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# DESIGN OF CONCRETE STRUCTURES

By
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| 3. | Design of Rectangular Doubly Reinforced Section by Working Stress Method | 2 | 0 | 0 | 1 | 1 | 1.10, 1.12, 1.13, 1.14 |
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* = Asked in different years



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| | Total Questions | 1 | 2 | 2 | 3 | 3 | |

* = Asked in different years

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| Part | Topics | 2017-18 | 2016-17 | 2015-16 | 2014-15 | 2013-14 | Que. No. |
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| | Total Questions | 3 | 4 | 2 | 3 | 4 | |



## 2 Marks Questions

| Units \ Year | 2017-18 | 2016-17 | 2015-16 | 2014-15 | 2013-14 | Total Questions |
|---|---|---|---|---|---|---|
| Unit-1 | 7 | 2 | 4 | 0 | 0 | 13 |
| Unit-2 | 0 | 1 | 2 | 0 | 0 | 3 |
| Unit-3 | 0 | 3 | 1 | 0 | 0 | 4 |
| Unit-4 | 0 | 2 | 2 | 0 | 0 | 4 |
| Unit-5 | 2 | 5 | 0 | 0 | 0 | 7 |

| Units | Ques. Asked (2013-14) | % Weightage of Units (2013-14) |
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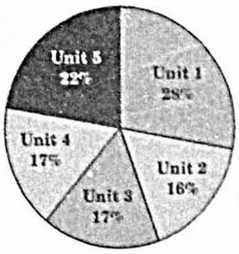
| Unit-1 | 5 |  |
| Unit-2 | 3 | |
| Unit-3 | 3 | |
| Unit-4 | 3 | |
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| Units | Ques. Asked (2014-15) | % Weightage of Units (2014-15) |
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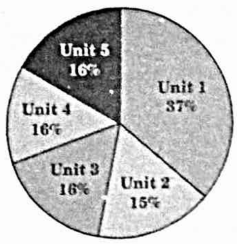
| Unit-1 | 7 |  |
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| Unit-5 | 3 | |

| Units | Ques. Asked (2015-16) | % Weightage of Units (2015-16) |
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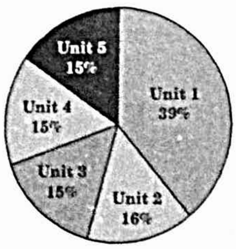
| Unit-1 | 5 |  |
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| Unit-5 | 2 | |



| Units | Ques. Asked (2016-17) | % Weightage of Units (2016-17) |
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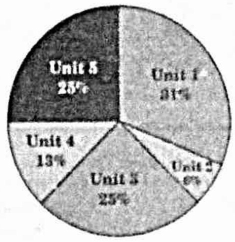
| Unit-1 | 5 |  |
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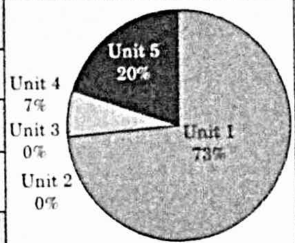
| Unit-3 | 4 | |
| Unit-4 | 2 | |
| Unit-5 | 4 | |

| Units | Ques. Asked (2017-18) | % Weightage of Units (2017-18) |
|---|---|---|
| Unit-1 | 11 |  |
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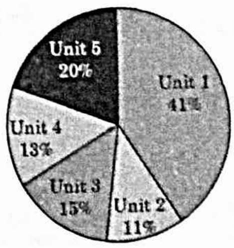
| Unit-3 | 0 | |
| Unit-4 | 1 | |
| Unit-5 | 3 | |

| Units | Total Questions (2013-14 to 2017-18) | % Weightage of Units (2013-14 to 2017-18) |
|---|---|---|
| Unit-1 | 33 |  |
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| Unit-4 | 11 | |
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# 1 UNIT

# Design of Beam

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## PART-1

*Introduction to Various Design Philosophies.*

### CONCEPT OUTLINE

**Design philosophies :** There are three design philosophies :

i. Working stress design,
ii. Ultimate load design, and
iii. Limit state design.

**Modular Ratio :** It is the ratio between the moduli of elasticity of steel and concrete.

**Neutral Axis :** It is an imaginary plane which divides the cross-section of the beam into the tension and compression zones lying on the opposite side of the plane. It is denoted by '$n$', it is calculated by following given formula :

$$\frac{bn^2}{2} = m A_{st} (d-n)$$

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 1.1.** What are various design philosophies ? Explain any one of these in detail. **AKTU 2014-15, Marks 05**

OR

Discuss the salient features of working stress method and ultimate load method. **AKTU 2016-17, Marks 10**

OR

Write assumption made in working stress method. **AKTU 2017-18, Marks 10**

**Answer**

There are three basic design philosophies :

A. **Working Stress Method (WSM) :**

1. This method is based on the elastic theory and assumes that both steel and concrete are elastic and obey Hook's law. It means that the stress is directly proportional to strain up to the point of collapse.
2. According to this method, the bond between steel and concrete is perfect, permissible stresses of the materials are obtained.

**Assumptions :** Following are the assumptions of WSM :

i. A section which is plane before bending remains plane after bending.
ii. All tensile stresses are taken up by steel and none by concrete.
iii. The moduli of elasticity of steel ($E_s$) and concrete ($E_c$) are constant.
iv. The modular ratio ($m$) has the value $\frac{280}{3\sigma_{cbc}}$, where $\sigma_{cbc}$ is the permissible compressive strength of concrete in bending in N/mm$^2$.
v. There are no initial stresses in steel and concrete.

3. **Advantages :** Following are the advantages of the WSM :
i. It is simple.
ii. As the working stresses are low, the serviceability requirements are automatically satisfied and there is no need to check them.
iii. Reasonably reliable.

4. **Limitations :** Following are the limitations of working stress method :
i. Concrete behaves inelastically on low level of stresses.
ii. It does not use any factor of safety with respect to loads.
iii. It does not account for shrinkage and creep which are time dependent and plastic in nature.
iv. This method gives uneconomical sections.

**B. Ultimate Load Factor Method :**

1. In this method, ultimate or collapse load is used as design load.
2. The ultimate loads are obtained by increasing the working/service loads suitably by some factor. These factors which are multiplied by the working loads to obtain ultimate loads are called as load factors.
3. These load factors give the exact margins of safety in terms of load.
4. This method uses the real stress-strain curve of concrete and steel and takes into account the plastic behaviour of these materials.

$$\text{Load factor} = \frac{\text{Collapse load}}{\text{Working load}}$$

**Advantages :** Following are the advantages of ULM :
i. This method is more realistic as compared to WSM.
ii. This method is more economical as compared to WSM.

**Limitations :** Following are the limitations of ULM :
i. This method gives very thin sections which leads to excessive deformations and cracking, thus making the structure unserviceable.
ii. No factors of safety are used for material stresses.

**C. Limit State Method :**



1. This is the most rational method which takes into account the ultimate strength of the structure and also the serviceability requirements.
2. It is a judicious combination of working stress and ultimate load methods of design.
3. This method is based on the concept of safety at ultimate load (ultimate load method) and serviceability at working loads (working stress method).
4. The two important limit states to be considered in design are :
i. Limit state of collapse.
ii. Limit state of serviceability.
5. This method is based upon the probabilistic variation in the loads and material properties. Limit state method takes into account the uncertainties associated with loads and material properties, thus uses partial factors of safety to obtain design loads and design stresses.

**Que 1.2.** **What is neutral axis ? Determine the location of neutral axis.**

**Answer**

**Neutral Axis :** It is an imaginary plane which divides the cross-section of a beam into the tension and compression zones lying on the opposite side of the plane.

**Location of Neutral Axis :** The neutral axis of a beam can be determined by two methods.

**A. 1st method :**

i. This method is applied when stresses developed in concrete and steel are known.

Let, $c$ = Compressive stress in the extreme fibre of concrete.
$t$ = Tensile stress in steel reinforcement,
$n = kd$ = Depth of neutral axis (NA) below the top of the beam.
$k$ = Neutral axis factor.

ii. From the stress diagram, we have

$$\frac{c}{t/m} = \frac{n}{d-n}$$

$$\frac{mc}{t} = \frac{n}{d-n}$$

$$k = \frac{n}{d} = \frac{mc}{mc+t} = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}}$$

iii. The permissible values of $c$ and $t$ are $\sigma_{cbc}$ and $\sigma_{st}$ respectively. From eq. (1.2.1)

**Assumptions :** Following are the assumptions of WSM :

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$$\frac{c}{t/m} = \frac{n}{d-n}$$

$$\frac{mc}{t} = \frac{n}{d-n}$$

$$k = \frac{n}{d} = \frac{mc}{mc+t} = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}}$$

iii. The permissible values of $c$ and $t$ are $\sigma_{cbc}$ and $\sigma_{st}$ respectively. From eq. (1.2.1)

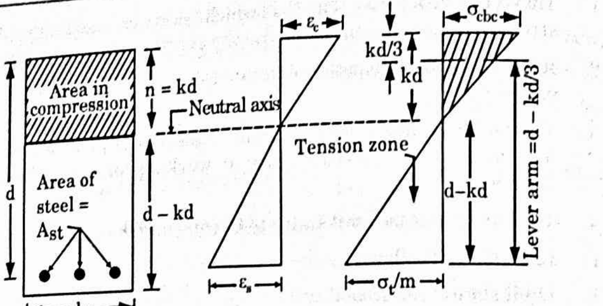



**Fig. 1.2.1.**

**B. 2nd method :**

i. This method is based on the assumption that the neutral axis of a homogenous beam always passes through the center of gravity of the section. Hence, the moments of area above and below the neutral axis (moment being taken about the neutral axis) must be equal.

ii. Taking the moments of area in compression and the tension, about the neutral axis, we have,

$$bn\frac{n}{2} = mA_{st}(d-n)$$

iii. Above equation will give two values of $n$, only positive value of $n$ should be considered.

**Que 1.3.** **Explain the following terms :**

**A. Balanced section.**

**B. Under-reinforced section.**

**C. Over-reinforced section.** **AKTU 2014-15, Marks 05**

**OR**

**Write formula to determine the moment of resistance of over reinforced section and under reinforced section. With diagram of section.** **AKTU 2017-18, Marks 10**

**OR**

**What is critical section and critical neutral axis ?** **AKTU 2017-18, Marks 10**

**Answer**

**A. Balanced Section :**

1. A balanced section is that in which stress in concrete and steel reach their permissible value at the same time.



2. The percentage of steel corresponding to this section is called as balanced steel and the neutral axis is called as critical neutral axis ($n_c$) as shown in Fig. 1.3.1. (*b*)

$$\frac{n_c}{d-n_c} = \frac{\sigma_{cbc}}{\sigma_{st}/m}$$

3. For a balanced section, the moment of resistance is calculated as :

$$M_r = \frac{\sigma_{cbc}}{2} b\,n_c\left(d-\frac{n_c}{3}\right)$$

$$M_r = \sigma_{st}A_{st}\left(d-\frac{n_c}{3}\right)$$

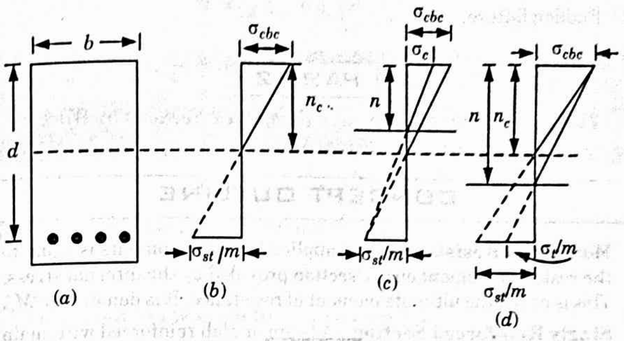



**Fig. 1.3.1.**

**B. Under Reinforced Section :**

1. In this section, the percentage of steel provided is less than that provided in balanced section. So the actual neutral axis will shift upwards *i.e.*, $n_c > n$ as shown in Fig. 1.3.1 (*c*).

2. In under reinforced section the stress in steel first reaches its permissible value, while the concrete is under stressed.

3. The moment of resistance of this section is calculated as :

$$M_r = \sigma_{st}A_{st}\left(d-\frac{n}{3}\right)$$

4. **Properties of Under Reinforced Section :**

i. Steel is fully stressed while concrete not.

ii. Ductile failure.

iii. The moment of resistance is less than balanced section.

**C. Over Reinforced Section :**

1. In an over reinforced section the percentage of steel provided is greater than the balanced section. So the actual neutral axis shift downwards *i.e.*, $n > n_c$ as shown in Fig. 1.3.1(*d*).

2. In this section, stress in concrete reaches its permissible value while steel is not fully stressed. Concrete is brittle and it fails by crushing suddenly.
3. The moment of resistance of this section is calculated as :

$$M_r = \frac{1}{2}\sigma_{cbc} bn\left(d - \frac{n}{3}\right)$$

4. **Properties of Over Reinforced Section :**

i. Concrete is fully stressed while steel is not.

ii. The percentage of steel is more than the balanced section, so the section is uneconomical.

iii. Sudden failure.

## PART-2

*Design of Rectangular Singly Reinforced Sections by Working Stress Method.*

### CONCEPT OUTLINE

**Moment of Resistance :** The applied bending moments is equal to the resisting moment on the section provided by the internal stress. This is called the ultimate moment of resistance. It is denoted by '$M_r$'.

**Singly Reinforced Section :** A beam or slab reinforced with main steel provided only in tension zone called singly reinforced section.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 1.4.** **Describe the procedure to determine the moments of resistance and design of section of singly reinforce.**

**Answer**

A. **To Determine the Moment of Resistance of the Given Section :**

**Procedure :**

i. For the given grade of concrete and steel, determine the permissible stresses *i.e.*, $\sigma_{cbc}$ and $\sigma_{st}$.

ii. Calculate modular ratio *m*.

$$m = \frac{280}{3\sigma_{cbc}}$$



iii. Determine critical neutral axis ($n_c$)

$$\frac{m\,\sigma_{cbc}}{\sigma_{st}} = \frac{n_c}{d - n_c}$$

iv. Determine actual neutral axis (*n*)

$$b\frac{n^2}{2} = m\,A_{st}\,(d - n)$$

v. Compare *n* and $n_c$.

vi. If $n = n_c$, the section is balanced and the moment of resistance can be calculated by any of the following equation

$$M_r = \frac{1}{2}\sigma_{cbc}\, b\, n_c\left(d - \frac{n}{3}\right)$$

or

$$M_r = \sigma_{st}\, A_{st}\left(d - \frac{n}{3}\right)$$

vii. If $n < n_c$, the section is under reinforced and the moment of resistance is calculated as

$$M_r = \sigma_{st}\, A_{st}\left(d - \frac{n}{3}\right)$$

viii. If $n > n_c$, the section is over reinforced and

$$M_r = \frac{1}{2}\sigma_{cbc}\, b\, n_c\left(d - \frac{n}{3}\right)$$

B. **To Design the Section for Given Loading :**

1. Determine the permissible stresses for materials from
2. Determine design constant *k*, *j* and *R*.
3. Assume suitable value of b/d ratio and calculate the moment of resistance using

$$M_r = Rnd^2$$

4. For the given loads and approximate self weight, compute the maximum bending moment (*M*).
5. Determine d by equating *M* and $M_r$

$$M_r = M$$
$$Rbd^2 = M$$
$$d = \sqrt{\frac{M}{Rb}}$$

6. Calculate b from assumed $\frac{b}{d}$ ratio $\left[\frac{b}{d} \text{ varies from } \frac{1}{2} \text{ to } \frac{2}{3}\right]$
7. Calculate ($A_{st}$) area of steel as follows :

$$M = \sigma_{st} A_{st}\, jd$$
$$A_{st} = \frac{M}{\sigma_{st}\, jd}$$

8. Provide suitable number of bars for the required area of steel, $A_{st}$.

**Que 1.5.** The moment of resistance of rectangular reinforced concrete beam of breadth '*b*' and effective depth '*d*' cm is '$0.9\ bd^2$'. If the stress in the outside fibre of concrete and in the steel do not exceed 5 N/mm² and 140 N/mm² respectively and the modular ratio equals 18, determine the ratio of depth of the neutral axis from the outside compression fibre to the effective depth of the beam and the ratio of area of tension steel to the effective area of the beam. The beam is reinforced for tension only. **AKTU 2015-16, Marks 10**

**Answer**

Given : Modular ratio, $m = 18$, $\sigma_{cbc} = 5$ N/mm², $\sigma_{st} = 140$ N/mm²

Moment of resistance, $M_r = 0.9\ bd^2$

**To Find :** $\frac{n}{d} = ?$ and $\frac{A_{st}}{bd} = ?$

1. As in the given question, reinforcement is provided only in tension side. Hence, from MOR of singly reinforced beam,

$$\text{MOR} = \frac{1}{2} b\,\sigma_{cbc} n\left(d - \frac{n}{3}\right)$$

$$0.9bd^2 = \frac{1}{2} b \times 5 \times n\left(d - \frac{n}{3}\right)$$

$$\frac{0.9 \times 2}{5} = \frac{n}{d}\left(1 - \frac{n}{3d}\right)$$

2. Assume $\frac{n}{d} = A$

$$0.36 = A\left(1 - \frac{A}{3}\right)$$

$$0.36 \times 3 = [3A - A^2]$$

$$A^2 - 3A + 1.08 = 0$$

$$A = n/d = 2.58 \text{ and } 0.42$$

3. $n/d$ should not greater than 1, so 0.42 is acceptable value.

Hence, $\frac{n}{d} = 0.42$

4. Force of compression = Force of tension

$$\frac{1}{2} b\sigma_{cbc} n = \sigma_{st} A_{st}$$

5. Multiply with '*d*' on both side, we get

$$\frac{1}{2} b\,\sigma_{cbc}\, nd = \sigma_{st}\, A_{st}\, d$$

$$\frac{A_{st}}{bd} = \frac{\sigma_{cbc}\, n}{2 \times \sigma_{st}\, d} = \frac{5 \times 0.42}{2 \times 140} = 7.5 \times 10^{-3}$$



**Que 1.6.** A beam section 230 mm × 300 mm effective depth is reinforced with 2 bars of 12 mm diameter. Determine its moment capacity and stresses developed in concrete and steel used concrete is M 20 and steel Fe 415. **AKTU 2013-14, Marks 10**

**Answer**

**Given :** Width of beam, $b = 230$ mm,

Effective depth of beam, $d = 300$ mm, Number of bar = 2,

Diameter of bar, $\phi = 12$ mm,

$\sigma_{cbc} = 7$ N/mm² for M20, $\sigma_{st} = 230$ N/mm² for Fe415.

**To Find :** Moment capacity and stress in concrete.

1. **Area of Reinforcement :** Area of reinforcement,

$$A_{st} = 2 \times \frac{\pi}{4} \times 12^2 = 226.2 \text{ mm}^2$$

2. **Position of Actual Neutral Axis :** Equating moment of the area of concrete in compression to the equivalent area of steel in tension about the neutral axis. We have,

$$\frac{bn^2}{2} = mA_{st}(d - n)$$

$$\frac{230}{2} n^2 = 13.33 \times 226.2\,(300 - n)$$

$$n^2 + 26.22n - 7866 = 0$$

$$n = 76.54 \text{ mm}$$

3. **Position of Critical Neutral Axis :** The depth of critical neutral axis ($n_c$) for the balanced section is given by,

$$\frac{n_c}{d} = \frac{m\,\sigma_{cbc}}{m\,\sigma_{cbc} + \sigma_{st}}$$

$$\frac{n_c}{300} = \frac{13.33 \times 7}{13.33 \times 7 + 230}$$

$$n_c = 86.58 \text{ mm}$$

4. **Moment of Resistance :** The section is under reinforced ($n < n_c$) the moment of resistance is given by,

$$M_r = \sigma_{st}\, A_{st}\left(d - \frac{n}{3}\right) = 230 \times 226.2\left(300 - \frac{76.54}{3}\right)$$

$$M_r = 14.28 \text{ kN-m}$$

5. **Stress in Concrete and Steel :**

Stress in steel, $\sigma_{st} = 230$ N/mm²

Stress in concrete,

$$\frac{\sigma_{cbc}}{\sigma_{st}/m} = \frac{n}{d-n}$$

$$\sigma_{cbc} = \left(\frac{76.54}{300-76.54}\right) \times \frac{230}{13.33} = 5.9 \text{ N/mm}^2$$

**Que 1.7.** **Cross section of a singly reinforced concrete beam is 300 mm wide and 500 mm deep. To centre of reinforcement which consist of 4 bars of 16 mm diameter. If stresses in concrete and steel are not to exceed 7 N/mm$^2$ and 140 N/mm$^2$, respectively. Determine the moment of resistance of beam. Take $m$ = 13.33.**

**AKTU 2017-18, Marks 10**

**Answer**

**Procedure :** Same as Q. 1.6, Page 1-10A, Unit-1.

i. Position of Neutral axis, $n$ = 156.65 mm
ii. Position of critical neutral axis $n_c$ = 200 m (Beam design as a under reinforcement)
iii. Moment of resistance, $m_r$ = 50.418 kN-m

**Que 1.8.** **A singly reinforced concrete beam in 300 mm wide and 450 mm deep to the centre of reinforcement which consists of 4 bars of 16 mm diameter. If safe stress in concrete and steel are 7 N/mm$^2$ and 230 N/mm$^2$, respectively. Find moment of resistance of section. Take $m$ = 13.33.**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Width of beam, $b$ = 300 mm, Effective depth of beam, $d$ = 450 mm, Modular ratio, $m$ = 13.33, Stress in concrete, $\sigma_{cbc}$ = 7 N/mm$^2$, Stress in steel, $\sigma_{st}$ = 230 N/mm$^2$

**To Find :** Moment of resistance.

1. **Area of Reinforcement, $A_{st}$ :** Area of four 16 mm $\phi$ bars,

$$A_{st} = 4 \times \frac{\pi}{4} \times 16^2 = 804.25 \text{ mm}^2$$

2. **Position of Actual Neutral Axis :** Equating moment of the area of concrete in compression to the equivalent area of steel in tension about the neutral axis, we get

$$\frac{bn^2}{2} = mA_{st}(d-n)$$

$$\frac{300 \times n^2}{2} = 13.33 \times 804.25 \times (450 - n)$$



$$150n^2 + 10720.65\, n - 4824293.63 = 0$$

$$n = 147.13 \text{ mm}$$

3. **Position of Critical Neutral Axis :** The depth of critical neutral axis ($n_c$) for the balanced section is given by,

$$\frac{n_c}{d} = \frac{m\,\sigma_{cbc}}{m\,\sigma_{cbc} + \sigma_{st}}$$

$$\frac{n_c}{450} = \frac{13.33 \times 7}{13.33 \times 7 + 230}$$

$$n_c = 129.87 \text{ mm}$$

$n_c < n$, hence, section is over reinforced.

4. **Moment of Resistance of the Section :** Section is over reinforced. The moment of resistance of beam is given by,

$$= \frac{1}{2} bn\,\sigma_{cbc}\left(d - \frac{n}{3}\right)$$

$$= \frac{1}{2} \times 300 \times 147.13 \times 7\left(450 - \frac{147.13}{3}\right)$$

$$M_r = 61942392.09 \text{ N-mm} = 61.94 \text{ kN-m.}$$

**Que 1.9.** **A singly reinforced rectangular beam 350 mm wide has a span of 6.25 m and carries a load of 16.3 kN/m. If stresses in concrete and steel shall not exceed 7 N/mm$^2$ and 230 N/mm$^2$. Find the effective depth and area of tensile reinforcement. Take $m$ = 13.33.**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Width of beam, $b$ = 350 mm, Effective span, $l$ = 6.25 m, Service load = 16.3 kN/m, Stress in concrete, $\sigma_{cbc}$ = 7 N/mm$^2$, Stress in steel, $\sigma_{st}$ = 230 N/mm$^2$.

**To Find :** Effective depth and tensile reinforcement.

1. **Moment due to Service Load :**

Moment, $$M = \frac{wl^2}{8} = \frac{16.3 \times 6.25^2}{8} = 79.59 \text{ kN-m}$$

2. **Value of $k$ :** $$k = \frac{n}{d} = \frac{m\sigma_{cbc}}{m\,\sigma_{cbc} + \sigma_{st}} = \frac{13.33 \times 7}{13.33 \times 7 + 230} = 0.289$$

3. **Value of $j$ :**

Lever arm factor, $$j = 1 - \frac{k}{3} = 1 - \frac{0.289}{3} = 0.904$$

4. **Value of $R$ :**

Co-efficient of resisting moment,

$$R = \frac{1}{2}\sigma_{cbc}\, jk = \frac{1}{2} \times 7 \times 0.904 \times 0.289 = 0.9144$$

5. **Depth of Section :**

$$Rd^2b = M_r$$

$$d = \sqrt{\frac{M_r}{Rb}} = \sqrt{\frac{79.59 \times 10^6}{0.9144 \times 350}} = 498.686 \text{ mm}$$

Provide, $d = 500$ mm

6. **Area of Reinforcement :**

i. Assume that section is design as under reinforced section.

$$A_{st} = \frac{M_r}{j\,d\sigma_{st}} = \frac{79.59 \times 10^6}{0.904 \times 500 \times 230} = 765.6 \text{ mm}^2$$

ii. Assume 16 mm diameter bars are provided, number of bar

$$= \frac{765.6}{\frac{\pi}{4} \times 16^2} = 3.8 \simeq 4$$

iii. Provide 4# 16 mm $\phi$ bars.

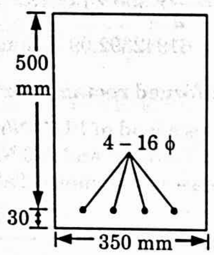



**Fig. 1.9.1.**

**PART-3**

*Design of Rectangular Doubly Reinforced Sections by Working Stress Method.*

**CONCEPT OUTLINE**

**Doubly Reinforced Beam :** A beam or slab reinforced with main steel both in tension and compression zones is said to be doubly reinforced section.

**Position of Neutral Axis :** Equating the moment of compressive areas about NA to the moment of tensile area about NA we have,

$$\frac{bn^2}{2} + (1.5\,m - 1)\,A_{sc}\,(n - d') = m\,A_{st}\,(d - n)$$

**Moment of Resistance of Doubly Reinforced Beam :**

$$M_r = bn\frac{\sigma_{cbc}}{2}\left(d - \frac{n}{3}\right) + (1.5\,m - 1)\,A_{sc}\,c'\,(d - d')$$



**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 1.10.** **What is doubly reinforced section and under what condition it is provided ?**

**OR**

**Under what circumstances a doubly reinforced beam is designed ?**

**AKTU 2014-15, Marks 05**

**Answer**

1. **Doubly Reinforced Section :** A beam or slab reinforced with main steel both in tension and compression zones is said to be doubly reinforced.
2. A doubly reinforced section is generally provided under the following conditions :
   i. When the depth and breadth of the beam are restricted and it has to resist greater bending moment than a singly reinforced beam of that section would do.
   ii. When the beam is continuous over several supports, the section of the beam at the supports is usually designed as a doubly reinforced-section.
   iii. When the member is subjected to eccentric loading.
   iv. When the bending moment in the member reverses according to the loading conditions e.g., the wall of an underground RCC storage reservoir, brackets etc.
   v. When the member is subjected to shocks impact or accidental lateral thrust.

**Que 1.11.** **Explain the design procedure of doubly reinforced beam.**

**Answer**

**Design Procedure :** Following are the steps for designing of a doubly reinforced beam :

1. Find the position of the actual neutral axis of the section. This is given by

$$\frac{bn^2}{2} + (m_c - 1)A_{sc}(n - d') = mA_{st}(d - n)$$

2. Find the position of the critical axis ($n_c$) by the equation

$$\frac{n_c}{d} = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}}$$

3. If the actual neutral axis lies above the critical neutral axis, the stress in

tensile steel attains its maximum permissible value (*i.e.*, $t = \sigma_{st}$) first and the corresponding value of stress in concrete at top ($c$) and stress in concrete surrounding compression steel ($c'$) will be given by,

$$c = \frac{\sigma_{st}}{m} \times \frac{n}{(d-n)}$$

Stress in concrete surrounding steel in compression is given by,

$$c' = c\frac{(n-d')}{n}$$

4. Having known the value of $c$ and $c'$, the moment of resistance of the section can be obtained by taking the moments of all the forces about the tensile steel. This is given by the equation.

$$M_r = bn\frac{c}{2}\left(d - \frac{n}{3}\right) + (m_c - 1)A_{sc}c'(d - d')$$

It may be noted that the value of (c) in the expression is different from permissible compression stress in concrete *i.e.*, $\sigma_{cbc}$.

5. If the actual neutral axis lies below the critical neutral axis or coincides with it, the stress in concrete attains its maximum permissible value first and hence the moment of resistance of the section is obtained by,

$$M_r = bn\frac{\sigma_{cbc}}{2}\left(d - \frac{n}{3}\right) + (1.5m - 1)A_{sc}c'(d - d')$$

**Que 1.12. A doubly reinforced rectangular beam is 300 mm wide and 500 mm deep to centre of tension steel. It is reinforced with 4 bars of 18 mm dia. as compressive steel at an effective cover of 40 mm and with 4 bars of 20 mm dia. as tensile steel. If stresses in concrete and steel are not to exceed 7 N/mm² and 230 N/mm², respectively. Find moment of resistance of section. Take $m$ = 13.33.**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Width of beam, $b$ = 300 mm, Effective depth of beam, $d$ = 500 mm, Diameter of compression steel = 18 mm,
Diameter of tension steel = 20 mm, Modular ratio, $m$ = 13.33,
Stress in concrete, $\sigma_{cbc}$ = 7 N/mm², Stress in steel, $\sigma_{st}$ = 230 N/mm²

**To Find :** Moment of resistance.

1. **Actual Neutral Axis :** Equating the moment of the area of concrete and equivalent concrete area of compression steel to the moment of the equivalent concrete area of steel in tension about the neutral axis, we get



$$\frac{bn^2}{2} + (m_c - 1)A_{sc}(n - d') = m A_{st}(d - n) \quad ...(1.12.1)$$

i. Area of compression steel,

$$A_{sc} = 4 \times \frac{\pi}{4}(18)^2 = 1017.88 \text{ mm}^2$$

ii. Area of tension steel,

$$A_{st} = 4 \times \frac{\pi}{4}(20)^2 = 1256.64 \text{ mm}^2$$

iii. Substituting the values in eq. (1.12.1), we get

$$\frac{300}{2}n^2 + (1.5 \times 13.33 - 1) \times 1017.88 \times (n - 40)$$

$$= 13.33 \times 1256.64\,(500 - n)$$

$$150n^2 + 19334.63n - 773385.224 = 8375505.6 - 16751.01n$$

$$150n^2 + 36085.64n - 9148890.824 = 0$$

$$n = 154.42 \text{ mm}$$

2. **Critical Neutral Axis :**

$$\frac{n_c}{d} = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}} = \frac{13.33 \times 7}{13.33 \times 7 + 230}$$

$$n_c = 0.289 \times 500 = 144.5 \text{ mm}$$

3. Since the actual NA lies below the critical NA, the stress in concrete will first reach its maximum permissible value.
Hence the stress in concrete surrounding compression steel is given by,

$$c' = \frac{\sigma_{cbc}}{n}(n - d') = \frac{7}{154.42}(154.42 - 40)$$

$$c' = 5.187 \text{ N/mm}^2$$

4. **Moment of Resistance :**

$$M_r = bn\frac{\sigma_{cbc}}{2}\left(d - \frac{n}{3}\right) + (1.5m - 1)A_{sc}c'(d - d')$$

$$= 300 \times 154.42 \times \frac{7}{2}\left(500 - \frac{154.42}{3}\right)$$

$$+ (1.5 \times 13.33 - 1) \times 1017.88 \times 5.187\,(500 - 40)$$

$$= 72.725 \times 10^6 + 46.133 \times 10^6$$

$$M_r = 118.86 \text{ kN-m}$$

**Que 1.13. Design a rectangular beam section to carry 160 kN-m moment with M 20 concrete and Fe 415 steel. The overall depth of the beam is restricted to 270 mm.**

**AKTU 2013-14, Marks 10**

**Answer**

**Given :** Moment, $M$ = 160 kN-m, Overall depth, $D$ = 270 mm
**To Find :** Design rectangular beam.
**Note :** In this question moment is not suitable to this depth. So we assume the moment as 16 kN-m
Assume width of beam, $b$ = 200 mm
Effective depth of beam, $d$ = 270 – 30 = 240 mm

**1. Calculation for $k$, $j$ and $R$ :**

i. $$k = \frac{m\,\sigma_{cbc}}{m\,\sigma_{cbc} + \sigma_{st}} = \frac{13.33 \times 7}{13.33 \times 7 + 230} = 0.289$$

ii. Liver arm factor, $j = 1 - \dfrac{k}{3} = 1 - \dfrac{0.289}{3} = 0.904$

iii. Coefficient of moment,

$$R = \frac{1}{2}\sigma_{cbc} \times j \times k = \frac{1}{2} \times 7 \times 0.904 \times 0.289 = 0.914$$

**2. Moment of Reinforced for Balanced Section :**

$$M_r = Rbd^2 = 0.914 \times 200 \times 240^2 = 10.53 \text{ kN-m}$$

**3. Moment of Resistance for Compression Zone :**

$$M = M_1 + M_2$$
$$M_2 = M - M_1 = 16 - 10.53 = 5.47 \text{ kN-m}$$

**4. Area of Steel for Tension Reinforcement :**

i. $$A_{st} = A_{st1} + A_{st2}$$
$$= \frac{M_1}{\sigma_{st}\left(d - \dfrac{n_c}{3}\right)} + \frac{M_2}{\sigma_{st}(d - d')}$$

Assume $d'$ = 0.1 $d$ = 240 × 0.1 = 24 mm

$d'$ = 25 mm

$$A_{st} = \frac{10.53 \times 10^6}{230\left(240 - 240 \times \dfrac{0.289}{3}\right)} + \frac{5.47 \times 10^6}{230 \times (240 - 25)}$$

$$= 211.1 + 110.62 = 321.72 \text{ mm}^2$$

ii. Use 12 mm $\phi$ bar,

$$\text{Number of bar} = \frac{321.72}{\dfrac{\pi}{4} \times 12^2} = 2.84 \simeq 3$$

Provide 3# 12 mm $\phi$ bar in tension zone.

**5. Area of Steel for Compression Reinforcement :**



i. $$A_{sc} = \frac{m_2}{c'(m_c + 1)(d - d)}$$

$$c' = \frac{c}{n_c}(n_c - d') = \frac{7}{69.36}(69.36 - 25) = 4.447 \text{ N/mm}^2$$

$$m_c = 1.5 \times 13.33 = 20$$

$$A_{sc} = \frac{5.47 \times 10^6}{4.477 \times (20 - 1)(240 - 25)} = 299.09$$

$$\simeq 300 \text{ mm}^2$$

ii. Use 12 mm $\phi$ bar,

$$\text{Number of bar} = \frac{300}{\dfrac{\pi}{4} \times 12^2} = 2.65 \simeq 3$$

Provide 3# 12 mm $\phi$ bar in compression zone.

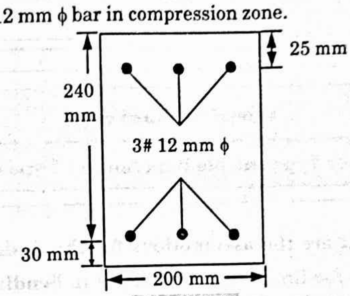



**Fig. 1.13.1.**

**Que 1.14.** A beam of reinforcement concrete is 300 mm wide and 450 mm deep to centre of tension steel. It is reinforced with 4 bars of 16 mm dia. as compressive steel and 4 bars of 25 mm dia. as tensile steel. Determine the moment of resistance of section. Cover to centre of compressions steel = 50 mm use M20 concrete and Fe 415 steel. Take $m$=13.33. **AKTU 2017-18, Marks 10**

**Answer**

**Procedure :** Same as Q. 1.12, Page 1-15A, Unit-1.

Moment of resistance, $M_r$ = 105.54 kN-m

**PART-4**

***Assumptions in Limit State Design, Design of Rectangular Singly Reinforced Beam by Limit State Method.***

## CONCEPT OUTLINE

**Limit State :** It means the acceptable limits for the safety and serviceability requirements before failure.

**Types of Limit State :** There are two types of limit state :

i. Limit state of collapse, and
ii. Limit state of serviceability.

**Characteristic Strength :** It means that value of the strength of material below which not more than 5 % of the results are expected to fall.

**Factored Load :** A factored load is obtained by multiplying a characteristic load by an appropriate partial safety factor.

**Relation between Strength of Steel and Neutral Axis :**

| $f_y$ (N/mm²) | 250 | 415 | 500 | 550 |
|---|---|---|---|---|
| $x_m$ | 0.53 $d$ | 0.48 $d$ | 0.46 $d$ | 0.44 $d$ |

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 1.15.** What are the assumptions for the design of reinforce concrete section for limit state of collapse in bending ? Derive the stress block parameters for a rectangular cross section.

**AKTU 2015-16, Marks 10**

**Answer**

A. **Assumptions :** Following are the assumption for design of reinforcement concrete section by limit state method :

1. Plane sections normal to the axis remain plane after bending.
2. The maximum strain in concrete at the outermost compression fibre is taken as 0.0035 in bending.
3. The relationship between the stress-strain distribution in concrete is assumed to be parabolic. For design purpose, the compressive strength of concrete is assumed to be 0.67 times the characteristic strength of concrete. The partial safety factor ($r_{mc}$) = 1.5 shall be applied in addition to this
4. Maximum compressive stress in concrete

$$= \frac{0.67 f_{ck}}{1.5}$$



where, $f_{ck}$ = Characteristic strength of concrete.

5. The tensile strength of the concrete is ignored.
6. The stresses in the reinforcement are taken from the stress-strain curve for the type of steel used. For design purpose, the partial safety factor ($r_{ms}$) equal to 1.15 shall be applied.
7. The maximum strain in the tension reinforcement in the section at failure shall not be less than

$$\frac{f_{ck}}{1.15 E_s} + 0.002$$

$f_y$ = Characteristics strength of steel

$E_s$ = Modulus of elasticity of steel.

B. **Derivation :**

1. For the stress-strain curve in Fig. 1.15.2, the design stress block parameters are as shown in Fig. 1.15.1 :

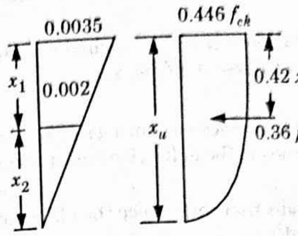



Fig. 1.15.1. Stress block parameters.

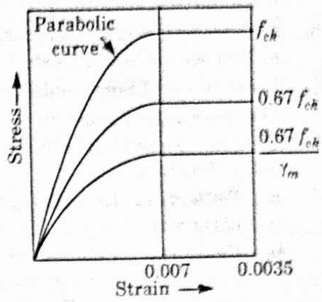



Fig. 1.15.2. Stress-strain curve for concrete.

2. Let $x_1$ = Height of the rectangular part of the stress block.
   $x_2$ = Height of the parabolic part of the stress block.

   Now, $\frac{x_2}{x_u} = \frac{0.002}{0.0035} = \frac{4}{7}$, $\therefore$ $x_2 = \frac{4}{7} x_u$ and $x_1 = \frac{3}{7} x_u$

3. Area of the parabolic part of the stress block

$$= \frac{2}{3} \times 0.446 f_{ck} \times \frac{4}{7} x_u = 0.17 f_{ck} x_u$$

4. Area of the rectangular part of the stress block

$$= 0.446 f_{ck} \times \frac{3}{7} x_u = 0.19 f_{ck} x_u$$

5. The total area of the stress block = $(0.17 + 0.19) f_{ck} x_u = 0.36 f_{ck} x_u$

   where, $f_{ck}$ = Characteristic compressive strength of concrete.
   $x_u$ = Depth of neutral axis.

**Que 1.16.** **What is meant by limit state ? Discuss the different limit state to be considered in reinforced concrete design.**

**AKTU 2014-15, Marks 05**

**Answer**

**Limit State :** The acceptable limit for the safety and serviceability requirements before failure occurs is known as limit state.

The various types of limit states are :

1. **Limit State of Collapse :**
   i. This limit state refers to the strength of the structure. A structure or its part should be strong enough to resist the applied design loads. This is called limit state of collapse.
   ii. The limit state of collapse includes the design for axial forces, flexure, shear, torsion, buckling, etc.
   iii. The strength of each section must be more than the applied stresses on that section due to all expected combination of loads.
2. **Limit State of Serviceability :**
   i. The structure or its part thereof shall be serviceable during its expected life span. The serviceability corresponds to the deflection and cracking of the structure.
      a. **Deflection :** Excessive deflections that can reduce the efficiency of the structure must be avoided.
      b. **Cracking :** Concrete structures have innumerable cracks, however if the crack widths are larger, the appearance of the structure will be affected.
3. **Limit State of Vibration :** Excessive vibration causes discomfort, alarm or actual damage, or interferes with the proper functioning of the structure.
4. **Limit State of Fatigue :** Effects of fatigue should be considered, thereby deflections or stresses may have to be limited.
5. **Limit State of Impact Resistance :** The structure or structural elements which may be subjected to impact explosion or earthquake must always be considered for structural collapse.
6. **Limit State of Durability :**
   i. The durability is an important factor influencing the long-term performance of a concrete structure. The codes stipulate the checking of structure for the durability of concrete and steel as an integral part of the design.
   ii. The durability of reinforced concrete structure can be enhanced by providing adequate cover to reinforcement bars, specifying the minimum cement content and minimum water-cement ratio.



7. **Limit State of Fire Resistance :** For a structural element, which may be subjected to fire, the conditions considered are :
   i. Resistance to structural collapse,
   ii. Resistance to penetration of flames, and
   iii. Resistance to heat penetration.

**Que 1.17.** **A beam of rectangular section 300 mm wide and 500 mm effective depth is provided with 4 bars of 18 mm dia. as tensile steel. Find depth of neutral axis, use M20 concrete and Fe 250 steel.**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Width of beam, $b$ = 300 mm, Effective depth of beam, $d$ = 500 mm, Diameter of bars = 18 mm, Number of bars = 4, $f_{ck}$ = 20 N/mm², $f_y$ = 250 N/mm²
**To Find :** Depth of neutral axis.

1. Area of steel, $A_{st} = 4 \times \frac{\pi}{4} \times 18^2 = 1017.87 \approx 1018 \text{ mm}^2$,
2. Equating tensile and compressive forces,

$$0.36 f_{ck}\, b\, x_u = 0.87 f_y A_{st}$$

$$0.36 \times 20 \times 300\, x_u = 0.87 \times 250 \times 1018$$

$$x_u = 102.5 \text{ mm}$$

**Que 1.18.** **A rectangular beam 200 mm wide and 400 mm effective depth is reinforced with 3 bars of 16 mm diameter. If grade of concrete is M20 and grade of steel Fe 415, determine bending moment capacity of the beam.**

**AKTU 2013-14, Marks 10**

**Answer**

**Given :** Effective depth, $d$ = 400 mm, Width of beam, $b$ = 200 mm, Reinforcement diameter, $\phi$ = 16 mm, Number of bars = 3
**To Find :** Bending moment capacity.

1. Area of reinforcement,

$$A_{st} = 3 \times \frac{\pi}{4} \times (16)^2 = 603.19 \text{ mm}^2$$

2. Percentage of steel,

$$p_t = \frac{A_{st}}{bd} = \frac{603.19}{200 \times 400} \times 100 = 0.75\ \%$$

. Neutral axis and depth ratio,

$$\frac{x_u}{d} = \frac{0.87 f_y A_{st}}{0.36 f_{ck} bd} = 2.417 \frac{f_y}{f_{ck}} \times p_t \qquad \left[\because \frac{A_{st}}{bd} = p_t\right]$$

$$= 2.417 \times \frac{415}{20} \times \frac{0.75}{100} = 0.334$$

4. We know that,

$$\frac{x_{u,max}}{d} = 0.479$$

5. $\frac{x_{u,max}}{d} > \frac{x_u}{d}$, Hence beam is under reinforced.

6. Moment of resistance is given by,

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

$$= 0.87 \times 415 \times 603.19 \times 400\left(1 - \frac{415}{20} \times \frac{603.19}{200 \times 400}\right)$$

$$= 73.484 \text{ kN-m}$$

7. Bending moment capacity, $M_u = 73.484 \times 10^6$ N-mm

**Que 1.19.** **A rectangular beam section is 20 cm wide and 35 cm deep upto the centre of reinforcement. Determine the reinforcement required at the bottom if it has to resist a factored moment of**

**A. 5 kN-m**

**B. 40 kN-m. Use M 25 mix concrete and TOR steel.**

**AKTU 2016-17, Marks 10**

**Answer**

**Given :** Width of beam, $b$ = 20 cm, Effective depth, $d$ = 35 cm
$f_y$ = 415 MPa, $f_{ck}$ = 25 MPa
**To Find :** Required reinforcement at the bottom.

**A. Case I :**

1. Factored bending moment,

$$M_u = 5 \text{ kN-m}$$

Moment of resistance,

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

$$= 0.138 \times 25 \times 200 \times 350^2 = 84.52 \text{ kN-m}$$

2. The actual factored moment, $M_u$ = 5 kN-m, is less than the limiting moment of resistance, the section must be designed as an under-reinforced section.



3. Let the depth of the neutral axis be $x_u$, therefore

$$0.36 f_{ck}\, bx_u\,(d - 0.42\, x_u) = 5 \times 10^6$$

$$0.36 \times 25 \times 200 \times x_u\,(350 - 0.42\, x_u) = 5 \times 10^6$$

$$350\, x_u - 0.42\, x_u^2 = 2777.78$$

$$x_u = 8.02 \text{ mm}$$

4. Equating the total tension to total compression

$$0.87 f_y A_{st} = 0.36 f_{ck}\, b\, x_u$$

$$0.87 \times 415 \times A_{st} = 0.36 \times 25 \times 200 \times 8.02$$

Area of tension steel,

$$A_{st} = 39.98 = 40 \text{ mm}^2$$

Minimum area of steel,

$$A_0 = 0.85 \times \frac{bd}{f_y} = \frac{0.85 \times 200 \times 350}{415}$$

$$= 143.37 \approx 144 \text{ mm}^2$$

Hence provide 2 bars of 10 mm ϕ ($A_{st}$ = 157 mm²)

5. Reinforcement details are shown in Fig. 1.19.1($a$).

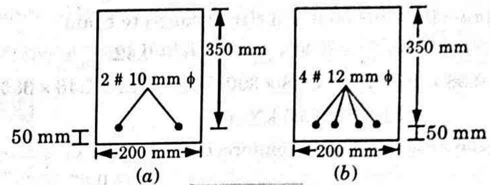



**Fig. 1.19.1.**

**B. Case II :**

1. Factored bending moment, $M_u$ = 40 kN-m

$$\because \; M_{u,\,lim} > M_u$$

$$0.36 \times f_{ck}\, b\, x_u\,(d - 0.42\, x_u) = 40 \times 10^6$$

$$0.36 \times 25 \times 200\,(350 - 0.42\, x_u) \times x_u = 40 \times 10^6$$

$$350\, x_u - 0.42\, x_u^2 = 22222.23$$

Depth of neutral axis,

$$x_u = 69.25 \text{ mm}$$

2. Area of tension steel,

$$A_{st} = \frac{0.36 \times 25 \times 200 \times 69.25}{0.87 \times 415} = 345.20 \text{ mm}^2$$

Minimum area of steel, $A_0 = 0.85 \times \frac{bd}{f_y} = \frac{0.85 \times 200 \times 350}{415}$

$$= 143.37 \approx 144 \text{ mm}^2$$

Hence provide 4# 12 mm diameter bars (Area = 452.39 mm²).

3. Reinforcement details are shown in Fig. 1.19.1($b$).

**Que 1.20.** **Design a reinforced concrete beam subjected to a BM of 20 kN-m. Use M20 concrete Fe 415 reinforcement. Keep the width of the beam equal to half the effective depth.**

**AKTU 2015-16, Marks 10**

**Answer**

**Given :** Bending moment = 20 kN-m, Width of beam, $b = d/2$
$f_{ck} = 20\ \text{N/mm}^2, f_y = 415\ \text{N/mm}^2$
**To Find :** Design of reinforced concrete beam.

1. For Fe 415, $M_u = 0.138 f_{ck}bd^2$

$$1.5 \times 20 \times 10^6 = 0.138 \times 20 \times \frac{d}{2} \times d^2$$

Effective depth, $d = 279.09\ \text{mm} \approx 280\ \text{mm}$
Width, $b = 140$ mm

Let us provide (150 × 300) mm size of concrete beam.

2. $M_{u\,lim} = 0.36 \times f_{ck}bx_{u\,lim}(d - 0.42x_{u\,lim})$

$$M_{u\,lim} = 0.36 \times 20 \times 150 \times 0.48 \times 300 (300 - 0.42 \times 0.48 \times 300)$$

$$M_{u\,lim} = 37.25\ \text{kN-m}$$

3. Hence, the section is under-reinforced.

$$m_u = 0.87 f_y A_{st}\left(d - 0.42 \times \frac{0.87}{0.36 f_{ck} b}\right)$$

$$30 \times 10^6 = 0.87 \times 415 A_{st}\left(300 - 0.42 \times 0.87 \times \frac{415 A_{st}}{0.36 \times 20 \times 150}\right)$$

$$A_{st} = 326.2\ \text{mm}^2$$

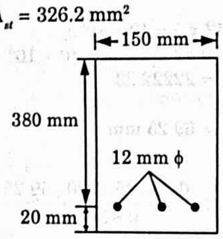



**Fig. 1.20.1.**

4. **Check :** $\frac{(A_{st})_{min}}{bd} = \frac{0.85}{f_y}$

$$A_{st_{min}} = \frac{0.85 \times 150 \times 300}{415} = 92.17\ \text{mm}^2 < 326.2\ \text{mm}^2, \text{(safe)}.$$



5. Provide 12 mm ϕ bars,

$$\text{Number of bar} = \frac{326.2}{\frac{\pi}{4} \times 12^2} = 2.88 \approx 3$$

**Que 1.21.** **Design a singly reinforced concrete beam of width 300 mm, subjected to an ultimate moment of 250 kN-m. Assume $f_{ck}$ = 25 MPa and $f_y$ = 415 MPa.**

**AKTU 2016-17, Marks 10**

**Answer**

**Procedure :** Same as Q. 1.20, Page 1-25A, Unit-1.

**Ans.**
i. Effective depth of beam $d$ = 500 m
ii. Area of reinforcement $A_{st}$ = 1707.5 mm²

**Que 1.22.** **A singly reinforced beam 250 mm wide is 400 mm deep to the centre of tensile reinforcement, determine the limiting moment of resistance of beam section and limiting area of reinforcement. Use M20 concrete and Fe250 steel.**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Width of beam, $b$ = 250 mm, Effective depth of beam, $d = 400$ mm, $f_{ck} = 20\ \text{N/mm}^2$ and $f_y = 250\ \text{N/mm}^2$
**To Find :** $M_{u,\,lim}$ and $A_{st}$.

1. Limiting bending moment for Fe250 steel is given by,

$$M_{u,\,lim} = 0.149 f_{ck}\, bd^2$$

$$M_{u,\,lim} = 0.149 \times 20 \times 250 \times 400^2 = 119.2\ \text{kN-m}$$

2. Limiting depth of neutral axis, $x_u = 0.53 \times 400 = 212$ mm

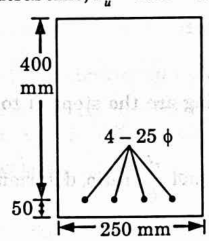



**Fig. 1.22.1.**

3. Area of tension steel corresponding to $M_{u,\,lim}$

$$M_{u,\,lim} = 0.87 \times f_y A_{st}(d - 0.42\, x_u)$$

$$119.2 \times 10^6 = 0.87 \times 250 \times A_{st}(400 - 0.42 \times 212)$$

$$A_{st} = 1762.43\ \text{mm}^2$$

Provide 4-25 mm bars in tension zone.

4. $A_{st}$ provided $= 4 \times \frac{\pi}{4} \times 25^2$

$= 1963.5 \text{ mm}^2 > 1762.43 \text{ mm}^2$

5. Reinforcement details : It is shown in Fig. 1.22.1.

## PART-5

*Design of Rectangular Doubly Reinforced Beam by Limit State Method.*

### CONCEPT OUTLINE

**Force of compression :** $0.36 f_{ck}\, b\, x_u + f_{sc} A_{sc}$

**Force of tension :** $0.87 f_y A_{st}$

**Moment of resistance :**

$$M_r = 0.36 f_{ck}\, b\, x_u (d - 0.42\, x_u) + (f_{sc} - f_{cc}) A_{sc} (d - d')$$

$$f_{cc} = 0.446 f_{ck}$$

$$f_{sc} = 700 \left(1 - \frac{d'}{x_u}\right)$$

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 1.23.** **Discuss the procedure of moment of resistance for doubly reinforced section.**

**Answer**

**Procedure :** Following are the steps of to calculate MOR of doubly reinforced section :

1. For the given of steel and $\frac{d'}{d}$ ratio, determine $f_{sc}$.
2. Determine the depth of neutral axis ($x_u$),

$$x_u = \frac{0.87 f_y A_{st} - f_{sc} A_{sc}}{0.36 f_{ck} b}$$

3. Determine $x_{u\,max}$ and type of beam by comparing $x_u$ and $x_{u\,max}$.
4. The moment of resistance of the section is calculated as :



$$M_u = 0.36 f_{ck} b x_u (d - 0.42 x_u) + (f_{sc} - f_{cc}) A_{sc} (d - d')$$

Neglecting $f_{cc}$, since it is very small,

$$M_u = 0.36 f_{ck} b x_u (d - 0.42 x_u) + f_{sc} A_{sc} (d - d')$$

i. If $x_u < x_{u\,max}$, under-reinforced section and $M_u$ is calculated by above equation.

ii. If $x_u > x_{u\,max}$, over-reinforced section and $M_u$ is calculated by using $x_u = x_{u\,max}$ in the above equation.

**Que 1.24.** **Discuss the design procedure of doubly reinforced beams by limit state method.**

**Answer**

**Procedure :** Following are the step to design a doubly reinforcement beam :

1. Determine the value of $f_{sc}$ for $d'/d$ ratio.
2. Determine $x_{u\,max}$ *i.e.*, limiting depth of neutral axis and $M_{u\,lim}$

$$M_{u\,lim} = 0.36 f_{ck} b (d - 0.42\, x_{u\,max})$$

3. **Determine $A_{st1}$ :**

$$A_{st1} = \frac{M_{u\,lim}}{0.87 f_y (d - 0.42\, x_{u\,max})}$$

4. **Determine $M_{u2}$ and $A_{st2}$ :** $M_{u2} = M_u - M_{u\,lim}$

$$A_{st2} = \frac{M_{u2}}{0.87 f_y (d - d')}$$

5. **Determine $A_{st}$ :** $A_{st} = A_{st1} + A_{st2}$.

Choose suitable diameter of bar and provide them.

6. **Determine area of Compression Steel ($A_{sc}$) :**

$$A_{sc} = \frac{M_{u2}}{f_{sc} (d - d')}$$

Provide $A_{sc}$ by choosing suitable diameter of the bar.

**Que 1.25.** **Determine the ultimate moment of resistance of a doubly reinforced beam section with the following data : $b$ = 350 mm, $d$ = 550 mm, $d'$ = 60 mm, $A_{st}$ = 5 – 32 mm $\phi$ bars, $A_{sc}$ = 3 – 25 mm $\phi$ bars, $f_y$ = 415 MPa and $f_{ck}$ = 25 MPa.**

**AKTU 2016-17, Marks 10**

**Answer**

**Given :** Width of beam, $b$ = 350 mm, Effective depth of beam, $d$ = 550 mm, Cover, $d'$ = 60 mm, Area of reinforcement in tension zone, $A_{st} = 5 \times (3.14/4) \times 32^2 = 4021.24 \text{ mm}^2$, Area of reinforcement in compression zone, $A_{sc} = 3 \times (3.14/4) \times 25^2 = 1472.62 \text{ mm}^2$

**To Find :** Ultimate moment of resistance.

1. **Calculation of $f_{sc}$ :** Strain at the level of compression steel,

$$x_{max} = 0.48 \times d = 0.48 \times 550 = 264 \text{ mm}$$

$$\varepsilon_{sc} = \frac{0.0035\,(264-60)}{264} = 0.0027$$

For $\varepsilon_{sc} = 0.0027$, from IS code and interpolation, $f_{sc} = 351 \text{ N/mm}^2$

2. **Position of Neutral axis :**

Total force of compression = Total force of tension

$$C = C_1 + C_2 = T$$

$$0.36 f_{ck}\, b x_{u,\max} + (f_{sc} - f_{cc}) A_{sc} = 0.87 f_y A_{st}$$

$$0.36 \times 25 \times 350 \times x_u + (351 - 0.446 \times 25) \times 1472.62 = 0.87 \times 415 \times 4021.24$$

$$x_u = 302.03 \text{ mm}$$

3. **Position of Critical Neutral Axis :**

Maximum depth of neutral axis, (∵ for $Fe$ 415 = 0.48 $d$)

$$x_{u,\max} = 0.48\, d = 0.48 \times 550 = 264 \text{ mm}$$

4. $x_u > x_{u,\max}$, hence, the section is over reinforced.

Moment of resistance ($M_u$) is calculated by taking

$$x_u = x_{u,\max} = 264 \text{ mm}$$

5. Ultimate moment of resistance,

$$M_u = 0.36 f_{ck}\, b\, x_u\,(d - 0.42\,x_u) + f_{sc} A_{sc}\,(d - d')$$

$$= 0.36 \times 25 \times 350 \times 264\,(550 - 0.42 \times 264) + 351 \times 1472.62\,(550 - 60)$$

$$M_u = 618.44 \times 10^6 \text{ N-mm} = 618.45 \text{ kN-m}$$

**Que 1.26.** **Determine reinforcement of a rectangular beam 300 mm wide and 400 mm effective depth. The beam is subjected to a factored bending moment of 150 kN-m. Use M 20 concrete and Fe 250 steel.**

**AKTU 2013-14, Marks 10**

**Answer**

**Given :** Size of beam = 300 mm × 400 mm, Factored BM = 150 kN-m.
**To Find :** Area of reinforcement.

1. Limiting bending moment,

$$M_{u\,\lim} = 0.148 f_{ck}\, bd^2 \quad \text{(for Fe250)}$$

$$M_{u\,\lim} = 0.148 \times 20 \times 300 \times 400^2 = 142.08 \text{ kN-m}$$

2. Factored moment = 150 kN-m, $M_u > M_{u\,\lim}$
3. So it is designed by doubly reinforced beam

$$x_m = 0.53 \times 400 = 212 \text{ mm}$$

4. Area of tension steel corresponding to $M_{\mu\lim}$

$$0.87 f_y A_{st1} = 0.36 f_{ck}\, b\, x_m$$



$$0.87 \times 250 \times A_{st1} = 0.36 \times 20 \times 300 \times 212$$

$$A_{st1} = 2105.38 \text{ mm}^2$$

5. If, $\dfrac{d'}{d} = 0.1$

$$d' = 0.1 \times 400 = 40 \text{ mm},\ f_{sc} = 217 \text{ N/mm}^2$$

6. Area of compression steel,

$$M_u - M_{\mu\lim} = (f_{sc} A_{sc} - f_{cc} A_{sc})\,(d - d')$$

$$A_{sc} = \frac{(150 - 142.08) \times 10^6}{(217 - 0.446 \times 20)(400 - 40)} \quad [\because f_{cc} = 0.446 f_{ck}]$$

$$= 105.73 \text{ mm}^2$$

7. Area of tension steel, $A_{st2}$

$$0.87 f_y A_{st_2} = f_{sc} A_{sc}$$

$$A_{st_2} = \frac{217 \times 105.73}{0.87 \times 250} = 105.5 \text{ mm}^2$$

8. Total area of tension steel,

$$A_{st} = A_{st1} + A_{st2} = 2105.38 + 105.5 = 2210.88 \text{ mm}^2$$

$$A_{sc} = 105.73 \text{ mm}^2$$

9. Provide 28 mm φ, bars in tension,

$$\text{Number of bar} = \frac{2210.88}{\frac{\pi}{4}(28)^2} \simeq 3.6 \simeq 4$$

10. Provide 12 mm φ, bars in compression,

$$\text{Number of bar} = \frac{105.73}{\frac{\pi}{4}(12)^2} \simeq 0.93 \simeq 2$$

11. Provide 4-28 mm bars in tension and 2-12 mm bars in compression.

**Que 1.27.** **Design the section of a doubly reinforced beam to resist a bending moment of 185 kN-m. The section of the beam is restricted to 350 mm × 700 mm. Assume 50 mm effective cover. Use M20 grade of concrete and Fe 415 steel.**

**AKTU 2014-15, Marks 10**

**Answer**

**Given :** Bending moment, $M$ = 185 kN-m,
Width of beam, $B$ = 350 mm, Depth of beam, $D$ = 700 mm,
Effective cover, $d'$ = 50 mm.
**To Find :** Design doubly reinforcement beam.

