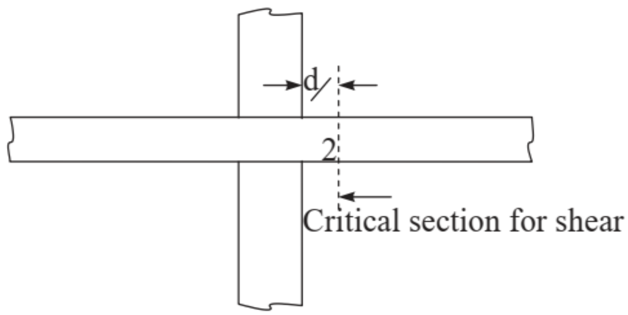
# DESIGN OF SPECIAL RCC MEMBERS

## FLAT SLABS

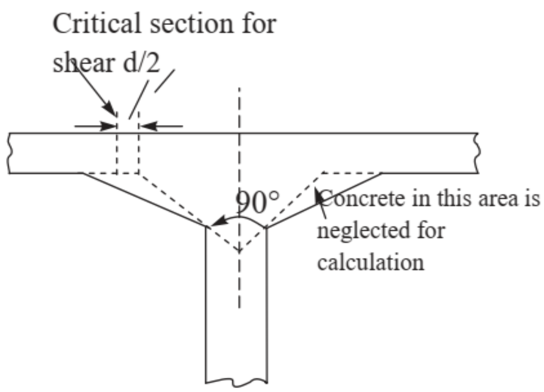
## Introduction

Common practice of design and construction is to support the slabs by beams and support the beams by columns. This may be called as beam-slab construction. The beams reduce the available net clear ceiling height. Hence in warehouses, offices and public halls sometimes beams are avoided and slabs are directly supported by columns. These types of construction are aesthetically appealing also. These slabs which are directly supported by columns are called **Flat Slabs.** Figure shows a typical flat slab.



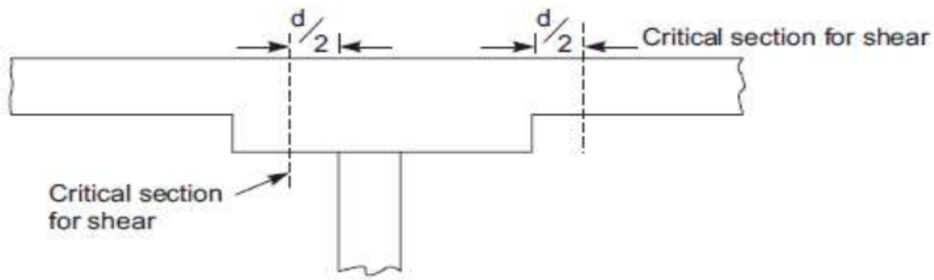

1. A typical flat slab (without drop and column head)

The column head is sometimes widened so as to reduce the punching shear in the slab. The widened portions are called **column heads.** The column heads may be provided with any angle from the consideration of architecture but for the design, concrete in the portion at 45º on either side of vertical only is considered as effective for the design



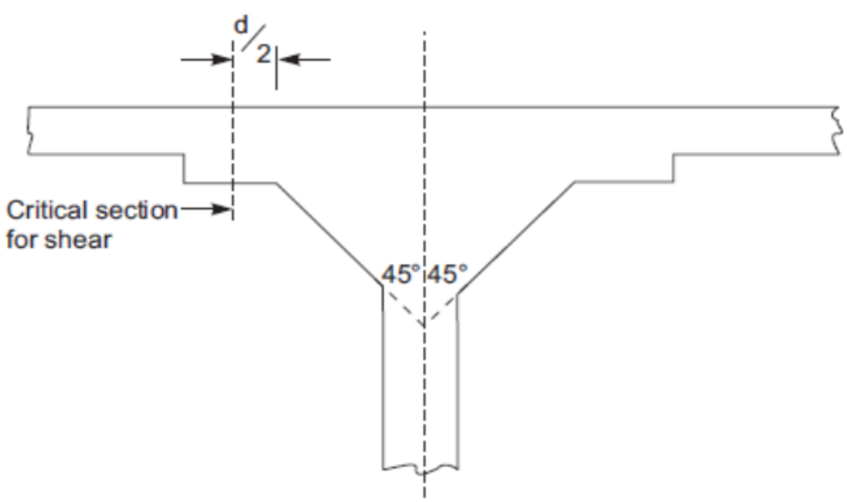

2. Slab without drop and Column with Column head

Moments in the slabs are more near the column. Hence the slab is thickened near the columns by providing the drops as shown in figure. Sometimes the drops are called as capital of the column. Thus we have the following types of flat slabs:



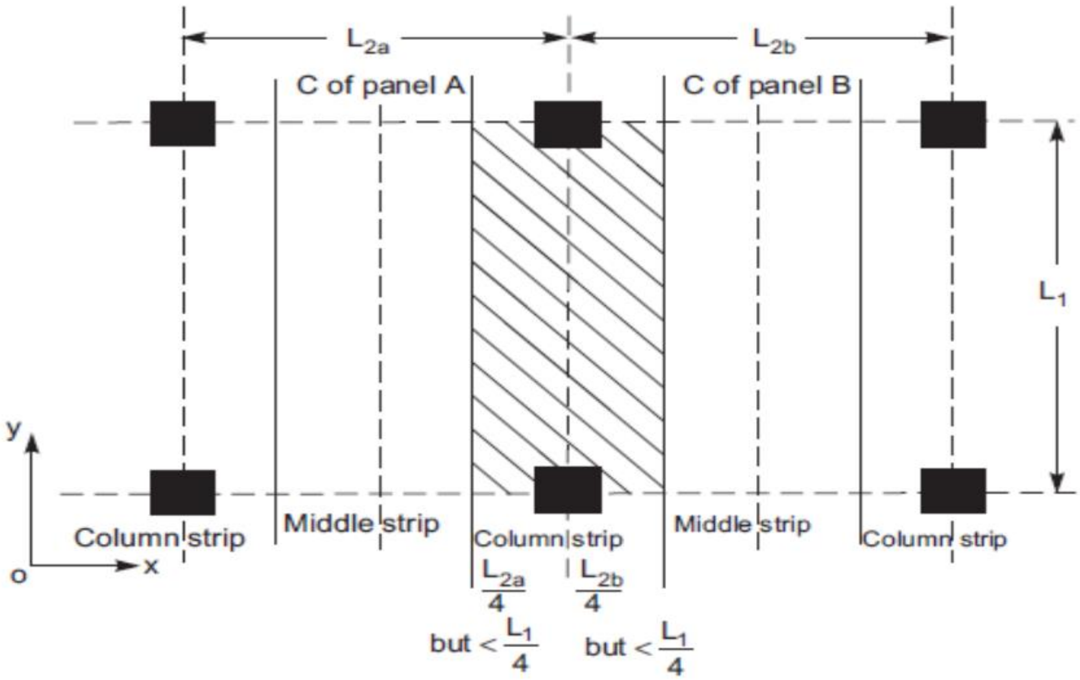

3. Slab with drop and column without column head

- Slabs without drop and column head (Fig. 1).
- Slabs without drop and column with column head (Fig. 2).
- Slabs with drop and column without column head (Fig. 3).
- Slabs with drop and column head as shown in (Fig. 4).




4. Slab with drop and column with column head

The portion of flat slab that is bound on each of its four sides by centre lines of adjacent columns is called a panel. The panel shown in Fig. 5 has size $L_1$ X $L_2$. A panel may be divided into column strips and middle strips. Column Strip means a design strip having a width of $0.25L_1$ or $0.25L_2$, whichever is less. The remaining middle portion which is bound by the column strips is called middle strip. Fig. 5 shows the division of flat slab panel into column and middle strips in the direction *y*.




5. Panels, Column strips, Middle strips in y direction

## Proportioning of Flat slabs

IS 456-2000 [Clause 31.2] gives the following guidelines for proportioning.

### Drops

The drops when provided shall be rectangular in plan, and have a length in each direction not less than one third of the panel in that direction. For exterior panels, the width of drops at right angles to the non continuous edge and measured from the centre-line of the columns shall be equal to one half of the width of drop for interior panels.

### Column heads

Where column heads are provided, that portion of the column head which lies within the largest right circular cone or pyramid entirely within the outlines of the column and the column head, shall be considered for design purpose as shown in Figs.2 and 4.

### Thickness of flat slab

From the consideration of deflection control IS 456-2000 specifies minimum thickness in terms of span to effective depth ratio. For this purpose larger span is to be considered. If drop as specified in 1.2.1 is provided, then the maximum value of ratio of larger span to thickness shall be

= 40, if mild steel is used

= 32, if Fe 415 or Fe 500 steel is used

If drops are not provided or size of drops do not satisfy the specification 1.2.1, then the ratio shall not exceed 0.9 times the value specified above *i.e*

= 40  0.9 = 36, if mild steel is used.

= 32  0.9 = 28.8, if HYSD bars are used

It is also specified that in no case, the thickness of flat slab shall be less than 125 mm.

## DETERMINATION OF BENDING MOMENT AND SHEARFORCE

For this IS 456-2000 permits use of any one of the following two methods

a) The Direct Design Method

b) The Equivalent Frame Method

## THE DIRECT DESIGN METHOD

This method has the limitation that it can be used only if the following conditions are fulfilled:

*a.* There shall be minimum of three continuous spans in each direction.

*b.* The panels shall be rectangular and the ratio of the longer span to the shorter span within a panel shall not be greater than 2.

*c.* The successive span length in each direction shall not differ by more than one-third of longer span.

*d.* The design live load shall not exceed three times the design dead load. (*e*) The end span must be shorter but not greater than the interior span.

*e.* It shall be permissible to offset columns a maximum of 10 percent of the span in the direction of the offset notwithstanding the provision in (*b*).

## TOTAL DESIGN MOMENT

The absolute sum of the positive and negative moment in each direction is given by

$$M_0 = WL_n/8$$

W = Design load on the area $L_2$ X $L_n$

$L_n$ = Clear span extending from face to face of columns, capitals, brackets or walls but not less than 0.65 $L_1$

$L_1$ = Length of span in the direction of $M_0$; and

$L_2$ = Length of span transverse to $L_1$

In taking the values of $L_n$, $L_1$ and $L_2$, the following clauses are to be carefully noted:

(*a*) Circular supports shall be treated as square supports having the same area *i.e.*, squares of size 0.886D.

(*b*) When the transverse span of the panel on either side of the centre line of support varies, $L_2$ shall be taken as the average of the transverse spans. In Fig.5 it is given by

$(L_{2A}+L_{2B})/2$

(*c*) When the span adjacent and parallel to an edge is being considered, the distance from the edge to the centre-line of the panel shall be substituted for $L_2$.

## Distribution of bending moments into –ve and +ve moments

The total design moment $M_0$ in a panel is to be distributed into –ve moment and +ve moment as specified below:

Table 1.1 shows the moment in the middle strip shall be the difference between panel and the column strip moments.

