Lecture No. 1 INTRODUCTION:— UNIT-I

Topic(s) to be covered	objectives of Structural design, steps in Rcc Structural design process, Types of loads on Structures and load Combination, code practices and specifications.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Design the structure for stability, Strength and Serviceability	Remembering.
LO2	Types of loads & load Combination	Remembering
LO3	Code of Practices and specifications	Remembering.

Teaching Learning Material	Student Activity
Chalk & Talk	listen

Lecture Notes

OBJECTIVE OF STRUCTURAL DESIGN :

Structural Analysis and designs are the methodical investigation of the stability, Strength and rigidity of Structures. The objectives in structural analysis and design are to;

i) Produce a Structure Capable of resisting all applied loads (external and self-weight) without failure.

ii) design the structure for stability, strength and serviceability.

iii) be economical and aesthetic.

Steps in Rcc Structural Design Process :-

Reinforced Cement Concrete (Rcc) is a Composite material, which is Concrete with steel bars embedded it.

The following are the Various steps involved in reinforced cement concrete design Process.

i) Preliminary data collection.
ii) Structural planning.
iii) Action of loads
iv) Analysis of structures.
v) Design of structural elements.
vi) Detailing and bar bending schedule preparation.

→ Preliminary data collection :-

i) Safe bearing Capacity ground soil.
ii) Number of floors.
iii) Seismic zone
iv) Grade of Concrete.
v) Grade of steel.
vi) Exposure Condition.
vii) Clear Cover.
viii) Depth of Water table.

→ Structural planning :-

Preparation of architectural plan is the first stage of structural planning. Architectural plan shows the floor, roof plans, spaces, room sizes and other physical features of a structure. After obtaining the architectural plan, structural plan is prepared which includes the following.

a) positioning and orientation of columns.
b) positioning of the beams.
c) spanning of the slabs.
d) staircase layout.
e) Type of footing in foundation plan.
f) center to center dimensions columns.

Actions of loads :-

The types of loads acting on the structures for buildings and other structures can be broadly classified as vertical loads, horizontal / lateral loads and special loads. The vertical loads consists of dead load, imposed load and snow load.

Analysis of structures:-

→ Static Analysis :-

Displacement, stress, strain and force in the structures caused by external loads which will not produce may inertia and damping effects is termed as static analysis. The static structural analysis can be either linear or non linear.

→ Dynamic Analysis :-

In dynamic Analysis, load varies with respect to time. Dynamic analysis can be used to determine natural frequency, dynamic displacements, time history results and model analysis of a structures.

Design of structural Elements :-

Structural elements / members are the primary load bearing components of a building, and each have their own structural properties. Such members include, slab, beam, column / load bearing wall, foundation and staircase.

Detailing and bar bending schedule preparation :

Reinforcement details clearly stated in the drawing is called as detailing. Detailing is very important for proper execution and safety of the structures.

Types of loads on Structures :-

→ Dead loads (DL)
→ Imposed loads or live loads (IL or LL)
→ Wind loads (WL)
→ Snow loads (SL)
→ Earthquake loads (EL)

load Combination :-

i) Load Combinations for limit state of collapse:

a) Ultimate load $UL = 1.5DL + 1.5IL = 1.5(DL + IL)$

b) $UL = 1.5DL \pm 1.5WL$ (or) $0.9DL \pm 1.5WL$

c) $UL = 1.2DL + 1.2IL + 1.2WL = 1.5(DL + IL + WL)$

ii) Load combinations for limit state of serviceability:

a) Serviceability load, SL = 1.0 DL + 1.0 DL = 1.0 (DL + IL)

b) SL = 1.0 DL + 1.0 WL = 1.0 (DL + WL)

c) SL = 1.0 DL + 0.8 IL + 0.8 WL

where,

DL = Dead load

IL = Imposed load (or) live load

WL = Wind load

EL = Earthquake load.

Code practices and specification:-

a) IS456 - 2000 plain and Reinforced Concrete - code of practice (fourth revision)

b) Code book for loads

IS 875 - 1987 code of practice for design loads (other than earthquake) for buildings and structures

Part 1 - Dead load

Part 2 - Imposed loads

Part 3 - Wind loads

Part 4 - Snow loads

Part 5 - Special loads such as shrinkage, creep temperature, soil & fluid pressure and load combinations.

c) IS1893 - Criteria for Earthquake resistant design of structures.

Part 1 : 2016 - General provisions & building

Part 2 : 2014 - liquid retaining tanks.

Part 3 : 2014 - Bridges and Retaining Walls.

Part 4 : 2015 - Industrial Structures including stack like structures.

Part 5 : Dams and embankments.

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Lecture No. 2

Topic(s) to be covered	Concept of Working stress method, Ultimate load design and limit state design methods for RCC, Properties of Concrete and Reinforcing steel.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Working stress Method, Ultimate load design method, limit state design method	Understanding
LO2	Partial Safety factor for materials & partial safety factor for loads.	Remembering

Teaching Learning Material	Student Activity
Chalk & Talk	listen.

Lecture Notes

CONCEPT OF WORKING STRESS METHOD, ULTIMATE LOAD DESIGN AND LIMIT STATE DESIGN METHODS FOR RCC.

Working stress Method :-

Working stress design is otherwise known as Elastic method of design. Elastic behaviour of materials are used in Working stress design. In this Method factor of safety is taken into account only on stress in materials, not on loads.

Permissible bending stress in Concrete (accordance with IS code)

Grade of concrete	M10	M15	M20	M25	M30	M35	M40
Permissible stress in bending in N/mm^2 (σ_{cbc})	3	5	7	8.5	10	11.5	13.

Modular ratio :-

Modular ratio 'M' is defined as the ratio of the elastic modulus of steel to that concrete.

$$\text{Modular ratio 'm'} = \frac{280}{3\,\sigma_{cbc}}$$

Concrete Grade	σ_{cbc} (N/mm^2)	Modular Ratio 'm'
M_{20}	7.0	13.33
M_{25}	8.5	10.98
M_{30}	10.0	9.33
M_{35}	11.5	8.12
M_{40}	13.0	7.18.

Ultimate load Design Method:

It is otherwise reffered to as the load factor method or the ultimate strength method. This method is based on the ultimate strength, when the design member would fail.

In this factor of safety is taken into account only on loads, and is called load factor.

Factored load = Ultimate load (or) design load.

Limit state design method :-

It is combination of working stress method and Ultimate load method. In this method partial factor of safety is considered on both loads and stresses. This method is advance over other two methods, since safety and serviceability are considered for design of structures.

Partial safety factors for materials (γ)

As per clause 36.4.2.1.1 (IS 456-2000)

a) Partial safety factor for concrete (γ_c) is taken as 1.5.

b) partial safety factor for steel (γ_s) is taken as 1.15

Partial safety factors for loads (γ_f)

As per code IS 456 - 2000 Table 18 gives the values of partial safety factors.

Properties of concrete and Reinforcing steel.

Table 1.7 partial safety factor (γ_f) for loads

load	Combination	limit state of collapse			limit state of serviceability		
		DL	IL	WL	DL	IL	WL
1.	Dead load + Imposed load	1.5	1.5	–	1.0	1.0	–
2.	Dead load + Wind load	1.5 0.9	– –	1.5 1.5	1.0	–	1.0
3.	Dead load + Imposed load + wind load	1.2	1.2	1.2	1.0	0.8	0.8

Lecture No.3 .

Topic(s) to be covered	Analysis And design of singly Reinforced Rectangular beams by working stress method.

Lecture Outcome (LO) At the end of this lecture, students will be able to		Bloom's Level
LO1	Design procedure for Singly Reinforced Section.	Understanding.
LO2	Design the Singly Reinforced Section	Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Practice & listen.

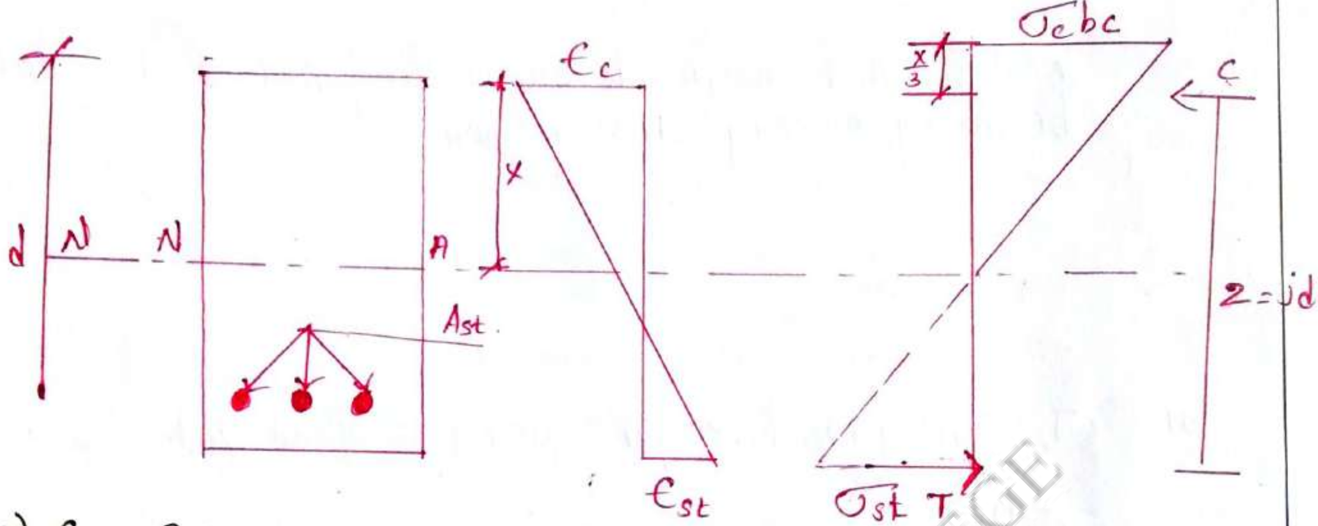
Lecture Notes

ANALYSIS AND DESIGN OF SINGLY REINFORCED RECTANGULAR BEAMS BY WORKING STRESS METHOD.

Analysis of rectangular Beam :

a) Singly reinforced Section :-

Beam Carries the dead, live loads from the slab, masonry wall and transfers to the column. steel reinforcement provided only at the tension zone is called Singly reinforced section.



a) Cross Section Of Rectangular Beam b) Strain diagram c) Stress diagram.

Stress - Strain diagram for Singly Reinforced Section.

b — Width of Beam.

d — Effective depth of Beam = Overall depth - effective Cover.

Effective Cover = clear cover - (diameter of bar/2)

σ'_{cbc} - Actual Compressive Stress in Extreme fibre of Concrete.

σ'_{st} - Actual tensile stress in tension Steel.

A_{st} - Area of tension steel.

m - modular Ratio

x - neutral axis depth

σ_{cbc} - Permissible Compressive Stress in bending in Concrete.

mA_{st} - equivalent area of Concrete.

Depth of Neutral axis Calculation :-

$$\left[b \times x \times \frac{x}{2}\right] - mA_{st}(d-x) = 0.$$

$$\frac{bx^2}{2} - mA_{st}(d-x) = 0.$$

Force of Compression in Concrete $C = \frac{bx\sigma'_{cbc}}{2}$

Force of tension in Steel $T = A_{st}\sigma'_{st}$.

Force of tension in steel, $T = A_{st}\sigma_{st}$.

Lever arm is the distance b/w the Points of action of compressive and tensile forces.

Lever arm, $z = jd = d - \frac{x}{3}$

j - Lever arm factor.

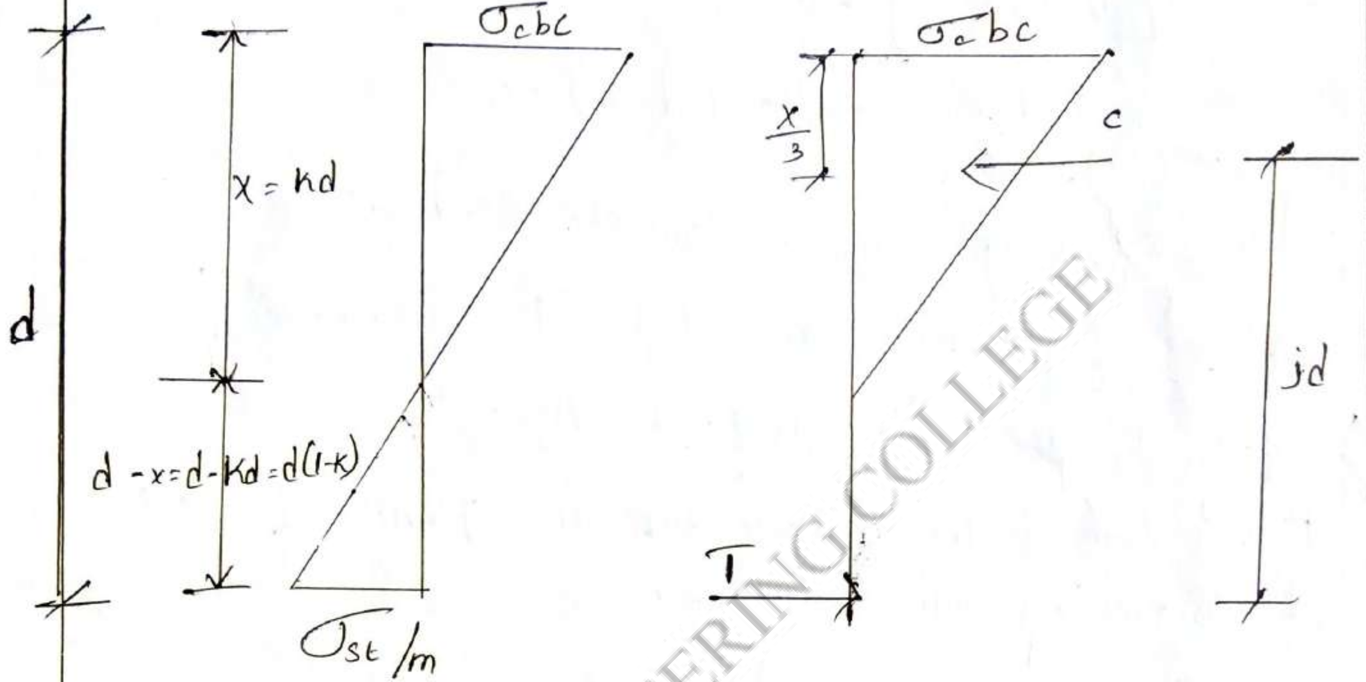
Moment of resistance w.r.to compression $= C.z = \left[bx\frac{\sigma_{cbc}}{2}\right]\left[d - \frac{x}{3}\right]$

Moment of Resistance w.r.to tension $= T.z = \left[A_{st}\sigma'_{st}\right]\left[d - \frac{x}{3}\right]$

Analysis of a balanced Section:

For a balanced section, Concrete and steel reaches maximum permissible stresses simultaneously.

Stress Strain diagram for a rectangular Beam with Balanced Section.



a) Neutral Axis depth factor (K).

Neutral Axis depth $x = kd$

K - Neutral Axis depth factor.

j - lever arm factor.

b - Width of Beam.

d - eff. depth of Beam.