1. Factored bending moment, $M_u = 1.5 \times 185 = 277.5$ kN-m
2. Limiting moment of resistance ($M_{u,\lim}$) :

$$M_{u\,lim} = 0.36 f_{ck}\, b\, x_{u\,max}\,(d - 0.42\, x_{u\,max})$$

$$x_{u\,max} = 0.48\, d = 0.48 \times 650 = 312 \text{ mm}$$

$$[d = 700 - 50 = 650 \text{ mm}]$$

$$= 0.36 \times 20 \times 350 \times 312\,(650 - 0.42 \times 312)$$

$$M_{u\,lim} = 408027110.4 = 408.027 \times 10^6 \text{ N-mm.}$$

As, $M_{u\,lim} > M_u$, so there is no need to design this beam as doubly reinforced beam.

Hence this beam is design as singly reinforced beam.

3. Required reinforcement :

$$A_{st} = \frac{M_u}{0.87 f_y\,(d - 0.42\, x_{u\,max})}$$

$$A_{st} = \frac{277.5 \times 10^6}{0.87 \times 415\,(650 - 0.42 \times 312)} = 1481.02 \text{ mm}^2$$

4. Provide 20 mm $\phi$ bars, number of bar $= \dfrac{1481.02}{\pi \times 20^2/4} = 4.71 \approx 5$

5. Provide 5 bars of 20 mm $\phi$ in tension zone.

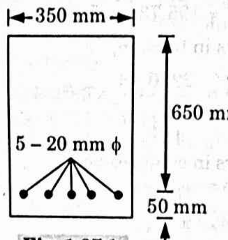



Fig. 1.27.1.

**Que 1.28.** **Design a rectangular beam for an effective span 6 m. The superimposed load or live load 80 kN/m and the size is limited to 300 mm width and 700 mm overall depth. Use M20 concrete mix and Fe 415 steel.**

**AKTU 2015-16, Marks 10**

**Answer**

**Given :** Overall depth, $D = 700$ mm, Width of beam, $b = 300$ mm

Superimposed load = 80 kN/m, Span of beam, $l = 6$ m

**To Find :** Design of a rectangular beam.

1. Moment due to superimposed load, $M = \dfrac{wl^2}{8} = \dfrac{80 \times 6^2}{8} = 360$ kN-m
2. Dead load of beam $= 0.3 \times 0.7 \times 25 = 5.25$ kN
3. Moment due to dead load $= \dfrac{5.25 \times 6^2}{8} = 23.625$ kN-m



4. Total moment = 360 + 23.625 = 383.625 kN-m
5. Factored moment, $M_u = 383.625 \times 1.5 = 575.44$ kN-m
6. Limiting bending moment, $M_{u,lim} = 0.138 f_{ck} bd^2$

$$= 0.138 \times 20 \times 300 \times 650^2$$

$$M_{u,lim} = 349.83 \text{ kN-m}$$

$M_u > M_{u,lim}$ Hence, section is over reinforced.

7. Area of tension steel corresponding to $M_{u\,lim}$

$$0.87 f_y A_{st1} = 0.36 f_{ck}\, b x_m$$

$$0.87 \times 415 \times A_{st1} = 0.36 \times 20 \times 300 \times 0.48 \times 650$$

$$A_{st1} = 1866.55 \text{ mm}^2$$

8. The remaining bending moment has to be resisted by a couple consisting of compression steel and the corresponding tension steel
9. If $\dfrac{d'}{d} = 0.1$, $d' = 0.1 \times 650 = 65$ mm

From IS code, $f_{sc} = 353$ N/mm²

Provided 50 mm cover on compression side for compressive reinforcement.

10. $M_u - M_{u,lim} = (f_{sc} - 0.446 f_{ck})\,(d - d')\,A_{sc}$

$$(575.44 - 349.83) \times 10^6 = (353 - 0.446 \times 20)\,(650 - 50)\,A_{sc}$$

$$A_{sc} = 1092.82 \text{ mm}^2$$

11. Corresponding tension steel, $A_{st_2}$

$$0.87 f_y A_{st_2} = f_{sc} A_{sc}$$

$$A_{st_2} = \frac{353 \times 1092.82}{0.87 \times 415} = 1068.45 \text{ mm}^2$$

12. Total area of tension steel,

$$A_{st} = A_{st_1} + A_{st_2} = 1866.55 + 1068.45 = 2935 \text{ mm}^2$$

13. Area of compression steel,

$$A_{sc} = 1092.82 \text{ mm}^2$$

Provide 5-28 mm $\phi$ bars in tension ($A_{st} = 3078$ mm² > 2935 mm²) and 4-20 mm $\phi$ bars in compression ($A_{sc} = 1256$ mm²)

14. **Check :**

Maximum tension steel

$$= 0.04\, bD = 0.04 \times 300 \times 700$$

$$= 8400 \text{ mm}^2 > 3078 \text{ mm}^2$$

15. **Reinforcement Details :**

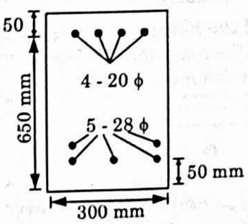



Fig. 1.28.1.

**Que 1.29.** **Design a doubly reinforced section for a rectangular beam at midspan having a simply supported effective span of 4 m. The superimposed load is 40 kN/m and section of beam is limited to 25 cm × 40 cm overall. Assume suitable data.**

**AKTU 2016-17, Marks 10**

**Answer**

**Procedure :** Same as Q. 1.28, Page 1-31A, Unit-1.

$x_{u,\,max}$ = 173 mm, $M_u$ = 127.5 kN-m

$M_{u,\,lim}$ = 89.5 kN-m

$A_{st\,1} = A_{st1} + A_{st2}$ = 862.5 + 330 = 1192.5 mm²

$A_{sc}$ = 346.33 mm²

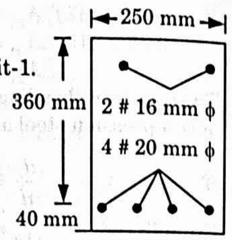


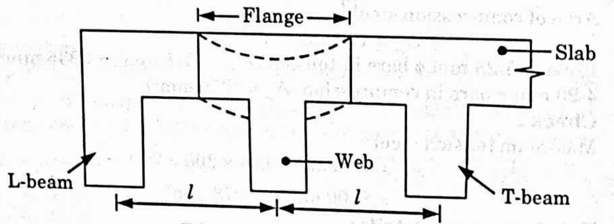

**Fig. 1.29.1.**

## PART-6

*Design of T-beams, L-beams, Cantilever beams by Limit State Method.*

### CONCEPT OUTLINE

**T-Beam and L-Beam :** The intermediate beams supporting the slab are called as T-beams and the end beams are called as L-beams.




T-beams and L-beams

**Effective Width of the Flange ($b_f$) :** It is that portion of slab which acts integrally with the beam and extends on either side of the beam forming the compression zone.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**



**Que 1.30.** **Discuss the analysis procedure of flanged beams (T-beams and L-beams) by limit state method.**

**Answer**

**Analysis of T-beam by Limit State Method :** Limit state method can be applied to T-beam following the same principles considered for rectangular beams.

Let,
$b_f$ = Flange width.
$D_f$ = Flange thickness.
$d$ = Effective depth.
$b_w$ = Width of rib.
$A_{st}$ = Area of tensile reinforcement.

Various types of problems associated with flanged beams :

**Case-I : When the Neutral Axis Lies within the Flange :**

i. Equating total tension to total compression

$$0.36 f_{ck} b_f x_u = 0.87 f_y A_{st}$$

$$x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} b_f},\quad D_f > x_u, \text{then}$$

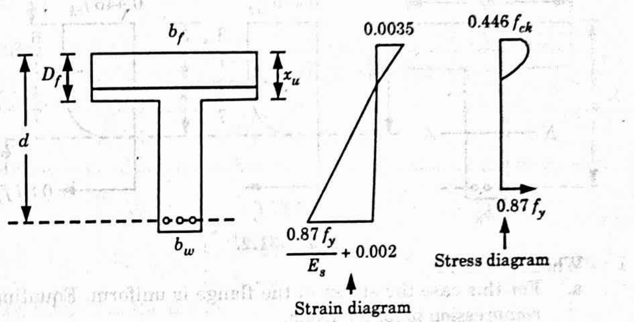



**Fig. 1.30.1.**

ii. Ultimate moment of resistance,

$$M_u = 0.36 f_{ck} b_f x_u (d - 0.42 x_u)$$
$$= 0.87 f_y A_{st}(d - 0.42 x_u)$$

**Case-II : When the Neutral Axis Lies Outside the Flange and the Beam Section is Balanced Section :**

In the geometry of the stress diagram at ultimate condition, the stress is uniform for a depth of (3/7)$x_{u,\,max}$.

i. When, $D_f < (3/7)x_{u,\,max}$.

a. Equating total compression to total tension,

$$0.36 f_{ck} b_w x_{u,\,max} + 0.446 f_{ck}(b_f - b_w) D_f = 0.87 f_y A_{st,\,lim}.$$

b. The limiting moment of resistance is given by,

$$M_{u,\,lim} = 0.36\, f_{ck}\, b_w x_{u,\,max}\,(d - 0.42\, x_{u,\,max}) + 0.446\, f_{ck} \times (b_f - b_w)\, D_f \left(d - \frac{D_f}{2}\right)$$

ii. When $D_f > \frac{3}{7} x_{u,\,max}$

a. Equating total compression to total tension,

$$0.36\, f_{ck}\, b_w x_{u,\,max} + 0.446\, f_{ck}\,(b_f - b_w)\, y_f = 0.87 f_y A_{st,\,lim}$$

where, $y_f$ = Height of equivalent stress block,

$$y_f = 0.15\, x_{u,\,max} + 0.65\, D_f$$

b. Above equation is used to determine $A_{st,\,lim}$.

iii. The limiting moment of resistance,

$$M_{u,\,lim} = 0.36\, f_{ck}\, b_w\,(d - 0.42\, x_{u,\,max}) + 0.446\, f_{ck}\,(b_f - b_w)\, y_f \left(d - \frac{y_f}{2}\right)$$

**Case-III : When the Neutral Axis Lies Out Side of Flange the Section is under Reinforced :**

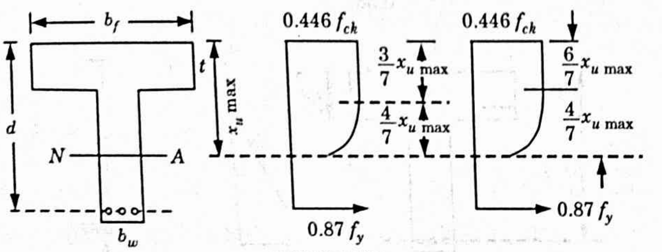



**Fig. 1.31.2.**

i. When $D_f < (3/7) x_u$.

a. For this case the stress in the flange is uniform. Equating total compression to total tension,

$$0.36\, f_{ck}\, b_w x_u + 0.446\, f_{ck}\,(b_f - b_w)\, D_f = 0.87 f_y A_{st}$$

b. This equation is used to determine the value of $x_u$.

Also verify the condition $x_u < x_{u,\,max}$.

c. Ultimate moment of resistance,

$$M_u = 0.36\, f_{ck}\, b_w\, x_u + (d - 0.42\, x_u) + 0.446\, f_{ck}\,(b_f - b_w)\, D_f \times \left(d - \frac{D_f}{2}\right)$$

ii. $D_f > \frac{3}{7} x_u$.

a. For this case, stress in flange is not uniform.

b. Total compression = total tension,



$$0.36\, f_{ck}\, b_w x_u + 0.446\, f_{ck}\,(b_f - b_w)\, y_f = 0.87 f_y A_{st}$$

where $y_f = 0.15\, x_u + 0.65\, D_f$

Also, verify $x_u < x_{u\,max}$.

c. Ultimate moment of resistance,

$$M_u = 0.36\, f_{ck}\, b_w x_u\,(d - 0.42\, x_u) + 0.446\, f_{ck}\,(b_f - b_w)\, y_f \left(d - \frac{y_f}{2}\right)$$

**Que 1.31.** **A T-beam, casted with M 20 concrete and Fe 415 steel, has following dimensions.**
**Width of flange = 2400 mm**
**Depth of flange = 100 mm**
**Width of web = 250 mm**
**Overall depth of beam = 450 mm**
**Effective cover to reinforcement = 50 mm**
**Tension reinforcement = 2 bars of 16 mm diameter**
**Determine moment of resistance of the beam.**

**AKTU 2013-14, Marks 10**

**Answer**

**Given :** $b_f$ = 2400 mm, $b_w$ = 250 mm, $D_f$ = 100 mm, $D$ = 450 mm, $d$ = 450 – 50 = 400 mm, $\phi$ = 16 mm, Number of bar = 2
**To Find :** Moment of resistance.

1. Area of steel, $A_{st} = 2 \times \pi \times 16^2/4 = 402.12\ \text{mm}^2$
2. Assuming neutral axis lie within the flange, equating total compression to total tension

$$0.36 \times f_{ck} b_f x_u = 0.87\, A_{st}\, f_y$$

$$x_u = \frac{0.87 \times 402.12 \times 415}{0.36 \times 20 \times 2400} = 8.4\ \text{mm} < D_f\,(100\ \text{mm})$$

Hence NA lies in the flange.

3. $x_{u,\,max} = 0.48 \times 400 = 192$ mm

$x_u < x_{u\,max}$ hence the section is under reinforced

4. Moment of resistance,

$$M = 0.87\, f_y A_{st}\,(d - 0.42\, x_u)$$
$$= 0.87 \times 415 \times 402.12\,(400 - 0.42 \times 8.4)$$

Moment of resistance, $M$ = 57.562 kN-m

**Que 1.32.** **Analyze a T-beam for the following data $b_f$ = 1500 mm, $D_f$ = 100 mm, $D$ = 600 mm, $b_w$ = 300 mm, $f_{ck}$ = 150 N/mm², $f_y$ = 415 N/mm², $A_{st}$ = 8 bars of 20 mm dia with effective cover 65 mm.**

**AKTU 2014-15, Marks 10**

**Answer**

**Given :** Width of flange, $b_f = 1500$ mm,
Depth of flange, $D_f = 100$ mm, Overall depth of beam, $D = 600$ mm,
Width of web, $b_w = 300$ mm, $f_{ck} = 150$ N/mm², $f_y = 415$ N/mm²,
$A_{st} = 8$ bars of 20 mm diameter, Effective cover = 65 mm
**To Find :** Moment of resistance of T-beam

**Note :** $f_{ck}$ given in the question is wrong
So we assume $f_{ck} = 15$ N/mm²

1. Let us assume that it is under reinforced section and neutral axis lies within the flange
$\therefore \quad 0.36 f_{ck} b_f x = 0.87 f_y A_{st}$
$0.36 \times 15 \times 1500\, x = 0.87 \times 415 \times 8 \times (\pi/4) \times 20^2$
$x = 112.03$ mm
2. The value of $x_u$ is more than 100 mm, hence our assumption was wrong the neutral axis lie in the web.
$$\frac{D_f}{d} = \frac{100}{535} = 0.187 = 0.19 < 0.20$$
$$\frac{D_f}{x_u} = \frac{100}{112} = 0.89 > 0.43$$
3. Equating compression and tension force :
$0.36 f_{ck} b_w x_u + 0.446 f_{ck} (b_f - b_w)(0.15 x + 0.65 D_f) = 0.87 f_y A_{st}$
$0.36 \times 15 \times 300\, x_u + 0.446 \times 15\, (1500 - 300)(0.15\, x_u + 0.65 \times 100) = 0.87 \times 415 \times 8 \times (\pi/4) \times 20^2$
$1620\, x_u + 8028(0.15\, x_u + 65) = 907417.62$
$x = 136.53$ mm
$x_{u\,lim} = 0.48\, d = 0.48 \times 535 = 256.8$ mm
$x_u < x_{u\,lim}$, Hence section is under reinforced.
4. Moment of resistance with respect to concrete,
$= 0.36 f_{ck} b_w x_u (d - 0.42\, x_u) + 0.446 f_{ck} (b_f - b_w) y_f (d - 0.5\, y_f)$
$y_f = 0.15\, x_u + 0.65 \not> D_f$
$= 0.15 \times 136.53 + 0.65 \times 100 \not> 100 = 85.48 \not> 100$ mm
$= 0.36 \times 15 \times 300 \times 136.53\, (535 - 0.42 \times 136.53) + 0.446 \times 15 \times (1500 - 300) \times 85.48\, (535 - 0.5 \times 85.48)$
$M_r = 443.5$ kN-m
Liver arm, $z = d - 0.5\, y_f = 535 - 0.5 \times 85.48 = 492.26$ mm
5. MOR w.r.t tension $= 0.87 f_y A_{st} \times z$
$= 0.87 \times 415\, [8 \times (\pi/4) \times 20^2] \times 492.26$
$M_r = 446.68$ kN-m



**Que 1.33.** **A T-beam of flange width 1400 mm, flange thickness 100 mm, rib width 300 mm and effective depth 500 mm has to be designed as a balanced section. Find the reinforcement required and limiting moment of resistance. Use M 20 concrete and Fe 250 steel.**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Width of flange, $b_f = 1400$ mm, Thickness of flange, $D_f = 100$ mm, Width of web, $b_w = 300$ mm, Effective depth of web, $d = 500$ mm, $f_{ck} = 20$ N/mm², $f_y = 250$ N/mm²
**To Find :** Limiting moment of resistance and required reinforcement.

1. Since the section is balanced,
$x_u = x_{u,\,max} = 0.53\, d = 0.53 \times 500 = 265$ mm
2. $$\frac{3}{7} x_{u,\,max} = \frac{3}{7} \times 265 = 113.6 \text{ mm}$$
3. But, $D_f = 100$ mm
$\therefore \quad D_f < \frac{3}{7} x_{u,\,max}$
The stress in the flange is uniform.
4. Equating total compression and total tension forces
$0.36 f_{ck} b_w x_{w,\,max} + 0.446 f_{ck} (b_f - b_w) D_f = 0.87 f_y A_{st,\,lim}$
$0.36 \times 20 \times 300 \times 265 + 0.446 \times 20\,(1400 - 300) \times 100 = 0.87 \times 250\, A_{st,\,lim}$
$572400 + 981200 = 0.87 \times 250\, A_{st,\,lim}$
Area of reinforcement, $A_{st,\,lim} = 7142.988$ mm²
5. Limiting moment of resistance,
$$M_{u,\,lim} = 0.36 f_{ck} b_w x_{u,\,max} (d - 0.42\, x_{u,\,max}) + 0.446 f_{ck} (b_f - b_w) D_f \left(d - \frac{D_f}{2}\right)$$
$= 0.36 \times 20 \times 300 \times 265(500 - 0.42 \times 265) + 0.446 \times 20\,(1400 - 300) \times 100 \times (500 - 50)$
$M_{u,\,lim} = 664.032$ kN-m

**Que 1.34.** **A T-beam floor consists of 150 mm thick RC slab monolithic with 300 mm wide beams. The beams are spaced at 3.5 m centre to centre and their effective span is 6 m. If the superimposed loads on the slab is 5 kN/m². Design an intermediate T-beam. Use M 20 mix and Fe 250 grade steel.**

**AKTU 2015-16, Marks 15**

**Answer**

**Given :** Depth of slab, $d$ = 150 mm, Width of beam, $b$ = 300 mm, Spacing of beam = 3.5 m = 3500 mm, Effective span, $L_{eff}$ = 6 m = 6000 mm, Live load = 5 kN/m²

**To Find :** Design of intermediate T-beam.

1. **Loads :**
   Dead load of slab = 0.15 × 25 = 3.75 kN/m²
   Superimposed load on slab = 5 kN/m²
   Total load on slab = 8.75 kN/m²
2. Load per meter run of beam = Load on slab per unit area × Centre to centre distance between beams
   $$= 8.75 \times 3.5 = 30.6 \text{ kN/m}$$
3. Effective width of flange,
   $$b_f = \frac{l_o}{6} + b_w + 6\,D_f = \frac{600}{6} + 30 + 6 \times 15 = 220 \text{ cm}$$
   Maximum value of flange width
   = 350 cm > 220 cm
   Therefore, effective width of flange, $b_f$ = 220 cm
4. Let us adopt overall depth $D$ of beam equal to 40 cm and effective cover equal to 40 mm so that effective depth is 36 cm.
   [Assume width of web = 300 mm]
5. Dead load of web of beam
   = Width of web × Depth of web × Density of concrete
   = 0.30 × 0.25 × 25 = 1.875 kN/m
   Total load on beam per meter run = 30.6 + 1.875 = 32.475 kN/m
6. Factored maximum bending moment,
   $$M_u = 1.5 \times wl^2/8 = 1.5 \times 32.475 \times 6^2/8 = 219.2 \text{ kN-m}$$
7. Let us assume that neutral axis lies in the flange, that is
   $$x_u = \frac{0.87\, f_y\, A_{st}}{0.36\, f_{ck}\, b_f} = \frac{0.87 \times 250\, A_{st}}{0.36 \times 20 \times 2200} = 0.0137\, A_{st}$$
8. Factored BM = Force of tension × Lever arm ($z$)
   $$219.2 \times 10^6 = 0.87\, f_y\, A_{st}\,(d - 0.42\, x_u)$$
   $$219.2 \times 10^6 = 0.87 \times 250\, A_{st}\,(360 - 0.42 \times 0.0137\, A_{st})$$
   $$A_{st}^2 - 62565.2\, A_{st} + 175150520 = 0$$
   $$A_{st} = 2938 \text{ mm}^2$$
   Provide 5 - 28 mm ϕ bars ($A_{st}$ = 3079 mm² > 2938 mm²)



9. And $x_u = 0.0137 \times 3079 = 42.18 \text{ mm} < 150 \text{ mm}$
   ∴ Neutral axis lies in the flange.
10. Minimum area of tension steel, $A_o = 0.85\,\dfrac{b_w d}{f_y}$
    $$= 0.85 \times \frac{300 \times 360}{250} = 367 \text{ mm}^2 < 3079 \text{ mm}^2$$
11. Maximum area of tension steel, $A_{st} = 0.04\, b_w\, D$
    $$= 0.04 \times 300 \times 400 = 4800 \text{ mm}^2 > 3079 \text{ mm}^2$$

**Que 1.35.** **A cantilever beam project 2.5 m beyond the fixed end and carries a superimposed load of 10 kN/m. Design the cantilever using M20 grade concrete and Fe 415 steel. Take width of support = 350 mm.**

**AKTU 2014-15, Marks 10**

**Answer**

**Given :** Length of cantilever beam = 2.5 m, Live load = 10 kN/m, $f_{ck}$ = 20 N/mm², $f_y$ =415 N/mm², Width of support = 350 mm.

**To Find :** Design of cantilever beam.

1. Effective length of beam = 2500 + 350 / 2 = 2675 mm
2. Minimum depth of beam,
   $$d = \frac{L}{7} = \frac{2675}{7} = 382.14 \text{ mm}$$
   Adopt overall depth 500 mm at the fixed end.
3. Width of beam, $b = \dfrac{D}{2} = \dfrac{500}{2} = 250$ mm
4. The depth of beam can be reduced to a minimum of 200 mm at free end.
   $$\text{Dead load of beam} = \left(\frac{0.5 + 0.2}{2}\right) \times 0.25 \times 2.5 \times 25 = 5.46 = 5.5 \text{ kN}$$
5. $$\text{CG of dead load of beam} = \frac{2.5}{3}\left[\frac{0.5 + 2 \times 0.2}{0.5 + 0.2}\right]$$
   = 1.07 m from the fixed end.
6. Factored bending moment
   $$= 1.5 \times 5.5 \times 1.07 + 1.5 \times 10 \times \frac{2.5^2}{2} = 55.7 \text{ kN-m}$$
7. Check for depth :
   $$0.138\, f_{ck}\, bd^2 = 55.7 \times 10^6$$
   $$d = \sqrt{\frac{55.7 \times 10^6}{0.138 \times 20 \times 250}}$$
   $$d = 284.12 \text{ mm}$$

Hence adopt 400 mm depth at fixed end and 200 mm at free ends.

Effective depth of fixed ends = 400 – 30 – 10 = 360 mm

Effective depth at free end = 200 – 30 – 10 = 160 mm

8. Area of tension steel, $A_{st} = \dfrac{0.36 f_{ck}\, b x_{u,\max}}{0.87 f_y}$

$$= \frac{0.36 \times 20 \times 250 \times 0.48 \times 360}{0.87 \times 415}$$

$$A_{st} = 861.5 \text{ mm}^2$$

Provide 3 # 20 mm $\phi$ at top and 2 # 10 mm $\phi$ bar along the bottom.

9. Minimum tension steel area, $A_0 = 0.85 \times \dfrac{bd}{f_y}$

$$= \frac{0.85 \times 250 \times \left(\dfrac{360 + 160}{2}\right)}{415} = 133.1 \text{ mm}^2$$

$$133.1 \text{ mm}^2 < 861.5 \text{ mm}^2$$

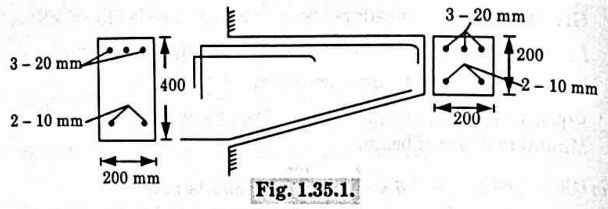



**Fig. 1.35.1.**

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# 2 UNIT

# Behaviour of RC Beam in Shear

## CONTENTS

## PART-1

### *Shear Strength of Beams With and Without Reinforcement, Minimum and Maximum Shear Reinforcement.*

## CONCEPT OUTLINE

**Shear Stress :** A beam loaded with transverse loads is subjected to shear force and bending moment. The shear force at any section is equal to the rate of change of bending moment.

**Stress Based Approach :** It is parabolic in the compression zone with zero at the top and maximum at the neutral axis. The value of shear-stress is constant in the tensile zone and is equal to the maximum shear-stress ($q$) because the concrete, below the neutral axis (tensile zone) is assumed to be cracked and neglected.

**Minimum Shear Reinforcement :** If $\tau_v < \tau_c$, the minimum or nominal shear reinforcement in the form of stirrups shall be provided in all the beams.

**Maximum Shear Reinforcement :** Maximum area of tension reinforcement should not exceed 4 % of the gross cross-sectional area *i.e.*, 0.04 $bD$, where $D$ = Overall depth of section.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 2.1.** **Explain behaviour of RC beam in shear.**

**Answer**

**Behaviour of RC Beam in Shear :**

1. RCC is a composite material so the exact shear distribution as per elastic theory is very complex.
2. It is shown in Fig. 2.1.1 by the hatched portion of the curve. It is parabolic in the compression zone with zero at the top and maximum at the neutral axis.
3. The value of shear stress is constant in the tensile zone and is equal to the maximum shear stress $\tau_v$ because the concrete, below the neutral axis (tensile zone) is assumed to be cracked and neglected.
4. The maximum value of shear stress as per elastic theory is given by,

$$\tau_v = \frac{V}{bdj}$$



where, $V$ = Shear force at the section.
$b$ and $d$ = Breath and depth of the section.
$j$ = Lever arm depth factor.

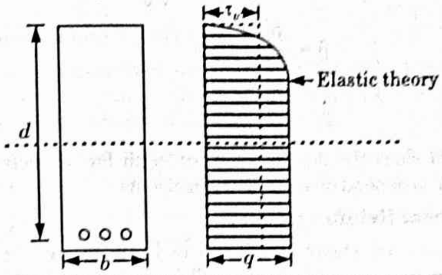



Fig. 2.1.1. Shear-stress distribution in RCC beam.

**IS Code Approach :**

1. As per IS code 456 : 2000 the stress based approach does not represent the true behaviour of the RCC beam in shear. Hence, the equation for shear stress *i.e.*, $q = \frac{V}{bdj}$ has been simplified.
2. IS code recommends the use of nominal shear stress ($\tau_v$) for RCC beams. The nominal shear stress ($\tau_v$) or average shear stress distribution is shown in Fig. 2.1.1 is given by,

$$\tau_v = \frac{V}{bd}$$

**Que 2.2.** **Study the shear strength of beam according to these points :**
A. Without shear reinforcement.
B. With shear reinforcement.

**Answer**

A. **Without Shear Reinforcement :**

1. The design shear strength $\tau_c$ of concrete in beams without shear reinforcement based on the percentage of longitudinal reinforcement and grade of concrete.
2. The value of '$\tau_c$' for different percentage of steel and different grade of concrete is shown in Table 2.2.1.

**Table 2.2.1.** $\tau_c$ of concrete (N/mm²).

| $100\frac{A_{st}}{bd}$ | Grade of Concrete | | | | | |
|---|---|---|---|---|---|---|
| | M15 | M20 | M25 | M30 | M35 | M40 |
| 0.20 | 0.32 | 0.32 | 0.33 | 0.33 | 0.34 | 0.34 |

3. The design shear strength $\tau_c$ is given by,

$$\tau_c = \frac{0.85\sqrt{0.80 f_{ck}}\,(\sqrt{(1+5\beta)}-1)}{6\beta}$$

4. where $\beta = \dfrac{0.8 f_{ck}}{6.89\, p_t} < 1$

$$p_t = \frac{100 A_{st}}{b_w d}$$

5. For solid slabs the design shear strength for concrete shall be $k\,\tau_c$, where '*k*' is depend on overall depth of slab.

**B. With Shear Reinforcement :**

1. When nominal shear stress ($\tau_v$) in beam exceeds $\tau_c$, then shear reinforcement is provided. $\tau_{c,\,max}$ will depend on grade of concrete which should be taken from Table 2.2.2.
2. $\tau_{c,\,max}$ also obtained as,

$$\tau_{c,\,max} = 0.62\sqrt{f_{ck}}$$

**Table 2.2.2.** $\tau_{c\,max}$ (N/mm²)

| Concrete Grade | M15 | M20 | M25 | M30 | M35 | M40 |
|---|---|---|---|---|---|---|
| $\tau_{c,\,max}$ (N/mm²) | 2.5 | 2.8 | 3.1 | 3.5 | 3.7 | 4.0 |

**Que 2.3.** **Write a short note on :**

**A. Minimum shear reinforcement in beam.**
**B. Maximum shear stress in beam.**

**Answer**

**A. Minimum Shear Reinforcement in Beam :**

1. When the nominal shear stress $\tau_v$ is less than the design shear strength ($\tau_c$) or shear strength of concrete, then no shear reinforcement is to be designed.
2. But in such cases minimum shear reinforcement is to be provided in the form of stirrups such as :

$$\frac{A_{sv}}{bs_v} \geq \frac{0.4}{0.87 f_y}$$

where, $A_{sv}$ = Total cross-sectional area of stirrup legs effective in shear.
$s_v$ = Spacing of stirrups along the length of the member.
$b$ = Breadth of the beam or breadth of web of the flanged beam.
$f_y$ = Characteristic compressive strength of the stirrup reinforcement in N/mm² which shall not be greater than 415 N/mm².



However, in members of minor importance, such as lintels or where $\tau_v < \frac{1}{2}\tau_c$ this provision need not be complied with.

**B. Maximum Shear Stress in Beam :**

1. If the shear strength of the concrete beam is less than the nominal shear stress ($\tau_v$) due to the loads coming on the beam, then shear reinforcement is to be provided.
2. The nominal shear stress in the beams with shear reinforcement shall not exceed maximum shear stress ($\tau_{c,\,max}$).
3. If nominal shear is greater than the maximum shear stress then the section is to be redesigned.

## PART-2
*Design of Beam in Shear.*

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 2.4.** **Describe the critical sections for shear design.**

**Answer**

**Critical Section for Shear Design :** The critical section for shear is that section at which the shear force is maximum. As per Cl.22.6 of IS 456:2000 the critical sections for shear design are taken as :

1. Critical section occur at a distance '*d*' from the face of the support where the support offers a compressive reaction Fig. 2.4.1.

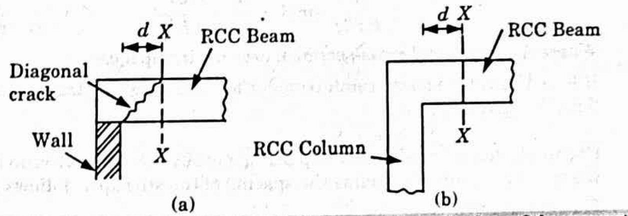



**Fig. 2.4.1.** Critical section at (XX) at distance d from the face of the support.

2. Critical section occurs at the face of the support where the support offers a tensile reaction Fig. 2.4.2.
3. Critical section occur at the face of the support when there is a

concentrated load between the face of the support and the distance '*d*' (Fig. 2.4.2).

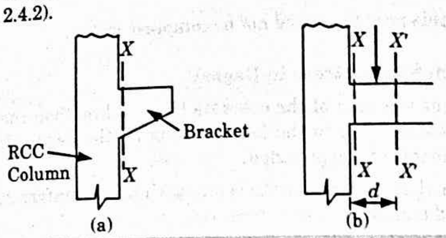



**Fig. 2.4.2. Critical section at the face of the support.**

**Que 2.5.** **Explain the design steps for shear reinforcement.**

**Answer**

The following steps to be considered while designing the shear reinforcement :

1. Determine the factored or ultimate design shear force '$V_u$'.
2. Determine the nominal shear stress on the section '$\tau_v$' by dividing $V_u$ by $bd$ *i.e.*,
$$\tau_v = V_u / bd$$
3. Compute the percentage of tension reinforcement provided in the section. Based on this percentage of tension steel, determine the shear strength of concrete '$\tau_c$' for the given concrete mix and hence the shear resisting capacity of the reinforcement concrete section, $V_c = \tau_c bd$.
4. Compare $\tau_v$ with $\tau_{c,\,max}$. If $\tau_v > \tau_{c,\,max}$ redesign the cross-section of the beam.
5. Compare $V_u$ with $V_c$ (or $\tau_v$ with $\tau_c$). If $V_u \le V_c$, no shear design is required. Provide nominal reinforcement in the form of vertical stirrups through the beam of the spacing '$S_v$' is given by,
$$\frac{A_{sv}}{bS_v} \ge \frac{0.4}{0.87f_y} \text{ or } S_v \le \frac{A_{sv} \times 0.87f_y}{0.4\,b}$$
Where $A_{sv}$ is the total cross-sectional area of stirrup legs.
6. If $V_u > V_c$, provide shear reinforcement for resisting the design shear force '$V_{us}$' given by,
$$V_{us} = V_u - V_c.$$
7. Choose the diameter of the stirrup bar (generally 6, 8, 10 or 12 mm) and the type of stirrup. Determine the spacing of the stirrup as follows :

i. For vertical stirrups,
$$S_v = \frac{0.87\,f_y\,A_{sv}d}{V_{us}} = \frac{0.87\,f_y\,A_{sv}}{(\tau_v - \tau_c)\,b}$$
The maximum spacing of vertical stirrups should not exceed 0.75 *d* or 300 mm.



ii. For inclined stirrups,
$$S_v = \frac{0.87\,f_y\,A_{sv}d}{V_{us}}(\sin\alpha + \cos\alpha)$$

iii. For bent up bars, if the tension steel is available for shear, bent up the bars from tension steel at 45° at distance '*d*' from the support. Compute the shear force taken by bent up bars.
$$V_s = \sigma_{sv}\,A_{sv}\sin\alpha = 0.87\,f_y\,A_{sv}\sin\alpha \qquad \left(\not> \frac{1}{2}V_{us}\right)$$
Here, $A_{sv}$ is the total cross-sectional area of bent-up bars.
Design the vertical stirrups for the shear force
$$V_d = V_{us} - V_s$$
Where, $V_{us} = 0.87\,f_y\,A_{sv}\sin\alpha$

8. Check whether the spacing of stirrups obtained above satisfies the code design requirements.

i. $S_v \not> 0.75\,d$ (Spacing governed by the depth of beam).

ii. $S_v \not> \left(\dfrac{A_{sv} \times 0.87f_y}{0.4\,b}\right)$ (Based on the minimum shear reinforcement).

iii. $S_v \not< 60$ mm (Suggested for better compaction of concrete).

9. Find the distance from the support up to which the design stirrups are required, for the rest of the portion provides minimum shear reinforcement.

**Que 2.6.** **A simply supported RC beam section 250 mm × 500 mm effective depth is reinforced with 4 bars of 22 mm dia as tension steel. If the beam is subjected to a factored shear of 65 kN at the support. Find the nominal shear stress at the support and design the shear reinforcement. Use M20 grade concrete and Fe415 steel.**

**AKTU 2014-15, Marks 10**

**Answer**

**Given :** Width of beam = 250 mm, Effective depth of beam = 500 mm.
Area of steel = 4 × (π/4) × $22^2$ = 1520.53 $mm^2$.
Factored shear force, $V_u$ = 65 kN, $f_{ck}$ = 20 N/$mm^2$, $f_y$ = 415 N/$mm^2$.

**To Find :** Shear stress and design shear reinforcement.

1. Percentage of area of steel,
$$p_t = \frac{100\,A_{st}}{bd} = \frac{100 \times 1520.53}{250 \times 500} = 1.216\,\%$$
2. Shear strength of concrete, $\tau_c$ = 0.66 N/$mm^2$ (from IS code 456 : 2000)
3. Nominal shear stress, $\tau_v = \dfrac{V_u}{bd} = \dfrac{65 \times 10^3}{250 \times 500}$ = 0.52 N/$mm^2$

4. Maximum shear stress, $\tau_{c,\,max}$ = 2.8 N/mm² (for M20 grade concrete)

$$\tau_v < \tau_c < \tau_{c,\,max}$$

5. Minimum shear reinforcement is provided.
6. Use 8 mm diameter 2-legged shear stirrups,

$$A_0 = 2 \times (\pi/4) \times 8^2 = 100.5 \text{ mm}^2$$

$$S_v = \frac{0.87 f_y A_0}{0.4b} = \frac{0.87 \times 415 \times 100.5}{0.4 \times 250}$$

$$= 362.8 \text{ mm} < 0.75\, d = 0.75 \times 500 = 375$$

$$= 375 \text{ mm or } 300\text{mm (whichever is less)}$$

7. Provide 8 mm diameter 2-legged stirrups @ 300 mm c/c spacing.

**Que 2.7.** **A concrete beam is 300 mm wide and 600 mm effective depth and is reinforced with 4 bars of 25 mm diameter bars in tension zone. Design shear reinforcement at a section experiencing shear force of 100 kN. Use M 20 concrete and Fe 415 steel.**

**AKTU 2013-14, Marks 10**

**Answer**

**Given :** Width of beam, $b$ = 300 mm, Effective depth, $d$ = 600 mm, Reinforcement = 4-25 mm $\phi$ bar, Shear force, $V$ = 100 kN.
**To Find :** Design shear reinforcement.

1. Area of reinforcement,

$$A_{st} = 4 \times (\pi/4) \times 25^2 = 1963.5 \text{ mm}^2$$

2. Shear force = 100 kN
Factored shear force = 1.5 × 100 = 150 kN

3. Nominal shear stress, $\tau_v = \dfrac{150 \times 10^3}{300 \times 600} = 0.833$ N/mm²

4. Percentage of area of steel,

$$p_t = \frac{A_{st}}{bd} \times 100 = \frac{1963.5}{300 \times 600} \times 100 = 1.09 \approx 1.1\ \%$$

5. Shear strength of concrete, $\tau_c$ = 0.64 N/mm² (From IS code 456 : 2000)
6. Maximum shear strength of concrete,

$$\tau_{c,\,max} = 2.8 \text{ N/mm}^2 \text{(For M20 grade concrete)}$$

$\tau_c < \tau_v < \tau_{c,\,max} \Rightarrow 0.64 < 0.83 < 2.8$ N/mm²

7. **Shear Reinforcement :**
i. Shear force taken by stirrups,

$$V_{us} = V_u - \tau_c\, bd = 150 \times 10^3 - 0.64 \times 300 \times 600$$

$$= 34800 \text{ N}$$

ii. Use 8 mm diameter 2-legged vertical stirrups,

$$A_{sv} = 2 \times \frac{\pi}{4} \times 8^2 = 100.6 \text{ mm}^2$$



iii. Spacing of shear stirrups,

$$S_v = \frac{0.87 f_y A_{sv} \times d}{V_{us}} = \frac{0.87 \times 415 \times 100.6 \times 600}{34800} = 626.23 \text{ mm c/c}$$

iv. But code requires that,

a. $S_v \not> 300$ mm

b. $S_v \not> 0.75\, d = 0.75 \times 600 = 450$ mm

v. Minimum shear reinforcement,

$$A_{sv} > \frac{0.4 \times 300 \times 300}{0.87 \times 415} = 99.71 \text{ mm}^2$$

8. Hence provide 8 mm $\phi$ 2-legged vertical stirrups @ 300 mm c/c.

**Que 2.8.** **A RC beam has an effective depth of 400 mm and breadth of 300 mm. It contains 3-25 mm Fe 500 grade bars in tension. Determine the shear reinforcement needed for a factored SF of 250 kN if M30 mix is used.**

**AKTU 2015-16, Marks 10**

**Answer**

**Given :** Width, $b$ = 300 mm, Effective depth, $d$ = 400 mm
Area of steel, $A_t = 3 \times (\pi/4) \times 25^2 = 1472.62$ mm², $f_{ck}$ = 30 N/mm²
$f_y$ = 500 N/mm², Factored shear force, $V_u$ = 250 kN
**To Find :** Shear reinforcement.

1. Percentage of area of steel, $= \dfrac{1472.62}{300 \times 400} \times 100 = 1.227\ \%$

2. From IS code 456 : 2000,
By interpolation shear stress of concrete,

$$\tau_c = 0.66 + \frac{(0.71 - 0.66)}{(1.25 - 1.00)} \times (1.227 - 1.00) = 0.7054 \text{ N/mm}^2$$

3. For M30 grade concrete, $\tau_{c,\,max}$ = 3.5 N/mm²
4. Nominal shear stress,

$$\tau_v = \frac{V_u}{bd} = \frac{250 \times 10^3}{300 \times 400} = 2.083 \text{ N/mm}^2$$

$$\tau_c < \tau_v < \tau_{c\,max}$$

$$V_c = \tau_c\, bd = 0.7054 \times 300 \times 400 = 84.65 \times 10^3 \text{ N}$$

5. Shear force resist by concrete,

$$V_{us} = V_u - V_c$$

$$V_{us} = (250 - 84.65) \times 10^3 = 165.35 \text{ kN}$$

6. Adopt 10 mm $\phi$ 2-legged stirrups,

$$A_{sv} = 2 \times (\pi/4) \times 10^2 = 157.08 \text{ mm}^2$$

7. Spacing, $S_v = \dfrac{0.87 f_y A_{sv} d}{V_{us}}$

$$S_v = \frac{0.87 \times 500 \times 157.08 \times 400}{165.35 \times 10^3} = 165.3 \text{ mm}$$

By code, spacing should not be more than

i. 300 mm
ii. $0.75\,d = 0.75 \times 400 = 300$ mm

8. Provided 10 mm $\phi$-2-legged stirrup @ 160 mm

**Que 2.9.** **A rectangular beam of size 250 mm width and 500 mm effective depth is reinforced with four bars of 25 mm diameter. Determine the required vertical shear reinforcement to resist factored shear force of**

**A. 80 kN B. 300 kN, and C. 600 kN.**

**Consider concrete of grade M 20 and steel of grade Fe 415.**

**AKTU 2016-17, Marks 10**

**Answer**

**Given :** Width of beam, $b = 250$ mm, Effective depth, $d = 500$ mm, Area of reinforcement, $A_{st} = 4 \times (\pi/4) \times 25^2 = 1963.50 \text{ mm}^2$

**To Find :** Vertical shear reinforcement.

**A. Case I :**

1. Factored shear force, $V_u = 80$ kN
2. Nominal shear stress, $\tau_v = \dfrac{80 \times 10^3}{250 \times 500} = 0.64 \text{ N/mm}^2$
3. Percentage of steel, $p_t = \dfrac{A_{st}}{bd} \times 100 = \dfrac{1963.50}{250 \times 500} \times 100 = 1.57\ \%$

   For $p = 1.57$ %, shear strength of concrete,
   $$\tau_c = 0.73 \text{ N/mm}^2$$
4. Maximum shear strength of concrete,
   $$\tau_{c,\,max} = 2.8 \text{ N/mm}^2$$
   $\tau_v < \tau_c < \tau_{c,\,max}$ Hence provide nominal shear reinforcement.
5. Spacing of shear stirrups,
   $$S_v = \frac{0.87\,f_y A_{sv}}{0.4\,b}$$
6. Provide 8 mm diameter 2-legged shear stirrups.
   $$A_{sv} = 2 \times \frac{\pi}{4} \times 8^2 = 100.53 \text{ mm}^2$$
   $$S_v = \frac{0.87 \times 415 \times 100.53}{0.4 \times 250} = 362.9 \text{ mm}$$
7. Spacing of stirrups should be minimum of following :

   i. 300 mm
   ii. $0.75 \times$ Depth of beam $= 0.75 \times 500 = 375$ mm



Provide 8 mm diameter 2-legged stirrups @ 300 mm c/c spacing.

**B. Case II :**

1. Factored shear force, $V_u = 300$ kN
2. Nominal shear stress, $\tau_v = \dfrac{300 \times 10^3}{250 \times 500} = 2.4 \text{ N/mm}^2$
3. Percentage of steel, $p_t = 1.57\ \%$
4. Shear strength of concrete for $p_t = 1.57\ \%$
   $$\tau_c = 0.73 \text{ N/mm}^2$$
   $$\tau_{c,\,max} > \tau_v > \tau_c$$
5. Design shear strength,
   $$V_{us} = V_u - \tau_c bd = 300 \times 10^3 - 0.73 \times 250 \times 500 = 208750 \text{ N}$$
6. Use 8 mm $\phi$ 4-legged stirrups,
   $$A_{sv} = 4 \times (\pi/4) \times 8^2 = 201.06 \text{ mm}^2$$
7. Spacing of vertical stirrups,
   $$S_v = \frac{0.87 \times 415 \times 201.06 \times 500}{208750} = 173.87 \text{ mm}$$

   Provide 8 mm $\phi$, 4-legged stirrups @ 170 mm c/c spacing.

**C. Case III :**

1. Factored shear force, $V_u = 600$ kN
2. Nominal shear stress, $\tau_v = \dfrac{600 \times 10^3}{250 \times 500} = 4.8 \text{ N/mm}^2$
3. Percentage of steel, $p_t = 1.57\ \%$

   For $p_t = 1.57\ \%$, $\tau_c = 0.73 \text{ N/mm}^2$
   $$\tau_{c,\,max} = 2.8 \text{ N/mm}^2$$
   $$\tau_v > \tau_{c,\,max}$$
4. Hence the section should be redesign means dimensions of beam will be change.

**Que 2.10.** **A cantilever beam is 230 mm wide and 400 mm deep at fixed end. Its span is 3 m and it carries a UDL 18 kN/m inclusive of self weight. Two bars of 20 mm diameter have been provided in tension zone. Design required shear reinforcement if concrete is of grade M20.**

**AKTU 2013-14, Marks 10**

**Answer**

**Given Data :** Width of beam, $b = 230$ mm.
Depth of beam, $D = 400$ mm. Spam, $l = 3$m.
Intensity of UDL = 18 kN/m, Reinforcement = 2-20 mm $\phi$.

**To Find :** Shear reinforcement.

1. Area of reinforcement,
   $$A_{st} = 2 \times (\pi/4) \times 20^2 = 628.32 \text{ mm}^2$$

2. Bending moment of cantilever beam of span 3 m,

$$M = \frac{wl^2}{2} = \frac{18 \times 3^2}{2} = 81 \text{ kN-m}$$

3. Factored BM, $M_u = 81 \times 1.5 = 121.5$ kN-m
4. Shear force, $V = 18 \times 3 = 54$ kN
5. Factored shear force = 1.5 × 54 = 81 kN
6. Nominal shear stress, $\tau_v = \frac{81 \times 10^3}{230 \times 400} = 0.88 \text{ N/mm}^2$
7. Percentage of steel, $p_t = \frac{100 A_{st}}{bd} = \frac{100 \times 628.32}{230 \times 400} = 0.683 \%$
8. Shear strength of section for $p_t = 0.683 \%$ and M20

$$\tau_c = 0.48 + \frac{0.56 - 0.48}{0.75 - 0.50} \times (0.683 - 0.50) = 0.538 \approx 0.54 \text{ N/mm}^2$$

9. Maximum shear strength for M20 grade;

$$\tau_{c,max} = 2.8 \text{ N/mm}^2$$

$$\tau_c < \tau_v < \tau_{c,max} \Rightarrow 0.54 < 0.88 < 2.8$$

Hence, shear reinforcement may be provided.

10. Design shear strength :

$$V_{us} = V_u - \tau_c bd = 81 \times 10^3 - 0.54 \times 230 \times 400 = 31320 \text{ N}$$

11. Use 8 mm 2-legged stirrups.

$$A_{sv} = 2 \times (\pi/4) \times 8^2 = 100.6 \text{ mm}^2$$

12. Spacing of vertical shear stirrups,

$$S_v = \frac{0.87 f_y A_{sv} d}{V_{us}} = \frac{0.87 \times 415 \times 100.6 \times 400}{31320} = 463.88 \text{ mm}$$

13. According to IS code 456 : 2000, spacing
    i. $S_v \not> 300$ mm
    ii. $S_v \not> 0.75 \times d = 0.75 \times 400 = 300$ mm
14. Provide 8 mm 2-legged vertical stirrups @ 300 mm c/c
15. Minimum area of shear reinforcement,

$$A_{sv} = \frac{0.4 \times 230 \times 300}{0.87 \times 415} = 76.44 < 100.6 \text{ mm}^2$$

## PART-3

***Development Length, Anchorage Bond, Flexural Bond.***

### CONCEPT OUTLINE

**Development Length :** It is an embedded length of the bar required to develop the design strength of reinforcement at critical section.



**Bond :** The force which prevents the relative movement between concrete and steel is known as bond.

**Anchorage Bond :**

$$L_d = \frac{0.87 f_y \phi}{4 \tau_{bd}}$$

$\phi$ = Diameter of bar in mm.

$\tau_{bd}$ = Bond stress.

The IS code requires that :
i. $\tau_{bd}$ value may be increase by 60 % for deformed bar in tension.
ii. 25 % further increment for bar in compression.

**Flexural Bond :**
In a simple beam, at the critical sections *i.e.*, at the face of the support, at points of inflection and at points of high shear force, high bond stress may develop due to the large variations in bending moment. These bond stresses are called as flexural bond stresses and should be checked carefully at all critical sections.

## Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 2.11. What is bond strength of concrete ? Derive expression for bond stress in reinforced concrete. AKTU 2013-14, Marks 10**

**Answer**

1. Let us consider a steel bar embedded in concrete. The bar is subjected to a tensile force $T$. Due to this tensile force, the steel bar will tend to come out and slip out of the concrete. This tendency of slipping is resisted by the bond stress developed over the surface of the bar.

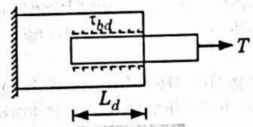



**Fig. 2.11.1.**

2. Bond strength ($\tau_{bd}$) is the shear stress developed along the contact surface between the reinforcing steel and the surrounding concrete, which prevents the bar from slipping out of concrete.
3. To avoid slipping, $T \le \tau_{bd} \times 2\pi \frac{\phi}{2} \times L_d$ $\left[\because \text{Surface area} = 2\pi \frac{\phi}{2} \times L_d\right]$ ...(2.11.1)

Shear strength, $T = 0.87 f_y A_s = 0.87 f_y \times (\pi/4) \times \phi^2$ ...(2.11.2)

$$0.87 f_y \times (\pi/4) \times \phi^2 \le \tau_{bd} \times 2p \times (\phi/2) \times L_d$$

$$\therefore \quad L_d \ge \frac{0.87 f_y \phi}{4\tau_{bd}}$$

where, $L_d$ = Development length of steel bar.
$f_y$ = Characteristic strength of the bar.
$\tau_{bd}$ = Design bond stress in limit state method.
$\phi$ = Diameter of bar.

4. $L_d$ is called the development length. It is the minimum length of bar which must be embedded in concrete beyond any section to develop its full strength.
5. This is also called as anchorage length in case of axial tension or axial compression and development length in case of flexural tension or flexural compression.
6. The permissible bond stress $\tau_{bd}$ depends upon the grade of concrete and type of steel. The values of permissible bond stress are given in clause 26.2.1.1 of IS 456 : 2000.
7. **Note :**
   i. For deformed bars $\tau_{bd}$ is 60 % more than that of plain bars.
   ii. It is easier to pull a bar than to push it inside. Therefore, permissible bond stress for plain and deformed bars in compression is taken as 25 % more than that for the bars in tension.
8. Development length in compression,

$$L_d = \frac{0.87 f_y \phi}{4(1.25\tau_{bd})} = \frac{0.87 f_y \phi}{5\tau_{bd}}$$

**Que 2.12.** **What do you mean by development length ? And also explain the factors affecting the development length.**

**Answer**

1. **Development Length :** Development length is an embedded length of the bar required to develop the design strength of reinforcement at the critical section.
2. **Factors Affecting the Development Length :** Various factors affecting the development length are as follows :
   i. **Grade of Concrete :** Since bond resistance is essentially an interfacial shear, it is a function of shear strength of concrete, and hence, of grade of concrete.
   Higher the grade, greater is the strength.
   ii. **Diameter of Bar :** Greater is the bar diameter lesser is the bond resistance for the same surface area because larger diameter of bar leads to greater cracking.



   iii. **Nature of Stress :** Since the transverse compression from concrete increases the grip and frictional resistance, bond strength is higher for bars in compression than in tension.
   iv. **Bends and Hooks :** The increase in bond resistance at bends is due to increase in frictional resistance on account of confinement of concrete inside the bend by radial component of the bar tension. The increase in bond is measured in terms of additional anchorage length provided by the bar bend.
   v. **Cover :** If the cover is inadequate or when the horizontal distance between two parallel main reinforcing bars is less, the splitting occurs resulting in ultimate cracking and in reduction in bond strength to a large extent.
   vi. **Curtailment of Bars in Tension Zone :** The curtailment of bars in tension zone creates a condition of differential strains in adjacent bars effecting loss of shear and bond.
   vii. **Grouping of Bars :** Bond- reduces for bundled bars due to reduction in surface area.

**Que 2.13.** **A simply supported RC beam of size 300 mm × 500 mm effective depth is reinforced with 4 bars of 16 mm dia. Determine the anchorage length of the bar at the simply supported end. if it is subjected to a factored shear force of 350 kN at the centre of 300 mm wide masonry support. Use M20 grade of concrete and Fe415 steel.**

**AKTU 2014-15, Marks 10**

**Answer**

**Given :** Size of beam = 300 mm × 500 mm.
Area of steel = $4 \times (\pi/4) \times 16^2 = 804.25$ mm².
Factored shear force = 350 kN.
Grade of concrete, M20, $f_{ck}$ = 20 N/mm².
Grade of steel, Fe415, $f_y$ = 415 N/mm².
**To Find :** Anchorage length of bar.

1. Depth of neutral axis, $x_u = \dfrac{0.87 f_y A_{st}}{0.36 f_{ck} b} = \dfrac{0.87 \times 415 \times 804.25}{0.36 \times 20 \times 300}$

$$x_u = 134.43 \text{ mm}$$

2. Maximum depth of neutral axis, $x_{u,max} = 0.48\,d$

$$x_{u,max} = 0.48 \times 500 = 240 \text{ mm}$$

3. Moment of resistance $= 0.87 f_y A_t (d - 0.42 x_u)$

$$= 0.87 \times 415 \times 804.25 (500 - 0.42 \times 134.43)$$

$$= 128.79 \text{ kN-m}$$

4. For M20 and Fe415 HYSD steel

$\tau_{bd} = 1.6 \times 1.2 = 1.92$ N/mm²

5. Development length, $L_d = \dfrac{0.87 f_y \phi}{4\tau_{bd}}$

$$L_d = \frac{0.87 \times 415 \times \phi}{4 \times 1.92} \approx 47\,\phi = 47 \times 16 = 752 \text{ mm}$$

6. Anchorage length, $L_0$ = Greater of $d$ or $12\,\phi$

$d = 500$ or $12 \times 16 = 192$

$L_0 = 500$ mm

7. $L_d < 1.3\,(M_1 / V) + L_0$

$$752 \leq 1.3 \times \frac{128.79 \times 10^6}{350 \times 10^3} + 500$$

$$752 \leq 978.36$$

Hence anchorage length, $L_0 = 500$ mm

## PART-4

*Failure of Beam under Shear, Concept of Equivalent Shear and Moments.*

### CONCEPT OUTLINE

**Mode of Shear Failure :**

i. Diagonal tension failure.

ii. Flexural shear failure.

iii. Diagonal compression failure.

The equivalent ultimate moment is given by,

$$M_e = M_u + M_t$$

The equivalent ultimate shear is given by,

$$V_e = V_u + 1.6\,T_u / b$$

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 2.14.** **Describe the modes of failure in shear of RC beam.**

**Answer**

Following are the modes of failure in shear of RC beam :

1. **Diagonal Tension Failure :** Diagonal tension failure occurs under large shear force and less bending moment. Such type of failure in RC beam in the forms of cracks at 45° with the horizontal is shown in Fig. 2.14.1.



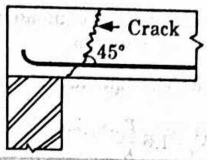



**Fig. 2.14.1. Diagonal tension failure.**

2. **Flexural Shear Failure :** Flexural failure occurs under large bending moment and less shear force. Such type of failure in RC beams in the forms of crack at 90° with the horizontal is shown in Fig. 2.14.2.

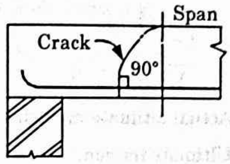



**Fig. 2.14.2. Flexural shear failure.**

3. **Diagonal Compression Failure :** Diagonal compression failure occurs under large shear force. It is characterized by the crushing of concrete. Normally, it occurs in beams which are reinforced against heavy shear as shown in Fig. 2.14.3.

