DESIGN OF SLABS

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1. GENERAL

A slab is a flat two dimensional planar structural element having thickness small compared to its other two dimensions. It provides a working flat surface or a covering shelter in buildings. It primarily transfer the load by bending in one or two directions. Reinforced concrete slabs are used in floors, roofs and walls of buildings and as the decks of bridges. The floor system of a structure can take many forms such as in situ solid slab, ribbed slab or pre-cast units. Slabs may be supported on monolithic concrete beam, steel beams, walls or directly over the columns. Concrete slab behave primarily as flexural members and the design is similar to that of beams.

2. CLASSIFICATION OF SLABS

Slabs are classified based on many aspects

1) **Based of shape:** Square, rectangular, circular and polygonal in shape.
2) **Based on type of support:** Slab supported on walls, Slab supported on beams, Slab supported on columns (Flat slabs).
3) **Based on support or boundary condition:** Simply supported, Cantilever slab, Overhanging slab, Fixed or Continues slab.
4) **Based on use:** Roof slab, Floor slab, Foundation slab, Water tank slab.
5) **Basis of cross section or sectional configuration:** Ribbed slab /Grid slab, Solid slab, Filler slab, Folded plate
6) **Basis of spanning directions :**
   One way slab – Spanning in one direction
   Two way slab _ Spanning in two direction

In general, rectangular one way and two way slabs are very common and are discussed in detail.

3. METHODS OF ANALYSIS

The analysis of slabs is extremely complicated because of the influence of number of factors stated above. Thus the exact (close form) solutions are not easily available. The various methods are:

a) Classical methods – Levy and Naviers solutions(Plate analysis)
b) Yield line analysis – Used for ultimate /limit analysis
c) Numerical techniques – Finite element and Finite difference method.
d) Semi empirical – Prescribed by codes for practical design which uses coefficients.

4. GENERAL GUIDELINES

a. **Effective span of slab :**

Effective span of slab shall be lesser of the two

1. l = clear span + d (effective depth)
2. l = Center to center distance between the support

b. **Depth of slab**:

The depth of slab depends on bending moment and deflection criterion. the trail depth can be obtained using:

- Effective depth d= Span /($(l/d)_{Basic}$ x modification factor)
- For obtaining modification factor, the percentage of steel for slab can be assumed from 0.2 to 0.5%
- The effective depth d of two way slabs can also be assumed using cl.24.1,IS 456 provided short span is ≤ 3.5m and loading class is < $3.5 KN/m^2$

Type of support	Fe-250	Fe-415
Simply supported	l/35	l/28
continuous	l/40	l/32

OR

The following thumb rules can be used

- One way slab d=(l/22) to (l/28).
- Two way simply supported slab d=(l/20) to (l/30)
- Two way restrained slab d=(l/30) to (l/32)

c. Load on slab:

The load on slab comprises of Dead load, floor finish and live load. The loads are calculated per unit area (load/m^2).

Dead load = D x 25 kN/m^2 (Where D is thickness of slab in m)

Floor finish (Assumed as)= 1 to 2 kN/m^2

Live load (Assumed as) = 3 to 5 kN/m^2 (depending on the occupancy of the building)

5. DETAILING REQUIREMENTS AS PER IS 456 : 2000

a. **Nominal Cover :**

For Mild exposure – 20 mm

For Moderate exposure – 30 mm

However, if the diameter of bar do not exceed 12 mm, or cover may be reduced by 5 mm. Thus for main reinforcement up to 12 mm diameter bar and for mild exposure, the nominal cover is 15 mm

b. **Minimum reinforcement :** The reinforcement in either direction in slab shall not be less than

- 0.15% of the total cross sectional area for Fe-250 steel
- 0.12% of the total cross sectional area for Fe-415 & Fe-500 steel.

c. **Spacing of bars :** The maximum spacing of bars shall not exceed

- Main Steel – 3d or 300 mm whichever is smaller

- Distribution steel –5d or 450 mm whichever is smaller

Where, ‘d’ is the effective depth of slab.

Note: The minimum clear spacing of bars is not kept less than 75 mm (Preferably 100 mm) though code do not recommend any value.

d. **Maximum diameter of bar**: The maximum diameter of bar in slab, shall not exceed D/8, where D is the total thickness of slab.

6. BEHAVIOR OF ONE WAY SLAB

When a slab is supported only on two parallel apposite edges, it spans only in the direction perpendicular to two supporting edges. Such a slab is called one way slab. Also, if the slab is supported on all four edges and the ratio of longer span(l_y) to shorter span (l_x) i.e ly/lx > 2, practically the slab spans across the shorter span. Such a slabs are also designed as one way slabs. In this case, the main reinforcement is provided along the spanning direction to resist one way bending.

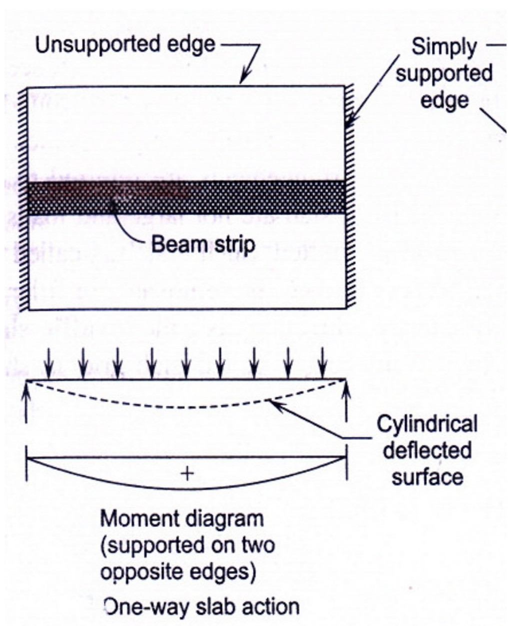


Fig.1: Behavior of one way slab

7. BEHAVIOR OF TWO WAY SLABS

A rectangular slab supported on four edge supports, which bends in two orthogonal directions and deflects in the form of dish or a saucer is called two way slabs. For a two way slab the ratio of ly/lx shall be ≤ 2.0 .

