GRAPH FOR THE DESIGN

OF

REINFORCED CONCRETE SLABS

BY

A. Mariasusai Pillai,

Assistant Engineer, P. W. D.,

Madras (India).

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OPINIONS

The graph with the Introductory Note which explains how it has been prepared, should be of very great use to those who have to design reinforced concrete slabs, or to check the designs prepared by others.

The graph has been very carefully prepared, and has been found to give accurate results; its general use can therefore be confidently recommended.

(Sd.) R. F. STONEY,
3rd Dec. 1930. *Chief Engineer, P.W.D.*
General, Buildings and Roads.

I have perused with interest the 'Graph' prepared by Mr. Mariasusai Pillai for the design of Reinforced-Concrete slabs as well as the attached note explaining its application and use. It is an excellent labour-saving device which gives accurate results and is recommended for use to all those who have anything to do with the design of R. C. slabs.

(Sd.) N. SWAMINATHA IYER,
Chief Engineer for Irrigation,
P.W.D., Madras.

CHEPAUK,
Madras,
16th Sept. 1930.

PREFACE

Reinforced Concrete Work is one of recent introduction in this land and its general use is so rapidly recognized that no important building is now under progress in which it has not replaced the time-honored Madras Terracing. It forms a feature chiefly in the construction of Pillars, Beams and Slabs for covering terraces. Amongst these the one that is commonly in use is the Slab.

The stability of Reinforced Concrete Works depends upon careful design entailing intricate calculations involving time and labour. The steady growth of their use demands a relief in these directions and that is the author's excuse for sending out the 'Graph for the Design of Reinforced Concrete Slabs' to the press. The graph is so simple that there is no need for making any calculations.

The accuracy of the graph has been kindly testified to by high authorities who have closely tested its results.

An explanatory note is attached and examples are worked out to render the use of the Graph clear to all.

The author begs to express his deep gratefulness to Mr. R. F. Stoney, Chief Engineer, P.W.D., General Buildings and Roads, Madras, and M. R. Ry. Dewan Bahadur N. Swaminatha Iyer Avergal, B.A., B.E., Chief Engineer for Irrigation, Madras, for the encouragement vouchsafed to him in the preparation of his work and the valuable suggestions he has been kindly favoured with at their hands.

Chepauk, Madras,
7th January 1931.

A. M.

MARIASUSAI PILLAI'S GRAPH

for the design of

REINFORCED CONCRETE SLABS

INTRODUCTION

The graph shows at a glance the minimum sizes of reinforced concrete slabs required to meet stresses under the different conditions in which they are produced and obviates the intricate calculations that have to be made in order to determine them. The thickness of the slab and the reinforcement required are read off at a glance. The author's claim for the graph is its simplicity; it can be understood even by a layman so easily that he will be enabled to design the slab and fix the reinforcement himself without the aid of Engineers. It is needless to mention that it will be found useful in all Drawing offices as it not only saves time, but also gives accurate results. Executive officers and subordinates on the field may, with the help of the graph, design slabs or check their correctness, in an instant.

DESCRIPTION OF THE GRAPH

The graph proper is at the centre of the drawing, with curved lines, showing various thicknesses of slabs. The reinforcement diagram is on the right side. The big table on the left shows spans of rooms or halls for various ratios of length and breadth, which carry slabs supported on all the four sides.

DEFINITION OF TERMS

Reinforced concrete slabs are always designed to an effective thickness to suit an effective span.

According to the London County Council (L. C. C.) Regulations the effective thickness is the depth from the top of concrete (compression side) to the centre of the reinforcement. The effective span is the distance from centre to centre of bearing or is the clear span plus the thickness of the slab, whichever is smaller.

The graph shows only effective depths and effective spans. It is compiled for a stress of 600 lbs. per sq. inch on concrete, 16,000 lbs. per sq. inch on mild steel and a reinforcement of 0·675%, the concrete being of 1 : 2 : 4 mix.

THE GRAPH

The dimensions on the curved lines indicate the effective thickness of the slab from 1¼″ to 12″.

Of the several columns of figures on the right of the central graph the two immediately close to it show the thickness of slabs and the area of reinforcement required for each thickness. The other columns next to these show the safe spans against shear for each description of slab and for different live and super loads. It will be seen that slabs are always safe for shear in all general cases.