σ_{st} - permissible stress in Concrete in bending Compression.

σ_{cbc} - Permissible stress in steel in tension.

From Similar triangle Principal of a stress diagram, N. A depth factor, K Can be calculated.

$$\frac{Kd}{\sigma_{cbc}} = \frac{d(1-k)}{\left[\frac{\sigma_{st}}{m}\right]}$$

$$Kd = \frac{m \cdot \sigma_{cbc} \cdot d(1-k)}{(\sigma_{st})}$$

$$K - \left[(1-k)\frac{\sigma_{cbc} \cdot m}{\sigma_{st}}\right] = 0.$$

$$K - \frac{\sigma_{cbc} m}{\sigma_{st}} + K\frac{\sigma_{cbc} \cdot m}{\sigma_{st}} = 0.$$

$$K\left[1 + \frac{\sigma_{cbc} \cdot m}{\sigma_{st}}\right] = \frac{\sigma_{cbc} \cdot m}{\sigma_{st}}$$

$$K = \frac{\left[\frac{\sigma_{cbc} \cdot m}{\sigma_{st}}\right]}{\left[1 + \frac{\sigma_{cbc} \cdot m}{\sigma_{st}}\right]}$$

multiplied and divided by

$$\left[\frac{\sigma_{st}}{m \cdot \sigma_{cbc}}\right], \quad K = \frac{1}{\left[\frac{\sigma_{st}}{m \cdot \sigma_{cbc}}\right] + 1}$$

b) Lever arm factor (j)

Lever arm depth, $jd = d - \frac{x}{3}$

$= d - \frac{Kd}{3} \quad (\because x = Kd)$

$jd = d\left[1 - \frac{K}{3}\right]$

Lever arm factor, $j = \left[1 - \frac{K}{3}\right]$

(c) Moment of Resistance (M)

(i) Moment of Resistance (M) w.r.to compressive force,

$$M = Cz = C \cdot jd = \frac{\sigma_{cbc}}{2} b K d \left[1 - \frac{K}{3}\right] d$$

1. A reinforced concrete beam of Rectangular section has the cross section of 300 x 500 mm. 4 Numbers of 20mm diameter steel bars is provided in tension reinforcement. Assuming that M20 grade Concrete and Fe 415 grade steel are used, determine the stresses induced in the top compression fibre of the concrete and tension steel when it is subjected to a moment of 65 kNm.

Given data :-

1. Size of beam = 300x500mm
2. Width of beam b = 300mm
3. Over all depth D = 500mm

Moment $M = 65 KNm = 65 \times 10^6 N mm.$

Area of tension steel, $A_{st} = 4 - 20 mm \phi$

Grade of steel : Fe 415 $\sigma_{st} = 230 N/mm^2$

Grade of concrete : M20, $\sigma_{cbc} = 7 N/mm^2$

Solution :-

1) Depth of Neutral Axis, x calculation :-

$$\frac{bx^2}{2} - m A_{st} (d - x) = 0.$$

$$\Rightarrow m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33$$

($\because$ For M20 grade concrete, $\sigma_{cbc} = 7 N/mm^2$)

$\Rightarrow A_{st} = 4 \times 314 = 1256 mm^2$

$\Rightarrow$ Assume clear cover, 25 mm.

$\Rightarrow$ Effective cover $= 25 + \left[\frac{20}{2}\right] = 35 mm.$

$\Rightarrow$ Effective depth

d = Overall depth - Effective cover

$d = 500 - 35 = 465 mm.$

$$\Rightarrow \frac{300 \times x^2}{2} - \left[13.33 \times 1256 \times (465 - x)\right] = 0.$$

$x = 178.74 mm.$

Set II $150 x^2 + 16742.48x - 7.785 \times 10^6 = 0.$

$\div 150, \; x^2 + 111.62 - 51900 = 0.$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$a = 1,\ b = 111.62,\ c = -51900.$

$$= \frac{-111.62 \pm \sqrt{111.62^2 + (4 \times 1 \times 51900)}}{2 \times 1} = \frac{-111.62 \pm 469.1}{2.}$$

$x = +178.74, -290.36$

Take positive value $\Rightarrow x = 178.74\,mm$

b) Stress Calculation:

Moment of resistance with respect to Tension steel,

$$M = (A_{st}\,\sigma'_{st})\left(d - \frac{x}{3}\right)$$

$$65 \times 10^6 = (1256 \times \sigma'_{st})\left(465 - \frac{178.74}{3}\right)$$

$$\boxed{\sigma'_{st} = 127.65\ N/mm^2}$$

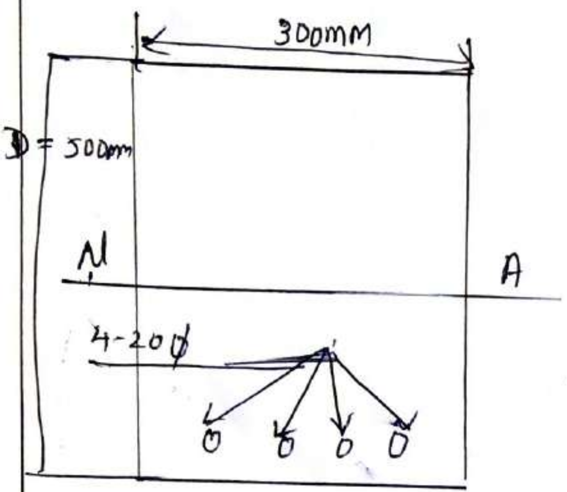
$$\boxed{\frac{\sigma'_{st}}{m} = \frac{127.65}{13.33} = 9.576.}$$

Stress in extreme Compression fiber of concrete can be calculated from the similar triangle of stress diagram.

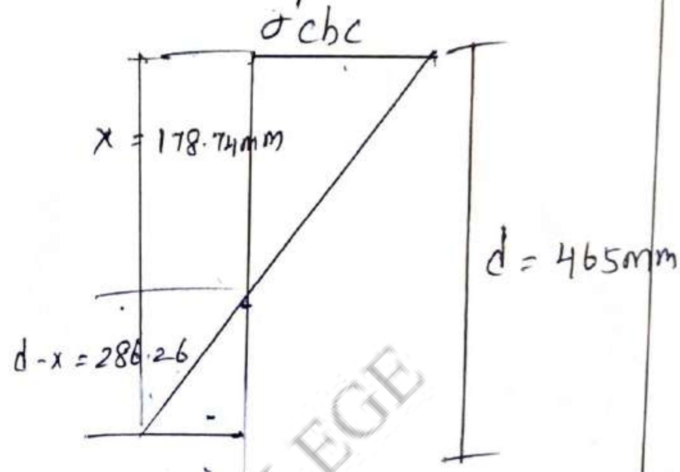
$$\frac{286.26}{9.576} = \frac{178.74}{\sigma'_{cbc}}$$

Stress in extreme Compression fiber of Concrete

$$\sigma'_{cbc} = 5.98\ N/mm^2$$



Cross Section Of Rectangular Beam



Stress diagram

$$\frac{\sigma_{st}}{m} = \frac{127.65}{13.33} = 9.576\ N/mm^2$$

—x—

Lecture No. 4

Topic(s) to be covered	Analysis and design of Singly reinforced Rectangular beams by working stress method.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Design of Rectangular Beam including self weight	Apply.

Teaching Learning Material	Student Activity
Chalk & Talk	Practice & listen.

Lecture Notes

A beam of rectangular Section of width 225mm and effective depth 500mm is simply supported over a span of 5m is reinforced with four numbers of 20mm diameter mild steel bars in tension side. Determine the position of neutral axis and the stresses in the topmost compression fiber of concrete and tension steel, if the beam carries a u.d.l of 9 kN/m (including self - weight) for the entire span. Use working stress method design.

Given data:-

1. Width of beam $b = 225mm$
2. Effective depth $d = 500mm$

Support condition : Simply supported.

Span $l = 5m$

Area of tension steel, $A_{st} = 4\text{-}20mm\,\phi = 4 \times 314 = 1256\,mm^2$

load over the beam, $w = 9\,kN/m$ (including self-weight)

Grade of concrete, M_{20} $\sigma_{cbc} = 7\,N/mm^2$

Grade of steel $Fe\,250$, $\sigma_{st} = 140\,N/mm^2$ (mild steel)

Solution:

a) Moment Calculation:

For Simply supported beam,

Maximum moment $M_{max} = \dfrac{wl^2}{8} = \dfrac{9 \times 5^2}{8} = 28.125\,kNm.$

b) Depth of Neutral axis calculation (x)

$m = \dfrac{280}{3\sigma_{cbc}} = \dfrac{280}{3 \times 7} = 13.33$ ($\sigma_{cbc} = 7\,N/mm^2$, for M_{20} concrete)

$$\frac{bx^2}{2} - m A_{st}(d - x) = 0.$$

$$\frac{225x^2}{2} - 13.33 \times 1256\,(500 - x) = 0$$

$$112.5x^2 - 8731240 + 16742.48x = 0.$$

$$\div \quad 112.5x^2 + 148.82x - 74411.02 = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$= \frac{-148.8 \pm \sqrt{(148.82)^2 + (4 \times 1 \times 74411.02)}}{2 \times 1}$$

$$x = \frac{-148.8 + 565.50}{2} = 208.35\,mm.$$

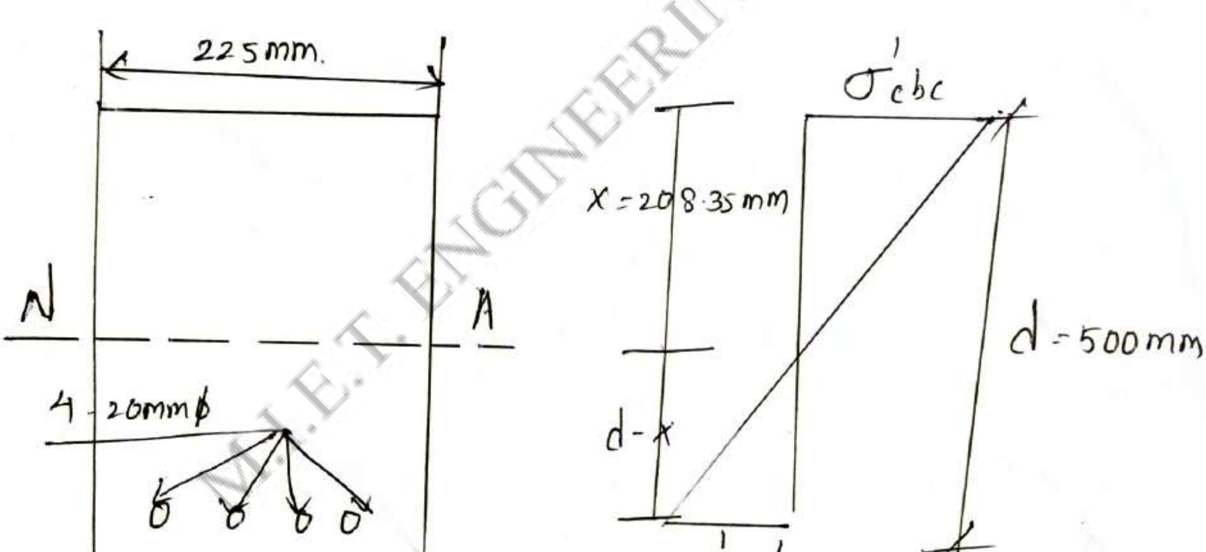
$$x = 208.35\,mm$$

c) Stress Calculation:

$$M = (A_{st}\,\sigma'_{st})\left(d - \frac{x}{3}\right)$$

$$(28.125 \times 10^6) = 1256 \times \sigma'_{st}\left(500 - \frac{208.35}{3}\right)$$

$$\sigma'_{st} = 52\ N/mm^2\ \text{(tension)}$$



Cross Section of Rectangular Beam

Stress diagram

From Similar triangle Principle,

$$\frac{(d-x)}{(\sigma'_{st}/m)} = \frac{x}{\sigma'_{cbc}}$$

$$\frac{(500-208.35)}{(52/13.33)} = \frac{208.35}{\sigma'_{cbc}}$$

Stress in extreme compression fibre of concrete

$$\sigma'_{cbc} = 2.79 \ N/mm^2.$$

—— x —— x ——

Lecture No. 5

Topic(s) to be covered	Analysis and design of Singly reinforced Rectangular beams by working stress method.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Determine the position of Neutral axis using Working stress method	Apply.

Teaching Learning Material	Student Activity
chalk & Talk	listen & Practice.

Lecture Notes

Determine the position of neutral axis and the moment of a beam 300mm wide and 550mm effective depth. It is reinforced with 3 bars of 16mm diameter. Use M20 grade concrete and Fe 415 grade steel. Adopt working stress method.

Given data :

Width of beam $b = 300mm$

Eff. depth $d = 550mm$

$A_{st} = 3 \times 201 = 603 \ mm^2$

M_{20}, $\sigma_{cbc} = 7\ N/mm^2$

Fe 415 $\sigma_{st} = 230\ N/mm^2$.

Solution :

a) Depth of Neutral axis Calculation :

Modular ratio $m = \dfrac{280}{3\sigma_{cbc}} = \dfrac{280}{3 \times 7} = 13.33$

$$\frac{bx^2}{2} - m A_{st}(d-x) = 0.$$

$$\frac{300x^2}{2} - 13.33 \times 603 \times (550 - x) = 0.$$

$$150x^2 - 4420900 + 8038x = 0.$$

$$\div\ 150x^2 - 29472.67 + 53.59x = 0.$$

$$x^2 + 53.59x - 29472.67 = 0.$$

$$x = \frac{-b \pm \sqrt{b^2 4ac}}{2a}.$$

$$x = \frac{-53.59 \pm \sqrt{53.59^2 + (4 \times 1 \times 29472.67)}}{2 \times 1}$$

$$= \frac{-53.59 \pm 347.52}{2}$$

$$x = 146.96mm.$$

b) Moment of Resistance Calculation :

Neutral axis depth factor K for a balanced Section.

$$K = \frac{1}{\left(\dfrac{\sigma_{st}}{m\sigma_{cbc}}\right) + 1} = \frac{1}{\left[\dfrac{230}{13.33 \times 7}\right] + 1} = 0.289$$

Depth of Neutral axis of balanced Section

$= Kd = 0.289\,d = 0.289 \times 550 = 158.95\,mm.$

$x < x_{bal}$. It is under reinforced Section. Steel reaches maximum permissible Stress earlier than Concrete.