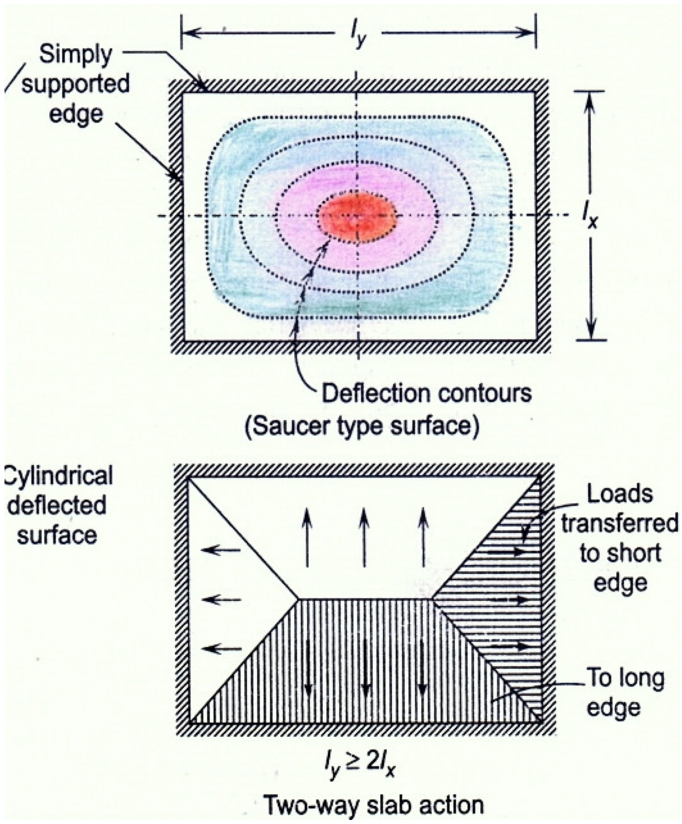


Fig. 2: Behavior of Two way slab

Since, the slab rest freely on all sides, due to transverse load the corners tend to curl up and lift up. The slab looses the contact over some region. This is known as lifting of corner. These slabs are called two way simply supported slabs. If the slabs are cast monolithic with the beams, the corners of the slab are restrained from lifting. These slabs are called restrained slabs. At corner, the rotation occurs in both the direction and causes the corners to lift. If the corners of slab are restrained from lifting, downward reaction results at corner & the end strips gets restrained against rotation. However, when the ends are restrained and the rotation of central strip still occurs and causing rotation at corner (slab is acting as unit) the end strip is subjected to torsion.

7.1 Types of Two Way Slab

Two way slabs are classified into two types based on the support conditions:

a) Simply supported slab
b) Restrained slabs

7.1.1 Two way simply supported slabs

The bending moments M_x and M_y for a rectangular slabs simply supported on all four edges with corners free to lift or the slabs do not having adequate provisions to prevent lifting of corners are obtained using

$$M_x = \alpha_x W l^2_x$$

$$M_y = \alpha_y W l^2_x$$

Where, α_x and α_y are coefficients given in Table 1 (Table 27,IS 456-2000)

W- Total load /unit area

l_x & l_y – lengths of shorter and longer span.

Table 1 Bending Moment Coefficients for Slabs Spanning in Two Directions at Right Angles, Simply Supported on Four Sides (Table 27:IS 456-2000)

l_y/l_x	1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	2.5	3.0
α_x	0.062	0.074	0.084	0.093	0.099	0.104	0.113	0.118	0.122	0.124
α_y	0.062	0.061	0.059	0.055	0.05 1	0.046	0.037	0.029	0.020	0.014

Note: 50% of the tension steel provided at mid span can be curtailed at $0.1l_x$ or $0.1l_y$ from support.

7.1.2 Two way Restrained slabs

When the two way slabs are supported on beam or when the corners of the slabs are prevented from lifting the bending moment coefficients are obtained from Table 2 (Table 26, IS456-2000) depending on the type of panel shown in Fig. 3. These coefficients are obtained using yield line theory. Since, the slabs are restrained; negative moment arises near the supports. The bending moments are obtained using;