On the left side of the graph are six different columns showing effective spans for various methods of support. The one close to the graph shows spans falling under "Ordinary cases" when the slabs will be supported on two ends (*i.e.*, under WL/8). The extreme one (under WL/2) gives safe spans for "cantilevers"; it should be remembered that the London County Council (L. C. C.) Regulations require that the length of the cantilevers should not exceed five times the depth. The figures under columns WL/12 and

WL 10 refer to safe spans when the slabs are "fixed" or are "continuous over two or more supports".

At the right hand top corner is a table which shows the live load to be provided for according to Madras practice.

In designing the slab, its dead-weight in each case has been taken into account as it is a definite figure. The super load alone, being a variable figure, has been shown as abscissa and the span as ordinate in the graph. The super load consists of the live load and the weight of any other covering material that may be specified; in fact it is the sum total of all other loads except the weight of the slab.

Provided the super load in each case and the effective span are known, which are always available in practical cases, the point of intersection on the graph shows the effective thickness of the slab.

To the thickness of slabs so obtained a cover should be added to protect the reinforcement and to make up the full thickness of the slab, the cover being not less than ¾″ up to 5″, not less than 1″ up to 9″ and not less than 1¼″ up to 12″. The slabs for buildings should not be less than 3″ in effective depth.

In the case of reinforced concrete *roofs* it has been recently ordered by the Chief Engineer of the Madras Province that a minimum thickness of 8″ should be secured by adding one or two courses of flat tiles and also ordinary lime concrete if necessary, to mitigate the heat of the sun and also to secure a fall for draining away the rain water. In such cases in addition to the live load of 50 lbs., an additional weight to provide for such covering should be allowed for.

REINFORCEMENT DIAGRAM

The vertical scale on the reinforcement diagram shows the area of reinforcement varying from 0·03 square inch to 5 sq. inches and the horizontal scale, the distance between reinforcing bars varying from 2″ to 20″. The inclined lines on the diagram indicate the description of square bars and round bars in dotted and firm lines respectively from ⅛″ up to 1½″ in size.

Given the area of reinforcement, the horizontal line starting from it intersects inclined lines representing various descriptions of rods; and the distance at which each rod is to be placed is obtained by following the point of intersection vertically to the scale either above or below.

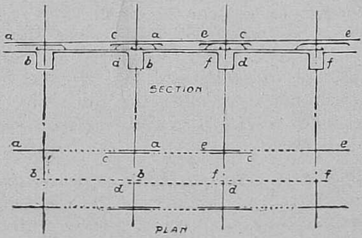
For the convenience of designers, the thickness of slab in the main graph is each connected to this diagram, by lines ending on the vertical scale at a point where the area of reinforcement corresponds to the quantity of reinforcement required. The lines end with an arrow on the reinforcement diagram. For any other thickness of slab than those shown on the graph, the quantity of reinforcement required can be obtained by interpolation. A 4¾″ slab can easily be found to require 0·344 sq. inch of steel and so on.

The steel rods should not be nearer than an inch and not more than 12″ or twice the effective depth apart from each other.

They are always necessary on the tension side and their ends should be hooked round to 4 diameters to give sound grip.

Where the rods available in the market are short in dimension and require lengthening, they are lashed together for a length equal to 40 diameters.

In continuous beams or slabs bending moments are greater at the points of support than at the midspans and hence rods should be bent up to meet them from a point approximately about the fourth of the span as shown in the illustrations on the graph. The following is considered by an eminent author* as the most popular and superior arrangement of bars in the case of slabs :—



* G. P. Manning on " Reinforced Concrete Design " pages 182 and 183—1924 Edition.

Instead of employing one short length of bar for each span, the bottom bars can also be laid in long lengths and be lapped with one another 40 diameters the lap occurring at any point of a span.

Example 1.—Design a floor slab for an office room 20′ × 9′.

The effective span is about 9′ – 4″.

The live load for office = 80 lbs.

Treating this as an ordinary case, follow the span under WL/8; the intersection with 80 lbs. live load gives an effective thickness of 4″.

The full thickness should be 4¾″.

The quantity of reinforcement required = 0·324 sq. in.

It might be arranged with one or the other of the following bars :—

1. Square bars ¼″ at 2¼″ centres (0·33 sq. in.).
2. " " ⅜″ at 5⅛″ " (0·325 sq. in.).
3. Round bars ⅜″ dia. at 4″ " (0·328 sq. in.).
4. " " ½″ dia. at 7¼″ " (0·324 sq. in.).

