

# Module

# 8

# Reinforced Concrete Slabs

# Lesson 18 One-way Slabs

## Instructional Objectives:

At the end of this lesson, the student should be able to:

- state the names of different types of slabs used in construction,
- identify one-way and two-way slabs stating the limits of  $l_y/l_x$  ratios for one and two-way slabs,
- explain the share of loads by the supporting beams of one- and two-way slabs when subjected to uniformly distributed vertical loads,
- explain the roles of the total depth in resisting the bending moments, shear force and in controlling the deflection,
- state the variation of design shear strength of concrete in slabs of different depths with identical percentage of steel reinforcement,
- assume the depth of slab required for the control of deflection for different support conditions,
- determine the positive and negative bending moments and shear force,
- determine the amount of reinforcing bars along the longer span,
- state the maximum diameter of a bar that can be used in a particular slab of given depth,
- decide the maximum spacing of reinforcing bars along two directions of one-way slab,
- design one-way slab applying the design principles and following the stipulated guidelines of IS 456,
- draw the detailing of reinforcing bars of one-way slabs after the design.

### 8.18.1 Introduction

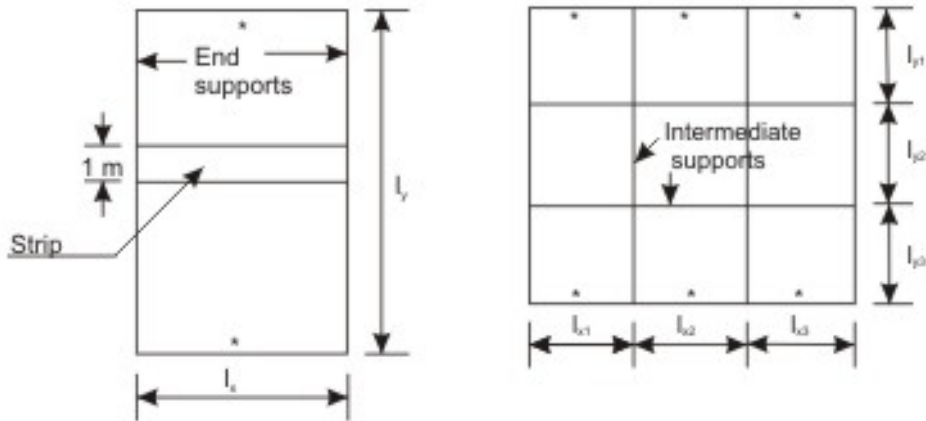


Fig. 8.18.1(a): One span      Fig. 8.18.1(c): Continuous in both directions

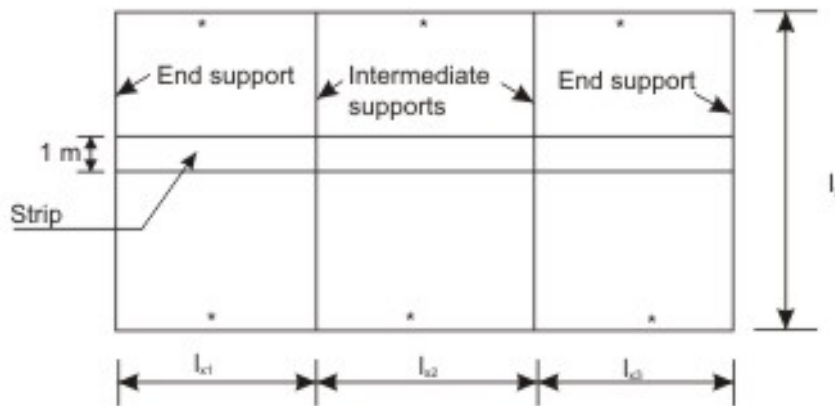


Fig. 8.18.1(b): Continuous in one direction

Notes:

1. One-way slab if  $l_y > 2l_x$
2. \* indicates that no support is needed if  $l_y > 2l_x$  and is needed if  $l_y \leq 2l_x$
3. End supports may be simply supported or clamped

Fig. 8.18.1: Horizontal slabs

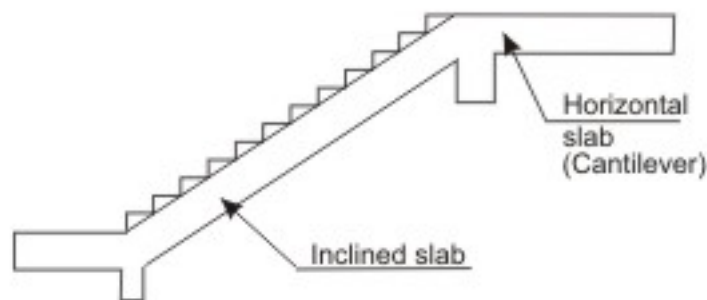
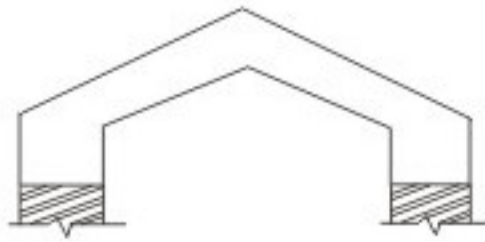


Fig. 8.18.2: Stair case



**Fig. 8.18.3: Inclined roof**

Slabs, used in floors and roofs of buildings mostly integrated with the supporting beams, carry the distributed loads primarily by bending. It has been mentioned in sec. 5.10.1 of Lesson 10 that a part of the integrated slab is considered as flange of *T*- or *L*-beams because of monolithic construction. However, the remaining part of the slab needs design considerations. These slabs are either single span or continuous having different support conditions like fixed, hinged or free along the edges (Figs.8.18.1a,b and c). Though normally these slabs are horizontal, inclined slabs are also used in ramps, stair cases and inclined roofs (Figs.8.18.2 and 3). While square or rectangular plan forms are normally used, triangular, circular and other plan forms are also needed for different functional requirements. This lesson takes up horizontal and rectangular /square slabs of buildings supported by beams in one or both directions and subjected to uniformly distributed vertical loadings.

The other types of slabs, not taken up in this module, are given below. All these slabs have additional requirements depending on the nature and magnitude of loadings in respective cases.

- (a) horizontal or inclined bridge and fly over deck slabs carrying heavy concentrated loads,
- (b) horizontal slabs of different plan forms like triangular, polygonal or circular,
- (c) flat slabs having no beams and supported by columns only,
- (d) inverted slabs in footings with or without beams,
- (e) slabs with large voids or openings,
- (f) grid floor and ribbed slabs.