$\sigma'_{st} = \sigma_{st} = 230\ N/mm^2$

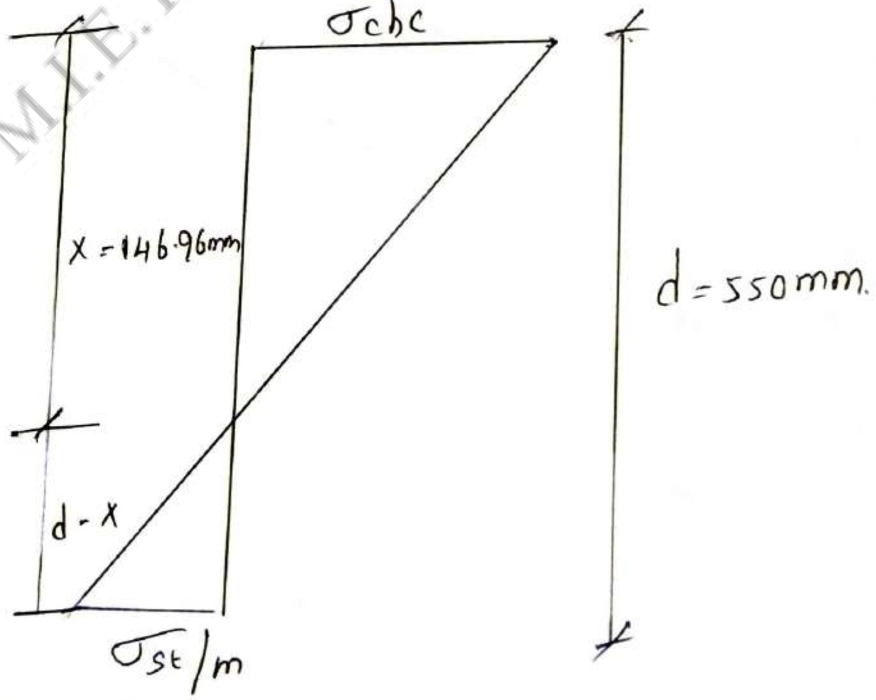
For Similar triangle Principle,

$$\frac{(d-x)}{\left[\frac{\sigma_{st}}{m}\right]} = \frac{x}{\sigma'_{cbc}}$$

The permissible shear stresses in different types of steel Reinforcement in Table 21, 22 IS 456:2000 pg. No. 81, 82

$$\frac{(550-146.96)}{\left[\frac{230}{13.33}\right]} = \frac{146.96}{\sigma'_{cbc}}$$

$\sigma'_{cbc} = 6.29\ N/mm^2$



Moment of Resistance of the section,

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

$$= (603 \times 230)\left(550 - \frac{146.96}{3}\right)$$

$$= 69.49 \times 10^{6} \text{ Nmm.}$$

$$M = 69.49 \text{ kNm.}$$

—— x —— x ——

Lecture No. 6.

Topic(s) to be covered	Analysis and design of design of Singly Reinforced Rectangular Beams by Working stress Method.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Design of Under Reinforced section and over Reinforced Section.	Apply.

Teaching Learning Material	Student Activity
Chalk & Talk	Practice & listen.

Lecture Notes

An Rc beam of Rectangular Section 300mm wide 650mm Overall depth is Reinforced with 4 bars of 32mm diameter of an effective cover of 50mm. Estimate the moment of Resistance of the Section using Working stress Method.

1. Given data:

Width of Beam $b = 300mm$.

Overall depth $D = 650mm$.

Area of tension steel, A_{st} = 4 nos, 32 mm ϕ = 4 x 804
= 3216 mm^2

Effective cover, d' = 50mm

Grade of concrete, M20 σ_{cbc} = 7 N/mm^2

Grade of steel Fe415, σ_{st} = 230 N/mm^2

Solution:

a) Depth of Neutral axis Calculation:

Modular ratio, $m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33$

Effective depth, $d = D - d' = 650 - 50 = 600mm$

$$\frac{bx^2}{2} - m A_{st} (d - x) = 0.$$

$$\frac{300x^2}{2} - 13.33 \times 3216 (600 - x) = 0.$$

$$150x^2 + 42869.28x - 25721568 = 0$$

$$\div 150, \quad x^2 + 285.80x - 171477.12 = 0.$$

$$x = \frac{-b \pm \sqrt{b^2 4ac}}{2a}$$

$$x = \frac{-285.80 \pm \sqrt{285.80^2 + (4 \times 1 \times 171477.12)}}{2 \times 1}$$

$$x = \frac{-285.80 \pm 876.12}{2}$$

$$\boxed{x = 295.16mm}$$

b) Moment of Resistance Calculation:

$$K = \frac{1}{\left(\frac{\sigma_{st}}{m\sigma_{cbc}}\right)+1} = \frac{1}{\left(\frac{230}{13.33\times 7}\right)+1} = 0.289.$$

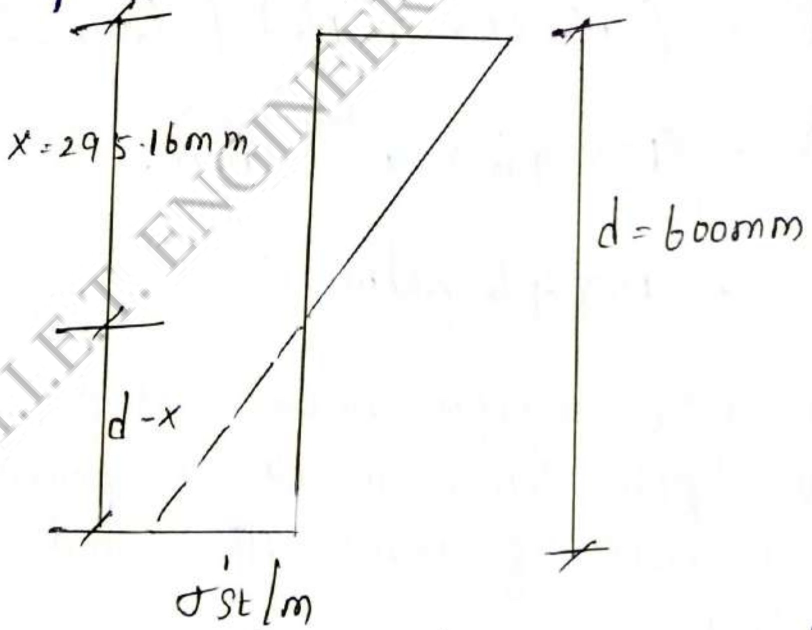
Depth of Neutral axis of balanced section

$= Kd = 0.289\,d = 0.289 \times 600 = 173.40\,mm$

$X_{balance} = 173.40\,mm$

$x > x_{balance}$.

It is Over Reinforced Section. Concrete Reaches maximum permissible stress earlier than steel.



Stress diagram for Rectangular beam

$\sigma'_{cbc} = \sigma_{cbc} = 7\,N/mm^2$

for Similar triangle Principle

$$\frac{(d-x)}{\left(\frac{\sigma'_{st}}{m}\right)} = \frac{x}{\sigma_{cbc}}$$

$$\frac{(600-295.16)}{\left(\frac{\sigma'_{st}}{13.33}\right)} = \frac{295.16}{7}$$

$$\sigma'_{st} = 96.37 \text{ N/mm}^2$$

Moment of Resistance of the Section.

$$M = (A_{st}\,\sigma'_{st})\left(d - \frac{x}{3}\right)$$

$$M = (96.37 \times 3216)\left(600 - \frac{295.16}{3}\right)$$

$$= 155.46 \times 10^6 \text{ Nmm}.$$

$$M = 155.46 \text{ kNm}.$$

2. Design a rectangular beam Section 300 x 500mm effective depth subjected to a moment of 60kNm. consider Concrete of grade M20 and steel of grade Fe415.

Given data:

Moment, $M = 60 \text{ kNm} = 60 \times 10^6 \text{ Nmm}$.

$b = 300\text{mm}$

$d = 500\text{mm}$.

Grade of concrete M_{20}, $\sigma_{cbc} = 7\ N/mm^2$

Grade of steel Fe 415, $\sigma_{st} = 230\ N/mm^2$

Solution:

Balanced moment, $M_{bal} = \frac{\sigma_{cbc}}{2} \times bd^2 K_{bal}\left[1 - \frac{K_{bal}}{3}\right]$

Modular Ratio $m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33$.

$$K_{bal} = \frac{1}{\left[\frac{\sigma_{st}}{m\sigma_{cbc}}\right]+1} = \frac{1}{\left[\frac{230}{13.33 \times 7}\right]+1}$$

$$K_{bal} = 0.289$$

$$M_{bal} = \frac{7}{2} \times 300 \times 500^2 \times 0.289 \left[1 - \frac{0.289}{3}\right]$$

$$M_{bal} = 68.55 \times 10^6\ Nmm.$$

Since $M < M_{bal}$, it is a singly Reinforced Section.

$$M = A_{st}\sigma_{st}\left[d - \frac{x}{3}\right]$$

$$x = Kd = 0.289 \times 500 = 144.50mm.$$

$$60 \times 10^6 = A_{st} \times 230\left[500 - \frac{144.5}{3}\right]$$

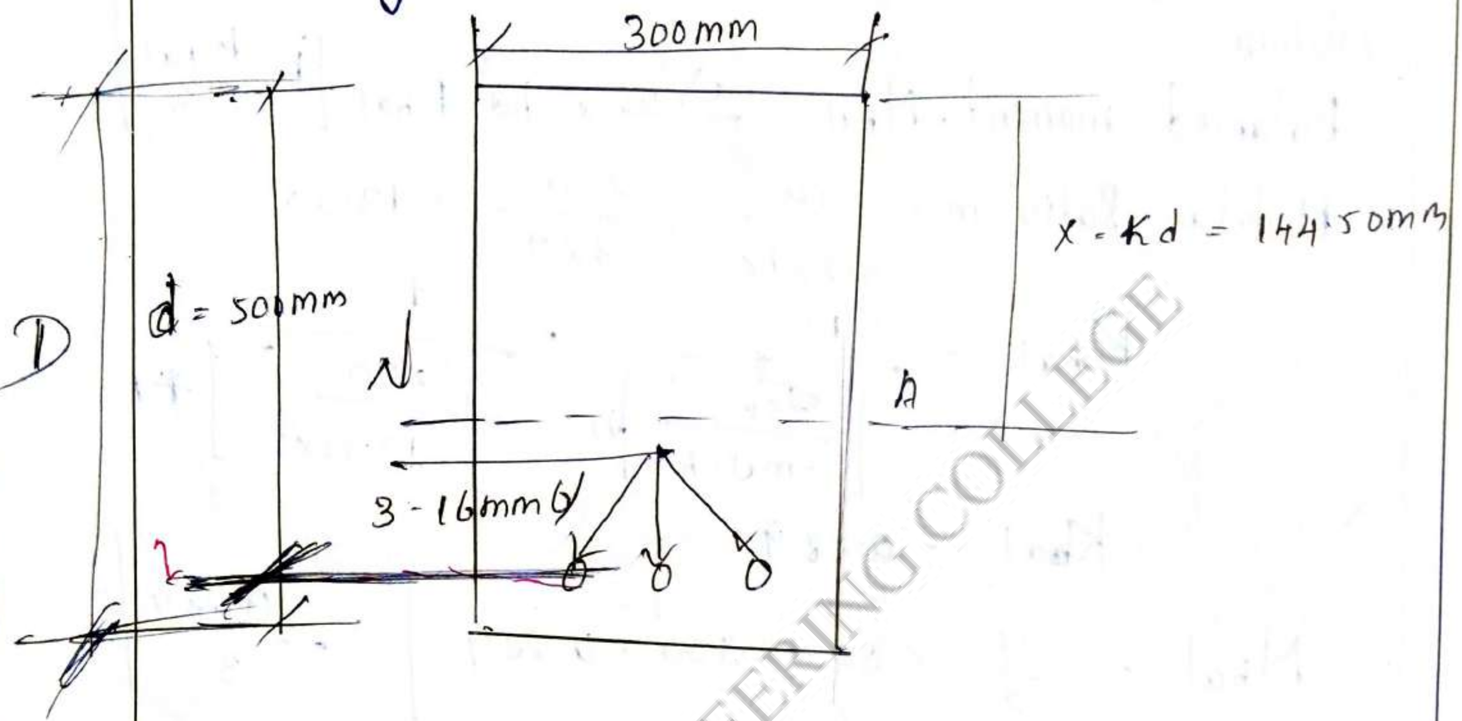
$$A_{st} = 577.36\ mm^2$$

Provide 16mm diameter bars,

Number of bars Required $= \frac{577.36}{201}$

$= 2.87 \simeq 3$ Nos.

Provide 3-16 mm diameter bars at tension zone only.



— x — x —

Lecture No. 7.

Topic(s) to be covered	limit state philosophy as detailed in IS code, Advantages of limit state method over ther methods.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	limit state philosophy and advantages of limit state method	Remembering.

Teaching Learning Material	Student Activity
Chalk & Talk	listen.

Lecture Notes

LIMIT STATE PHILOSOPHY AS DETAILED IN IS CODE

Limit state philosophy is advancement over the traditional working stress design philosophies. In limit state design, safety at the ultimate load and serviceability at the working load are considered. According to clause no. 35, section 5, IS 456-2000, the acceptable limit for the safety and serviceability requirements before failure occurs is called limit state.

Limit State Design

limit state collapse

a) Flexure
b) Compression
c) Shear
d) Torsion

limit state Serviceability

a) Deflection
b) Cracking.

Assumption. (As per clause no 38.1, IS456 - 2000)

Depth of Neutral axis (X_u) Determination :

Neutral axis (N.A) divides the Section into 2 zones to Satisfy equilibrium of forces. Depth of Neutral axis can be determined from the following equilibrium of forces equation.

$$C_u = T_u$$

$$\text{Tensile force } T_u = \frac{\text{Tensile stress} \times \text{Area of Steel}}{\text{partial factor of safety steel}}$$

$$= \frac{f_y A_{st}}{1.15} = 0.87 f_y A_{st}$$

f_y - characteristic strength of steel

A_{st} - Area of tension Reinforcement.

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

f_{ck} — characteristic compressive strength of Concrete.

x_u — Depth of Neutral axis.

Advantages of limit state method over other methods:-

1) Ultimate load method only deals with on safety such as strength, overturning, sliding buckling fatigue etc...

b) Working stress method only deals with serviceability such as deflection, crack, vibration

c) limit state method advance than over other two methods, hence by considering safety at ultimate loads and Serviceability at working loads.

Analysis and Design of singly and doubly Reinforced Rectangular Beam by limit state Method.

Beam → A beam is a horizontal structural element which is subjected to flexure or bending.

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

f_{ck} — characteristic compressive strength of Concrete.

x_u — Depth of Neutral axis.

Advantages of limit state method over other methods:-

1) Ultimate load method only deals with on safety such as strength, overturning, sliding buckling fatigue etc...

b) Working stress method only deals with serviceability such as deflection, crack, vibration

c) limit state method advance than over other two methods, hence by considering safety at ultimate loads and serviceability at working loads.

Analysis and Design of singly and doubly Reinforced Rectangular Beam by limit state Method.

Beam → A beam is a horizontal structural element which is subjected to flexure or bending.

Types of beam: 1. Rectangular Beam:

a) Singly Reinforced Beam

Reinforcement is Provided in a beam to take only the flexure tension is called singly Reinforced beam.

b) doubly Reinforced Beam:

Reinforcements provided in a Beam to take both flexural tension and Compression is called doubly Reinforced beam.

ii) Flanged Beam:

Beam and the slab are acting together as single structural member, which is known as flanged beams. for flanged sections, beam and slab Reinforcements are interlinked and Concreting is poured for beam and slab at the Same time.

a) singly Reinforced beam

b) doubly Reinforced Beam.