**Table 1.** Distribution of Moments Across the Panel Width in a Column Strip

| *S. No.* | *Distributed Moment* | *Per cent of Total Moment* |
|---|---|---|
| *a* | Negative BM at the exterior support | 100 |
| *b* | Negative BM at the interior support | 75 |
| *c* | Positive bending moment | 60 |

## MOMENTS IN COLUMNS

In this type of constructions column moments are to be modified as suggested in IS 456–2000

**SHEAR FORCE**

The critical section for shear shall be at a distance *d/2* from the periphery of the column/capital drop panel. Hence if drops are provided there are two critical sections near columns. These critical sections are shown in Figs. 1 to 4. The shape of the critical section in plan is similar to the support immediately below the slab as shown in Fig. 6

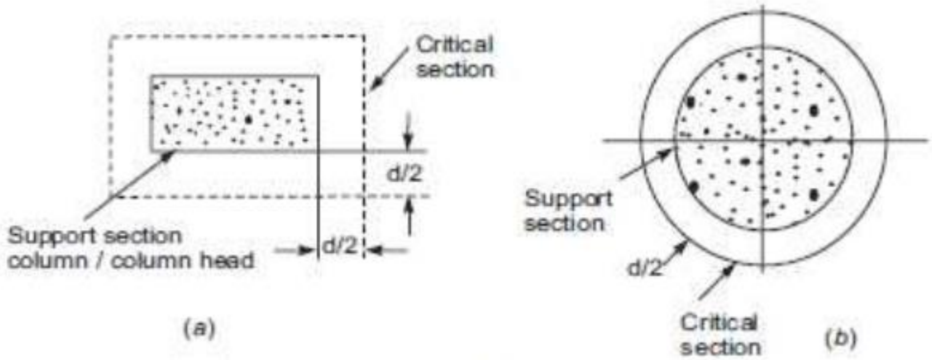



Fig. 6

For columns sections with re-entrant angles, the critical section shall be taken as indicated in Fig. 7.

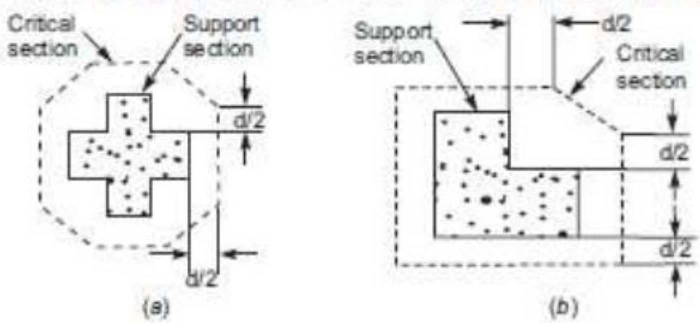



Fig. 7

In case of columns near the free edge of a slab, the critical section shall be taken as shown in Fig 8.

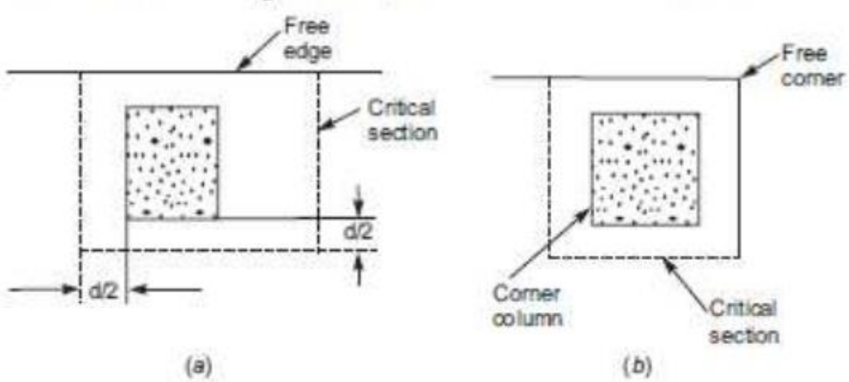



Fig. 8

The nominal shear stress may be calculated as

$$\tau_v = \frac{V}{b_0 d}$$

where $V$ – is shear force due to design

$b_0$ – is the periphery of the critical section

$d$ – is the effective depth

The permissible shear stress in concrete may be calculated as $k_s\ \tau_c$, where $k_s = 0.5 + \beta_c$ but not greater than 1, where $\beta_c$ is the ratio of short side to long side of the column/capital; and

$$\tau_c = 0.25\sqrt{f_{ck}}$$

If shear stress $\tau_v < \tau_c$ – no shear reinforcement are required. If $\tau_c < \tau_v < 1.5\ \tau_c$, shear reinforcement shall be provided. If shear stress exceeds $1.5\ \tau_c$ flat slab shall be redesigned.

## EQUIVALENT FRAME METHOD

IS 456–2000 recommends the analysis of flat slab and column structure as a rigid frame to get design moment and shear forces with the following assumptions:

(*a*) Beam portion of frame is taken as equivalent to the moment of inertia of flat slab bounded laterally by centre line of the panel on each side of the centre line of the column. In frames adjacent and parallel to an edge beam portion shall be equal to flat slab bounded by the edge and the centre line of the adjacent panel.

(*b*) Moment of inertia of the members of the frame may be taken as that of the gross section of the concrete alone.

(*c*) Variation of moment of inertia along the axis of the slab on account of provision of drops shall be taken into account. In the case of recessed or coffered slab which is made solid in the region of the columns, the stiffening effect may be ignored provided the solid part of the slab does not extend more than 0.15 $l_{ef}$ into the span measured from the centre line of the columns. The stiffening effect of flared columns heads may be ignored.