Example 2.—A hall in a hospital 36′ × 24′ carries a floor slab supported on two intermediate girders. Design the slab.

The effective span is about 12′ – 2¼″ for the end span and 12′ for the centre span.

The live load = 60 lbs.

As the slab will be continuous the centre span should be designed for WL/12 and the two end spans for WL/10. Except in competitive designs the slabs in a room are generally cast to be of the same thickness and it is usual in such cases to design them for WL/10. If they should be separately designed :—

The thickness of the end slabs should be 4½″ effective and 5¼″ full.

The thickness of the centre slab can be nearly 4″ effective and 4¾″ full.

The reinforcement for a slab of 4½″ effective thickness is 0·364 sq. inch.

The following rods can be used :—

1. Square bars ¼″ at 2″ centres (= ·375 sq. in.).
2. „ „ ⅜″ at 4⅝″ „ (= ·364 sq. in.)

3. Square bars $\frac{1}{2}''$ at $8\frac{1}{4}''$ centres (= ·364 sq. in.).

4. Round bars $\frac{3}{8}''$ Dia. at $3\frac{5}{8}''$ „ (= ·364 sq. in.).

5. „ „ $\frac{1}{2}''$ „ at $6\frac{1}{4}''$ „ (= ·376 sq. in.).

GRASHOF AND RANKINE'S DESIGN OF SLABS SUPPORTED ON ALL THE FOUR SIDES

A slab supported on all the four sides is reinforced both longitudinally and crosswise and is therefore stronger and stiffer than one treated as supported on two sides only. This principle has been recognised by the London County Council (L.C.C.) Regulations and the world in general.

The double reinforcement will be needed only when the length of the slab does not exceed twice its width. In such cases the load to be borne by the slab is modified by a coefficient $\left(\text{a fraction} = \frac{L^4}{L^4+B^4} \text{ or } \frac{B^4}{L^4+B^4}\right)$ which varies according to the ratio of the length to the breadth.

The table at the extreme left shows ratios of L/B varying from 1 to 1·9. Under each ratio there are two columns one under '*f*' and the other under "*r*". The figures under '*f*' show the effective width and those under "*r*" the effective length of the room or hall. These figures are connected to the central graph by horizontal guide lines which help to find out the thickness of slab required.

In these cases the slab is primarily designed for its thickness and reinforcement with reference to the width in column 'f' under the respective L/B ratio.

The thickness is obtained from the central graph and the reinforcement from the right hand side diagram as already described. *The longitudinal reinforcement to be provided for can be obtained by following the length under column 'r' to the required thickness of the slab and thence to the reinforcement diagram.*

The longitudinal reinforcement which is also known as distributors should not be farther apart than four times the effective depth or 18".

Example 3.—Design a floor slab of a room in a Residence measuring 18′ × 12′.

The slab thickness can roughly be found to be about $4\frac{3}{4}''$ from the graph.

The effective span is $12' - 4\frac{3}{4}''$.

" length " $18' - 4\frac{3}{4}''$.

$$\therefore L/B = \frac{18{\cdot}4}{12{\cdot}4} \text{ or } 1{\cdot}5 \text{ nearly.}$$

The live load is 60 lbs.; if any extra finish such as tiling etc. is allowed, its weight should be added on for determining the slab thickness.

The 12·4′ point in the '*f*' column under L/B = 1·5, carried horizontally to 60 lbs. live load in the next graph indicates an effective depth of $4\frac{3}{4}''$.

The reinforcement required = 0·385 sq. in. Any of the following arrangements will suit :—

i. Square bars $\frac{3}{8}''$ at $4\frac{3}{8}''$ centres.
ii. " " $\frac{1}{2}''$ at $7\frac{3}{4}''$ "
or iii. Round bars $\frac{3}{8}''$ Dia. at $3\frac{3}{8}''$ "
iv. " " $\frac{1}{2}''$ Dia. at $6''$ "
v. " " $\frac{9}{16}$ Dia. at $7\frac{1}{2}''$ "

The longitudinal reinforcement is obtained by connecting the 18·4′ point under the "r" column (in L/B = 1·5) to the slab diagram where d under 60 lbs. is found to be $2\frac{3}{4}''$ and the corresponding reinforcement 0·223 sq. inch; the longitudinal distributors can be:—

i. Square bars $\frac{3}{8}''$ at $7\frac{1}{2}''$ centres.

ii. " " $\frac{1}{2}''$ at $13\frac{1}{4}''$ "

or iii. Round bars $\frac{3}{8}''$ Dia. at $5\frac{7}{8}''$ centres.

iv. " " $\frac{1}{2}''$ Dia. at $10\frac{1}{2}''$ centres.