## 8.18.2 One-way and Two-way Slabs

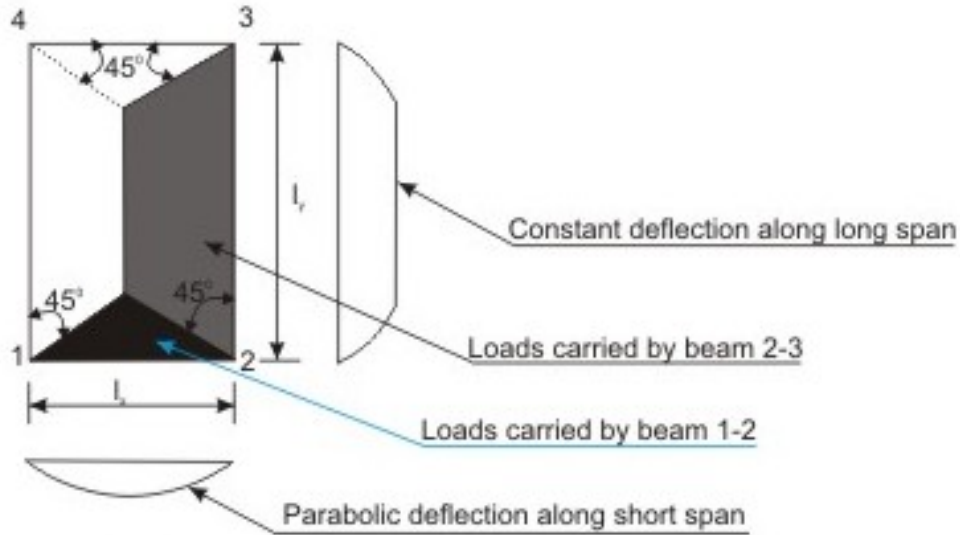


Fig. 8.18.4(a): One-way slab ( $l_y/l_x > 2$ ) Gtg

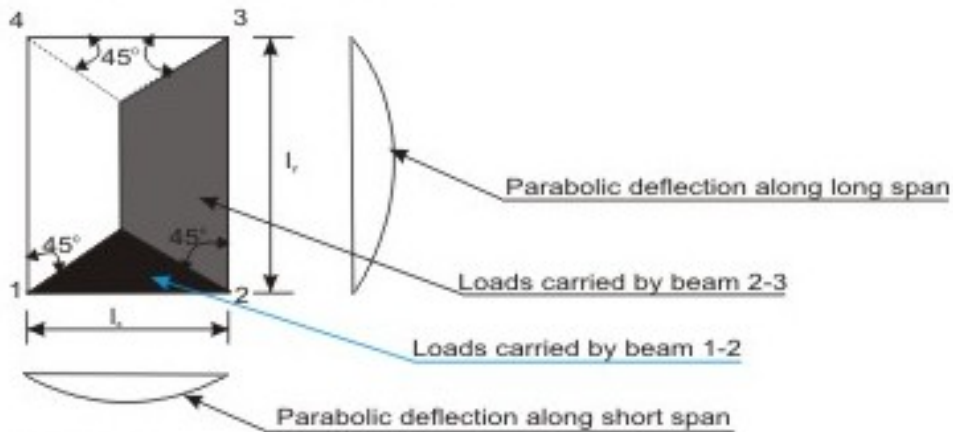


Fig. 8.18.4(b): Two-way slab ( $l_y/l_x \leq 2$ )

### Fig. 8.18.4: Sharing of loads

Figures 8.18.4a and b explain the share of loads on beams supporting solid slabs along four edges when vertical loads are uniformly distributed. It is evident from the figures that the share of loads on beams in two perpendicular directions depends upon the aspect ratio  $l_y/l_x$  of the slab,  $l_x$  being the shorter span. For large values of  $l_y$ , the triangular area is much less than the trapezoidal area (Fig.8.18.4a). Hence, the share of loads on beams along shorter span will gradually reduce with increasing ratio of  $l_y/l_x$ . In such cases, it may be said that the loads are primarily taken by beams along longer span. The deflection profiles of the slab along both directions are also shown in the figure. The deflection profile is found to be constant along the longer span except near the edges for the slab panel of Fig.8.18.4a. These slabs are designated as one-way slabs as

they span in one direction (shorter one) only for a large part of the slab when  $l_y / l_x > 2$ .

On the other hand, for square slabs of  $l_y / l_x = 1$  and rectangular slabs of  $l_y / l_x$  up to 2, the deflection profiles in the two directions are parabolic (Fig.8.18.4b). Thus, they are spanning in two directions and these slabs with  $l_y / l_x$  up to 2 are designated as two-way slabs, when supported on all edges.

It would be noted that an entirely one-way slab would need lack of support on short edges. Also, even for  $l_y / l_x < 2$ , absence of supports in two parallel edges will render the slab one-way. In Fig. 8.18.4b, the separating line at 45 degree is tentative serving purpose of design. Actually, this angle is a function of  $l_y / l_x$ .

This lesson discusses the analysis and design aspects of one-way slabs. The two-way slabs are taken up in the next lesson.

### 8.18.3 Design Shear Strength of Concrete in Slabs

Experimental tests confirmed that the shear strength of solid slabs up to a depth of 300 mm is comparatively more than those of depth greater than 300 mm. Accordingly, cl.40.2.1.1 of IS 456 stipulates the values of a factor  $k$  to be multiplied with  $\tau_c$  given in Table 19 of IS 456 for different overall depths of slab. Table 8.1 presents the values of  $k$  as a ready reference below:

Table 8.1 Values of the multiplying factor  $k$

Overall depth of slab (mm)	300 or more	275	250	225	200	175	150 or less
$k$	1.00	1.05	1.10	1.15	1.20	1.25	1.30

Thin slabs, therefore, have more shear strength than that of thicker slabs. It is the normal practice to choose the depth of the slabs so that the concrete can resist the shear without any stirrups for slab subjected to uniformly distributed loads. However, for deck slabs, culverts, bridges and fly over, shear reinforcement should be provided as the loads are heavily concentrated in those slabs. Though, the selection of depth should be made for normal floor and roof slabs to avoid stirrups, it is essential that the depth is checked for the shear for these slabs taking due consideration of enhanced shear strength as discussed above depending on the overall depth of the slabs.

### 8.18.4 Structural Analysis

As explained in sec. 8.18.2, one-way slabs subjected to mostly uniformly distributed vertical loads carry them primarily by bending in the shorter direction. Therefore, for the design, it is important to analyse the slab to find out the bending moment (both positive and negative) depending upon the supports. Moreover, the shear forces are also to be computed for such slabs. These internal bending moments and shear forces can be determined using elastic method of analysis considering the slab as beam of unit width i.e. one metre (Fig.8.18.1a). However, these values may also be determined with the help of the coefficients given in Tables 12 and 13 of IS 456 in cl.22.5.1. It is worth mentioning that these coefficients are applicable if the slab is of uniform cross-section and subjected to substantially uniformly distributed loads over three or more spans and the spans do not differ by more than fifteen per cent of the longer span. It is also important to note that the average of the two values of the negative moment at the support should be considered for unequal spans or if the spans are not equally loaded. Further, the redistribution of moments shall not be permitted to the values of moments obtained by employing the coefficients of bending moments as given in IS 456.