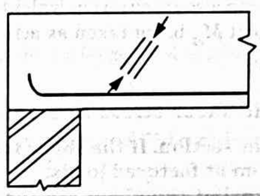


**Fig. 2.14.3. Diagonal compression failure.**

**Que 2.15.** **What do you mean by torsion in beam ? Explain the equivalent shear and moment when RCC member subjected to torsion.**

**Answer**

**Torsion in Beams :** Reinforced concrete sections are also subjected to torsional moments which cause twisting or warping of the section.

The reinforcements for the beam consist of the following :

i. Longitudinal reinforcement determined for an equivalent ultimate bending moment which is based on the actual bending moment and torsion.

ii. Web reinforcement determined for an equivalent ultimate shear which is based on the actual shear and torsion.

1. **Equivalent Shear Force :** The equivalent ultimate shear is given by,

$$V_e = V_u + 1.6\frac{T_u}{b}$$

where, $V_u$ = Ultimate shear force.

2. **Equivalent Moment :** The equivalent ultimate moment is given by,

$$M_{el} = M_u + M_t$$

and

$$M_t = T_u\left[\frac{1+\frac{D}{b}}{1.7}\right]$$

where, $M_u$ = Actual ultimate moment.
$T_u$ = Ultimate torsion.
$D$ = Overall depth of the beam.
$b$ = Width of the beam.

If the numerical value of $M_t$ exceeds the numerical value of $M_u$ then the longitudinal reinforcement shall be provided on the flexural compression face, such that the beam can also reach an equivalent ultimate moment $M_{e2} = M_t - M_u$, the moment $M_{e2}$ being taken as acting in the opposite sense to the moment $M_u$.

**Que 2.16.** **Determine the shear stress in a 250 mm × 400 mm effective depth rectangular section. If the shear force is 10 kN and torsional moment is 2 kN-m at factored loads. Assume 0.25 % tension steel at the given section. State whether torsional reinforcement is required or not. Use M20 grade concrete and Fe415 steel.**

**AKTU 2014-15, Marks 10**

**Answer**

**Given :** Factored shear force, $V_u$ = 10 kN.
Factored torsional moment, $T_u$ = 2 kN-m.
Width of beam = 250 mm. Effective depth of beam = 400 mm.
**To Find :** Shear stress

1. Equivalent shear force, $V_e = V_u + 1.6\ \frac{T_u}{b}$

$$= 10 + 1.6 \times \frac{2}{0.25} = 22.8 \text{ kN}$$



2. Equivalent nominal shear stress,

$$\tau_e = \frac{V_e}{bd} = \frac{22.8 \times 10^3}{250 \times 400} = 0.228 \text{ N/mm}^2$$

3. Shear strength of M20 concrete at 0.25 % tension steel,

$$\tau_c = 0.36 \text{ N/mm}^2$$

Since $\tau_c > \tau_e$, no torsional reinforcement is required.

4. Depth of beam is less than 450 mm, no side torsional reinforcement is required.

5. Minimum shear reinforcement should be provided, that is

$$\frac{A_{sv}}{b_{sv}} \geq \frac{0.4}{0.87\,\sigma_y}$$

i. Use 8 mm $\phi$ 2-legged stirrups of Fe415 steel

$$A_{sv} = 2 \times (\pi/4) \times 8^2 = 100.6 \text{ mm}^2, f_y = 415 \text{ N-mm}^2$$

$$S_v \leq \frac{100.6 \times 0.87 \times 415}{0.4 \times 250} = 363.2 \text{ mm}$$

ii. Spacing should not be exceed of following :
a. $0.75 \times d = 0.75 \times 400 = 300$ mm
b. 300 mm

iii. Hence provide 8 mm 2-legged Fe415 grade steel stirrups @ 300 mm c/c.

**Que 2.17.** **Design the torsional reinforcement in a rectangular beam section, 350 mm wide and 750 mm deep, subjected to an ultimate twisting moment of 140 kN-m, combined with an ultimate BM of 200 kN-m and an ultimate SF of 110 kN. Assume M25 concrete and Fe415 grade of steel.**

**AKTU 2015-16, Marks 15**

**Answer**

**Given :** Width of beam = 350 mm, Depth of beam, $D$ = 750 mm, Factored twisting moment, $T_u$ =140 kN-m, Factored bending moment, $M_u$ = 200 kN-m, Factored shear force, $V_u$ = 110 kN.
$f_{ck}$ = 25 N/mm², $f_y$ = 415 N/mm²,
**To Find :** Design of torsional reinforcement.

1. Assuming 50 mm effective cover all around the beam.
Effective depth, $d$ = 750 – 50 = 700 mm.

2. **Design of Longitudinal Reinforcement :**

i. Effective bending moment due to torsion, $M_t = T_u\,(1 + D/b)/1.7$

$= 140 \times (1 + 750/350)/1.7 = 259$ kN-m

ii. Equivalent bending moments for design, $M_e = M_t \pm M_u$

$$= 259 \pm 200 = \begin{cases} 459\,\text{kN-m} & \text{(Flexural tension at bottom)} \\ 59\,\text{kN-m} & \text{(Flexural tension at top)} \end{cases}$$

iii. **Design of Bottom Steel :**

$$R_1 = \frac{M_{e1}}{bd^2} = \frac{459 \times 10^6}{350 \times (700)^2} = 2.676 \text{ N/mm}^2$$

$$\left(R_1 < \frac{M_{u,\text{lim}}}{bd^2} = 0.1389 \times 25 = 3.472\right)$$

Percentage of steel, $p_t = \frac{A_{st}}{bd} = \frac{f_{ck}}{2f_y}\left[1 - \sqrt{1 - 4.598\, R_1 / f_{ck}}\right]$

$$= \frac{25}{2 \times 415}\left[1 - \sqrt{1 - 4.598 \times 2.676/25}\right] = 0.866 \times 10^{-2}$$

$$(A_{st})_{\text{reqd}} = 0.866 \times 10^{-2} \times 350 \times 700 = 2122 \text{ mm}^2$$

Provide 2–28 $\phi$ and 2 – 25 $\phi$ bars at bottom

$$[A_{st} = (616 \times 2) + (491 \times 2) = 2214 \text{ mm}^2]$$

iv. **Design of Top Steel :**

$$R_2 = \frac{M_{e2}}{bd^2} = \frac{59 \times 10^6}{350 \times (700)^2} = 0.344$$

$$\therefore \quad \frac{(p_t)_{\text{reqd}}}{100} = \frac{25}{2 \times 415}\left[1 - \sqrt{1 - \frac{4.598 \times 0.344}{25}}\right]$$

$$= 0.097 \times 10^{-2} \text{ (very low)}$$

v. Provide minimum reinforcement :

$$\frac{A_{st}}{bd} = \frac{0.85}{415} = 0.205 \times 10^{-2}$$

$$(A_{st})_{\text{reqd}} = 0.205 \times 10^{-2} \times 350 \times 700 = 502 \text{ mm}^2$$

Provide 3-16 mm $\phi$ ($A_{st} = 201 \times 3 = 603$ mm²) bar at top

3. **Side Face Reinforcement :**

i. As $D > 450$ mm, side face reinforcement for torsion is required.

$$(A_{st})_{reqd} = 0.001bD = 0.001 \times 350 \times 750 = 263 \text{ mm}^2$$

Provide 4 – 10 $\phi$ ($A_{st} = 78.5 \times 4 = 314$ mm²), two bars on each side face.

ii. The (vertical) spacing between longitudinal bars will be less than 300 mm, as required by the Code.



iii. The designed cross-section is shown in Fig. 2.17.1.

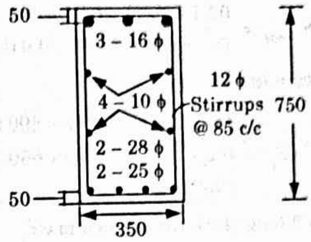



**Fig. 2.17.1.**

4. **Design of Transverse Reinforcement :**

i. Equivalent nominal shear stress,

$$\tau_{ve} = \frac{V_u + 1.6T_u / b}{bd} = \frac{110 \times 10^3 + 1.6 \times (140 \times 10^6)/350}{350 \times 700}$$

$$= 3.06 \text{ N/mm}^2 < \tau_{c,\max} = 3.1 \text{ N/mm}^2 \text{ (For M25 concrete)}$$

ii. Shear strength of concrete

For $\quad p_t = \frac{2214 \times 100}{350 \times 700} = 0.904$

From IS code,

$\tau_c = 0.618$ MPa (For M25 concrete)

iii. As torsional shear is relatively high, following equation is likely to govern the design of stirrups

Assuming 10 mm $\phi$ 2–legged stirrups, $A_{sv} = 78.5 \times 2 = 157$ mm².

$$(S_v)_{\text{reqd}} = \frac{A_{sv} d_1 (0.87 f_y)}{T_u / b_1 + V_u / 2.5}$$

With 50 mm effective cover assumed all around,

$$d_1 = 750 - 50 \times 2 = 650 \text{ mm}$$

$$b_1 = 350 - 50 \times 2 = 250 \text{ mm}$$

$$(S_v)_{\text{reqd}} = \frac{157 \times 650 \times (0.87 \times 415)}{(140 \times 10^6 / 250) + (110 \times 10^3 / 2.5)}$$

$$= 61.0 \text{ mm (low)}$$

iv. Alternatively, providing 12 mm $\phi$ 2-legged stirrups,

$$A_{sv} = 113 \times 2 = 226 \text{ mm}^2$$

$$(S_v)_{\text{reqd}} = 61.0 \times \frac{226}{157} = 87.8 \text{ mm}$$

v. Further, applying equation,

$$(S_v)_{reqd} = \frac{0.87 f_y A_{sv}}{(\tau_{ve} - \tau_c)b} = \frac{0.87 \times 415 \times 226}{(3.06 - 0.618) \times 350} = 95.5 \text{ mm}$$

vi. Maximum spacing requirements

$$(S_v) \le \begin{cases} x_1 = 250 + 28 + 12 = 290 \text{ mm} \\ (x_1 + y_1)/4 = (290 + 650 + 34)/4 = 243 \text{ mm} \\ 300 \text{ mm} \end{cases}$$

Provide 12 mm $\phi$ 2-legged stirrups @ 85 mm c/c.

5. **Check for Cover :** With 50 mm effective cover, 12 mm $\phi$ stirrups and 28 mm $\phi$ longitudinal bars, clear cover to stirrups is 50 – 12 – 28/2 = 24 mm, > 20 mm (safe).

☺☺☺

3

UNIT

# Design of Solid Slabs

## CONTENTS

## PART-1

*Design of One Way, Continuous and Cantilever Solid Slab by Limit State Design Method.*

### CONCEPT OUTLINE

**One-way Slab :** When length of slab is more than twice of the breadth, the slab is known as one way slab, this may be simply supported or continuous.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 3.1.** **What are the difference between one way slab and two way slab ?**

**Answer**

| S. No. | One Way Slab | Two Way Slab |
|---|---|---|
| 1. | $(l_y / l_x) > 2.0$ | $(l_y / l_x) \le 2.0$ |
| 2. | The bending takes place in one direction only *i.e.*, shorter span. | The bending takes place in both directions. |
| 3. | Depth required is more. | Depth required is less. |
| 4. | Main steel reinforcement is provided along shorter span. | Main steel reinforcement is provided along both the spans. |
| 5. | Less economical as thickness is more and the amount of steel is also more. | More economical as the thickness of slab is less and the amount of steel required is less. |

**Que 3.2.** **Write the recommendation of IS : 456-2000 for design of slabs. And also explain the reinforcement of slabs.**

**Answer**

IS : 456-2000 recommendations for design of slabs are as follows :

**A. Effective Span :**

1. For simply supported slab the effective span is taken as smaller of the following :



i. Centre to centre distance of supports.

ii. Clear distance between the supports plus the effective depth.

**B. Deflection Control :**

For slabs, the vertical deflection limits are specified by maximum *l/d* ratio.

1. *l/d* for spans up to 10 m

| Types of Slab | Cantilever | Simply supported | Continuous |
|---|---|---|---|
| ***l/d* Ratio** | 7 | 20 | 26 |

2. For two-way slabs of small spans (up to 3.5 m) with mild steel reinforcement, the shorter span to overall depth ratios may be assumed to satisfy the deflection limits of loading class up to 3000 N/m$^2$.

Simply supported : 35

Continuous slab : 40

For high strength deformed bars the above given values should be multiplied by 0.8.

**C. Reinforcement in Slabs :**

1. **Minimum Reinforcement :** The area of reinforcement in either direction in a slab should not be less than 0.15 % of the total cross-sectional area in case of mild steel reinforcement. In the case of high strength deformed bars, this value can be reduced to 0.12 %.
2. **Maximum Diameter to Reinforcement :** The maximum diameter of the reinforcing bar in a slab should not exceed 1/8$^{th}$ of the total thickness of the slab.
3. **Distribution Reinforcement :** Distribution reinforcement is provided in the longer span of one way slab. This steel is as per the minimum reinforcement criteria.

**D. Spacing of Reinforcements :**

1. **Minimum Distance between Bars :**

i. The minimum horizontal distance between two parallel main bars shall not be less than :

a. The diameter of the bar (largest diameter bar is to be considered).

b. 5 mm more than the nominal maximum size of coarse aggregate used in concrete.

ii. The vertical distance between two layers of main reinforcement shall be more than :

a. 15 mm or

b. (2/3)rd the nominal maximum size of aggregate.

2. **Maximum Distance between Bars in Tension :**

i. The spacing of main steel in a slab should not exceed the following :

a. 3 times the effective depth of slab.

b. 300 mm.

ii. The spacing of the bars provided to act as distribution steel or bars provided for preventing temperature and shrinkage stresses shall not exceed the following :

a. 5 times the effective depth of slab or

b. 450 mm.

E. **Cover :** Nominal cover to be provided in a slab is 20 mm.

F. **Bent-up Bars :** Some of the main reinforcement in slabs is generally bent-up near the supports to take up negative moment which may develop due to partial fixity.

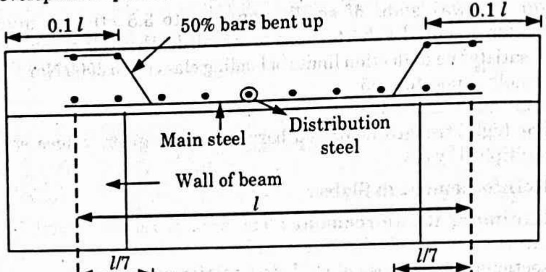



**Fig. 3.2.1.**

G. **Shear Design :** Slabs are safe in shear (nominal shear stress is very low since $b$ is large) therefore no shear reinforcement is provided in slabs except that the alternate bars are bent-up near the supports.

**Que 3.3.** **Write the design procedure for one-way slab.**

**Answer**

The following steps may be adopted in the design of a simply supported one-way slab :

**Step 1 : Effective Span :** The effective span to be taken as centre to centre distance between bearings.

**Step 2 : Thickness of the Slab :** The thickness of slab is governed by deflection consideration rather than flexural strength consideration.

**Step 3 : Actual Effective Span of Slab :** Actual effective span of the slab is the lesser of the following :

i. Distance between centres of bearings.

ii. Clear span + effective depth.

**Step 4 : Loads on the Slab :** Estimate the total load on the slab, per square meter.

**Step 5 : Factored Load and Factored Bending Moment :**

i. The factored load,



$$W_u = 1.5\,W$$

ii. Factored moment is given by,

$$M_u = \frac{W_u l^2}{8} \quad \text{where, } l = \text{Effective span of the slab.}$$

**Step 6 : Required Effective Depth :**

i. The required effective depth to be obtained by equating the limiting moment resistance to the factored bending moment.

ii. Effective depth from flexural strength consideration :

$$\text{Effective depth required, } d_{req} = \sqrt{\frac{M_{u,\lim}}{R_u b}}$$

**Step 7 : Area of Steel Required Per Metre Width of Slab :**
Area of steel required per m width, $A_{st}$

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

**Step 8 : Spacing of Reinforcements :**
By assuming diameter of bar, the spacing of bars are computed as,

$$\text{Spacing of bars} = \frac{\text{Area of one bar} \times b}{A_{st,req}}$$

Provide 8 mm diameter bars of Fe415 or 10 mm diameter bars to 12 mm diameter bars of Fe250.

**Step 9 : Check for Serviceability :** Find the percentage of steel provided. This should not be greater than the percentage of steel assumed initially. However if the percentage of steel exceed the values assumed initially then find the actual modification factor corresponding to the percentage of steel provided and find the depth required for serviceability.

**Step 10 : Distribution Steel :** Provide distribution steel running at right angles to the main steel. The distribution steel shall be 0.12 % of the gross area of the slab when Fe415 steel is used and 0.15 % of the gross area of the slab when Fe250 steel is used.

**Step 11 : Check for Shear :** Generally shear stresses in a slab are quite low. However if it is desired to check for shear, the nominal shear stress $\tau_v$ at the support should be lesser of design shear strength.

**Step 12 : Check for Development Length :**
According to IS : 456-2000, the condition to be satisfied is

$$L_d < 1.3\,(M_r / V_u) + L_0,$$

**Step 13 : Anchorage Length :** All bars must be taken into the support at least for a distance equal to $L_d / 3$.

**Que 3.4.** **Design a simply supported roof slab for a room 7.5 m × 3.5 m clear in size. The slab is carrying an imposed load of 5 kN/m². Use M20 grade concrete and Fe415 steel.**

**AKTU 2014-15, Marks 10**

**Answer**

**Given :** Size of slab = 7.5 m × 3.5 m, Live load = 5 kN/m²
**To Find :** Design the one way slab

1. **Effective Depth and Span :**
   i. $\frac{l_y}{l_x} = \frac{7.5}{3.5} > 2$ hence it is a one-way slab.

   Assuming total depth,
   $D = 150$ mm
   $d = 150 - 20 - 5 = 125$ mm

   Clear cover 20 mm and diameter of main bar = 10 mm
   ii. Effective Span Length ($l_{eff}$) : It should be least of the following :
   a. Centre to centre distance = 3.5 + 0.2 = 3.7 m
   b. Clear span + effective depth = 3.5 + 0.125 = 3.625 m
   ∴ Effective span, $l_{eff}$ = 3.625 m
2. **Design Load ($w_u$), Factored Moment ($M_u$), and Shear Force ($V_u$) :**
   i. Load for 1 m width of slab :
   Self weight of slab = 25 *bD* = 25 × 1 × 0.15 = 3.75 kN/m
   Live load = 5 kN/m
   Total load = 5 + 3.75 = 8.75 kN/m
   ii. Design load, $w_u$ = 1.5 × 8.75 = 13.125 kN/m
   iii. Factored moment, $M_u = \frac{w_u l^2}{8} = \frac{13.125 \times (3.625)^2}{8} = 21.60$ kN-m
   iv. Factored shear force,
   $$V_u = \frac{w_u l}{2} = \frac{13.125 \times 3.5}{2} = 22.97 \text{ kN}$$
3. **Check for Effective Depth of Slab :**
   Effective depth required, (∵ For Fe415 and M20, $R_u$ = 2.76)
   $$d_{reqd} = \sqrt{\frac{M_u}{R_u b}} = \sqrt{\frac{21.6 \times 10^6}{2.76 \times 1000}}$$
   = 88.5 mm < 125 mm
   Hence provide 125 mm thick slab of one way slab.
4. **Area of Tensile Steel ($A_{st}$) :**
   i. $$M_u = 0.87 f_y A_{st} d \left[1 - \frac{A_{st} f_y}{f_{ck} bd}\right]$$
   $$21.6 \times 10^6 = 0.87 \times 415 \times A_{st} \times 125 \left[1 - \frac{A_{st} \times 415}{20 \times 1000 \times 125}\right]$$
   $A_{st}$ = 524.2 mm²
   ii. Using 10 mm diameter bars,



$A_\phi = (\pi / 4) \times 10^2 = 78.5$ mm²

   iii. Spacing of 10 mm diameter bars
   $$= \frac{1000 \times A_\phi}{A_{st}} = \frac{1000 \times 78.5}{524.2} = 150 \text{ mm}^2$$
   Provide 10 mm diameter bar @ 150 mm c/c, $A_{st}$ = 524.2 mm².
   iv. Bending alternate bars at 510 mm $\left[\frac{l}{7} = \frac{3625}{7} = 517 \text{ mm}\right]$ from centre of support or 410 mm from the face of support $\left(\frac{A_{st}}{2} = \frac{524.2}{2} = 262.1\right)$
5. **Distribution Steel :**
   Distribution reinforcement is provided in the longer direction *i.e.*, 7.5 m,
   = 0.12 % of cross-sectional area
   $$= \frac{0.12}{100} \times 1000 \times 150 = 180 \text{ mm}^2$$
   Using 6 mm diameter bar
   $$\text{Spacing, } S = \frac{1000 \times A_\phi}{A_{st}} = \frac{1000 \times 28.3}{180} = 157.22 \text{ mm}$$
   Provide 6 mm diameter bar @ 150 mm c/c in the longer direction.
6. **Check for Shear :**
   i. Factored shear force,
   $V_u$ = 22970 N
   ii. Nominal shear stress $\tau_v$,
   $$\tau_v = \frac{V_u}{bd} = \frac{22970}{1000 \times 125} = 0.184 \text{ N/mm}^2$$
   iii. Design shear strength of concrete ($\tau_c$) :
   $$p_t = \frac{100 \times A_{st}}{bd} = \frac{100 \times 262.1}{1000 \times 125} = 0.21 \%$$
   For percentage of steel and M20 concrete
   $$\tau_c = 0.28 + \left(\frac{0.36 - 0.28}{0.25 - 0.15}\right)(0.21 - 0.15) = 0.328 \text{ N/mm}^2$$
   ∵ $\tau_v < \tau_c$, hence design is safe.
7. **Check for Deflection :**
   i. $$p_t = \frac{100 A_{st}}{bd} = \frac{100 \times 524.2}{1000 \times 125} = 0.42 \%$$
   ii. $$f_s = 0.58 f_y \left[\frac{A_{st} \text{ required}}{A_{st} \text{ provide}}\right] = 0.58 \times 415 \left[\frac{524.2}{524.2}\right] = 240 \text{ N/mm}^2$$
   iii. For $p_t$ = 0.4 %, and $f_s$ = 240 N/mm², $k_t$ = 1.55
   iv. $(l / d)_{max} = 20 \times k_t = 20 \times 1.55 = 31$
   v. $$(l / d)_{provided} = \frac{3625}{125} = 29$$
   vi. $(l / d)_{max} > (l / d)_{provided}$, Hence design is safe.

8. **Check for Development Length :**

i. Moment of resistance at support by 10 mm diameter bars @ 300 mm c/c.

Reinforcement at supports,

Provide, $A_{st} = \frac{524.2}{2} = 262.1 \text{ mm}^2$

$$M_r = 0.87 f_y A_{st} d \left[1 - \frac{f_y A_{st}}{f_{ck} bd}\right]$$

$$= 0.87 \times 415 \times 262.1 \times 125 \left[1 - \frac{415 \times 262.1}{20 \times 1000 \times 125}\right]$$

$$= 11.30 \times 10^6 \text{ N-mm}$$

ii. Factored shear force

$$V_u = 22970 \text{ N}$$

iii. Providing no hooks,

$$l_0 = 0$$

iv. $$\frac{M_r}{V} + l_0 = \frac{11.30 \times 10^6}{22970} = 492 \text{ mm}$$

$$L_d = \frac{(0.87 f_y)\phi}{4\tau_{bd}} = \frac{0.87 \times 415 \times 10}{4 \times 1.2 \times 1.6} = 470 \text{ mm}$$

$$\frac{M_r}{V} + l_0 > L_d$$

Hence slab is safe.

9. **Reinforcement Details :**

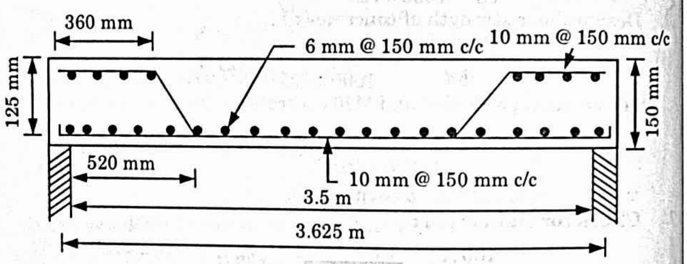



**Fig. 3.4.1.**

**Que 3.5.** **A 3 m wide gallery is connecting two blocks. The slab of gallery is resting over two longitudinal beams. The slab is supporting a live load of 3 kN/m². Design gallery slab and show the details with neat sketches. Use M 20 concrete.**

**AKTU 2013-14, Marks 10**



**Answer**

**Procedure :** Same as Q. 3.4, Page 3-5A, Unit-3.

1. Effective length = 3.15 m.
2. Factored moment = 13.5 kN-m
3. Factored shear force = 17.13 kN
4. Provide effective depth = 150 mm
5. Reinforcement :

i. Required area of reinforcement = 260.5 mm²

ii. Provide main reinforcement 8 mm $\phi$ bars @ 180 c/c.

6. Provide distribution reinforcement, 6 mm $\phi$ bars 150 mm c/c.

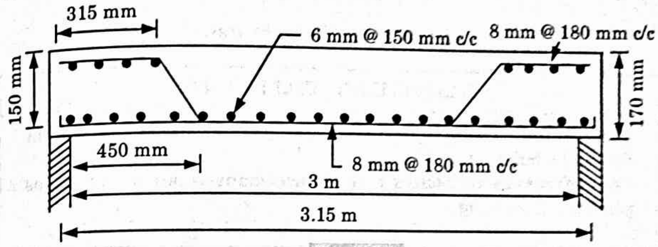



**Fig. 3.5.1.**

**Que 3.6.** **Design a one way slab, with a clear span of 4.0 m, simply supported on 230 mm thick masonry walls and subjected to a live load of 4 kN/m² and a surface finish of 1 kN/m². Assume M25 mix and Fe415 grade steel.**

**AKTU 2015-16, Marks 10**

**Answer**

**Procedure :** Same as Q. 3.4, Page 3-5A, Unit-3.

1. Provide effective length = 4.15 mm
2. Factored moment = 29.88 kN-m
3. Factored shear = 28.8 kN
4. i. Required depth = 93.06 mm

   ii. Provide effective depth = 130 mm
5. i. Required main reinforcement area = 700 mm²

   ii. Provide main reinforcement, 10 mm $\phi$ base @ 110 mm c/c ($A_{st}$ = 714 mm²)
6. Provide distribution reinforcement, 6 mm $\phi$ bars @ 180 mm c/c.

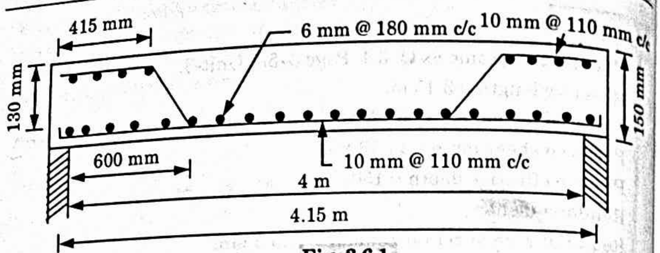



Fig. 3.6.1.

**PART-2**

*Design of RCC Staircases.*

**CONCEPT OUTLINE**

**Stair Slabs :** The staircase is used to give an access to different floors of a building.

**Classification of Stairs :** There are many types of staircases provided in building.

i. Straight stair. ii. Dog-legged stair. iii. Open well stair.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 3.7.** **Define the staircase and also define the terminolog used in staircase.**

**Answer**

**Staircase :**

i. A staircase is a means of giving access to different floors or levels of building.

ii. Staircases are used in almost all buildings. It consists of a number of steps arranged in a way that a person can move from one level to another.

Following are the different parts include in staircase :

1. **Flight :** Flight is the length of the staircase between two landings. It is the sloping and portion (slab) of the stairs. The number of steps in flight varies from 3 to 12.
2. **Landing :** Landing is the intermediate, horizontal portion provided in staircase. It is provided for relaxing while climbing entering or existing a staircase.



3. **Rise :** The vertical height of a step is called rise or riser. It varies from 150 mm to 180 mm for residential building and 120 to 150 mm for public building.

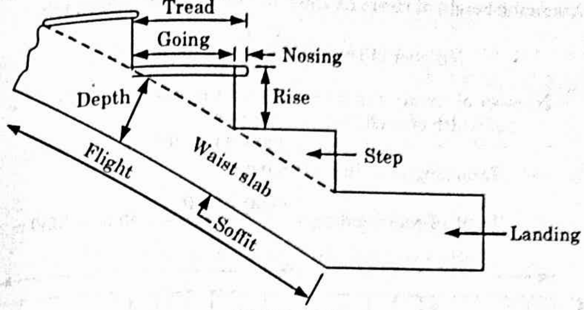



Fig. 3.7.1.

4. **Tread :** The horizontal distance between two risers on a step is called as tread. The width of a tread is kept as 200 mm to 250 mm for residential building and 200 to 300 mm for public building.
5. **Going and Nosing :** The horizontal distance between two risers is known as going and the portion projecting out from the riser surface is called as nosing. Nosing is provided when the available horizontal distance for a tread is less.
6. **Head Room :** It is the clear height available between one flight and other above it.
7. **Soffit :** It is the bottom surface of the waist slab.

**Que 3.8.** **Design a dog legged staircase for an office building in a room measuring 3.0 m × 6.0 m (clear dimensions). Floor to floor height is 3.5 m. The building is a public building liable to overcrowding. Stairs are supported on brick walls 230 mm thick at the end of landings. Use M20 concrete Fe 415 steel.**

**Answer**

**Given :** Dimension of room = 3 m × 6 m
Floor to floor height = 3.5 m, Width of wall = 230 mm grade M20 and Fe 415.
**To Find :** Design dog legged staircase.

1. **Proportioning of Various Dimensions of Staircase :**

i. Available width of staircase = 3.0 m

ii. Considering 2 flights of dog logged staircase, let us assume width of each flight as 1.35 m

iii. Space between the two flights = 3.0 – 2 × 1.35 = 0.30 m

iv. Floor to floor height = 3.5 m

v. As there will be two flights, each flight will have a height of 3.50 / 2 = 1.75 m

vi. Assuming height of risers as 150 mm as it is a public building.

vii. $$\text{Number of risers} = \frac{1750}{150} = 11.66 \text{ say } 12$$

viii. Number of treads required = Number of risers – 1 = 12 – 1 = 11

ix. Let width of each tread = 300 mm

x. Total going = 300 × 11 = 3300 mm = 3.30 m

xi. Total length available = 6.0 m

xii. $$\text{Width of each landing} = \frac{6.00 - 3.30}{2} = 1.35 \text{ m} = 1350 \text{ mm.}$$

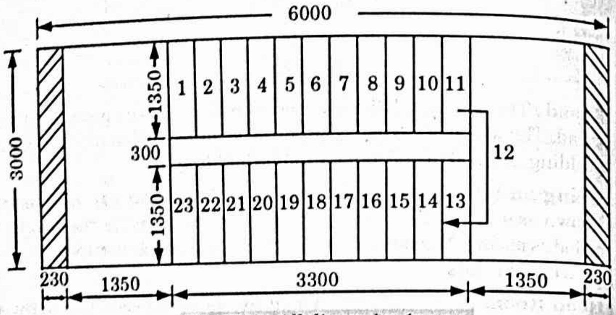



**Fig. 3.8.1.** All dimension in mm.

2. **Design of Staircase :**

i. Effective span of flight = Centre to centre distance of walls

$$= 6.00 + \frac{0.23}{2} + \frac{0.23}{2} = 6.23 \text{ m} = 6230 \text{ mm}$$

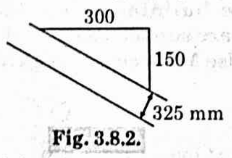



**Fig. 3.8.2.**

ii. Thickness of waist slab = 1/20 of span (approx.)

$$= \frac{6.23}{20} \times 1000 = 311.5 \text{ mm}$$

Let us take $d$ = 300 mm and $D$ = 325 mm.

3. **Loads :**

i. Weight of waist slab in plan (per m width of flight)

$$D\sqrt{1 + \frac{R^2}{T^2}} \times 25 = 0.325\sqrt{1 + \frac{150^2}{300^2}} \times 25 = 9.1 \text{ kN/m}$$



ii. Weight of steps (per m width of flight)

$$= \frac{25RT}{2T} = \frac{1}{2} \times \frac{0.15 \times 0.30}{0.30} \times 25 = 1.875 \text{ kN/m}$$

iii. Total dead load = 9.1 + 1.875 = 10.975 kN/m

iv. Live load = 5 kN/m² = 5 kN/m per m width of staircase

v. Total load $DL + LL = w$ = 10.975 + 5 = 15.975 kN/m ≃ 16 kN/m

vi. Factored load, $w_u$ = 16 × 1.5 = 24 kN/m

vii. For landing, $DL$ = 0.325 × 25 × 1.0 = 8.125 kN/m

$LL$ = 1 × 5.0 kN/m² = 5.0 kN/m per m width of landing

viii. Total, $DL + LL$ = 13.125 kN/m

ix. Factored load = 1.5 × 13.125 kN/m = 19.70 kN/m

4. **Load Diagram of the Stairs Shall be as Follows :**

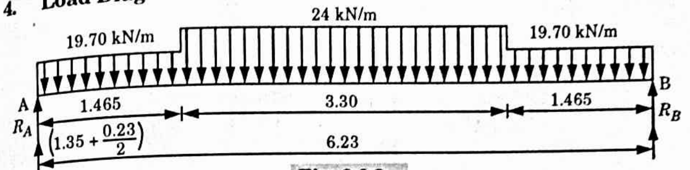



**Fig. 3.8.3.**

5. **Design Moment :**

i. Reaction at supports,

$$R_A = R_B = \frac{(2 \times 19.70 \times 1.465) + (24 \times 3.30)}{2} = 68.5 \text{ kN}$$

ii. $$\text{BM at mid span, } M_u = \left(68.5 \times \frac{6.23}{2}\right) - \left[19.70 \times 1.465 \times \left(\frac{1.465 + 3.30}{2}\right)\right]$$

$$- \left(24 \times \frac{3.30}{2} \times \frac{3.30}{4}\right) = 112 \text{ kN-m}$$

iii. Maximum BM allowed for a singly reinforced section with Fe 415 bars.

$$M_{u\,lim} = 0.138 f_{ck} bd^2 = 0.138 \times 20 \times 1000 \times 300^2 \times \frac{1}{10^6}$$

= 248.4 kN-m > 112 kN-m.

Hence section can be designed as singly reinforced.

6. **Area of Reinforcement :**

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

$$112 \times 10^6 = 0.87 \times 415 \times A_{st} \times 300\left(1 - \frac{A_{st}}{1000 \times 300} \times \frac{415}{20}\right) = 1121 \text{ mm}^2$$

ii. Using 16 mm bars, $A_\phi = (\pi/4) \times 16^2 = 201$ mm²

$$\text{Spacing} = \frac{201}{1121} \times 1000 = 179.3 \text{ mm}$$

Provide 16 mm $\phi$ @ 170 c/c.

iii. Distribution steel = 0.12 % of area = 0.12 / 100 × 1000 × 325 = 390 mm²

$$\text{Spacing of 10 } \phi \text{ bars} = \frac{78.5}{390} \times 1000 = 201 \text{ mm}$$

Provide 10 mm $\phi$ @ 200 mm c/c.

7. **Development Length :**

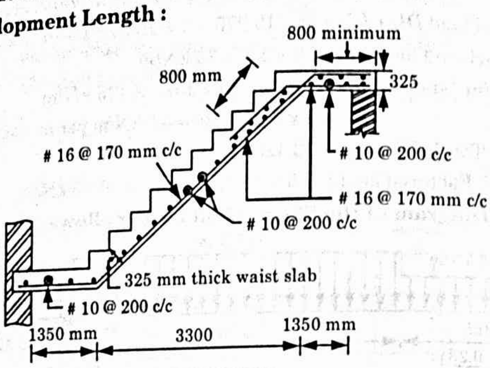



**Fig. 3.8.4.**

$$L_d = \frac{\phi(0.87 f_y)}{4 \tau_{bd}} = \frac{16 \times 0.87 \times 415}{4 \times 1.6 \times 1.2} = 752 \text{ mm}$$

Providing 800 mm length of bars at points where $L_d$ is required as shown in Fig. 3.8.4.

## PART-3

*Design of Lintel and Chajja.*

### CONCEPT OUTLINE

**Lintel :** The lintel is a beam which supports brick or other masonry over an opening like door, window, ventilator etc.

**Chajja :** A chajja is a projecting or overhanging eaves or cover of a roof, usually supported on large carved brackets.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 3.9.** **Describe the different types of action of load on lintel.**



**Answer**

**Action of Loads on Lintel :**

1. The brick masonry transfers its load by arch action. Hence, the load on a lintel from masonry shall usually be of a triangular shape.
2. For good masonry work the height of the triangle is taken as one-half the base, *i.e.*, base angle of a triangle is considered as 45°. For second class masonry work this angle may be considered as 60°.
3. Different cases of loads on a lintel are shown in Fig. 3.9.1. To get the perfect arch action the following conditions should be satisfied :

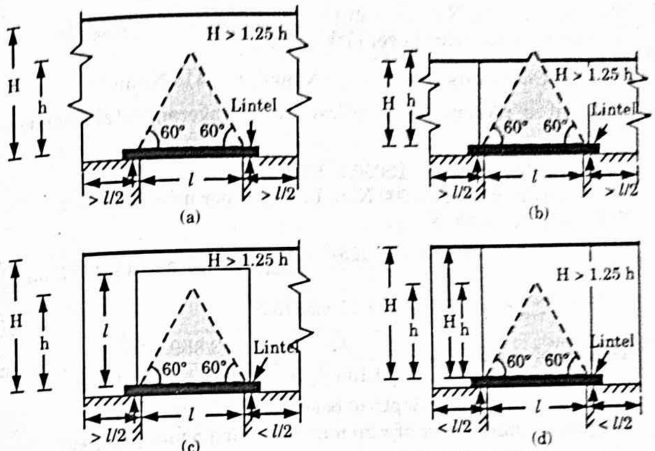



**Fig. 3.9.1. Examples of lintel loading.**

i. The height of masonry above lintel should be at least 1.25 times the height of a triangle considered above.

ii. The length of the masonry wall on either side of lintel should be more than $l$ / 2 where $l$ is the span of lintel.

If the above conditions are not satisfied, a rectangular load should be considered over the lintel.

4. Fig. 3.9.1(a) shows a usual case where the height of masonry ($H$) above lintel is greater than 1.25 $h$ and the length on either side of a lintel is greater than $l$ / 2. The perfect arch action can be observed in this case and a triangular loading can be considered above the lintel.
5. In Fig. 3.9.1(c), $H$ > 1.25 $h$ but the length of wall on one of the side of the opening is less than $l$ / 2. The perfect arch action cannot be observed. In such a case, a rectangular load of masonry of height $l$ should be considered.

6. In Fig. 3.9.1(d), $H > 1.25\,h$ but the length of wall on either side of the opening is less than $l/2$. In such a case, a rectangular load of masonry of full height of wall (*i.e.*, $H$) should be considered.

**Que 3.10. Design a cantilever slab having an overhang of 1.25 m. Take live load intensity of 1000 N/m² on the cantilever. Use M 20 concrete and HYSD bars. Assume weight of finishing at the top of slab as 800 N/m².**

**Answer**

**Given :** Overhang length = 1.25 m, Load = 1000 N/m²,
Finish load = 800 N/m², Use grade M20 and HYSD.
**To Find :** Design cantilever slab.

1. **Design Constants :** For $f_{ck}$ = 20 N/mm², $f_y$ = 415 N/mm²
2. **BM and SF :** Assume the cantilever to be of average total thickness of 100 mm.

Dead weight = 0.1 × 1 × 25000 = 2500 N/m
Dead weight of finish = 800 N/m, Live load per m² = 1000 N/m
Total weight = 4300 N

$$\therefore \quad M = \frac{wL^2}{2} = \frac{4300(1.25)^2}{2} = 3359 \text{ N-m} = 3.359 \times 10^6 \text{ N-mm}$$

$$V_{max} = wL = 4300 \times 1.25 = 5375 \text{ N}$$

3. **Design of Section :** $d = \sqrt{\dfrac{M}{0.138 f_{ck}\, b}} = \sqrt{\dfrac{3.359 \times 10^6}{0.138 \times 20 \times 1000}} = 35$ mm

Hence provide overall depth of beam, $D$ = 150 mm
Keeping nominal cover of = 20 mm, and using 8 mm $\phi$ bars,
$d$ = 150 – 20 – 8/2 = 126 mm. Reduce $D$ = 100 mm at free end.

4. **Reinforcement :**

i. $$3.359 \times 10^6 = 0.87 \times 415 \times A_{st} \times 126 \left(1 - \frac{A_{st}\, 415}{1000 \times 126 \times 20}\right)$$

$$A_{st} = 74.76 \text{ mm}^2$$

Minimum area of reinforcement = 0.12 % of $X$-sectional area

$$= \frac{0.12 \times 1000 \times 150}{100}$$

Choosing 8 mm $\phi$ bars, $A_\phi = (\pi/4) \times 8^2 = 50.3$ mm².

ii. Spacing, $$S = \frac{1000\, A_\Phi}{A_{st}} = \frac{1000 \times 50.3}{180} = 280 \text{ mm}$$

iii. Maximum permissible spacing = 3 $d$ or 300 mm whichever is smaller
Hence provide 8 mm $\phi$ bars @ 250 mm c/c. Actual,

$$A_{st} = \frac{1000 \times 50.3}{250} = 201.2 \text{ mm}^2.$$



5. **Embedment of Reinforcement in the Support :**

i. In order to develop full tensile strength at the face of the support, each bar should be embedded into the support by a length equal to $L_d = 45\,\phi = 45 \times 8 = 360$ mm.

ii. This could be best achieved by providing one bend of 90° where anchorage value of this bend = 8 $\phi$ = 8 × 8 = 64 mm.

iii. Thus, total anchorage value achieved

$$= (300 - 20) + 64 + (150 - 2 \times 20 - 4) \simeq 450 \text{ mm} > L_d.$$

6. **Check for Shear :**

i. Neglecting the taper and taking an average,

$$d = 110 \text{ mm}, \; \tau_v = \frac{V}{bd} = \frac{5375}{1000 \times 110} = 0.049 \text{ N/mm}^2$$

ii. This is much less than the permissible value of
$\tau_c$ = 1.3 × 0.18 = 0.234 N/mm² for M 20 concrete for

$$p_t = \frac{100\, A_s}{bd} = \frac{100 \times 169}{1000 \times 110} = 0.15\%. \text{ Hence safe.}$$

7. **Distribution Reinforcement :**

i. $$A_{sd} = \frac{0.12\, bD}{100} = \frac{0.12 \times 1000\, D}{100}$$

$$= 1.2\, D \text{ mm}^2 = 1.2 \times 150 = 180 \text{ mm}^2$$

Using 8 mm $\phi$ bars, each having $A_\Phi$ = 50.27 mm².

Spacing, $$S = \frac{1000\, A_\Phi}{A_{sd}} = \frac{1000 \times 50.23}{180} = 280 \text{ mm.}$$

However, provide these @ 280 mm c/c. The section of the cantilever slab is shown in Fig. 3.10.1.

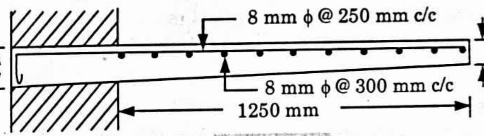



**Fig. 3.10.1.**

**PART-4**

*Design of Two Way Slabs by Limit State Method.*

**CONCEPT OUTLINE**

**Two Way Slab :** The ratio of length to breadth of slab is less than 2. The slab is known as two-way slab. Two-way slabs are supported on four sides.
**Design Procedure of Two Way Slab :**
The design of two-way slab can be carried out as per the steps given below :

i. Determine the effective span.
ii. Calculate the ultimate load in kN/m for one meter width of slab.
$W_u = 1.5 (25 D + LL + FF)$
iii. Obtain design moment coefficients ($\alpha_x$, $\alpha_y$) along short and long span.
iv. Calculate $M_{u, max}$.
v. Calculate the area of steel at mid-span and at support.
vi. Check for deflection.
vii. Provided torsional steel.
viii. Provided distribution steel.
ix. Check for shear.
x. Check for development length.

## Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 3.11. Internal dimensions of a room are 3 m × 4 m, it is resting over beams 300 mm wide. The live load on slab is 4 kN/m² Design the slab with M 20 concrete and Fe 415 steel. Show reinforcement by neat sketches.** **AKTU 2013-14, Marks 10**

**Answer**

**Given :** Dimensions of room = 3 m × 4 m.
Width of beam = 300 mm, Live load = 4 kN/m².
**To Find :** Design slab.

1. **Depth of Slab :** $l_x = 3$ m, $l_y = 4$ m, $(l_y/l_x) = 1.33 < 2$
Assume, depth = (Span/25) = (3000/25) = 120 mm
Take effective depth slab, $d$ = 125 mm
Overall depth of slab, $D$ = 150 mm
2. **Effective Span :**
i. Effective span = Clear span + Effective depth = 3 + 0.125 = 3.125 m
Effective span = Clear span + Width of bearing = 3 + 0.3 = 3.3 m
(Whichever is less of above two values is taken as effective span.)
3. **Loads :**
i. Self weight of slab = 0.15 × 25 = 3.75 kN/m²
ii. Live load on slab = 4.00 kN/m²
ii. Total working load, $w$ = 7.75 kN/m²
Design ultimate load, $W_u$ = 1.5 × 7.75 = 11.625 kN/m²
4. **Ultimate Design Moments and Shear Forces :**
i. Since the slab is supported on all the four sides and its corners are held down. It corresponds to case 9, as IS code.



ii. The moment coefficients for $(l_y/l_x)$ 4/3 = 1.3 [From IS code]
$\alpha_x = 0.079$, $\alpha_y = 0.056$
iii. Ultimate moment in short span,
$$M_{ux} = \alpha_x w_u l_x^2 = 0.079 \times 11.625 \times (3.125)^2 = 8.97 \text{ kN-m}$$
iv. Ultimate moment in longer span,
$$M_{uy} = \alpha_y w_u l_x^2 = 0.056 \times 11.625 \times (3.125)^2 = 6.36 \text{ kN-m}$$
v. Ultimate shear force in short span,
$$V_{ux} = 0.5\, w_u l_x = 0.5 \times 11.625 \times 3.125 = 18.164 \text{ kN}$$

5. **Check for Depth :**
$$M_{u\,max} = 0.138 f_{ck} bd^2$$
or
$$d_{req} = \sqrt{\frac{8.97 \times 10^6}{0.138 \times 20 \times 10^3}} = 57.008 \text{ mm} < 125 \text{ mm.}$$
The effective depth selected is sufficient to resist the design ultimate moment.

6. **Reinforcement along Short Span :**
i. Ultimate moment,
$$M_u = 0.87 A_{st} f_y d\left[1 - \frac{A_{st} f_y}{bdf_{ck}}\right]$$
$$8.97 \times 10^6 = 0.87 \times A_{st} \times 415 \times 125\left[1 - \frac{A_{st} \times 415}{1000 \times 125 \times 20}\right]$$
$$A_{st} = 205.78 \text{ mm}^2$$
ii. Minimum reinforcement,
$$A_{st} = \frac{0.12}{100} \times 1000 \times 150 = 180 \text{ mm}^2$$
iii. Use 10 mm diameter bars,
$$\text{Spacing, } S = \frac{\pi/4\,(10)^2 \times 1000}{205.78} = 381.66 \text{ mm}$$
Spacing in tension should not be more then :
i. 3 × Effective depth of slab = 3 × 125 = 375 mm
ii. 300 mm
Hence, provide 10 mm $\phi$ bars @ 300 mm c/c provide, $A_{st}$ = 261.8 mm²

7. **Reinforcement along Long Span :**
$$6.36 \times 10^6 = 0.87 \times 415 \times A_{st} \times 125\left[1 - \frac{A_{st} \times 415}{20 \times 125 \times 1000}\right]$$
$$A_{st} = 144.38$$
Hence, $A_{st,\,min}$ = 180 mm² provide in long span provide 10 mm $\phi$ bars @ 450 mm c/c distance in long span.

8. **Check for Shear :**
i. Considering the short span $l_x$ and unit width of slab, the shear stress is given by,

$$\tau_v = \frac{V_u}{bd} = \frac{18.164 \times 1000}{1000 \times 125} = 0.15 \text{ N/mm}^2$$

ii. Percentage of steel, $p_t = \frac{100 A_{st}}{bd} = \frac{100 \times 261.8}{1000 \times 125} = 0.209\ \%$

From IS : 456 permissible shear stress,

$$\tau_v' = k\tau_c = 1.26 \times 0.32 = 0.40 \text{ N/mm}^2$$

iii. $\tau_v' > \tau_v$, Hence the slab is safe against shear force.

9. **Check for Deflection :** Considering unit width of slab in the short span direction $l_x$

i. $(l/d)_{basic} = 20$ and

$k_t = 1.7$, for $p_t = 0.20$

ii. $(l/d)_{max} = 20 \times 1.7 = 34$

$\therefore$ $(l/d)_{provided} = 3125 / 125 = 25 < 34$

Hence deflection control is satisfied.

11. **Torsion Reinforcement at Corners :**

i. Area of reinforcement in each of the four layers = $(0.75 \times 205.78)$ = 154.335 mm².

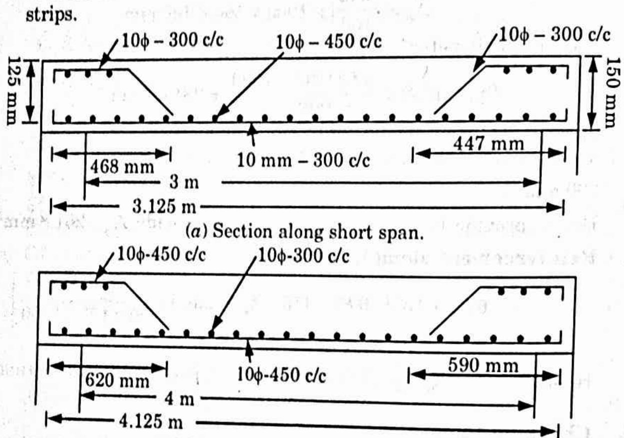
ii. Distance over which torsion reinforcement is provided = (1/5 short span) = $(0.2 \times 3000)$ = 600 mm.

iii. Provide 6 mm diameter bars @ 100 mm c/c for a length of 600 mm at all four corners in 4 layers.

12. **Reinforcements in Edge Strips :**

i. $A_{st}$ = 0.12 percent of cross-sectional area = $(0.0012 \times 10^3 \times 150)$ = 180 mm²/m

ii. Provide 10 mm diameter bars @ 300 mm ($A_{st}$ = 262 mm²) in all edge strips.




(a) Section along short span.

(b) Section along long span.

**Fig. 3.11.1.**



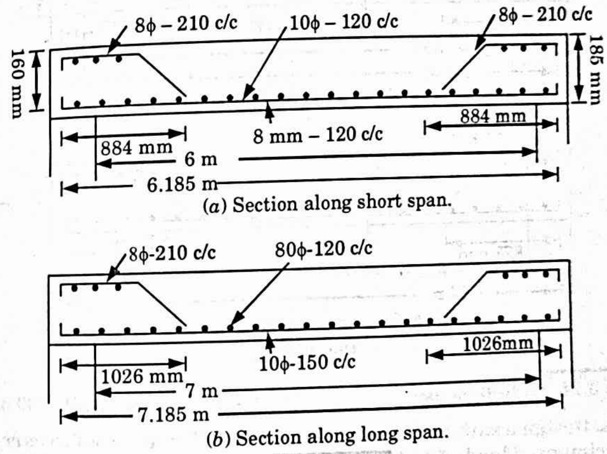
**Que 3.12.** **Design a RC slab for a room measuring 6 m × 7 m size. The slab is simply supported on all the four edges, with corners held down and carries a super imposed load of 3500 N/m², inclusive of floor finish etc. Use M20 grade concrete and Fe415 steel.**

**AKTU 2014-15, Marks 10**

**Answer**

**Procedure :** Same as Q. 3.11, Page 3–18A, Unit-3.

1. Effective length, $l_x$ = 6.185 m and $l_y$ = 7.185 m
2. Moment, $M_{ux}$ = 34.14 kN-m and $M_{uy}$ = 28.12 kN-m
3. Required depth, $d$ = 112.2 mm, But provide effective depth as 160 mm
4. Reinforcement along short span :
   i. In middle strip — 8 mm φ bars @ 120 c/c.
   ii. In edge strip — 8 mm φ mm @ 210 mm c/c.
5. Reinforcement along long span :
   i. In middle strip — 10 mm φ bars @ 150 mm c/c.
   ii. In edge strip — 8 mm φ bars @ 210 mm c/c.
6. Torsional reinforcement — 8 mm φ bars @ 210 mm c/c.




(a) Section along short span.

(b) Section along long span.

**Fig. 3.12.1.**

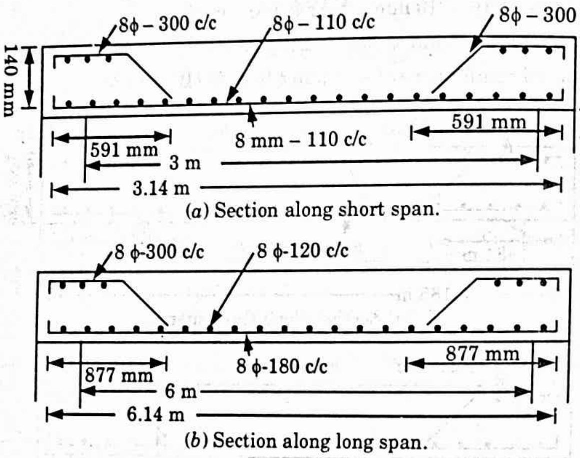
**Que 3.13.** **Design a SS slab to cover a room of internal dimensions of 4 m × 6 m and 230 mm thick brick walls all around. It carries live load of 3 kN/m² and floor finish of 1 kN/m². Use M 20 concrete and**

Fe 415 steel. Consider that the slab corners are prevented from lifting. **AKTU 2015-16, Marks 10**

**Answer**

**Procedure :** Same as Q. 3.11, Page 3–18A, Unit-3.

1. Effective depth = 140 mm
2. Effective length, $l_x$ = 4.14 m and $l_y$ = 6.14 mm.
3. Moment, $M_{ux}$ = 20.6 kN-m and $M_{uy}$ = 13 kN-m
4. Shear force, $V_{ux}$ = 28 kN
5. Reinforcement along short span :
   i. In middle strip — 8 mm $\phi$ bars @ 110 mm c/c.
   i. In edge strip — 8 mm $\phi$ bars @ 300 mm c/c.
6. Reinforcement along Long span :
   i. In middle strip — 8 mm $\phi$ bars @ 180 mm c/c.
   ii. In edge strip — 8 mm $\phi$ bars @ 300 mm c/c.




(*a*) Section along short span.

(*b*) Section along long span.

**Fig. 3.13.1.**

**Que 3.14.** **A hall measures 10 m × 6 m inside and has walls 400 mm thick. Design a suitable reinforced concrete T beam roof to carry a superimposed load of 2 kN/m². Use M 20 grade concrete and Fe 415 grade steel.** **AKTU 2016-17, Marks 10**



**Answer**

**Given :** Dimensions = 10 m × 6 m, Thickness of wall = 400 mm, Superimposed load = 2 kN/m².

**To Find :** Design of T-beam roof.

1. Let us keep end spans of slab slightly less than the middle span so that approximately equal maximum BM is induced in all the three spans.
2. Assuming the width of web ($b_w$) of T-beam as 300 mm, the following spans of the slab are selected :
   i. End span = 3 m (clear)
   ii. Intermediate span = 3.4 m (clear).
3. The clear span of each T-beam will be 6 m while the RC slab monolithic with the beam will be continuous over the three spans. For M 20 - Fe 415 combination, we have

$$f_{ck} = 20\text{ N/mm}^2; f_y = 415\text{ N/mm}^2$$

$$\frac{x_{u,\max}}{d} = \frac{700}{1100 + 0.87 \times 415} = 0.479$$

$$R_u = 0.36 f_{ck} \frac{x_{u,\max}}{d}\left(1 - 0.416\frac{x_{u,\max}}{d}\right)$$

$$= 0.36 \times 20 \times 0.479\,(1 - 0.416 \times 0.479) = 2.761$$

**A. Design of Continuous Slab :**

**1. Fixation of *D* and *d* :**

i. For stiffness, $L/d$ = 26 for continuous slab. Using an under-reinforced section and $p_t$ = 0.25 %, we have modification factor = 1.6.

ii. Also, assuming total thickness of slab = 100 mm and effective depth as 80 mm, effective end span = 3 + (1 / 2) × 0.08 = 3.04 m

iii. Hence $$d = \frac{\text{Span}}{26 \times 1.6} = \frac{3040}{26 \times 1.6} = 73\text{ mm for end spans}$$

$$d = \frac{3400}{26 \times 1.6} = 82\text{ mm for intermediate span.}$$

iv. Let us keep $D$ = 100 mm. Using 8 mm $\phi$ bars and a nominal cover of 15 mm, available $d$ = 100 – 15 – 4 = 81 mm.

Dead load / m², $w_d$ = 0.1 × 1 × 1 × 25000 = 2500 N/m²

Superimposed load/m², $w_s$ = 2000 N/m²

**2. Computation of BM and Effective Depth from Flexure :**

**i. For End Span :** Near middle of end span

a. Moment due to dead load $$= \frac{w_d L^2}{12} = \frac{2500 \times 3.04^2}{12} \times 1000$$

$$= 1.925 \times 10^6\text{ N-mm}$$

b. Moment due to live load $$= \frac{w_l L^2}{10} = \frac{2000 \times 3.04^2}{10} \times 1000$$

$$= 1.848 \times 10^6\text{ N-mm}$$

c. Total moment, $M = 3.773 \times 10^6$ N-mm,

d. Factored moment, $M_u = 1.5 \times 3.773 \times 10^6 = 5.66 \times 10^6$ N-mm

**ii. For Intermediate Span (at the Middle) :**

a. Moment due to dead load,

$$M_d = \frac{w_d L^2}{16} = \frac{2500 \times 3.4^2}{16} \times 1000 = 1.806 \times 10^6 \text{ N-mm}$$

b. Moment due to live load,

$$M_l = \frac{w_l L^2}{12} = \frac{2000 \times 3.4^2}{12} \times 1000 = 1.927 \times 10^6 \text{ N-mm}$$

c. Total moment, $M = 3.733 \times 10^6$ N-mm

Factored moment, $M_u = 1.5 \times 3.733 \times 10^6 = 5.6 \times 10^6$ N-mm

**iii. At Support next to End Support :**

a. Moment due to dead load,

$$M_d = \frac{w_d L^2}{10} = \frac{2500 \times 3.04^2}{10} \times 1000 = 2.310 \times 10^6 \text{ N-mm}$$

b. Moment due to live load,

$$M_l = \frac{w_l L^2}{9} = \frac{2000 \times 3.04^2}{9} \times 1000 = 2.054 \times 10^6 \text{ N-mm}$$

c. Total moment, $M = 2.310 \times 10^6 + 2.054 \times 10^6$
$= 4.364 \times 10^6$ N-mm

d. Factored moment, $M_u = 1.5 \times 4.364 \times 10^6 = 6.546 \times 10^6$ N-mm

Hence $M_u = 6.546 \times 10^6$ N-mm

e. Overall depth, $D = \sqrt{\frac{M_u}{R_u\, b}} = \sqrt{\frac{6.546 \times 10^6}{2.761 \times 1000}} = 48.7$ mm

However, from deflection point of view, we provide $D$ = 100 mm and $d$ = 81 mm.