Example 4.—Design a roof slab for the room in Example 3—above.

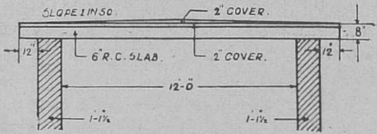
The graph shows roughly that an effective thickness of 5″ slab or a full thick ness of 6″ will be required.

The effective length is 18′ – 5″.

The effective span 12′ – 5″.

$$\therefore \text{L/B} = \frac{18'{\cdot}42''}{12'{\cdot}42''} \text{ or } 1{\cdot}48 \text{ or say } 1{\cdot}5.$$

The weight for designing is reckoned as follows:—



Live load for roof	=50 lbs.
Extra cover required for protection from heat (2" of tiling and concrete to make up 8")	=20 „
Do. for draining rain water (½ of 2" of tiling and concrete) ...	=10 „
Total live and extra load.	80 lbs.

The 12′ – 5″ point under the '*f*' column taken to 80 lbs. live load on the central graph gives a depth $= 5\frac{1}{4}''$. ∴ Full depth may be 6″.

The reinforcement required = 0·425 sq. inch.

The longitudinal reinforcement is obtained as follows:—

Following the 18′ – $5\frac{1}{4}''$ point under the '*r*' column to 80 lbs. $d = 3{\cdot}1''$.

The reinforcement required will be found to be about 0·25 sq. in.

For the longitudinal and crosswise reinforcement any suitable arrangement of steel bars as described under Example 3 can be made.

In such cases where the slabs have to be reinforced in both the directions the size of the longitudinal rods is 'kept the same as far as possible as the main crosswise bars but the distance apart alone is varied so as to avoid mistakes on the field.

To the right of the reinforcement diagram is another useful table which gives the area, the perimeter and the weight per running foot of reinforcement of square and round bars varying from $\frac{1}{8}''$ to $1\frac{1}{2}''$.

NOTE (1) For convenience in execution it is usual to allow the full thickness of slab to vary by $\frac{1}{2}''$ only.

(2) In the graph for slabs the various thicknesses are found to end at definite spans along the zero line of the live load. This indicates that at those spans the slabs will be able to support their own weight only.

(3) In applying the Grashof and Rankine's coefficients the Bending Moment has been calculated as WL/8 throughout although for 'fixed and continuous conditions it may be reduced. The slabs supported on four sides designed' with the graph will therefore err on the safe side.