— x — x —

Lecture No. 8.

Topic(s) to be covered	Analysis and design of singly and doubly Reinforced rectangular beams by limit state method.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Design of Rectangular R.C. Simply supported beam.	Apply.

Teaching Learning Material	Student Activity
chalk & Talk	Practice & listen.

Lecture Notes

SOLVED PROBLEMS ON RECTANGULAR BEAM (LIMIT STATE METHOD)

1. Design a Rectangular R.C simply supported beam carrying LL of 12 kN/m and DL 6 kN/m. Effective span of a beam is 6m. Assume M20 & Fe415 combination. Assume thickness of masonry wall 230mm.

Given data:

1. live load = 12 kN/m

2. Dead load = 6 kN/m
3. Effective span l_e = 6m.
4. Thickness of masonry wall = 230mm
5. Grade of Concrete, M20, f_{ck} = 20 N/mm^2
6. Grade of steel, Fe415 = 415 N/mm^2

Soln :-

a) load calculation.

Over all depth $\left[\frac{\text{Effective span}}{12}\right] = \frac{6000}{12} = 500mm$

Consider a trial section of size 300mm x 500mm

~~live~~ Dead load = 18 kN/m.

Self weigh = $0.3 \times 0.5 \times 25$ kN/m^3

= 3.75 kN/m.

Dead load W = 21.75 kN/m.

Factored load W_u = $1.5 \times 21.75 = 32.625$ kN/m.

Factored Bending moment $= \frac{wl^2}{8} = \frac{32.625 \times 6^2}{8}$

= 146.81 kNm.

For Fe415 steel,

$$M_u = 0.138 f_{ck} bd^2$$

$$d = \sqrt{\frac{M_u}{0.138 f_{ck} b}}$$

$d = 421.07$ mm

Adopt 500mm Overall depth. Provide 16mm ϕ bars

Eff. depth $d = D -$ clear cover $- \phi/2$

$= 500 - 25 - 8 = 467$ mm

b) Area of steel, Ast calculation.

Method 1

from Annex - G, Clause G-1.1, b, IS 456-2000

$$M_u = 0.87 \times f_y A_{st}\, d \left[1 - \frac{A_{st}\, f_y}{b d\, f_{ck}}\right]$$

$$146.81 \times 10^6 = 0.87 \times 415 \times A_{st} \times 467 \left[1 - \frac{A_{st} \times 415}{300 \times 467 \times 20}\right]$$

$$'' = 168610.35\, A_{st} \left(1 - 1.481 \times 10^{-7} A_{st}\right)$$

$$146.81 \times 10^6 = 168610.35\, A_{st} - 24.97\, A_{st}^2$$

$$24.97\, A_{st}^2 - 168610.35\, A_{st} + 146.81 \times 10^6 = 0$$

$$A_{st} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$A_{st} = \frac{168610.35 \pm 117328.88}{(2 \times 24.97)}$$

$$A_{st} = 1026.86\,mm^2$$

Provide 20mm ϕ bars.

No. of bars = $\frac{1026.86}{314} = 3.27$

Provide 4 - Nos - 20mm ϕ bars

Method:

$$\frac{M_u}{bd^2} = \frac{146.81 \times 10^6}{300 \times 467^2} = 2.24\ N/mm^2$$

From Table 2, SP16, $f_{ck} = 20 N/mm^2$

$f_y = 415\ N/mm^2$

$p_t = 0.733\ \%$

$$A_{st} = p_t bd = \frac{0.733}{100} \times 300 \times 467 = 1026.93\ mm^2$$

No. of bars $= \frac{1026.93}{314} = 3.27$.

Provide 4 Nos. of 20mm ϕ bars

— x —

Lecture No. 9

Topic(s) to be covered	Analysis and design of singly and doubly Reinforced Rectangular beams by limit state method

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Design of Ultimate Moment of Resistance by limit state method	Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Practice & listen.

Lecture Notes

Analyze a Rectangular beam section of 250mm width and 450mm effective depth. Determine the ultimate moment of Resistance for Area of tension steel, A_{st} = 3- 16mm ϕ consider M20 and Fe415 combination.

Given data:

Width of Beam b = 250mm

Effective depth of beam d = 450mm.

Area of tension steel A_{st} = 3-16mm ϕ

$= 3 \times 201 = 603\ mm^2$

$f_{ck} = 20\ N/mm^2$

$f_y = 415\ N/mm^2$

Solution:

a) Depth of Neutral axis calculation.

Consider the Beam as a singly under Reinforced section.

$$x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} b} = \frac{0.87 \times 415 \times 603}{0.36 \times 20 \times 250} = 120.95mm$$

$$\frac{x_{u\,limit}}{d} = 0.48 \text{ for Fe415 steel}$$

$x_{u\,limit} = 0.48 \times d$

$= 0.48 \times 450$

$= 216mm.$

$x_u < x_{u\,limit}$ It is Under Reinforced Section. Steel Reaches maximum permissible stress.

b) Ultimate moment of Resistance (Mu) calculation:

$$Mu = 0.87 fy \, Ast \, (d - 0.42 xu)$$

$$= 0.87 \times 415 \times 603 \, (450 - 0.42 \times 120.95)$$

$$= 86.91 \times 10^6 \, N/mm.$$

$$= 86.91 \, kNm.$$

2. Drive the expressions for the depth of neutral axis, moment of Resistance of a rectangular singly Reinforced balanced beam section under flexure and obtain the design constants K, j, Q for M20 grade Concrete and Fe415 grade steel. Use working stress method.

Given data:

Grade of Concrete M20 $\sigma_{cbc} = 7 \, N/mm^2$

Grade of Steel Fe415 $\sigma_{st} = 230 \, N/mm^2$

Solution:

a) Neutral axis depth factor, K for a balanced section

$$K = \frac{1}{\left[\frac{\sigma_{st}}{m \sigma_{cbc}}\right] + 1} \quad ; \text{ for a balanced section}$$

$$K = \frac{1}{\left[\frac{230}{13.33 \times 7}\right] + 1} = 0.2896 \simeq 0.289.$$

(b) lever arm factor, j

$$j = 1 - \frac{K}{3} = 1 - \frac{0.289}{3} = 0.904.$$

(c) Moment of Resistance of Balanced Section

$$M.R_{bal} = Q_{bal}\, bd^2$$

$$Q = \text{Moment factor},$$

$$M.R = \frac{\sigma_{cbc}}{2} \times b \times Kd \left[1 - \frac{K}{3}\right] \times d$$

$$= \frac{\sigma_{cbc}}{2} \times K \left[1 - \frac{K}{3}\right] bd^2$$

$$= \frac{7}{2} \times 0.289 \times \left[1 - \frac{0.289}{3}\right] \times bd^2$$

$$M = 0.914\, bd^2$$

$$Q = \frac{\sigma_{cbc}}{2} K \left[1 - \frac{K}{3}\right] = 0.914$$

d) Moment of Resistance of Balanced Section

$$M = Qbd^2$$

$$= 0.914\, bd^2$$

Lecture No. 10

Topic(s) to be covered	Analysis and design of singly and doubly reinforced rectangular beams by limit state method.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Determine the Ultimate moment of Resistance with over reinforced Section	Apply.

Teaching Learning Material	Student Activity
Chalk & Talk	Practice & listen.

Lecture Notes

Analyze a rectangular beam section of 300mm width and 500mm effective depth. Determine the ultimate moment of Resistance for the beam for area of tension steel, 4-25mmϕ consider M20 and Fe 415 combination.

Given data:

1. Width of Beam $b = 300mm$
2. Eff. depth of beam $d = 500mm$

Area of tension steel, $A_{st} = 4 - 25mm\ \phi$

$= 4 \times 491 = 1964\ mm^2$

$M_{20} = f_{ck} = 20\ N/mm^2$

$f_y = 415\ N/mm^2$

a) Depth of Neutral axis calculation.

Consider the Singly Under Reinforced Section

$$X_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} b} = \frac{0.87 \times 415 \times 1964}{0.36 \times 20 \times 300} = 328.49mm$$

$$\frac{X_{u\,limit}}{d} = 0.48 \Rightarrow X_{u\,limit} = 0.48 \times d$$

$= 0.48 \times 500$

$X_u > X_{u\,limit}$

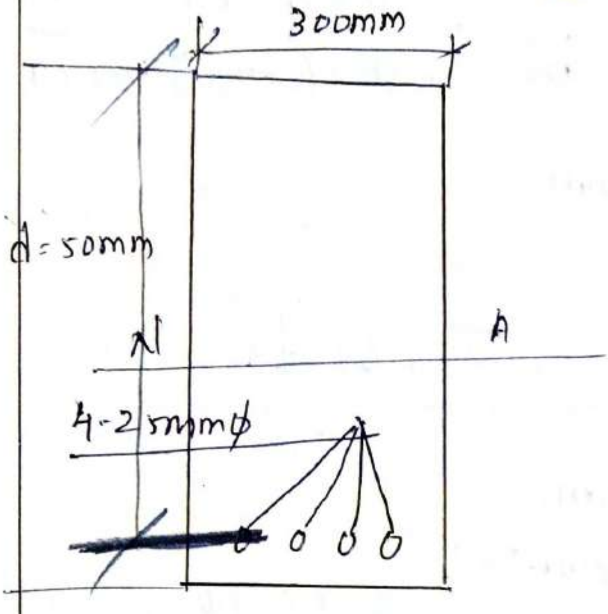
$= 240mm$

It is the an Over Reinforced Section concrete Reaches maximum permissible stress Earlier than steel. Assumption is not correct X_u value can be calculated by iteration process.

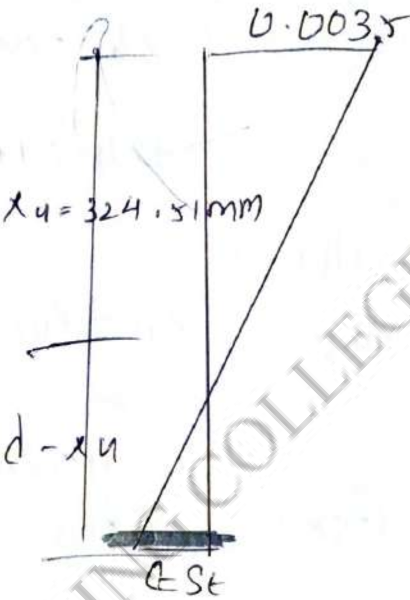
i) Iteration - I

$$X_{u1} = \frac{X_{u1} + X_{u\,limit}}{2}$$

$$= \frac{328.29 + 240}{2} = 284.65\,mm.$$



Cross Section



strain diagram

Strain at tension Steel, ϵ_{st} can be calculated by similar triangle principle,

$$\frac{(d - x_{u1})}{\epsilon_{st}} = \frac{x_{u1}}{0.035}$$

$$\epsilon_{st} = \frac{(d - x_{u1}) \times 0.0035}{x_{u1}} = \frac{(500 - 284.65) \times 0.0035}{284.65}$$

$$= 0.0026$$

from figure 23A, IS 456 - 2000 - Representative stress strain Curve for Reinforcement

Stress Corresponding to Strain 0.0026 = 0.86 fy

$$X_{u2} = \frac{0.86\, f_y\, A_{st}}{0.36\, f_{ck}\, b} = \frac{0.86 \times 415 \times 1964}{0.36 \times 20 \times 300}$$

$$= 324.51\,mm$$

ii) Iteration-2

$$X_{u3} = \frac{X_{u1} + X_{u2}}{2} = \frac{284.65 + 324.51}{2}$$

$$= 304.58\,mm.$$

$$\epsilon_{st} = \frac{(500 - 304.58)}{304.58} \times 0.0035 = 0.0022$$

23 A IS456 - 2000

$$X_{u4} = \frac{0.86\, f_y\, A_{st}}{0.36\, f_{ck}\, b} = 324.51\,mm.$$

X_u modified $X_{um} = X_{u2} = X_{u4} = 324.51$

b) Ultimate moment of Resistance calculation

$$M_u = 0.36\, f_{ck}\, b X_{um} (d - 0.42\, X_{um})$$

$$= 0.36 \times 20 \times 300 \times 324.51 (500 - 0.42 \times 324.51)$$

$$= 254.94\ kNm.$$

Lecture No. 11

Topic(s) to be covered	Analysis and design of singly and doubly reinforced rectangular beams by limit state method.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Analyse the Rectangular beam with doubly Reinforced section.	Apply.

Teaching Learning Material	Student Activity
Chalk & Talk	Practice & listen.

Lecture Notes

Analyse a Rectangular beam of 300mm width and 550mm effective depth Determine the Ultimate moment of Resistance of the doubly Reinforced Section with A_{st} = 3-25 mm ϕ and A_{sc} = 2-16mm. d' = 50mm. Grade of concrete is M20 & Grade of steel used is Fe415

Width of beam = b = 300mm

d = 550mm

A_{st} = 3-25mm ϕ = 3×491 = 1473 mm^2

A_{sc} = 2-16mm ϕ = 2×201 = 402 mm^2

d^1 = 50mm

f_{ck} = 20 N/mm^2

f_y = 415 N/mm^2

Soln :-

a) Depth of Neutral axis calculation.