**3. Computation of Reinforcement :**

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

$$= \frac{0.5 \times 20}{415}\left[1 - \sqrt{1 - \frac{4.6 \times 6.546 \times 10^6}{20 \times 1000 \times 81^2}}\right] \times 1000 \times 81 = 238.5 \text{ mm}^2$$

ii. Spacing of 8 mm $\phi$ bars, $S_v = \frac{1000 A_\phi}{A_{st}} = \frac{1000 \times 50.3}{238.52} = 210.9$ mm

iii. However provide 8 mm $\phi$ bars @ 200 c/c at the middle of each span. Bend up alternative bars from the bottom at a distance of $L/5 = 3040 / 5 = 600$ mm from the centre of intermediate support and at $L / 7 = 450$ mm from the end support.

iv. Thus reinforcement available at each intermediate support will be 8 mm $\phi$ bars @ 200 mm c/c. Actual $A_s$ provided $= 1000 \times 50.3 / 200 = 251.5$ mm² and $p_t (\%) = 251.5 \times 100 / (1000 \times 100) = 0.25$ %.

v. Distribution reinforcement :



$$A_{st} = \frac{0.12 \times 1000}{100} D = 1.2\, D = 1.2 \times 100 = 120 \text{ mm}^2$$

Using 8 mm $\phi$, $S_v = 1000 \times 50.3 / 120 = 419$ mm. Hence provide 8 mm $\phi$ bars @ 400 mm c/c.

**4. Check for Shear :**

i. Shear force, $V = 0.4\, w_d L + 0.45\, w_s L$ at the outer support.
$= (0.4 \times 2500 + 0.45 \times 2000) \times 3.04 = 5776$ N

Factored shear force,
$V_u = 1.5 \times 5776 = 8664$ N

ii. Nominal shear stress,

$$\tau_v = \frac{V_u}{bd} = \frac{8664}{1000 \times 81} = 0.11 \text{ N/mm}^2$$

iii. This is much less than the permissible value of $1.3 \times 0.28$ N/mm² even for a minimum reinforcement of 0.15 %. Hence safe.

**5. Check for Development Length at the End Support :**

i. At the end supports alternate bars are bent up. Hence available area of steel,

$A_{st1} = (1 / 2) \times 251.5 = 125.7$ mm².

$$x_u = \frac{0.87 f_y A_{st1}}{0.36 \times f_{ck}\, b} = \frac{0.87 \times 415 \times 125.7}{0.36 \times 20 \times 1000} = 6.3 \text{ mm}$$

$M_1 = 0.87 f_y A_{st1}(d - 0.416 x_u) = 0.87 \times 415 \times 125.7(81 - 0.416 \times 6.3)$
$= 3.56 \times 10^6$ N-mm

$L_d = 47\,\phi = 47 \times 8 = 376$ mm

ii. Taking the bars straight into supports, without any bend or hook,

$$L_0 = \frac{l_s}{2} - x' = \frac{400}{2} - 20 \text{ (say)} = 180 \text{ mm}$$

$$1.3 \frac{M_1}{V_u} + L_0 = 1.3 \times \frac{3.56 \times 10^6}{8664} + 180 = 534 + 180 = 714 \text{ mm} > L_d.$$

Hence code requirements are satisfied.

**B. Design of T-Beams :**

**1. Determination of $b_w$ and $D$ :**

i. Let the width of web, $b_w$ = 300 mm.
Effective span, $l_0$ = 6.4 m

ii. Effective flange, $b_f = (l_0 / 6) + b_w + 6\, D_f$
$= 6400 / 6 + 300 + 6 \times 100 = 196$ mm

iii. Assume overall depth, $D = l / 15 = 6000 / 15 = 400$ mm for the purpose of computation of dead load. Hence depth of web
$= 400 - 100 = 300$ mm.

**2. Computation of Load and BM :**

i. Load from slab $= (w_d + w_s)\left[\frac{3 + 3.4}{2} + 0.3\right]$
$= (2500 + 2000)\, 3.5 = 15750$ N/m

ii. Weight of web $= 0.3 \times 0.3 \times 25000 = 2250$ N/m

iii. Total load, $w = 15750 + 2250 = 18000$ N/m;

Factored load, $w_u = 18000 \times 1.5 = 27000$ N/m

iv. Factored bending moment,

$$M_u = \frac{w_u (l_0)^2}{8} = \frac{2700 \times 6.4^2}{8} \times 1000$$
$$= 138.24 \times 10^6 \text{ N-mm}$$

**3. Calculation of Effective Depth and Total Depth :**

i. Let
$$d = \sqrt{\frac{M_u}{R_u\, b_w}} = \sqrt{\frac{138.24 \times 10^6}{2.761 \times 300}} = 408 \text{ mm}$$

ii. Provide 400 mm effective depth

iii. Hence provide $D = 450$ mm. so that using main bars of 20 mm stirrups of 8 mm $\phi$ and nominal cover of 25 mm.

iv. Due to this increased depth, weight of web
$$= 0.3 \times 0.35 \times 25000 = 2625 \text{ N/m},$$

and total weight
$$w = 15750 + 2625 = 18375 \text{ N/mm.}$$

Hence $w_u = 1.5 \times 18375 \approx 27565$ N/m

v. Moment, $M_u = 275612.5\,(6.4)^2 / 8 = 141.1 \times 10^5$ N-m

**4. Determination of Reinforcement :**

i. Assume $x_u = D_f = 100$ mm

$$M_{u,\text{lim}} = 0.36 f_{ck}\, b_f D_f (d - 0.416\, D_f)$$
$$= 0.36 \times 20 \times 1966 \times 100\,(407 - 0.416 \times 100)$$
$$= 517.5 \times 10^6 \text{ kN-m}$$

ii. Since $M_{u,\text{lim}} > M_u$, NA falls inside the flange, *i.e.*, $x_u \le D_f$

$$A_{st} = \frac{0.5 f_{ck}}{f_y}\left[1 - \sqrt{1 - \frac{4.6\, M_{uD}}{f_{ck}\, b_f\, d^2}}\right] b_f d$$

$$= \frac{0.5 \times 20}{415}\left[1 - \sqrt{1 - \frac{4.6 \times 141.1 \times 10^6}{20 \times 1967\,(407)^2}}\right] \times 1967 \times 407 = 986 \text{ mm}$$

iii. Using 20 mm $\phi$ bars, number of bars = 986 / 314.16 = 3.14. However provide 4 bars of 20 mm $\phi$ giving actual area of steel,
$$A_{st} = 314.16 \times 4 = 1256.6 \text{ mm}^2$$

**5. Check for Shear and Design of Shear Reinforcement :**

i. Bend 2 bars up at 45° at a distance of 1.414 (0.9 $d$) = 1.414 × 0.9 × 4 ≈ 500 mm from the face of the support.

ii. The critical section for shear is at a distance of $d$ (= 407) from the face the support or at a distance of (400 / 2) + 407 ≈ 600 mm from the cent of the support, where SF is given by,

$$V_u = \frac{w_u L}{2} - w_u x = \frac{27560 \times 6.4}{2} - 27560 \times 0.6 = 71656 \text{ N}$$

iii. Nominal shear stress,



$$\tau_v = \frac{V_u}{b_w\, d} = \frac{71656}{300 \times 407} = 0.59 \text{ N/mm}^2$$

iv. Percentage of steel,

$$p_t = \frac{100\, A_s}{b_w\, d} = \frac{100\,(2 \times 314.16)}{300 \times 407} = 0.51\,\%$$

Hence, from code $\tau_c = 0.48$ N/mm².

v. Since $\tau_v > \tau_c$, shear reinforcement is necessary.

$$V_{uc} = \tau_c\, b_w\, d = 0.48 \times 300 \times 407 = 58608 \text{ N}$$
$$V_{us} = 71656 - 58608 = 13048 \text{ N}$$

vi. Apart from shear resistance of bent up bars, the shear resistance of nominal stirrups = $0.4\, b_w\, d = 0.4 \times 300 \times 407 = 48840$ N.

vii. Hence provide only nominal shear stirrups consisting of 8 mm $\phi$, 2 legged stirrups at spacing,

$$S_v \le \frac{2.175\, A_{sv}\, f_y}{b_w} = \frac{2.175 \times 100.5 \times 415}{300} = 302.4 \text{ mm}$$

Hence provide 8 mm $\phi$, 2-legged stirrups @ 300 mm c/c throughout. Provide 2-12 mm $\phi$ bars at top as anchor bars.

**6. Check for Development Length at Supports :**

i. At supports,
$$1.3\,(M_1 / V_u) + L_0 \ge L_d$$
$$A_{st1} = 2 \times 314.16 = 628.32 \text{ mm}^2$$

Neutral axis, $x_u = \dfrac{0.87 f_y\, A_{st1}}{0.36 f_{ck}\, b_w} = \dfrac{0.87 \times 415 \times 628.32}{0.36 \times 20 \times 300} = 105$ mm

$$M_1 = 0.87 f_y\, A_{st1}\,(d - 0.416\, x_u)$$
$$= 0.87 \times 415 \times 628.32\,(407 - 0.416 \times 105)$$
$$= 82.42 \times 10^6 \text{ N-mm}$$

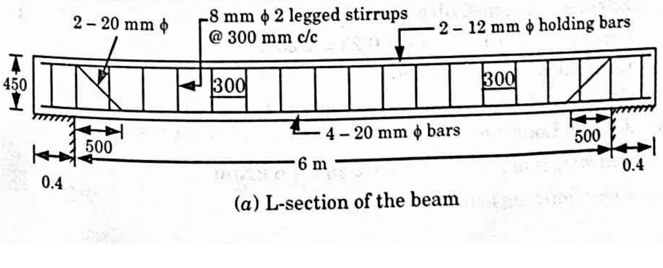
$$V_u = \frac{w_u\, L}{2} = \frac{27560 \times 6.4}{2} = 88192 \text{ N}$$

ii. Taking the bars straight into the support, without any hook or bend.

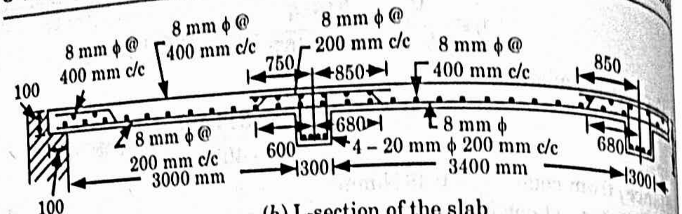
$$L_0 = \frac{L_s}{2} - x' = \frac{400}{2} - 30 = 170 \text{ mm}$$
$$L_d = 47\,\phi = 47 \times 20 = 940 \text{ mm}$$

$$1.3\,\frac{M_1}{V_u} + L_0 = \frac{1.3 \times 82.4 \times 10^6}{88192} + 170 = 1215 + 170 = 1385 \text{ mm} > L_d$$

**7. Details of Reinforcement :**




(*a*) L-section of the beam




(b) L-section of the slab

**Fig. 3.14.1.**

**Que 3.15.** **Design a continuous two-way slab system shown in Fig. 3.15.1. It is subjected to an imposed load of 3 kN/m² and surface finish of 1 kN/m². Consider M 25 concrete, grade Fe 415 steel, in moderate environment. Assume that the supporting beams are 230 mm × 500 mm.**

**AKTU 2016-17, Marks**

**Answer**

**Given :** Imposed load = 3 kN/m², Surface finish load = 1kN/m²,
Width of beam = 230 mm, Depth of beam = 450 mm
**To Find :** Design of continuous two way slab.

1. **Note :**
Figure is not given in the question. So, assume dimension of two way slab is 4 m × 5 m as shown in Fig. 3.15.1.

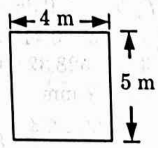



**Fig. 3.15.1.**

2. From Fig. 3.15.1. $l_y / l_x = 5/4 = 1.25 < 2$
i. Hence this slab is a two way slab.

Assuming $\frac{l}{d} = 25 \Rightarrow d = \frac{4000}{25} = 160$ mm

ii. Overall depth, $D = 160 + 20$ mm $= 180$ mm [∵ Cover = 20 mm]

3. **Effective Span :**
Effective span in X-direction, $l_{ex}$
i. Centre to centre $= 4 + 0.23 = 4.23$ m
ii. Clear span + Effective depth $= 4 + 0.16 = 4.16$ m
iii. Similarly effective span in Y-direction, $l_y = 5.16$ m

4. **Design Load ($w$) :**
i. Self weight of slab $= 0.18 \times 1 \times 25 = 4.5$ kN/m
ii. Floor finishing load $= 1 \times 1 = 1$ kN/m



iii. Live load $= 3 \times 1 = 3$ kN/m
iv. Total load = 8.5 kN/m
v. Factored or design load $= 1.5 \times 8.5 = 12.75$ kN/m.
vi. Since the slab is supported on all four side and its edge is continuous. It corresponding to case-1 of IS code.

5. **Moment Coefficients :**
i. For negative moment coefficient at continuous edge,

$$\alpha_x = 0.043 + \frac{(0.047 - 0.043)}{(1.3 - 1.2)} \times (1.25 - 1.2) = 0.045$$

ii. For positive moment coefficient at mid span,

$$\alpha_x = 0.032 + \frac{(0.036 - 0.032)}{(1.3 - 1.2)} \times (1.25 - 1.2) = 0.034$$

iii. For negative moment coefficient at continuous edge, $\alpha_y = 0.032$
iv. For positive moment coefficient at mid-span, $\alpha_y = 0.024$

6. **Design Moment and Shear :**
i. Negative moment at continuous edge,

$$M_{ux} = \alpha_x w_u l_{ex}^2 = 0.045 \times 12.75 \times 4.16^2 = 9.93 \text{ kN-m}$$

ii. Positive moment at mid-span,

$$M_{ux} = \alpha_x w_u l_{ex}^2 = 0.034 \times 12.75 \times 4.16^2 = 7.5 \text{ kN-m}$$

iii. Negative moment at continuous edge,

$$M_{uy} = \alpha_y w_u l_{ex}^2 = 0.032 \times 12.75 \times 4.16^2 = 7.06 \text{ kN-m}$$

iv. Positive moment at mid-span,

$$M_u = \alpha_y w_u l_{ex}^2 = 0.024 \times 12.75 \times 4.16^2 = 5.3 \text{ kN-m}$$

v. Maximum shear force,

$$V_u = w_u \frac{l_x}{2} = 12.75 \times \frac{4.16}{2} = 26.52 \text{ kN}$$

7. **Minimum Depth Required ($d_{req}$) :**

$$d_{req} = \sqrt{\frac{9.93 \times 10^6}{3.45 \times 1000}} = 53.7 \text{ mm}$$

(∵ $R_u = 3.45$ for M 25 and Fe 415)

$d_{assumed} > d_{req}$ Hence safe

8. **Design of Main Reinforcement :**
i. **Along Shorter Span in X-Direction (Middle Strip) :**
a. Width of middle strip $= (3/4)l_y = (3/4) \times 5.16 = 3.87$ m
b. Width of edge strip $= \left(\frac{5.16 - 3.87}{2}\right) = 0.65$ m
c. Area of reinforcement along shorter span,

$$M_u = 0.87 f_y A_{st} d \left[1 - \frac{A_{st} f_y}{bd f_{ck}}\right]$$

$$9.93 \times 10^6 = 0.87 \times 415 \times A_{st} \times 160\left[1 - \frac{A_{st} \times 415}{1000 \times 160 \times 25}\right]$$

$$A_{st} = 173.28 \text{ mm}^2$$

d. Minimum reinforcement,

$$A_{st} = \frac{0.12 \times 1000 \times 180}{100} = 216 \text{ mm}^2$$

e. Using 8 mm φ bars,

$$\text{Spacing, } S_v = \frac{\pi/4 \times 8^2 \times 1000}{216} = 232.7 \text{ mm}$$

f. Provide 8 mm φ bars @ 230 mm c/c in middle strip of width 3.87 m.

ii. **Along Longer Span Y-Direction (Middle Strip) :**

a. Width of middle strip = (3/4) × 4.16 = 3.12 m

b. Width of edge strip = $\frac{(4.16 - 3.12)}{2}$ = 0.52 m

$$M_{uy} = 5.3 \text{ kN-m}$$

c. Provide minimum reinforcement at middle strip.

d. Provide 8 mm φ bars @ 230 mm c/c in middle strip of width 3.12 m.

iii. **Reinforcement in Edge Strip :**

a. Maximum bending moment in X-direction and Y-direction is 9.93 kN-m and 7.06 kN-m respectively.

b. So, provide minimum reinforcement = 216 mm²

Using 8 mm φ bars,

$$\text{Spacing, } S_v = \frac{1000 \times (\pi/4) \times 8^2}{216} = 232.7 \text{ mm.}$$

c. Provide 8 mm φ bars @ 230 mm c/c in the middle strip of width 0.65 m along X-direction and 0.52 m in Y-direction.

d. Provide $A_{st}$ at middle strip,

$$A_{st,\ provided} = \frac{1000 \times (\pi/4) \times 8^2}{230} = 218.5 \text{ mm}^2$$

9. **Check for Shear :**

i. Nominal shear stress, $\tau_v = \frac{V_u}{bd}$

$$\tau_v = \frac{26.52 \times 10^3}{1000 \times 160} = 0.166 \text{ N/mm}^2$$

ii. Percentage of steel, $p_t = \frac{100 \times A_{st}}{bd} = \frac{100 \times 218.5}{1000 \times 160} = 0.14\ \%$

For $p_t$ = 0.14 % and M 25 concrete

iii. Shear strength of section,

$$\tau_c = 0.29 \text{ N/mm}^2$$

Since, $\tau_c > \tau_v$, hence, shear reinforcement is not required.



10. **Check for Deflection :**

i. Percentage of steel, $p_t$ = 0.14 %

$$f_s = 0.58 f_y \left[\frac{A_{st,\ req}}{A_{st,\ provided}}\right]$$

$$= 0.58 \times 415 \left[\frac{175.08}{218.5}\right] = 193 \text{ N/mm}^2$$

ii. For $p_t$ = 0.14 %, $f_s$ = 193 N/mm², from IS code

iii. Modification factor, $k_t$ = 2

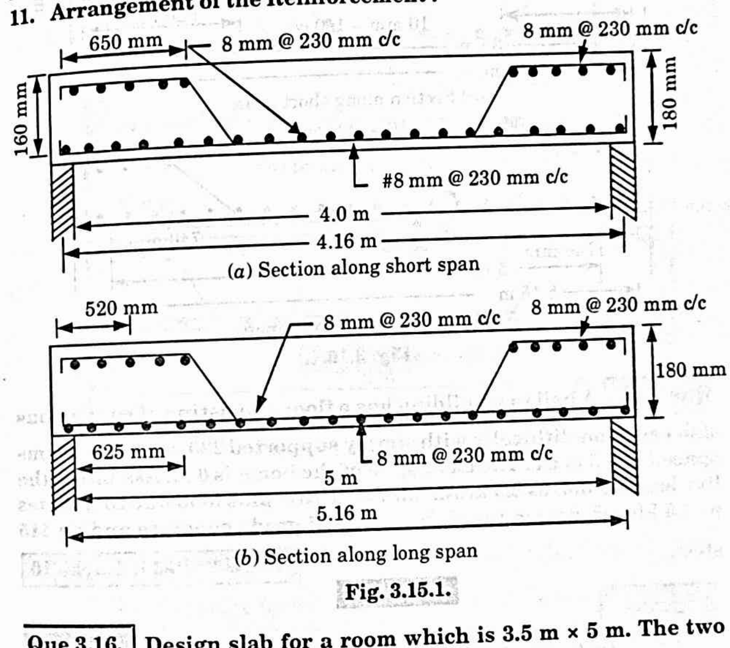
$$\left(\frac{l}{d}\right)_{max} = 20 \times 2 = 40$$

$$\left(\frac{l}{d}\right)_{provided} = \frac{4.16 \times 1000}{160} = 26$$

$$\left(\frac{l}{d}\right)_{max} > \left(\frac{l}{d}\right)_{provided}$$

iv. Hence slab is safe in deflection.

11. **Arrangement of the Reinforcement :**




(*a*) Section along short span

(*b*) Section along long span

**Fig. 3.15.1.**

**Que 3.16. Design slab for a room which is 3.5 m × 5 m. The two adjacent edges are continuous. The slab is supporting live load of 4 kN/m² and floor finish of 1 kN/m². Use M 25 concrete and Fe 415 steel; design the slab.**

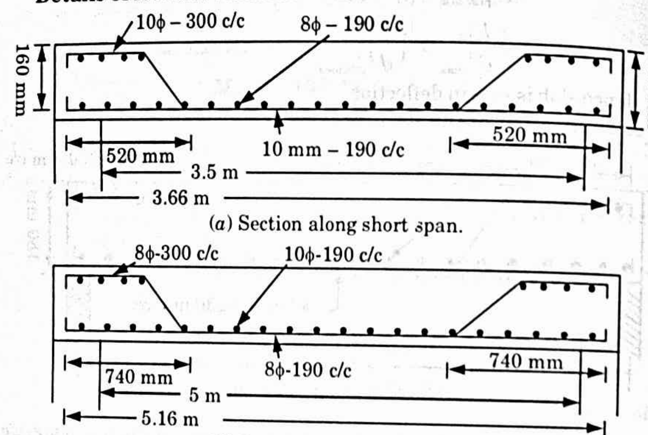
**AKTU 2013-14, Marks 10**

**Answer**

**Procedure :** Same as Q. 3.15, Page 3–28A, Unit-3.

1. Moment, $M_{ux}$ = 13.55 kN-m and $M_{uy}$ = 8.972 kN-m
2. Provide reinforcement along short span :
   i. In middle strip — 10 mm φ bars @ 190 mm c/c.
   ii. In edge strip — 10 mm φ bars @ 300 mm c/c.
3. Provide reinforcement along long span :
   i. In middle strip — 8 mm φ bars @ 190 mm c/c.
   ii. In edge strip — 8 mm φ bars @ 300 mm c/c.
4. Torsional reinforcement — 8 mm φ bars @ 120 mm c/c.

**Details of Reinforcement :**




(a) Section along short span.

(b) Section along long span.

**Fig. 3.16.1.**

**Que 3.17.** **A hall in a building has a floor consisting of continuous slab cast monolithically with simply supported 230 mm wide beams spaced at 3.5 m c/c. The clear span of the beam is 6 m. Assuming the live load on slab as 3.0 kN/m² and partition plus load due to finishes as 1.5 kN/m², design the slab with M 25 grade concrete and Fe 415 steel.**

**AKTU 2016-17, Marks 10**

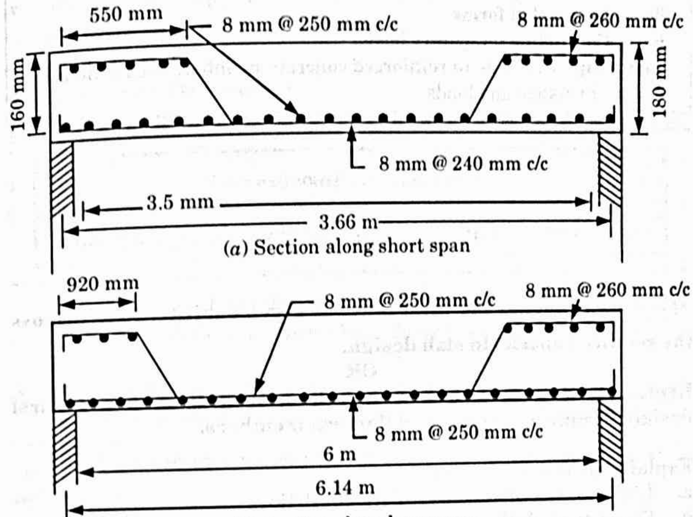
**Answer**

**Procedure :** Same as Q. 3.15, Page 3–28A, Unit-3.

1. Effective depth = 140 mm
2. Effective length, $l_x$ = 3.66 m and $l_y$ = 6.14 m
3. Design moment along short span :



   i. Negative moment at edge, $M_{ux}$ = 10 kN-m
   ii. Positive moment at middle, $M_{ux}$ = 7.55 kN-m
4. Design moment along long span :
   i. Negative moment at edge, $M_{uy}$ = 5.5 kN-m
   ii. Positive moment at middle, $M_{uy}$ = 4.1 kN-m
5. Reinforcement along short span :
   i. In edge strip — 8 mm φ bars 240 mm c/c.
   ii. At middle strip — 8 mm φ bars 260 mm c/c.
6. Reinforcement along long span :
   i. In edge strip — 8 mm φ bars 250 mm c/c.
   ii. In middle strip — 8 mm φ bars 260 mm c/c.




(a) Section along short span

(b) Section along long span

**Fig. 3.17.1.**

**PART-5**

***Serviceability Limit State, Control of Deflection, Control of Deflection, Cracking and Vibrations.***

## CONCEPT OUTLINE

**Limit State of Serviceability :** It consist of
i. Deflection. ii. Vibration. iii. Cracking.
**Type of Deflection :** Deflection are two types :
i. short term deflection.
ii. long term deflection.
Total deflection, $\Delta = \Delta_e + \Delta_s + \Delta_c$
$\Delta_e$ = Short term elastic deflection,
$\Delta_c$ = Long term deflection due to creep,
$\Delta_s$ = Long term deflection due to shrinkage.
**Control of Deflection on Site :** Apart from the theoretical calculations to control the deflection, the following techniques are applied on site.
i. Cambering.
ii. Controlling concrete work.
iii. Removal of forms.
iv. Controlling temporary loads.
**Cracking :** Cracking in reinforced concrete members occurs mainly due to shrinkage and loads.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 3.18. Discuss the limit state of serviceability. Also discuss the required checks in slab design.**

**OR**

**Explain the importance of serviceability limit state in the structural design of reinforced concrete flexural members.**

**OR**

**Explain the following term :**
**a. Limit states of serviceability condition,**
**b. Short-term deflection, and**
**c. Long-term deflection.**

**Answer**

A. **Serviceability of Limit State :**
1. A structure must fulfill three basic requirements, namely, structural, functional and aesthetic, during its life span under normal service conditions.
2. Excessive deflection and cracking of the concrete adversely affect the appearance and efficiency of the structure and cause discomfort the user.



3. Excessive deformation may lead to local damage to finishes. Excessive cracking leads to corrosion and adversely affects the appearance.
4. The deflection that occurs in case of RC structure can be divided into the following types :
i. Short term deflection.
ii. Long term deflection.

B. **Short Term Deflection :**
1. The short term or instantaneous deflection occurs due to initial elastic deformation of member under dead load and permanent imposed load under service condition.
2. The factors affecting the short term deflection are as under :
i. Span and supporting conditions.
ii. Magnitude and distribution of live load.
iii. Cross-sectional dimension.
iv. Tension and compression reinforcements.
v. Stress in steel.
vi. Grade of concrete.

C. **Long Term Deflection :**
1. Long term deflection occurs due to creep and shrinkage under sustained load and additional elastic deflection due to temporary live loads.
2. It is about two to three times larger than the short-term deflection.
3. The main factors that affect long term deflection are as follows :
   i. Age of concrete at the time of loading.
   ii. Humidity and temperature condition at the time of curing.
   iii. All other factors affecting creep and shrinkage.
4. This type of deflection causes local damage like cracking of partition walls etc.

D. **Total Deflection :** The total deflection inclusive of short-term and long-term deflection is a quantity which requires overall control.

**Que 3.19. How can we calculate the short term and long term deflection ?**

**OR**

**What do you understand by the term "Limit state of serviceability" ? Explain the method of calculating long term deflection.**

**AKTU 2014-15, Marks 10**

**Answer**

A. **Limit State of Serviceability :** Refer Q. 3.18, Page 3–34A, Unit-3.

B. **Short Term Deflection ($\Delta_e$) :**

1. The short term deflection may be calculated by the conventional methods for elastic deflection.
2. In the above formula the value of $E$ is taken as :

$$E_c = 5000\sqrt{f_{ck}}$$

where, $f_{ck}$ = Characteristics strength of concrete.

3. The moment of inertia used in the formula is the effective moment of inertia which is obtained as follows :

$$I_{eff} = \frac{I_{cr}}{1.2 - \frac{M_{cr}}{M} \times \frac{z}{d}\left(1 - \frac{x}{d}\right)\frac{b_w}{b_f}}$$

but $I_{cr} \le I_{eff} \le I_{gr}$

where, $I_{cr}$ = MOI of the cracked section.

$I_{gr}$ = MOI of the gross section neglecting the reinforcement.

$M_{cr}$ = Cracking moment = $\frac{\sigma_{cr} I_{gr}}{y_t}$

$M$ = Maximum moment under service loads.

$x$ = Depth of NA.

$y_t$ = Distance from the centroidal axis of the cross-section to the extreme fibre to tension.

$z$ = Lever arm = $d - (x/3)$ (by elastic theory).

$b_w$ = Breadth of web.

$b_f$ = Breadth of compression face or flange.

$\sigma_{cr}$ = Modulus of rupture of concrete.

$= 0.7\sqrt{f_{ck}}$ N / mm².

5. For continuous beams, a weighted average value of $I_{eff}$ is used by modifying the values of $I_{cr}$, $I_{gr}$ and $M_{cr}$ as follows :

$$X_e = k_1\left[\frac{X_1 + X_2}{2}\right] + (1 - k_1)X_0$$

where, $k_1$ = A coefficient taken form table 3.19.1.

$$k_2 = \frac{M_1 + M_2}{M_{F1} + M_{F2}}$$

**Table 3.19.1 : For values of $k_1$.**

| $k_2$ | 0 to 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 |
|---|---|---|---|---|---|---|---|---|---|---|
| $k_1$ | 0 | 0.03 | 0.08 | 0.16 | 0.3 | 0.5 | 0.73 | 0.91 | 0.97 | 1.0 |

$M_1, M_2$ = Support moments.

$M_{F1}, M_{F2}$ = Fixed end moments.

$X$ = Values of $I_{cr}$, $I_{gr}$ or $M_{cr}$ as appropriate.

$X_0$ = Value of $X$ at mid-span.

$X_e$ = Effective value of $X$.



$X_1, X_2$ = Values of $X$ at supports.

## C. Long Term Deflection :

### 1. Deflection due to Shrinkage :

Deflection due to shrinkage occurs over a long period of time and depends upon the environmental conditions (humidity and temperature) at the time of curing of concrete.

The deflection due to shrinkage $\Delta_s$ is given by,

$$\Delta_s = k_3 \psi_s L^2 \quad ...(3.19.1)$$

where, $k_3$ = A constant depending on the support condition.

= 0.5 for cantilevers.

= 0.125 for simply supported.

= 0.086 for continuous at one end.

= 0.063 for continuous members.

$\psi_s$ = Shrinkage curvature = $k_4 \frac{\epsilon_s}{D}$

$\epsilon_s$ = Ultimate shrinkage strain of concrete = 0.0003

$D$ = Total depth of the section.

$$k_4 = 0.72\frac{(p_t - p_c)}{\sqrt{p_t}} \le 1; \text{ for } 0.25 \le (p_t - p_c) \le 1.0$$

$$k_4 = 0.65\frac{(p_t - p_c)}{\sqrt{p_t}} \le 1; \text{ for } (p_t - p_c) \ge 1.0$$

$$p_t = \frac{100 A_{st}}{bd},\ p_c = \frac{100 A_{sc}}{bd},\ L = \text{Span}$$

### 2. Deflection due to Creep :

i. The effect of creep is to increase the compressive strain in concrete.

ii. The strain in tension steel also increases depending upon the reduction in the lever arm.

iii. This leads to increase in deflection and depends mainly on the magnitude of permanent load on the structure.

iv. The deflection due to creep $\Delta_c$ may be obtained as follows :

$$\Delta_c = \Delta_{ci} - \Delta_{cs}$$

where, $\Delta_{ci}$ = Initial plus creep deflection due to permanent loads obtained using an elastic analysis with an effective modulus of elasticity

$$\left(E_{ce} = \frac{E_c}{1 + \theta}\right)$$

where, $\theta$ = 2.2 ; for 7 days.

= 1.6 ; for 28 days.

= 1.1 ; for 365 days.

$\Delta_{cs}$ = Short-term deflection due to permanent loads using $E_c$.

**Que 3.20.** **A rectangular cantilever beam of span 3.5 m is 30 cm × 50 cm. Bending moment at the fixed end due to uniformly distributed service load is 100 kN-m out of which 40 % moment is due to permanent loads. Check the beam for deflection. Assume M 25 concrete.**

**AKTU 2016-17, Marks 10**

**Answer**

**Given :** Span = 3.5 m, Area = 300 mm × 500 mm,
Bending moment = 100 kN-m.
**To Find :** Check the beam for deflection.

1. Total deflection is given by,
$$\Delta = \Delta_e + \Delta_s + \Delta_c$$
2. Elastic deflection, $\Delta_e = \dfrac{wL^4}{8EI} = \dfrac{ML^2}{4EI}$

Assume 3 – 25 mm $\phi$ bars in tension at an effective cover of 50 mm.

3. $E = E_c = 5000\sqrt{25} = 25000 \text{ N/mm}^2$
4. $I_{gr} = \dfrac{300 \times 500^3}{12} = 31.25 \times 10^8 \text{ mm}^4$
5. $\sigma_{cr} = 0.7\sqrt{f_{ck}} = 3.5 \text{ N/mm}^2$
6. $M_{cr} = \dfrac{\sigma_{cr}\, I_{gr}}{y_t} = \dfrac{3.5 \times 31.25 \times 10^8}{250} = 43.75 \times 10^6 \text{ N-mm}$
7. **Depth of Neutral Axis :**
   i. Take the moment of effective areas about the neutral axis which is, say, at distance $x$ from the extreme compression fibre :
$$300 \times x\left(\frac{x}{2}\right) = m \times 3 \times \frac{\pi}{4}(25)^2 \times (d - x)$$
   ii. Modular ratio, $m = \dfrac{E_s}{E_c} = \dfrac{2 \times 10^5}{25000} = 8$
$$300 \times \frac{x^2}{2} = 8 \times 1472.62\,(450 - x)$$
$$x = 152.8 \text{ mm}$$
8. Lever arm, $z = 450 - \dfrac{152.8}{3} = 399.07$ mm.
9. $I_{cr} = \dfrac{300 \times (152.8)^3}{3} + 8 \times 1472.62\,(450 - 152.8)^2$
$$= 13.97 \times 10^8 \approx 14 \times 10^8 \text{ mm}^4$$
10. $I_{\text{eff}} = \dfrac{14 \times 10^8}{1.2 - \dfrac{43.75 \times 10^6}{100 \times 10^6}\left(\dfrac{399.07}{450}\right)\left(1 - \dfrac{152.8}{450}\right) \times 1}$



$$= 14.83 \times 10^8 \text{ mm}^4$$
$$I_{\text{eff}} < I_{gr}$$

11. Elastic deflection,
$$\Delta_e = \frac{ML^2}{4\,E_c I_{eff}} = \frac{100 \times 10^6 \times (3500)^2}{4 \times 25000 \times 14.83 \times 10^8} = 8.26 \text{ mm}$$
12. Shrinkage deflection,
$$\Delta_s = k_3\, \psi_s\, L^2$$
   i. $k_3 = 0.5$, $L = 3500$ mm
   ii. $p_t = \dfrac{100\, A_{st}}{bd} = \dfrac{100 \times 1472.62}{300 \times 450} = 1.09\ \%$
   iii. $P_c = \dfrac{100 \times A_{sc}}{bd} = 0\ \%$ $\quad (\because\ A_{sc} = 0)$
   iv. $k_4 = \dfrac{0.72 \times 1.09}{\sqrt{1.09}} = 0.75 < 1$
   v. $\psi_s = k_4 \dfrac{\varepsilon_s}{D} = \dfrac{0.75 \times 0.0003}{500} = 4.5 \times 10^{-7}$
   vi. $\Delta_s = 0.5 \times 4.5 \times 10^{-7} \times (3500)^2 = 2.756$ mm
13. Creep deflection,
$$\Delta_c = \Delta_{ci} - \Delta_{cs}$$
   i. Creep coefficient,
   Let us assume that age of the concrete at loading is 28 days.
   Creep coefficient, $\theta = 1.6$
   ii. $E_{ce} = \dfrac{E_c}{1 + \theta} = \dfrac{25000}{1 + 1.6} = 9615.38 \text{ N/mm}^2$
   iii. Modular ratio, $m = \dfrac{E_s}{E_{ce}} = \dfrac{2 \times 10^5}{9615.38} = 20.8$
   iv. Let recalculate, $I_{\text{eff}}$
      a. $150\, x^2 = 20.6 \times 1472.62\,(450 - x)$
$$x = 217.77 \text{ mm}$$
      b. Lever arm, $z = 450 - \dfrac{217.77}{3} = 377.41$
      c. $I_{cr} = \dfrac{300 \times (217.77)^3}{3}$
$$+ 20.8 \times 1472.62\,(450 - 217.77)^2$$
$$= 26.85 \times 10^8 \text{ mm}^4$$
$$I'_{\text{eff}} = \frac{26.85 \times 10^8}{1.2 - \dfrac{43.15 \times 10^6}{100 \times 10^6}\left(\dfrac{377.41}{450}\right)\left(1 - \dfrac{217.77}{450}\right)}$$

$= 26.57 \times 10^8 \text{ mm}^4 \not> I_{gr}.$

v. $\Delta_{ci} = \dfrac{M' L^2}{4 E_{ce} I'_{eff}}$

$= \dfrac{(0.4 \times 100 \times 10^6) \times (3500)^2}{4 \times 9615.38 \times 26.57 \times 10^8} = 4.8 \text{ mm}$

vi. $\Delta_{cs} = \dfrac{M' L^2}{4 E_c I_{eff}}$

$= \dfrac{(0.4 \times 100 \times 10^6) \times (3500)^2}{4 \times 25000 \times 14.83 \times 10^8} = 3.3 \text{ mm}$

vii. Deflection due to creep,

$\Delta_c = 4.8 - 3.3 = 1.5 \text{ mm}$

14. Total deflection, $\Delta = \Delta_e + \Delta_s + \Delta_c$

$= 8.26 + 2.756 + 1.5 = 12.516 \text{ mm}$

15. Total permissible deflection $= \dfrac{L}{250} = \dfrac{3500}{250} = 14 \text{ mm}$

Hence, the beam is safe in deflection.

☺☺☺

# 4 UNIT

# Design of Columns

## CONTENTS

PART-1

*Effective Height of Columns, Assumptions, Minimum Eccentricity.*

CONCEPT OUTLINE

**Column :** A column may be defined as an element used primarily to support axial compressive load and with a height of at least three times its least lateral dimension.

Column may be rectangular, square, circular or polygon in cross-section.

**Classification of Columns :** A columns may be classified based on different criteria such as :

**A. Based on the Shape of the Cross Section :**

i. Rectangular column. ii. Square column.

iii. Circular column. iv. Polygonal column.

**B. Based on Slenderness Ratio :** A column may be classified as short or long column depending on its effective slenderness ratio.

**C. Based on Type of Loading :**

i. Axially loaded column,

ii. A column subjected to axial load and uniaxial bending, and

iii. A column subjected to axial load and biaxial bending.

**D. Based on Pattern of Lateral Reinforcement :**

i. Tied column.

ii. Spiral column.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 4.1.** **Discuss effective length of columns.**

**Answer**

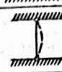
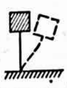
1. We know that Euler's buckling load for columns with different end conditions works out to be of the form

$$P_{cr} = \frac{\pi^2 EI}{l_e}$$



where $l_e$ is the effective length of column. Effective length of columns is given in the Table 4.1.1.

**Table 4.1.1.** Effective length of compression members.

| Degree of End Restraint of Compression Members | Symbol | Theoretical Value of Effective Length | Recommended Value of Effective Length |
|---|---|---|---|
| Effectively held in position and restrained against rotation in both end. |  | 0.50 $l$ | 0.65 $l$ |
| Effectively held in position at both ends, restrained against rotation at one end. |  | 0.70 $l$ | 0.80 $l$ |
| Effectively held in position at both ends, but not restrained against rotation. |  | 1.00 $l$ | 1.00 $l$ |
| Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position. |  | 1.00 $l$ | 1.20 $l$ |
| Effectively held in position and restrained against rotation in one end, and at the other partially restrained against rotation but not held in position. |  | – | 1.50 $l$ |
| Effectively held in position at one end but not restrained against rotation and at the other end restrained against rotation but not held in position. |  | 2.00 $l$ | 2.00 $l$ |
| Effectively held in position and restrained against rotation, at one end but not held in position not restrained against rotation at the other end. |  | 2.00 $l$ | 2.00 $l$ |

**Que 4.2.** **What are the assumptions for the limit state of collapse in compression ?**

**Answer**

**Assumptions :** The following assumptions are made for the limit state of collapse in compression :

1. Plane sections normal to the axis remain plane after bending.
2. The relationship between stress-strain distribution in concrete is assumed to be parabolic. The maximum compressive stress is equal to $0.446 f_{ck}$.

3. The tensile strength of concrete is ignored.
4. The stresses in reinforcement are derived from the representative stress-strain curve for the type of steel used.
5. The maximum compressive strain in concrete in axial compression is taken as 0.002.
6. The maximum compression strain at the highly compressed extreme fibre in concrete subjected to axial compression and bending, but when there is no tension on the section, is taken as 0.0035 minus 0.75 times the strain at the least compressed extreme fibre.
7. The maximum compressive strain at the highly compressed extreme fibre in concrete subjected to axial compression bending when part of the section is in tension, is taken as 0.0035.
8. All the members in compression shall be designed for the minimum eccentricity.

**Que 4.3.** **What is the minimum eccentricity specified for design of column ?**

**OR**

**Why does the code require all columns to be able to resist a minimum eccentricity of loading ?**

**Answer**

1. According to code, all compression members are to be designed for a minimum eccentricity of the load in two principal directions.
2. The code specifies the following minimum eccentricity '$e_{min}$' for the design of column.

$$e_{min} = \frac{l}{500} + \frac{D}{30}, \text{ subject to a minimum of 20 mm}$$

where, $l$ = Unsupported length of the column in the direction under consideration.

$D$ = Lateral dimension of the column in the direction under consideration.

3. If X-axis is the major axis and Y-axis is the minor axis of bending, then we have

$$e_{x,\,min} = \frac{l_x}{500} + \frac{D}{30}, \text{ and}$$

$$e_{y,\,min} = \frac{l_y}{500} + \frac{b}{30}, \text{ each not less than 20 mm.}$$

where,

$e_{x,\,min}$ and $e_{y,\,min}$ = Minimum eccentricities for bending about X and Y axes respectively



$l_x$ and $l_y$ = Unsupported length of the column for bending in the two directions respectively.

**Case I : Design of Short Axially Loaded Column when $e_{min} \leq 0.05D$ :** If the value of minimum eccentricity is less than or equal to $0.05D$, the code permits the design of short axially loaded compression member by the following equation :

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$

**Case II : Design of Short Axially Loaded Column when $e_{min} > 0.05D$ :**

If the minimum eccentricity is greater than $0.05D$, the section is designed for combined axial load and bending.

**Que 4.4.** **What are the differences between short column and long column ?**

**Answer**

| S. No. | Short Column | Long Column |
|---|---|---|
| 1. | A column is considered to be short if the ratio of effective length to its least lateral dimension is less than or equal to 12. | A column is considered to be long if the ratio of effective length to its least lateral dimension is greater than 12. |
| 2. | The ratio of effective length of a short column to its least radius of gyration is less than or equal to 40. | The ratio of effective length of a long column to its least radius of gyration is greater than 40. |
| 3. | Buckling tendency is very low. | Long and slender columns buckle easily. |
| 4. | The load carrying capacity is high as compared to long column of the same cross-sectional area. | The load carrying capacity of a long column is less as compared to short column of the same cross-sectional area. |
| 5. | The failure of the short column is by crushing. | The column generally fails in bucking. |

**PART-2**

*Short Column Under Axial Compression.*

## CONCEPT OUTLINE

**Short RCC Columns :** A column is said to be short column when both slenderness ratio ($l_{ex}/D$) and ($l_{ey}/B$) are less than 12.

## Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 4.5.** **How can you design a square column when only load and length of column is given ?**

**Answer**

Following are the step to design a square column :

**Step 1 :** According to given condition, we first determine the effective length of column with the help of IS : 456-2000.

**Step 2 :** Determine design load ($P_u$) which is equal to *FOS* (1.5) × given load.

**Step 3 :** Determine the area of steel and area of concrete in terms of gross area. Generally, $A_{sc} = 1\ \%\ A_g$ and $A_c = 99\ \%\ A_g$.

**Step 4 :** Apply following formula which is given by IS : 456-2000.

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$

where, $P_u$ = Designed load.

$f_{ck}$ = Characteristics strength of concrete (N/mm²).

$f_y$ = Characteristics strength of steel (N/mm²).

$A_c$ = Area of concrete in terms of gross area.

$A_{sc}$ = Area of steel in terms of gross area.

**Step 5 :** Determine the gross area ($A_g$)

$$a^2 = A_g$$

where, $a$ = Side of column.

Hence, our column size is determined.

**Step 6 : Reinforcement Calculation :** For area of steel or reinforcement calculation, we use step-3 and putting the value of $A_g$, then determine area of steel ($A_{sc}$) in compression.

After this,

$$\text{Numbers of bars} = \frac{A_{sc}}{\text{One bar area}}$$



**Step 7 : Lateral Ties or Transverse Reinforcement :** There are two criteria for transverse reinforcement as per IS code :

i. Diameter of lateral ties should not be less than $\phi/4$

where, $\phi$ = Diameter of main bars used.

ii. Lateral ties diameter should not be less than 6 mm.

**Step 8 : Check for Spacing :** There are three criteria for spacing of lateral ties as per IS 456-2000 :

i. Spacing should not be more than 300 mm.

ii. Spacing should be least lateral side of column.

iii. 16 $\phi$, where $\phi$ = Diameter of main bar.

Provide the lateral ties, whichever the lesser valve.

**Step 9 : Check for Stability :** For this, as per IS code,

$$\frac{\text{Effective length}}{\text{Least lateral length}} < 12$$

**Que 4.6.** **Write down the provision of IS : 456 with respect to following :**

**A. Longitudinal reinforcement in RC column.**

**B. Lateral reinforcement in RC column.**

**Answer**

**A. Longitudinal Reinforcement :**

1. The minimum area of cross-section of longitudinal bars must be at least 0.8 % of the cross-sectional area of the column.
2. The maximum area of cross-section of longitudinal bars must not exceed 6 %.
3. The bar should not be less than 12 mm in diameter.
4. The minimum number of longitudinal bars provided in a column must be four in rectangular columns and six in circular columns.
5. A reinforced concrete column having helical reinforcement must have at least six bars of longitudinal reinforcement within the helical reinforcement. These bars must be in contact with the helical reinforcement and equidistant around its inner circumference.
6. Spacing of longitudinal bars measured along the periphery of a column should not exceed 300 mm.

**B. Transverse Reinforcement :** Transverse reinforcement may be in the form of lateral ties or spirals. The lateral ties may be in the form of polygonal links with internal angles not exceeding 135°. The ends of the transverse reinforcement should be properly anchored.

The transverse reinforcement should satisfy the following requirements :

1. The diameter of the polygonal links or lateral ties should not be less than one-fourth of the diameter of the largest longitudinal bar, and in no case less than 6 mm.
2. The pitch of the lateral ties should not exceed the following distances :
i. The least lateral dimension of the compression member.
ii. 16 times the smallest diameter of the longitudinal reinforcement bar.
iii. 48 times the diameter of the lateral ties.

**Helical Reinforcement :**

1. The diameter of the helical reinforcement should not be less than one-fourth of the diameter of the longitudinal bar, and in no case less than 6 mm.
2. Helical reinforcement should be of regular formation with the turn of the helix spaced evenly and its ends should be anchored properly by providing one and a half extra turns of the spiral bar.
3. If an increased load on the column on the strength of the helical reinforcement is allowed for, its pitch should not exceed the following distances :
i. 75 mm.
ii. One-sixth of the core diameter of the column.

The pitch should not be less than the following distance :
i. 25 mm.
ii. Three times the diameter of the steel bar forming the helix.
4. If an increased load on the column on the strength of helical reinforcement is not allowed for, its pitch should not exceed the following distances :
i. The least lateral dimension of the compression member.
ii. 16 times the smallest diameter of the longitudinal bar to be tied.
iii. 48 times the diameter of the helical bars.

**Cover :** The minimum cover to the column reinforcement equals 40 mm or diameter of the bar whichever is greater.

**Que 4.7.** **Design a reinforced concrete column which is 4.5 m long and fixed at both ends. It is carrying an axial load of 2000 kN (service). Use M 25 concrete and Fe415 steel.**

**AKTU 2013-14, Marks 10**

**Answer**

**Given :** Length of column, $l = 4.5$ m, Axial load, $P = 2000$ kN.
**To Find :** Design a column.



1. **Effective Length and Factored Load :**
i. Fixed at both end, effective length of column,
$$l_e = 0.65\, l = 0.65 \times 4.5 = 2.925 \text{ m}$$
ii. Check the slenderness ratio $= \dfrac{2925}{500} = 5.85 < 12$

Hence, column is short.
iii. Factored load, $P_u = 1.5 \times 2000 \text{ kN} = 3000 \text{ kN}$
2. Assuming area of steel = 1 % of gross area
$$A_{sc} = 0.01 A_g$$
Area of concrete,
$$A_c = 0.99 A_g$$
3. **Area of Column :**
$$P_u = 0.4 A_c f_{ck} + 0.67 f_y A_{sc}$$
$$3000 \times 10^3 = 0.4 \times 0.99 \times A_g \times 25 + 0.67 \times 415 \times 0.01 A_g$$
$$A_g = 236583.73 \text{ mm}^2$$
4. **Dimension of Column :** Provide square column.
i. Side of column, $a = \sqrt{A_g}$
$$a = \sqrt{236583.73} = 486.4 \text{ mm}$$
ii. Provide a square column of size 500 × 500 mm
5. **Longitudinal Reinforcement :**
i. Provide area of steel,
$$A_{sc} = 0.01 \times A_g = 0.01 \times 500^2 = 2500 \text{ mm}^2$$
ii. Use 20 mm $\phi$ bars, number of bars $= \dfrac{2500}{\dfrac{\pi}{4} \times 20^2} = 7.957 \simeq 8$
iii. Hence, provide 8-20 mm $\phi$ bars as longitudinal reinforcement.
6. **Transverse Reinforcement :**
i. According to IS code the lateral ties should not be less than :
a. $\dfrac{\phi}{4} = \dfrac{20}{4} = 5$ mm.
b. 6 mm.
ii. Use 8 mm diameter bar as lateral ties.
7. **Pitch :** According to IS code pitch should not be greater than the following value :
i. 300 mm.
ii. Least lateral dimension = 500 mm.

iii. $16\,\phi = 16 \times 20 = 320$ mm.

Hence, provide the 8 mm $\phi$ lateral ties at the spacing of 300 mm c/c.

8. **Reinforcement Details :**

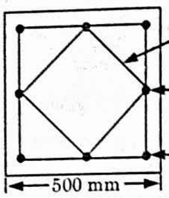



**Fig. 4.7.1.** Cross-section of column.

**Que 4.8.** **A column height of 1.5 m is pinned at the bottom effectively restrained against rotation but not held in position at the top. It is subjected to a factored axial load of 2500 kN under the combination of dead load and live load. Design the column, using M 30 concrete and Fe 415 steel.** **AKTU 2016-17, Marks 15**

**Answer**

**Procedure :** Same as Q. 4.7, Page 4–8A, Unit-4.

1. Assume the reinforcement is provided 2 % of gross area.
2. Required size of square column = 380 mm.
3. Required longitudinal reinforcement, $A_{sc} = 2888$ mm$^2$.
4. Provide 8-22 mm $\phi$ along the periphery of square column.
5. Provide 6 mm $\phi$ @ 300 mm c/c as transverse reinforcement.
6. **Reinforcement Details :**

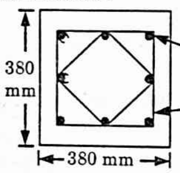



**Fig. 4.8.1.**

**Que 4.9.** **Design a short axially loaded square column 500 × 500 mm for a working load of 2000 kN. Use M20 concrete and Fe 415 grade steel.** **AKTU 2015-16, Marks 10**



**Answer**

**Given :** Size of column = 500 mm × 500 mm,
Working load = 2000 kN
**To Find :** Design of short axially loaded column.

1. Factored load = 1.5 × 2000 = 3000 kN
2. Gross area of column section, $A_g = 500 \times 500 = 250000$ mm$^2$
3. Area of concrete, $A_c = 250000 - A_{sc}$
4. $P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$

$$3000 \times 10^3 = 0.4 \times 20\,(250000 - A_{sc}) + 0.67 \times 415 \times A_{sc}$$
$$A_{sc} = 3703.0 \text{ mm}^2$$

5. Use 25 mm $\phi$ bars as longitudinal reinforcement

$$\text{Number of bars} = \frac{3703}{\frac{\pi}{4} \times 25^2} = 7.54 \approx 8$$

Provide 8# 25 mm $\phi$ bars along the periphery of the column.
Actual area of steel provided = 8 × (π/4) × 25$^2$ = 3927 mm$^2$ > 3703 mm$^2$

6. **Lateral Ties :** Diameter of ties should not be less than,

i. 6 mm,  ii. $\frac{\phi_L}{4} = \frac{25}{4} = 6.25$

Provide 8 mm $\phi$ bar as lateral reinforcement.

7. **Pitch :** Spacing of lateral ties should not be exceed :

i. Least lateral dimension = 500 mm.
ii. $16 \times \phi_L = 16 \times 25 = 400$ mm.
iii. $48 \times \phi_t = 48 \times 8 = 384$ mm.
iv. 300 mm.

Provide 8 mm $\phi$ bars @ 300 mm c/c.

8. **Reinforcement Details :**

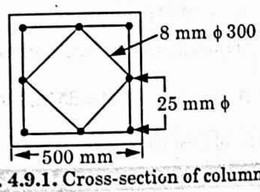



**Fig. 4.9.1.** Cross-section of column.

**Que 4.10.** **A reinforced concrete column is 450 mm × 400 mm and has to carry a factored load of 1800 kN. Length of column is 2 m. Find area of reinforcement required. Use M20 concrete and Fe 250 steel.** **AKTU 2017-18, Marks 10**

**Answer**

**Given :** Size of column = 450 mm × 400 mm,
Factored load, $P_u$ = 1800 kN
Unsupported length, $l$ = 2 m, $f_{ck}$ = 20 N/mm², $f_y$ = 250 N/mm²
**To Find :** Area of reinforcement.

1. **Slenderness Ratio :**

i. in X-direction, $\lambda_x = \dfrac{l_x k_x}{D_x} = \dfrac{2000 k_x}{450} = 4.44\, k_x$

ii. in Y-direction, $\lambda_y = \dfrac{l_y k_y}{D_y} = \dfrac{2000\, k_y}{400} = 5\, k_y$

iii. Assume, the column is braced against sideway in both direction, effective length ratio $k_x$ and $k_y$ are both less than unity and hence the both slenderness ratio are less than 12.

iv. Column may be designed as short column.

2. **Minimum Eccentricities :**

i. $$e_{x,\,min} = \frac{2000}{500} + \frac{450}{30} = 19 \text{ mm } (< 20 \text{ mm})$$

ii. $$e_{y,\,min} = \frac{2000}{500} + \frac{400}{30} = 17.33 \text{ mm } (< 20 \text{ mm})$$

iii. Also, $0.05D_x = 0.05 \times 450 = 22.5 > 19$ mm

$0.05D_y = 0.05 \times 400 = 20 > 17.33$ mm

Column can be design as short column.

3. **Design of Longitudinal Reinforcement :**

i. $$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$
$$1800 \times 10^3 = 0.4 \times 20 \times (450 \times 400 - A_{sc}) + 0.67 \times 250 \times A_{sc}$$
$$A_{sc} = 2257 \text{ mm}^2$$

ii. Provide 8# 20 mm diameter bars as longitudinal reinforcement.

$$A_{sc} = 8 \times \frac{\pi}{4} \times 20^2 = 2513.3 > 2257 \text{ mm}^2$$

iii. Percentage (%) of steel provide

$$= \frac{2513.3}{450 \times 400} \times 100 = 1.4\,\% > 0.8\,\%, \text{ hence OK.}$$

4. **Minimum Diameter of Lateral Ties :** Lateral ties should not be less than,



Tie diameter, $\phi_t > \begin{cases} 20/4 = 5 \text{ mm} \\ 6 \text{ mm} \end{cases}$

Provide 8 mm diameter bars for lateral ties.

5. **Spacing of Lateral Reinforcement :** Consider the minimum of the following values :

i. Least lateral dimension = 400 mm

ii. $16 \times \phi_L = 16 \times 20 = 320$ mm

iii. 300 mm

Provide 8 mm $\phi$ ties @ 300 mm c/c

6. **Reinforcement Details :**

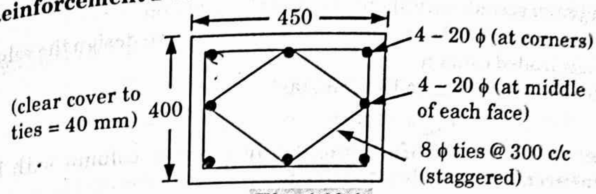



**Fig. 4.10.1.**

**PART-3**

*Requirements of Reinforcement for Column, Design of Column with Helical Reinforcement.*

**CONCEPT OUTLINE**

**Requirement of Reinforcement :** There are two kinds of reinforcement in a column:

i. Longitudinal reinforcement
ii. Transverse reinforcement.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 4.11.** **How can you design circular column with helical reinforcement ?**

**Answer**

Following are the step to design a circular column with helical reinforcement :

**Step 1 :** Determine effective length of column with given condition ($l$) and check

$l / D < 12$

where, $l$ = Effective length,

$D$ = Diameter of column.

If above condition is fulfill, then our column is short column; otherwise it is long column.

**Step 2 :** Check about minimum eccentricity which is given by :

$$e_{min} = \frac{l}{500} + \frac{D}{30}$$

where, $l$ = Given length of column,

$D$ = Diameter of column.

Minimum eccentricity should be less than 20 mm.

If step-1 and step-2 conditions are fulfill, then we design the column as axially loaded column.

After this, according to IS : 456-2000

$$e_{min} \not> 0.05D$$

**Step 3 : Main Reinforcement :** In circular column with helical reinforcement, according to IS code

$$P_u = [0.4 f_{ck} A_c + 0.67 f_y A_{sc}] \times 1.05$$

Here, 1.05 factor is for helical reinforcement.

**Step 4 :** After determining the actual percentage of steel, we determine area of steel in compression ($A_{sc}$)

*i.e.,* $A_{sc} = p \% A_g$

**Step 5 :** After determining the area of steel in compression, we determine numbers of bars *i.e.,*

Number of bars = $A_{sc}$ / One bar area

**Step 6 : Calculation of Helical Reinforcement :** In the calculation of helical reinforcement, we adopt the following steps :

i. Diameter of core, $d$ = Main diameter – 2 × Cover
ii. Area of core = $(\pi / 4)d^2$ – Area of bars
iii. Volume of core per pitch height '$S$'

$$V_c = \text{Area of core} \times \text{Pitch } (S)$$

iv. Length of one spiral *i.e.,* periphery of one spiral is calculated by, $\pi d$ – Diameter of bar used for spiral.
v. Volume of one spiral,

$$V_{us} = \text{Area of spiral bar} \times \text{Length of spiral.}$$

**Step 7 :** Determine the spacing of main bars.

$$\rho_s \left( = \frac{4a_{sp}}{D_c S} \right) \leq 0.36 \left( \frac{A_g}{A_c} - 1 \right) \frac{f_{ck}}{f_y}$$

**Step 8 : Check for Maximum Spacing :** According to IS code spacing should not be greater than following two :

i. 75 mm.
ii. Core diameter/6.