MARIASUSAI PILLAI'S DIAGRAMS FOR THE DESIGN OF

R.C.SLABS

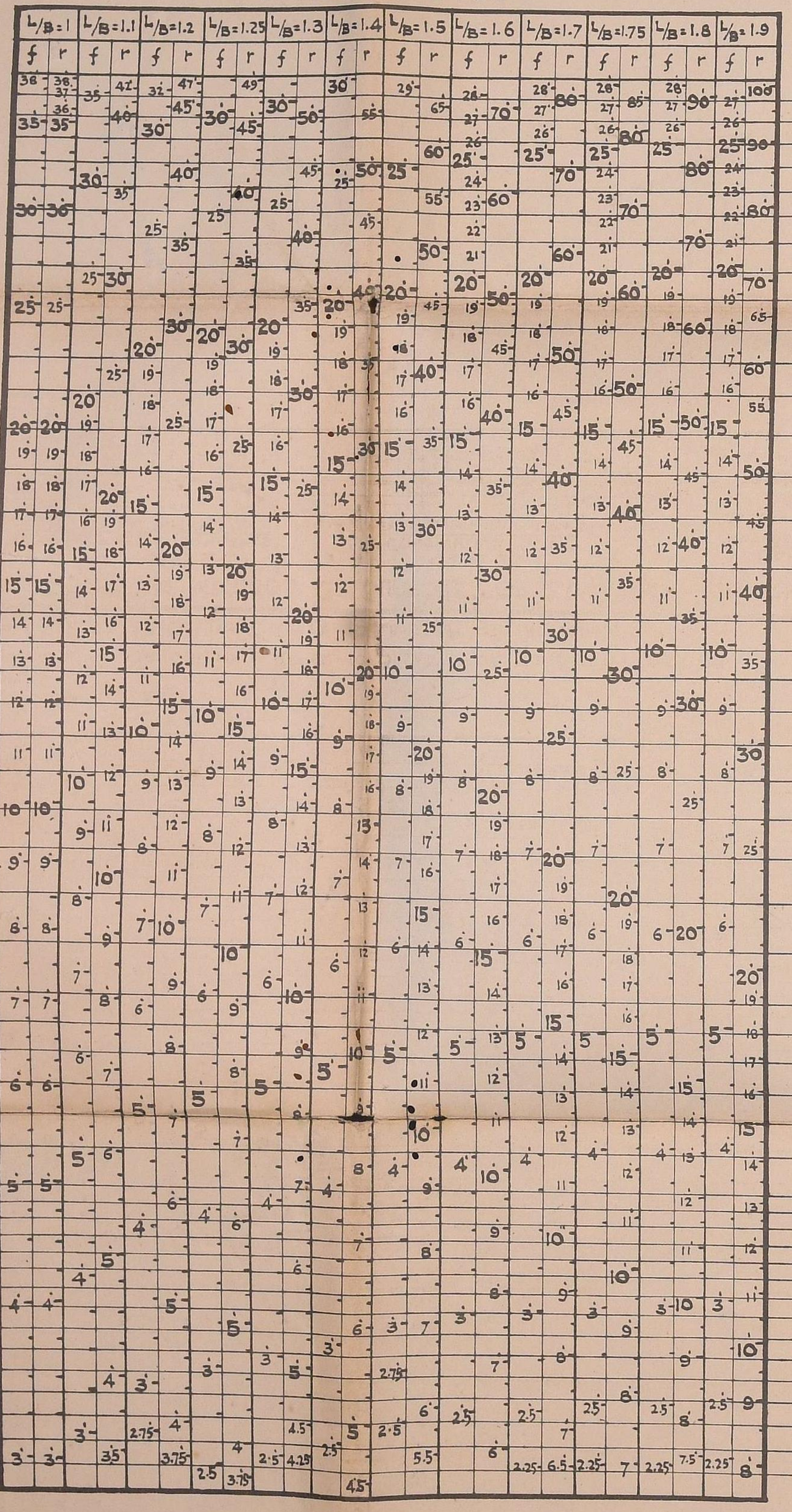
NOTE:- THE DIAGRAM SHOWS EFFECTIVE DEPTHS ONLY (SAY d).
THE ACTUAL THICKNESS D SHALL BE d+K WHERE K THE COVER IS NOT LESS THAN 3/4" UP TO 5", 1" UP TO 9", & 1¼" UP TO 12" THICKNESS.

DATA:- MIX 1:2:4; WEIGHT OF R.C. SLAB 150 LBS PER CUBIC FOOT., C = 600 LBS PER SQUARE INCH, t = 16000 LBS PER SQUARE INCH, MODULAR RATIO = 15, QUANTITY OF REINFORCEMENT = 0.00675 OF THE SECTIONAL AREA OF SLAB.