$$M_x \text{ (Negative)} = \alpha_x^{(-)} W l^2_x$$

$$M_x \text{ (Positive)} = \alpha_x^{(+)} W l^2_x$$

$$M_y \text{ (Negative)} = \alpha_y^{(-)} W l^2_x$$

$$M_y \text{ (Positive)} = \alpha_y^{(+)} W l^2_x$$

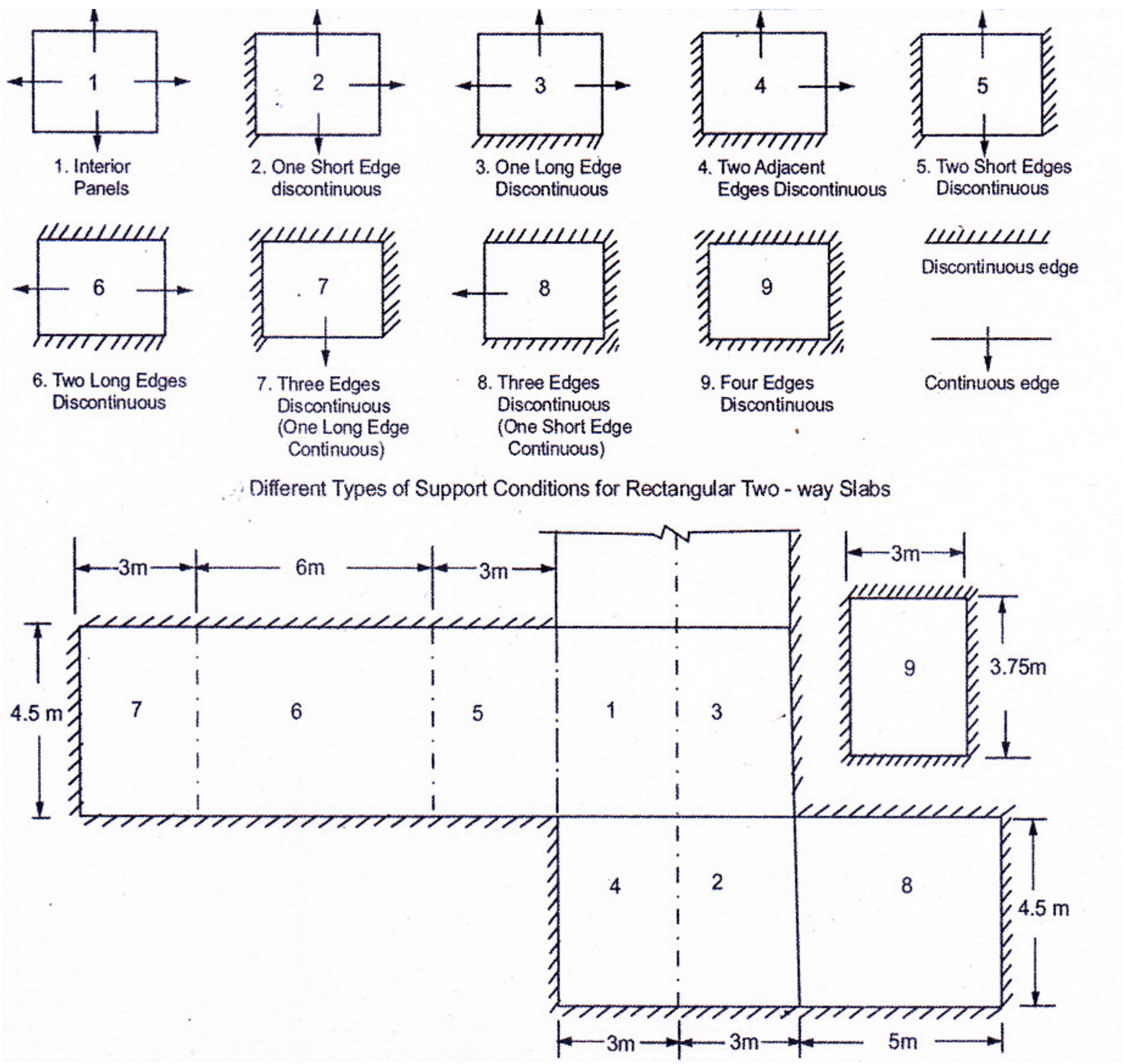


Fig. 3: Different Boundary conditions of Two way Restrained slabs

Table 2: Bending moment coefficients for two way restrained slabs (Table 26, IS 456-2000)

Case No.	Type of Panel and Moments Considered	Short Span Coefficients α_x (Values of l_y/l_x)								Long Span Coefficients α_y for All Values of l_y/l_x
		1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	*Interior Panels*:									
	Negative moment at continuous edge	0.032	0.037	0.043	0.047	0.051	0.053	0.060	0.065	0.032
	Positive moment at mid-span	0.024	0.028	0.032	0.036	0.039	0.041	0.045	0.049	0.024
2	*One Short Edge Continuous*:									
	Negative moment at continuous edge	0.037	0.043	0.048	0.051	0.055	0.057	0.064	0.068	0.037
	Positive moment at mid-span	0.028	0.032	0.036	0.039	0.041	0.044	0.048	0.052	0.028
3	*One Long Edge Discontinuous*:									
	Negative moment at continuous edge	0.037	0.044	0.052	0.057	0.063	0.067	0.077	0.085	0.037
	Positive moment at mid-span	0.028	0.033	0.039	0.044	0.047	0.051	0.059	0.065	0.028
4	*Two Adjacent Edges Discontinuous*:									
	Negative moment at continuous edge	0.047	0.053	0.060	0.065	0.071	0.075	0.084	0.091	0.047
	Positive moment at mid-span	0.035	0.040	0.045	0.049	0.053	0.056	0.063	0.069	0.035
5	*Two Short Edges Discontinuous*:									
	Negative moment at continuous edge	0.045	0.049	0.052	0.056	0.059	0.060	0.065	0.069	—
	Positive moment at mid-span	0.035	0.037	0.040	0.043	0.044	0.045	0.049	0.052	0.035
6	*Two Long Edges Discontinuous*:									
	Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.045
	Positive moment at mid-span	0.035	0.043	0.051	0.057	0.063	0.068	0.080	0.088	0.035
7	*Three Edges Discontinuous (One Long Edge Continuous)*:									
	Negative moment at continuous edge	0.057	0.064	0.071	0.076	0.080	0.084	0.091	0.097	—
	Positive moment at mid-span	0.043	0.048	0.053	0.057	0.060	0.064	0.069	0.073	0.043
8	*Three Edges Discontinuous (One Short Edge Continuous)* :									
	Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.057
	Positive moment at mid-span	0.043	0.051	0.059	0.065	0.071	0.076	0.087	0.096	0.043
9	*Four Edges Discontinuous*:									
	Positive moment at mid-span	0.056	0.064	0.072	0.079	0.085	0.089	0.100	0.107	0.056

Detailing requirements as per IS 456-2000

a. Slabs are considered as divided in each direction into middle and end strips as shown below
b. The maximum moments obtained using equations are apply only to middle strip.
c. 50% of the tension reinforcement provided at midspan in the middle strip shall extend in the lower part of the slab to within 0.25l of a continuous edge or 0.15l of a discontinuous edge and the remaining 50% shall extend into support.
d. 50% of tension reinforcement at top of a continuous edge shall be extended for a distance of 0.15l on each side from the support and atleast 50% shall be provided for a distance of 0.3l on each face from the support.

e. At discontinuous edge, negative moment may arise, in general 50% of mid span steel shall be extended into the span for a distance of 0.1l at top.

f. Minimum steel can be provided in the edge strip

g. Tension steel shall be provided at corner in the form of grid (in two directions) at top and bottom of slab where the slab is discontinuous at both the edges . This area of steel in each layer in each direction shall be equal to ¾ the area required (A_{st}) for maximum mid span moment. This steel shall extend from the edges for a distance of $l_x/5$. The area of steel shall be reduced to half (3/8 $A_{st}x$) at corners containing edges over only one edge is continuous and other is discontinuous.