For slabs built into a masonry wall developing only partial restraint, the negative moment at the face of the support should be taken as  $Wl/24$ , where  $W$  is the total design loads on unit width and  $l$  is the effective span. The shear coefficients, given in Table 13 of IS 456, in such a situation, may be increased by 0.05 at the end support as per cl.22.5.2 of IS 456.

### 8.18.5 Design Considerations

The primary design considerations of both one and two-way slabs are strength and deflection. The depth of the slab and areas of steel reinforcement are to be determined from these two aspects. The detailed procedure of design of one-way slab is taken up in the next section. However, the following aspects are to be decided first.

#### (a) Effective span (cl.22.2 of IS 456)

The effective span of a slab depends on the boundary condition. Table 8.2 gives the guidelines stipulated in cl.22.2 of IS 456 to determine the effective span of a slab.

Table 8.2 Effective span of slab (cl.22.2 of IS 456)

Sl.No.	Support condition	Effective span
1	Simply supported not built integrally with its supports	Lesser of (i) clear span + effective depth of slab, and (ii) centre to centre of supports



2	Continuous when the width of the support is $< 1/12^{\text{th}}$ of clear span	Do
3	Continuous when the width of the support is $>$ lesser of $1/12^{\text{th}}$ of clear span or 600 mm (i) for end span with one end fixed and the other end continuous or for intermediate spans,  (ii) for end span with one end free and the other end continuous,  (iii) spans with roller or rocker bearings.	(i) Clear span between the supports  (ii) Lesser of (a) clear span + half the effective depth of slab, and (b) clear span + half the width of the discontinuous support  (iii) The distance between the centres of bearings
4	Cantilever slab at the end of a continuous slab	Length up to the centre of support
5	Cantilever span	Length up to the face of the support + half the effective depth
6	Frames	Centre to centre distance

**(b) Effective span to effective depth ratio (cls.23.2.1a-e of IS 456)**

The deflection of the slab can be kept under control if the ratios of effective span to effective depth of one-way slabs are taken up from the provisions in cl.23.2.1a-e of IS 456. These stipulations are for the beams and are also applicable for one-way slabs as they are designed considering them as beam of unit width. These provisions are explained in sec.3.6.2.2 of Lesson 6.

**(c) Nominal cover (cl.26.4 of IS 456)**

The nominal cover to be provided depends upon durability and fire resistance requirements. Table 16 and 16A of IS 456 provide the respective values. Appropriate value of the nominal cover is to be provided from these tables for the particular requirement of the structure.

**(d) Minimum reinforcement (cl.26.5.2.1 of IS 456)**

Both for one and two-way slabs, the amount of minimum reinforcement in either direction shall not be less than 0.15 and 0.12 per cents of the total cross-sectional area for mild steel (Fe 250) and high strength deformed bars (Fe 415 and Fe 500)/welded wire fabric, respectively.

**(e) Maximum diameter of reinforcing bars (cl.26.5.2.2)**

The maximum diameter of reinforcing bars of one and two-way slabs shall not exceed one-eighth of the total depth of the slab.

**(f) Maximum distance between bars (cl.26.3.3 of IS 456)**

The maximum horizontal distance between parallel main reinforcing bars shall be the lesser of (i) three times the effective depth, or (ii) 300 mm. However, the same for secondary/distribution bars for temperature, shrinkage etc. shall be the lesser of (i) five times the effective depth, or (ii) 450 mm.

### 8.18.6 Design of One-way Slabs

The procedure of the design of one-way slab is the same as that of beams. However, the amounts of reinforcing bars are for one metre width of the slab as to be determined from either the governing design moments (positive or negative) or from the requirement of minimum reinforcement. The different steps of the design are explained below.

**Step 1: Selection of preliminary depth of slab**

The depth of the slab shall be assumed from the span to effective depth ratios as given in section 3.6.2.2 of Lesson 6 and mentioned here in sec.8.18.5b.

**Step 2: Design loads, bending moments and shear forces**

The total factored (design) loads are to be determined adding the estimated dead load of the slab, load of the floor finish, given or assumed live loads etc. after multiplying each of them with the respective partial safety factors. Thereafter, the design positive and negative bending moments and shear forces are to be determined using the respective coefficients given in Tables 12 and 13 of IS 456 and explained in sec.8.18.4 earlier.

**Step 3: Determination/checking of the effective and total depths of slabs**

The effective depth of the slab shall be determined employing Eq.3.25 of sec.3.5.6 of Lesson 5 and is given below as a ready reference here,

$$M_{u,lim} = R_{,lim} b d^2 \quad \dots \quad (3.25)$$

where the values of  $R_{,lim}$  for three different grades of concrete and three different grades of steel are given in Table 3.3 of Lesson 5 (sec.3.5.6). The value of  $b$  shall be taken as one metre.

The total depth of the slab shall then be determined adding appropriate nominal cover (Table 16 and 16A of cl.26.4 of IS 456) and half of the diameter of the larger bar if the bars are of different sizes. Normally, the computed depth of the slab comes out to be much less than the assumed depth in Step 1. However, final selection of the depth shall be done after checking the depth for shear force.

#### Step 4: Depth of the slab for shear force

Theoretically, the depth of the slab can be checked for shear force if the design shear strength of concrete is known. Since this depends upon the percentage of tensile reinforcement, the design shear strength shall be assumed considering the lowest percentage of steel. The value of  $\tau_c$  shall be modified after knowing the multiplying factor  $k$  from the depth tentatively selected for the slab in Step 3. If necessary, the depth of the slab shall be modified.

#### Step 5: Determination of areas of steel

Area of steel reinforcement along the direction of one-way slab should be determined employing Eq.3.23 of sec.3.5.5 of Lesson 5 and given below as a ready reference.

$$M_u = 0.87 f_y A_{st} d \{1 - (A_{st})(f_y)/(f_{ck})(bd)\} \quad \dots \quad (3.23)$$

The above equation is applicable as the slab in most of the cases is under-reinforced due to the selection of depth larger than the computed value in Step 3. The area of steel so determined should be checked whether it is at least the minimum area of steel as mentioned in cl.26.5.2.1 of IS 456 and explained in sec.8.18.5d.