For doubly Reinforced section

$$x_u = \frac{f_{st}\ A_{st} - A_{sc}\ (f_{sc} - f_{cc})}{0.36\ f_{ck}\ b}$$

for balanced and Reinforced Section:

$f_{sc} = f_{st} = 0.87\ f_y$ & $f_{cc} = 0.447\ f_{ck} = 0.45 f_{ck}$

Assume that the given beam is an Under Reinforced Section.

$$x_u = \frac{0.87\ f_y\ A_{st} - A_{sc}\ (0.87\ f_y - 0.45\ f_{ck})}{0.36\ f_{ck}\ b}$$

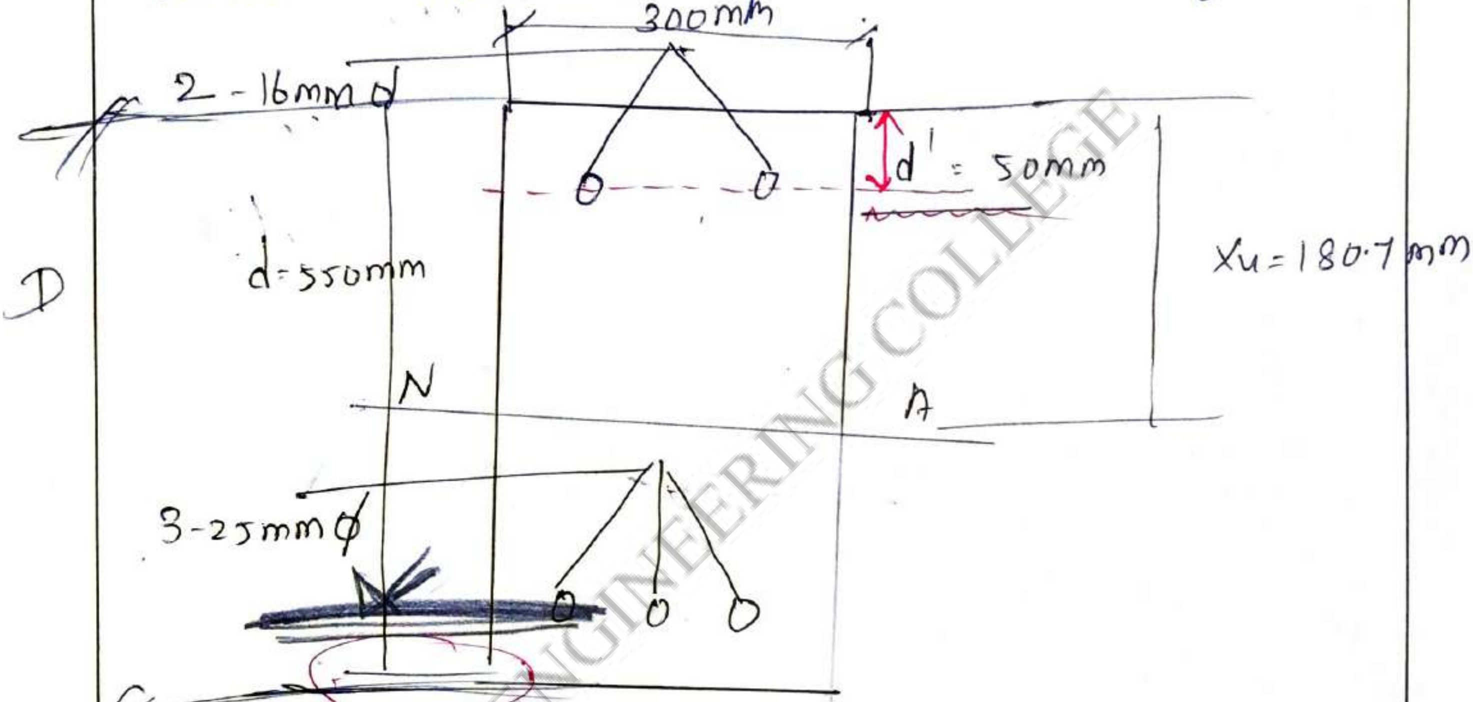
$$= \frac{(0.87 \times 415 \times 1473) - (402 \times (0.87 \times 415 - 0.45 \times 20)]}{0.36 \times 20 \times 300}$$

$$x_u = \frac{531826.65 - 141524.1}{2160} = 180.7mm.$$

$X_u\,limit = 0.48\,d$

$= 0.48 \times 550 = 264\,mm.$

$X_u < X_u\,limit$, It is an Under Reinforced Section. Hence assumptions are justified.



Ultimate moment of Resistance:

$$M_u = \left[0.36\, f_{ck}\, b\, x_u\, (d - 0.42 x_u)\right] + \left((0.87 f_y - 0.45 f_{ck})\, A_{sc}\, (d - d')\right)$$

$$= \left(0.36 \times 20 \times 300 \times 180.70\, (550 - 0.42 \times 180.70)\right\} + \left((0.87 \times 415 - 0.45 \times 20) \times 402\, (550 - 50)\right)$$

$$= (185.05 \times 10^6) + (70.76 \times 10^6)$$

$$= 255.81 \times 10^6\ Nmm.$$

Lecture No. 12

Topic(s) to be covered	Analysis and design of singly and doubly Reinforced rectangular beams by limit state method.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Determine the Ultimate moment of resistance of doubly reinforced section with over reinforced section.	Apply.

Teaching Learning Material	Student Activity
Chalk & Talk	listen & Practice.

Lecture Notes

Analyze a rectangular beam Section of 300mm width and 550mm effective depth. Determine the Ultimate moment of Resistance of the doubly Reinforced section with $A_{st} = 6-25mm\phi$ and $A_{sc} = 4-16mm$. $d' = 50mm$. Grade of Concrete used is M20 & Grade of steel is Fe415.

Given data :-

1. $b = 300mm$
2. $d = 550mm$

$A_{st} = 6-25mm\,\phi = 6 \times 491 = 2946\ mm^2$

$A_{sc} = 4-16mm\,\phi = 4 \times 201 = 804\ mm^2$

$d' = 50mm.$

$f_{ck} = 20 N/mm^2$

$f_y = 415 N/mm^2$

a) Depth of Neutral Axis Calculation:

For doubly Reinforced Section.

$$x_u = \frac{f_{st} A_{st} - A_{sc}(f_{sc} - f_{cc})}{0.36 f_{ck} b.}$$

for balanced Under Reinforced Section.

$f_{sc} = f_{st} = 0.87 \times f_y$ & $f_{cc} = 0.45 f_{ck}.$

$$x_u = \frac{0.87 f_y A_{st} - A_{sc}(0.87 f_y - 0.45 f_{ck})}{0.36 f_{ck} \times b.}$$

$$= \frac{(0.87 \times 415 \times 2946) - (804 \times (0.87 \times 415 - 0.45 \times 20))}{0.36 \times 20 \times 300.}$$

$x_u = 361.39mm.$

$x_u\,limit = 0.48\,d = 0.48 \times 550 = 264mm$

$x_u > x_{u\,limit}$.

It is an Over reinforced section. Concrete reaches maximum permissible stress earlier than steel. Hence assumption is wrong and correct x_u value can be calculated by iteration process

i) Iteration - 1.

$$x_{u1} = \frac{x_{u1} + x_{u\,lim}}{2} = \frac{361.39 + 264}{2}$$

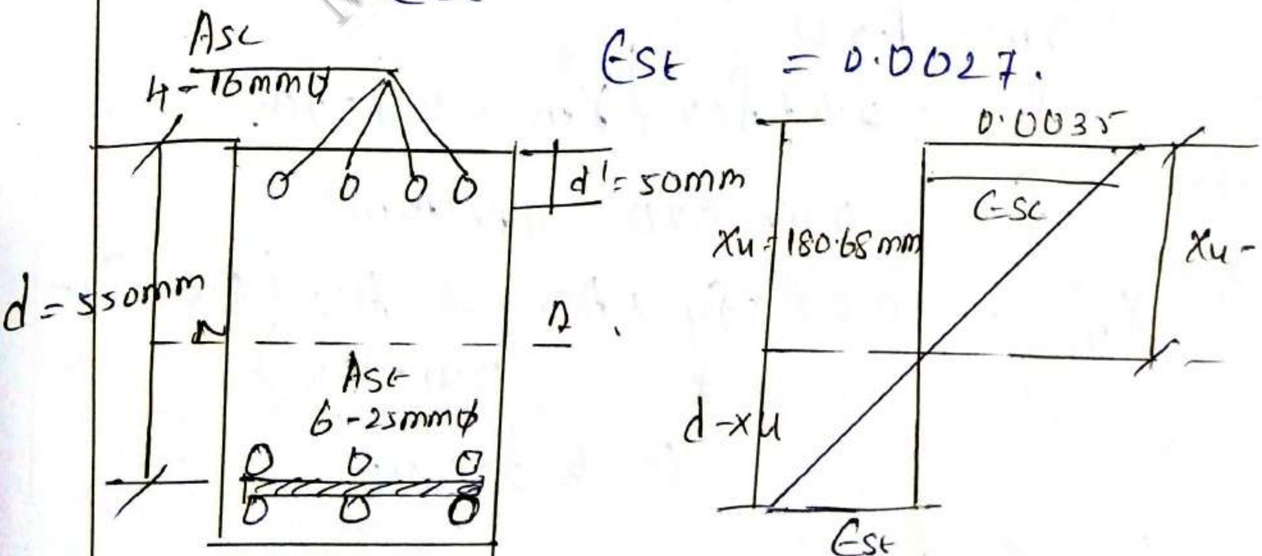
$= 312.70\,mm$.

Strain at tension steel, ϵ_{st} can be calculated from similar triangle principle.

$$\frac{(d - x_{u1})}{\epsilon_{st}} = \frac{x_{u1}}{0.0035}$$

$$\frac{(550 - 312.70)}{\epsilon_{st}} = \frac{312.70}{0.0035}$$

$\epsilon_{st} = 0.0027$.



Strain diagram

From figure 23A, IS456-2000, Representative stress strain curve for reinforcement.

Stress Corresponding to strain 0.0027 = 0.86fy.

$$\frac{x_u - d'}{\epsilon_{sc}} = \frac{x_u}{0.0035}$$

$$\epsilon_{sc} = \frac{0.0035\,(x_u - d')}{x_u}$$

$$= \frac{0.0035 \times (312.70 - 50)}{312.70} = 0.0029.$$

from figure 23A, IS456-2000

Stress Corresponding to strain 0.0029, f_{sc} = 0.86 fy.

According to figure 21, IS456-2000, f_{cc} = 0.67 fck/γm – Design stress strain curve of concrete

$$\gamma_m = 1.50$$

$$f_{cc} = 0.67 f_{ck} / \gamma_m = 0.45 f_{ck}.$$

$$f_{cc} = 0.45 \times 20 = 9\,N/mm^2$$

$$x_{u2} = \frac{0.87 \times f_y \times A_{st} - A_{sc}(0.87 f_y - 0.45 f_{ck})}{0.36 f_{ck}\, b.}$$

$$= \frac{(0.87 \times 415 \times 2946) - (804 \times (0.87 \times 415 - 0.45 \times 20))}{0.36 \times 20 \times 300}$$

$X_{u2} = 361.39mm.$

ii) Iteration - 2

$$X_{u3} = \frac{X_{u1} + X_{u2}}{2} = \frac{312.70 + 361.39}{2}$$
$$= 337.05mm.$$

$$\epsilon_{sc} = \frac{0.0035(550 - 337.05)}{337.02} = 0.0022$$

from figure 23 A, IS456 - 2000 $f_{st} = 0.86 f_y$

$$\epsilon_{sc} = \frac{0.0035(x_u - d')}{x_u} = \frac{0.0035(337.05 - 50)}{337.05}$$

$= 0.003.$

from figure 23A IS456 2000

$f_{sc} = 0.86 f_y$

$f_{cc} = 0.45 f_{ck}$ (from figure 21, IS456-2000)

$X_{u4} = 361.39mm.$

$X_{u\,modified}$, $X_{um} = X_{u2} = X_{u4} = 361.39mm$

b) Moment of Resistance Calculation:

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

$$= (0.36 \times 20 \times 300 \times 361.39 \times (500 - 0.42 \times 361.39)) + (804 \times (0.86 \times 415 - 0.45 \times 20) \times (550 - 50))$$

$$= (271.82 \times 10^6) + (139.86 \times 10^6)$$

$$= 411.68 \times 10^6 \text{ N.mm.}$$

— x — x —

UNIT-III

Lecture No. 13 UNIT – III – DESIGN OF SLABS AND STAIRCASE

Topic(s) to be covered	Analysis and design of Cantilever

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Analysis and design procedure for oneway simply supported slab	Understanding.

Teaching Learning Material	Student Activity
chalk & Talk	Listen.

Lecture Notes

Analysis and design of Cantilever slab

Slab :-

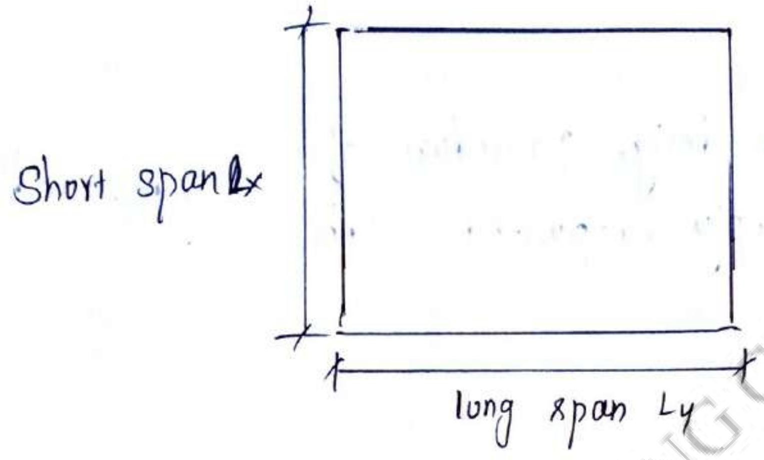
It is a structural member subjected to flexure that transmits imposed and dead load to the supports.

one way slab :

Ratio between long span and short span more than two is known as one way slab.

$$\frac{\text{Effective long span}, l_y}{\text{Effective short span } l_x} > 2$$

In one way slab, main reinforcement is required along short span, since loads are distributed along short span only. Minimum reinforcement is provided for distribution steel along long span to resist temperature stress.



Two way slab :-

Ratio between effective long span and short span less than or equal two is known as two way slab.

$$\frac{\text{Effective long span}, L_y}{\text{Effective Short span}, L_x} \leq 2$$

In two way slab, main reinforcements are provided along short and long directions, since loads are distributed along both directions.

Analysis and design Procedure of One way simply supported Slab:-

Step1: Thickness of slab, D calculation.

In practice, Fe415 steel is commonly used and for such grade percentage of steel to be provided assumed as 0.4

Based on chart 22, Sp16, corresponding to 0.4% of tension reinforcement, for simply supported slab,

$$\text{Eff. depth} = \frac{\text{Eff. span}}{25}$$

Overall depth = Eff. depth + eff. cover.

Eff. cover = clear cover + (diameter of main bar/2)

b) Eff. span, l_e calculation:

Eff. span is equal to the smaller values of case (i) & (ii)

i) Eff. span l_e = c/c distance b/w supports = clear span + Width of masonry wall.

$$l_e = l_c + 2\left(\frac{b_m}{2}\right)$$
$$= l_c + b_m.$$

ii) l_e = clear span + eff. depth of slab

$$l_e = l_c + d$$

c) Load calculation:-

i) self weight of slab = overall depth of slab × density of reinforced concrete.

$= D \times 25$ kN/m³

(∴ Weight density of reinforced concrete = 25 kN/m³)

ii) Consider self-weight of flooring ≃ 1 kN/m²

iii) live load Based on type of Building

For Commercial building minimum live load $= 2.5\ kN/m^2$ (Imposed load for diff. type of structures available in IS 875 - 1987 - part 2)

Total load w = Dead load + Live load

= Self weight of slab + Weight of flooring

Factored load $W_u = 1.5\,w$

Step 4: Bending moment Calculation:

$$M_u = \frac{W_u l_{ex}^2}{8}\ kN.m/m.$$

Step 5: Depth Calculation based on flexural moment:

$$d_{req.}\ \sqrt{\frac{M_u}{0.138 f_{ck} b}}\ \text{in mm.}$$

b = width of slab in mm = 1000 mm (∴ Consider 1m width strip).

$d_{req} < d_{pro}$ Hence safe.

<u>Note:-</u>

$f_y = 500$; $X_{u\,limit}/d = 0.456$

$X_{u\,limit} = 0.456d$.

$M_u = 0.36 f_{ck}\, b\, x_{um} (d - 0.42 x_{um})$.