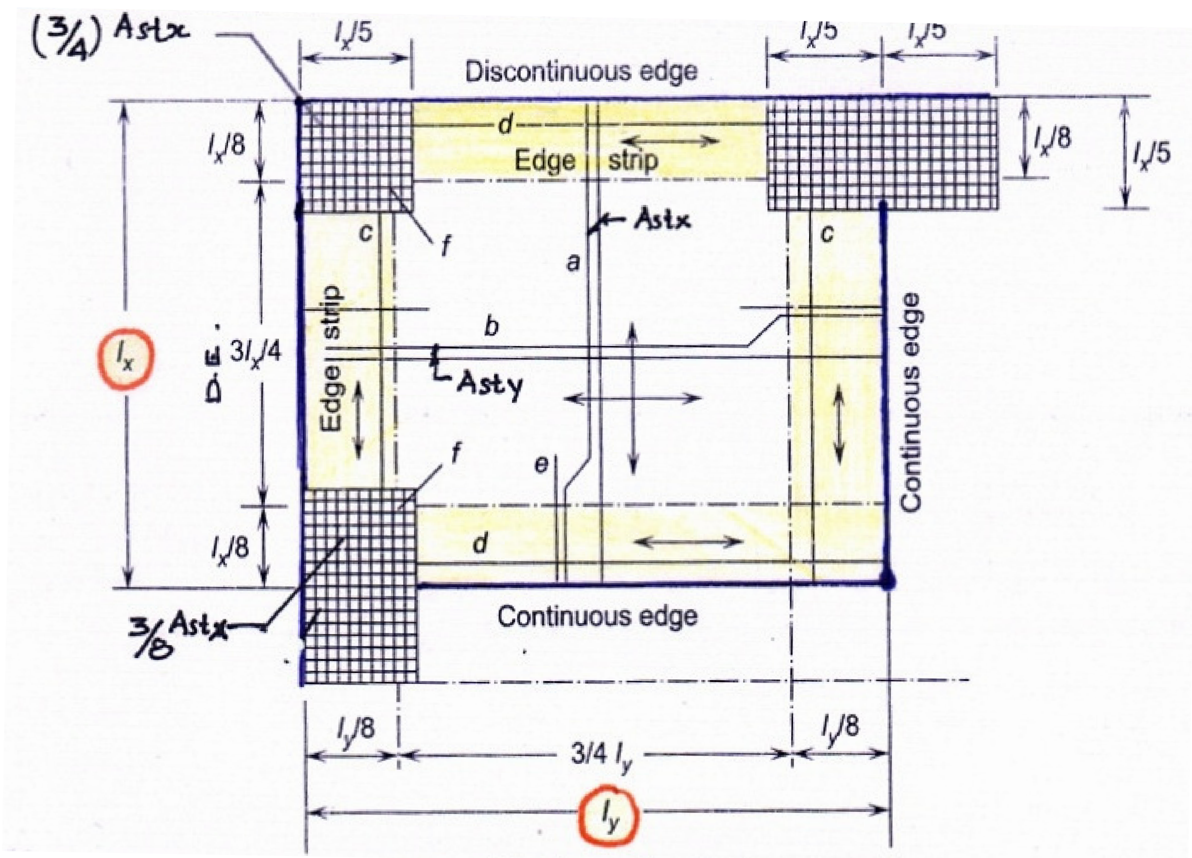


Fig. 4: Reinforcement details and strips in Two way restrained slabs

8. ONE WAY CONTINUOUS SLAB

The slabs spanning in one direction and continuous over supports are called one way continuous slabs.These are idealised as continuous beam of unit width. For slabs of uniform section which support substantially UDL over three or more spans which do not differ by more than 15% of the longest, the B.M and S.F are obtained using the coefficients available in Table 12 and Table 13 of IS 456-2000. For moments at supports where two unequal spans meet or in case where the slabs are not equally loaded, the average of the two values for the negative moments at supports may be taken. Alternatively, the moments may be obtained by moment distribution or any other methods.

Table 3: Bending moment and Shear force coefficients for continuous slabs
(Table 12, Table 13, IS 456-200)

IS 456 : 2000

Table 12 Bending Moment Coefficients
(*Clause* 22.5.1)

Type of Load	Span Moments		Support Moments	
	Near Middle of End Span	At Middle of Interior Span	At Support Next to the End Support	At Other Interior Supports
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	$+\frac{1}{12}$	$+\frac{1}{16}$	$-\frac{1}{10}$	$-\frac{1}{12}$
Imposed load (not fixed)	$+\frac{1}{10}$	$+\frac{1}{12}$	$-\frac{1}{9}$	$-\frac{1}{9}$

NOTE — For obtaining the bending moment, the coefficient shall be multiplied by the total design load and effective span.

Table 13 Shear for Coefficients
(*Clauses* 22.5.1 *and* 22.5.2)

Type of Load	At End Support	At Support Next to the End Support		At All Other Interior Supports
		Outer Side	Inner Side	
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	0.4	0.6	0.55	0.5
Imposed load (not fixed)	0.45	0.6	0.6	0.6

NOTE — For obtaining the shear force, the coefficient shall be multiplied by the total design load.

DESIGN EXAMPLES

1. Design a simply supported one –way slab over a clear span of 3.5 m. It carries a live load of 4 kN/m^2 and floor finish of 1.5 kN/m^2. The width of supporting wall is 230 mm. Adopt M-20 concrete & Fe-415 steel.