**Step 9 : Check for Minimum Spacing :** According to IS code, spacing should not be less than following two :

i. 25 mm.
ii. 3 times diameter of helical bars.



**Que 4.12. An RCC circular column of effective length 2.40m carrying an axial service load 900 kN. Design column with M20 concrete and Fe 415 steel.**

**AKTU 2013-14, Marks 10**

**Answer**

**Given Data :** Effective length, $l_{eff}$ = 2.40 m, Load, $P_u$ = 900 kN, $f_{ck}$ = 20 N/mm², $f_y$ = 415 N/mm².

**To Find :** Design circular column.

1. **Design Load or Factored Load :**

$$P_u = 1.5 \times 900 = 1350 \text{ kN}$$

2. According to IS code, area of steel should be in between of 0.8 % to 6 % of gross area.

Taken area of reinforcement,

$$\therefore \quad A_{sc} = 1 \% A_g$$

3. **According to IS Code :**

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$

$$1350 \times 10^3 = 0.4 \times 20 (1 - 0.01) A_g + 0.67 \times 415 \times 0.01 A_g$$

Area of column, $A_g$ = 126162.33 mm²

4. Since we have to design circular column, therefore

$$A_g = (\pi/4) D^2 = 126162.33$$

$$D \simeq 400 \text{ mm}$$

Adopt diameter of column, $D$ = 400 mm

5. **Area of Steel :** $A_{sc} = 0.01 A_g$

Area of steel, $A_{sc}$ = 0.01 × 126162.33 = 1261.63 mm²

Use 16 mm $\phi$ bar, then number of bar $= \frac{A_{sc}}{(\pi / 4) d^2} = \frac{1262.63}{(\pi / 4) \times 16^2} = 6.28 \simeq 7$

6. **Lateral Ties :** According to IS code it should not less than following value :

i. $\phi / 4 = 16 / 4 = 4$ mm
ii. 6 mm.

Use 6 mm bar as lateral ties.

7. **Pitch :** According to code it should not be more than following :

i. ≤ 400 mm (Lateral dimension or diameter).
ii. $\leq 16 \phi_L = 16 \times 16 = 256$ mm
iii. ≤ 300 mm

Provide lateral ties 6 mm $\phi$ bar @ 250 mm c/c

8. **Check for Slenderness :** According to IS code :

$$\frac{l_{eff}}{\text{Least lateral length}} < 12 = \frac{2400}{400} = 6 < 12$$

Hence, column is a short column.

9. **Reinforcement Details :**

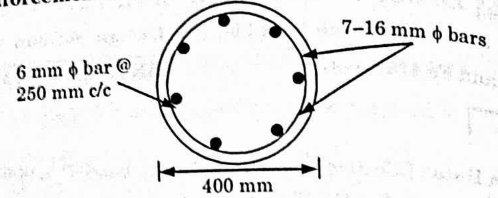



**Fig. 4.12.1.**

**Que 4.13.** **Design a circular column to carry an axial load of 1000 kN. Use M20 mix and Fe 415 grade steel.** **AKTU 2015-16, Marks 10**

**Answer**

**Procedure :** Same as Q. 4.12, Page 4–15A, Unit-4.

1. Factored load, $P_u$ = 1500 kN
2. Assuming area of steel, $A_{sc} = 0.8\ \%\ A_g$
3. Require area of column, $A_g$ = 147632 mm²
4. Provide diameter of column, $D$ = 500 mm
5. Require area of steel, $A_{sc}$ = 1181.06 mm²
6. Provide 6-16 mm ϕ bars as longitudinal reinforcement.
7. Provide 6 mm ϕ @ 250 mm c/c as lateral ties.
8. **Reinforcement Details :**

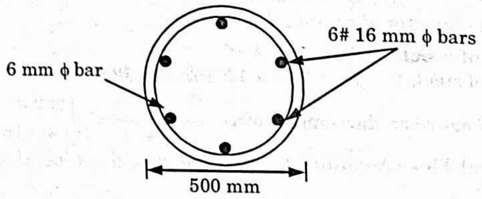



**Fig. 4.13.1.**

**Que 4.14.** **A circular RCC column of 450 mm dia is reinforced with 8 bars of 18 mm dia and are tied together with helical reinforcement of 8 mm dia at a pitch of 60 mm c/c. Find load carrying capacity of the column, when effective length of column is 4.5 m. Take clear cover to helical reinforcement 50 mm. Use M20 grade concrete and Fe415 steel.** **AKTU 2014-15, Marks 10**



**Answer**

**Given :** Diameter of column = 450 mm,
Area of steel, $A_{sc} = 8 \times (\pi/4) \times 18^2 = 2035.75\ mm^2$, Pitch = 60 mm c/c,
Effective length of column ($l_{eff}$) = 4.5 m, Clear cover = 50 mm.
**To Find :** Load carrying capacity

1.
$$\frac{P_u}{1.05} = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$
$$A_c = A_g - A_{sc}$$
$$= (\pi/4) \times 450^2 - 8 \times (\pi/4)\ 18^2 = 157007.38\ mm^2$$
$$P_u = [0.4 \times 20 \times 157007.38 + 0.67 \times 415 \times 2035.75] \times 1.05$$
$$= 1822.1\ kN \times 1.05 = 1913.2\ kN$$

2. Core diameter, $D_c = 450 - 2 \times 50 = 350$ mm

3.
$$\frac{V_{us}}{V_c} = \rho_s = \frac{\text{Volume of spiral in one loop}}{\text{Volume of core for a length pitch } (S)}$$
$$\leq 0.36\left(\frac{A_g}{A_c} - 1\right)\frac{f_{ck}}{f_{sy}}$$
$$\therefore\ 0.36\left(\frac{A_g}{A_c} - 1\right)\frac{f_{ck}}{f_y} = 0.36\left[\left(\frac{450}{350}\right)^2 - 1\right] \times \frac{20}{250} = 0.0187$$

4. Area of lateral ties, $a_{sp} = (\pi/4) \times 8^2 = 50.26\ mm^2$
$$\text{Volume of core} = \frac{\pi}{4} D_C^2\, S$$

5. Volume of spiral in one loop $= \pi a_{sp} (D_C - \phi s_p) = \pi a_{sp} D_C$
$$\rho_s = \frac{4a_{sp}}{D_c S} \leq 0.0187$$
$$\frac{4 \times 50.26}{350 \times S} \leq 0.0187$$
$$S \leq 30.716\ mm$$

6. IS recommendation for pitch of helical reinforcement :
$$S \leq \begin{cases} 75\ mm \\ \dfrac{D_c}{6} = \dfrac{350}{6} = 58.33\ mm \end{cases}$$
$$S > \begin{cases} 25\ mm \\ 3 \text{ times of diameter of lateral ties} = 3 \times 8 = 24\ mm \end{cases}$$

7. Hence, provide the 8 mm ϕ bar at the 30 mm c/c.

**PART-4**

*Design of Short Column Under Axial Load and Uniaxial Bending.*

## CONCEPT OUTLINE

**Interaction Curve :** It is a curve, which is construct between axial load $P$ and moment $M$.

**Short Columns Under Axial Load and Uniaxial Bending :** Short column section subjected to axial load $P$ and moment $M$. The moment $M$ is equivalent to the axial load $P$ acting at an eccentricity $e = M / P$. This type of problem is solved by the interactions curve.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 4.15.** **What are interactive curves used in the design of columns ? How these curves are used in design of columns subjected to axial load and moments ?** **AKTU 2013-14, Marks 10**

**Answer**

A. **Interactive (Interaction) Curve :**

1. It is a curve, which is constructed between axial load $P$ and moment $M$.
2. If different combinations of $P_u$ and $M_u$ for each failure mode of a given column section are determined and plotted.

B. **Use of Interactive (Interaction) Curve :**

1. An RCC column of size $b \times D$ is subjected to an axial factor load of $P_u$ and a factored moment $M_u$.
2. The steps to use the interaction diagrams from IS code are as follows :
   i. Select the diameter of the bars to be used and calculate $d' / D$.
   ii. IS code contains interaction diagrams for $d' / D = 0.05, 0.1, 0.15$ and $0.20$.
   iii. Select the nearest higher value of referring to the diagram.
   iv. For example, if $d' / D = 0.12$, select $d' / D = 0.15$.
   v. Alternatively, we may find reinforcement for $d' / D = 0.10$ and that for $d' / D = 0.15$, using two different charts and interpolate for $d' / D = 0.12$.
2. Select the arrangement of reinforcement, viz., reinforcement for two opposite faces or reinforcement equally distributed on all four faces.
3. For selected grade of steel, the arrangement of reinforcement and for different values of $d' / D$, the interaction diagrams are drawn in IS code. Refer to the respective diagram.
4. Determine $\frac{P_u}{f_{ck}\, b\, D}$ and $\frac{M_u}{f_{ck}\, b\, D^2}$ (with usual notation). By visual inspection and also using scale and pencil, determine the value of $\frac{p_t}{f_{ck}}$ from the interaction chart. Subsequently, determine $p_t$ and $A_s = \frac{p_t bD}{100}$.



**Que 4.16.** **What are interactive curves ? Explain the failure of a column subjected to compression and uniaxial bending with the help of interaction curve.** **AKTU 2014-15, Marks 10**

**OR**

**Describe $P_u - M_u$ interaction diagram used in the analysis of eccentric column.** **AKTU 2016-17, Marks 10**

**Answer**

A. **Interactive Curve :** Refer Q. 4.15, Page 4–18A, Unit-4.

B. **Failure of Column :**

1. Region I in which the eccentricity $e$ is less than $e_{min}$ specified in the code.
2. Region II in which eccentricity $e$ exceeds $e_{min}$. The first region is indicated by line $EA$ of the interaction curve. Point $E$ indicates the failure load $P_{uz}$ when a column section is subjected to a perfectly axial load, with zero eccentricity.

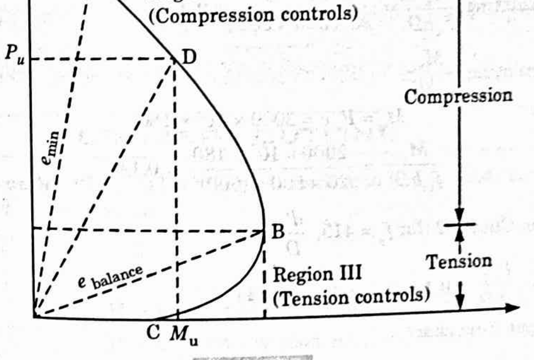



**Fig. 4.16.1.**

4. Point $A$ indicates the failure load of the column subjected to axial load with nominal eccentricity equal to $e_{min}$. The moment corresponding to this eccentricity is equal to $P_u e_{min}$.

4. The region II where compression controls, indicated by $AB$, is controlled by crushing strain in concrete, indicated by increasing moment on the column. Point $B$ on the interaction curve is called the balanced load point, where in the column will fail by simultaneous occurrence of limiting strains in concrete and reinforcement.

5. With further increase of moment, we enter into the region III (curve $BC$), where tension failure occurs. In region III tension controls. The axial load carrying capacity of the section decreases rapidly in the zone $BC$, as the moment increases, which is because of higher tensile force of reinforcement.

6. When the compressive axial load is zero, corresponding to point $C$, the column section behaves as a doubly reinforced beam and its moment capacity (or pure bending moment capacity) $M_0$ is equal to $R_u bd^2$.

**Que 4.17.** **Design a reinforced concrete square column of 500 mm side to carry an ultimate load of 2000 kN at an eccentricity of 180 mm. Use M20 grade concrete and Fe415 steel.**

**AKTU 2014-15, Marks 10**

**Answer**

**Given :** $b = D = 500$ mm, $P_u = 2000$ kN, $e = 180$ mm, $f_{ck} = 20$ N/mm², $f_y = 415$ N/mm².
**To Find :** Design of column.

1. Assuming effective cover, $d = 50$ mm

2. Calculating $\dfrac{P_u}{f_{ck}bD} = \dfrac{2000 \times 10^3}{20 \times 500 \times 500} = 0.4$

3. Calculating $\dfrac{M_u}{f_{ck}bD^2}$

$$M_u = P_u e = 2000 \times 10^3 \times 180$$

$$\frac{M_u}{f_{ck}bD^2} = \frac{2000 \times 10^3 \times 180}{20 \times 500 \times (500)^2} = 0.144$$

4. From Chart 32 (for $f_y = 415$, $\dfrac{d'}{D} = 0.1$)

For $\dfrac{P_u}{f_{ck}bD} = 0.4$ and $\dfrac{M_u}{f_{ck}bD^2} = 0.144$

We get from chart,



$$\frac{p_t}{f_{ck}} = 0.09$$

$$p_t = 0.09 \times 20 = 1.8\ \%$$

5. **Calculating $A_{sc}$ :** $A_{sc} = \dfrac{p_t}{100} \times bD = \dfrac{1.8 \times 500 \times 500}{100} = 4500$ mm²

Using 6-32 mm diameter bars

$$A_{sc} = 6 \times (\pi / 4) \times 32^2 = 4825 \text{ mm}^2 > 4500 \text{ mm}^2$$

6. **Transverse Reinforcement :** According to IS code lateral ties should not be less than :

i. $\dfrac{\phi_L}{4} = \dfrac{32}{4} = 8$ mm

ii. 6 mm

7. **Pitch of Ties :** It should not be greater than following :

Least lateral dimension, $b = 500$ mm

i. $16\ \phi_L = 16 \times 32 = 512$ mm

ii. $48\ \phi = 48 \times 8 = 384$ mm

iii. 300 mm

iv. Hence, provide 8 mm ties @ 300 mm c/c as shown in Fig. 4.17.1.

8. **Detail of Reinforcement :**

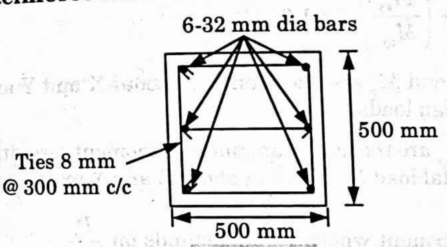



**Fig. 4.17.1.**

**PART-5**

*Design of Column Under Bi-axial Loading by Design Charts.*

**CONCEPT OUTLINE**

**Column under Bi-axial Loading :** According to IS Code 456 : 2000 for biaxial loaded columns :

$$\left(\frac{M_{ux}}{M_{ux_1}}\right)^{\alpha_n} + \left(\frac{M_{uy}}{M_{uy_1}}\right)^{\alpha_n} \le 1$$

$M_x = pe_x$, factorial moment along X-axis.
$M_y = pe_y$, factorial moment along Y-axis.

## Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 4.18.** **Explain Bresler load contour approach.**

**OR**

**Discuss the design criteria of column subjected to combined axial and biaxial bending.**

**Answer**

1. Exact design of columns subjected to combined axial load and biaxial bending moments is very complicated and extremely laborious.
2. To simplify the process, IS 456 : 2000 permits the design of such columns by the following equation.

$$\left(\frac{M_{ux}}{M_{ux_1}}\right)^{\alpha_n} + \left(\frac{M_{uy}}{M_{uy_1}}\right)^{\alpha_n} \le 1.0$$

where $M_x$ and $M_y$ are the moments about X and Y axes respectively due to design loads.
3. $M_{ux}$ and $M_{uy}$ are the maximum uniaxial moment capacities of the column with an axial load $P_u$, bending about X and Y axes respectively.
4. $\alpha_n$ is an exponent whose value depends on $\frac{P_u}{P_{uz}}$

where $P_{uz} = 0.45 f_{ck} A_c + 0.75 f_y A_{sc}$

5.

| $\frac{P_u}{P_{uz}}$ | $\alpha_n$ | |
|---|---|---|
| ≤ 0.2 | 1.0 | {α varies linearly from 1.0 to 2.0 for $P_{uz}$ less |
| ≥ 0.8 | 2.0 | than 0.2 and greater than 0.8} |

6. For intermediate values *i.e.*, from 0.2 to 0.8, linear interpolation may be done.

**Que 4.19.** **Design the reinforcement to be provided for a short column 400 mm × 500 mm subjected to following forces :**



**$P_u$ = 1600 kN, $M_{ux}$ = 150 kN-m, $M_{uy}$ = 100 kN-m**

**Use M 25 concrete and Fe 415 steel.**

**Answer**

**Given :** $b$ = 400 mm, $D$ = 500 mm, $P_u$ = 1600 kN, $M_{ux}$ = 150 kN-m, $M_{uy}$ = 100 kN-m, $f_{ck}$ = 25 N/mm², $f_y$ = 415 N/mm²,

**To Find :** Reinforcement details.

1. Assuming that the moment due to minimum eccentricity is less than the given moments $M_{ux}$ and $M_{uy}$.
2. Assuming 20 mm diameter bars, equally distributed on all the four sides of the column, with an effective cover of 50 mm,

$$d' = 50 \text{ mm}$$

$$\therefore \quad \frac{d'}{D} = \frac{50}{500} = 0.1$$

3. Assuming $p$ = 1.5 %,

$$\frac{p}{f_{ck}} = \frac{1.5}{25}$$

4. From chart 45, for $\frac{p}{f_{ck}}$ = 0.06 and $\frac{P_u}{f_{ck}\,bD}$ = 0.32, we get

$$\frac{M_u}{f_{ck}\,bD^2} = 0.097$$

i. $M_{ux}$

$$M_{ux} = 0.097 f_{ck}\,bD^2$$
$$= 0.097 \times 25 \times 400 \times (500)^2 = 242.5 \text{ kN-m}$$

ii. $M_{uy}$

$$\frac{d'}{D} = \frac{50}{400} = 0.125, \text{ chart for } \frac{d'}{D}$$
= 0.15 will be used which is chart 45, we get

$$\frac{M_u}{f_{ck}\,bD^2} = 0.09$$

$$M_{uy_1} = 0.09 f_{ck}\,bD^2$$
$$= 0.09 \times 25 \times 500 \times (400)^2 = 180 \text{ kN-m}$$

5. **Calculating $P_{uz}$ :**

i. From chart 63, for $p = 1.5, f_y = 415 \text{ N/mm}^2, f_{ck} = 25 \text{ N/mm}^2$

$$\frac{P_{uz}}{A_g} = 15.8 \text{ N/mm}^2$$

$$P_{uz} = 15.8 \times 400 \times 500 = 3160 \text{ kN}$$

ii. $$\frac{P_u}{P_{uz}} = \frac{1600}{3160} = 0.506$$

iii. $$\frac{M_{ux}}{M_{ux_1}} = \frac{150}{242.5} = 0.618$$

iv. $$\frac{M_{uy}}{M_{uy_1}} = \frac{100}{180} = 0.55$$

v. For $\frac{P_u}{P_{uz}} = 0.506$ and $\frac{M_{uy}}{M_{uy_1}} = 0.55$ from chart 64,

We get $$\left(\frac{M_{ux}}{M_{ux_1}}\right)_{\text{permissible}} = 0.7$$

vi. $$\frac{M_{ux}}{M_{ux_1}} < \left(\frac{M_{ux}}{M_{ux_1}}\right)_{\text{permissible}}$$

Hence the design is safe.

6. **Calculation of $A_{sc}$ :**

$$A_{sc} = \frac{PbD}{100} = \frac{1.5 \times 400 \times 500}{100} = 3000 \text{ mm}^2$$

Providing 10 bars of 20 mm diameter (provide, $A_{sc} = 3140 \text{ mm}^2$)

7. **Design of Lateral Ties :**

i. Diameter of ties should not be less than $\frac{\phi}{4} = \frac{25}{4} = 6.25$ mm

ii. 6 mm.

Hence provide 8 mm diameter ties.

8. **Spacing :** Pitch of ties should not be more than :

i. Least lateral dimension = 500 mm

ii. 16 × 20 = 320 mm



iii. 300 mm

Hence provide 8 mm $\phi$ ties @ 300 mm c/c.

9. **Reinforcement Details :**

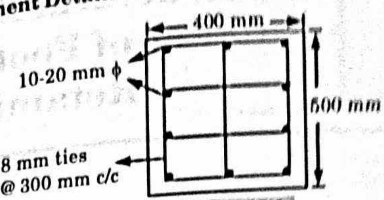



**Fig. 4.19.1.**

☺☺☺

# 5 UNIT

# Structural Behavior of Footing and Retaining Wall

## CONTENTS







## PART-1

### *Structural Behaviour of Footings.*

### CONCEPT OUTLINE

**Footing :** The enlarged portion of the foundation is called footing.

**Classification of Foundation :** Foundation may be broadly classified under two heads :

i. **Shallow Foundation :**
   a. Isolated footings.
   b. Combined footings.
   c. Strap footings.
   d. Strip or wall footings.
   e. Raft or mat foundation.

ii. **Deep Foundation :**
   a. Pile foundation.
   b. Pier foundation.
   c. Well foundation.

**Minimum Depth of Foundation :** It is given by,

$$d = \frac{q_c}{\gamma}\left[\frac{1-\sin\phi}{1+\sin\phi}\right]^2$$

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 5.1.** **Define the term foundation. Describe the types of footing.**

**Answer**

**Foundation :** It is also known as substructure. Foundation is the part of structure which is in direct contact with the soil generally below the ground level and transfers the loads from super structure to the subsoil safely.

**Types of Footing :** Following are the various types of footing :

1. **Continuous Wall Footing :** A footing that supports a continuous long masonry or RCC wall is known as continuous footing. In this case, the width of the footing is very small than the length of footing.
2. **Isolated Footing :**
   i. An individual footing under a single column is known as an isolated footing. It is the most commonly used footing.
   ii. These may be pad, slopped, stepped or with isolated beam and slab type footings.

3. **Combined Footing :**
 i. A footing that supports a group of columns is known as combined footing.
 ii. Where the distance between two columns is small and is the isolated footings for these columns coincide, a combined footing is used.
 iii. This may result in a rectangular or trapezoidal shape of the footing.
4. **Strap Footing :** If a combined footing is required due to site conditions, but the distance between the columns is large, a strap footing is used for economy.
5. **Strip Footing :**
 i. If a number of footings in a line are to be combined, a strip footing is used.
 ii. Differential settlement can be minimized by using such footings.
6. **Raft Foundation :**
 i. A single slab or a slab beam footing that covers the entire stratum beneath the entire area of the super-structure is known as a mat or raft footing.
 ii. When safe bearing capacity of soil is low and columns carry heavy loads, then footings of a group of columns or all the columns in a structure are combined to form a raft foundation.
7. **Pile Foundation :**
 i. If good soil is available at a higher depth (more than 3 m) below the ground level, pile foundations are economical.
 ii. Piles transfer the loads from columns to the hard soil by end bearing and to the surrounding soil by friction.

## PART-2

*Design of Isolated Footings.*

### CONCEPT OUTLINE

**Isolated Footings :** The footings which are provided under single columns are called as isolated footings.

**Types of Isolated Footings :** Isolated footings are of two types :
 i. Uniform thickness footings.
 ii. Tapered thickness footings (sloped footing).

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**



**Que 5.2.** **Determine the plan dimensions of a RCC footing for a column subjected to a characteristics load of 1000 kN and moment about the major axis $M_x$ = 180 kN-m the size of the column is 300 mm × 750 mm. the safe bearing capacity of the soil is 200 kN/m².**

**AKTU 2017-18, Marks 10**

**Answer**

**Given :** Characteristics load = 1000 kN. Moment, $M_x$ = 180 kN-m.
Size of the column = 300 mm × 750 mm,
Safe bearing capacity = 200 kN/m².
**To Find :** Plan dimensions.

1. Ultimate load = 1.5 × 1000 = 1500 kN
 Approximate weight of footing

$$= \frac{10}{100} \times 1500 = 150 \text{ kN}$$

2. Total load = 1500 + 150 = 1650 kN
 Moment = 180 kN-m = 180 × 10³ N-m

3. $$\text{Eccentricity, } e = \frac{180 \times 10^6}{1650 \times 10^3} = 0.0111 \text{ m} \approx 11 \text{ mm}$$

4. $$\text{Area of footing} = \frac{\text{Total load}}{\text{Safe bearing capacity}} = \frac{1650 \times 10^3}{200 \times 10^3} = 8.25 \text{ m}^2$$

5. Provide side of foundation = 3.5 m × 2.5 m
6. The footing will be provided so that the centre of gravity of column load will coincide with the centre of gravity of footing area. Footing is placed symmetrical with respect to *X-X* axis of column projection of the footing beyond the column face will be
 1750 – 11 – 375 = 1364 mm.
 and 1750 + 11 – 375 = 1386 mm respectively.

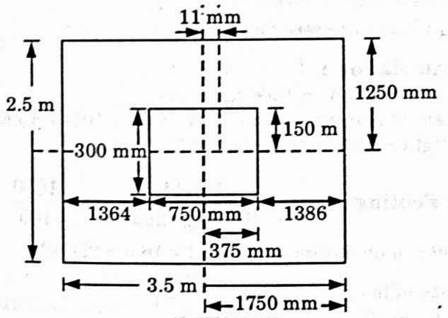



**Fig. 5.2.1.**

7. Net upward pressure intensity = $\frac{1500}{3.5 \times 2.5}$ = 171.43 kN/m²

8. **Depth of Footing :**

i. BM at the critical section, $M_{ux} = 3.5 \times 1.386 \times 171.43 \times \frac{1.386}{2}$

$$M_{ux} = 576.3 \text{ kN-m}$$

ii. Equating $M_{u,lim}$ to $M_{ux}$

$$M_{u,lim} = 0.138 f_{ck} bd^2$$
$$576.3 \times 10^6 = 0.138 \times 20 \times 750 \times d^2$$
$$d = 527 \text{ mm}$$

iii. BM of section along $Y - Y$

$$M_{uy} = 171.43 \times 2.5 \times 1.1 \times (1.1/2) = 259.29 \text{ kN-m}$$

iv. Required depth, $d = \sqrt{\frac{259.29 \times 10^6}{0.138 \times 20 \times 300}}$ = 559.6 mm

9. Provide effective depth of footing is 600 mm and 650 mm overall depth.
10. Provided plan dimension of footing 3.5 m × 2.5 m and depth 600 mm.

**Que 5.3.** **Design a square spread footing to carry an axial load of 1500 kN from a 400 mm square tied column containing 20 mm bars as the main reinforcement. The bearing capacity of soil is 100 kN/m². Consider base of footing at 1.2 m below the ground level. The unit weight of soil is 20 kN/m³. Use M20 grade concrete and Fe415 grade steel.**

**AKTU 2013-14, Marks 10**

**Answer**

**Given :** Axial load ($W$) = 1500 kN
Bearing capacity of soil = 100 kN/m²
Depth of base of footing = 1.0 m, Unit weight of soil ($\gamma$) = 20 kN/m³
$f_{ck}$ = 20 N/mm², $f_y$ = 415 N/mm²
**To Find :** Design square footing.

1. **Load Calculation :**

$$W_c = 1500 \text{ kN}$$

Self weight of footing = 10% × of $W_c$ = (10 / 100) × 1500 = 150 kN
Total weight = 1500 + 150 = 1650 kN

2. **Area of Footing :** Area = $\frac{\text{Total load}}{\text{Bearing capacity}} = \frac{1650}{100}$ = 16.5 m²

Weight of soil on footing = 20 × 1.2 × 16.5 = 396 kN

ii. Size of footing = $\sqrt{16.5}$ = 4.06 m

Provide 4.5 m size of square footing.



3. **Depth of Footing by One Way Shear Criterion :**

i. Net upward pressure,

$$p = \frac{1500}{4.5^2} = 74.074 \text{ kN/m}^2$$

ii. Critical section is at distance '$d$' away from the face of the column

Shear force, $V_u = 1.5 \times 74.074 \times 4.5 \left[\left(\frac{4.5 - 0.4}{2}\right) - d\right]$

$$= 500(2.05 - d) \quad ...(5.3.1)$$

iii. Assuming 0.2% steel, $\tau_c$ = 0.32 N/mm²

iv. Shear force resisted by the section = $\tau_c \times bd = 0.32 \times 10^3 \times 4.5 \times d$

$$= 1440\, d \quad ...(5.3.2)$$

v. Equating eq. (5.3.1) and eq. (5.3.2), we get

$$500(2.05 - d) = 1440\, d$$
$$d = 0.529 \text{ m} \quad ...(5.3.3)$$

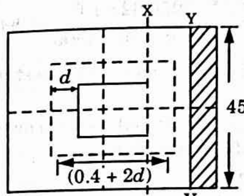



**Fig. 5.3.1.**

4. **Depth of Footing by Two Way Shear Criterion :**

i. Critical section is taken at a distance $d/2$ away from the face of column
ii. Perimeter of critical section = $4(0.4 + d) = 1.6 + 4d$
iii. Shear force at critical section = $1.5 \times 74.074\,(4.5^2 - (0.4 + d)^2)$

$$= 111.11\,(20.25 - (0.4 + d)^2)$$
$$2250 = 111.11(0.4 + d)^2 \quad ...(5.3.4)$$

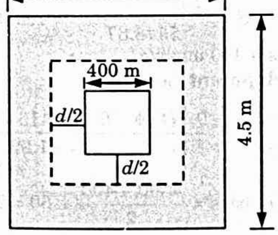



**Fig. 5.3.2.**

iv. Shear force resisted by the critical section maximum allowable shear stress = $0.25\sqrt{f_{ck}} = 0.25\sqrt{20}$

$= 1.118 \text{ kN/mm}^2 = 1118 \text{ N/mm}^2$

v. Shear force resisted = $1118(1.6 + 4d)d = 1788.8 + 4472d$

vi. Equating the eq. (5.3.3) and eq. (5.3.5), we get

$2250 - 111.11(0.4 + d)^2 = 1788.8\, d + 4472\, d^2$ ...(5.3.5)

$d = 0.522$ m

5. **Depth of Footing by Bending Moment Criterion :** ...(5.3.6)

i. Bending moment about an axis X-X pass through the face of column as shown in Fig. 5.3.1.

ii. BM at critical section, $M_u$

$$= 1.5 \times 74.074 \times 4.5 \times \frac{(4.5 - 0.4)^2}{8} = 1050.62 \text{ kN-m}$$

iii. The effective depth required,

$$M = 0.138 f_{ck} bd^2$$

or
$$d = \sqrt{\frac{1050.62 \times 10^6}{0.138 \times 20 \times 4500}} = 290.85 \text{ mm} \quad ...(5.3.7)$$

From eq. (5.3.3), (5.3.6) and (5.3.7) the highest value of $d$ obtained is 0.529 m

iv. Provide 550 mm effective depth and 600 mm overall depth. Increased depth is taken due to shear considerations.

6. **Area of Reinforcement :**

i. Area of tension steel is given by,

$$M = 0.87 f_y A_t \left(d - \frac{f_y A_t}{f_{ck} b}\right)$$

$$1050.62 \times 10^6 = 0.87 \times 415 \times A_t \left(550 - \frac{415 \times A_t}{20 \times 4500}\right)$$

$$A_{st} \approx 5548.87 \text{ mm}^2$$

ii. Use 16 mm $\phi$ bars,

Spacing, $$S = \frac{\frac{\pi}{4}(16)^2 \times 4500}{5548.87} = 163.06 \text{ mm}$$

Use 16 mm $\phi$ bars @ 160 mm c/c.

7. **Check for Development Length :**

$$L_d = \frac{0.87 f_y \phi}{4\tau_{bd}} = \frac{0.87 \times 415 \times 16}{4 \times 1.92} = 752.19 \text{ mm}$$

Available length of bars = $\frac{4500 - 400}{2} - 50 = 2000 \text{ mm} > 752.19$ mm

then safe

8. **Reinforcement Details :**



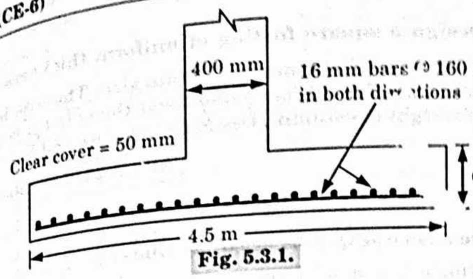



**Fig. 5.3.1.**

**Que 5.4.** **A square column 450 mm × 450 mm support an axial load 1600 kN. Design a square footing for the column. The safe bearing capacity of the soil in 250 kN/m². Use M25 concrete and Fe415 grade steel.**

**AKTU 2014-15, Marks 10**

**Answer**

**Procedure :** Same as Q. 5.3, Page 5–5A, Unit-5.

1. Provide size of footing is 2.7 m × 2.7 m
2. Net soil pressure, $p = 329.22 \text{ kN/m}^2$
3. Bending moment, BM = 562.5 kN-m
4. **Required Depth of Footing :**
   i. By one way action, $d = 0.537$ m
   ii. By two way action, $d = 0.465$ m
   iii. By bending moment, $d = 0.24$ m
   Provide 560 mm effective depth and 610 mm overall depth.
5. **Reinforcement :**
   i. Required, $A_{st} = 2873 \text{ mm}^2$
   ii. Provide 12 mm $\phi$ bar @ 100 mm c/c (Actual provide 3054 mm²)
6. **Development Length :**
   i. Required, $L_d = 483.6$ mm
   ii. Provided development length = 1075 mm
7. **Detailed Reinforcement :**

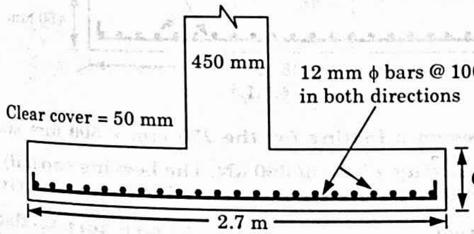



**Fig. 5.4.1.**

**Que 5.5.** Design a square footing of uniform thickness for an axially loaded column of 450 mm × 450 mm size. The safe bearing capacity of the soil is 190 kN/m². Load from the column is 850 kN (including self weight of column). Use M 20 concrete and Fe415 steel.

**AKTU 2017-18, Marks 10**

**Answer**

**Procedure :** Same as Q. 5.3, Page 5–5A, Unit-5.

1. Size of footing is 2.25 m × 2.25 m
2. Net soil pressure, $p_u$ = 251.85 kN/m²
3. Bending moment BM = 229.498 kN-m
4. **Required Depth of Footing :**
   i. By one way shear action $d$ = 0.396 m
   ii. By two way shear action $d$ = 0.367 m
   iii. By bending moment, $d$ = 0.192 m

   Provide the 400 mm effective depth and overall depth is 460 mm
5. **Reinforcement :**
   i. Required reinforcement, $A_{st}$ = 1652.03 mm²
   ii. Provide 16 mm $\phi$ bars @ 270 mm c/c in each direction.
6. **Development Length :**
   i. Required, $L_d$ = 752.2 mm
   ii. Provide, $L_d$ = 900 mm
7. **Detail Reinforcement :**

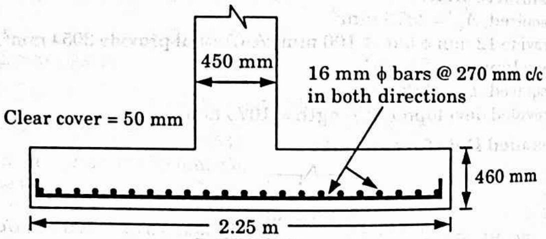



**Fig. 5.5.1.**

**Que 5.6.** Design a footing for the 250 mm × 500 mm size RCC column transmitting a load of 300 kN. The bearing capacity of soil to be taken as 90 kN/m² at 1.0 m below GL. Use M20 concrete and Fe415 grade steel.

**AKTU 2014-15, Marks 10**



**Answer**

**Given :** Size of column = 250 mm × 500 mm.
Load, $W_c$ = 300 kN, Bearing capacity, $q_u$ = 90 kN/m²
**To Find :** Design a footing.

1. **Loads :**
   i. Column load, $W_c$ = 300 kN
   ii. Weight of footings, $W_f$ = 10% of $W_c$ = 30 kN
   iii. Total load = 300 + 30 = 330 kN
2. **Area of Footing :**
   i. Area of footing, $A = \dfrac{W_c + W_f}{q_u} = \dfrac{330}{90} = 3.67\ \text{m}^2$
   ii. Considering length to width ratio of footing is same as that of column, *i.e.*, 2.
   iii.
$$y = 2x$$
$$\text{Area of footing} = x \times y = x \times 2x$$
$$3.67 = 2x^2$$
$$x = 1.35\ \text{m} \approx 1.36\ \text{m}$$
$$y = 2.72\ \text{m}$$
3. Soil pressure due to column load only,
$$p = \frac{300}{2.72 \times 1.36} = 81.09\ \text{kN/m}^2$$
4. Factored soil pressure = 1.5 × 81.09 = 121.65 kN/m²
5. **Calculation of Depth of Footing :**
   i. **By One Way Shear Criteria :**
   a. Critical section is at $d$ from face to column.
   b. SF in longer direction $= 121.65 \times 2.72 \times \left(\dfrac{1.36 - 0.250}{2} - d\right)$
$$= 183.64 - 330.88\,d$$
   c. Shear force in shorter direction
$$= 121.65 \times 1.36 \times \left(\frac{2.72 - 0.500}{2} - d\right)$$
$$= 183.64 - 165.44\,d \qquad ...(5.6.1)$$
   d. Shear force resisted by the concrete
$$= \tau_c x d$$
   (Assume 0.2 % steel, $\tau_c$ = 0.32 N/mm²)
$$= \frac{0.32}{10^3} \times 10^6 \times 1.36\,d = 435.2\,d \qquad ...(5.6.2)$$
   e. Now, equating the eq. (5.6.1) and (5.6.2), we get
$$183.64 - 165.44d = 435.2\,d$$
$$d = 0.306\ \text{m} \qquad ...(5.6.3)$$

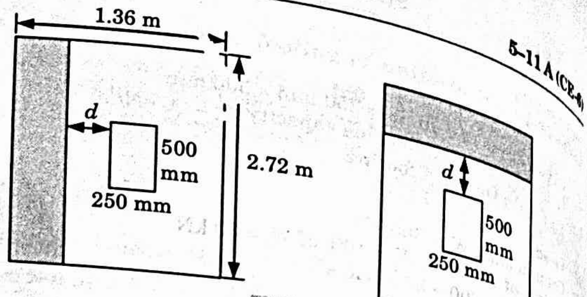



**Fig. 5.6.1.**

**ii. Depth of Footing by Two Way Shear Criteria :**

a. Critical section will occur at $d/2$ from face of column.

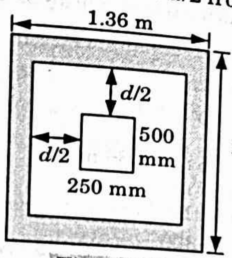



**Fig. 5.6.2.**

b. Shear force at critical section due to shaded area

$$= 121.65 \times [2.72 \times 1.36 - (0.250 + d) \times (0.500 + d)]$$
$$= 450 - 121.65\,(0.125 + 0.75\,d + d^2)$$
$$= 434.80 - 91.23\,d - 121.65\,d^2 \quad ...(5.6.4)$$

c. Punching shear resisted by section $= \tau_c \times A$

where,
$$\tau_c = 0.25\sqrt{f_{ck}} = 0.25\sqrt{20} = 1.12 \text{ N/mm}^2$$
$$A = [(0.25 + d) + (0.500 + d)] \times d$$
$$= (0.75 + 2d) \times d = 0.75d + 2d^2$$

d. Shear force resisted $= 1.12 \times \dfrac{10^6}{10^3} \times (0.75\,d + 2d^2)$

$$= 840\,d + 2240\,d^2 \quad ...(5.6.5)$$

Equating both eq. (5.6.4) and eq. (5.6.5), we get

$$434.80 - 91.23\,d - 121.65\,d^2 = 840\,d + 2240\,d^2$$
$$2361.65\,d^2 + 931.23\,d - 434.80 = 0$$
$$d = 0.275 \text{ m} \quad ...(5.6.6)$$

**iii. Depth of Footing by Bending Moment Criteria :**

a. Critical section is at the face of the column.

b. Bending moment in longer direction

$$= 121.65 \times 1.36 \times 1.11 \times 1.11/2 = 101.92 \text{ kN-m}$$





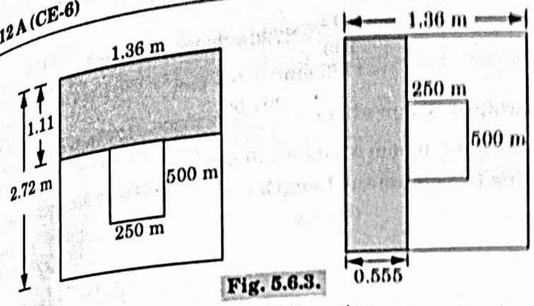



**Fig. 5.6.3.**

c. Bending moment in shorter direction

$$= 121.65 \times 2.72 \times \frac{(0.555)^2}{2} = 50.96 \text{ kN-m.}$$

Hence bending moment in longer direction is more.

d. Moment of resistance in longer direction,

$$M_r = 0.138\,f_{ck}\,bd^2$$
$$= 0.138 \times 20 \times 1360 \times d^2$$
$$101.92 \times 10^6 = 3753.6\,d^2$$
$$d = 164.78 \text{ mm} \approx 0.164 \text{ m} \quad ...(5.6.7)$$

From eq. (5.7.3), (5.7.6) and (5.7.7)

e. Hence, provide depth of footing,

$$d = 300 \text{ mm}$$

f. Using 16 mm diameter bars and 50 mm clear cover.

$$\text{Overall depth, } D = 300 + \frac{16}{2} + 50$$
$$= 358 \text{ mm say } 360 \text{ mm}$$

**6. Area of Reinforcement :**

**i. For Longer Direction :**

a.
$$M_u = 0.87\,f_y\,A_{st}\,d\left(1 - \frac{A_{st}\,f_y}{bd\,f_{ck}}\right)$$
$$101.92 \times 10^6 = 0.87 \times 415 \times A_{st} \times 300\left(1 - \frac{A_{st} \times 415}{1360 \times 300 \times 20}\right)$$
$$A_{st} = 990.9 \text{ mm}^2$$

b. Using 16 mm diameter bars,

$$\text{Spacing, S} = \frac{201.06}{990.9} \times 1000 = 203 \text{ mm} \approx 200 \text{ mm c/c}$$

**ii. For Shorter Direction :**

a.
$$50.96 \times 10^6 = 0.87 \times 415 \times A_{st} \times 300\left(1 - \frac{A_{st} \times 415}{2720 \times 300 \times 20}\right)$$
$$A_{st} = 465 \text{ mm}^2$$

b. Minimum reinforcement @ 0.12 %

$$= \frac{0.12}{100} \times 2720 \times 360 = 1175 \text{ mm}^2$$

$$= 1175 \text{ mm}^2 > 465 \text{ mm}^2$$

c. Spacing of 16 mm $\phi$ bars $= \frac{201.06}{1175} \times 1000 = 170$ mm c/c

d. Provide the 16 mm $\phi$ bars @ 170 mm c/c

7. **Check for Development Length :**

i. $L_d = \frac{087 f_y \phi}{4\tau_{bd}}$

where $\tau_{bd} = 1.92$ for M20.

$$L_d = \frac{0.87 \times 415 \times 16}{4 \times 1.92} = 752.2 \text{ mm}$$

ii. Available length in shorter direction.

$$= \frac{1360 - 170}{2} = 595 \text{ mm} < 752.2 \text{ mm}$$

iii. Provide standard U Type hook,
Anchorage value = 16 $\phi$ = 256 mm

iv. Hence, total anchorage length = 595 + 256 = 811 mm > 752.2 mm
Hence ok

8. **Reinforcement Details :**

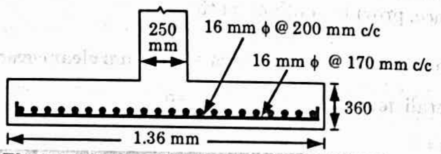



**Fig. 5.6.4.** Cross section along shorter direction.

## PART-3

*Design of Strip Footings.*

### CONCEPT OUTLINE

**Strip Footing :** It is a continuous footing provided under the masonry or concrete walls. The design of such footing is done by considering the footing to consist of cantilevers projecting out from the wall.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**



**Que 5.7.** **Design a footing of 250 mm the masonry wall which supports a load of 150 kN/m and moment of 15 kN-m at service state. Consider,**
**Unit weight of soil = 20 kN/m$^3$,**
**Angle of repose = 30°, Allowable bearing capacity of soil = 150 kN/m$^2$.**
**Use M 20 and Fe 415.**

**AKTU 2016-17, Marks 10**

**Answer**

**Given :** Thickness of wall = 250 mm = 0.25 m
Loading intensity = 150 kN/m, Moment = 15 kN-m
Unit weight of soil = 20 kN/m$^3$, Angle of repose = 30°
Allowable bearing capacity of soil = 150 kN/m$^2$
Use grade of concrete M 20 and Fe 415.
**To Find :** Design of footing.

1. **Size of Footing :**

i. Intensity of load, $W = 150$ kN/m

ii. Assume weight of foundation,

$$W' = 10 \% \text{ of } W = \frac{10 \times 150}{100} = 15 \text{ kN/m}$$

iii. Width of footing, $B = \frac{1.5 \times (150 + 15)}{150} = 1.65$ m

iv. Net upward pressure, $p = \frac{1.5 \times 150}{1.65} = 136.36 \text{ kN/m}^2 < 150 \text{ kN/m}^2$

2. **Section Design :**

i. Maximum bending moment occurs at a section X-X distance $b/4$ from the centre of the wall, and its magnitude is given by,

$$M = \left[\frac{B-b}{2} + \frac{b}{4}\right]^2 \text{ kN-mm}$$

$$M = \frac{136.36}{2} \times \left[\frac{1.65 - 0.25}{2} + \frac{0.25}{4}\right]^2 = 39.64 \text{ kN-m}$$

ii. Total moment = 1.5 × 15 + 39.64 = 62.14 kN-m

iii. Required depth, $d = \sqrt{\frac{62.14 \times 10^6}{1000 \times 2.76}} = 150$ mm

Provide a total depth 250 mm and cover equal to 50 mm. So that available effective depth,

$$d = 250 - 50 = 200 \text{ mm}$$

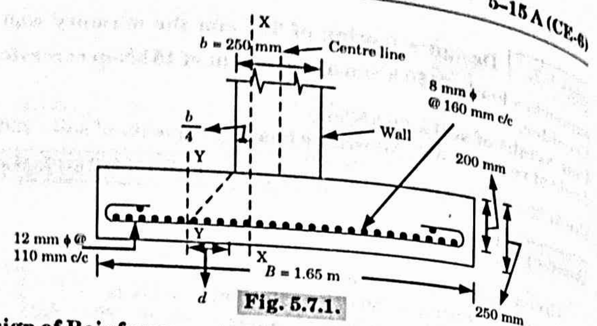



**Fig. 5.7.1.**

3. **Design of Reinforcement :**

i. Area of reinforcement,

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

$$62.14 \times 10^6 = 0.87 \times 415 \times A_{st}\left(200 - \frac{415 A_{st}}{20 \times 1000}\right)$$

$$A_{st} = 955.2 \text{ mm}^2$$

ii. Using 12 mm ϕ bars,

Area of 12 mm ϕ bars,

$$A_\phi = \frac{\pi}{4} \times 12^2 = 113.097 \text{ mm}^2$$

iii. Spacing, $S = \dfrac{1000 \times A_\phi}{A_{st}} = \dfrac{1000 \times 113.097}{955.2} = 118.4$ mm

iv. Hence, provide 12 mm ϕ bars @ 110 mm c/c.

v, $A_{st}$ provide = 1028.2 mm² (% of steel = $\dfrac{1028.2}{1000 \times 200} = 0.514\%$)

4. **Area of Transverse Reinforcement :**

= 0.12 % area of cross section of footing.

$$= \frac{0.12 \times 1000}{100} \times D = 1.2 \times 250 = 300 \text{ mm}^2$$

i. Let use 8 mm ϕ bars,

$$A_\phi = \frac{\pi}{4} \times (8)^2 = 50.265 \text{ mm}^2$$

ii. Spacing, $S = \dfrac{50.265 \times 1000}{300} = 167.55$ mm

Provide 8 mm ϕ bars @ 160 mm c/c.

5. **Check for Shear :**

i. For balanced section,

$p = 0.5$ % for M 20 concrete and Fe 415.



Hence, from IS code $\tau_c = 0.48$ N/mm². Also from IS code,

$k_s = 1.1$ for $D = 250$ mm.

Hence, permissible shear stress,

$= k_s \tau_c = 1.1 \times 0.48 = 0.528$ kN/mm²

ii. The critical section Y-Y lies at a distance of $d = 200$ m from the face of the wall, Hence, distance of Y-Y from the edge of the footing.

$= 1/2 \times (B - b) - d = 1/2 \times (1.65 - 0.25) - 0.12 = 0.5$ m

iii. Shear force, $V_u = 150 \times 10^3 \times 0.5 \approx 75$ kN/m

iv. Nominal shear stress,

$$\tau_v = \frac{V_u}{bd} = \frac{75 \times 10^3}{1000 \times 200} = 0.375 \text{ N/mm}^2 < \tau_c$$

Hence safe.

6. **Check for Development Length :**

i. For M 20 and Fe 415,

$$L_d = \frac{\phi(0.87 f_y)}{4 \tau_{bd}} = 47\phi = 47 \times 12 = 564 \text{ mm}$$

ii. Providing 50 mm side cover, length of bars available

$= (1/2) \times (B - b) - 50 = (1/2) \times (1650 - 250) - 50$

$= 650 \text{ mm} > L_d$

Hence safe.

**Que 5.8.** **Design a footing for the foundation of brick wall 400 mm thick and transmitting a load of 120 kN/m of its length. The bearing capacity of soil is 65 kN/m². The unit weight of earth is 17 kN/m³. Use M 20 grade concrete and Fe 415 grade steel.**

**AKTU 2013-14, Marks 10**

**Answer**

**Procedure :** Same as Q. 5.7, Page 5–14A, Unit-5.

1. Width of footing, $B = 3.05$ m
2. Net upward pressure, $p_u = 59.016$ kN/m²
3. Bending moment, BM = 59.92 kN-m
4. **Depth of Footing :**
   i. Required depth $d = 150$ mm
   ii. Provide depth $D = 250$ mm
5. **Reinforcement :**
   i. Required reinforcement, $A_{st} = 917.5$ mm²
   ii. Provided main reinforcement 12 mm ϕ bars @ 120 mm c/c
6. **Development Length :**
   i. Required $L_d = 564$ mm
   ii. Provided $L_d = 1375$ mm

7. **Detailed Reinforcement :**

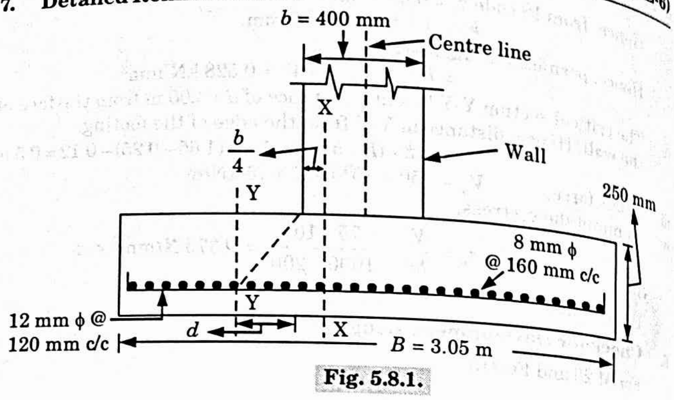



**Fig. 5.8.1.**

## PART-4

*Design of Combined Footings.*

### CONCEPT OUTLINE

**Principle of Design Combined Footing :** A combined footing may be rectangular or trapezoidal in shape. The basic principle of design of a combined footing is that the centre of gravity of the footing should coincide with the centre of gravity of the loads, which results in uniform base pressure distribution.

### Questions-Answers

**Long Answer Type and Medium Answer Type Questions**

**Que 5.9.** **Define the combined footing. Why are needed of combined footing ?**

**Answer**

**Combined Footings :** A footing that supports a group of columns is known as combined footing.

**Necessity :** Combined footings are needed for the following reasons :

1. When distance between two columns is small, the allowable bearing pressure on soil is lower and their isolated footings coincide with each other.



2. When a column is placed at the property line. If an isolated footing is tried, the c.g. of column load does not coincide with that of its footing. The eccentricity is so large that it produces negative pressure on the footing. Thus it is necessary to combine its footing with that of another suitable internal column, means provide combined footing.
3. When the dimensions of the footing is restricted to some lower value so that the footings of the columns coincide with each other.

**Que 5.10.** **Design a combined footing for two columns carrying axial loads of 500 kN and 800 kN. Both columns are 30 cm in diameter and are spaced at 3 m centre to centre. Columns are reinforced with 18 mm bars and consist of M 25 Grade. The bearing capacity of the soil is 80 kN/m². Use M 30 and Fe 415 grade steel.**

**AKTU 2016-17, Marks 10**

**Answer**

**Given :** Column size = 30 cm = 300 mm, Load on column – 1 = 500 kN
Load on column – 2 = 800 kN, Distance between two column = 3 m c/c.
Bearing capacity of soil = 80 kN/m²
Reinforcement bars diameter = 18 mm
**To Find :** Design a combined footing.

1. **Position of Resultant Load ($\bar{x}$) from Column $C_1$ :**

i. $$\bar{x} = \frac{P_2 \times l}{P_1 + P_2} = \frac{800 \times 3}{(500 + 800)} = 1.85 \text{ m}$$

ii. Length of footing = $2(\bar{x} + x') = 2(1.85 + 0.4)$

$l = 4.5$ m

[Let columns is apart 0.4 m from property line]

2. **Width of Footing ($B$) and Upward Pressure :**

i. Assuming self weight of footing = 10 % of total load

= (10 / 100) × (500 + 800) = 130 kN

ii. Total load, $P$ = 1300 + 130 = 1430 kN

iii. $$\text{Area of footing} = \frac{P}{q_0} = \frac{1430}{80} = 17.875 \text{ m}^2$$

iv. $$\text{Width of footing, } B = \frac{17.875}{4.5} = 3.97 \text{ m}$$

Adopt width of footing 4 m.

v. $$\text{Upward soil pressure} = \frac{\text{Total load}}{\text{Area of footing}} = \frac{1300}{4.5 \times 4} = 72.22 \text{ kN/m}^2$$

vi. Factored pressure = 1.5 × 72.22 = 108.33 kN/m²

vii. Upward soil pressure per unit length,

$$P_0 = 108.33 \times 4 = 433.32 \text{ kN/m}$$

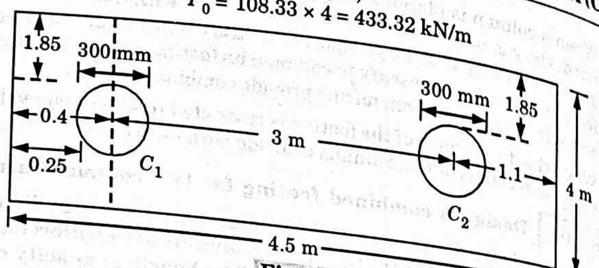



**Fig. 5.10.1.**

**3. Calculation of Moments and Shear Forces :** Fig. 5.10.1 shows the loading, SFD and BMD for slab footing :

i. SF at just right column $C_2$ $= 433.32 \times 1.1 = 476.652$ kN

ii. SF at just left column $C_2$ $= 476.652 - 1.5 \times 800 = -723.348$ kN

iii. SF at just left column $C_1$ $= -433.32 \times 0.4 = -173.328$ kN

iv. SF at just right column $C_1$ $= -173.328 + 1.5 \times 500 = +576.672$ kN

v. Point of zero shear force from column $C_2$

$$\frac{723.348}{x} = \frac{576.672}{3 - x}$$

$$x = 1.7 \text{ m}$$

**4. Calculation of Bending Moment :**

i. Moment at $C_1 = 433.32 \times 0.4^2 / 2 = 34.66$ kN-m

ii. Moment at $C_2 = 433.32 \times \dfrac{(1.1)^2}{2} = 262.16$ kN-m

iii. Maximum moment occurs at the point of minimum (zero) shear force,

$$M_{max} = 433.32 \times \frac{(1.7 + 1.1)^2}{2} - 1.5 \times 800 \times 1.7$$

$$M_{max} = -341.386 \text{ kN-m}$$

iv. Point of zero moment or point of contraflexure.

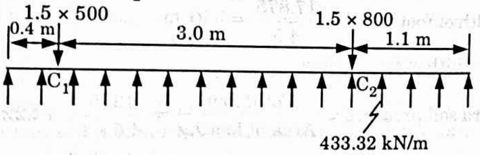
$$M_x = 0$$

$$M_x = 433.32 \times \frac{x^2}{2} - 1.5 \times 800 \times (x - 1.1)$$

$$0 = 216.66\,x^2 - 1200x + 1320$$

$$x_1 = 4.025 \text{ m}$$

$$x_2 = 1.514 \text{ m}$$





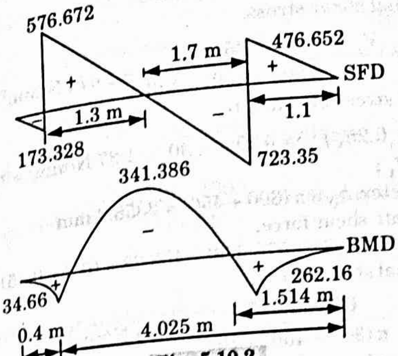




**Fig. 5.10.2.**

**5. Depth Required from Moment Consideration :**

$$M_u = 341.4 \times 10^6 \text{ N-mm}$$

$$d_{req} = \sqrt{\frac{341.4 \times 10^6}{2.76 \times 4000}} = 175.85 \text{ mm}$$

**6. One Way Shear at Column $C_2$ (Heavier load) :**

i. Shear at distance $d$ from face of column,

$$V_u = \left[723.35 - 433.32\left(0.15 + \frac{d}{1000}\right)\right] \times 10^3$$

ii. Assuming percentage of tensile steel as 0.2 %, stress in concrete,

$$\tau_c = 0.32 \text{ N/mm}^2$$

$$\frac{V_u}{bd} < 0.32 \text{ N/mm}^2$$

iii.

$$\frac{723.35 \times 10^3 - 65 \times 10^3 - 433.32 \times d}{4000 \times d} < 0.32$$

$$\frac{658.35 \times 10^3 - 433.32 \times d}{4000 \times d} < 0.32$$

$$658.35 \times 10^3 < 1713.32\, d$$

$$d > 384.25 \text{ mm}$$

Hence adopting a total depth of 500 mm, effective depth as 450 mm and checking for two way shear.

**7. Two Way Shear :** The critical section is at $d/2$ from the face of the column.

i. **Column $C_2$ :**

a. Area resisting punching shear [$b_0$ = perimeter]

$$= b_0 \times d = \pi\,(300 + 450) \times 450$$

b. Shear force at $\dfrac{d}{2}$, $V_u = 1200 - 108.33 \times (0.3 + 0.45)^2$

$V_u$ = 1139.06 kN

c. Nominal shear stress,

$$\tau_v = \frac{V_u}{b_o d} = \frac{1139.06 \times 10^3}{\pi(300 + 450) \times 450} = 1.074 \text{ N/mm}^2$$

d. Shear stress of concrete,

$$\tau_c = 0.25\sqrt{f_{ck}} = 0.25 \times \sqrt{30} = 1.37 \text{ N/mm}^2 > \tau_v \text{ (Hence safe)}$$

ii. **Column $C_1$ :**

a. Perimeter, $b_0 = \pi\,(300 + 450) = 2356.2$ mm

b. Ultimate shear force,

$$V_u = (173.328 + 576.672) - 108.33 \times (0.3 + 0.45)^2 = 689.06 \text{ kN}$$

c. Nominal shear stress,

$$\tau_v = \frac{689.06 \times 10^3}{\pi\,(300 + 450) \times 450} = 0.65 \text{ N/mm}^2 < \tau_c$$

Hence safe.