(*d*) Analysis of frame may be carried out with substitute frame method or any other accepted method like moment distribution or matrix method.

### Loading Pattern

When the live load does not exceed ¾th of dead load, the maximum moments may be assumed to occur at all sections when full design live load is on the entire slab.

If live load exceeds ¾th dead load analysis is to be carried out for the following pattern of loading also:

(*i*) To get maximum moment near mid span

– ¾th of live load on the panel and full live load on alternate panel

(*ii*) To get maximum moment in the slab near the support

– ¾th of live load is on the adjacent panel only

It is to be carefully noted that in no case design moment shall be taken to be less than those occurring with full design live load on all panels.

The moments determined in the beam of frame (flat slab) may be reduced in such proportion that the numerical sum of positive and average negative moments is not less than the value of total design moment $M_0 = \frac{WL_n}{8}$. The distribution of slab moments into column strips and middle strips is to be made in the same manner as specified in direct design method.

## SLAB REINFORCEMENT

### Spacing

The spacing of bars in a flat slab, shall not exceed 2 times the slab thickness.

### Area of Reinforcement

When the drop panels are used, the thickness of drop panel for determining area of reinforcement shall be the lesser of the following:

(*a*) Thickness of drop, and

(*b*) Thickness of slab plus one quarter the distance between edge of drop and edge of capital.

The minimum percentage of the reinforcement is same as that in solid slab *i.e.*, 0.12 percent if HYSD bars used and 0.15 percent, if mild steel is used.

### Minimum Length of Reinforcement

At least 50 percent of bottom bars should be from support to support. The rest may be bent up. The minimum length of different reinforcement in flat slabs should be as shown in Fig. 1.9 (Fig. 16 in IS 456–2000). If adjacent spans are not equal, the extension of the –ve reinforcement beyond each face shall be based on the longer span. All slab reinforcement should be anchored property at discontinuous edges.

**Example 1.1:** *Design an interior panel of a flat slab of size 5 m × 5 m without providing drop and column head. Size of columns is 500 × 500 mm and live load on the panel is 4 kN/m². Take floor finishing load as 1 kN/m². Use M20 concrete and Fe 415 steel.*

### Solution

### Thickness

Since drop is not provided and HYSD bars are used span to thickness ratio shall not exceed

$$\frac{1}{0.9 \times 32} = \frac{1}{28.8}$$

∴ Minimum thickness required

$$= \frac{\text{Span}}{28.8} = \frac{5000}{28.8} = 173.6 \text{ mm}$$

Let $d = 175$ mm and D = 200 mm

### Loads

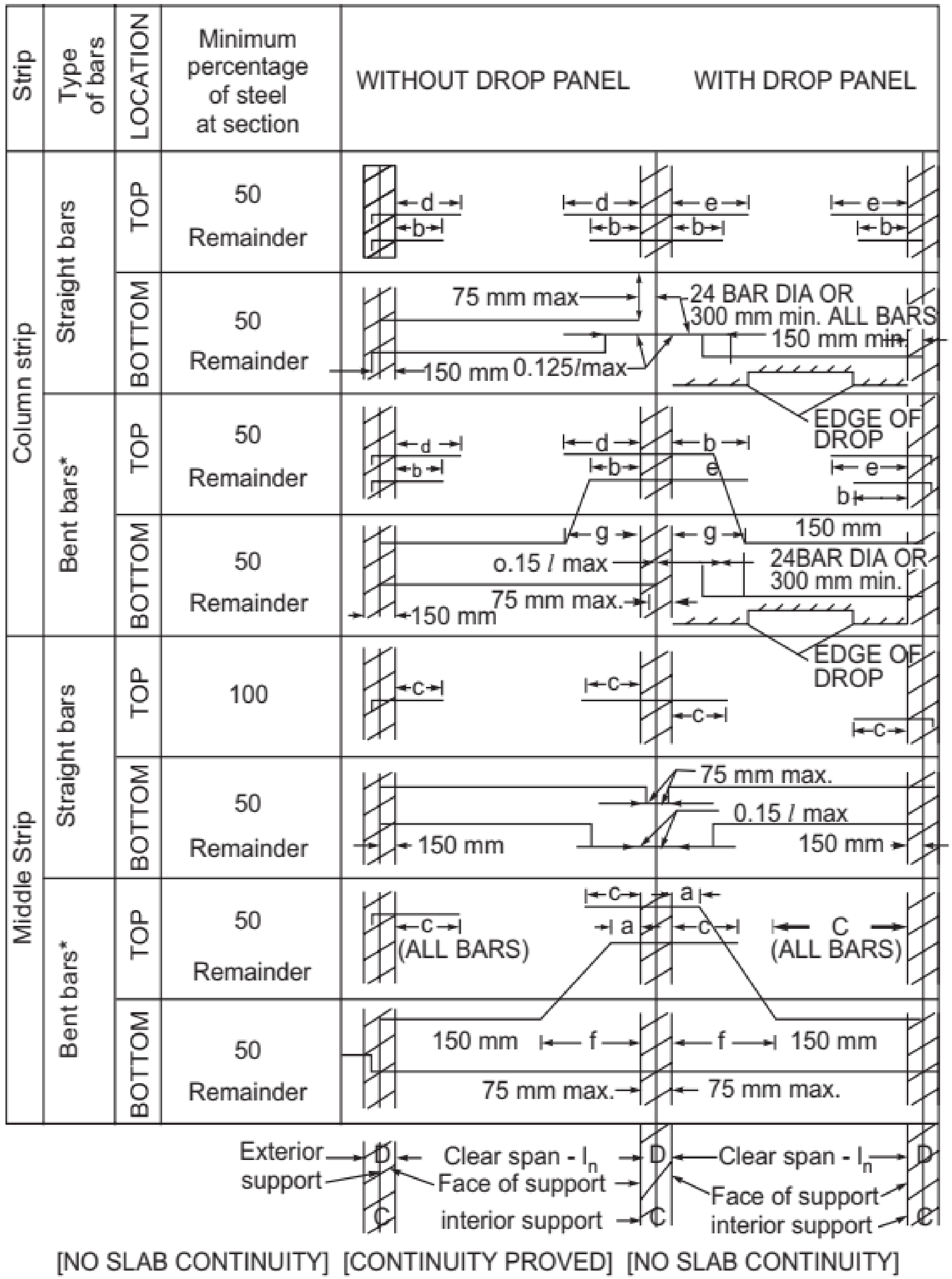
Self weight of slab = 0.20 × 25 = 5 kN/m²