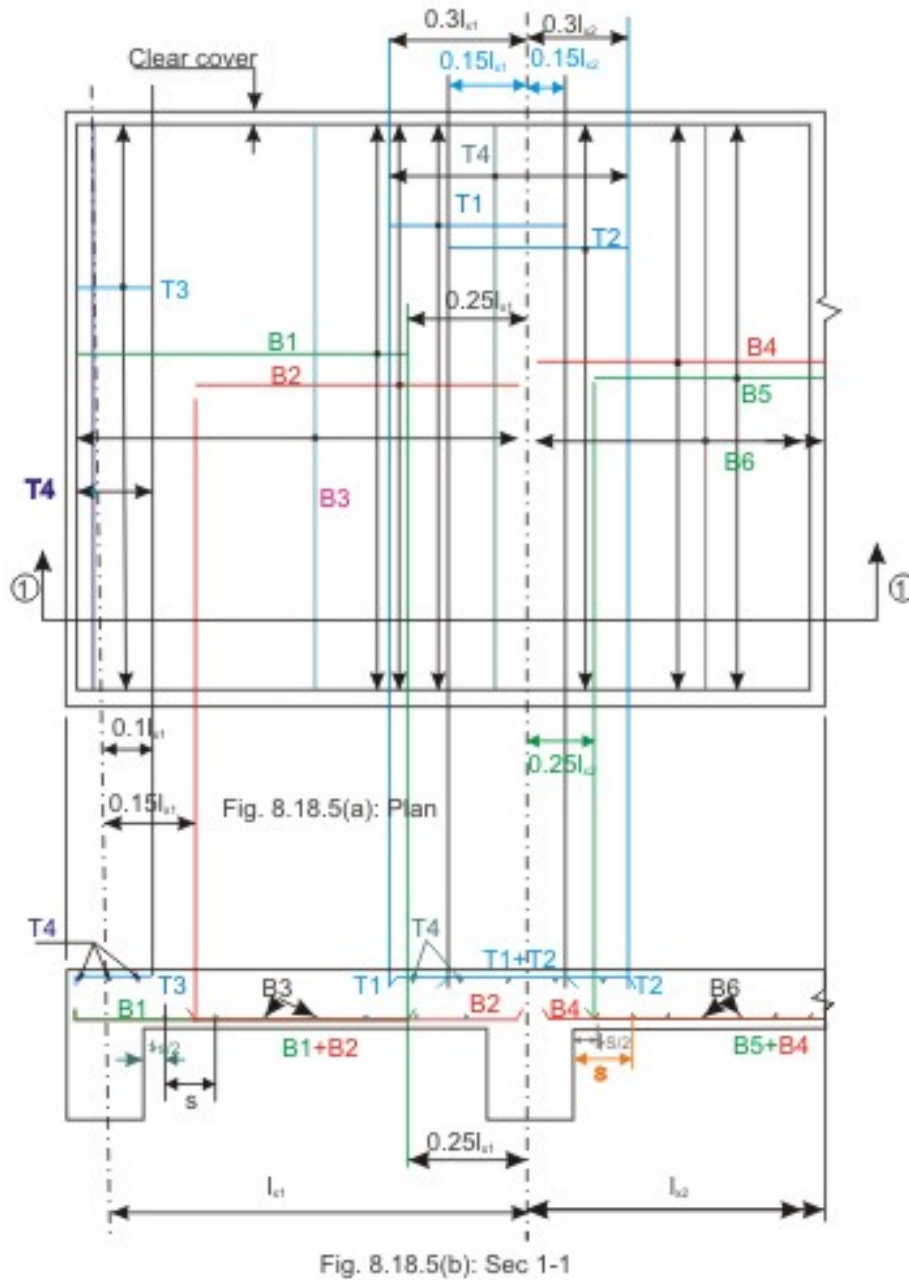
Alternatively, tables and charts of SP-16 may be used to determine the depth of the slab and the corresponding area of steel. Tables 5 to 44 of SP-16 covering a wide range of grades of concrete and Chart 90 shall be used for determining the depth and reinforcement of slabs. Tables of SP-16 take into consideration of maximum diameter of bars not exceeding one-eighth the depth of the slab. Zeros at the top right hand corner of these tables indicate the region where the percentage of reinforcement would exceed  $\rho_{t,lim}$ . Similarly, zeros at the lower left and corner indicate the region where the reinforcement is less than the minimum stipulated in the code. Therefore, no separate checking is needed for the allowable maximum diameter of the bars or the computed area of steel exceeding the minimum area of steel while using tables and charts of SP-16.

The amount of steel reinforcement along the large span shall be the minimum amount of steel as per cl.26.5.2.1 of IS 456 and mentioned in sec.8.18.5d earlier.

**Step 6: Selection of diameters and spacings of reinforcing bars (cls.26.5.2.2 and 26.3.3 of IS 456)**

The diameter and spacing of bars are to be determined as per cls.26.5.2.2 and 26.3.3 of IS 456. As mentioned in Step 5, this step may be avoided when using the tables and charts of SP-16.

**8.18.7 Detailing of Reinforcement**



**Fig. 8.18.5: Reinforcement of one-way slab**

Figures 8.18.5a and b present the plan and section 1-1 of one-way continuous slab showing the different reinforcing bars in the discontinuous and continuous ends (DEP and CEP, respectively) of end panel and continuous end of adjacent panel (CAP). The end panel has three bottom bars B1, B2 and B3 and four top bars T1, T2, T3 and T4. Only three bottom bars B4, B5 and B6 are shown in the adjacent panel. Table 8.3 presents these bars mentioning the respective zone of their placement (DEP/CEP/CAP), direction of the bars (along  $x$  or  $y$ ) and the resisting moment for which they shall be designed or if to be provided on the basis of minimum reinforcement. These bars are explained below for the three types of ends of the two panels.

**Table 8.3 Steel bars of one-way slab (Figs.8.18.5a and b)**

Sl.No.	Bars	Panel	Along	Resisting moment
1	B1, B2	DEP	$x$	+ 0.5 $M_x$ for each,
2	B3	DEP	$y$	Minimum steel
3	B4, B5	CAP	$x$	+ 0.5 $M_x$ for each,
4	B6	CAP	$y$	Minimum steel
5	T1, T2	CEP	$x$	- 0.5 $M_x$ for each,
6	T3	DEP	$x$	+ 0.5 $M_x$
7	T4	DEP	$y$	Minimum steel

Notes: (i) DEP = Discontinuous End Panel  
(ii) CEP = Continuous End Panel  
(iii) CAP = Continuous Adjacent Panel

**(i) Discontinuous End Panel (DEP)**

- Bottom steel bars B1 and B2 are alternately placed such that B1 bars are curtailed at a distance of  $0.25 l_{x1}$  from the adjacent support and B2 bars are started from a distance of  $0.15 l_{x1}$  from the end support. Thus, both B1 and B2 bars are present in the middle zone covering  $0.6 l_{x1}$ , each of which is designed to resist positive moment  $0.5 M_x$ . These bars are along the direction of  $x$  and are present from one end to the other end of  $l_y$ .
- Bottom steel bars B3 are along the direction of  $y$  and cover the entire span  $l_{x1}$  having the minimum area of steel. The first bar shall be placed at a distance not exceeding  $s/2$  from the left discontinuous support, where  $s$  is the spacing of these bars in  $y$  direction.
- Top bars T3 are along the direction of  $x$  for resisting the negative moment which is numerically equal to fifty per cent of positive  $M_x$ . These

bars are continuous up to a distance of  $0.1/x_1$  from the centre of support at the discontinuous end.