8. **Longitudinal Reinforcement :**

i. **Negative Moment Reinforcement :**

a. $M_{max}$ = 341.4 kN-m

$$341.4 \times 10^6 = 0.87 \times 415 \times A_{st} \times 450\left(1 - \frac{415 \times A_{st}}{30 \times 4000 \times 450}\right)$$

$$A_{st} = 2136.36 \text{ mm}^2$$

b. Minimum reinforcement

$$A_{st,\,min} = \frac{0.12 \times 4000 \times 450}{100} = 2160 \text{ mm}^2$$

c. Using 18 mm diameter bars.

$$A_\phi = (\pi / 4) \times 18^2 = 254.47 \text{ mm}^2$$

d. Spacing required, $S = \dfrac{254.47 \times 4000}{2160} = 471.24$ mm

Hence provide 18 mm ϕ bars @ 300 mm c/c in all length.

ii. **Positive Moment Reinforcement :**

a. $M_u$ = 262.16 kN-m

$$262.16 \times 10^6 = 0.87 \times 415 \times A_{st} \times 450\left(1 - \frac{415\, A_{st}}{30 \times 4000 \times 450}\right)$$

$$A_{st} = 1634 \text{ mm}^2 < A_{st,\,min} = 2160 \text{ mm}^2$$

b. Hence provide 18 mm ϕ bars @ 300 mm c/c.

9. **Transverse Reinforcement :** The transverse reinforcement is provided under each column within a band having a width equal to the width of the column plus two times the effective depth of the foundation.

i. **Column-2 :**

a. Bandwidth for column $C_2$ = 0.3 + 0.45 + 0.45 = 1.2 m

b. Upward pressure = 1200 / 4 = 300 kN/m

c. Negative moment at a face of the column $C_2$

$$= 300 \times \frac{(1.85)^2}{2} = 513.375 \text{ kN-m}$$





d. Area of reinforcement is given by,

$$513.375 \times 10^6 = 0.87 \times 415 \times A_{st} \times 450\left(1 - \frac{415 \times A_{st}}{30 \times 1200 \times 450}\right)$$

$$A_{st} = 3467.84 \text{ mm}^2$$

e. $$A_{st\,min} = \frac{0.12 \times 1200 \times 500}{100} = 720 \text{ mm}^2$$

f. Spacing required, $S = \dfrac{254.47 \times 1200}{3467.84} = 88.05$ mm

$$\left[A_\phi = \frac{\pi}{4} \times 18^2 = 254.47 \text{ mm}^2\right]$$

Hence provide 18 mm ϕ bars @ 80 mm c/c.

ii. **Column-1 :**

a. Bandwidth = 0.3 + 0.45 + 0.25 = 1.0 m

[On the outer side only 0.25 m length available]

b. Upward pressure under column $C_1 = \dfrac{750}{4} = 187.5$ kN/m

c. BM at the face of the column

$$= 187.5 \times \frac{(1.85)^2}{2} = 320.86 \text{ kN-m}$$

d. Area of steel required

$$320.86 \times 10^6 = 0.87 \times 415 \times A_{st} \times 450 \times \left(1 - \frac{415 \times A_{st}}{30 \times 1000 \times 450}\right)$$

$$A_{st} = 2112 \text{ mm}^2$$

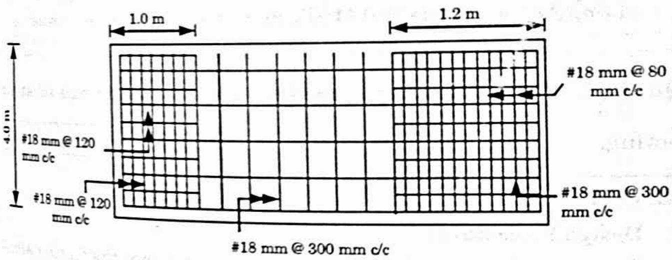
$$A_{st\,min} = \frac{0.12 \times 1000 \times 500}{100} = 600 \text{ mm}^2$$

e. Provide 18 mm ϕ bars,

Spacing, $S = \dfrac{254.47 \times 1000}{2112} = 120.5$ mm

Hence, provide 18 mm ϕ bars @ 120 mm c/c.

10. **Reinforcement Details :**




Plan of bottom reinforcement

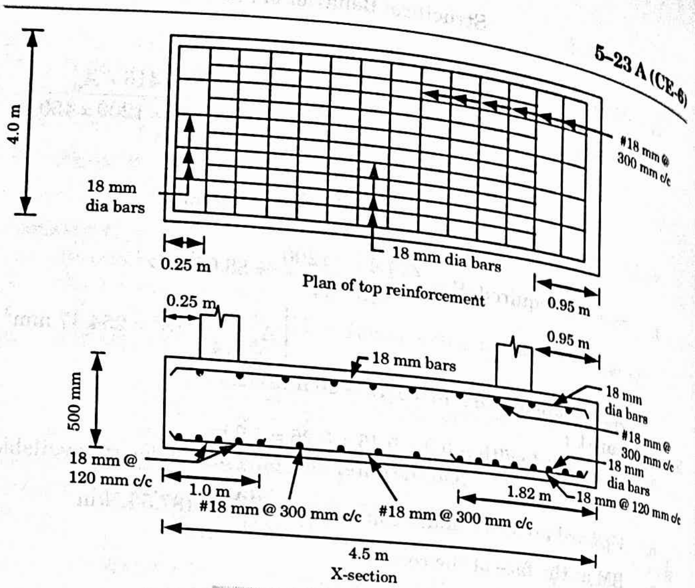



**Fig. 5.10.3.** Plan of reinforcement.

## PART-5

*Design of Strap Footing.*

### CONCEPT OUTLINE

**Strap Footing :** It is a special type of combined footing used for two columns. In this type of footing, the two columns have their separate footings which are connected by a rigid beam called as strap beam.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 5.11.** **Write down the procedure involved in design of strap footing.**

**AKTU 2015-16, Marks 10**

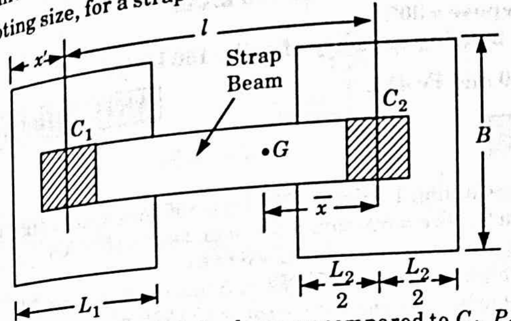
**Answer**

**Design Procedure :**

1. The basic principle of design of a strap footing is that the footing areas under the columns are proportioned such that the pressure under the two footings is equal and uniform and the centre of gravity of the loads coincides with the centre of gravity of the footings.



2. The strap beam is a rigid beam and does not transfer any load directly to the soil. It helps in transferring the load from one column to other so that uniform pressure distribution is obtained under both footing.
3. The footing size, for a strap footing, calculated as given below :




Note : $C_2$ is heavily loaded column as compared to $C_1$, $P_2 > P_1$

**Fig. 5.11.1.**

i. The distance of resultant of loads from $C_2$

$$\bar{x} = \frac{P_1 l}{P_1 + P_2} \quad ...(5.11.1)$$

ii. Taking moment of the areas of footing at column $C_2$

$$A_1\left(l + x' - \frac{L_1}{2}\right) = A\,\bar{x} \quad ...(5.11.2)$$

where, $A_1 = BL_1$ (Area of footing under column $C_1$)

$l$ = Distance between two columns.

$x'$ = Distance of column $C_1$ from footing edge or property line.

$A$ = Total area of both the footings.

$A = B(L_1 + L_2)$

iii. By eq. (5.12.1) and (5.12.2), $L_1$ can be calculated and knowing $A$, $L_2$ can be calculated.

5. Following are the steps of design of strap footing :
   i. Proportion the footing ($B$, $L_1$, $L_2$) as given above at service loads.
   ii. Calculate factored net soil pressure under the footings.
   iii. Determine the shear force and moment values at all critical sections.
   iv. Check the depth required from maximum moment and shear criteria.
   v. Design the reinforcement for footing.
   vi. Determine the maximum moment and maximum shear force values for the strap beam.
   vii. Check the depth required and design reinforcement.
   viii. Check bearing strength of column and footing.

**Que 5.12.** **Design a strap footing for two columns spaced at 6 m c/c face of one of the column of section 400 mm × 400 mm and subjected to a load of 1000 kN at service coincides with the property line and other column is of section 500 mm × 500 mm and subjected to a load of 1500 kN at service state.**
**Consider, Unit weight of soil = 15 kN/m³**
**Angle of repose = 30°**
**Allowable bearing capacity of soil = 150 kN/m²**
**Grade M 20 and Fe 415.**

**AKTU 2016-17, Marks 10**

**Answer**

**Given :** Column 1 : Size = 400 mm × 400 mm, load = 1000 kN
Column 2 : Size = 500 mm × 500 mm, load = 1500 kN
Spacing between two column = 6 m c/c
Unit weight of soil, $\gamma$ = 15 kN/m³, Angle of repose, $\phi$ = 30°
Allowable bearing capacity of soil = 150 kN/m²
Grade M 20 and Fe 415
**To Find :** Design the strap footing.

1. **Size of Footing :**

i. Assuming 10 % self weight of footing.

ii. Total load,
$$P_u = P_1 + P_2 = 1000 + 1500 = 2500 \text{ kN}$$

iii. Area of footing required $= \dfrac{2500 + 250}{150} = 18.33 \text{ m}^2$

iv. Assuming,
$$B = 3 \text{ m}$$
$$B(L_1 + L_2) = 18.33 \text{ m}^2$$
$$L_1 + L_2 = 6.11 \text{ m}$$

v. Distance of resultant of load from $C_2$,
$$\bar{x} = \frac{p_1 l}{p_1 + p_2} = \frac{1000 \times 6}{2500} = 2.4 \text{ m}$$

vi. Moment area of column $C_2$,
$$A\bar{x} = A_1\left(l + x' - \frac{L_1}{2}\right) = BL_1\left(l + x' - \frac{L_1}{2}\right)$$
$$\bar{x} = \frac{3 \times L_1\left(6 + 0 - \dfrac{L_1}{2}\right)}{18.33} = 2.4 \text{ m}$$
$$18L_1 - 1.5L_1^2 = 44$$
$$1.5L_1^2 - 18L_1 + 44 = 0$$
$$L_1 = 3.418 \approx 3.5 \text{ m}$$
$$L_1 + L_2 = 6.11$$
$$L_2 = 6.11 - 3.5 = 2.61 \text{ m} \approx 2.6 \text{ m}$$



2. *Design of Slab Footing Under Columns :*

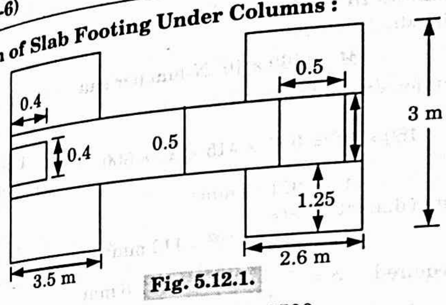



**Fig. 5.12.1.**

i. Soil pressure $= \dfrac{P_u}{A} = \dfrac{1.5 \times 2500}{3 \times (3.5 + 2.6)}$
$$= 204.9 \text{ kN/m}^2$$

ii. Assuming the width of strap footing to be equal to column-2 *i.e.*, 500 mm.

iii. Cantilever projection of slab $= \dfrac{3 - 0.5}{2} = 1.25$ m

iv. Maximum moment at the face of strap beam,
$$M_u = 204.9 \times \frac{(1.25)^2}{2} = 160 \text{ kN-m}$$

v. Depth required from moment criteria,
$$d_{req} = \sqrt{\frac{M_u}{R \times b}} = \sqrt{\frac{160 \times 10^6}{2.76 \times 1000}} = 240.77 \text{ mm}$$

Provide the depth, $d$ = 250 mm

3. **Depth Required from One Way Shear Criteria : Critical section for** shear force is at distance $d$ from the face of the strap beam :

i. Factored shear force, $V_u = 204.9\left(1.25 - \dfrac{d}{1000}\right)$ kN

ii. Shear stress in concrete,
Assuming 0.2 % steel, $\tau_c$ = 0.32 N/mm²

iii. Nominal shear stress, $\tau_v = \dfrac{V_u}{bd} = \dfrac{204.9\left(1.25 - \dfrac{d}{1000}\right) \times 1000}{1000 \times d}$

iv. Assuming
$$\tau_v < \tau_c$$
$$\frac{204.9\left(1.25 - \dfrac{d}{1000}\right) \times 1000}{1000 \times d} = 0.32$$
$$256.125 - 0.2049d = 0.32\,d$$
$$d_{req.} = 488 \text{ mm}$$

Hence providing overall depth as 550 mm, effective cover = 50 mm
Effective depth, $d$ = 500 mm

4. **Reinforcement in Footing Slab :**

i. Factored bending moment,

$$M_u = 160 \times 10^6 \text{ N-mm per run}$$

ii. Area of reinforcement is given by,

$$160 \times 10^6 = 0.87 \times 415 \times A_{st} \times 500 \left(1 - \frac{415 \times A_{st}}{20 \times 1000 \times 500}\right)$$

$$A_{st} = 921.54 \text{ mm}^2$$

iii. Using 12 mm diameter bars,

$$A_\phi = (\pi/4) \times 12^2 = 113 \text{ mm}^2$$

iv. Spacing required, $S = \dfrac{113 \times 1000}{921.54} = 122.6$ mm

v. Hence provide 12 mm $\phi$ bars @ 120 mm c/c.

vi. $$A_{st,\ provide} = \frac{113 \times 1000}{120} = 941.67 \text{ mm}^2$$

vii. Percentage of steel, $p_t = \dfrac{941.67 \times 100}{1000 \times 500} = 0.19\ \%$

Hence increasing $p_t$ to 0.2 % to satisfy shear criteria and providing 12 mm $\phi$ bars @ 120 mm c/c.

viii. Distribution steel = 0.12 % of cross sectional area

$$= \frac{0.12 \times 1000}{100} \times 550 = 660 \text{ mm}^2$$

ix. Using 12 mm diameter bars,

Spacing, $S = \dfrac{113 \times 1000}{660} = 171.2$ mm

Hence, providing 12 mm $\phi$ bars @ 170 mm c/c.

5. **Bending Moment and Shear Force Diagrams for Strap Beam:**

The loading, BMD and SFD for the strap beam is shown is Fig. 5.13.2.

i. Upward load per metre run, on the strap, $w = 204.9 \times 3 = 614.9$ kN/m

ii. Downward load intensity under column $A$, $w_1 = \dfrac{1.5 \times 1000}{0.4}$

$= 3750$ kN/m

iii. Downward load intensity under column $B$, $w_2 = \dfrac{1.5 \times 1500}{0.5}$

$= 4500$ kN/m

iv. SF at inner face of column $A$, $F_1 = 3750 \times 0.4 - 614.9 \times 0.4 = 1254.04$ kN

v. SF at edge $D$, $F_2 = 614.9 \times 3.5 - 1.5 \times 1000 = 652.15$ kN

vi. SF at edge $C = 652.15$ kN

vii. SF at inner edge of column $B = 652.15 + 614.9\ [(1/2) \times (2.6 - 0.5)]$

$= 1297.8$ kN

viii. SF at outer edge of column $B = 1.5 \times 1500 - 1297.8 - (614.9 \times 0.5)$

$= 644.75$ kN

ix. In the range $FD$, shear force is zero at distance $x_1$ from inner face of column $A$, its value being given by,



$$x_1 = \frac{1254.04}{614.9} = 2.04 \text{ m}$$

x. Hogging bending moment will be maximum at this section $x$, its values being given by,

$$M_1 = (3750 \times 0.4)(2.04 + 0.2) - 614.9 \times \frac{(0.4 + 2.04)^2}{2} = 1529.6 \text{ kN-m}$$

xi. Hogging BM at edge $D$ is given by,

$$M_2 = (3750 \times 0.4)(3.5 - 0.2) - 614.9 \times \frac{(3.5)^2}{2} = 1183.7 \text{ kN-m}$$

xii. Sagging BM at the outer face of column $B$ is given by,

$$M_3 = \frac{614.9}{2}\left[\frac{1}{2}(2.6 - 0.5)\right]^2 = 338.96 \text{ kN-m}$$

xiii. Let the point of contraflexure occur at $x_2$ from point $A$

$$M_x = 0 = 614.9\left(\frac{x_2^2}{2}\right) - (4500 \times 0.5)(x_2 - 1.3)$$

$$307.45\ x_2^2 - 2250\ x_2 + 2925 = 0$$

$$x_2 = 1.7 \text{ m}$$

xiv. Shear force at the point of contraflexure is given by,

$$F_5 = (4500 \times 0.5) - (614.9 \times 1.7) = 1204.67 \text{ kN}$$

6. **Depth of Strap Beam :**

$$d_{raq} = \sqrt{\frac{1529.6 \times 10^6}{2.76 \times 500}} \approx 1052.8 \text{ mm}$$

Hence providing a total depth of beam, $D = 1100$ mm as the depth required from shear criteria will be larger effective depth,

$$d = 1100 - \text{effective cover}$$

$$= 1100 - 50 = 1050 \text{ mm}$$

7. **Area of Steel Required :**

i. $$1529.6 \times 10^6 = 0.87 \times 415 \times A_{st} \times 1050 \times \left(1 - \frac{415 \times A_{st}}{20 \times 500 \times 1050}\right)$$

$$A_{st} = 5037.94 \approx 5038 \text{ mm}^2$$

ii. Providing 28 mm diameter bars,

$$A_\phi = (\pi/4) \times 28^2 = 615.75 \text{ mm}^2$$

iii. Number of bars required $= \dfrac{5038}{615.75} \approx 8.18 \approx 9$

Hence provide 9 bars of 28 mm diameter at bottom portion of the beam in all length.

iv. $$A_{st,\ provided} = 9 \times \frac{\pi}{4}(28)^2 = 5541.7 \text{ mm}^2$$

v. Minimum, $A_{st} = \dfrac{0.85\,bd}{f_y} = \dfrac{0.85 \times 500 \times 1050}{415}$

$= 1075.3 \text{ mm}^2 < 5541.7 \text{ mm}^2$ (Hence safe)

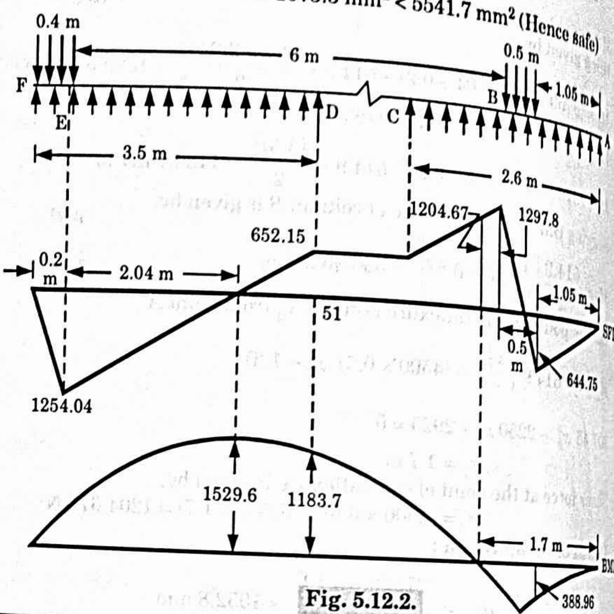



Fig. 5.12.2.

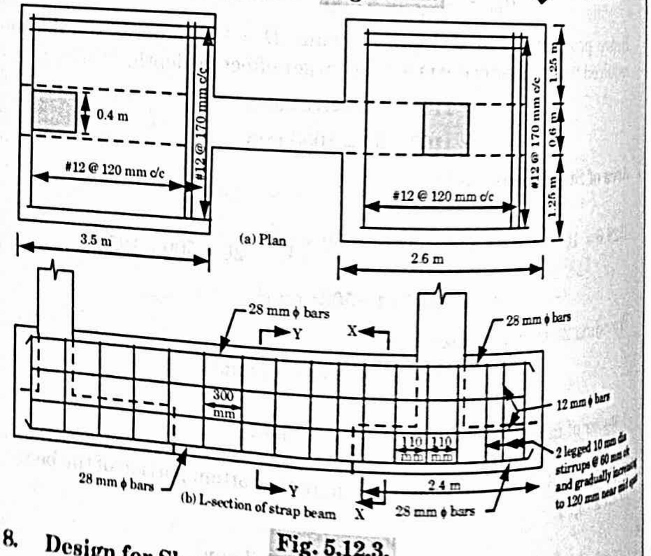



Fig. 5.12.3.

**8. Design for Shear :**

i. The critical section for shear is at the left face of column-2





$V_u = 1297.8$ kN

ii. Nominal shear stress, $\tau_v = \dfrac{V_u}{bd} = \dfrac{1297.8 \times 10^3}{500 \times 1050} = 2.47 \text{ N/mm}^2$

iii. Percentage of steel, $p_t = \dfrac{5541.7 \times 100}{500 \times 1050} = 1.05\%$

iv. From table 19 of IS 456,

$\tau_c = 0.60 \text{ N/mm}^2$

$\tau_v > \tau_c$. Hence, shear reinforcement is necessary

v. $V_{us} = 1297.8 \times 10^3 - 0.6 \times 500 \times 1050$

$V_{us} = 982800$ N

vi. Using 2-legged 10 mm diameter stirrups

$A_{sv} = 2 \times 78.5 \text{ mm}^2$

vii. Spacing, $S_v = \dfrac{0.87\, f_y\, A_{sv} d}{V_{us}}$

$S_v = \dfrac{0.87 \times 415 \times 2 \times 78.5 \times 1050}{982800} = 60.56 \text{ mm}$

Hence, provide 2-legged 10 mm diameter @ 60 mm c/c at supports and gradually increasing to 120 mm c/c towards the centre of the beam.

## PART-6

### *Structural Behaviour of Retaining Wall.*

### CONCEPT OUTLINE

**Retaining Walls :** These are used to retain earth or other loose materials. These walls are commonly constructed in the following cases :

i. In the construction of building basements.
ii. As wing wall or abutment in the bridge construction.
iii. In the construction of embankments.

**Types of Retaining Walls :** Following are the common types of retaining walls :

i. Gravity retaining wall.
ii. Cantilever retaining wall.
iii. Counterfort retaining wall.
iv. Buttress retaining wall.

### Questions-Answers

### Long Answer Type and Medium Answer Type Questions

**Que 5.13.** Define the retaining wall. Give a brief classification of retaining walls.

**Answer**

**Retaining Wall :** It is a structure which is constructed to retain or support earth or some other material in a relatively vertical position on one or both sides of it at different heights.

**Types of Retaining Walls :** Following are the various types of retaining walls :

1. **Gravity Wall :**
   i. Gravity wall is usually a plain concrete or masonry wall.
   ii. The dead weight in such a structure is a major factor providing stability against overturning and horizontal sliding under the action of lateral earth pressure.
   iii. The dimensions of wall are so proportioned that there is no tension induced in the wall *i.e.*, the resultant of forces remain within the middle third of the base.
   iv. It is used for walls up to about 3 m height.

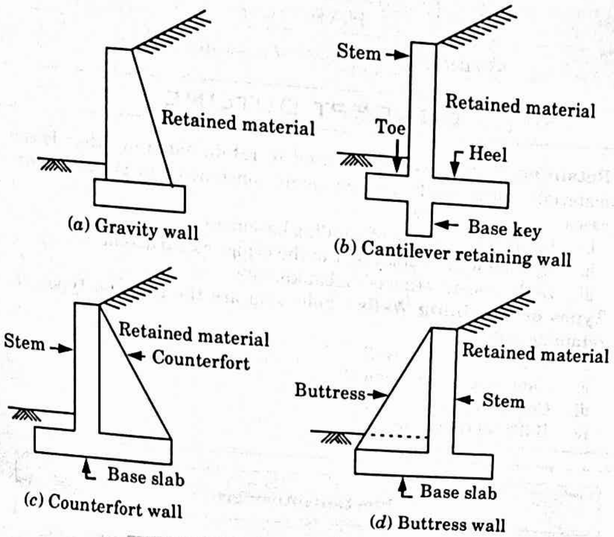



**Fig. 5.13.1.** Types of retaining wall.



2. **Cantilever Wall :**
   i. This retaining wall is commonly used for 3 m to 8 m height. It consists of three cantilever slabs known as stem, heel and toe.
   ii. The wall may be inverted T-shaped or L-shaped where toe projection is missing.
   iii. The stem acts as a vertical cantilever and stability is provided by the weight of earth on base slab and self weight of the wall.
   iv. Sometimes a key is provided in base slab for stability against sliding.
3. **Counterfort Wall :**
   i. In the counterfort wall, the stem and the base slab are tied together by counterforts.
   ii. A counterfort is a transverse wall spaced at intervals which ties the stem and the base slab. Because of the counterfort, the stem is supported on three sides by counterforts and base slab.
   iii. In this wall, the stability is provided by the weight of the earth on base. Counterfort walls are used for heights over about 6 m.
4. **Buttress Wall :** This is similar to counterfort wall. The buttresses are provided similar to the counterfort, but on opposite side to the retained material and act as compression struts.

**Que 5.14.** Describe the structural behaviour of retaining wall.

**Answer**

Consider the Fig. 5.14.1 showing a cantilever retaining wall subjected to a lateral force $P_{ah}$.

1. **Stem :**
   i. The vertical wall or stem acts like a cantilever subjected to a triangular loading as shown in Fig. 5.14.1 with maximum pressure developed at the base. The base of the stem is subjected to maximum bending moment ($M_B = k_a \gamma h^3/6$).
   ii. The stem of the retaining wall deflects as shown in the Fig. 5.14.1, developing tension on the face *AB*, retaining the earth.
2. **Heel Slab :**
   i. The heel slab is subjected to an upward soil pressure and a downward pressure due to the weight of the backfill supported on heel as shown in Fig. 5.14.1.
   ii. The resultant pressure is calculated by subtracting these two and is downward as the pressure due to weight of backfill is more than the upward soil pressure. This causes tension on the top face *i.e.*, *BC*.
3. **Toe Slab :**
   i. The toe slab is also subjected to an upward soil pressure and a downward pressure due to the weight of the front fill supported on toe slab as shown in Fig. 5.14.1.

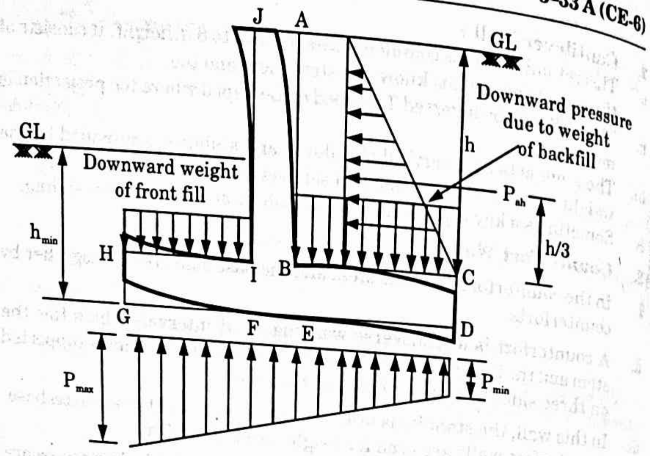



Fig. 5.14.1.

ii. The weight of the front fill is very small and hence neglected so the resultant pressure on the toe slab is upward which causes tension on the bottom face of the toe slab *i.e.*, *GF*.

## PART-7

*Stability of Retaining Wall.*

### CONCEPT OUTLINE

**Stability of a Cantilever Retaining Wall :**

A cantilever retaining wall may fail in the following ways :

i. Overturning. ii. Sliding. iii. Failure of the undersoil.

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 5.15.** **Discuss the stability requirements of a retaining wall in terms of stabilizing moment, overturning moment, and factor of safety.**

**Answer**

**Stability Requirements :** Fig. 5.15.1 shows the forces act on a retaining wall. The following requirements should be compiled for the stability of a retaining wall :



The restoring moment (stabilizing moment) should be more than the overturning moment so as to get a factor of safety not less than 1.55.

1. **Stabilizing Moment :**
   i. The sum of vertical loads $\Sigma W$ is composed of weight of backfill on the heel, the vertical component of earth pressure $p_{av}$ when backfill is inclined, and the dead weight of wall itself.
   ii. If the centre of gravity of $\Sigma W$ is at $x_1$ from the toe of the footing, the stability moment is given by $\Sigma W x_1$.
2. **Overturning Moment :**
   i. The overturning force is composed of active earth pressure and pressure due to surcharge if any.
   ii. It is equal to $p_{ah}$, the horizontal component of earth pressure. The overturning moment is given by $= p_{ah} \times \dfrac{H}{3}$.

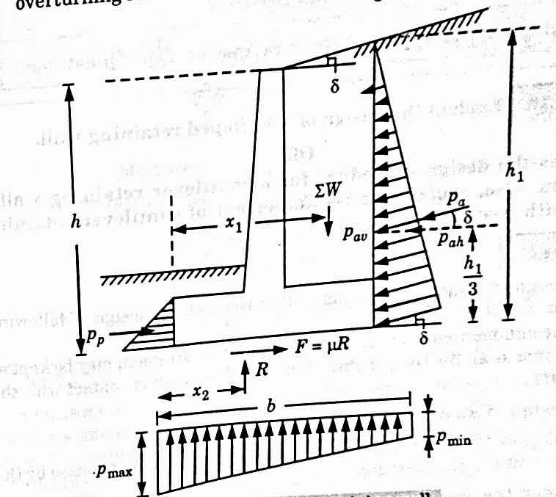



Fig. 5.15.1. Forces on retaining wall.

3. **Factor of Safety :**
   i. According to clause 20.1 of IS : 456-2000. 'The stability of a structure as a whole against overturning shall be ensured so that the restoring moment shall not be less than the sum of 1.2 times the maximum overturning moment due to characteristic dead load and 1.4 times the maximum overturning moment due to the characteristic imposed loads.
4. The vertical pressure on the soil under the base should not exceed the permissible bearing pressure on soil.

5. The restoring force against sliding should not be more than sliding force so as to get a factor of safety not less than 1.55.

## PART-8
### *Design of Cantilever Retaining Wall.*

**CONCEPT OUTLINE**

**Design of Cantilever Retaining Wall :** Following are the part design in cantilever retaining wall :
i. Stem ii. Toe slab iii. Heel slab

**Questions-Answers**

**Long Answer Type and Medium Answer Type Questions**

**Que 5.16.** **Explain the design of a T-shaped retaining wall.**

**OR**

**What is the design procedure for a cantilever retaining wall ? Explain. Also, explain the reinforcement of cantilever retaining wall with neat sketches.**

**Answer**

Design of T-shaped retaining wall consists of the design of following four terms :

The minimum concrete cover to the main reinforcement may be kept as 40 mm as all the components of the wall are in direct contact with the earth.

1. **Design of Stem :**
   i. Calculate the maximum bending moment and shear force caused by the horizontal earth pressure.
   ii. Design the wall for moment steel which may be curtailed where not required for flexure if rules for curtailment are satisfied.
   iii. The horizontal secondary reinforcement is provided (0.15 percent for mild steel and 0.12 percent for HYSD bars) at the inner face of the wall.
   iv. At the external face, the reinforcement should be provided horizontally and vertically.
2. **Design of Heel :** The heel is subjected to an upward soil pressure and downward weight of earth above it. The net pressure on heel acts in downward direction causing tension at top face of the heel. The reinforcement is designed for this moment.



3. **Design of Toe :** The moment due to earth pressure causes tension at the bottom face of the toe. Here the weight of the front fill may reduce the moment, but this will not be taken into account as the front fill may get scoured or may be excavated. The reinforcement for toe is designed at the bottom face.
4. **Base Key :** The dimensions of base key are calculated considering stability requirements. It is a practice to extend temperature bars of stem into the key.
5. **Design of T-shaped Retaining Wall :**

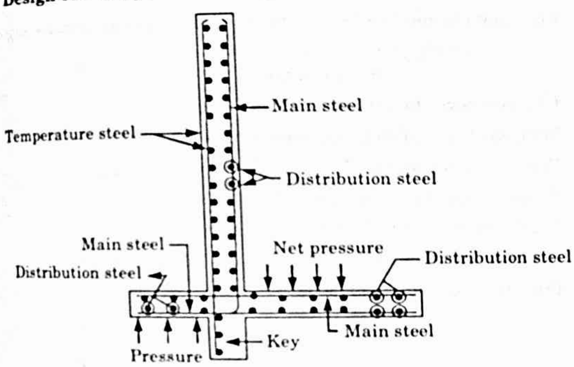



**Fig. 5.16.1.** Reinforcement details of cantilever wall.

**Que 5.17.** **Desgin a cantilever retaining wall to retain earth embankment 4 m high above GL. The density of earth is 18 kN/m$^3$ and its angle of repose is 30°. The embankment is horizontal at its top. The safe bearing capacity of the soil may be taken as 200 kN/m$^2$ and the co-efficient of friction between the soil and concrete is 0.5. Adopt M20 grade of concrete and Fe 415 HYSD bars.**

**AKTU 2015-16, Marks 10**

**Answer**

**Given :** Height of embankment = 4 m
Density of earth = 18 kN/m$^3$, Angle of repose = 30°
Bearing capacity of soil = 200 kN/m$^2$, Coefficient of friction = 0.5
**To Find :** Design of retaining wall.

1. **Wall Proportions :**

i. Thickness of the stem at the top = 200 mm

ii. Maximum bending moment per metre run of the wall,

$$M = k_p \frac{\gamma h^3}{6}$$

$$k_p = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 30^\circ}{1+\sin 30^\circ} = \frac{1}{3}$$

$$M = \frac{1}{3} \times 18 \times \frac{(4)^3}{6} = 64 \text{ kN-m}$$

iii. Equating the moments of resistance to the maximum bending moment,

$$0.138 f_{ck} bd^2 = 1.5 \times 64 \times 10^6$$

$$d = 186.5 \text{ mm}$$

Effective cover to reinforcement = 40 mm

iv. Total thickness of stem required = 190 + 40 = 230 mm

Provide a thickness of 350 mm at bottom of the stem.

v. The base slab thickness also will be 350 mm.

vi. Total height of wall, $H = 4 + 0.350 = 4.35$ m

vii. Width of base slab, $b = 0.5H$ to $0.6H = 2.175$ to $2.61$ m

Provide a base width of 2.50 m.

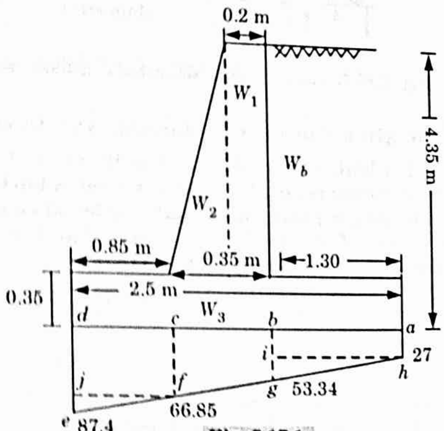



**Fig. 5.17.1.**

viii. **Toe Projection :** This may be made about one-third the base width.

$$\text{Toe width} = \frac{2.50}{3} = 0.83 \approx 0.85 \text{ m}$$



2. Stability Calculations for One Metre Length of Wall :

| Load due to | Magnitude (kN) | Distance from a (m) | Moment about a (kN-m) |
|---|---|---|---|
| $W_1 = 0.20 \times 4 \times 25$ | 20 | 1.40 | 28 |
| $W_2 = \frac{0.15 \times 4}{2} \times 25$ | 7.5 | 1.55 | 11.625 |
| $W_3 = 2.5 \times 0.35 \times 25$ | 21.875 | 1.25 | 27.35 |
| $W_b = 1.3 \times 4 \times 18$ | 93.6 | 0.65 | 60.84 |
| Moment of lateral pressure $= k_p \frac{\gamma H^3}{6} = \frac{1}{3} \times 18 \times \frac{(4.35)^3}{6}$ | | | 82.32 |
| Total | 142.975 | | 210.135 |

3. Distance from the point of application of the resultant force from the heel end $a$.

$$\bar{x} = \frac{\text{Bending moment}}{\text{total load}} = \frac{210.135}{142.975}$$

$$\bar{x} = 1.47 \text{ m}$$

4. Eccentricity,

$$e = \bar{x} - \frac{b}{2} = 1.47 - \frac{2.5}{2} = 0.22 \text{ m}$$

But

$$\frac{b}{6} = \frac{2.5}{6} = 0.41 \text{ m}$$

$\therefore$ $e < b/6$

5. Extreme pressure intensity at the base,

$$P = \frac{W}{b}\left(1 \pm \frac{6e}{b}\right) = \frac{142.975}{2.5}\left(1 \pm \frac{6 \times 0.22}{2.5}\right)$$

$$p_{max} = 87.4 \text{ kN/m}^2$$

$$p_{min} = 27 \text{ N/m}^2$$

Safe bearing capacity = 200 kN/m²

6. **Design of Stem :**

i. Maximum bending moment for the stem

Ultimate moment, $M_u = 1.5 \times 64 = 96$ kN-m

ii. Effective depth, $d = 350 - 40 = 310$ mm

iii. Area of steel,

$$= 50\left[\frac{1-\sqrt{1-\frac{4.6\,M_u}{f_{ck}\,bd^2}}}{f_y/f_{ck}}\right]$$

$$= 50\left[\frac{1-\sqrt{1-\frac{4.6\times96\times10^6}{20\times1000\times310^2}}}{415/20}\right] = 0.295\ \%$$

$$A_{st} = \frac{0.295}{100}\times1000\times310 = 914.5\ \text{mm}^2$$

iv. Spacing for 16 mm diameter bars, $\left[A_\phi = \frac{3.14}{4}\times16^2 = 201\ \text{mm}^2\right]$

Spacing, $S = \frac{201\times1000}{914.5} = 219.8\ \text{mm} \approx 200\ \text{mm c/c}$

Provide 16 mm $\phi$ @ 200 mm c/c distance.

v. Distribution steel, $A_{st} = \frac{0.12}{100}\times350\times1000 = 420\ \text{mm}^2$

vi. Spacing for 8 mm diameter bars,

Spacing, $S = \frac{50\times1000}{420} = 119.05\ \text{mm} \approx 110\ \text{mm c/c}$

If the distribution steel is provided near both faces, then the spacing will be @ 220 mm c/c near each face.

7. **Design of Toe Slab :**

i. The bending moment for 1 meter wide strip of the toe slab can be calculate as :

| Load due to | Magnitude (kN) | Distance from c (m) | Moment about c (kN-m) |
|---|---|---|---|
| Upward pressure [cdjf] 66.85 × 1 × 0.85 | 56.82 | 0.425 | 24.15 |
| $ejf = \frac{1}{2}\times0.85\times20.53$ | 8.73 | 0.57 | 4.98 |
| Total | | | 29.13 |
| Deduct for self weight of the toe slab 0.85 × 0.35 × 25 | 7.44 | 0.425 | 3.16 |
| Bending moment for toe slab | | | 25.97 |



For base slab effective cover = 60 mm

i. Maximum bending moment for a 1 meter wide strip of the toe slab.

$$M = 25.97\ \text{kN-m}$$

ii. Area of steel, $A_{st} = \frac{M_u}{bd^2} = \frac{1.5\times25.97\times10^6}{1000\times290^2} = 0.4632$

$$p_t = 50\left[\frac{1-\sqrt{\frac{1-4.6\times0.4632}{20}}}{415/20}\right] = 0.132\ \%$$

Minimum % of steel when Fe 415 is used = 0.2 %

$$A_{st} = \frac{0.2}{100}\times1000\times290 = 580\ \text{mm}^2$$

iv. Spacing of 12 mm $\phi$ bars, $S = \frac{113\times1000}{580} = 195$ mm c/c

Provide 12 mm $\phi$ bars @ 190 mm c/c

8. **Design of the Heel Slab :**

i. The BM calculations for 1 meter wide strip of the heel slab are given in the table :

| Load due to | Magnitude (kN) | Distance from *b* (m) | Moment about *b* (kN-m) |
|---|---|---|---|
| Weight of the backing 1.3 × 4 × 18 | 93.6 | 0.65 | 60.84 |
| Weight of the heel slab 1.30 × 0.35 × 25 | 11.375 | 0.65 | 7.4 |
| | | | 68.24 |
| Deduct for upward pressure *abih*, 27 × 1.30 × 1 | 35.1 | 0.65 | 22.815 |
| $igh = \frac{1}{2}\times1.30\times31.4$ | 20.4 | 0.433 | 8.84 |
| | | | 31.655 |
| BM for heal slab | | | 36.585 |

ii. Maximum bending moment,

$$M = 36.585\ \text{kN-m}$$

iii. Steel required, $A_{st} = \frac{M_u}{bd^2} - \frac{1.5\times36.58\times10^6}{1000\times290^2} = 0.6525\ \text{mm}^2$

$$p_t = 50\left[\frac{1-(46\times6525/20)}{415/20}\right] = 0.108\ \%$$

Minimum % of steel = 0.2 %

$$A_{st} = \frac{0.2}{100} \times 1000 \times 290 = 580 \text{ mm}^2$$

iv. Spacing of 12 mm diameter bars, $\left[A_\phi = \frac{3.14}{4} \times 12^2 = 113 \text{ mm}^2\right]$

Spacing, $S = \frac{113 \times 1000}{580} = 195$ mm c/c

Provide 12 mm $\phi$ bars @ 190 mm c/c

9. **Check for Sliding :**

i. Total horizontal soil pressure force per meter run of the wall,

$$P_h = k_p \frac{\gamma H^2}{2} = \frac{1}{3} \times 18 \times \frac{(4.35)^2}{2} = 56.77 \text{ kN}$$

ii. Limiting friction = $\mu$W = 0.5 × 142.975 = 71.49 kN

iii. Factor of safety against sliding

$$= \frac{\mu W}{P_h} = \frac{71.49}{56.77} = 1.26 < 1.55$$

Hence, we have to provide a shear key to increase the resistance against sliding.

10. **Check for Overturning :**

$$F = \frac{\Sigma M_R}{M_0} = \frac{210.635}{82.82} = 2.54 > 1.55$$

Hence Safe.

11. **Design a Shear Key :**

i. Safe horizontal pressure force = 1.55 $P_h$ = 1.55 × 56.77 = 88 kN

ii. Maximum available force = 71.49 kN

iii. Unbalance horizontal force = 88 – 71.49 = 16.51 kN

iv. Safe horizontal soil reaction = 0.7 × Safe bearing capacity = 0.7 × 200 = 140 kN/m²

v. Let the height of the key be $y$

$$140 \times 1000 \times y = 16.51 \times 10^3$$

$$y = 0.118 \text{ m}$$

vi. Minimum height of key = 300 mm

vii. Maximum BM = 16.15 × $\frac{0.3}{2}$ = 2.48 kN-m

viii. Ultimate BM = 1.5 × 2.48 = 3.72 kN-m

$$0.138 f_{ck} bd^2 = 3.72 \times 10^6$$

$$d = 36.71 \text{ mm}$$

ix. Minimum thickness of key = 200 mm

Provide 300 × 200 mm shear key.



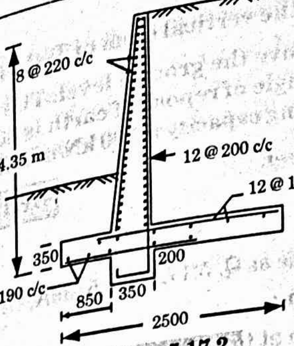



Fig. 5.17.2.

**Que 5.18.** **Design the stem of RC cantilever retaining wall, retaining levelled earth 5 m above base slab. Take the density of earth as 18 kN/m³ and angle of repose of soil as 30°. Toe projection 1.8 m, heel projection 1.7 m and thickness of base slab as 450 mm.**

**AKTU 2014-15, Marks 10**

**Answer**

**Procedure :** Same as Q. 5.17, Page 5–36A, Unit-5.

1. **Design of stem :**

i. Bending moment, $M$ = 187.5 kN-m

ii. Required thickness of stem = 260.64 mm

iii. Provided thickness of stem at bottom 400 mm and at top 200 mm

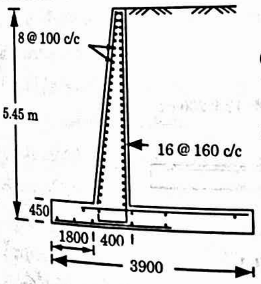
iv. Area of reinforcement, $A_{st}$ = 1227.6 mm²

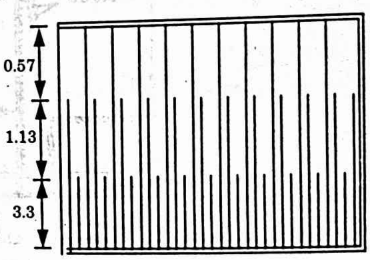
v. Provide main reinforcement 16 mm $\phi$ bars @ 160 mm c/c.

vi. Area of distribution steel = 480 mm²

vii. Provide distribution reinforcement 8 mm $\phi$ bar @ 100 mm c/c.

2. **Details of Reinforcement :**




Stem reinforcement (Longitudinal view)

Fig. 5.18.1.

**Que 5.19.** **Design the vertical stem of T-shaped retaining wall for a height of 3.5 m above the ground level. The top of earth retained is horizontal. The angle of repose of earth is 30° and its density is 20 kN/m³, the safe bearing capacity is 100 kN/m². Use M 25 grade concrete and Fe 415 grade steel.**

**AKTU 2013-14, Marks 10**

**Answer**

**Procedure :** Same as Q. 5.17, Page 5–36A, Unit-5.

1. **Wall Proportion :**
   - i. Thickness of stem at top = 200 mm
   - ii. Thickness of stem at bottom = 400 mm
   - iii. Thickness of base = 400 mm
   - iv. Required Length of toe = 800 mm,
   - v. Length of heel = 1300 mm
2. Provide width of base slab = 2500 mm
3. Height of stem = 3.5 m
4. Pressure intensity,

$$P_{max} = 72.88 < 120 \text{ kN/m}^2$$
$$P_{min} = 40.92 < 120 \text{ kN/m}^2$$

5. **Design of Stem :**
   - i. Ultimate bending moment, $M_u$ = 71.46 kN/m²
   - ii. Required area of reinforcement, $A_{st}$ = 546.48 mm²
   - iii. Provide main reinforcement 12 mm ϕ bars @ 200 mm c/c
   - iv. Area of distribution steel = 432 mm²
   - v. Provide distribution reinforcement 8 mm ϕ bars @ 110 mm c/c
6. **Details of Reinforcement :**

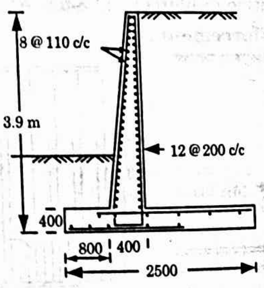



**Fig. 5.19.1.**





**Que 5.20.** **Design a T-shaped cantilever retaining wall for retaining 5 m high earth above the ground level. Consider the weight of soil = 15 kN/m³, Angle of repose of soil = 30°, Coefficient of friction at base = 0.5, Allowable bearing pressure of soil = 150 kN/m². Grade M20 for concrete and Fe415 for steel.**

**AKTU 2016-17, Marks 10**

**Answer**

**Procedure :** Same as Q. 5.17, Page 5–36A, Unit-5.

1. **Wall Proportions :**
   - i. Height of stem = 5.4 m
   - ii. Thickness of slab = 400 mm
   - iii. Width of base slab = 3 m
   - iv. Length of toe = 1.0 m
   - v. Length of heel = 1.6 m
2. Ultimate bending moment, $M_u$ = 156.25 kN-m
3. Provide thickness of stem at bottom 400 mm and at top 200 mm

Pressure intensity,

$$P_{max} = 101.25 < 150 \text{ kN-m}^2$$
$$P_{min} = 23.75 < 150 \text{ kN-m}^2$$

5. **Design of Stem :**
   - i. Ultimate Bending Moment, $M_u$ = 156.25 kN-m
   - ii. Area of reinforcement, $A_{st}$ = 1299.45 mm²
   - iii. Provide main reinforcement, 12 mm ϕ bars @ 80 mm c/c
   - iv. Area of distribution steel = 480 mm²
   - v. Distribution reinforcement, 8 mm ϕ bars @ 100 mm c/c
6. **Design of Toe Slab :**
   - i. Ultimate moment, $M_u$ = 62.235 kN-m
   - ii. Area of steel, $A_{st}$ = 492.81 mm²
   - iii. $A_{st}$ min = 800 mm²
   - iv. Provide main reinforcement 12 mm ϕ bars @ 140 mm c/c
7. **Design of Heel Slab :**
   - i. Ultimate bending moment, $M_u$ = 91.148 kN-m
   - ii. Area of steel, $A_{st}$ = 732.17 mm²
   - iii. $A_{st}$ min = 800 mm²
   - iv. Provide main reinforcement 12 mm ϕ bars @ 140 mm c/c
8. **Check in Sliding :** Factor of safety, 1.28 < 1.55, therefore wall is unsafe, hence provide shear key.

9. Shear key provided 400 mm deep and 400 mm thick.

10. **Details of Reinforcement :**

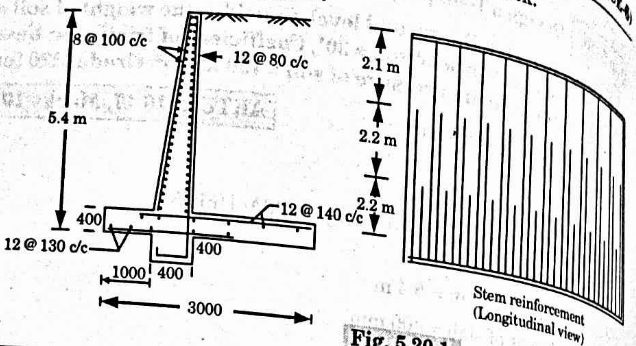



**Fig. 5.20.1.**

**Que 5.21. Design a cantilever type of retaining wall to retain sand for 3075m above the ground level. The sand fill slopes at the rate of 1 vertical to 2 horizontal. The weight of sand is 18 kN/m³. The safe bearing capacity of the soil is 200 kN/m² at a depth of 1.25 m below the ground level. The angle of repose of the soil is 30°. Use M20 concrete and Fe-415 steel. Take μ = 0.6.** **AKTU 2017-18, Marks 10**

**Answer**

**Given :** Height of embankment = 3.75 m
Weight of sand = 18 kN/m³, Angle of repose = 30°
Bearing capacity of soil = 200 kN/m², Coefficient of friction = 0.6
**To Find :** Design of retaining wall.

**Note :** Height of retaining wall above the ground level is given 3075 m which is not possible. Hence assume the height of retaining wall is 3.75 m.

1. **Design Proportion :**

i. Total height of the wall, $H = 3.75 + 1.25 = 5$ m

ii. Width of the base slab $= 0.7\,H = 0.7 \times 5 = 3.5$ m

iii. Toe projection = About one-third the base width $= 3.5 / 3 = 1.17$ mm

iv. Provide a toe projection of 1 m. Making an allowance of 300 mm for the thickness of the base slab, the height of the stem $= 5 - 0.30 = 4.70$ m

v. Let $\alpha = \dfrac{1}{2}$, $\sin\alpha = \dfrac{1}{\sqrt{5}}$, $\cos\alpha = \dfrac{2}{\sqrt{5}} = 0.8944$

vi. Coefficient of pressure, $k_p = \cos\alpha \dfrac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}$

$\cos^2\alpha - \cos^2\phi = 0.8 - 0.75 = 0.05$



$$\sqrt{\cos^2\alpha - \cos^2\phi} = \sqrt{0.05} = 0.2236$$

$$k_p = 0.8944 \times \frac{0.8944 - 0.2236}{0.8944 + 0.2236} = 0.5366$$

2. **Calculation for depth :**

i. Maximum bending moment for the stem per metre run of the wall,

$$M = k_p \frac{wh^3}{6}\cos\alpha$$

$$= 0.55366 \times 18000 \times \frac{4.70^3}{6} \times \frac{2}{\sqrt{5}} = 149.490 \text{ kN-m}$$

ii. Ultimate moment, $M_u = 1.5 \times 149490 = 224.235$ kN-m

$$0.138 f_{ck} bd^2 = 0.138 \times 20 \times 1000\, d^2 = 224.235 \times 10^6$$

$$d = 285 \text{ mm}$$

iii. Effective cover to stem reinforcement = 40 mm

iv. Total thickness = 285 + 40 = 325 mm

v. For an economical design this thickness may increased by 30 % to 40 %.

vi. Provide a thickness of 450 mm at the bottom of the stem.

vii. The base slab also will be made 450 mm thick.

viii. Heel projection = 3.50 – 1 – 0.45 = 2.05 mm
Actual height of the stem : $h = 5 - 0.45 = 4.55$ m

ix. Height of soil above the heel slab near the heel end,

$$h' = h + y = 4.55 + 2.05 \tan\alpha$$

$$= 4.55 + 2.05 \times 0.5 = 4.55 + 1.025 = 5.575 \text{ m}$$

x. Height of the soil surface above the heel edge $a$,

$$h_1 = 5.575 + 0.450 = 6.025 \text{ m}$$

xi. Total lateral pressure on the whole wall per metre run, $P = k_p \dfrac{wh_1^2}{2}$

$$= 0.5366 \times 18 \times \frac{6.025^2}{2} = 175.310 \text{ kN}$$

xii. Horizontal component of $P = P_h = P\cos\alpha = 175.310 \times \dfrac{2}{\sqrt{5}} = 156.797$ kN

xiii. Vertical component of $P = P_v = P\sin\alpha = 175.310 \times \dfrac{1}{\sqrt{5}} = 78.399$ kN

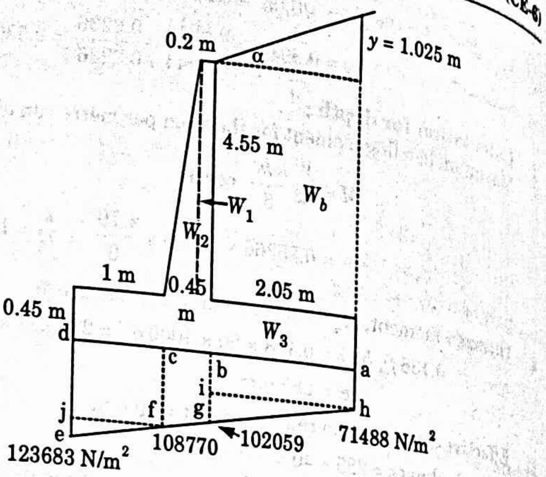



**Fig. 5.21.1.**

3. **Stability Calculations :**

**Stability Calculations for one metre length of Wall :**

| Load due to | Magnitude (kN) | Distance from a (m) | Moment about a (kN-m) |
|---|---|---|---|
| $W_1 = 0.20 \times .55 \times 25$ | 22.75 | 2.15 | 48.9125 |
| $W_2 = \frac{0.25 \times 4.55}{2} \times 25$ | 14.22 | 2.333 | 33.1725 |
| $W_3 = 3.5 \times 0.45 \times 25$ | 39.375 | 1.75 | 68.906 |
| $W_b = 2.05 \times 4.55 \times 18$ | 167.9 | 1.025 | 172.09 |
| $0.5 \times 2.05 \times 1.025 \times 18$ | 18.91 | 2.05/3 | 12.92 |
| $P_v$ | 78.4 | 0 | 0 |
| Moment of lateral pressure $= 156.8 \times 6.025 / 3$ | | | 314.9 |
| Total | 341.55 | | 650.901 |

i. Distance of the point of application of the resultant force from the heel end *a*,

$$Z = \frac{650.901}{341.55} = 1.906 \text{ m}$$



ii. *Eccentricity*, $e = Z - \frac{b}{2} = 1.906 - 1.750 = 0.156$ m

$$\frac{b}{6} = \frac{3.50}{6} = 0.583 \text{ m} \quad \therefore \quad e < \frac{b}{6}$$

iii. *Extreme pressure intensity at the base*

$$= \frac{W}{b}\left(1 \pm \frac{6e}{b}\right) = \frac{341.55}{3.50}\left(1 \pm \frac{6 \times 0.156}{3.50}\right)$$

$$p_{max} = 123.683 \text{ N/m}^2 \text{ and } p_{min} = 71.488 \text{ N/m}^2$$

iv. Safe bearing capacity of the soil = 200 kN/m²

4. **Design of the Stem :**

i. Actual bending moment for the stem per metre run

$$M = k_p \frac{wh^3}{6} \cos \alpha$$

$$= 0.5366 \times 18 \times \frac{4.55^3}{6} \times 0.8944 = 135.624 \text{ kN-m}$$

ii. Ultimate moment, $M_u = 1.5 \times 135.624 = 203.436$ kN-m

iii. Effective depth, $d = 450 - 40 = 410$ mm

$$\frac{M_u}{bd^2} = \frac{203.436 \times 10^6}{1000 \times 410^2} = 1.21$$

iv. Percentage of steel $= p_t = \left[\frac{1 - \sqrt{1 - \frac{4.6 \times 1.21}{20}}}{\frac{415}{20}}\right] = 0.363\,\%$

v. Area of steel, $A_{st} = \frac{0.363}{100}(1000 \times 410) = 1489 \text{ mm}^2$

vi. Spacing of 18 mm diameter bars $= \frac{254 \times 1000}{1489} = 171$ mm

vii. Provide 18 mm $\phi$ bars @ 170 mm c/c

viii. Distribution steel $= \frac{0.12}{100}(1000 \times 450) = 540 \text{ mm}^2$

ix. Spacing of mm diameter bars $= \frac{50 \times 1000}{540} = 92$ mm say 90 mm

x. Provide 8 mm $\phi$ bars @ 180 mm c/c near each face.

5. **Design of the Toe Slab :**

BM calculations for a 1 m wide strip of the toe slabs.

| Load due to | Magnitude of Load (kN) | Distance from c (m) | Moment about c (kN-m) |
|---|---|---|---|
| Upward pressure at part *cdjf* | 108.77 × 1 = 108.77 | 0.5 | 54.385 |
| at part *jfe* | 0.5 × 1 × 14.913 = 7.456 | 2/3 | 4.971 |
| | | | 59.356 |
| Deduct self weight of toe slab | 1 × 0.45 × 25 = 11.25 | 0.5 | 5.625 |
| BM for toe slab | | | 53.731 |

i. BM for toe slab, $M = 53.731$ kN-m

ii. Ultimate moment, $M_u = 1.5 \times 53.731 = 80.596$ kN-m

iii. Effective depth, $d = 450 - 60 = 390$ mm

$$\frac{M_u}{bd^2} = \frac{80.596 \times 10^6}{1000 \times 390^2} = 0.53$$

iv. Percentage of steel $= p_t = 50 \left[\frac{1-\sqrt{1-\frac{4.6 \times 0.53}{20}}}{\frac{415}{20}}\right] = 0.15\,\%$

v. Minimum percentage of steel = 0.2 %

$$A_{st} = \frac{0.2}{100}(1000 \times 390) = 780 \text{ mm}^2$$

vi. Spacing of 12 mm diameter bars $= \frac{113 \times 1000}{780} = 144$ mm

viii. Provide 12 mm diameter bars @ 140 mm c/c.