Finishing load = 1 kN/m²

Live load = 4 kN/m²

∴ Total working load = 10 kN/m²

Factored load = 1.5 × 10 = 15 kN/m²




| Bar Length From Face of Support | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Minimum Length | | | | | | Maximum Length |
| Mark | a | b | c | d | e | f | g |
| Length | $0.14\ l_n$ | $0.20\ l_n$ | $0.22\ l_n$ | $0.30\ l_n$ | $0.33\ l_n$ | $0.20\ l_n$ | $0.24\ l_n$ |

* Bent bars at exterior supports may be used if a general analysis is made.

**Note.** D is the diameter of the column and the dimension of the rectangular column in the direction under consideration.

**Fig. 1.9** *Minimum bend joint locations and extensions for reinforcement in flat slabs*

$$L_n = 5 - 0.5 = 4.5 \text{ m}$$

$\therefore$ Total design load in a panel $W = 15\,L_2\,L_n = 15 \times 5 \times 4.5 = 337.5$ kN

**Moments**

Panel Moment $\quad M_0 = \dfrac{WL_n}{8} = 337.5 \times \dfrac{4.5}{8} = 189.84$ kNm

Panel –ve moment $\quad = 0.65 \times 189.84 = 123.40$ kNm

Panel +ve moment $\quad = 0.35 \times 189.84 = 0.35 \times 189.84 = 66.44$ kNm

Distribution of moment into column strips and middle strip:

| | *Column Strip in kNm* | *Middle Strip in kNm* |
|---|---|---|
| –ve moment | $0.75 \times 123.40 = 92.55$ | 30.85 |
| +ve moment | $0.60 \times 66.44 = 39.86$ | 26.58 |

Checking the thickness selected:

Since Fe 415 steel is used,

$$M_{u\,lim} = 0.138\, f_{ck}\, b\, d^2$$

Width of column strip $\quad = 0.5 \times 5000 = 2500$ mm

$\therefore \quad M_{u\,lim} = 0.138 \times 20 \times 2500 \times 175^2 = 211.3125 \times 10^6$ Nmm

$\quad = 211.3125$ kNm

Hence singly reinforced section can be designed *i.e.*, thickness provided is satisfactory from the consideration of bending moment.

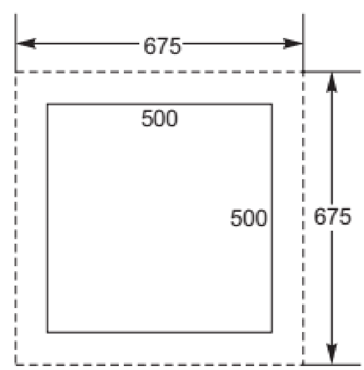
**Check for Shear**

The critical section for shear is at a distance $\dfrac{d}{2}$ from the column face. Hence periphery of critical section around a column is square of a size $= 500 + d = 500 + 175 = 675$ mm

Shear to be resisted by the critical section

$$V = 15 \times 5 \times 5 - 15 \times 0.675 \times 0.675$$

$$= 368.166 \text{ kN}$$




$\therefore \quad \tau_v = \dfrac{368.166 \times 1000}{4 \times 675 \times 175} = 0.779$ N/mm$^2$

$k_s = 1 + \beta_c$ subject to maximum of 1.

$$\beta_c = \frac{L_1}{L_2} = \frac{5}{5} = 1$$

$\therefore \quad k_s = 1$

$$\tau_c = 0.25\sqrt{f_{ck}} = 0.25\sqrt{20} = 1.118 \text{ N/mm}^2$$

safe in shear since $\tau_v < \tau_c$

# DESIGN CONCEPT FOR FLAT PLATE SYSTEM

## STEEL/ CONCRETE COLUMN WITH FLAT PLATE SYSTEM

With increasing demand for flexibility in interior layout, the use of flat plate for landed houses is gaining much popularity amongst architects. The main and unique feature of this system is that it provides a way for the architect to achieve the concept of high and completely flat ceiling with no beam protrusion.

Some projects have reported an improvement in the construction speed and cost savings from using this system which requires only simple formwork. The use of flat plate appeals to designers particularly because design flexibility is possible through shifting of walls without the need for columns to be properly aligned. The services can be installed within or below the slab and there are flexibilities in relocating vertical small penetrations. The soffit is often flat and high ceiling height can be achieved.