1) Trail depth and effective span

Assume approximate depth d =L/26

3500/26 = 134 mm

Assume overall depth D=160 mm & clear cover 15mm for mild exposure

d = 160-15 (cover) -10/2 (dia of Bar/2) =140 mm

Effective span is lesser of the two

i. l =3.5 + 0.23 (width of support) = 3.73 m

ii. l= 3.5 + 0.14 (effective depth) =3.64 m

effective span = 3.64 m

2) Load on slab

i. Self weight of slab = 0.16 x 25 = 4.00

ii. Floor finish = 1.50

iii. Live load = 4.00

= 9.5 kN/m^2

Ultimate load W_u = 9.5 x 1.5 = 14.25 kN/m^2

3) Design bending moment and check for depth

$M_u = W_u l^2/8 = \frac{14.25X\,3.64^2}{8}$ =23.60 kN/m

Minimum depth required from BM consideration

$d=\sqrt{\frac{Mu}{0.138\,f_{ck}\,b}} = \sqrt{\frac{23.60X\,10^6}{0.138X20X1000}}$ = 92.4 > 140 (OK)

4) Area of Reinforcement

Area of steel is obtained using the following equation

$Mu=0.87 f_y A_{st} d \left(1-\frac{f_y A_{st}}{f_{ck}\, bd}\right)$

$23.60X10^6 = 0.87X415XA_{st}X140\left(1 - \frac{415XA_{st}}{20X1000X140}\right)$

$23.60X10^6 = 50547A_{st} - 749A_{st}^2$

Solving $A_{st} = 504 mm^2$

OR

$$A_{st} = \frac{0.5f_{ck}}{f_y}\left[1 - \sqrt{1 - \frac{4.6M_u}{f_{ck}bd^2}}\right]bd$$

$$A_{st} = \frac{0.5X20}{415}\left[1 - \sqrt{1 - \frac{4.6X23.60X10^6}{20X1000X140^2}}\right]1000X140$$

$= 505 mm^2$

Spacing of 10mm $S_V = \frac{a_{st}}{A_{st}}X1000$

$S_V = \frac{78}{505}X1000 = 154$ mm

Provide 10mm @ 150 C/C ($< 3d$ or 300)

(420 or 300) OK

Provided steel ($A_{st}=524mm^2$, $P_t=0.37\%$)

Distribution steel@ 0.12% of the Gross area.

$\frac{0.12}{100}X1000X160 = 192 mm^2$

Spacing of 8 mm $S_V = \frac{50}{192}X1000 = 260$ mm

Provide 8 mm @260 mm C/C (<5d or 450)

(700 or 450) OK

5) Check for shear

Design shear $V_u = W_u l/2$

$= 14.25X\frac{3.64}{2} = 25.93$ kN

$$\tau_v = \frac{25.93X10^3}{1000X140} = 0.18\ N/mm^2 \qquad (<\tau_{c\,max} = 2.8\ N/mm^2)$$

Shear resisted by concrete $\tau_c = 0.42\ for\ p_t = 0.37$ (Table 19, IS 456-2000)

However for solid slab design shear strength shall be

$$= \tau_c k$$

Where, K is obtained from Cl.40.2.1.1, IS 456 -2000

$$\tau_{cd} = 0.42X1.28 = 0.53\ N/mm^2$$

$$\tau_{cd} > \tau_v \qquad \text{OK}$$

6) Check for deflection

$$\left(\frac{l}{d}\right)_{Actual} < \left(\frac{l}{d}\right)_{Allowable}$$

$$\left(\frac{l}{d}\right)_{Allowable} = \left(\frac{l}{d}\right)_{Basic} Xk_1Xk_2Xk_3Xk_4.$$

k_1- Modification factor for tension steel

k_2 _ Modification factor for compression steel

k_3 _ Modification factor for T-sections k_4-Only if span exceeds 10 m (10/span)

$k_1 = 1.38\ for\ P_t = 0.37$ (Fig. 4,cl.32.2.1)

$$\left(\frac{l}{d}\right)_{Allowable} = 20X1.38 = 27.6$$

$$\left(\frac{l}{d}\right)_{Actual} = 3630/140 = 25.92$$

$$\left(\frac{l}{d}\right)_{Actual} < \left(\frac{l}{d}\right)_{Allowable} \qquad \text{(OK)}$$

7) Check for Development length

Development length

$$L_d = \frac{\phi\,\sigma_s}{4\,\tau_{bd}}$$

L_d = (0.87x415x10) / (4x1.2x1.6) =470 mm

At simple support, where compressive reaction confines the bars, to limit the dia. of bar

$$L_d \leq 1.3 \left(\frac{M_1}{V}\right) + L_o$$

Since alternate bars are cranked $M_1 = M_u/2 = 23.2/2 = 11.8$ kN.m

$V_1 = 5.93$ kN., Providing 90o bend and 25 mm end cover

$L_o = 230/2 - 25 + 3(\text{dia of bar}) = 120$

470 < (1.3x11.8x106) / (25.9x103) + 120 = 711 mm O. K.