- Top bars T4 are along the direction of  $y$  and provided up to a distance of  $0.1/x_1$  from the centre of support at discontinuous end. These are to satisfy the requirement of minimum steel.

### (ii) Continuous End Panel (CEP)

- Top bars T1 and T2 are along the direction of  $x$  and cover the entire  $l_y$ . They are designed for the maximum negative moment  $M_x$  and each has a capacity of  $-0.5M_x$ . Top bars T1 are continued up to a distance of  $0.3/x_1$ , while T2 bars are only up to a distance of  $0.15/x_1$ .
- Top bars T4 are along  $y$  and provided up to a distance of  $0.3/x_1$  from the support. They are on the basis of minimum steel requirement.

### (iii) Continuous Adjacent Panel (CAP)

- Bottom bars B4 and B5 are similar to B1 and B2 bars of (i) above.
- Bottom bars B6 are similar to B3 bars of (i) above.

Detailing is an art and hence structural requirement can be satisfied by more than one mode of detailing each valid and acceptable.

## 8.18.8 Numerical Problems

### (a) Problem 8.1

Design the one-way continuous slab of Fig.8.18.6 subjected to uniformly distributed imposed loads of  $5 \text{ kN/m}^2$  using M 20 and Fe 415. The load of floor finish is  $1 \text{ kN/m}^2$ . The span dimensions shown in the figure are effective spans. The width of beams at the support = 300 mm.

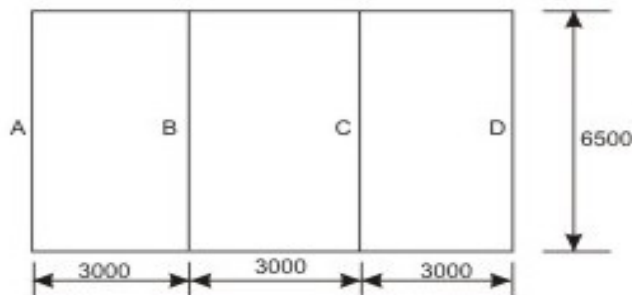


Fig. 8.18.6: Problem 8.1

## Solution of Problem 8.1

### Step 1: Selection of preliminary depth of slab

The basic value of span to effective depth ratio for the slab having simple support at the end and continuous at the intermediate is  $(20+26)/2 = 23$  (cl.23.2.1 of IS 456).

Modification factor with assumed  $p = 0.5$  and  $f_s = 240 \text{ N/mm}^2$  is obtained as 1.18 from Fig.4 of IS 456.

Therefore, the minimum effective depth  $= 3000/23(1.18) = 110.54 \text{ mm}$ . Let us take the effective depth  $d = 115 \text{ mm}$  and with 25 mm cover, the total depth  $D = 140 \text{ mm}$ .

### Step 2: Design loads, bending moment and shear force

Dead loads of slab of 1 m width  $= 0.14(25) = 3.5 \text{ kN/m}$

Dead load of floor finish  $= 1.0 \text{ kN/m}$

Factored dead load  $= 1.5(4.5) = 6.75 \text{ kN/m}$

Factored live load  $= 1.5(5.0) = 7.50 \text{ kN/m}$

Total factored load  $= 14.25 \text{ kN/m}$

Maximum moments and shear are determined from the coefficients given in Tables 12 and 13 of IS 456.

Maximum positive moment  $= 14.25(3)(3)/12 = 10.6875 \text{ kNm/m}$

Maximum negative moment  $= 14.25(3)(3)/10 = 12.825 \text{ kNm/m}$

Maximum shear  $V_u = 14.25(3)(0.4) = 17.1 \text{ kN}$

### Step 3: Determination of effective and total depths of slab

From Eq.3.25 of sec. 3.5.6 of Lesson 5, we have

$M_{u,lim} = R_{lim} b d^2$  where  $R_{lim}$  is  $2.76 \text{ N/mm}^2$  from Table 3.3 of sec. 3.5.6 of Lesson 5. So,  $d = \{12.825(10^6)/(2.76)(1000)\}^{0.5} = 68.17 \text{ mm}$

Since, the computed depth is much less than that determined in Step 1, let us keep  $D = 140$  mm and  $d = 115$  mm.

#### Step 4: Depth of slab for shear force

Table 19 of IS 456 gives  $\tau_c = 0.28$  N/mm<sup>2</sup> for the lowest percentage of steel in the slab. Further for the total depth of 140 mm, let us use the coefficient  $k$  of cl. 40.2.1.1 of IS 456 as 1.3 to get  $\tau_c = k \tau_c = 1.3(0.28) = 0.364$  N/mm<sup>2</sup>.

Table 20 of IS 456 gives  $\tau_{c \max} = 2.8$  N/mm<sup>2</sup>. For this problem  $\tau_v = V_u/bd = 17.1/115 = 0.148$  N/mm<sup>2</sup>. Since,  $\tau_v < \tau_c < \tau_{c \max}$ , the effective depth  $d = 115$  mm is acceptable.

#### Step 5: Determination of areas of steel

From Eq.3.23 of sec. 3.5.5 of Lesson 5, we have

$$M_u = 0.87 f_y A_{st} d \{1 - (A_{st})(f_y)/(f_{ck})(bd)\}$$

(i) For the maximum negative bending moment

$$12825000 = 0.87(415)(A_{st})(115)\{1 - (A_{st})(415)/(1000)(115)(20)\}$$

or  $A_{st}^2 - 5542.16 A_{st} + 1711871.646 = 0$

Solving the quadratic equation, we have the negative  $A_{st} = 328.34$  mm<sup>2</sup>

(ii) For the maximum positive bending moment

$$10687500 = 0.87(415) A_{st}(115) \{1 - (A_{st})(415)/(1000)(115)(20)\}$$

or  $A_{st}^2 - 5542.16 A_{st} + 1426559.705 = 0$

Solving the quadratic equation, we have the positive  $A_{st} = 270.615$  mm<sup>2</sup>

#### Alternative approach: Use of Table 2 of SP-16

(i) For negative bending moment

$$M_u/bd^2 = 0.9697$$



Table 2 of SP-16 gives:  $p_s = 0.2859$  (by linear interpolation). So, the area of negative steel =  $0.2859(1000)(115)/100 = 328.785 \text{ mm}^2$ .

(ii) For positive bending moment

$$M_u/bd^2 = 0.8081$$

Table 2 of SP-16 gives:  $p_s = 0.23543$  (by linear interpolation). So, the area of positive steel =  $0.23543(1000)(115)/100 = 270.7445 \text{ mm}^2$ .