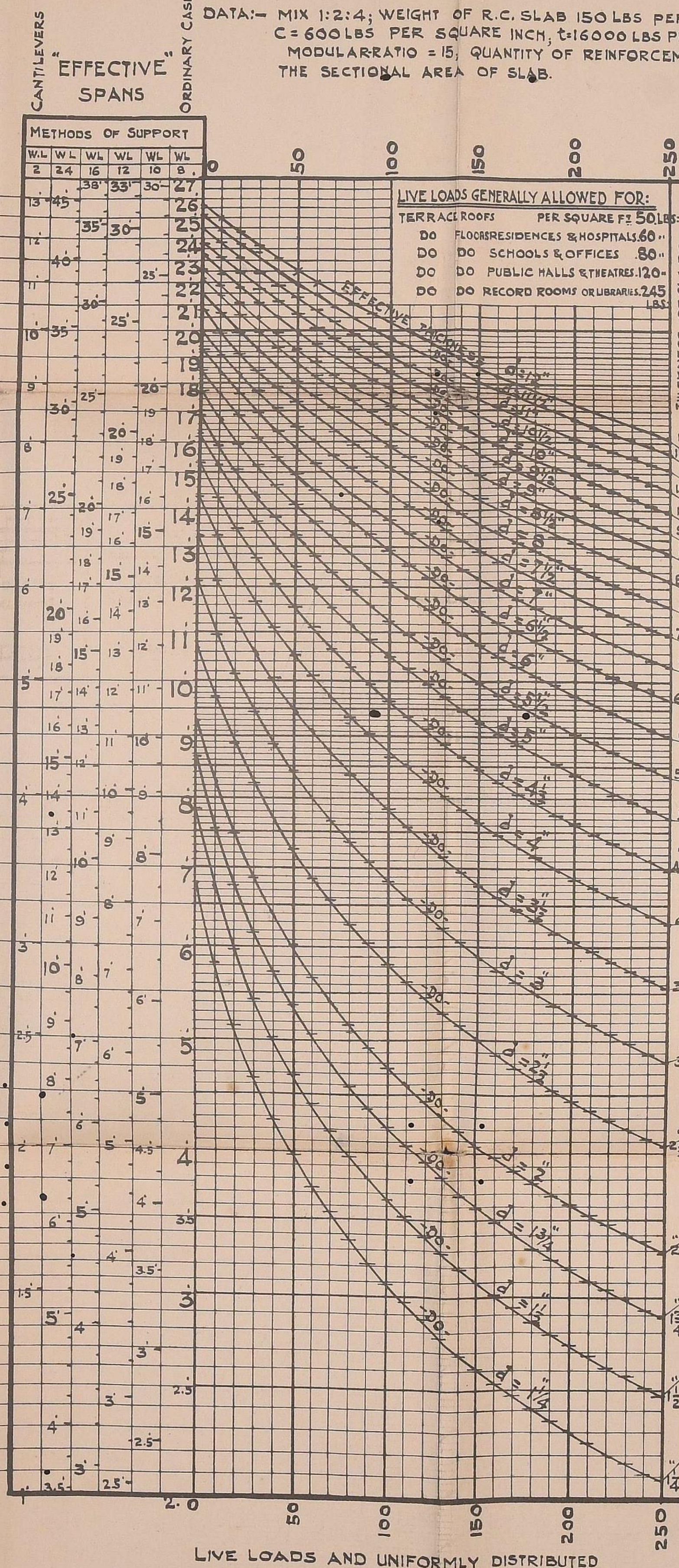
SLABS SUPPORTED ON ALL THE FOUR SIDES

TABLE OF SPANS OF ROOMS RELATING TO—
(MODIFIED WITH REFERENCE TO GRASHOF & RANKINE'S COEFFICIENTS)
FOR VARIOUS PROPORTIONS OF LENGTH TO BREADTH

"EFFECTIVE SPANS"



NOTE:-
FIGURES UNDER COLUMN "f" REFER TO BREADTHS OR THE SHORTER DIMENSION.
FIGURES UNDER COLUMN "l" REFER TO LENGTHS OR THE LONGER DIMENSION.



LIVE LOADS GENERALLY ALLOWED FOR:		
TERRACE ROOFS	PER SQUARE FT.	50 LBS:
DO	FLOORS RESIDENCES & HOSPITALS	60 "
DO	DO SCHOOLS & OFFICES	80 "
DO	DO PUBLIC HALLS & THEATRES	120 "
DO	DO RECORD ROOMS OR LIBRARIES	245 LBS:

THICKNESS OF SLABS	AREA OF REINFORCEMENT REQUIRED IN SQUARE INCHES.	SAFE SPANS FOR SHEAR UNDER LIVE LOADS LBS. PER SQUARE FT. 50	60	80	120	250
12"	0.974	70	66	61	52	36
11½"	0.933	69	65	60	51	35
11"	0.892	68	64	59	50	34
10½"	0.851	67	63	58	49	33
10"	0.810	65	62	56	48	32
9½"	0.770	64	61	55	46	31
9"	0.729	64	61	55	46	30
8½"	0.688	63	59	53	44	28
8"	0.648	61	58	52	42	27
7½"	0.608	60	56	50	41	26
7"	0.567	58	54	48	39	25
6½"	0.527	56	53	46	38	23
6"	0.486	54	51	44	36	22
5½"	0.445	52	48	42	34	20
5"	0.405	51	47	41	32	19
4½"	0.364	48	44	38	30	17
4"	0.324	45	42	36	27	16
3½"	0.283	42	38	32	25	14
3"	0.243	38	35	29	22	12
2½"	0.202	34	31	26	19	10
2"	0.162	29	26	21	16	8
1¾"	0.1417	27	24	19	14	7
1½"	0.1215	24	21	17	12	6
1¼"	0.1013	20	18	14	10	5