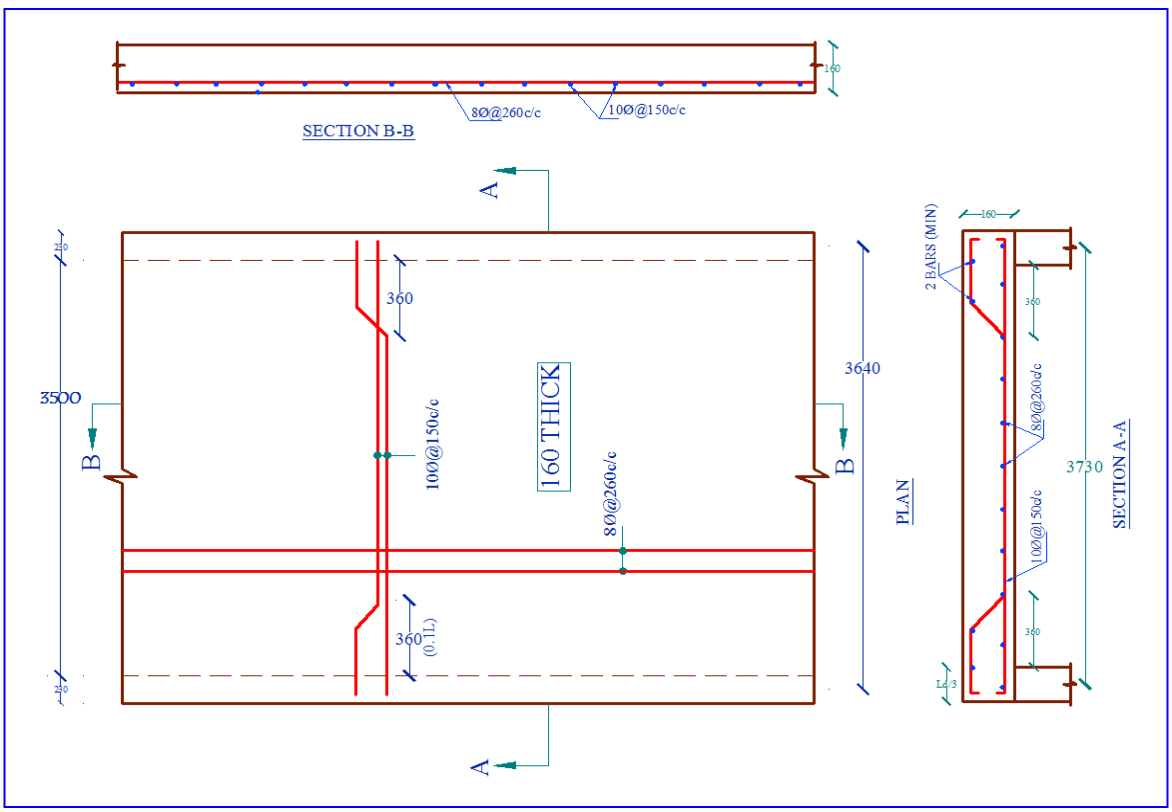
However, from the end anchorage requirement

extend the bars for a length equal to ld/3 = 156 mm from inner face of support

8) Check for cracking

- Steel is more than 0.12% of the gross area.
- Spacing of steel is < 3d
- Diameter of bar used is < 160/8=20mm

Check for cracking is satisfied.



Reinforcement Detail of One way slab

2. **Design a R.C Slab for a room measuring 6.5mX5m. The slab is cast monolithically over the beams with corners held down. The width of the supporting beam is 230 mm.The slab carries superimposed load of 4.5kN/m^2. Use M-20 concrete and Fe-500 Steel.**

Since, the ratio of length to width of slab is less than 2.0 and slab is resting on beam, the slab is designed as two way restrained slab (case-9)

1) **Trail depth and effective span**

Assume approximate depth d=l/30=5000/30=166mm

Assume D=180 mm & clear cover 15 mm for mild exposure

d=180-15-10/2=160 mm.

Effective span is lesser of the two

i). l_y=6.5+0.23=6.73 m , l_x=5.0+0.23=5.23 m

ii). l_y=6.5+0.16=6.66 m, l_x=5+0.16=5.16 m

l_y= 6.66 m l_x= 5.16 m

$$\alpha = \frac{l_y}{l_x} = \frac{6.66}{5.16} = 1.3$$

2) **Load on slab**

i). Self weight of slab=0.18X25=4.50 kN/m^2

ii). Super imposed load =4.50

9.0 kN/m^2

Ultimate load w_u = 9X1.5=13.5 kN/m^2

3) **Design bending moment and check for depth**

The boundary condition of slab in all four edges discontinuous (case 9, Table 9.5.2)

$M_x = \alpha_x W_u l^2_x$

$M_y = \alpha_y W_u l^2_x$

For ly/lx =1.3, α_x=0.079

α_y=0.056

Positive moment at mid span of short span =M_x= 0.079X13.5X5.16^2

=28.40 kN.m

Positive moment at mid span of longer span $=M_y=0.056X13.5X5.16^2$

$=20.13$ kN.m

Minimum depth required from Maximum BM consideration

$$d=\sqrt{\frac{Mu}{0.133 f_{ck} b}}=\sqrt{\frac{28.40X10^6}{0.133X20X1000}}$$ **=103 mm**

However, provide d=160 mm

4) Area of Reinforcement

$$Mu=0.87 f_y A_{st} d\left(1-\frac{f_y A_{st}}{f_{ck} b d}\right)$$

Steel along shorter direction (M_x)

$$28.17X10^6=0.87X500XA_{st}X160\left(1-\frac{500XA_{st}}{20X1000X160}\right)$$

$$28.40X10^6=69600A_{st}-10.875A_{st}^2$$

Solving A_{st} x=438 mm²

Provide 10 mm@ 175 C/C (P_t =0.27%)

Steel along longer direction (M_y)

Since long span bars are placed above short span bars d=160-10=150

$$20.13X10^6=0.87X500XA_{st}X150\left(1-\frac{500XA_{st}}{20X1000X150}\right)$$

$$20.13X10^6=65250Ast-10.875A_{st}^2$$

Solving, $A_{st}=327$ mm²

Spacing at 10 mm; $\frac{79}{327}X100=241$

Provide 10 mm @ 240 mm c/c (<3d=450)

5) Check for shear & development

Check for shear and development length are generally satisfied in case of slab and hence they are not checked.

6) Check for deflection

$$\left(\frac{l}{d}\right)_{Actual}<\left(\frac{l}{d}\right)_{Allowable}$$

$$\left(\frac{l}{d}\right)_{Allowable} = \left(\frac{l}{d}\right)_{Basic} X k_1$$

k_1 =1.5 for p_t=0.27% & f_s=0.58xfy = 240

(Fig.4, Cl 32.2.1, IS 456-200)

$$\left(\frac{l}{d}\right)_{Allowable} = 26X1.5 = 39$$

$$\left(\frac{l}{d}\right)_{Actual} = 5.16/0.16 = 32$$

$$\left(\frac{l}{d}\right)_{Actual} < \left(\frac{l}{d}\right)_{Allowable} \quad \text{(OK)}$$

7) Check for cracking

Since steel is more than 0.12% of the gross area,

Spacing of steel is <3d and

Diameter of bar used is <D/8=180/8=22 mm OK.