The columns used in this system are either cast in-situ concrete columns or circular steel hollow sections. When the columns used are steel hollow sections with concrete in-fill, the desired finish with exposed steel can be easily achieved.

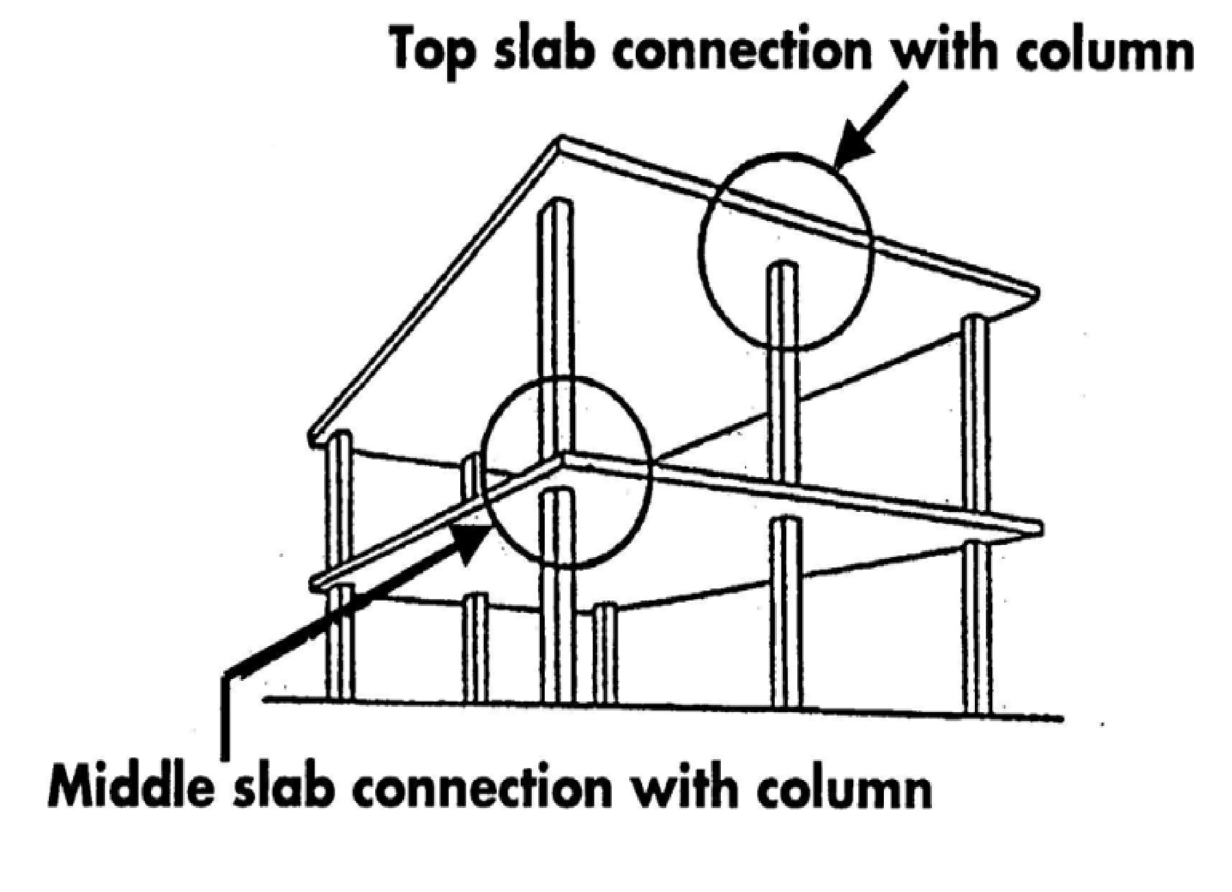
Flat plate system with circular steel column

## CONNECTION AND DETAILING

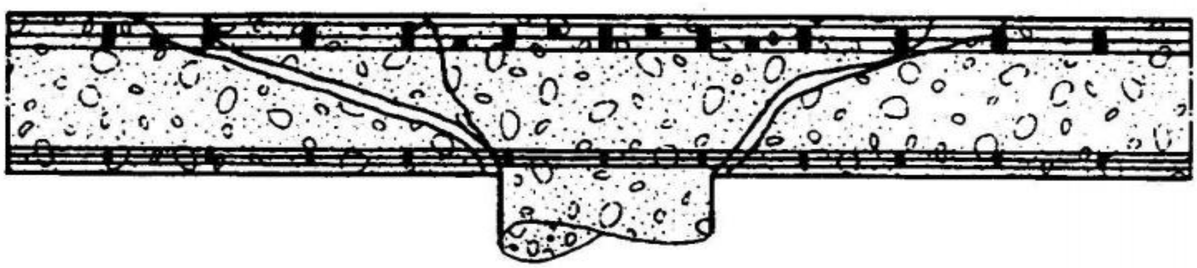
The main consideration for steel column connection to flat plate is to ensure that the base plate for the steel columns are cast into the concrete flat plate. Hence the positioning and alignment of the base plates are of utmost importance.

If concrete in-fill and column bars are required within the steel hollow section, the starter bars for the columns have to be placed and fixed in position prior to casting of concrete flat plate (see figure 5.5 for base plate connection).