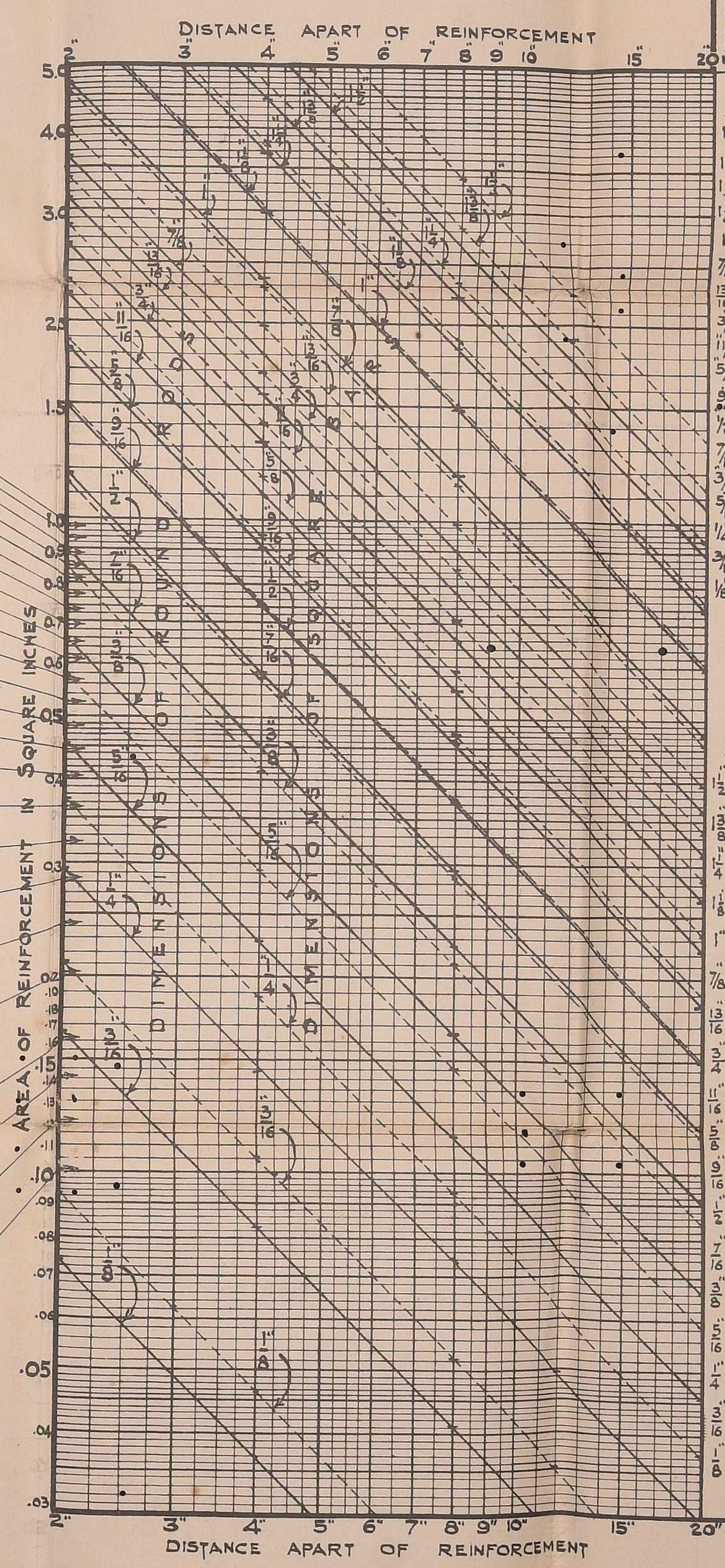
LIVE LOADS AND UNIFORMLY DISTRIBUTED SUPER-LOADS ONLY IN POUNDS PER SQUARE FOOT.

NOTE:- WEIGHT OF SLAB SHOULD BE OMITTED WHEN USING THIS GRAPH

EFFECTIVE THICKNESS OF R.C.SLAB IS THE DEPTH FROM THE TOP OF CONCRETE (COMPRESSION SIDE) TO THE CENTRE OF THE REINFORCEMENT.

EFFECTIVE SPAN IS THE DISTANCE FROM CENTRE TO CENTRE OF BEARING OR IS THE CLEAR SPAN PLUS THE THICKNESS OF THE SLAB WHICHEVER IS LESS.