<u>Detailing</u>

Torsion steel

Area of Torsion steel=0.75X A_{st} =0.75X438=328 mm^2

Provide 8 mm bars at spacing (50/328)X1000=152 mm.

Size of mesh =(l_x/5)=5160/5=1032 mm

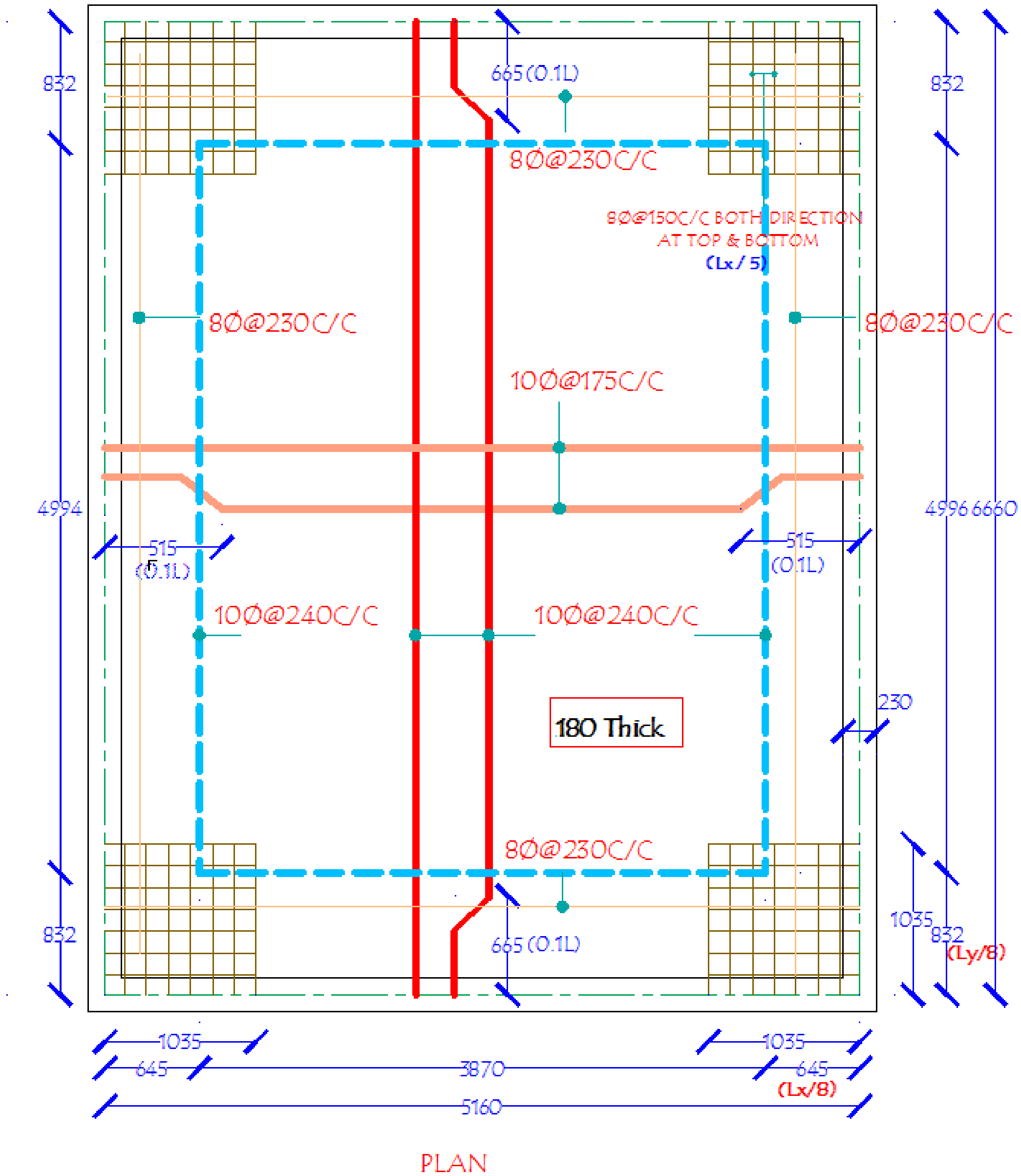
Provide 8 mm @ 150 c/c in both direction for a length of 1035 mm mesh at top and bottom

The calculated steel in shorter and longer direction is to be provided only in the middle strip.

The steel in the edge strip contains only 0.12% of the gross area

Steel in the edge strip=(0.12/100)X1000X180=216 mm^2

Spacing of 8 mm (50/216)X1000=230 mm c/c.



Reinforcement Detail of Two way Restrained slab

3. A hall in a building of clear dimension 14.10 mX9.7 m is to be provided a floor consisting of a continuous slab cast monolithically with 300 mm wide beams spaced at 3.6 m c/c and supported on 300 mm wall at ends. The floor is to support a live load of 3 kN/m^2, Partition load of 1.0 kN/m^2 and finishes at 1.0 kN/m^2. Design the continuous slab taking M-20 grade of concrete and Fe-415 steel.

1) Trail depth and Effective span

Consider 1 m width of slab and effective span shall be taken equal to c/c of beams

Assume trail depth d = l /30 , 3600/30 =120 mm

OR

Assume P_t=0.3%, Modification factor K1 =1.2;

Basic (L/d) ratio for continuous slab =26.

Trail depth d=3600/(26X1.2) = 115 mm.

However, Assume Total depth =150 mm, Dia of bar 10 mm and nominal cover 15 mm

Effective depth d= 150-15-10/2 = 130 mm.