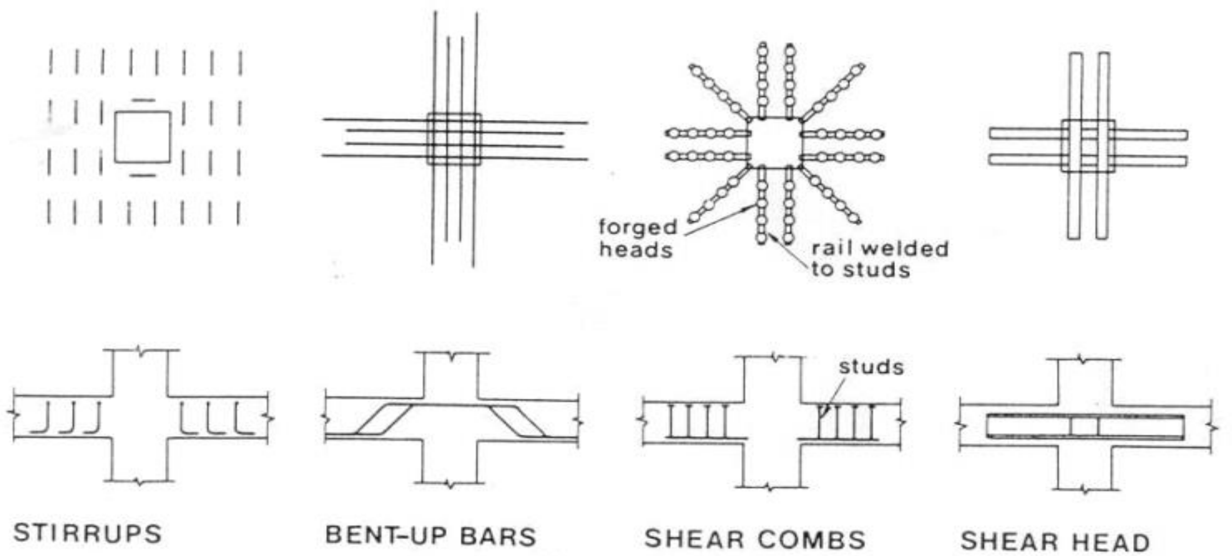
In the concrete column with flat plate design, the connection is more simplified without the need for base plate connection. In this case, reinforcement bars should be properly detailed between the columns and slabs. Punching shear checks are critical and vertical shear reinforcement should be detailed accordingly.




Critical connection between slab and columns

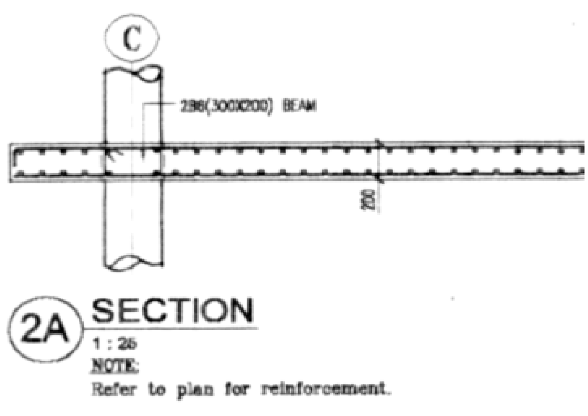


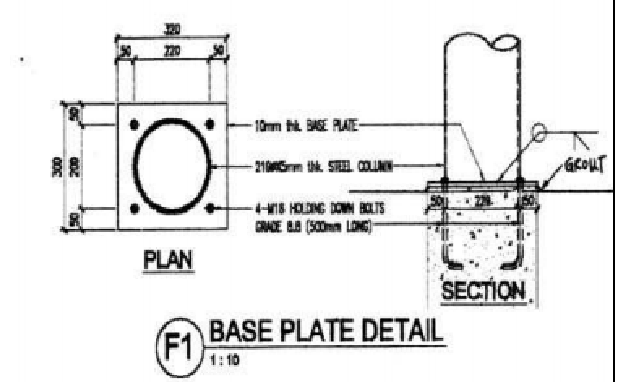
Typical shear failure near column. Proper detailing of shear reinforcement must be provided




Examples of shear reinforcement

Alternatively, designers may introduce hidden beam within slab along column strip to cater for the shear stresses near column location.




Hidden beam within column strip

Base plate details for column

# DESIGN OF GRIDS

## GENERAL INTRODUCTION

### DEFINITION

Interconnected grid systems are being commonly used or supporting building floors bridge decks and overhead water tanks slabs .A grid is a planar structural system composed of continuous members that either intersect or cross each other. Grids are used to cover large column free areas and have been constructed in number of areas in India n abroad. Is subjected to loads applied normally to its plane, the structure is referred as Grid . It is composed of continuous member that either intersect or cross each other .Grids in addition to their aesthetically pleasing appearance, provide a number of advantages over the other types of roofing systems.

### ADVANTAGES OF GRID BEAMS

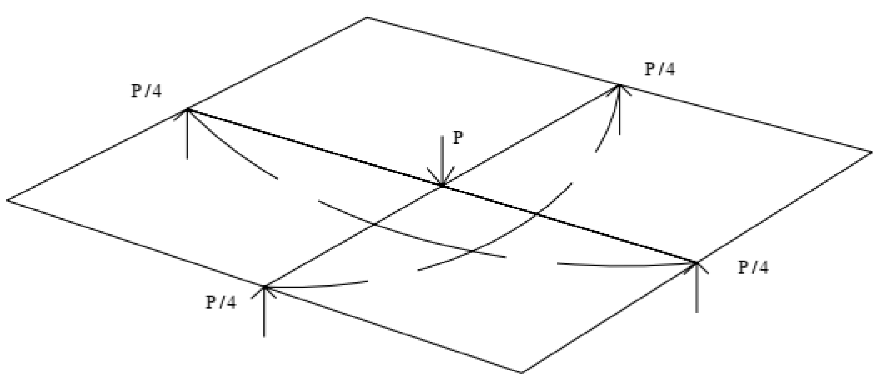
- Grids are very efficient in transferring concentrated loads and in having the entire structure participate in the load carrying action .
- Reduces the depth to span ratio of rectangular grids .
- Reduction in depth ,towers ,structural and other cost by reducing the height of the building .