**6. Design of the Heel Slab :**

**i. Note :** The soil resting on the heel slab will produce an additional hogging moment due to the vertical component of the lateral pressure.

This additional hogging moment,

$$= k_p \frac{wl_h^2}{6}(h + 2h')\sin\alpha \tan\alpha$$

$$= 0.5366 \times 18000 \times \frac{2.05^2}{6}(4.55 + 2 \times 5.575)$$

$$\times \frac{1}{\sqrt{5}} \times \frac{1}{2} = 23750 \text{ N-m}$$

ii. BM Calculations for a 1 metre wide strip of the heel slab.





| Load due to | Magnitude (kN) | Distance from *b* (m) | Moment about *b* (kN-m) |
|---|---|---|---|
| Weight of the backing 2.05 × 4.55 × 18 | 167.9 | 1.025 | 172.092 |
| Weight of the heel slab 0.5 × 2.05 × 1.025 × 18 | 18.9 | 4.1/3 | 25.83 |
| Moment due to vertical component of lateral pressure | | | 23.75 |
| | | | 221.68 |
| Deduct for upward pressure *abih*, 71.49 × 2.05 | 146.55 | 1.025 | 150.214 |
| *igh* = 0.5 × 2.05 × 30.571 | 31.335 | 2.05/3 | 21.412 |
| Total deduction | | | 171.626 |
| BM for heel slab | | | 50.06 |

iii. BM for heel slab = $M$ = 50.060 kN-m

iv. Ultimate moment, $M_u = 1.5 \times 50.060.1$ kN-m = 75.090 kN-m

$$\frac{M_u}{bd^2} = \frac{75.090 \times 10^6}{1000 \times 390^2} = 0.494$$

v. Percentage of steel, $p_t = 50 \left[\frac{1-\sqrt{1-\frac{4.6 \times 0.494}{20}}}{\frac{415}{20}}\right] = 0.14\,\%$

vi. Minimum percentage of steel = 0.2 %

$$A_{st} = \frac{0.2}{100}(1000 \times 390) = 780 \text{ mm}^2$$

vii. Spacing of 18 mm diameter bar as $= \frac{254 \times 1000}{780} = 325$

viii. Provide 18 mm $\phi$ bars @ 180 mm c/c so as to match with the spacing of stem reinforcement

**7. Check for Sliding :**

i. Total horizontal force per metre length of the wall = $P_h$ = 156797 N

ii. Limiting friction = $\mu W = 0.6 \times 341.55 = 204.93$

iii. Factor of safety against sliding = $\frac{\mu W}{P_h} = \frac{204.93}{156.797} = 1.31$

iv. This is less than 1.55. Hence we will provide a key. To provide a factor of safety of 1.55, the wall should be safe for a horizontal pressure force $1.55\, P_h$.

$1.55\, P_h = 1.55 \times 156.797 = 243.035$ kN

v. Maximum available friction = 204.93 kN

vi. Unbalanced horizontal force = 38.105 kN

vii. Safe horizontal soil reaction = 0.7 × safe bearing capacity = 0.7 × 200 = 140 kN/m²

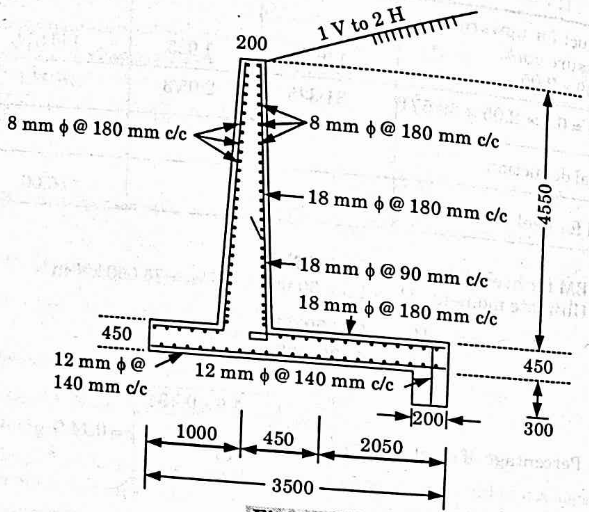



**Fig. 5.21.2.**

viii. Let the height for the key be $y$ metre.

$$140 \times 1000\, y = 38.105 \times 10^3$$

$$y = 0.27 \text{ m}$$

ix. Minimum height of a key = 0.3 m = 300 mm

x. Maximum BM for the key, $M = 38.105 \times 0.3 / 2 = 5.716$ kN-m

xi. Ultimate moment, $M_u = 1.5 \times 5.716 = 8.573$ kN-m

$$0.138\, f_{ck}\, bd^2 = 0.138 \times 20 \times 1000\, d^2 = 8.573 \times 10^6$$

$$d = 56 \text{ mm}$$



xii. Minimum thickness of a key = 200 mm

xiii. Effective depth, $d = 200 - 60 = 140$ mm

$$\frac{M_u}{bd^2} = \frac{8.573 \times 10^6}{1000 \times 140^2} = 0.44$$

xiv. Percentage of steel,

$$p_t = 50\, \frac{1 - \sqrt{1 - \frac{4.6 \times 0.44}{20}}}{\frac{415}{20}} = 0.125\,\%$$

xv. This is very small. Extend alternate bars of the toe slab into the key.

**Que 5.22.** **Determine the dimensions of a T-shaped retaining wall for a height of 5 m above the ground level. The top of the earth is surcharged at 20° with the horizontal. The angle of repose of earth is 30° and its density is 20 kN/m³. The safe bearing capacity of soil is 90 kN/m² and coefficient of friction between concrete and soil is 0.55.**

**AKTU 2013-14, Marks 10**

**Answer**

**Procedure :** Same as Q. 5.21, Page 5–45A, Unit-5.

1. **Approximate Proportion :**
   - i. Total height, $H = 6$ m
   - ii. Width of base slab, $B = 4$ m
   - iii. Toe projection = 2.5 m
   - iv. $k_a = 0.42$
   - v. Heel projection = 1 m
   - vi. Height of stem = 5.6 m
2. Ultimate moment, $M_u = 246.68$ kN-m
3. Effective depth, $d = 298.95$ mm
4. Provided total depth, $D = 400$ mm
5.
   - i. Pressure at toe $P = 68.84 \text{ kN/m}^2 < 90 \text{ kN/m}^2$
   - ii. Pressure at heel, $P = 61.75 \text{ kN/m}^2 < 90 \text{ kN/m}^2$
6. Check against overturning (1.57 > 1.5 safe)
7. Check against sliding (0.9 unsafe). Hence provide shear key.

☺☺☺

# 1 UNIT

# Design of Beam (2 Marks Questions)

**1.1. Write down the name of different philosophies for the design of reinforced concrete structure.**

**Ans.** There are four philosophies used in the designing :

i. Working stress design,
ii. Ultimate load design,
iii. Limit state design, and
iv. Performance based design.

**1.2. What is modular ratio ? Determine the modular ratio for M 20 grade concrete.** **AKTU 2015-16, Marks 02**

**OR**

**What is modular ratio ?** **AKTU 2017-18, Marks 02**

**OR**

**Determine the modular ratio for M 20 grade concrete.** **AKTU 2017-18, Marks 02**

**Ans.** Modular ratio is the ratio of the modulus of elasticity of steel to modulus of elasticity of concrete. It is denoted by $m$.

$$m = \frac{E_s}{E_c} = \frac{280}{3\sigma_{cbc}}$$

For M20, $\sigma_{cbc} = 7 \text{ N/mm}^2$

$$m = \frac{280}{3 \times 7} = 13.33$$

**1.3. Discuss the drawbacks of the working stress method.**

**Ans.** The main drawbacks of the WSM are as follows :

i. Concrete is not elastic.
ii. It is difficult to account for shrinkage and creep effects by using the WSM.

**1.4. Discuss the merits of ultimate load method.**

**Ans.** Following are the merits of ultimate load method :

i. The load factor gives the exact margin of safety against collapse.
ii. The method allows to use different load factors for different types of loads and the combination thereof.





**1.5. Give the demerits of ultimate load method.**

**Ans.** Following are the demerits of ultimate load method :

i. This method does not take into consideration the serviceability criteria of deflection and cracking.
ii. The use of high strength reinforcing steel and concrete results in increase of deflection and crack width.

**1.6. Define characteristics strength.** **AKTU 2015-16, Marks 02**

**Ans.** The characteristics strength means that value of the strength of material below which not more than 5 % of the results are expected to fall.

$$\sigma_{ch} = \sigma_T - 1.64\,\sigma$$

where, $\sigma_T$ = Target mean strength.
$\sigma$ = Standard deviation.

**1.7. What is characteristics load ?**

**Ans.** A characteristics load is defined as that value of load which has a 95 % probability of not being exceeded during the life of the structure.

**1.8. Define factor of safety and load factor.** **AKTU 2015-16, Marks 02**

**Ans.** **Factor of Safety :** It is defined as the ratio of yield stress of member to the maximum expected stress.

$$\text{Factor of safety} = \frac{\text{Yield stress}}{\text{Maximum expected stress}}$$

**Load Factor :** The ratio of the ultimate load to the working load is called load factor.

$$\text{Load Factor} = \frac{\text{Ultimate road}}{\text{Working load}}$$

**1.9. What are the assumptions of ultimate load method ?**

**Ans.** Following are the assumptions of ultimate load method :

i. A section which is plane before bending remains plane after bending.
ii. Tensile strength of concrete is ignored in sections subjected to bending.
iii. Maximum fibre strength in concrete does not exceed 0.68 $\sigma_{cm}$.

**1.10. Define singly reinforced section.**

**Ans.** A beam or slab reinforced with main steel provided only in tension zone called singly reinforced section.

**1.11. Where doubly reinforced sections are provided ?**

**Ans.** A doubly reinforced section is generally provided under the following conditions :

i. When the member is subjected to shocks, impact or accidental lateral thrust.

ii. When the bending moment in the member reverse according to the loading conditions e.g., wall of tank, brackets etc.

iii. When the member is subjected to eccentric loading.

iv. When the section of member restricted.

**1.12. What are the assumptions of limit state method ?**

**Ans.** Following are the assumptions of limit state method :

i. Plane section normal to the axis remains plane after bending.

ii. The maximum strain in concrete at the outermost compression fibre is taken as 0.35 % in bending regardless of the strength of the concrete.

iii. The tensile strength of concrete is ignored.

iv. The maximum strain in tension reinforcement in the section at failure should not be less than the following :

$$\epsilon_s \geq \frac{\sigma_y}{1.15E_s} + 0.002$$

**1.13. What is limit state and give the classification of limit state?**

**Ans.** Limit state is the load case beyond which a structure no longer satisfies the design requirements. There are two main limit state:

i. Collapse limit state.

ii. Serviceability limit state.

**1.14. Write down the types of reinforced concrete beam.**

**Ans.** These are the three types of reinforced concrete beam :

i. Singly reinforced beams,

ii. Doubly reinforced beams, and

iii. Singly or doubly reinforced flanged beams.

**1.15. Write down the expression of moment of resistance of singly reinforced beam.**

**Ans.** Following are the equation used to calculated MOR :

$M_{u.lim}$ with respect to concrete = $0.36\,\sigma_{ck}\,b\,x_u\,(d - 0.42\,x_u)$

$M_{u.lim}$ with respect to steel = $0.87\,\sigma_y A_{st}\,(d - 0.42\,x_u)$

**1.16. Define limit state of serviceability.**

**AKTU 2015-16, Marks 02**

**Ans.** The structure or its part thereof shall be serviceability during its expected life span. The serviceability corresponds to the deflection and cracking of the structure.

**1.17. How is it determine whether a beam of a given dimension is to be designed as doubly reinforced ?**

**AKTU 2016-17, Marks 02**



**Ans.** Beam is design as doubly reinforced beam, when dimension of beam is restricted and design moment is greater than resistance ultimate moment of beam.

**1.18. What is lever arm ?**

**AKTU 2017-18, Marks 02**

**Ans.** Lever arm is the distance between the line of action of the resultant compression and the line of action of the resultant tension force.

**1.19. Explain why is the concrete cover to reinforcement required ?**

**Ans.** A concrete cover shall have to be provided to the reinforcement for the following reasons :

1. To protect the reinforcement from weather and fire, so that it does not corrode or melt.

2. To ensure the grip of concrete over reinforcement so that they act as one and resist the loads.

**1.20. What is effective depth in a beam section ?**

**AKTU 2017-18, Marks 02**

**Ans.** Effective depth is defined as the distance from extreme compression fibre to the centroid of tensile reinforcement.

**1.21. What is minimum grade of concrete for general reinforced concrete work recommended by the IS code-456 : 2000.**

**AKTU 2017-18, Marks 02**

**Ans.** M20

**1.22. What is neutral axis ?**

**AKTU 2017-18, Marks 02**

**Ans.** Neutral axis is an imaginary plane which divides the cross section of a beam into the tension and compression zone lying on the opposite side of the plane.

**1.23. What is effective cover ?**

**AKTU 2017-18, Marks 02**

**Ans.** Effective cover (concrete cover) is defined as the minimum distance between the surface of concrete to the centroid of the tension reinforcement.

Effective cover = $D - d$ = Total depth – Effective depth

**1.24. What is meant by shear lag in T-beams ?**

**AKTU 2016-17, Marks 02**

**Ans.** The phenomenon that dissipates the compression in the T-beam slab that lies further away from the beam's web is known as shear lag. In other word, the decrease in flange compression away from the loaded edge due to shear distortion is called shear lag.

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2
UNIT

# Behaviour of RC Beam in Shear (2 Marks Questions)

**2.1. What are the different modes of shear failure ?**

**Ans.** Following are the modes of shear failure :

i. Diagonal tension failure,
ii. Flexural shear failure, and
iii. Diagonal compression failure.

**2.2. Define the term diagonal tension failure.**

**Ans.** Diagonal tension failure occurs under large shear force and less bending moment. Such cracks are normally at 45° with the horizontal.

**2.3. What do you mean by flexural shear cracks ?**

**AKTU 2015-16, Marks 02**

**Ans.** Flexural shear crack occurs under large bending moment and less shear force. Such cracks are normally at 90° with the horizontal.

**2.4. Give the reasons for providing vertical stirrups for preventing shear crack.**

**Ans.** Following are the reasons for providing vertical stirrups :

i. Stirrups help to prevent cracks due to shear shrinkage and thermal stresses.
ii. Stirrups assist in confining the concrete and to increase the strength.
iii. These reinforcement prevent a sudden failure with diagonal crack, stirrups allow considerable ductility so as to provide indication of impending failure.

**2.5. What do you understand by diagonal compression failure ?**

**Ans.** Diagonal compression failure occurs under large shear force. It is characterized by the crushing of concrete. Normally, it occurs in beams which are reinforced against heavy shear.

**2.6. In what cases shear stirrups are not provided in the beams ?**

**Ans.** The IS code requires that shear reinforcement need not be provided in the following cases :





i. Where shear force $V_u$ is less than 0.5 times the shear capacity of the section, and
ii. In member of minor structural importance such as lintels.

**2.7. Write down the expression for minimum shear reinforcement.**

**Ans.** Minimum shear reinforcement should be provided if the nominal shear stress ($\tau_v$) is less than or equal to shear strength of the concrete.

Minimum shear reinforcement,

$$\frac{A_{sv}}{bLs_v} = \frac{0.4}{0.87 f_y}$$

**2.8. When shear reinforcement is to be provided ?**

**Ans.** Shear reinforcement should be provided if the normal shear stress $\tau_v$ exceeds the shear strength of concrete ($\tau_c$).

**2.9. Explain the expression for spacing of shear stirrups.**

**Ans.** Spacing,

$$S = \frac{0.87\,\sigma_y\,A_{sv}d}{V_{us}}$$

where, $V_{us}$ = Net design shear = $V_u - bd\tau_c$

$A_{sv}$ = Area of stirrups.

$b$ = Breadth of beam.

**2.10. What is the specification of Indian Standard Code for spacing of stirrup ?**

**Ans.** According to IS code spacing should not exceed the following :

i. For vertical stirrup – 0.75$d$ or 300 mm.
ii. For inclined stirrup – $d$(effective depth of beam) or 300 mm.

**2.11. Define bond stress.**

**Ans.** Bond stress is defined as the shear force per unit of nominal surface area of a reinforcing bar acting parallel to the bar on the interface between the bars and the surrounding concrete.

**2.12. Discuss the factors affecting shear resistance of RC member.**

**Ans.** The shear resistance of rectangular beams depends upon the following factors :

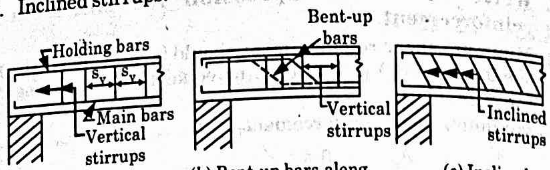
i. Grade of concrete.
ii. Percentage and grade of tensile reinforcement.

**2.13. Enumerate the types of shear reinforcement with neat sketch.**

**AKTU 2015-16, Marks 02**

**Ans.** Shear reinforcement is provide in any one of the following three forms :

i. Vertical stirrups,
ii. Bent up bars along with stirrups, and
iii. Inclined stirrups.




(a) Vertical stirrups (b) Bent-up bars along with vertical stirrups (c) Inclined stirrups

**Fig. 2.13.1.** Types of shear reinforcement.

**2.14. Classify the bond.**

**Ans.** Following are the two types of bond :

i. Flexural bond or local bond.
ii. Anchorage bond or development bond.

**2.15. What is flexural bond ?**

**Ans.** Flexural bond is one which arises from the change in tensile force carried by the bar along its length due to change in bending moment along the length of the member.

**2.16. What do you mean by anchorage bond ?**

**Ans.** Anchorage bond is that which arises over the length of anchorage provided for a bar. It also arises near the bend or cutoff point of a reinforcing bar.

**2.17. Define the development length.**

**Ans.** Development length is defined as the length of the bar required on either side of the section under consideration to develop the required stress in steel at that section through bond.

**2.18. Give the expression for development length.**

**Ans.** Development length is calculated by given expression :

Development length,

$$L_d = \frac{0.87\, \sigma_y\, \phi}{4\, \tau_{bd}}$$

**2.19. Write down the critical points where development length checked.**

**Ans.** Special checking for development length is essential at the following location :

i. At simple supports,
ii. At cantilever supports,



iii. At point of contraflexure.
iv. At lap splices.
v. At point of bar cutoff.
vi. For stirrups and transverse ties.

**2.20. Give the IS specification for anchorage value of bends and hooks.**

**Ans.** IS code gives the anchorage value of bends and hooks as follows :

i. The anchorage value of a bend should be taken as $4\phi$ for each 45° bend subjected to a maximum of $16\phi$.
ii. The anchorage value of a standard U-type hook is equal to $16\phi$.

**2.21. Write down the IS code specification for design bond stress ($\tau_{bd}$).**

**Ans.** IS code specification for design bond stress :

i. The value of $\tau_{bd}$ may be increased by 60 % for deformed bar in tension.
ii. It is further increased by 25 % for bars in compression.
iii. For bundled bars in contact the development length is given by that for the individual bars when increased by,
   a. 10 % for two bars in contact.
   b. 20 % for three bars in contact.
   c. 33 % for four bars in contact.

**2.22. How does the shear span influence the mode of shear failure ?**

**AKTU 2016-17, Marks 02**

**Ans.** Depending upon the shear span and effective depth ratio, a beam may be fail as :

Case I : $a_v/d < 1$, splitting or compression failure.
Case II : $1 < a_v/d < 2.5$, shear tension failure.
Case III : $2.5 < a_v/d < 6$, diagonal shear failure.
Case IV : $a_v/d > 6$, flexural failure.

where, $a_v$ = Shear span between the support and load.
$d$ = Effective depth.

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# 3 UNIT

# Design of Solid Slabs (2 Marks Questions)

**3.1. Define the term 'slab'.**

**Ans.** Slabs are plate elements forming floors and roofs of buildings and carrying distributed loads primarily by flexure. A slab may be supported by beams or walls and may be used as the flange of a T or L beam.

**3.2. How are also classified ? List the various classifications.**

**AKTU 2016-17, Marks 02**

**Ans.** Slabs are classified as follows :

i. One way slab.
ii. Two way slab.
iii. Circular slab.
iv. Flat slab.
v. Grid floor and ribbed slab.

**3.3. Classify the deflection.**

**Ans.** Deflection is classified as follows :

i. Short term deflection.
ii. Long term deflection.

**3.4. Explain the short term deflection of members.**

**Ans.** The short term or instantaneous deflection occurs due to initial elastic deformation of member under dead load and permanent imposed load under service condition.

**3.5. What is long term deflection ?**

**Ans.** Long term deflection occurs due to creep and shrinkage under sustained load and additional elastic deflection due to temporary live loads. It is about 2–3 times longer than the short term deflection.

**3.6. Explain the factors affecting the short term deflection.**

**Ans.** Following are the factors affecting the short term deflection :

i. Magnitude and distribution of live load.
ii. Span and type of end restraints.
iii. Cross-sectional properties including steel percentages.



iv. Stress in steel reinforcement.
v. Amount and extent of cracking.

**3.7. What are the factors that affect the long term deflection ?**

**Ans.** Following are the factors affecting the long term deflection :

i. Humidity and temperature condition at the time of curing of concrete.
ii. Age of concrete at the time of loading/
iii. All the other factors influencing shrinkage and creep such as type and size of aggregate, water cement ratio, etc.

**3.8. Write down the factors that influence the cracking in members.**

**Ans.** Cracking is a complex phenomenon and is influenced by number of factors, such as :

i. Stress in member.
ii. Surface characteristics of steel.
iii. Diameter and spacing of steel.
iv. Covers of bars.
v. Quality of concrete.
vi. Shear stirrups and other form of reinforcement.

**3.9. Define one way slab and two way slab.**

**AKTU 2015-16, Marks 02**

**Ans.** **One Way Slab :** When length of slab is more than twice of the breadth, the slab is known as one way slab. This may be simply supported or continuous.

**Two Way Slab :** The ratio of length to breadth of slab is less than two, the slab is known as two way slab. Two way slab are supported on four sides.

**3.10. Explain main steel distribution in slab.**

**Ans.** This reinforcement consisting the main bars is based on the maximum bending moment. This reinforcement shall not be less than 0.12 % of the gross area for Fe 415 and 0.15 % of the gross sectional area for Fe250 grade steel.

**3.11. Discuss the distribution (temperature) steel in slab.**

**Ans.**

i. These reinforcements are provided running at right angle to the main bars in order to distribute the load and the temperature and shrinkage stresses.
ii. This steel shall have an area not less than 0.12 % of the gross sectional area when Fe415 are used and 0.15 % of the gross sectional area when mild steel bars are used.

**3.12. Give the IS specification for diameter main bars.**

**Ans.** Following are the IS specifications for diameter of main bars :

i. For Fe415 grade steel, 8 or 10 mm bars used as diameter of main bar.

ii. Fe250 grade steel 10 or 12 mm bars used.

iii. The diameter of bar shall not exceed 1/8th of thickness of slab.

**3.13. Give the IS specification for spacing of main bars.**

**Ans.** The spacing of the main bars shall not exceed the following :

i. Three times the effective depth of the slab.

ii. 300 mm.

**Minimum Spacing of Bars :** The spacing of the bars shall not be less than 75 mm for satisfactory concreting.

**3.14. Write down the IS code recommendation for spacing and diameter of bar, of temperature reinforcement.**

**Ans.** **Minimum Spacing of Distribution Bars :** The spacing of distribution bars shall not exceed the following :

i. Five times the effective depth of the slab.

ii. 300 mm.

**Diameter of Distribution Bars :** Generally 6 or 8 mm diameter bars of mild steel are used as distribution bars.

**3.15. Write the measure to control the deflection in slab.**

**AKTU 2016-17, Marks 02**

**Ans.** Deflection can be controlled by restricting the span/effective depth ratio of a member.

**3.16. Write situations in which one-way behaviour can be assumed of a slab supported on four sides.**

**AKTU 2016-17, Marks 02**

**Ans.** When length of slab is more than twice of the breadth of the slab.

**3.17. What is the dog legged stair ?**

**Ans.** The staircase which is used to give an access to different floors of a building is known as dog legged stair.

**3.18. Define the term lintel.**

**Ans.** The lintel is a beam which supports brick or other masonry over an opening like door, window, ventilator, etc.

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**4**

**UNIT**

# Design of Columns (2 Marks Questions)

**4.1. Define the term 'column'.**

**Ans.** A column may be defined as an element used primarily to support axial compressive load and with a height of atleast three times its least lateral dimension.

**4.2. What is the effective height of a column ?**

**Ans.** The effective height of a column is defined as the height between the points of contraflexure of the buckled column.

**4.3. Explain the assumptions which are made for limit state of collapse in compression.**

**Ans.** Following are the assumptions made for the limit state of collapse in compression :

i. Plane sections normal to the axis remain planes after bending.

ii. The tensile strength of concrete is ignored.

iii. The maximum compressive strain in concrete in axial compression is taken as 0.002 unit etc.

**4.4. Give the recommendations of IS code for minimum eccentricity of load.**

**Ans.** Clause 25.4 of the IS code requires that the minimum eccentricity should be as follows :

$$e_{min} \geq \frac{l}{500} + \frac{D}{30}$$
$$> 20 \text{ mm}$$

where, $l$ = Unsupported length of column in mm.

$D$ = Lateral dimension of column in the direction under consideration in mm.

**4.5. What is the role of minimum eccentricity in the design of column ?**

**AKTU 2016-17, Marks 02**

**Ans.** If the value of minimum eccentricity is less than or equal to 0.05$D$, the column is designed as axially loaded column, but if, the minimum eccentricity is greater than 0.05$D$, the column should be designed for combined axial load and bending, where $D$ = Lateral dimension of the column in the direction under consideration.

**4.6. Give the IS code recommendations for lateral ties of column design.**

**Ans.** Following are the recommendation for diameter and pitch of lateral ties :

i. The diameter of lateral ties should not be less than one fourth of the diameter of the largest longitudinal bar and in no case less than 6 mm.

ii. The pitch of the lateral ties should not exceed the following distances :

a. Least lateral dimension.

b. Six times of the smallest diameter of longitudinal reinforcement bar.

c. 300 mm.

**4.7. Enumerate different types of column.**

**AKTU 2015-16, Marks 02**

**Ans.** Following are various types of column :

i. Rectangular column.
ii. Square column.
iii. Circular column.
iv. Polygonal column.

**4.8. What is slenderness ratio ?**

**Ans.** The ratio of effective column length ($l_{eff}$) to its least radius of gyration ($r$), is called slenderness ratio.

$$\text{Slenderness ratio} = \frac{l_{eff}}{r}$$

**4.9. How can we say that column is long or short ?**

**Ans.** A column will be considered as short when the ratio of the effective length to its least lateral dimension is less than or equal to 12. When this ratio exceeds 12, the column will be considered as long column.

**4.10. Classify the column on the basis of lateral reinforcement.**

**Ans.** A reinforced concrete column can also be classified according to the manner in which the longitudinal bars are laterally supported that is,

i. Tied column, and

ii. Spiral column.

**4.11. Explain the codal provision used in compressive members with helical reinforcement.**

**AKTU 2015-16, Marks 02**

**Ans.** Codal provision are given below :

i. **Diameter of Helical Reinforcement :** The diameter of the helical reinforcement shall not be less than one fourth of the diameter of the largest longitudinal bar and in no case less than 6 mm.



ii. **Pitch of Helical Reinforcement :** The pitch of the helical turns shall not be neither more than 75 mm, nor more than one-sixth of the core diameter of the column; nor less than 25 mm, nor less than three times of the diameter of the steel bar forming the helix.

**4.12. What are the functions of transverse reinforcement in compression member ?**

**Ans.** Functions of transverse reinforcement are as follows :

i. To hold the longitudinal reinforcement in position at the time of concreting.

ii. To prevent longitudinal buckling of longitudinal reinforcement.

iii. To confine the concrete thereby preventing its longitudinal splitting.

iv. To impart ductility to the column.

**4.13. Give the applications of longitudinal reinforcement.**

**Ans.** Applications of longitudinal reinforcement are given below :

i. To resist tensile stresses caused by eccentric load, moment, transverse load.

ii. To prevent sudden brittle failure of the column.

iii. To reduce the effects of creep and shrinkage due to sustained loading.

**4.14. What is pedestal and where does it use ?**

**AKTU 2016-17, Marks 02**

**Ans.** The compression member whose effective length is less than three times its least lateral dimensions is called pedestal. These can be used in building, bridges, supporting system of tanks, etc.

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# 5 UNIT Structural Behavior of Footing and Retaining Wall (2 Marks Questions)

**5.1. Differentiate between shallow foundation and deep foundation.**

**AKTU 2017-18, Marks 02**

**Ans.**

| S. No. | Shallow Foundation | Deep Foundation |
|---|---|---|
| 1. | Shallow foundation is a type of foundation in which depth of footing is less than or equal to width of footing, $D_f \leq B$ | Deep foundation is the foundation in which the depth of footing is much greater than the width of footing, $B < D_f$ |
| 2. | **Example :** Isolated footing, Combined footing, etc. | **Example :** Pile foundation, Pier foundation, etc. |

**5.2. Explain safe bearing pressure.**

**Ans.** The intensity of the load at the base of the foundation that the soil can sustain without undergoing settlement more than the permissible value for the structure is known as safe bearing pressure.

**5.3. Define ultimate bearing pressure.**

**Ans.** Ultimate bearing pressure or ultimate bearing capacity is the intensity of the loading at the base of foundation which will cause shear failure of the soil support.

**5.4. On which parameters, variation of pressure depends ?**

**Ans.** Following are the various parameters on which pressure depends :

i. Rigidity of the footing base.
ii. Size of footing.
iii. Type of underlying soil.
iv. Depth of the base of footing.

**5.5. Classify the types of combined footing or multiple column footing.**

**Ans.** Following are the various types of combined footing :

i. Rectangular footings.
ii. Trapezoidal footings.



iii. Strap footings.

**5.6. Define depth of foundation.**

**Ans.** The depth of foundation is the depth measured from the ground level to the bottom level of the base concrete. The depth of foundation should be such as to project the foundation concrete and soil below the foundation.

**5.7. What is retaining wall ?**

**Ans.** A retaining wall is a structure constructed primarily to retain or support earth or some other material in a relatively vertical position on one or both sides of it at different heights.

**5.8. Write the name of types of retaining wall.**

**AKTU 2017-18, Marks 02**

**Ans.** Retaining walls may be classified according to their mode of resisting the earth pressure, and according to their shape. Some types of retaining walls are :

i. Gravity walls,
ii. Cantilever retaining walls,
(a) T-shaped, and
(b) L-shaped.
iii. Counterfort retaining walls, and
iv. Buttressed walls.

**5.9. Define the angle of repose.**

**Ans.** The materials like earth, loose stone, when unsupported, attain a natural slope, the angle of which to the horizontal is known as angle of repose. It varies with the type of material and its moisture content.

**5.10. What is surcharge ?**

**Ans.** The portion of the backfill lying above a horizontal plane at the top of the wall is called surcharge.

**5.11. What are the stability requirements for the retaining walls ?**

**Ans.** The stability requirements for the retaining walls are as follows :

i. The restoring moment should be more than the overturning moment so as to get a factor of safety not less than 1.55.
ii. The vertical pressure on the soil under the base should not exceed the permissible bearing pressure on soil.
iii. The restoring force against sliding should not be more than sliding force so as to get a factor of safety not less than 1.55.

**5.12. What are the different forces acting on retaining wall ?**

**Ans.** The forces acting on the retaining walls may be grouped as :

i. Self weight of retaining wall.
ii. Weight of the soil on the heel.
iii. Vertical component of the soil pressure.
iv. Horizontal component of the soil pressure.
v. Surcharge load.
vi. Soil reaction on the footing.
vii. Frictional force on the footing against sliding.

**5.13. Enlist the components of T or L-shaped retaining wall.**

**Ans.** These are the various components of T or L-shaped retaining walls :

i. Stem.
ii. Heel slab.
iii. Toe slab.
iv. Shear key (if required).

**5.14. Define backfill.**

**Ans.** It is the soil material which is placed into an area that has been excavated, such as against retaining walls and in pipe trenches.

**5.15. What is active earth pressure ?**

**Ans.** It is the pressure developed when the soil mass stretches due to movement of a retaining wall away from the soil.

**5.16. Define passive earth pressure.**

**Ans.** It is the pressure developed when the soil mass compress due to movement of a retaining wall towards the soil.

**5.17. Discuss the significance of base key in retaining wall.**

**Ans.** When all the reliable resisting force to sliding are calculated and still the factor of safety is less than 1.55 then, a base key is provided to get additional resisting force to sliding due to passive earth pressure.

**5.18. List the principles in design of strap footing.**

**AKTU 2016-17, Marks 02**

**Ans.** Three basic considerations for strap footing design are :

1. Strap must be rigid—perhaps $I_{strap}/I_{footing} > 2$. This rigidity is necessary to control rotation of the exterior footing.
2. Footings should be proportioned for approximately equal soil pressures and avoidance of large differences in columns to reduce differential settlement.
3. Strap should be out of contact with soil so that there are no soil reactions.

**5.19. What are the situations in which combined footings are preferred over isolated footings ?**

**AKTU 2016-17, Marks 02**

**Ans.** Combined footing is provided in the following circumstances :

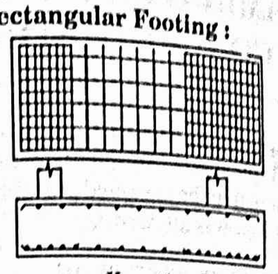
i. Width of the foundation is restricted.
ii. Projection of the footing parallel to the length of footing is restricted on one side.



**5.20. Draw a typical reinforcement detail of combined rectangular and trapezoidal footings.**

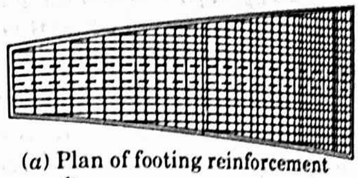
**AKTU 2016-17, Marks 02**

**Ans.** **A. Combined Rectangular Footing :**

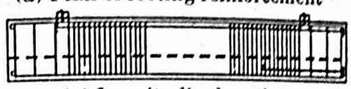


X-section
**Fig. 1.**

**B. Reinforcement Detail of Trapezoidal Footing :**



(*a*) Plan of footing reinforcement



(*a*) Longitudinal section
**Fig. 2.**

**5.21. Write short notes on segmental retaining walls.**

**AKTU 2016-17, Marks 02**

**Ans.** Segmental retaining walls consist of modular concrete blocks that interlock with each other. They are used to hold back a sloping face of soil to provide a solid, vertical front. Without adequate retention, slopes can cave, slump or slide.

**5.22. What are the two theories for calculating earth pressure on retaining wall ?**

**AKTU 2016-17, Marks 02**

**Ans.** These are the following theories which are used to calculate lateral earth pressure :

i. Coulomb's theory,
ii. Rankine's theory.

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# B. Tech.
## (SEM. V) ODD SEMESTER THEORY EXAMINATION, 2013-14
## DESIGN OF CONCRETE STRUCTURES-I

**Time : 3 Hours** **Max. Marks : 100**

**Note :** 1. Attempt all questions. All question carry equal marks. Any data if missing may be assumed suitably.
2. Use of IS code 456 is allowed.

1. Attempt any two of the following : (2 × 10 = 20)

a. **Do the design mix for M 20 concrete for moderate exposure for which standard deviation is 4.6 and water cement ratio is 0.52. The coarse aggregate is 20 mm graded and sand is of grading zone II, SP. gravity of cement is 3.15, SP. gravity of coarse aggregate and sand is 2.6.**

**Ans.** This Question is Out of Syllabus from Session 2018-19.

b. **Design a rectangular beam section to carry 160 kN-m moment with M 20 concrete and Fe415 steel. The overall depth of the beam is restricted to 270 mm.**

**Ans.** Refer Q. 1.13, Page 1–16A, Unit-1.

c. **A beam section 230 mm × 300 mm effective depth is reinforced with 2 bars of 12 mm diameter. Determine its moment capacity and stresses developed in concrete and steel, used concrete is M 20 and steel Fe 415.**

**Ans.** Refer Q. 1.6, Page 1–10A, Unit-1.

2. Attempt any two parts of the following : (2 × 10 = 20)

a. **Determine reinforcement of a rectangular beam 300 mm wide and 400 mm effective depth. The beam is subjected to a factored bending moment of 150 kN-m. Use M-20 concrete and Fe-250 steel.**

**Ans.** Refer Q. 1.26, Page 1–29A, Unit-1.

b. **A rectangular beam 200 mm wide and 400 mm effective depth is reinforced with 3 bars of 16 mm diameter. If grade of concrete is M20 and grade of steel Fe415, determine bending moment capacity of the beam.**

**Ans.** Refer Q. 1.18, Page 1–22A, Unit-1.

c. **A T-beam, casted with M20 concrete and Fe415 steel, has following dimensions.**

| | | |
|---|---|---|
| **Width of flange** | = | **2400 mm** |
| **Depth of flange** | = | **100 mm** |
| **Width of web** | = | **250 mm** |
| **Overall depth of beam** | = | **450 mm** |
| **Effective cover to reinforcement** | = | **50 mm** |
| **Tension reinforcement** | = | **2 bars of 16 mm dia.** |

**Determine moment of resistance of the beam.**

**Ans.** Refer Q. 1.31, Page 1–36A, Unit-1.

3. Attempt any two parts of the following : (2 × 10 = 20)

a. **What is bond strength of concrete ? Derive expression for bond stress in reinforced concrete.**

**Ans.** Refer Q. 2.11, Page 2–13A, Unit-2.

b. **A concrete beam is 300 mm wide and 600 mm effective depth and is reinforced with 4 bars of 25 mm diameter bars in tension zone. Design shear reinforcement at a section experiencing shear force of 100 kN. Use M 20 concrete and Fe 415 steel.**

**Ans.** Refer Q. 2.7, Page 2–8A, Unit-2.

c. **A cantilever beam is 230 mm wide and 400 mm deep at fixed end. Its span is 3 m and it carries a UDL 18 kN/m inclusive of self weight. Two bars of 20 mm diameter have been provided in tension zone. Design required shear reinforcement if concrete is of grade M20.**

**Ans.** Refer Q. 2.10, Page 2–11A, Unit-2.

4. Attempt any two parts of the following : (2 × 10 = 20)

a. **Internal dimensions of a room are 3 m × 4 m, it is resting over beams 300 mm wide. The live load on slab is 4kN/m². Design the slab with M 20 concrete and Fe 415 steel. Show reinforcement by neat sketches.**

**Ans.** Refer Q. 3.11, Page 3–18A, Unit-3.

b. **A 3 m wide gallery is connecting two blocks. The slab of gallery is resting over two longitudinal beams. The slab is supporting a live load of 3 kN/m². Design gallery slab and show the details with neat sketches. Use M20 concrete.**

**Ans.** Refer Q. 3.5, Page 3–8A, Unit-3.

c. **Design slab for a room which is 3.5 m × 5 m. The two adjacent edges are continuous. The slab is supporting live load of 4 kN/m² and floor finish of 1 kN/m². Use M 25 concrete and Fe 415 steel; design the slab.**

**Ans.** Refer Q. 3.16, Page 3–31A, Unit-3.

5. Attempt any two parts of the following : (2 × 10 = 20)

a. **What are interactive curves used in the design of columns ? How these curves are used in design of columns subjected to axial load and moments ?**

**Ans.** Refer Q. 4.15, Page 4–18A, Unit-4.

b. **An RCC circular column of effective length 2.40 m carrying an axial service load 900 kN. Design column with M20 concrete and Fe 415 steel.**

**Ans.** Refer Q. 4.12, Page 4–15A, Unit-4.

c. **Design a reinforced concrete column which is 4.5 m long and fixed at both ends. It is carrying an axial load of 2000 kN (service). Use M 25 concrete and Fe415 steel.**

**Ans.** Refer Q. 4.7, Page 4–8A, Unit-4.

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# B. Tech.

# (SEM. V) ODD SEMESTER THEORY EXAMINATION, 2014-15

# DESIGN OF CONCRETE STRUCTURES-I

**Time : 3 Hours** **Max. Marks : 100**

**Note :** 1. Attempt **all** questions. All question carry equal marks.
2. Any data if missing may be assumed suitably.
3. Use of IS code 456-2000 is allowed.

1. Attempt any **four** parts of the following : **(4 × 5 = 20)**

a. **What is meant by segregation and bleeding of concrete ? Under what circumstances, they take place.**

**Ans.** This Question is Out of Syllabus from Session 2018-19.

b. **Explain the following terms :**
i. **Balanced section.**
ii. **Under-reinforced section.**
iii. **Over-reinforced section.**

**Ans.** Refer Q. 1.3, Page 1–5A, Unit-1.

c. **What are various design philosophies ? Explain any one of these in detail.**

**Ans.** Refer Q. 1.1, Page 1–2A, Unit-1.

d. **Explain why is the concrete cover to reinforcement required ?**

**Ans.** Refer Q. 1.19, 2 Marks Questions, Page SQ–4A, Unit-1.

e. **Under what circumstances a doubly reinforced beam is designed ?**

**Ans.** Refer Q. 1.10, Page 1–14A, Unit-1.

f. **What is meant by limit state ? Discuss the different limit state to be considered in reinforced concrete design.**

**Ans.** Refer Q. 1.16, Page 1–21A, Unit-1.

2. Attempt any **two** parts of the following : **(2 × 10 = 20)**

a. **Design the section of a doubly reinforced beam to resist a bending moment of 185 kN-m. The section of the beam is restricted to 350 mm × 700 mm. Assume 50 mm effective cover. Use M20 grade of concrete and Fe415 steel.**

**Ans.** Refer Q. 1.27, Page 1–30A, Unit-1.

b. Analyze a T-beam for the following data $b_f$ = 1500 mm, $D_f$ = 100 mm, $D$ = 600 mm, $b_w$ = 300 mm, $f_{ck}$ = 150 N/mm², $f_y$ = 415 N/mm², $A_{st}$ = 8 bars of 20 mm dia with effective cover 65 mm.

**Ans.** Refer Q. 1.32, Page 1–36A, Unit-1.

c. A cantilever beam project 2.5 m beyond the fixed end and carries a superimposed load of 10 kN/m. Design the cantilever using M20 grade concrete and Fe415 steel. Take width of support = 350 mm.

**Ans.** Refer Q. 1.35, Page 1–40A, Unit-1.

3. Attempt any two parts of the following : (2 × 10 = 20)

a. Determine the shear stress in a 250 mm × 400 mm effective depth rectangular section. If the shear force is 10 kN and torsional moment is 2 kN-m at factored loads. Assume 0.25 % tension steel at the given section. State whether torsional reinforcement is required or not. Use M20 grade concrete and Fe415 steel.

**Ans.** Refer Q. 2.16, Page 2–18A, Unit-2.

b. A simply supported RC beam of size 300 mm × 500 mm effective depth is reinforced with 4 bars of 16 mm dia. Determine the anchorage length of the bar at the simply supported end. If it is subjected to a factored shear force of 350 kN at the centre of 300 mm wide masonry support. Use M20 grade of concrete and Fe415 steel.

**Ans.** Refer Q. 2.13, Page 2–15A, Unit-2.

c. A simply supported RC beam section 250 mm × 500 mm effective depth is reinforced with 4 bars of 22 mm dia as tension steel. If the beam is subjected to a factored shear of 65 kN at the support. Find the nominal shear stress at the support and design the shear reinforcement. Use M20 grade concrete and Fe415 steel.

**Ans.** Refer Q. 2.6, Page 2–7A, Unit-2.

4. Attempt any two parts of the following : (2 × 10 = 20)

a. What do you understand by the term "Limit state of serviceability" ? Explain the method of calculating long term deflection.

**Ans.** **Limit state of serviceability : Refer Q. 3.18, Page 3–34A, Unit-3.**
**Long Term deflection : Refer Q. 3.19, Page 3–35A, Unit-3.**



b. Design a RC slab for a room measuring 6 m × 7 m size. The slab is simply supported on all the four edges, with corners held down and carries a super imposed load of 3500 N/m², inclusive of floor finish etc. Use M20 grade concrete and Fe415 steel.

**Ans.** Refer Q. 3.12, Page 3–21A, Unit-3.

c. Design a simply supported roof slab for a room 7.5 m × 3.5 m clear in size. The slab is carrying an imposed load of 5 kN/m². Use M20 grade concrete and Fe415 steel.

**Ans.** Refer Q. 3.4, Page 3–5A, Unit-3.

5. Attempt any two parts of the following : (2 × 10 = 20)

a. What are interactive curves ? Explain the failure of a column subjected to compression and uniaxial bending with the help of interaction curve.

**Ans.** **Interactive Curves :** Refer Q. 4.15, Page 4–18A, Unit-4.
**Failure of Column :** Refer Q. 4.16, Page 4–19A, Unit-4.

b. Design a reinforced concrete square column of 500 mm side to carry an ultimate load of 2000 kN at an eccentricity of 180 mm. Use M20 grade concrete and Fe415 steel.

**Ans.** Refer Q. 4.17, Page 4–20A, Unit-4.

c. A circular RCC column of 450 mm dia is reinforced with 8 bars of 18 mm dia and are tied together with helical reinforcement of 8 mm dia at a pitch of 60 mm c/c. Find load carrying capacity of the column, when effective length of column is 4.5 m. Take clear cover to helical reinforcement 50 mm. Use M20 grade concrete and Fe415 steel.

**Ans.** Refer Q. 4.14, Page 4–16A, Unit-4.

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# B. Tech.
# (SEM. V) ODD SEMESTER THEORY EXAMINATION, 2015-16
# DESIGN OF CONCRETE STRUCTURES-I

**Time : 3 Hours** **Max. Marks : 100**

## Section-A

1. Attempt all parts. All parts carry equal marks. Write answer of each part in short : **(10 × 2 = 20)**

**a. What is modular ratio ? Determine the modular ratio at M20 grade concrete.**

**Ans.** Refer Q. 1.2, 2 Marks Questions, Page SQ–1A, Unit-1.

**b. Define characteristic strength.**

**Ans.** Refer Q. 1.6, 2 Marks Questions, Page SQ–2A, Unit-1.

**c. Define limit state of serviceability.**

**Ans.** Refer Q. 1.16, 2 Marks Questions, Page SQ–3A, Unit-1.

**d. Define factor of safety and load factor.**

**Ans.** Refer Q. 1.8, 2 Marks Questions, Page SQ–2A, Unit-1.

**e. What do you mean by flexural shear cracks ?**

**Ans.** Refer Q. 2.3, 2 Marks Questions, Page SQ–5A, Unit-2.

**f. Enumerate types of shear reinforcement with neat sketch.**

**Ans.** Refer Q. 2.13, 2 Marks Questions, Page SQ–6A, Unit-2.

**g. Define one way slab and two way slab.**

**Ans.** Refer Q. 3.9, 2 Marks Questions, Page SQ–10A, Unit-3.

**h. Explain main steel and distribution steel in slab.**

**Ans.** **Main Steel :** Refer Q. 3.10, 2 Marks Questions, Page SQ–10A, Unit-3.
**Distribution Steel :** Refer Q. 3.11, 2 Marks Questions, Page SQ–10A, Unit-3.

**i. Enumerate different types of column.**

**Ans.** Refer Q. 4.7, 2 Marks Questions, Page SQ–13A, Unit-4.

**j. Explain the codal provisions used in compression members with helical reinforcement.**

**Ans.** Refer Q. 4.11, 2 Marks Questions, Page SQ–13A, Unit-4.



## Section - B

Attempt five questions from this section. **(5 × 10 = 10)**

**2. The moment of resistance of rectangular reinforced concrete beam of breadth 'b' and effective depth 'd' cm is '0.9 $bd^2$'. If the stress in the outside fibre of concrete and in the steel do not exceed 5 N/mm² and 140 N/mm² respectively. And the modular ratio equals 18, determine the ratio of depth of the neutral axis from the outside compression fibre to the effective depth of the beam and the ratio of area of tension steel to the effective area of the beam. The beam is reinforced for tension only.**

**Ans.** Refer Q. 1.5, Page 1–9A, Unit-1.

**3. Design a reinforced concrete beam subjected to a BM of 20 kN-m. Use M20 concrete Fe 415 reinforcement. Keep the width of the beam equal to half the effective depth.**

**Ans.** Refer Q. 1.20, Page 1–25A, Unit-1.

**4. What are the assumptions for the design of reinforce concrete section for limit state of collapse in bending? Derive the stress block parameters for a rectangular cross section.**

**Ans.** Refer Q. 1.15, Page 1–19A, Unit-1.

**5. Design a rectangular beam for an effective span 6 m. The superimposed load or live load 80 kN/m and the size is limited to 300 mm width and 700 mm overall depth. Use M20 concrete mix and Fe 415 steel.**

**Ans.** Refer Q. 1.28, Page 1–31A, Unit-1.

**6. A RC beam has an effective depth of 400 mm and breadth of 300 mm. It contains 3-25 mm Fe 500 grade bars in tension. Determine the shear reinforcement needed for a factored SF of 250 kN if M30 mix is used.**

**Ans.** Refer Q. 2.8, Page 2–9A, Unit-2.

**7. Design a one way slab, with a clear span of 4.0 m, simply supported on 230 mm thick masonry walls and subjected to a live load of 4 kN/m² and a surface finish of 1 kN/m². Assume M25 mix and Fe415 grade steel.**

**Ans.** Refer Q. 3.6, Page 3–9A, Unit-3.

**8. Design a short axially loaded square column 500 × 500 mm for a working load of 2000 kN. Use M20 concrete and Fe 415 grade steel.**

**Ans.** Refer Q. 4.9, Page 4–10A, Unit-4.

9. **Design a circular column to carry an axial load of 1000 kN. Use M20 mix and Fe 415 grade steel.**

**Ans.** Refer Q. 4.13, Page 4–16A, Unit-4.

## Section-C

**Note : Attempt any two question from this section. (2 × 15 = 30)**

10. **Design the torsional reinforcement in a rectangular beam section, 350 mm wide and 750 mm deep, subjected to an ultimate twisting moment of 140 kN-m, combined with an ultimate BM of 200 kN-m and an ultimate SF of 110 kN. Assume M25 concrete and Fe415 grade of steel.**

**Ans.** Refer Q. 2.17, Page 2–19A, Unit-2.

11. **Design a SS slab to cover a room of internal dimensions of 4 m × 6 m and 230 mm thick brick walls all around. It carries live load of 3 kN/m² and floor finish of 1 kN/m². Use M20 concrete and Fe415 steel. Consider that the slab corners are prevented from lifting.**

**Ans.** Refer Q. 3.13, Page 3–21A, Unit-3.

12. **A T-beam floor consists of 150 mm thick RC slab monolithic with 300 mm wide beams. The beams are spaced at 3.5 m centre to centre and their effective span is 6 m. If the superimposed loads on the slab is 5 kN/m². Design an intermediate T-beam. Use M20 mix and Fe 250 grade steel.**

**Ans.** Refer Q. 1.34, Page 1–38A, Unit-1.

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# B. Tech.
# (SEM. V) ODD SEMESTER THEORY EXAMINATION, 2016-17
# DESIGN OF CONCRETE STRUCTURES-I

**Time : 3 Hours** **Max. Marks : 100**

## Section-A

1. **Attempt all parts. All parts carry equal marks. Write answer of each part in short. (10 × 2 = 20)**

a. **What is pedestal and where does it use ?**

**Ans.** Refer Q. 4.14, 2 Marks Questions, Page SQ–14A, Unit-4.

b. **Write the measure to control the deflection in slab.**

**Ans.** Refer Q. 3.15, 2 Marks Questions, Page SQ–11A, Unit-3.

c. **Define admixture ? List different types of admixtures.**

**Ans.** This Question is Out of Syllabus from Session 2018-19.

d. **Write situations in which one-way behaviour can be assumed of a slab supported on four sides.**

**Ans.** Refer Q. 3.16, 2 Marks Questions, Page SQ–11A, Unit-3.

e. **State water-cement law and how does it influence the strength of concrete ?**

**Ans.** This Question is Out of Syllabus from Session 2018-19.

f. **How is it determine whether a beam of a given dimension is to be designed as doubly reinforced ?**

**Ans.** Refer Q. 1.17, 2 Marks Questions, Page SQ–3A, Unit-1.

g. **What is meant by shear lag in T-beams ?**

**Ans.** Refer Q. 1.24, 2 Marks Questions, Page SQ–4A, Unit-1.

h. **How does the shear span influence the mode of shear failure ?**

**Ans.** Refer Q. 2.22, 2 Marks Questions, Page SQ–8A, Unit-2.

i. **How are slabs classified ? List the various classifications.**

**Ans.** Refer Q. 3.2, 2 Marks Questions, Page SQ–12A, Unit-3.

j. **What is the role of minimum eccentricity in the design of column ?**

**Ans.** Refer Q. 4.5, 2 Marks Questions, Page SQ–12A, Unit-4.

## Section-B

2. Attempt any five questions from this section. (5 × 10 = 50)

a. A rectangular beam section is 20 cm wide and 35 cm deep upto the centre of reinforcement. Determine the reinforcement required at the bottom if it has to resist a factored moment of

i. 5 kN-m.

ii. 40 kN-m. Use M 25 mix concrete and TOR steel.

**Ans.** Refer Q. 1.19, Page 1–23A, Unit-1.

b. i. Discuss the salient features of working stress method and ultimate load method.

**Ans.** Refer Q. 1.1, Page 1–2A, Unit-1.

ii. Discuss the need and salient features of performance based design.

**Ans.** This Question is Out of Syllabus from Session 2018-19.

c. Design a doubly reinforced section for a rectangular beam at midspan having a simply supported effective span of 4 m. The superimposed load is 40 kN/m and section of beam is limited to 25 cm × 40 cm overall. Assume suitable data.

**Ans.** Refer Q. 1.29, Page 1–33A, Unit-1.

d. Design a singly reinforced concrete beam of width 300 mm, subjected to an ultimate moment of 250 kN-m. Assume $f_{ck}$ = 25 MPa and $f_y$ = 415 MPa.

**Ans.** Refer Q. 1.21, Page 1–26A, Unit-1.

e. Determine the ultimate moment of resistance of a doubly reinforced beam section with the following data : $b$ = 350 mm, $d$ = 550 mm, $d'$ = 60 mm, $A_{st}$ = 5 – 32 mm $\phi$ bars, $A_{sc}$ = 3 – 25 mm $\phi$ bars, $f_y$ = 415 MPa and $f_{ck}$ = 25 MPa.

**Ans.** Refer Q. 1.25, Page 1–28A, Unit-1.

f. A rectangular beam of size 250 mm width and 500 mm effective depth is reinforced with four bars of 25 mm diameter. Determine the required vertical shear reinforcement to resist factored shear force of

i. 80 kN ii. 300 kN, and iii. 600 kN.

Consider concrete of grade M 20 and steel of grade Fe 415.

**Ans.** Refer Q. 2.9, Page 2–10A, Unit-2.

g. A hall in a building has a floor consisting of continuous slab cast monolithically with simply supported 230 mm wide beams spaced at 3.5 m c/c. The clear span of the beam is 6 m. Assuming the live load on slab as 3.0 kN/m² and partition plus load due to finishes as 1.5 kN/m², design the slab with M 25 grade concrete and Fe 415 steel.



**Ans.** Refer Q. 3.17, Page 3–32A, Unit-3.

h. A hall measures 10 m × 6 m inside and has walls 400 mm thick. Design a suitable reinforced concrete T beam roof to carry a superimposed load of 2 kN/m². Use M20 grade concrete and Fe415 grade steel.

**Ans.** Refer Q. 3.14, Page 3–22A, Unit-3.

## Section-C

**Note.** Attempt any two questions from this section : (2 × 15 = 30)

3. A column height of 1.5 m is pinned at the bottom effectively restrained against rotation but not held in position at the top. It is subjected to a factored axial load of 2500 kN under the combination of dead load and live load. Design the column, using M 30 concrete and Fe 415 steel.

**Ans.** Refer Q. 4.8, Page 4–10A, Unit-4.

4. a. A rectangular cantilever beam of span 3.5 m is 30 cm × 50 cm. Bending moment at the fixed end due to uniformly distributed service load is 100 kN-m out of which 40 % moment is due to permanent loads. Check the beam for deflection. Assume M 25 concrete.

**Ans.** Refer Q. 3.20, Page 3–38A, Unit-3.

b. Describe $P_u - M_u$ interaction diagram used in the analysis of eccentric column.

**Ans.** Refer Q. 4.16, Page 4–19A, Unit-4.

5. Design a continuous two-way slab system shown in Fig. 7. It is subjected to an imposed load of 3 kN/m² and surface finish of 1 kN/m². Consider M 25 concrete, grade Fe 415 steel, and moderate environment. Assume that the supporting beams are 230 mm × 500 mm.

**Ans.** Refer Q. 3.15, Page 3–28A, Unit-3.

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# B.Tech.