REINFORCEMENT DIAGRAM



SIZE OF RODS.	AREA OF RODS IN SQUARE INCH	PERIMETER OF RODS IN INCH	WEIGHT OF RODS. LBS. PER FT. RUN.
SQUARE BARS.			
1½"	2.25	6.00	7.65
1⅜"	1.891	5.50	6.43
1¼"	1.562	5.00	5.31
1⅛"	1.266	4.50	4.30
1"	1.00	4.00	3.40
7/8"	0.766	3.50	2.60
13/16"	0.660	3.25	2.25
3/4"	0.563	3.00	1.91
11/16"	0.473	2.75	1.61
5/8"	0.391	2.50	1.33
9/16"	0.316	2.25	1.08
1/2"	0.25	2.00	0.85
7/16"	0.194	1.75	0.65
3/8"	0.141	1.50	0.48
5/16"	0.098	1.25	0.33
1/4"	0.063	1.00	0.21
3/16"	0.035	0.75	0.12
1/8"	0.0156	0.50	0.05
ROUND RODS.			
1½"	1.767	4.712	6.01
1⅜"	1.484	4.319	5.05
1¼"	1.227	3.927	4.17
1⅛"	0.994	3.534	3.38
1"	0.785	3.141	2.67
7/8"	0.601	2.748	2.04
13/16"	0.518	2.553	1.76
3/4"	0.441	2.356	1.50
11/16"	0.371	2.159	1.26
5/8"	0.306	1.963	1.04
9/16"	0.248	1.767	0.85
1/2"	0.196	1.570	0.67
7/16"	0.150	1.374	0.51
3/8"	0.110	1.178	0.38
5/16"	0.076	0.981	0.26
1/4"	0.049	0.785	0.17
3/16"	0.027	0.589	0.095
1/8"	0.012	0.392	0.042

NOTE:-
—FIRM LINES RELATE TO ROUND BARS AND DOTTED LINES TO SQUARE BARS—

SPACE BETWEEN BARS:- THERE SHALL BE A DISTANCE OF AT LEAST ONE INCH BETWEEN BARS IN SLAB AND THE MAXIMUM DISTANCE BETWEEN BARS OF THE TENSILE REINFORCEMENT SHALL NOT BE GREATER THAN 12 INCHES, AND NOT MORE THAN TWICE THE EFFECTIVE DEPTH OF THE SLAB.

WHERE BARS ARE LAID IN ONE DIRECTION ONLY, DISTRIBUTING BARS AT RIGHT ANGLES, NOT FARTHER APART THAN 18 INCHES, SHOULD BE PROVIDED TO AN AGGREGATE AREA OF ATLEAST 0.08 PER CENT OF THE EFFECTIVE CROSS SECTIONAL AREA OF THE SLAB.

END COVER:- BEYOND THE ANCHORED ENDS OF A BAR THE END COVER SHALL NOT BE LESS THAN TWO INCHES AND NOT LESS THAN TWICE THE DIAMETER OF THE RODS TO BE COVERED.

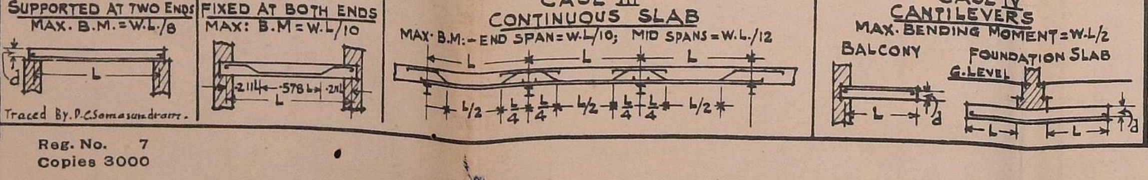
DIAGRAMS SHOWING METHODS OF SUPPORT OF R.C.SLABS (UNIFORMLY LOADED)

CASE I — SUPPORTED AT TWO ENDS — MAX. B.M. = W.L/8

CASE II — FIXED AT BOTH ENDS — MAX: B.M = W.L/10

CASE III — CONTINUOUS SLAB — MAX. B.M.:- END SPAN = W.L/10; MID SPANS = W.L/12

CASE IV — CANTILEVERS — MAX. BENDING MOMENT = W.L/2



Traced By. P.C.Somasundaram.

A. Mariasusai,
10.8.28.
ASSISTANT ENGINEER P.W.D.
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