### LOAD DISTRIBUTION IN GRID BEAMS

A load set on a cable or a beam is channelled to the support along the cable line or the beam axis, an arch ,a frame, and continuous beam produce the same type of "one –directional load dispersal". These structures are labelled "one – dimensional resisting structures" because they can be described by a straight or curved line , along which the stresses channel the loads.

If they are used to cover a rectangular area ,the system becomes impractical and insufficient. Grid beams structure are two way load dispersal system. When two identical ,simply supported beams at right angles to each other are placed one on the top of other and a concentrated load is applied at their intersection ,the load is transferred to the supports at the ends o both beams and dispersed in two way direction .Being identical they have same deflection and carry half the load .Thus each support reactions equal to one –fourth of load .

In a planar frame structure ,joint displacement are considered as translation in X and Y direction and rotation about Z-axis .However when plane frame is normally loaded ,the displacement of joint are a translation in the Z direction and rotation X and Y axis .In grid connection ,the connection between the members are assumed to be rigid .When beams connected at mid span .It moves downward but remains vertical because of symmetry but when connection is not at mid span the beam rotates and deflects .The continuity introduced by rigid connection transforms the bending rotation of one section into a twisting rotation of other .A grid frame is considered as a special case of a rigid space frame in which the joint rotations may take place about all the three axes and joint displacements may have components along all the three axes.



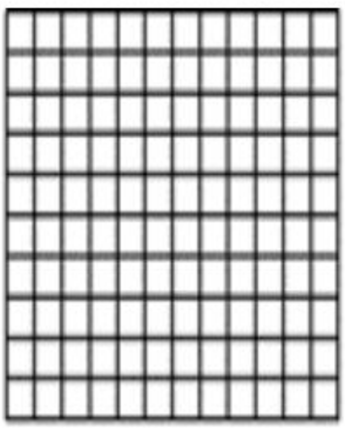

concentrated load on two dimensional system

# TYPES OF GRIDS

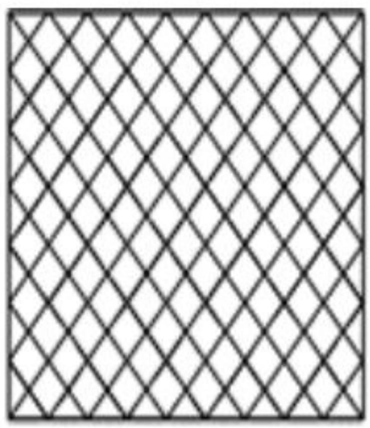
Grids may be divided into two types in structural analysis point of view

1. Supported along all four sides
   These are generally used for buildings roofs and floors .They can be used to cover square rectangular ,triangular ,hexagonal or circular areas .
   - Orthogonal grid
   - Diagonal grid
   - Three way grid
   - Hexagonal grid
   - Skew grid (It is comparatively strong as the stress distribution is uniform )

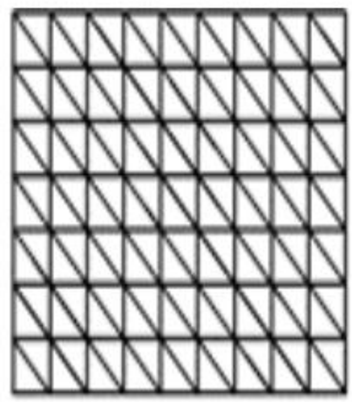
2. Supported along two sides
   These are used rectangular grid is more popular especially for concrete construction .



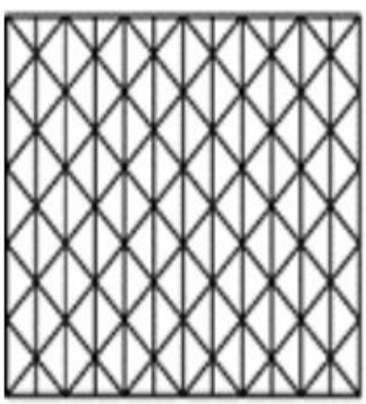
**(a)** Two-way grid



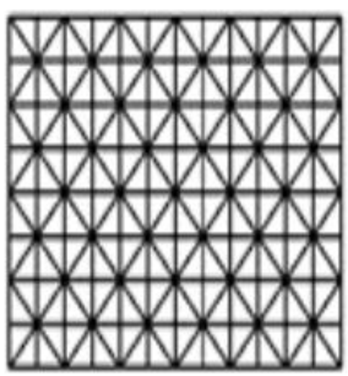
**(b)** Diagonal grid



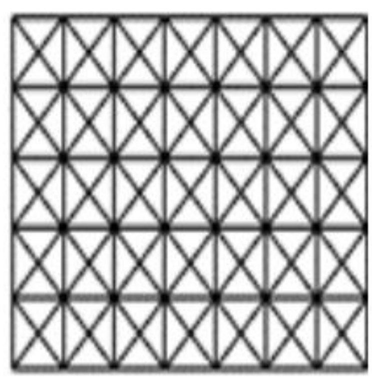
**(c)** Three-way grid



**(d)** Three-way grid



**(e)** Four-way grid



**(f)** Four-way grid