$M_u = 0.36 \times f_{ck} \times b \times 0.456d \times (d - 0.42 \times 0.456d)$

For Fe500 $M_u = 0.155 f_{ck} bd^2$; $d_{req} = \sqrt{\frac{M_u}{0.155 f_{ck} b}}$

Step6 : Area of Main reinforcement:

$$M_u = 0.87 f_y A_{st} d \left[1 - \frac{A_{st} f_y}{bd f_{ck}}\right]$$

Spacing = [Area of one bar / Ast] X 1000

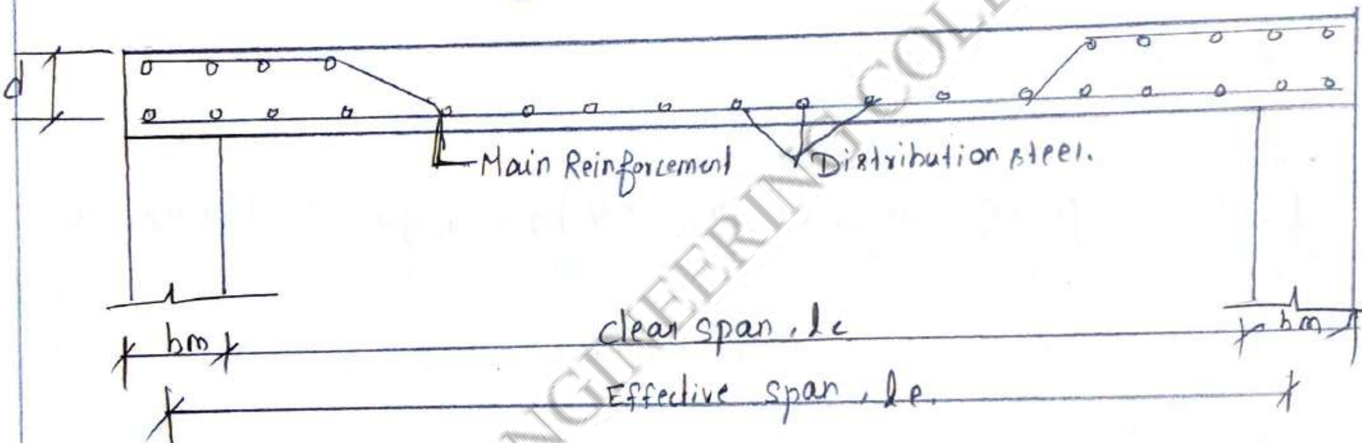
∴ Max. spacing = 3d or 300mm, whichever is less.

Step7 : Area of distribution steel ; Ast (distribution)

Provide min. Rein. based on clause no. 26.5.2.1, IS456-2000

$$A_{st(dist)} = 0.12\%.\ \text{Gross.Sec.Area} = \frac{0.12}{100} \times b \times D$$

∴ Max. spacing = 5d or 450mm, whichever is less.



Step8 :

Deflection check :

$$P_t \text{ Provided} = \frac{100\, A_{st\,main\,prov.}}{bd}$$

Calculation modification factor (MF) for tension reinforcement from figure 4, IS456 2000

$$\left[\frac{\text{Actual span}}{d\ \text{prov.}}\right] < \left[\frac{l}{d}\right]_{max}$$ ∴ Section is safe.

$$\left[\frac{l}{d}\right]_{max} = \text{Basic value} \times MF$$

Based on clause no. 23.2.1, IS456-2000, basic values of span to eff. depth ratios for span upto 10m are

Cantilever 7

S.S 20

Continous 26

Lecture No. 14

Topic(s) to be covered	Analysis and design of Cantilever slab.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Analysis and design of Cantilever slab	Apply.

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Practice.

Lecture Notes

Solved Problems on Cantilever slab,

1. Design a cantilever slab to carry a live load of 2.5 kN/m². The projection of slab is 1.5 m. M20 & Fe 500 grades are used.

Step 1: Given data:

1. Live load = 2.5 kN/m²
2. length of slab from the support l = 1.5 m
3. Grade of Con. M20, f_{ck} = 20 N/mm²
4. Grade of steel Fe500, f_y = 500 N/mm²

Step2 : load calculation :

$\therefore$ Consider slab thickness $= 125mm$.

1. self wt of slab $= 0.125m \times 25\ kN/m^3 = 3.125\ kN/m^2$
2. Live load $= \Rightarrow 2.5\ kN/m^2$
3. floor finish $= 1\ kN/m^2$
4. Total load $= 6.625\ kN/m^2$

Factored load $W_u = 1.5 \times 6.625 = 9.94\ kN/m^2$

Step3 : Bending Moment calculation :-

Cantilever $M_u = \frac{lwl^2}{2} = \frac{9.94 \times 1.5^2}{2} = 11.18\ kNm.$
$= 11.18 \times 10^6\ Nmm.$

Step4 : Thickness of slab calculation :

$M_u = 0.155 f_{ck} bd^2$

$11.18 \times 10^6 = 0.155 \times 20 \times 1000 \times d^2$ $(\because b = 1000\ mm, 1m\ strip)$

$d_{req} = 60.05mm$

$d_{prov} = D - \text{clear cover} - \frac{\text{bar dia}}{2}$

Clear cover $= 15\ mm$ and try $8mm$ dia. HYSD bars

$d_{pro} = 125 - 15 - 8/2 = 106mm.$

$d_{pro} = 106mm > d_{rq}$. $\therefore$ Hence Safe.

Step5 : Area of main steel calculation :

From Annex - G, clause G-1.1 b, IS456-2000

$$M = 0.87\ f_y\ A_{st}\ d \left[1 - \frac{A_{st}\ f_y}{bd\ f_{ck}}\right]$$

$$11.18 \times 10^6 = 0.87 \times 500 \times A_{st} \times 106 \times \left[1 - \frac{A_{st} \times 500}{1000 \times 106 \times 20}\right]$$

$A_{st} = 258.19\,mm^2$

Step 6 : Minimum Reinforcement:

$a_{st} = 0.12\%\ bD = \frac{0.12}{100} \times 1000 \times 125 = 150\,mm^2$

provide 8mm dia. bar.

spacing $= \frac{\text{Area of one rod}}{A_{st}} = \frac{50}{258.19} \times 1000 = 193.66\,mm$

Provide 8mm diameter bar at 190mm c/c.

Max. spacing = 3d or 300mm whichever is less

i) $= 3d = 3 \times 106 = 318\,mm$

ii) $= 300\,mm$

spacing Provided < Max. spacing Hence ok.

Step 7 : Area of distribution Steel calculation :-

$$A_{st\,dist} = \frac{0.12}{100} \times bD$$

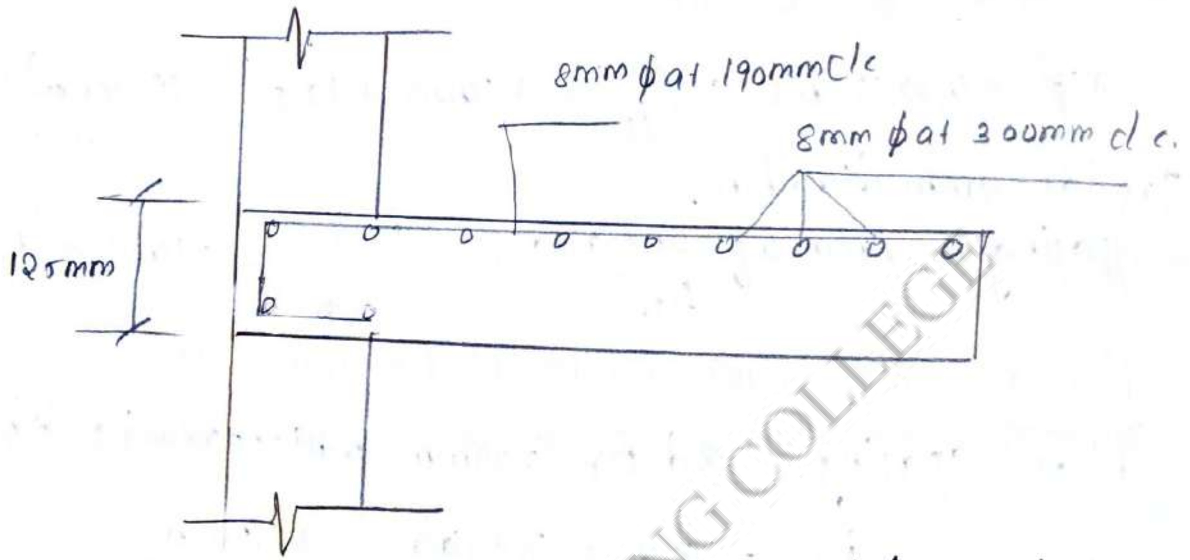
$$= \frac{0.12}{100} \times 1000 \times 125$$

$$= 150\,mm^2$$

$$\text{Spacing} = \frac{50}{150} \times 1000$$

$$= 333.33\,mm,$$

Provide 8mm diameter bar at 300mm c/c



Reinforcement details for Cantilever slab.

Lecture No. 15

Topic(s) to be covered	oneway simply supported slab

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Analysis and design of one way simply supported slab.	Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Practice.

Lecture Notes

1. Solved Problems on Simply supported one way slab:

1. Design a simply supported one way one way slab of inside dimensions 3m x 8m. It is subjected to a live load of 3 kN/m². Consider Concrete of grade M20 and steel of grade. Fe415. Width of support = 230mm.

Step 1: Given data:

1. live load = 3 kN/m²

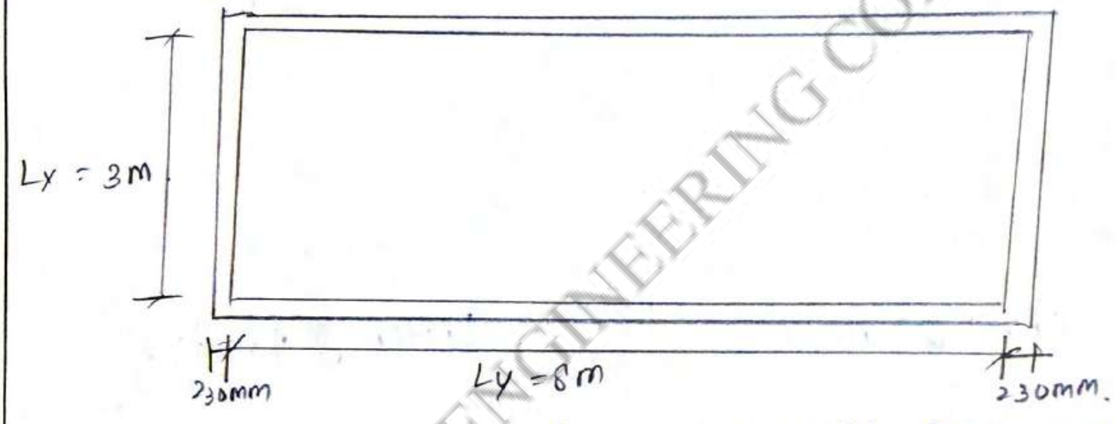
2. Room dimensions = 3m x 8m
3. Width of support = 230mm.
4. M20 = f_{ck} = 20N/mm^2
5. Fe415 f_y = 415 N/mm^2

Solution:

$$d = \frac{l_x}{25} = \frac{3000}{25} = 120mm$$

eff. depth = 125mm.

i) Eff. short span = clear span + d = 3 + 0.125 = 3.125m.



ii) Eff. short span = Clear span + Width of support
= 3 + 0.23 = 3.23m.

Eff span l_{ex} = 3.125m (smaller value of condition i) and ii))

D = d + clear cover + diameter / 2
= 125 + 15 + 10/2 = 145mm (provide 10mm ∅ for main Rein).

~~Live~~ Step 3: load calculation:

1. live load = 3 kN/m^2
2. Self-wt of slab = 0.145 x 25 kN/m^3 = 3.625 kN/m^2
3. floor finish = 1 kN/m^2

Total load W $= 7.625\ kN/m^2$

Factored design W_u $= 1.5 \times W = 1.5 \times 7.625$

$= 11.44\ kN/m^2$.

Step4 : Total Bending Moment :

$$M_u = \frac{W_u l_e^2}{8} = \frac{11.44 \times 3.125^2}{8} = 13.96\ kNm.$$

Step5 : Thickness of slab calculation :

$$M_u = 0.138 f_{ck}\, b d^2$$

$$13.96 \times 10^6 = 0.138 \times 20 \times 1000 \times d^2 \quad (b = 1000mm\ \ 1m\ strip)$$

$d_{req} = 71.12mm$

$d_{req} = 125 > d_{rq}$. Hence safe.

Step6 : Ast main calculation :

from Annex - G, clause G-1.1b IS 456-2000

$$M = 0.87 f_y A_{st} d \left[1 - \frac{A_{st} f_y}{b d f_{ck}}\right]$$

$$13.96 \times 10^6 = 0.87 \times 415 \times A_{st} \times 125 \left[1 - \frac{A_{st}\ 415}{1000 \times 125 \times 20}\right]$$

$A_{st} = 327\ mm^2$

Step7 : Minimum Reinforcement :

Spacing =

$$= 0.12\%\ bD = \frac{0.12}{100} \times 1000 \times 145$$

$= 174\ mm^2$

Provide 10mm diameter bar,

$$\text{spacing} = \frac{\text{Area of one rod}}{A_{sc}} \times 1000 = \frac{79}{327} \times 1000$$

Provide 10mm diameter bar at 240mm c/c = 241.59mm.

Max. Spacing = 3d or 300mm

i) = 3 × 125 mm = 375 = 300mm.

spacing < Max. spacing.

Step 8: Area of distribution:

$$A_{st\,dist} = 0.12\%\ bD = \frac{0.12}{100} \times 1000 \times 145 = 174\ mm^2$$

Provide 8mm diameter bar,

$$\text{spacing} = \frac{\text{Area of one rod}}{A_{st}} \times 1000$$

$$= \frac{50}{174} \times 1000$$

$$= 287.35\text{mm}.$$

Provide 8mm dia bar 285mm c/c

maximum spacing = 5d (or) 450

i) = 5 × 125
= 625mm

ii) = 450mm

spacing pro < Max. spacing.

Step 7 : check for shear :

Factored shear force $V_u = \frac{W_u l}{2} = \frac{11.44 \times 3.125}{2} = 17.875$ kN.

Actual shear stress $\tau_v = \frac{V_u}{bd} = \frac{17.875 \times 10^3}{1000 \times 125} = 0.143$ N/mm^2

$$A_{st}\ pro = \frac{79}{240} \times 1000 = 329.17\ mm^2$$

% of steel provided p_t = $100 \times A_{st}\ prov / bd = \frac{100 \times 329.17}{1000 \times 125}$

$= 0.26\%$.

From Table 19, IS456-2000;

$\tau_c = 0.36$ N/mm^2 corresponding to $p_t = 0.25\%$

$\tau_v < \tau_c$, hence, the section is safe in shear.

Step 8 : Check for deflection :

Percentage of steel, $P_t\ pro = 0.28\%$.

