slabs.
ϕ	Angle of repose of a granular material.
α	Angle of surcharge of a granular material.
θ	Angle of bend of shear steel.
μ	Coefficient of friction.

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