These areas of steel are comparable with those obtained by direct computation using Eq.3.23.

### Distribution steel bars along longer span $l_y$

Distribution steel area = Minimum steel area =  $0.12(1000)(140)/100 = 168 \text{ mm}^2$ . Since, both positive and negative areas of steel are higher than the minimum area, we provide:

(a) For negative steel: 10 mm diameter bars @ 230 mm c/c for which  $A_{st} = 341 \text{ mm}^2$  giving  $p_s = 0.2965$ .

(b) For positive steel: 8 mm diameter bars @ 180 mm c/c for which  $A_{st} = 279 \text{ mm}^2$  giving  $p_s = 0.2426$

(c) For distribution steel: Provide 8 mm diameter bars @ 250 mm c/c for which  $A_{st}$  (minimum) =  $201 \text{ mm}^2$ .

### Step 6: Selection of diameter and spacing of reinforcing bars

The diameter and spacing already selected in step 5 for main and distribution bars are checked below:

For main bars (cl. 26.3.3.b.1 of IS 456), the maximum spacing is the lesser of  $3d$  and 300 mm i.e., 300 mm. For distribution bars (cl. 26.3.3.b.2 of IS 456), the maximum spacing is the lesser of  $5d$  or 450 mm i.e., 450 mm. Provided spacings, therefore, satisfy the requirements.

Maximum diameter of the bars (cl. 26.5.2.2 of IS 456) shall not exceed  $140/8 = 17 \text{ mm}$  is also satisfied with the bar diameters selected here.

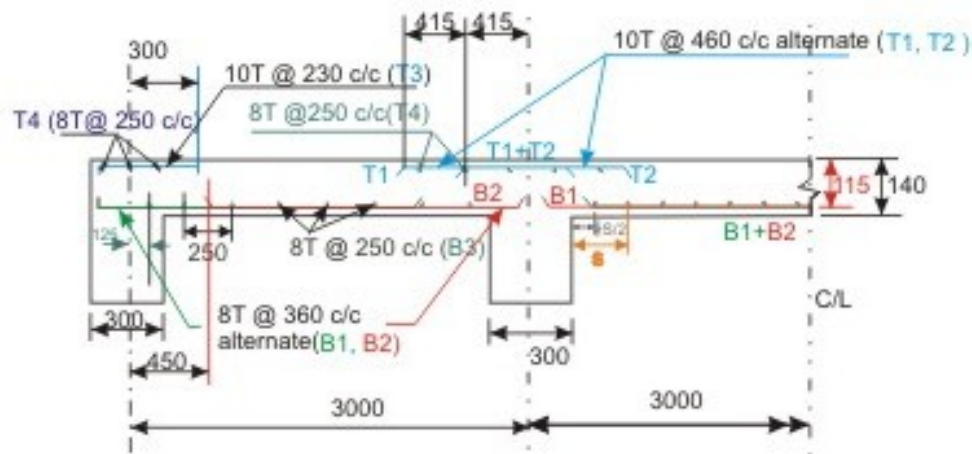


Fig. 8.18.7: Problem 8.1

Figure 8.18.7 presents the detailing of the reinforcement bars. The abbreviation B1 to B3 and T1 to T4 are the bottom and top bars, respectively which are shown in Fig.8.18.5 for a typical one-way slab.

The above design and detailing assume absence of support along short edges. When supports along short edges exist and there is eventual clamping top reinforcement would be necessary at shorter supports also.

### 8.18.9 Practice Questions and Problems with Answers

**Q.1:** State the names of different types of slabs used in construction.

**A.1:** See sec. 8.18.1.

**Q.2:** (a) State the limit of the aspect ratio of  $l_y/l_x$  of one- and two-way slabs.  
(b) Explain the share of loads by the supporting beams in one- and two-way slabs.

**A.2:** (a) The aspect ratio  $l_y/l_x$  ( $l_x$  is the shorter one) is from 1 to 2 for two-way slabs and beyond 2 for one-way slabs.

(b) See sec. 8.18.2.

**Q.3:** How to determine the design shear strength of concrete in slabs of different depths having the same percentage of reinforcement?

**A.3:** See sec. 8.18.3.

**Q.4:** State span to depth ratios of one-way slabs for different support conditions to be considered for the control of deflection.

**A.4:** See sec. 8.18.5b.

**Q.5:** State the minimum amounts of reinforcing bars to be provided in slabs?

**A.5:** See sec. 8.18.5d.

**Q.6:** State the maximum diameter of a bar to be used in slabs.

**A.6:** See sec. 8.18.5e.

**Q.7:** How do we determine the effective depth of a slab for a given factored moment?

**A.7:** See sec. 8.18.6, Step 3, Eq.3.25.

**Q.8:** How do we determine the area of steel to be provided for a given factored moment?

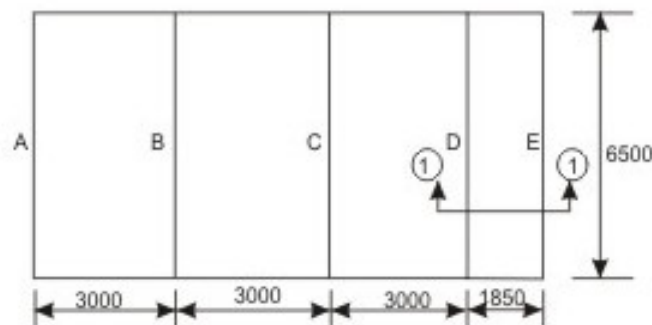
**A.8:** See sec. 8.18.6, Step 5, Eq.3.23.

**Q.9:** How do we determine the amount of steel in the longer span direction?

**A.9:** Minimum amount of steel shall be provided for temperature, shrinkage etc. as per cl. 26.5.2.1 of IS 456. These are known as distribution bars.

**Q.10:** Design the cantilever panel of the one-way slab shown in Fig.8.18.8 subjected to uniformly distributed imposed loads  $5 \text{ kN/m}^2$  using M 20 and Fe 415. The load of floor finish is  $0.75 \text{ kN/m}^2$ . The span dimensions shown in the figure are effective spans. The width of the support is 300 mm.

**A.10:**



**Fig. 8.18.8:** Problem Q-10

### Step 1: Selection of preliminary depth of slab

Basic value of span to depth ratio (cl. 23.2.1 of IS 456) = 7

Modification factor = 1.18 (see Problem 8.1)

Minimum effective depth =  $1850/7(1.18) = 223.97$  mm

Assume  $d = 225$  mm and  $D = 250$  mm.