## (SEM. V) ODD SEMESTER THEORY EXAMINATION, 2017-18

## DESIGN OF CONCRETE STRUCTURE-I

**Time : 3 Hours** **Max. Marks : 100**

**Note :** Attempt all sections. Assume any missing data.

### SECTION–A

1. Attempt all questions in brief. (2 × 10 = 20)

a. **What is modular ratio ?**

**Ans.** Refer Q. 1.2, 2 Marks Questions, Page SQ–1A, Unit-1.

b. **Determine the modular ratio of M20 grade concrete.**

**Ans.** Refer Q. 1.2, 2 Marks Questions, Page SQ–1A, Unit-1.

c. **What is effective depth in a beam section ?**

**Ans.** Refer Q. 1.20, 2 Marks Questions, Page SQ–4A, Unit-1.

d. **What is minimum grade of concrete for general reinforced concrete work recommended by the IS code-456 : 2000.**

**Ans.** Refer Q. 1.21, 2 Marks Questions, Page SQ–4A, Unit-1.

e. **What is determined in slump cone test ?**

**Ans.** This Question is Out of Syllabus from Session 2018-19.

f. **What is neutral axis ?**

**Ans.** Refer Q. 1.22, 2 Marks Questions, Page SQ–4A, Unit-1.

g. **What is effective cover ?**

**Ans.** Refer Q. 1.23, 2 Marks Questions, Page SQ–4A, Unit-1.

h. **What is lever arm ?**

**Ans.** Refer Q. 1.18, 2 Marks Questions, Page SQ–4A, Unit-1.

i. **What is creep of concrete ?**

**Ans.** This Question is Out of Syllabus from Session 2018-19.

j. **What is shrinkage of concrete ?**

**Ans.** This Question is Out of Syllabus from Session 2018-19.



### SECTION–B

2. Attempt any **three** of the following : (10 × 3 = 30)

a. **Write short note on water-cement ratio.**

**Ans.** This Question is Out of Syllabus from Session 2018-19.

b. **Write assumption made in working stress method.**

**Ans.** Refer Q. 1.1, Page 1–2A, Unit-1.

c. **What are the over reinforced section and under reinforced section.**

**Ans.** Refer Q. 1.3, Page 1–5A, Unit-1.

d. **Write formula to determine the moment of resistance of over reinforced section and under reinforced section. With diagram of section.**

**Ans.** Refer Q. 1.3, Page 1–5A, Unit-1.

e. **What is critical section and critical neutral axis ?**

**Ans.** Refer Q. 1.3, Page 1–5A, Unit-1.

### SECTION–C

3. Attempt any **one** part of the following : (10 × 1 = 10)

a. **Cross section of a singly reinforced concrete beam is 300 mm wide and 500 mm deep. To centre of reinforcement which consist of 4 bars of 16 mm diameter. If stresses in concrete and steel are not exceed 7 N/mm$^2$ and 140 N/mm$^2$, respectively. Determine the moment of resistance of beam. Take $m$ = 13.33.**

**Ans.** Refer Q. 1.7, Page 1–11A, Unit-1.

b. **A singly reinforced concrete beam in 300 mm wide and 450 mm deep to the centre of reinforcement which consists of 4 bars of 16 mm diameter. If safe stress in concrete and steel are 7 N/mm$^2$ and 230 N/mm$^2$, respectively. Find moment of resistance of section. Take $m$ = 13.33.**

**Ans.** Refer Q. 1.8, Page 1–11A, Unit-1.

4. Attempt any **one** part of the following : (10 × 1 = 10)

a. **A singly reinforced rectangular beam 350 mm wide has a span of 6.25 m and carries a load of 16.3 kN/m. If stresses in concrete and steel shall not exceed 7 N/mm$^2$ and 230 N/mm$^2$. Find the effective depth and area of tensile reinforcement. Take $m$ = 13.33.**

**Ans.** Refer Q. 1.9, Page 1–12A, Unit-1.

**b. A doubly reinforced rectangular beam is 300 mm wide and 500 mm deep to centre of tension steel. It is reinforced with 4 bars of 18 mm dia. as compressive steel at an effective cover of 40 mm and with 4 bars of 20 mm dia. as tensile steel. If stresses in concrete and steel are not to exceed 7 N/mm² and 230 N/mm², respectively. Find moment of resistance of section. Take $m$ = 13.33.**

**Ans.** Refer Q. 1.12, Page 1–15A, Unit-1.

5. Attempt any one part of the following : **(10 × 1 = 10)**

**a. A beam of reinforcement concrete is 300 mm wide and 450 mm deep to centre of tension steel. It is reinforced with 4 bars of 16 mm dia. as compressive steel and 4 bars of 25 mm dia. as tensile steel. Determine the moment of resistance of section. Cover to centre of compressions steel = 50 mm use M20 concrete and Fe415 steel. Take $m$=13.33.**

**Ans.** Refer Q. 1.14, Page 1–18A, Unit-1.

**b. What is meant by segregation and bleeding of concrete ?**

**Ans.** This Question is Out of Syllabus from Session 2018-19.

6. Attempt any **one** part of the following : **(10 × 1 = 10)**

**a. A singly reinforced beam 250 mm wide is 400 mm deep to the centre of tensile reinforcement, determine the limiting moment of resistance of beam section and limiting area of reinforcement. Use M20 concrete and Fe250 steel.**

**Ans.** Refer Q. 1.22, Page 1–26A, Unit-1.

**b. A beam of rectangular section 300 mm wide and 500 mm effective depth is provided with 4 bars of 18 mm dia as tensile steel. Find depth of neutral axis, use M20 concrete and Fe250 steel.**

**Ans.** Refer Q. 1.17, Page 1–22A, Unit-1.

7. Attempt any one part of the following : **(10 × 1 = 10)**

**a. A T beam of flange width 1400 mm, flange thickness 100 mm, rib width 300 mm and effective depth 500 mm has to be designed as a balanced section. Find the reinforcement required and limiting moment of resistance. Use M20 concrete and Fe250 steel.**

**Ans.** Refer Q. 1.33, Page 1–38A, Unit-1.

**b. A reinforced concrete column is 450 mm × 400 mm and has to carry a factored load of 1800 kN. Length of column is 2 m. Find area of reinforcement required. Use M20 concrete and Fe 250 steel.**

**Ans.** Refer Q. 4.10, Page 4–11A, Unit-4.

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# B. Tech.

# (SEM. VI) EVEN SEMESTER THEORY EXAMINATION, 2018-19

# DESIGN OF STRUCTURES-II

**Time : 3 Hours** **Max. Marks : 70**

**Note :** 1. Attempt all sections. Assume missing data suitable, if any.
2. Use of IS 456:2000 permitted.

## Section-A

1. Attempt all questions in brief. **(7 × 2 = 14)**

**a. Find the depth of neutral axis and lever arm for a balanced section of a singly reinforced beam using M20 and Plain steel by WSM.**

**Ans.** Refer Q. 1.2, Page 1–4, Unit-1.

**b. Draw the strain diagram of a singly reinforced beam for LSM.**

**Ans.** Refer Q. 1.2, (Fig. 1.2.1), Page 1–5, Unit-1.

**c. Give two examples of structures subjected to torsional moments.**

**Ans.** Structures subjected to torsional moments :
i. L-beam.
ii. Beam curved in plan.

**d. Why helical reinforcement better than lateral ties in circular column ?**

**Ans.** Circular concrete column reinforced with helical reinforcement can withstand more loads than tied column. This phenomenon happens because when load eccentricities are small, spirally or helically reinforced columns shows greater toughness, greater ductility than the circular columns with lateral ties.

**e. What is the difference between main bars and distribution bars in slab ?**

**Ans.** **Main Bars :** Refer Q. 3.10, 2 Marks Questions, Page SQ–10A, Unit-3.
**Distribution Bars :** Q. 3.11, 2 Marks Questions, Page SQ–10A, Unit-3.

**f. Draw the diagram of counterfort retaining wall.**

**Ans.** Refer Q. 5.13, (Fig. 5.13.1(c)), Page 5–31, Unit-5.

**g. What are the uses of shear key in retaining wall ?**

**Ans.** Refer Q. 5.17, 2 Marks Questions, Page SQ–17A, Unit-5.

## Section-B

**2. Attempt any three of the following :** **(3 × 7 = 21)**

**a. Find the moment of resistance of an RCC cantilever beam of 300 mm width and 500 mm effective depth reinforced with 2 bars of 16 mm diameter. Use M 20 concrete and Fe 415 steel. Also find the safe load, including its self weight, if the span of the beam is 2 m. Use working stress method and design.**

**Ans.**

**Given :** Width, $b$ = 300 mm, Effective depth, $d$ = 500 mm, Reinforcement = 2 – 16$\phi$ mm, Grade = M 20 and Fe 415, Span = 2 m
**To Find :** Moment of resistance, safe load.

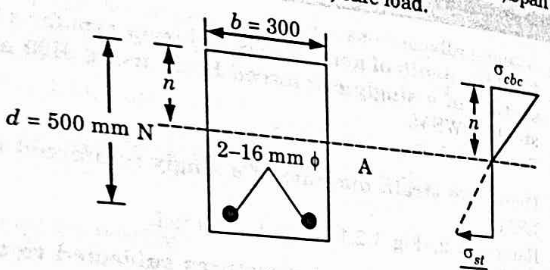


Fig. 1.

**1. Calculate the Critical Neutral Axis :**

$$k = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}}$$

for $M_{20}$, $\sigma_{cbc}$ = 7N/mm²
for Fe 415, $\sigma_{st}$ = 230 N/mm²

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33$$

$$k = \frac{13.33 \times 7}{13.33 \times 7 + 230} = 0.289$$

Critical neutral axis, $n_c = kd = 0.289 \times 500 = 144.5$ mm ...(1)

**2. Calculate the Actual Neutral Axis :**

Area moment in compression about neutral axis
= Area of moment in tension about neutral axis

$$(nb)\frac{n}{2} = m\,A_{st}\,(d - n)$$

$$n^2 \times \frac{300}{2} = 13.33 \times \left(2 \times \frac{\pi}{4} \times 16^2\right)(500 - n) \quad ...(2)$$

$$150\,n^2 = 5360.31\,(500 - n)$$

After solving equation (2) we get,
Actual neutral axis, $n$ = 117 mm
Here, $n_c > n \Rightarrow$ section is under reinforcement.




**3. Moment of Resistance :**

$$M_r = A_{st}\,\sigma_{st}(d - n/3)$$

$$= 2 \times \frac{\pi}{4}(16)^2 \times 230\left(500 - \frac{117}{3}\right) = 42.64 \text{ kN-m}$$

**4. Calculate the Safe Load :**

Moment of resistance = Moment of cantilever beam

$$42.64 = \frac{wl^2}{2}$$

$$42.64 = \frac{w \times 2^2}{2}$$

$$w = 21.32 \text{ kN/m}$$

**b. Write the steps for design of shear reinforcement for a beam.**

**Ans.** Refer Q. 2.5, Page 2–6A, Unit-2.

**c. Find the reinforcement for lintel for a window opening of 2.1 m wide. The window is centrally located in a 300 mm thick brick wall, the height of the masonry above the lintel 3 m. Use M20 concrete and Fe415 steel. Unit weight of masonry = 19 kN/m³.**

**Ans.**

**Given :** Clear span = 2.1 m, $f_{ck}$ = 20 N/mm², $f_y$ = 415 N/mm², $\gamma$ = 19 kN/m³, Thickness of brick wall = 300 mm
**To Find :** Area of reinforcement in lintel.

1. Assuming, 200 mm bearing of lintel on each wall.
Effective length of lintel, $l_{eff}$ = 2.1 + 0.2 = 2.3 m
2. Assuming 200 mm overall depth of lintel, 300 mm width of lintel and effective cover as 25 mm. So, effective depth,

$$d = 200 - 25 = 175 \text{ mm}$$

$$\therefore \quad l_{eff} = 2.1 + 0.175 = 2.275 \text{ m}$$

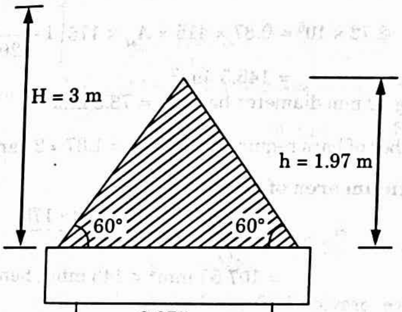


Fig. 2.

**3. Load Calculation :**

i. Height of equilateral triangle = $\frac{\sqrt{3}}{2} \times l_{eff} = \frac{\sqrt{3}}{2} \times 2.275$

$h = 1.97$ m

$1.25h = 1.25 \times 1.97 = 2.46$ m

Height of wall above lintel = 3 m > 1.25 $h$

Hence, the load of equivalent triangle will be transferred to the lintel.

ii. Total load of equilateral triangle, $W = \left(\frac{1}{2} \times 1.97 \times 2.275\right) 0.3 \times 19$

$W = 12.773$ kN

iii. Maximum bending moment due to this load at mid span

$$= \frac{WL}{6} = \frac{12.773 \times 2.275}{6} = 4.843 \text{ kN-m}$$

iv. Self weight of lintel, $w = 0.3 \times 0.2 \times 25 = 1.5$ kN/m

v. Moment due to self weight = $\frac{1.5 \times 2.275^2}{8} = 0.97$ kN-m

vi. Total moment = 4.843 + 0.97 = 5.813 kN-m

vii Ultimate moment, $M_u = 1.5 \times 5.813 = 8.72$ kN-m

**4. Depth Check :** $d_{req} = \sqrt{\frac{M_u}{R_u b}}$ [$R_u$ = 2.76, for Fe 415 and M 20]

$$= \sqrt{\frac{8.72 \times 10^6}{2.76 \times 300}} = 102.6 \text{ mm} \approx 103 \text{ mm}$$

$d_{req}$ = 103 mm < 175 mm. Hence, OK

**5. Area of Steel :** $M_u = 0.87 f_y A_{st} d\left[1 - \frac{A_{st} f_y}{f_{ck} bd}\right]$

$$8.72 \times 10^6 = 0.87 \times 415 \times A_{st} \times 175\left[1 - \frac{A_{st} \times 415}{20 \times 300 \times 175}\right]$$

We get, $A_{st} = 146.5$ mm²

Using 10 mm diameter bars, $A_\phi = 78.5$ mm²

Number of bars required = $\frac{146.5}{78.5} = 1.87 \approx 2$ bars

**6. Minimum area of steel ($A_{st\ min}$) :**

$$A_{st\ min} = \frac{0.85bd}{f_y} = \frac{0.85 \times 300 \times 175}{415}$$

$= 107.53$ mm² < 146 mm², hence OK

Hence, provide 2-10 mm diameter bars.

**7. Shear Design :**

i. Shear force, $V = \frac{W}{2} + \frac{wl}{2} = \frac{12.77}{2} + \frac{1.5 \times 2.275}{2} = 8.1$ kN

ii. Ultimate shear force, $V_u = 1.5 \times 8.1 = 12.15$ kN



iii. Shear stress, $\tau_v = \frac{12.15 \times 1000}{300 \times 175} = 0.231$ N/mm²

iv. Percentage of steel,

$$p_t = \frac{100A_{st}}{bd} = \frac{100 \times 2 \times \pi / 4 \times 10^2}{300 \times 175} = 0.3\ \%$$

v. From IS code, for $p_t$ = 0.3 % and M 20 concrete,

$$\tau_c = 0.36 + \frac{0.12}{0.25} \times 0.05$$

$\tau_c = 0.384$ N/mm²

$\therefore$ $\tau_c > \tau_v$

Hence, no shear reinforcement is required. However, providing nominal shear reinforcement using 2 legged-8$\phi$ stirrups.

vi. Spacing of stirrups, $S_v = \frac{0.87 f_y . A_{sv}}{0.4b}$

$$= \frac{0.87 \times 415 \times 100.5}{0.4 \times 300} \quad \left[\because A_{sv} = 2 \times \frac{\pi}{4} \times (8)^2\right]$$

= 302.4 mm

vii. Maximum spacing permitted = 0.75 $d$ (131.25) or 300 mm whichever is minimum.

Hence, provide 2 legged-8$\phi$ stirrups @ 130 mm c/c throughout the lintel length.

Provide 2–8 mm diameter anchor bars at top.

**8. Check for development length at supports :**

i. As no bar is curtailed

$M_1 = 8.72 \times 10^6$ N-mm

$V = 12150$ N

ii. $L_d$, for 10 mm diameter bars

$$= \frac{0.87 f_y \phi}{4\tau_{bd}} = \frac{0.87 \times 415 \times 10}{4 \times 1.6 \times 1.2} = 470.12 \text{ mm}$$

iii. Assuming, straight bars without any hook,

$l_0 = \frac{200}{2} - 25 = 75$ mm [End cover = 25 mm]

$$L_d \le 1.3 \frac{M_1}{V} + l_0$$

$$1.3 \frac{M_1}{V} + l_0 = \frac{1.3 \times 8.72 \times 10^6}{12150} + 75 = 1008 \text{ mm} > 470 \text{ mm}$$

$\therefore$ $1.3 \frac{M_1}{V} + l_0 > L_d$. Hence, OK

9. The reinforcement details of lintel are shown in Fig. 3.

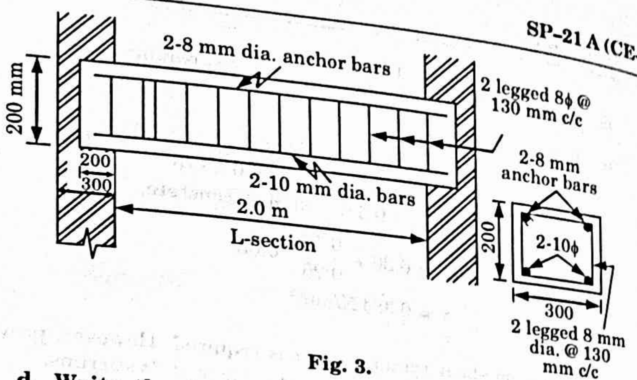


Fig. 3.

**d. Write the functions of longitudinal reinforcement and transverse reinforcement for column.**

**Ans.** **Function of Longitudinal Reinforcement :** Following are the functions of longitudinal reinforcement :

1. To share the compressive loads along with concrete, thus reducing the overall size of the column and leaving more usable area.
2. To resist tensile stresses developed due to any moment or accidental eccentricity.
3. To impart ductility to the column.
4. To reduce the effect of creep and shrinkage due to continuous constant loading applied for a long time.

**Functions of Transverse Reinforcement :** Following are the functions of transverse reinforcement :

1. To hold the longitudinal bars in position.
2. To prevent buckling of the main longitudinal bars.
3. To resist diagonal tension caused due to transverse shear developed because of any moment or load.
4. To impart ductility to the column.
5. To prevent longitudinal splitting or bulging out of concrete by confining it in the core.

**e. A brick masonry wall 230 mm thick carries a load of 370 kN/m inclusive of its own weight. The bearing capacity of soil is 151 kN/m² at 1 m depth. Design the footing of the wall. Use M20 concrete and Fe415 steel.**

**Ans.**

**Given :** Thickness of wall, $b$ = 230 mm, Load, $w$ = 370 kN/m including self weight bearing capacity, $q_0$ = 151 kN/m², $f_y$ = 415 N/mm², $f_{ck}$ = 20 N/mm²

**To Find :** Design the footing of the wall.

1. **Size of Footing :**

i. Ultimate factored design load,





$$w_u = 1.5 \times 370 = 555 \text{ kN/m}$$

ii. Width of footing = $\frac{555}{151}$ = 3.68 m

Hence, providing a width of 3.8 m *i.e.*, $B$ = 3.8 m

iii. Taking 10 % of total load as self weight of footing and subtracting it from total ultimate load

Net downward load on soil = 555 × 0.9 = 500 kN/m

iv. Net upward pressure = $\frac{500}{3.8}$ = 131.57 kN/m²

$$P_0 \approx 132 \text{ kN/m}^2\text{/m length of footing}$$

2. **Bending Moment Calculation :**

i. In the case of brick masonry wall, the critical section for maximum bending is taken at a section midway between the edge of the wall and centre of wall,

$$M_u = \frac{P_0}{2}\left[\frac{B-b}{2}+\frac{b}{4}\right]^2 = \frac{132}{2}\left[\frac{3.8-0.23}{2}+\frac{0.23}{4}\right]^2$$

$$M_u = 224.1 \text{ kN-m per m} = 224.1 \times 10^6 \text{ N-mm}$$

ii. Effective depth,

$$d_{reqd} = \sqrt{\frac{224.1\times10^6}{2.76\times1000}} \quad [R_u = 2.76 \text{ for M20 and Fe 415}]$$

$$= 285 \text{ mm}$$

Taking 50 mm clear cover and 20 mm diameter bars.

iii. Overall depth, $D$ = 350 mm

$$d = 350 - 50 - 10 = 290 \text{ mm}$$

3. **Area of Steel :**

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

$$224.1 \times 10^6 = 0.87 \times 415 \times A_{st} \times 290\left(1-\frac{415 A_{st}}{20\times1000\times290}\right)$$

$$A_{st} = 2638.4 \text{ mm}^2$$

Using 20 mm dia bars, $A_\phi$ = 314 mm²

ii. Spacing required = $\frac{314 \times 1000}{2638.4}$ = 119 mm

Hence, providing 20 mm dia bars @ 110 mm c/c.

iii. $$A_{st\text{ provided}} = \frac{314 \times 1000}{110} = 2854.55 \text{ mm}^2$$

iv. $$p_t = \frac{100 A_{st}}{bd} = \frac{100 \times 2854.55}{1000 \times 290} = 0.984\ \%$$

v. Minimum steel required = 0.12 % $bD$ = $\frac{0.12\times1000\times350}{100}$

= 420 mm² < 2854.55 mm². Hence OK

Distribution steel is provided @ 0.12 % = 420 mm²

Using 10 mm diameter bars and Spacing required = 110 mm
Hence, providing 10 mm dia bars @ 110 mm c/c in the longitudinal direction.

4. **Check for Shear (One Way Shear) :**
The critical section for shear is at a distance '*d*' from the face of the wall as shown below :

$$V_u = P_0\left[\frac{(B-b)}{2} - d\right] = 132\left[\left(\frac{3.8-0.23}{2}\right) - 0.29\right]$$

$$V_u = 197.34 \text{ kN per m}$$

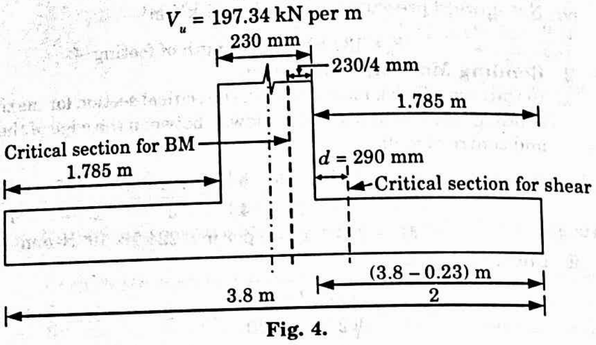


**Fig. 4.**

Nominal shear stress,

$$\tau_v = \frac{V_u}{bd} = \frac{197.34 \times 1000}{1000 \times 290} = 0.68 \text{ N/mm}^2$$

$$\tau_c = k.\, \tau_c$$

For $p_t$ = 0.984 % and M 20 concrete,

$\tau_c$ = 0.60 N/mm² and $k$ = 1 for 300 mm or more thickness.

$$\tau_v > \tau_c$$

Hence the footing is not safe in shear therefore revising its depth.

$$\frac{197.34 \times 1000}{1000 \times d} = 0.60 \text{ N/mm}^2$$

$$d \cong 330 \text{ mm}$$

Hence, providing $D$ = 400 mm
Effective depth, $d$ = 400 – 50 – 10 = 340 mm

5. **Check for Development Length :**
Development length is given by,

$$L_d = \frac{\phi(0.87 f_y)}{4\tau_{bd}} = \frac{20 \times 0.87 \times 415}{4 \times 1.92}$$

$$L_d = 941 \text{ mm} = 0.941 \text{ m}$$

Providing 50 mm clear cover, length of bar available

$$= \left[\frac{1}{2}(B-b) - 0.50\right] = \left[\frac{1}{2}(3.8 - 0.23) - 0.5\right]$$



= 1.285 m > 0.941 m. Hence OK

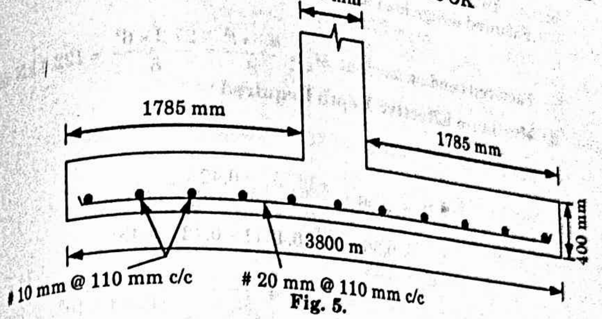


**Fig. 5.**

## Section-C

3. Attempt any one part of the following : **(1 × 7 = 7)**

a. **Write design steps of doubly reinforced beam by WSM. The span of the beam is *l*, size of beam (*b* × *d*), loading on the beam and grade of concrete and steel are known.**

**Ans.** Refer Q. 1.11, Page 1–14A, Unit-1.

b. **A rectangular reinforced concrete beam is simply supported on two masonry wall 230 mm thick and 6 m span center to center. The beam is carrying an imposed load of 15 kN/m. Design the beam and check only for deflection. Use M25 concrete and Fe415 steel. Take effective cover 50 mm.**

**Ans.**

**Given :** Effective span, $l_{cc}$ = 6 m, Imposed load = 15 kN/m, $f_{ck}$ = 25 N/mm², $f_y$ = 415 N/mm², Width of wall = 230 mm, Effective cover = 50 mm
**To Find :** Design the beam and check only for deflection.

Assuming, total depth $D$ = 500 mm $\left(\frac{l}{12} = \frac{6000}{12} = 500 \text{ mm}\right)$

Width of beam, $b$ = 250 mm
Effective depth, $d$ = 500 – 50 = 450 mm

1. **Effective Span ($l$) :** The effective span is least of following :
i. Centre to centre of supports = 6.0 m
ii. Clear span + $d$ = 5.77 + 0.45 [Clear span = 6.0 – 0.23 = 5.77 m]
= 6.22 m
Hence, effective span, $l$ = 6.0 m

2. **Design Load ($w_u$) and Factored Moment ($M_u$) :**
i. Self weight of beam = 0.5 × 0.25 × 25 = 3.125 kN/m
ii. Imposed load = 15 kN/m

iii. Total load, $w = 3.125 + 15 = 18.125$ kN/m

Factored design load = $w \times 1.5 = 18.125 \times 1.5$

$w_u = 27.2$ kN/m

iv. Factored bending moment, $M_u = \frac{w_u \times l^2}{8} = \frac{27.2 \times 6^2}{8} = 122.4$ kN-m

**3. Minimum Effective Depth Required :**

For Fe415, $\frac{x_{u\,max}}{d} = 0.48$

$$\therefore \quad R_u = 0.36 f_{ck} \frac{x_{u\,max}}{d}\left(1 - \frac{0.42\, x_{u\,max}}{d}\right)$$

$$= 0.36 \times 25 \times 0.48 (1 - 0.42 \times 0.48)$$

$$R_u = 3.45$$

Effective depth required, $d_{reqd} = \sqrt{\frac{M_u}{R_u \times b}} = \sqrt{\frac{122.4 \times 10^6}{3.45 \times 250}}$

$d_{reqd} = 376.7$ mm < 450 mm, hence OK

Since the depth of section is more than that required for balanced section. The section is designed as an under-reinforced section.

Adopt $D = 500$ mm and $b = 250$ mm

$$\therefore \quad d = 500 - 20 - 8 - \frac{20}{2} = 462 \text{ mm}$$

[Assuming clear cover as 20 mm, 8 mm as dia of stirrups and 20 mm dia main bars]

**4. Area of Steel Required :**

For an under reinforced section the area of steel required is calculated as follows :

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

$$122.4 \times 10^6 = 0.87 \times 415 A_{st} \times 462\left(1 - \frac{415 A_{st}}{250 \times 462 \times 25}\right)$$

$$A_{st\,reqd} = 834 \text{ mm}^2$$

**5. Minimum area of steel ($A_s$) :**

$$A_s = \frac{0.85\, bd}{f_y} = \frac{0.85 \times 250 \times 462}{415}$$

$A_s = 236.56$ mm² < 834 mm², hence OK.

Using 20 mm dia bars, $A_\phi = \frac{\pi}{4} \times 20^2 = 314$ mm²

Number of bars required, $n = \frac{A_{st}}{A_\phi} = \frac{834}{314} = 2.66$ say 3

Hence, provide 3–20 mm dia bars,

$A_{st\ provided} = 3 \times 314 = 942$ mm².



**6. Check for Deflection :**

Percentage of steel,

$$p_t = \frac{100 \times 942}{250 \times 462} = 0.815\ \%$$

$$f_s = 0.58 f_y \left[\frac{A_{st\,reqd}}{A_{st\,provided}}\right] = 0.58 \times 415 \left[\frac{834}{942}\right] = 213.1 \text{ N/mm}^2$$

Interpolating for $f_s = 212$ N/mm² and $p_t = 0.815\ \%$

$$\therefore \quad k_t = 1.35 - \frac{(1.35 - 1.2)}{(240 - 190)} \times (212 - 190)$$

[For $f_s = 190$, $k_t = 1.35$ and $f_s = 240$, $k_t = 1.2$]

$$k_t = 1.29$$

$$\therefore \quad \left(\frac{l}{d}\right)_{max} = 20 \times 1.29 = 25.8$$

$$\left(\frac{l}{d}\right)_{provided} = \frac{6000}{462} = 12.9$$

$$\therefore \quad \left(\frac{l}{d}\right)_{max} > \left(\frac{l}{d}\right)_{provided}, \text{ Hence OK}$$

**4. Attempt any one part of the following : (7 × 1 = 7)**

**a. A rectangular simply supported beam 300 mm × 500 mm spanning over 5 m is subjected to a maximum moment of 150 kN-m at the mid span. The beam is reinforced with four bars of 25 mm diameter, on the tension side at an effective depth of 450 mm. The bars are spaced at 50 mm centre to centre. Check the beam for serviceability limit state of cracking. If M 20 and Fe 415 steel is used.**

**Ans.**

**Given :** $b = 300$ mm, $D = 500$ mm, $d = 450$ mm, $l = 5$ m,

$M = 150$ kN-m, $A_{st} = 4 \times \frac{\pi}{4} \times 25^2 = 1963.5$ mm², $\sigma_{cbc} = 7$ N/mm²,

$\sigma_{st} = 230$ N/mm², Spacing between the bars = 50 mm,

Effective cover = 50 mm

**To Find :** Check the beam for serviceability limit state of cracking.

Modular ratio, $m = \frac{280}{3\,\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33$ [for M 20, $\sigma_{cbc} = 7$ N/mm²]

**1. Depth of Neutral Axis ($n$) :**

$$b\frac{n^2}{2} = m\, A_{st}(d - n)$$

$$300\frac{n^2}{2} = 13.33 \times 1963.5\,(450 - n)$$

$$n^2 + 174.5n - 78520.365 = 0$$

We get, $n = 206.234$ mm

**2. Moment of Inertia of Beam (Transformed Section or Cracked) about NA :**

$$I_{cr} = \frac{bn^3}{3} + m\,A_{st}(d-n)^2$$

$$= \frac{300 \times 206.234}{3} + 13.33 \times 1963.5\,(450 - 206.234)^2$$

$$I_{cr} = 24.33 \times 10^8 \text{ mm}^4$$

**3. Maximum Crack Width :** Crack width is maximum at the bottom of the beam :

$$\therefore \quad a_{cr} = \left[\left(\frac{S}{2}\right)^2 + C_{min}^2\right]^{1/2} \qquad [C_{min} = 50 - 12.5 = 37.5 \text{ mm}]$$

$$= \left[\left(\frac{50}{2}\right)^2 + 37.50^2\right]^{1/2} \Rightarrow a_{cr} = 45.07 \text{ mm}$$

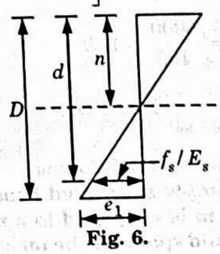


Fig. 6.

$$\frac{\varepsilon_1}{(D-n)} = \frac{f_s}{E_s(d-n)} \Rightarrow \varepsilon_1 = \frac{f_s}{E_s}\left[\frac{D-n}{d-n}\right]$$

$$f_s = m\left(\frac{M.y}{I_{cr}}\right) = 13.33\left(\frac{150 \times 10^6 \times 243.77}{24.33 \times 10^8}\right) = 200.34 \text{ N/mm}^2$$

$$\varepsilon_1 = \frac{200.34}{2 \times 10^5}\left(\frac{500 - 206.234}{450 - 206.234}\right) = 1.2072 \times 10^{-3}$$

$$\varepsilon_m = \varepsilon_1 - \left[\frac{b_1(D-n)(a-n)}{3E_s A_{st}(d-n)}\right] \qquad [\text{Here, } a = D]$$

$$\varepsilon_m = 1.2072 \times 10^{-3} - \left[\frac{300(500 - 206.234)(500 - 206.234)}{3 \times 2 \times 10^5 \times 1963.5 \times (450 - 206.234)}\right]$$

$$\varepsilon_m = 1.117 \times 10^{-3}$$

Maximum crack width as per IS 456 :

$$W_{cm} = \frac{3a_{cr}\varepsilon_m}{1 + 2\left(\frac{a_{cr} - C_{min}}{D - n}\right)} = \frac{3 \times 45.05 \times 1.117 \times 10^{-3}}{1 + 2\left(\frac{45.05 - 37.5}{500 - 206.234}\right)}$$

$$W_{cr} = 0.1436 \text{ mm}$$



**Checking of Limit State of Cracking :**

Under normal environmental conditions, maximum crack width is 0.3 mm, which is greater than 0.14. Hence OK.

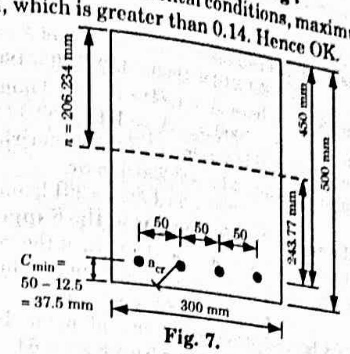


Fig. 7.

**b. Design a cantilever slab for chajja of an overhang 1.1 m. The imposed load on slab is 1 kN/m² and weight of finishing is 0.8 kN/m². Use M20 concrete and Fe 415 steel. Also check for shear.**

**Ans.**

**Given :** Overhang length = 1.1 m, Load = 1000 N/m², Finishing load = 800 N/m², $f_{ck}$ = 20 N/mm², $f_y$ = 415 N/mm².

**To Find :** Design cantilever slab.

**1. Bending Moment and Shear Force :** Assume the cantilever to be of average total thickness of 100 mm.

Dead weight = 0.1 × 1 × 25000 = 2500 N/m

Total weight, $w$ = 2500 + 800 + 1000 = 4300 N/m

$$\text{Moment,} \quad M = \frac{wL^2}{2} = \frac{4300(1.1)^2}{2}$$

$$= 2601.5 \text{ N-m} = 2.6015 \times 10^6 \text{ N-mm}$$

Factored bending moment

$$M_{u\,lim} = 1.5 \times 2.6015 = 4 \text{ kN-m}$$

$$V_{max} = wL = 4300 \times 1.1 = 4730 \text{ N}$$

**2. Design of Section by LSM :**

$$d = \sqrt{\frac{M_{u\,lim}}{0.138\,f_{ck}\,b}} = \sqrt{\frac{4 \times 10^6}{0.138 \times 20 \times 1000}} = 38.07 \text{ mm}$$

Hence, provide overall depth of beam, $D$ = 150 mm

Keeping nominal cover of 20 mm and using 8 mm ϕ bars,

Effective depth, $d$ = 150 – 20 – 8/2 = 126 mm. Reduce $D$ = 100 mm at free end.

**3. Area of Reinforcement :**

i.
$$M_{u\,lim} = 0.87\,A_{st} f_y d\left(1 - \frac{f_y A_{st}}{bdf_{ck}}\right)$$

$$4 \times 10^6 = 0.87 \times 415 \times A_{st} \times 126\left(1 - \frac{A_{st} \times 415}{1000 \times 126 \times 20}\right)$$

$A_{st} = 89.24$ mm²

Minimum area of reinforcement = 0.12 % of X-sectional area

= (0.12 × 1000 × 150)/100 = 180 mm²

Choosing 8 mm $\phi$ bars, $A_\phi = (\pi/4) \times 8^2 = 50.3$ mm².

ii. Spacing, $S = 1000\,A_\phi / A_{st} = 1000 \times 50.3 / 180 = 280$ mm

iii. Maximum permissible spacing = 3 *d* or 300 mm whichever is smaller. Hence provide 8 mm $\phi$ bars @ 250 mm c/c.

Actual, $A_{st} = (1000 \times 50.3)/250 = 201.2$ mm².

**4. Embedment of Reinforcement in the Support :**

i. In order to develop full tensile strength at the face of the support, each bar should be embedded into the support by a length equal to

$L_d = 45\,\phi = 45 \times 8 = 360$ mm.

ii. This could be best achieved by providing one bend of 90° where anchorage value of this bend = 8 $\phi$ = 8 × 8 = 64 mm.

iii. Thus, total anchorage value achieved

= (300 – 20) + 64 + (150 – 2 × 20 – 4) = 450 mm > $L_d$.

**5. Check for Shear :**

i. Neglecting the taper and taking an average, *d* = 110 mm,

Nominal shear stress, $\tau_v = \frac{V_u}{bd} = \frac{1.5 \times 4730}{1000 \times 110} = 0.0645$ N/mm²

ii. This is much less than the permissible value of

$\tau_c = 1.3 \times 0.18 = 0.234$ N/mm² for M 20 concrete for

$p_t = \frac{100\,A_s}{bd} = \frac{100 \times 201.2}{1000 \times 110} = 0.183$ %. Hence safe.

**6. Distribution Reinforcement :**

i. $A_{sd} = 0.12bD / 100 = 0.12 \times 1000D / 100$

$= 1.2\,D$ mm² $= 1.2 \times 150 = 180$ mm²

Using 8 mm $\phi$ bars, each having $A_\phi = 50.3$ mm².

Spacing, $S = 1000\,A_\phi / A_{sd} = 1000 \times 50.3 / 180 = 280$ mm.

However, provide these @ 280 mm c/c. The section of the cantilever slab is shown in Fig. 8.

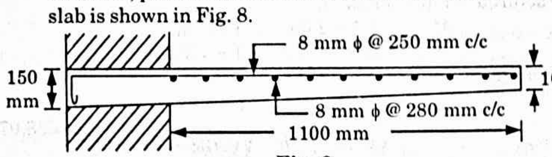


**Fig. 8.**

5. Attempt any one part of the following : **(1 × 7 = 7)**

**a. Design a column of size 450 mm × 600 mm and having 3 m unsupported length. The column is subjected to a ultimate load of 3000 kN and is effectively held in position but not restrained against rotation. Use M20 concrete and Fe415 steel. Draw the sketch also.**



**Ans.**

**Given :** Size of column = 450 mm × 600 mm,

Factored load, $P_u$ = 3000 kN

Unsupported length, $l$ = 3 m, $f_{ck}$ = 20 N/mm², $f_y$ = 415 N/mm²

**To Find :** Design a column and draw sketch.

**1. Slenderness Ratio :**

i. in X-direction, $\lambda_x = l_{\cdot}k_x / D_x = 3000k_x / 450 = 6.67$

ii. in Y-direction, $\lambda_y = l_{\cdot}k_y / D_y = 3000k_y / 600 = 5$  $[k_x = k_y = 1]$

iii. Hence the both slenderness ratio are less than 12.

iv. Column may be designed as short column.

**2. Minimum Eccentricities :**

i. $e_{x,\,min} = \frac{l}{500} + \frac{D}{30} = \frac{3000}{500} + \frac{450}{30} = 21$ mm (> 20 mm)

ii. $e_{y,\,min} = \frac{3000}{500} + \frac{600}{30} = 26$ mm (> 20 mm)

iii. Also, $0.05D_x = 0.05 \times 450 = 22.5 > 21$ mm

$0.05D_y = 0.05 \times 600 = 30 > 26$ mm

Column can be design as short column with axial load.

**3. Design of Longitudinal Reinforcement :**

i. $P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$

$3000 \times 10^3 = 0.4 \times 20 \times (450 \times 600 - A_{sc}) + 0.67 \times 415 \times A_{sc}$

$A_{sc} = 3111$ mm²

ii. Provide 20 mm diameter bars as longitudinal reinforcement.

Number of bars = $\frac{3111}{\pi / 4\,(20)^2} = 9.9 \approx 10$

Provide 10 bars of 20 mm diameter along the periphery of the column.

Area of steel provide, $A_{sc} = 10 \times \frac{\pi}{4} \times 20^2 = 3142 > 3111$ mm²

iii. Percentage (%) of steel provide

$= \frac{3142}{450 \times 600} \times 100 = 1.16\,\% > 0.8\,\%$ and less than 4 %

Hence OK.

**4. Minimum Diameter of Lateral Ties :** Lateral ties should not be less than,

Tie diameter, $\phi_t > \begin{cases} 20/4 = 5 \text{ mm} \\ 6 \text{ mm} \end{cases}$

Provide 8 mm diameter bars for lateral ties.

**5. Spacing of Lateral Reinforcement :** Consider the minimum of the following values :

i. Least lateral dimension of column = 450 mm

ii. $16 \times \phi_L = 16 \times 20 = 320$ mm

iii. 300 mm

Provide 8 mm $\phi$ ties @ 300 mm c/c

6. **Reinforcement Details :**

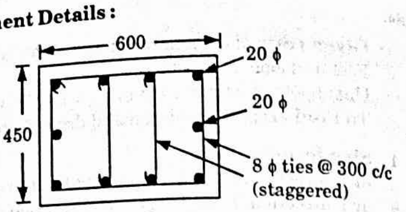


**Fig. 9.**

**b. Write the design steps for isolated square footing of a column.**

**Ans.** Refer Q. 4.5, Page 4–6A, Unit-4.

6. Attempt any one part of the following : **(7 × 1 = 7)**

**a. Draw the structural behavior of a combined footing with L-section, Plan and section at column.**

**Ans.**

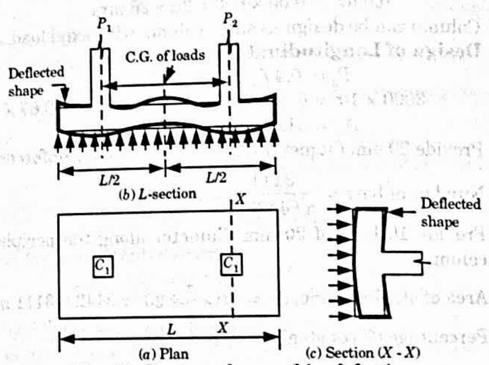


**Fig. 10.** Rectangular combined footing.

**b. Design a combined footing for two columns 500 mm × 500 mm each, 5 m apart center to center of column carrying a load of 1600 kN each. The width restriction is 2.4 m. The safe bearing capacity is 200 kN/m². Use M25 concrete and Fe415 steel. Check depth of BM criteria, and one way shear criteria.**

**Ans.**

**Given :** Size of column = 500 mm × 500 mm each, Distance b/w two column, $l$ = 5 m, Load, $W$ = 1600 kN (each), width restriction = 2.4 m, Bearing capacity of soil, $q_0$ = 200 kN/m², $f_{ck}$ = 25 N/mm² $f_y$ = 415 N/mm²

**To Find :** Design combined footing.



1. **Calculate Area of Footing :**
   i. Total column load = 2 × 1600 = 3200 kN
   ii. Assuming self weight of footing as 10 % of total weight = 320 kN
   iii. Total load, $W$ = 3520 kN
   iv. Area of footing required = $W / q_0$ = 3520 / 200 = 17.6 m²
   v. Available width of footing = 2.4 m
   Length of footing = 17.6 / 2.4 = 7.33 m
   Hence adopting a length of 7.5 m such that the CG of the load system coincides with the CG of the footing as shown in Fig. 10.
   vi. Upward soil pressure = $\frac{\text{Total load}}{\text{Area of footing}} = \frac{1600 \times 2}{7.5 \times 2.4}$ = 177.8 kN/m²
   vii. Factored soil pressure = 1.5 × 177.8 = 266.67 kN/m²
   viii. Upward soil pressure per unit length = 266.67 × 2.4 = 640 kN/m

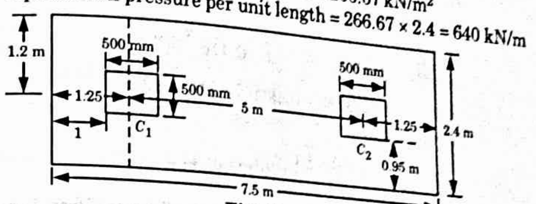


**Fig. 11.**

2. **Calculation of Maximum Bending Moment and Shear Force Fig. 12 :**

i. **Shear Force Distribution :**

a. Shear force at $C_1$ = – 640 × 1.25 = – 800 kN [just left of centre]
b. Shear force at $C_2$ = – 800 + 1.5 × 1600 = 1600 kN [just right of centre]
c. Similarly, Shear force at $C_1$ = + 800 kN [just right of centre]
d. Shear force at $C_2$ = + 800 – 1.5 × 1600 = – 1600 kN [just left of centre]

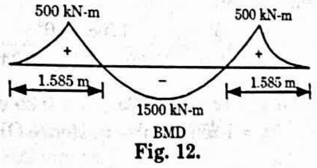


**Fig. 12.**

**ii. Bending Moment Distribution :**

a. Bending moment at $C_1$ or $C_2 = 640 \times 1.25^2 / 2 = 500$ kN-m

b. Bending moment at midspan $= 640 \times 3.75^2 / 2 - 2400 \times 2.5$
$= -1500$ kN-m

c. Point to zero moment or contraflexure :
$M_x = 640 \times x^2 / 2 - 2400 (x - 1.25) = 0$
$x^2 - 7.5x + 9.375 = 0$
$x = 1.585$ m

**3. Depth of Footing :**

**i. From BM Consideration :**

Factored bending moment, $M_u = 1500 \times 10^6$ N-mm

Depth of footing, $d_{reqd} = \sqrt{M_u / R_u b}$

For M25 and Fe415 steel,

$$R_u = 0.36 f_{ck} \frac{x_{u\,max}}{d}\left[1 - 0.416 \frac{x_{u\,max}}{d}\right] \qquad \left(\because \frac{x_{u\,max}}{d} = 0.48\right)$$

$$= 0.36 \times 25 \times 0.48[1 - 0.416 \times 0.48]$$

$$R_u = 3.45$$

$$d_{reqd} = \sqrt{\frac{1500 \times 10^6}{3.45 \times 2400}} = 425.63 \text{ mm}$$

ii. From one way shear consideration : (at a distance '*d*' from face of column)

$$V_u = \left[1600 - 640\left[0.25 + \frac{d}{1000}\right]\right] \times 10^3 \text{ N}$$

Assuming 0.2 % steel, $\tau_c = 0.32$ N/mm² from IS code

$V_u / bd < 0.32$

$$\frac{\left[1600 - 640\left(0.25 + \frac{d}{1000}\right)\right] \times 10^3}{2400 \times d} < 0.32$$

On solving we get, $d = 1023$ mm

Hence adopting total depth of 1100 mm and effective depth, $d = 1100 - 60 = 1040$ mm

**iii. Checking Depth For Two Way Shear :**

a. The critical section for two way or punching shear is at a distance $d/2$ from the face of column.

b. Area resisting punching shear $= b_0 d = 4(500 + 1040) \times 1040$

c. Shear force at critical section $= 2400 - 266.67(0.5 + 1.04)^2$
$V_u = 1768$ kN

d. Nominal shear stress,

$$\tau_v = \frac{V_u}{b_0 d} = \frac{1768 \times 10^3}{4(500 + 1040) \times 1040} = 0.276 \text{ N/mm}^2$$

e. Permanent shear stress, $\tau_c = 0.25\sqrt{f_{ck}} = 0.25\sqrt{25}$
$\tau_c = 1.25$ N/mm² $> \tau_v$. Hence OK



**4. Longitudinal Reinforcement :**

**i. Negative Moment or Hogging Moment Reinforcement :**

a. Maximum negative moment, $M_u = 1500$ kN-m

b. $1500 \times 10^6 = 0.87 \times 415 \times A_{st} \times 1040\left[1 - \frac{415 A_{st}}{25 \times 2400 \times 1040}\right]$

On solving we get, $A_{st} = 4106.934$ mm²

c. Using 16 mm diameter bars, $A_\phi = \pi \times 16^2 / 4 = 201$ mm²

d. Spacing required $= 201 \times 2400 / 4106.934 = 117.46$ mm

e. Number of bars $= \frac{4106.934}{201} = 20.43 \approx 21$ bars

f. Hence, provide 21-16 $\phi$ @ 110 mm c/c at top as hogging moment reinforcement.

g. $A_{st\,min} = 0.12$ % of X-sectional area
$= 0.12 / 100 \times 2400 \times 1100 = 3168$ mm²

h. Number of 16 mm dia bars $= 3168 / 201 = 15.76 \approx 16$ bars

**ii. Positive Moment Reinforcement :**

a. Maximum positive bending moment, $M_u = 500$ kN-m

b. $500 \times 10^6 = 0.87 \times 415 \times A_{st} \times 1040\left(1 - \frac{415 A_{st}}{25 \times 2400 \times 1040}\right)$

$A_{st} = 1343.6$ mm² $< A_{st\,min}$

c. Hence providing 16-16 mm diameter bars under columns $C_1$ and $C_2$ as + *ve* moment reinforcement.

**5. Transverse Reinforcement :**

i. In the transverse direction, the footing is designed as cantilever supported on columns.

ii. The transverse reinforcement is provided under each column within a band having a width equal to the width of the column plus two times the effective depth of foundation.

iii. Bandwidth under column, $C_1$ or $C_2 = 0.5 + 1.04 + 1.0 = 2.54$ m
[On the outer side only 1.0 m length is available]

iv. Upward pressure $= 1.5 \times 1600 / 2.4 = 1000$ kN/m

v. Bending moment at the face of the column in transverse direction :

$$= \frac{1000 \times 0.95^2}{2} = 451.25 \text{ kN-m}$$

vi. Hence providing, $A_{st\,min} = \frac{0.12}{100} \times 2540 \times 1100 = 3353$ mm²

vii. Spacing of 16 mm diameter bars $= \frac{201 \times 2540}{3353} = 152.3$ mm

viii. Hence provide 16 mm diameters bars @ 150 mm c/c (17 bars) under columns $C_1$ and $C_2$ in the width 2.54 m and in rest of the portion 16 mm bars @ 300 mm c/c.

6. **Reinforcement Details :**

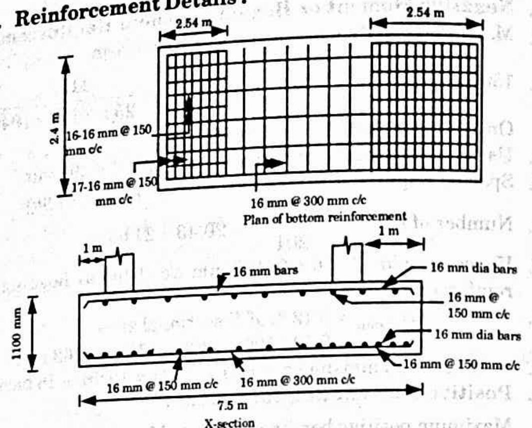


**Fig. 13.**

7. Attempt any **one** part of the following : **(10 × 1 = 10)**

a. **Draw the diagram of cantilever retaining wall and show the forces acting on the wall. Also draw reinforcement details in stem, heel slab, and toe slab.**

**Ans.** Diagram and Forces : Refer Q. 5.15, Page 5–34, Unit-5.
Reinforcement Details : Refer Q. 5.16, Page 5–34, Unit-5.

b. **Design a cantilever retaining wall to retain earth embankment 4.2 m high above GL the density of earth is 18 kN/m² and angle of repose is 30°. The embankment is horizontal at its top. The safe bearing capacity of the soil is 190 kN/m² and the coefficient of friction between soil and concrete is 0.5. Adopt M20 grade concrete and Fe415 grade steel.**

**Ans.**

**Given :** Height of embankment = 4.2 m
Density of earth = 18 kN/m³, Angle of repose = 30°
Bearing capacity of soil = 190 kN/m²
Coefficient of friction = 0.5
**To Find :** Design of retaining wall.

1. **Wall Proportions :**

i. Thickness of the stem at the top = 200 mm

ii. Maximum bending moment per metre run of the wall

$$M = k_p \gamma h^3 / 6$$

$$k_p = \frac{1-\sin\phi}{1+\sin\varphi} = \frac{1-\sin 30°}{1+\sin 30°} = \frac{1}{3}$$

$$M = (1/3) \times 18 \times 4.2^2 / 6 = 74.088 \text{ kN-m}$$

iii. Equating the moments of resistance to the maximum bending moment, $0.913 \times 1000 \times d^2 = 74.088 \times 10^6$



$$d = 284.8 \text{ mm} \approx 285 \text{ mm}$$

Effective cover to reinforcement = 40 mm

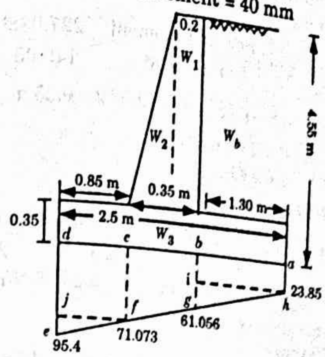


**Fig. 14.**

iv. Total thickness of stem required = 285 + 40 = 325 mm
Provide a thickness of 350 mm.

v. The base slab thickness also will be 350 mm.

vi. Total height of wall, $H = 4.2 + 0.350 = 4.55$ m

vii. Width of base slab, $b = 0.5\,H$ to $0.6\,H = 2.275$ to $2.73$ m
Provide a base width of 2.50 m.

viii. **Toe Projection :** This may be made about one-third the base width.
Toe width = 2.50 / 3 = 0.83 ≈ 0.85 m

2. **Stability calculations for one metre length of wall :**

| Load due to | Magnitude (kN) | Distance from a (m) | Moment about a (kN-m) |
|---|---|---|---|
| $W_1 = 0.20 \times 4.2 \times 25$ | 21 | 1.40 | 29.4 |
| $W_2 = \frac{0.15 \times 4.2}{2} \times 25$ | 7.875 | 1.55 | 12.206 |
| $W_2 = 2.5 \times 0.35 \times 25$ | 21.875 | 1.25 | 27.35 |
| $W_b = 1.3 \times 4.2 \times 18$ | 98.28 | 0.65 | 63.882 |
| Moment of lateral pressure $= k_p \frac{\gamma H^3}{6} = \frac{1}{3} \times 18 \times \frac{(4.55)^3}{6}$ | | | 94.2 |
| Total | 149.03 | | 227.038 |

3. Distance from the point of application of the resultant force from the heel end $a$.

$$\bar{x} = \frac{\text{Bending moment}}{\text{total load}} = \frac{227.038}{149.03} = 1.5 \text{ m}$$

4. Eccentricity, $e = \bar{x} - b/2 = 1.5 - 2.5/2 = 0.25$ m

But $b/6 = 2.5/6 = 0.41$ m

$\therefore$ $e < b/6$

5. Extreme pressure intensity at the base,

$$P = \frac{W}{b}\left(1 \pm \frac{6e}{b}\right) = \frac{149.03}{2.5}\left(1 \pm \frac{6 \times 0.25}{2.5}\right)$$

$p_{max} = 95.4$ kN/m²; $p_{min} = 23.85$ N/m²

Safe bearing capacity = 190 kN/m²

6. **Design of Stem :**

i. Maximum bending moment for the stem = 74.088 kN-m

ii. Effective depth, $d = 350 - 40 = 310$ mm

iii. Area of steel, $A_{st} = \frac{74.088 \times 10^6}{230 \times 0.90 \times 310} = 1154.56 \text{ mm}^2$

iv. Spacing for 16 mm diameter bars, $\left(\because A_\phi = \frac{\pi}{4} \times 16^2 = 201 \text{ mm}^2\right)$

$S = 201 \times 1000 / 1154.56 = 174.09$ mm ≈ 170 mm c/c

Provide 16 mm ϕ @ 170 mm c/c distance.

v. Distribution steel, $A_{st} = 0.12 \times 350 \times 1000 / 100 = 420$ mm²

vi. Spacing for 8 mm diameter bars,

$s = 50 \times 1000 / 420 = 119.05$ mm ≈ 110 mm c/c

If the distribution steel is provided near both faces, then the spacing will be @ 220 mm c/c near each face.

7. **Design of Toe Slab :**

i. The bending moment for 1 meter wide strip of the toe slab can be calculate as :

| Load due to | Magnitude (kN) | Distance from c (m) | Moment about c (kN-m) |
|---|---|---|---|
| Upward pressure [*cdjf*]<br>71.073 × 1 × 0.85<br>*cjf* = (1 / 2) × 0.85 × 24.33 | 60.41<br>10.3 | 0.425<br>0.567 | 25.68<br>5.87 |
| | | | 31.55 |
| Deduct for self weight of the toe slab<br>0.85 × 0.35 × 25 | 7.44 | 0.425 | 3.16 |
| Bending moment for toe slab | | | 28.39 |



Effective cover = 60 mm

ii. Maximum bending moment for a 1 meter wide strip of the toe slab.

$M = 28.39$ kN-m

iii. Area of steel, $A_{st} = \frac{28.39 \times 10^6}{230 \times 0.90 \times 290} = 473 \text{ mm}^2$

iv. Spacing of 12 mm ϕ bars, $s = \frac{113 \times 1000}{473} = 238.9 \approx 230$ mm c/c

Provide 12 mm ϕ bars @ 230 mm c/c

8. **Design of the Heel Slab :**

i. The BM calculations for 1 meter wide strip of the heel slab are given in the table :

| Load due to | Magnitude (kN) | Distance from *b* (m) | Moment about *b* (kN-m) |
|---|---|---|---|
| Weight of the backing<br>1.3 × 4.2 × 18 | 98.28 | 0.65 | 63.88 |
| Weight of the heel slab<br>1.30 × 0.35 × 25 | 11.375 | 0.65 | 7.4 |
| | | | 71.28 |
| Deduct for upward pressure *abih*,<br>23.85 × 1.30 × 1 | 31 | 0.65 | 20.15 |
| igh = $\frac{1}{2} \times 1.30 \times 37.206$ | 24.2 | 0.433 | 10.5 |
| | | | 30.65 |
| BM for heal slab | | | 40.63 |

ii. Maximum bending moment,

$M_u = 40.63$ kN-m

iii. Steel required,

$$A_{st} = \frac{40.63 \times 10^6}{230 \times 0.90 \times 290} = 676.8 \approx 677 \text{ mm}^2$$

Using 12 mm dia. bars, $A_\phi = \frac{3.14}{4} \times 12^2 = 113 \text{ mm}^2$

iv. Spacing of 12 mm diameter bars,

$$s = \frac{113 \times 1000}{677} = 166.92 \approx 160 \text{ mm c/c}$$

Provide 12 mm ϕ bars @ 160 mm c/c spacing.

9. **Check for Sliding :**

i. Total horizontal soil pressure force per meter run of the wall

$$P_H = k_p \frac{\gamma H^2}{2} = \frac{1}{3} \times 18 \times \frac{(4.55)^2}{2} = 62.1 \text{ kN}$$

ii. Limiting friction = $\mu W = 0.5 \times 149.03 = 74.515$ kN

iii. Factor of safety against sliding = $\frac{\mu W}{P_H} = \frac{74.515}{62.1} = 1.2 < 1.55$

Hence, we have to provide a shear key to increase the resistance against sliding.

**10. Check for Overturning :**

$$F = \frac{\Sigma M_R}{M_0} = \frac{227.038}{94.2} = 2.41 > 1.55$$

Hence Safe.

**11. Design a Shear Key :**

i. Safe horizontal pressure force = $1.55\,P_H = 1.55 \times 62.11 = 96.27$ kN

ii. Maximum available force = 74.515 kN

iii. Unbalance horizontal force = 96.27 – 74.515 = 21.755 kN

iv. Safe horizontal soil reaction = 0.7 × Safe bearing capacity = 0.7 × 190 = 133 kN/m²

v. Let the height of the key is $y$

$$133 \times 1000 \times y = 21.755 \times 10^3$$

$$y = 0.164 \text{ m}$$

vi. Minimum height of key = 200 mm

vii. Maximum BM = $21.755 \times \frac{0.3}{2} = 3.26$ kN-m

viii. $$0.913 f_{ck}\, bd^2 = 3.26 \times 10^6$$

$$0.913 \times 1000 \times d^2 = 3.26 \times 10^6$$

$$d = 59.755 \text{ mm}$$

ix. Minimum thickness of key = 200 mm

Provide 350 × 200 mm shear key.

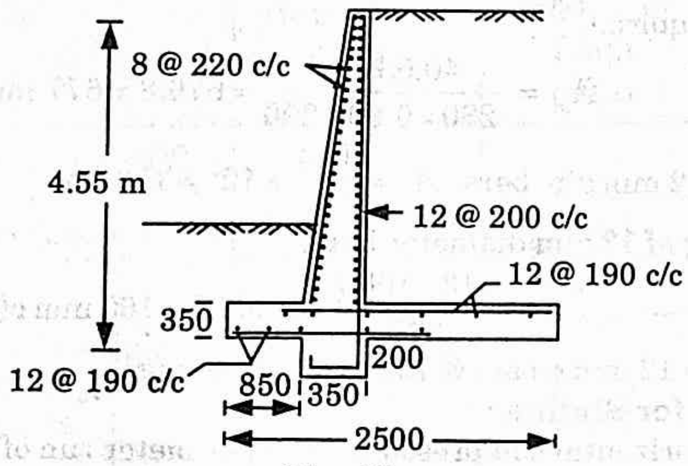


**Fig. 15.**

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