2) Load on slab

a) Total Dead load

i).	Self weight of slab= 0.15 x 25	= 3.75 kN/m^2
ii).	Floor Finish	= 1.00
iii).	Partition load	= <u>1.00</u>
	Total	= <u>5.75</u> kN/m^2

Factored Dead load W_d=1.5 x5.75=8.625 kN/m^2

b) Factored live load W_L=1.5 x3.00=4.50 kN/m^2

3) Design bending moment

The bending moments and shear force are calculated at different sections using Bending moment coefficient given in Table 12 and Table 13 of IS 456-2000

B.M at any section $M_u = \alpha_d \omega_d l^2 + \alpha_l \omega_l l^2$

i). B.M at middle of end span

(1)= $\frac{1}{12}X8.625X3.6^2 + \frac{1}{10}X4.5X3.6^2 = 15.15$ kN-m

ii). B.M at middle of Interior span(3)=

$\frac{1}{16}X8.625X3.6^2 + \frac{1}{12}X4.5X3.6^2 = 11.85$

iii). B.M at support next to end support(2)=

$\frac{1}{10}X8.625X3.6^2 + \frac{1}{9}X4.5X3.6^2 = 17.66$

iv). B.M at other intermediate support(4)=

$\frac{1}{12}X8.625X3.6^2 + \frac{1}{9}X4.5X3.6^2 = 15.80$

Depth required from maximum B.M considerations

$$d=\sqrt{\frac{Mu}{0.138 f_{ck} b}} \quad \text{(for Fe 415 steel)}$$

$$d=\sqrt{\frac{17.66X10^6}{0.138X20X1000}} = 80 \text{ mm} > 130 \text{ mm} \quad \text{OK.}$$

4) Area of Reinforcement

From practical consideration, Spacing cannot be varied at different locations. Hence steel is calculated only at middle of end span and at support next to end support.

A_{st} at middle of end span

$$Mu=0.87 f_y A_{st} d \left(1-\frac{f_y A_{st}}{f_{ck} bd}\right)$$

$$15.15X10^6=0.87X415XA_{st,p}X130\left(1-\frac{415XA_{st,p}}{20X1000X130}\right)$$

$$15.15X10^6=46936A_{st,p}-7.49A_{st,p}^2$$

$$A_{st,p}=341 \text{ mm}^2$$

Spacing of 8 mm $\frac{50}{341}X1000 = 146$ mm

Provide 8 mm @ 145 c/c (349 mm^2)

A_{st} at support next to end support

$$17.66X10^6=0.87X415XA_{st,p}X130\left(1-\frac{415XA_{st,p}}{20X1000X130}\right)$$

Solving, $A_{st, N}$ =402 mm^2

Provide 8 mm @ 280 c/c + 10 mm @ 280 c/c

Area of steel provided= $\frac{50}{280}X1000 + \frac{79}{280}X1000 = 460mm^2 > 402$ (OK)

(P_t=0.34%)

Distribution steel @ 0.12 % of gross area

$$= \frac{0.12}{100}X(1000X150) = 180\ mm^2$$

Spacing of 8 mm $S_v = \frac{50}{180}X1000 = 277$ mm

Provide 8 mm @ 275 c/c (<5d or 450, OK)

5) Check for deflection

Steel provided at mid span is considered

A_{st}=340 mm^2 (P_t =0.26%)

Design stress f_s =0.58 x 415X 1 =240 N/mm^2

From Figure M.F= 1.52 (Fig. 4, Cl 32.2.1, IS 456-200)

$$\left(\frac{l}{d}\right)_{Actual} < \left(\frac{l}{d}\right)_{Allowable}$$

$$\left(\frac{l}{d}\right)_{Allowable} = 26X1.52 = 39.5$$

$$\left(\frac{l}{d}\right)_{Actual} = \frac{3600}{130} = 27.6 \quad (OK)$$

6) Check for shear

Maximum shear occurs at support next to end support (outer side)

Max. S.F = $0.6\ w_d\ l + 0.6\ w_l\ l$

=(0.6 x 8.625 +0.6 x 4.5)3.6

= 28.35 kN.

Nominal shear stress $\tau_v = V_u/bd$

$$= \frac{28.35\ X10^3}{1000X130} = 0.22 \text{ N/mm}^2$$

For M-20 concrete with P_t =0.35 (at support)

$\tau_c = 0.4$ N/mm^2

For solid slab shear strength = k. τ_c

k = 1.3 (for thickness 150 mm & less)

=1.3 x 0.4 =0.52 N/mm^2 > 0.22 N/mm^2 (OK)

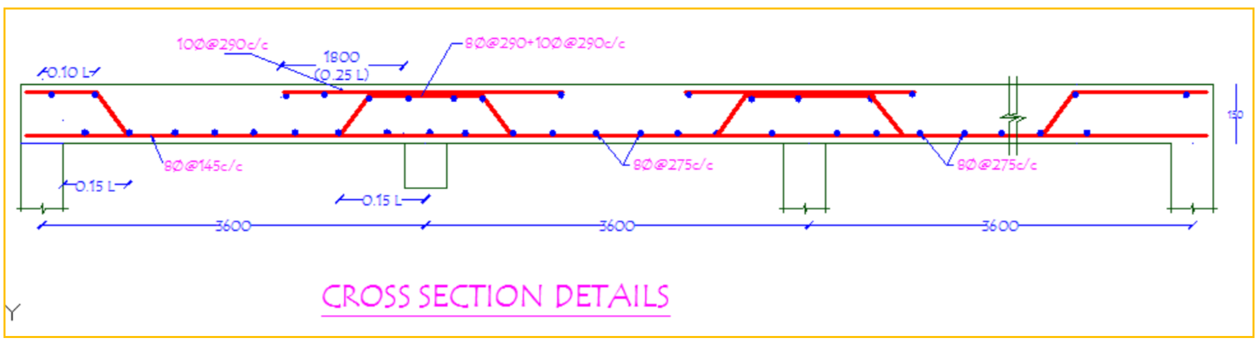
7) Check for cracking

Since steel is more than 0.12% of the gross area,

Spacing of steel is <3d and

Diameter of bar used is 8 and 10 mm and are < D/8=150/8=19 mm

(OK)



Reinforcement Detail of One way Continuous slab