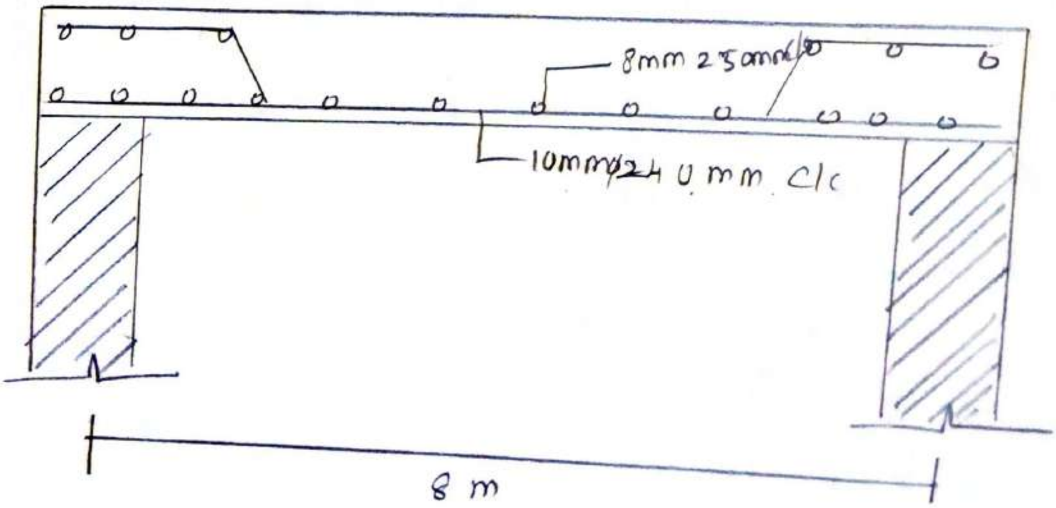
From fig 4, IS456 - 2000,

Modification factor M.F = 1.42 [$\therefore p_t = 0.28\%$ & $f_c = 240$ N/mm^2]

$[l/d]_{max}$ = Basic value × MF = 20×1.42 = 28.4

$(l/d)_{pro} = \frac{3125}{125} = 25 < 28.4$

Hence safe in deflection.



Reinforcement details

Lecture No. 17

Topic(s) to be covered	Two way Slab.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Analysis and design of Two way Slab.	Apply.

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Practice.

Lecture Notes

Problems Solved on Two way slab

1. Design a simply supported slab of dimension 3m×4.5m c/c with 230mm thick brick walls all around. Consider a live load of 2.5 kN/m² and a floor finish of 1kN/m². M20 and Fe415 combinations are used. Assume that the corners are free to lift up.

Step 1 : Given data :

Slab dimension = 3m x 4.5m c/c

live load = $2.5\ kN/m^2$

Floor finish = $1\ kN/m^2$

M_{20}, f_{ck} = $20\ N/mm^2$

Fe_{415} f_y = $415\ N/mm^2$

Step 2 : load calculation :

Room size 3m x 4.5m c/c

$$\frac{\text{Eff. long span}}{\text{Eff. short span}} = \frac{l_y}{l_x} = \frac{4.5}{3} = 1.5 < 2$$

∴ Two way slab

For simply supported slab,

$$d_{req} = \frac{span}{25} = \frac{3000}{25} = 120\ mm.$$

$$D_{req} = 120 + 15 + 10/2 = 140\ mm.$$

Provide $\underline{D = 140\ mm}$; $\phi = 10\ mm.$

$$d_{pro} = 140 - \left[15 + \frac{10}{2}\right] = 120\ mm.$$

1. self wt of slab $= 140 - \left[15 + \frac{10}{2}\right]$

$= 120\ mm.$

$= 25\ kN/m^3 \times 0.140\ m$

$= 3.5\ kN/m^2$

Floor finish load = 1 kN/m^2

Live load = 2.5 kN/m^2

W = 7 kN/m^2

Step3 : Bending Moment Calculation:

$W_u = 7 \times 1.5 = 10.5$ kN/m^2

Calculate bending moment co-efficients α_x & α_y based on Table 27, IS 456 - 2000

$\frac{l_y}{l_x} = 1.5$ $\alpha_x = 0.104$, $\alpha_y = 0.046$

short span moment $M_{ux} = \alpha_x W_u l_x^2$

$= 0.104 \times 10.5 \times 3^2$

$= 9.83$ kNm.

Long span moment $M_{uy} = 0.046 \times 10.5 \times 3^2$

$= 4.35$ kNm

Step4 : Area of steel calculation:

(i) Area of steel along short span:

$M_{ux} = 0.87 f_y A_{st} \times d \left[1 - \frac{A_{st} f_y}{bd f_{ck}}\right]$

$9.83 \times 10^6 = 0.87 \times 415 \times A_{st} \times 120 \left[1 - \frac{A_{st} \times 415}{1000 \times 120 \times 20}\right]$

$A_{st} = 236.56$ mm^2

Minimum $A_{st} = \frac{0.12}{100} bD = \frac{0.12}{100} \times 140$

$= 168$ mm^2

$$\text{Spacing} = \frac{79}{236.56} \times 1000 = 333.96 \text{ mm c/c}$$

Provide 10mm ϕ bar at 300mm c/c < 3d (or) 300 mm

Step 5: Area of steel along long span.

$$d = 140 - 15 - 10 - \frac{10}{2} = 110 \text{ mm}$$

$$4.35 \times 10^6 = 0.87 \times 415 \times A_{st} \times 110 \left[1 - \frac{A_{st} \times 415}{1000 \times 110 \times 20}\right]$$

$$A_{st} = 111.89 \text{ mm}^2$$

$$\text{Minimum } A_{st} = \frac{0.12}{100} bD = \frac{0.12}{100} \times 1000 \times 140$$

$$= 168 \text{ mm}^2.$$

$$\text{spacing} = \frac{50}{168} \times 1000 = 297.62 \text{ mm c/c.}$$

Provide 8mm ϕ at 290 mm c/c < 3d (or) 300 mm.

Step 6: check for shear.

$$A_{st} \text{ provided} = \frac{79}{300} \times 1000 = 263.33 \text{ mm}^2$$

$$p_t \text{ of steel provided} = \frac{100 A_s}{bd} = \frac{100 \times 263.33}{1000 \times 85}$$

$$p_t = 0.30\,\%.$$

Design shear stress of concrete, τ_c can be taken from Table 19, IS 456 - 2000

P_t % τ_c (N/mm^2)

$x_1 = 0.25$ $y_1 = 0.36$

$x_2 = 0.50$ $y_2 = 0.48$

$x = 0.30$ $y = ?$

$$y = y_1 + \frac{(y_2 - y_1)}{(x_2 - x_1)}(x - x_1)$$

$$\tau_c = y = 0.36 + \frac{(0.48 - 0.36)}{(0.50 - 0.25)}(0.30 - 0.25)$$

$$= 0.36 + \frac{0.12}{0.25} \times 0.05$$

$$\tau_c = 0.384 \ N/mm^2.$$

Actual shear stress $\tau_v = \frac{V}{bd}$.

$W_u = 10.5 \ N/mm^2$

$$V = \frac{W_u l}{2} = \frac{10.5 \times 3}{2}$$

$$= 15.75 \ kN.$$

$$\tau_v = \frac{V}{bd} = \frac{15.75 \times 10^3}{1000 \times 120}$$

$$= 0.13 \ N/mm^2$$

$\tau_v < \tau_c$ Hence, the section is safe in shear.

Step 7: check for deflection:

From Fig 4, IS 456-2000,

Modification factor, M.F = 1.42 Corresponding to

$p_t = 0.33\%$

$f_s = 0.58 f_y \times \frac{A_{req}}{A_{spro}}$

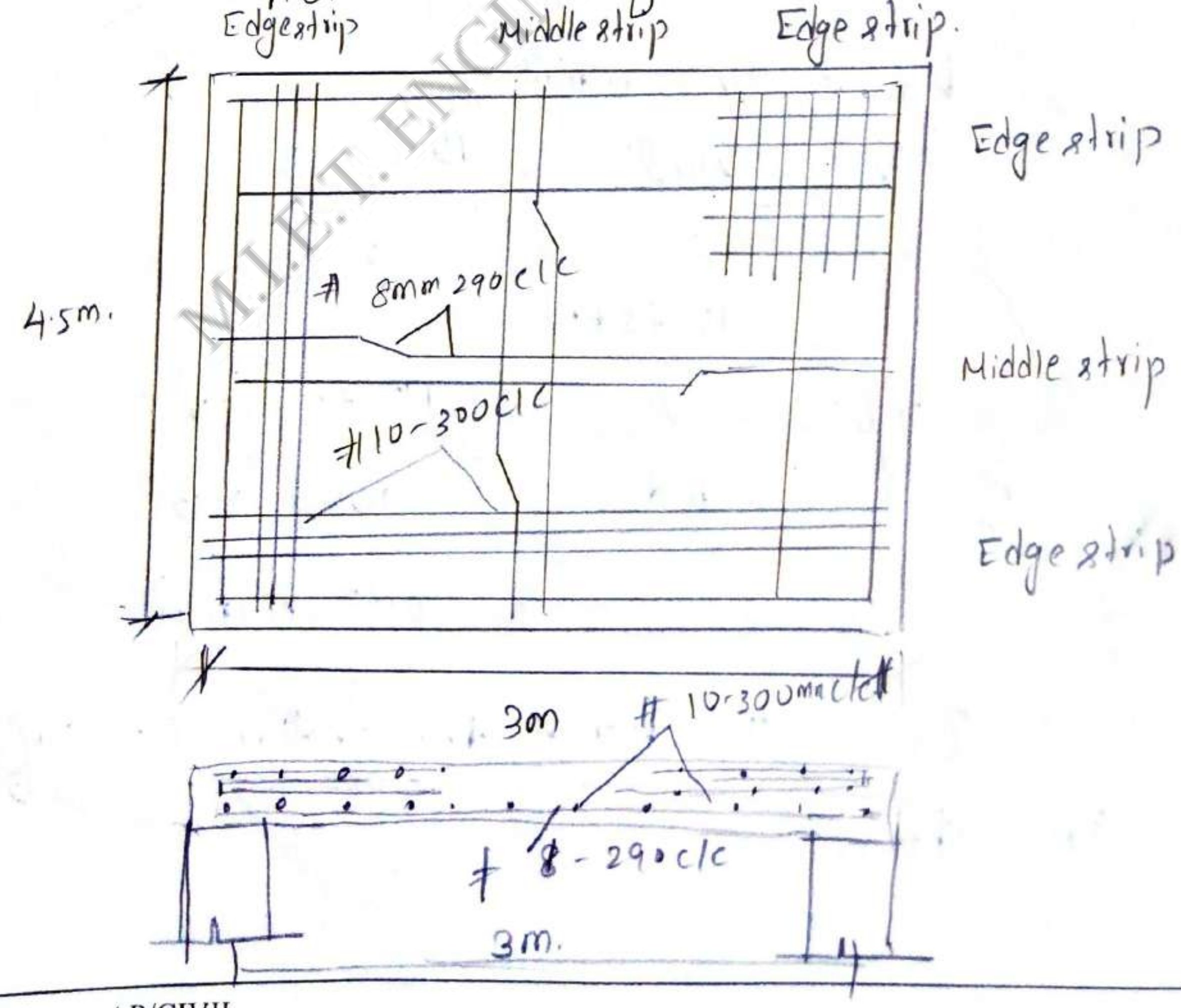
$= 0.58 \times 415 \times \frac{236.56}{263.33} = 216.23 N/mm^2$

$\left[l/d \right]_{max}$ = Basic value × MF = 20 × 1.42 = 28.4

[∴ Basic value for simply supported beam]

$\left[l/d \right]_{pro} = \frac{3000}{120} = 25 < 28.4.$

Hence, it is safe in deflection.



Lecture No. 18

Topic(s) to be covered	Design of simply supported slab using IS code co-efficients.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Design and Analysis of simply supported slab	Apply

Teaching Learning Material	Student Activity
chalk & Talk	listen & practice.

Lecture Notes

2. Design a simply supported slab supported on masonry walls to the following requirements.

1. clear span = 3.50m
2. Live load = 3 kN/m^2
3. M20 & Fe 415 combinations are used.

Thickness of masonry wall as 230mm.

Step1: Given data :

1. clear span = 3.5 m = 3500mm
2. Live load = 3 kN/m^2

3. Thickness of support = 230mm
4. $f_{ck} = 20 N/mm^2$
5. $f_y = 415 N/mm^2$

Step2: Eff. Span Calculation :

$$d = \frac{\text{Eff. span}}{25} \approx \frac{3500}{25} \approx 140$$

$d = 150mm = 0.15 m.$

Eff. span = clear span + d = 3 + 0.15 = 3.15 m (or)

Eff. span = clear span + width of support

= 3 + 0.23 = 3.23m.

$l_e = 3.15m.$

$D = d +$ clear cover $+ \phi/2 = 150 + 15 + 5 = 170mm.$

Step3: Moment Calculation :-

$$M = \frac{W_u l_e^2}{8} \text{ (simply supported edges)}$$

L.L = $3 KN/m^2$

self wt of slab = $0.17 \times 25 \; KN/m^3 = 4.25 \; KN/m^2$

Floor finish load = $1 \; KN/m^2$

Total load W = $8.25 \; KN/m^2$

Factored lod $W_u = 1.5 \times W = 1.5 \times 8.25$

$= 12.375 \; KN/m^2$

$$M = \frac{W_u l_e^2}{8} = \frac{12.375 \times 3.15^2}{8} = 15.35 \; KNm$$

Step5 : Thickness of slab calculation :

$$M_u = 0.138 \; f_{ck} \; bd^2$$

$$d_{req} = \sqrt{\frac{M_u}{0.138 f_{ck} \, b}}$$

$$= \sqrt{\frac{15.35 \times 10^6}{0.138 \times 20 \times 1000}} \quad (b = 1m = 1000mm)$$

$$= 74.58mm$$

$d_{prov} = 150 > d_{req}$. Hence safe.

Step6 : Ast calculation :

$$M_u = 0.87 \, f_y \, A_{st} \, d \left[1 - \frac{A_{st} f_y}{b \, d \, f_{ck}}\right]$$

$$15.35 \times 10^6 = 0.87 \times 415 \times A_{st} \times 150 \left[1 - \frac{A_{st} \times 415}{1000 \times 150 \times 20}\right]$$

$$A_{st} = 295.51 mm^2$$

$$\text{spacing} = \frac{79}{295.51} \times 1000 = 267.33mm.$$

Provide 10 mm dia bar 265 mm c/c

$$A_{st} \text{ dist} = 0.12\% \, bD = \frac{0.12}{100} \times 1000 \times 170$$

$$= 204 \, mm^2$$

Provide 8mm ϕ bar.

$$\text{spacing} = \frac{50}{204} \times 1000 = 245 \, mm.$$

Provide 8mm ϕ bar at 240 mm c/c

Step 7: Check for deflection:

Provided Ast main $= \frac{79}{265} \times 1000 = 298 mm^2$

P_t Provided $= \frac{100 A_{st}}{b d} = \frac{100 \times 298}{1000 \times 150} = 0.20\%$

From Figure, 4 IS456-2000

Modification factor ∴ M.F = 1.67 Corresponding $P_t = 0.208$

$f_s = 240 N/mm^2$

$[L/d]_{max}$ = Basic value × MF

$= 20 \times 1.67 = 33.4$

[∵ Basic value for simply supported Beam slab $= 20$]

$[l/d]_{pro} = \frac{3150}{150} = 21 < 33.4.$

Hence safe.

Lecture No. 19.