### Step 2: Design loads, bending moment and shear force

Factored dead loads =  $(1.5)(0.25)(25) = 9.375$  kN/m

Factored load of floor finish =  $(1.5)(0.75) = 1.125$  kN/m

Factored live loads =  $(1.5)(5) = 7.5$  kN/m

Total factored loads = 18.0 kN/m

Maximum negative moment =  $18.0(1.85)(1.85)(0.5) = 30.8025$  kNm/m

Maximum shear force =  $18.0(1.85) = 33.3$  kN/m

### Step 3: Determination of effective and total depths of slab

From Eq.3.25, Step 3 of sec. 8.18.6, we have

$d = \{30.8025(10^6)/2.76(10^3)\}^{0.5} = 105.64$  mm, considering the value of  $R = 2.76$  N/mm<sup>2</sup> from Table 3.3 of sec. 3.5.5 of Lesson 5. This depth is less than assumed depth of slab in Step 1. Hence, assume  $d = 225$  mm and  $D = 250$  mm.

### Step 4: Depth of slab for shear force

Using the value of  $k = 1.1$  (cl. 40.2.1.1 of IS 456) for the slab of 250 mm depth, we have  $\tau_c$  (from Table 19 of IS 456) =  $1.1(0.28) = 0.308$  N/mm<sup>2</sup>. Table 20 of IS 456 gives  $\tau_{c\max} = 2.8$  N/mm<sup>2</sup>. Here,  $\tau_v = V_u/bd = 33.3/225 = 0.148$  N/mm<sup>2</sup>. The depth of the slab is safe in shear as  $\tau_v < \tau_c < \tau_{c\max}$ .

### Step 5: Determination of areas of steel (using table of SP-16)

Table 44 gives 10 mm diameter bars @ 200 mm c/c can resist 31.43 kNm/m > 30.8025 kNm/m. Fifty per cent of the bars should be curtailed at a

distance of larger of  $L_d$  or  $0.5l_x$ . Table 65 of SP-16 gives  $L_d$  of 10 mm bars = 470 mm and  $0.5l_x = 0.5(1850) = 925$  mm from the face of the column. The curtailment distance from the centre line of beam =  $925 + 150 = 1075$ , say 1100 mm.

The above, however, is not admissible as the spacing of bars after the curtailment exceeds 300 mm. So, we provide 10 mm @ 300 c/c and 8 mm @ 300 c/c. The moment of resistance of this set is  $34.3 \text{ kNm/m} > 30.8025 \text{ kNm/m}$  (see Table 44 of SP-16).

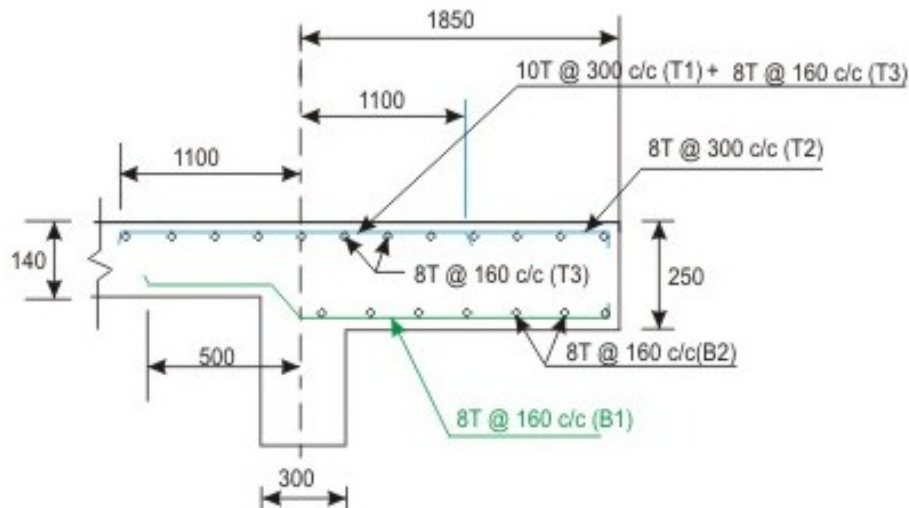


Fig. 8.18.9: Detailing of bars of Problem Q-10 (sec. 1-1 of Fig. 8.18.8)

Figure 8.18.9 presents the detailing of reinforcing bars of this problem.

### 8.18.10 References

1. Reinforced Concrete Limit State Design, 6<sup>th</sup> Edition, by Ashok K. Jain, Nem Chand & Bros, Roorkee, 2002.
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14. Reinforced Concrete Designer's Handbook, 10<sup>th</sup> Edition, by C.E.Reynolds and J.C.Steedman, E & FN SPON, London, 1997.
15. Indian Standard Plain and Reinforced Concrete – Code of Practice (4<sup>th</sup> Revision), IS 456: 2000, BIS, New Delhi.
16. Design Aids for Reinforced Concrete to IS: 456 – 1978, BIS, New Delhi.

### 8.18.11 Test 18 with Solutions

Maximum Marks = 50, Maximum Time = 30 minutes

Answer all questions.

**TQ.1:** (a) State the limit of the aspect ratio of  $l_y/l_x$  of one- and two-way slabs.  
(b) Explain the share of loads by the supporting beams in one- and two-way slabs.

(10 marks)

**A.TQ.1:** (a) The aspect ratio  $l_y/l_x$  ( $l_x$  is the shorter one) is from 1 to 2 for two-way slabs and beyond 2 for one-way slabs.

(b) See sec. 8.18.2.

**TQ.2:** How to determine the design shear strength of concrete in slabs of different depths having the same percentage of reinforcement?  
(10 marks)

**A.TQ.2:** See sec. 8.18.3.

**TQ3:** Determine the areas of steel, bar diameters and spacings in the two directions of a simply supported slab of effective spans 3.5 m x 8 m (Figs.8.18.10a and b) subjected to live loads of 4 kN/m<sup>2</sup> and the load of

floor finish is  $1 \text{ kN/m}^2$ . Use M 20 and Fe 415. Draw the diagram showing the detailing of reinforcement. (30 marks)

A.TQ.3:

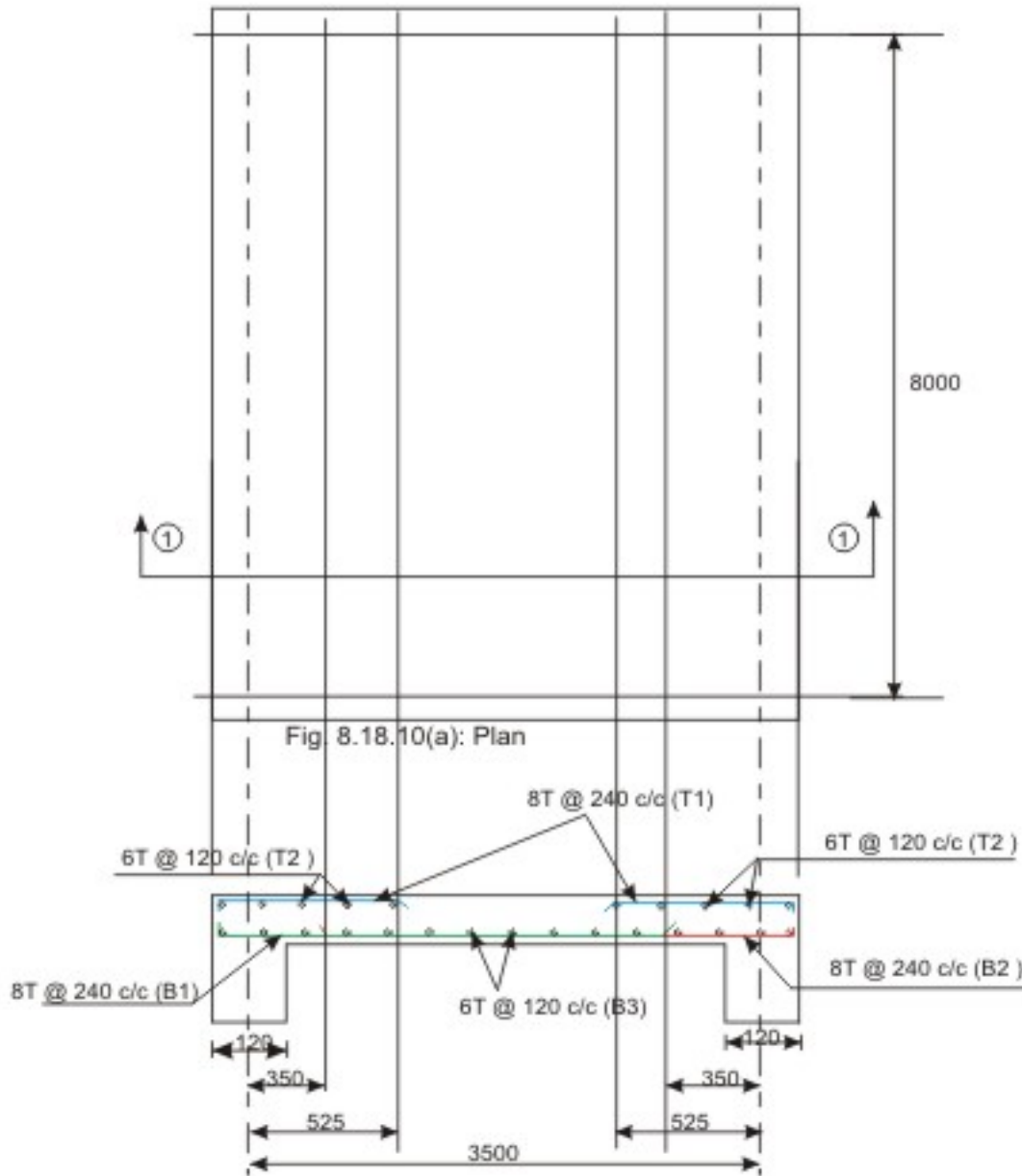


Fig. 8.18.10: Detailing of bars of Problem TQ. 1

This is one-way slab as  $l_y/l_x = 8/3.5 = 2.285 > 2$ . The calculations are shown in different steps below:

### Step 1: Selection of preliminary depth of slab

Clause 23.2.1 stipulates the basic value of span to effective depth ratio of 20. Using the modification factor of 1.18 from Fig.4 of IS 456, with  $p = 0.5$  per cent and  $f_s = 240 \text{ N/mm}^2$ , we have the span to effective depth ratio =  $20(1.18) = 23.6$ .

So, the minimum effective depth of slab =  $3500/23.6 = 148.305 \text{ mm}$ . Let us take  $d = 150 \text{ mm}$  and  $D = 175 \text{ mm}$ .

### Step 2: Design loads, bending moment and shear force

$$\text{Factored dead loads of slab} = (1.5)(0.175)(25) = 6.5625 \text{ kN/m}$$

$$\text{Factored load of floor finish} = (1.5)(1) = 1.5 \text{ kN/m}$$

$$\text{Factored live load} = (1.5)(4) = 6.0 \text{ kN/m}$$

$$\text{Total factored load} = 14.0625 \text{ kN/m}$$

$$\text{Maximum positive bending moment} = 14.0625(3.5)(3.5)/8 = 21.533 \text{ kNm/m}$$

$$\text{Maximum shear force} = 14.0625(3.5)(0.5) = 24.61 \text{ kN/m}$$

### Step 3: Determination/checking of the effective and total depths of slab

Using Eq.3.25 as explained in Step 3 of sec. 8.18.6, we have

$$d = \{21.533(10^6)/(2.76)(10^3)\}^{0.5} = 88.33 \text{ mm} < 150 \text{ mm}, \text{ as assumed in Step 1. So, let us keep } d = 150 \text{ mm and } D = 175 \text{ mm.}$$

### Step 4: Depth of the slab for shear force

With the multiplying factor  $k = 1.25$  for the depth as 175 mm (vide Table 8.1 of this lesson) and  $\tau_c = 0.28 \text{ N/mm}^2$  from Table 19 of IS 456, we have  $\tau_c = 1.25(0.28) = 0.35 \text{ N/mm}^2$ .

$$\text{Table 20 of IS 456 gives } \tau_{c \max} = 2.8 \text{ N/mm}^2. \text{ For this problem:}$$
$$\tau_v = 24.61(1000)/(1000)(150) = 0.1641 \text{ N/mm}^2.$$

Thus, the effective depth of slab as 150 mm is safe as  $\tau_v < \tau_c < \tau_{c \max}$ .



### Step 5: Determination of areas of steel

Table 41 of SP-16 gives 8 mm diameter bars @ 120 mm c/c have 22.26 kNm/m > 21.533 kNm/m. Hence, provide 8 mm T @ 120 mm c/c as main positive steel bars along the short span of 3.5 m.

The minimum amount of reinforcement (cl. 26.5.2.1 of IS 456) =  $0.12(175)(1000)/100 = 210 \text{ mm}^2$ . Provide 6 mm diameter bars @ 120 mm c/c ( $236 \text{ mm}^2$ ) along the large span of 8m.

Figure 8.18.10b shows the detailing of reinforcing bars.

### 8.18.12 Summary of this Lesson

This lesson mentions the different types of slabs used in construction and explains the differences between one and two-way slabs. Illustrating the principles of design as strength and deflection, the methods of determining the bending moments and shear forces are explained. The stipulated guidelines of assuming the preliminary depth, maximum diameter of reinforcing bars, nominal covers, spacing of reinforcements, minimum amount of reinforcing bars etc. are illustrated. The steps of the design of one-way slabs are explained. Design problems are solved to illustrate the application of design guidelines. Further, the detailing of reinforcement bars are explained for typical one-way slab and for the numerical problems solved in this lesson.