Topic(s) to be covered	Design of simply supported ~~and~~ slabs and Supporting beams.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Design and analysis of supporting Beams	Apply.

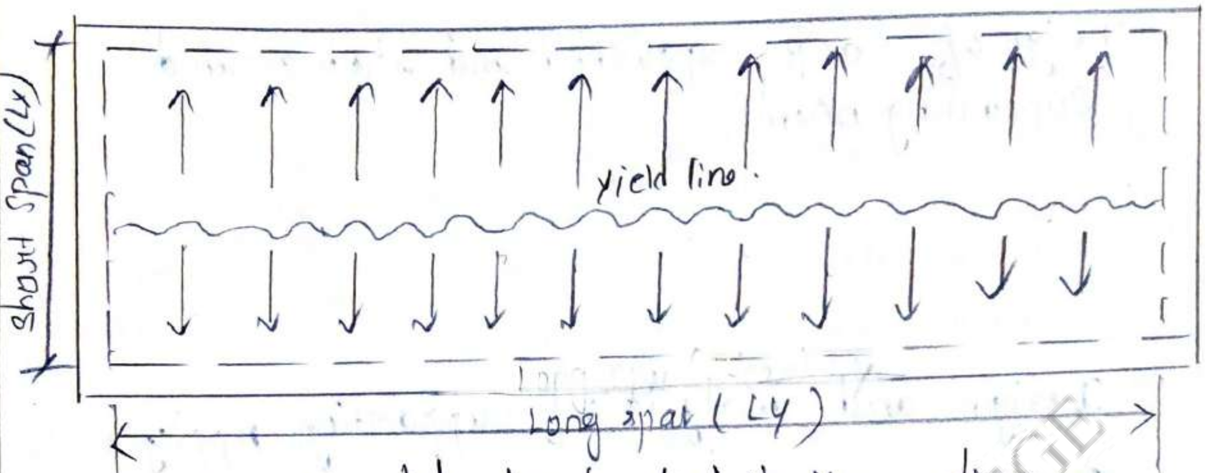
Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Apply.

Lecture Notes

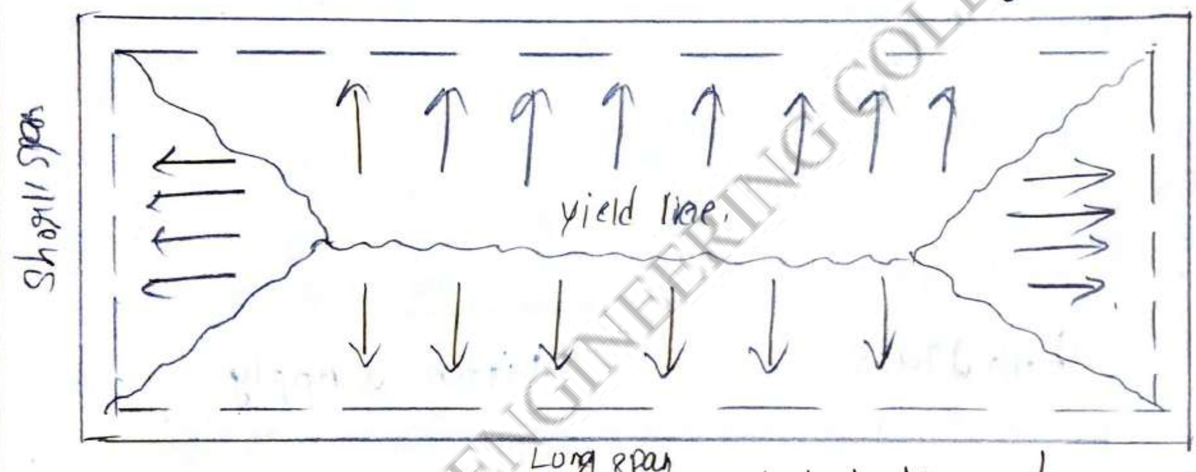
Design of Supporting Beams

Beam Carries the dead, live loads from the slab, masonry wall and transfers to the column. Slab distribution to the beam depends upon the upon the type of slab. Load distribution for one way slab is different from two way slab.

In one way slab, load distribution in the long span direction is considerably less and it can be neglected.



One way slab load distribution diagram.



Two way slabl load distribution diagram

1. Design the supporting beam of a one way slab with inside dimensions 3m x 8m. The slab is subjected to a live load of 3 kN/m^2 and floor finish load of 1 kN/m^2. Also, 230mm thick brick wall with 3.6m height is acting on all the beam. Consider Concrete of grade M20 and steel of grade Fe500. width of beam = 230mm. Design the beam as flanged section and consider beam ends are fixed with the columns.

Step 1: Given data:

1. Live load = 3 kN/m²
2. Floor finish load = 1 kN/m²
3. Room dimensions = 3m x 8m
4. Width of beam = 230mm.
5. Height of brick wall = 3.6m.
6. M20 ; f_{ck} = 20 N/mm²
7. Fe 500 f_y = 500 N/mm²

Step 2: load calculation.

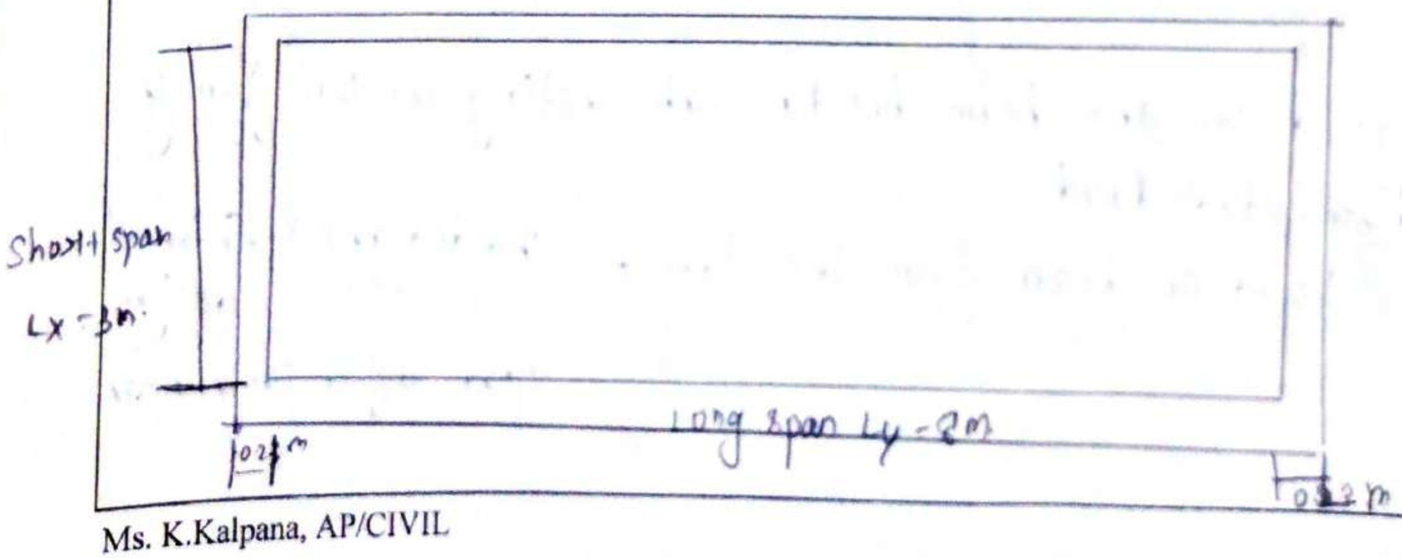
a) slab $d = \frac{l_x}{25} = \frac{3000}{25} = 120$ mm.

(i) Effective short span = clear span + d
= 3 + 0.125 = 3.125 m (or)

(ii) Eff. short span = clear span + width of support
= 3 + 0.23 m
= 3.23 m

D = d + clear cover + dia/2

D = 125 + 15 + 10/2 = 145 mm (p. 10mm φ)



Live load = 3 kN/m^2

self wt of slab = $0.145 \times 25 = 3.625$ kN/m^2

Floor finish = 1 kN/m^2

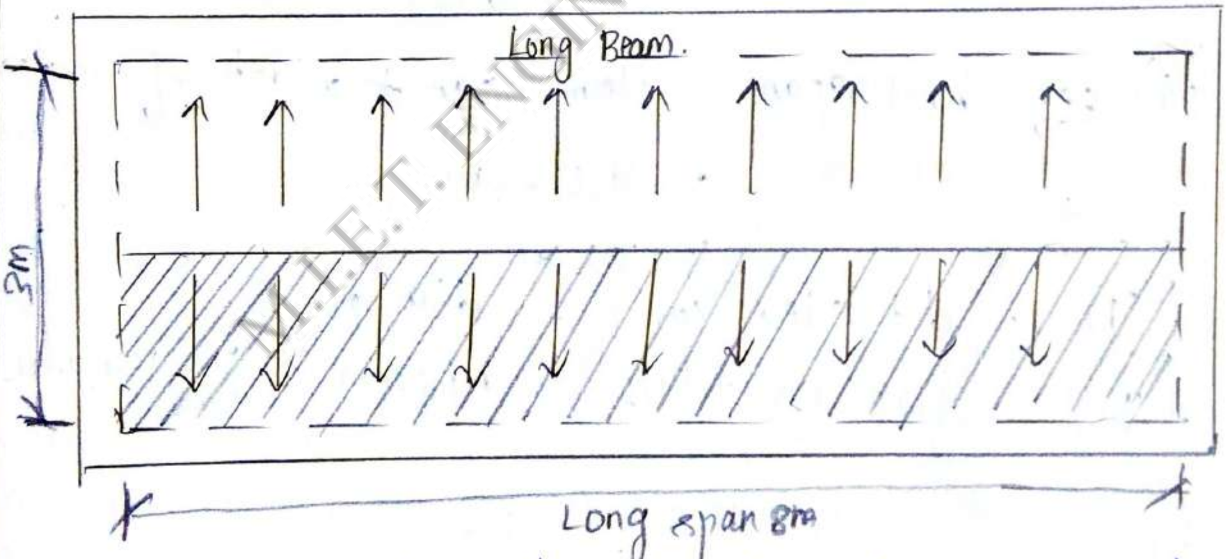
$W = 7.625$ kN/m^2

Factored design load $W_u = 1.5 \times W$

$= 1.5 \times 7.625 = 11.44$ kN/m^2

For oneway slab, load distribution in the long span direction is considerably less and it can be neglected. All the loads coming from the one way slab are to be distributed through the short span direction (8m beam) only.

Step 3: load on long beam and bending moment calculation.



Load on the beam due to slab acting as Uniformly distributed load.

Load on beam from the slab = $\dfrac{\text{shaded are} \times \text{Factored design}}{\text{span of a long beam}}$

Load on beam from the slab $= \dfrac{\left[8m \times \frac{3}{2} m\right] \times 11.44\ kN/m^2}{8m}$

Factored load on the beam due to slab load $= 17.16\ kN/m$

Factored load due to wall load

= Wall thickness x height of wall x Desity of wall x factor of safety.

Load due to wall load

$= 0.23m \times 3.6m \times 22\ kN/m^3 \times 1.5$

$= 27.33\ kN/m.$

Design the beam 'L' beam, since the beam and the slab act together as molithic member.

$d = span/12 = 8000/12 = 666.67mm.$

$\therefore D = 750mm.$

1. self wt of beam = width of web x Depth of the beam x Density of con. x Factor. S

$= 0.23 \times 0.75 \times 25 \times 1.5$

$= 6.47\ kN/m.$

2. Total load W_u = slab load + wall load + self wt

$= 17.16\ kN/m + 27.33\ kN/m + 6.47$

$= 50.96\ kNM.$

Provide 20mm dia. bars with clear cover 25mm.

depth of beam $= 750 - 25 - 10 = 715mm.$

Step 4 - limiting moment of Resistance calculation.

$M_u < M_{ulim}$ L - beam Can be designed as singly reinforced section.

$$M_{ulim} = 0.36 f_{ck} b_f x_{ulim} (d - 0.42 x_{ulim})$$

$$X_{ulim} = D_f = 145 \text{ mm} \longrightarrow (1).$$

Limiting neutral axis coincides with the bottom of flange.

$$f_y = 500 \quad x_{ulim}/d = 0.456 \longrightarrow (2)$$

Eq (1) & (2)

$$D_f = 0.456 d$$

$$d = \frac{D_f}{0.456} = \frac{145}{0.456} = 317.98 \text{ mm}$$

$$M_{ulim} = 0.36 \times 20 \times 1145.08 \times 145 \times (317.98 - 0.42 \times 145)$$

$$= 307.33 \times 10^6 \text{ N mm} = 307.33 \text{ kNm}.$$

$M_u < M_{ulim}$ Beam Can be designed as singly Reinforced beam

Step 5 : Area of steel calculation:

$$A_{st} = \frac{M_u}{0.87 f_y (d - 0.42 x_u)}$$

i) Eff. span = clear span + d
$= 8 + 0.715 = 8.175m$

ii) Eff. span = clear span + width of support
$= 8 + 0.23m = 8.23m.$

The Bending Moment span (mid) = $M_{mid} = \frac{W_u l_{eff}^2}{24}$

$$M_{mid} = \frac{50.96 \times 8.23^2}{24} = 143.82 \text{ kN m.}$$

$$M_{max} = \frac{W_u l_{eff}^2}{12} = \frac{50.96 \times 8.23^2}{12} = 287.64 \text{ kNm}$$

$$M_u = 287.64 \text{ kN m.}$$

For L beam, Eff width of flange $b_f = \frac{l_o}{12} + b_w + 3D_f$

l_o = distance b/w points of zero moments in beam $= 0.7 l_{eff} = 0.7 \times 8.23 m = 5.761 m.$

for interior span l_o = distan b/w points of zero moments in a beam $= 0.7 l_{eff}$

$b_w = 230mm$

$D_f = 145mm$

$$b_f = \frac{5761}{12} + 230 + (3 \times 145)$$

$= 1145.08mm$

Provide 20φ $M_u = 287.64$ kN/m.

i) $x_u < D_f$

$M_u = 0.36\, f_{ck}\, b_f\, x_u\, (d - 0.42\, x_u)$

$(287.64 \times 10^6) = 0.36 \times 20 \times 1145.08 \times x_u\, (715 - 0.42 x_u)$

$x_u = 50.28$ mm $< D_f$

$A_{st} = \dfrac{M_u}{0.87\, f_y\, (d - 0.42 x_u)}$

$= \dfrac{287.64 \times 10^6}{0.87 \times 500 \times (715 - 0.42 \times 50.28)}$

$= 952.96\,mm^2$

No. of bars $= \dfrac{952.96}{314} = 3.03 \simeq 4$ Nos.

Provide A_{st} = 4 nos. of 20mm φ bars at top of the beam at supports

Area of steel mid span, $A_{st} = \dfrac{M_u}{0.87\, f_y\, (d - 0.42 x_u)}$

$= \dfrac{43.82 \times 10^6}{0.87 \times 500\, (715 - 0.42 \times 50.28)}$

$= 476.48\,mm^2$

$= \dfrac{476.48}{314} = 1.523 \simeq 2$ nos

Lecture No. 20

Topic(s) to be covered	Types of staircase, Design and Analysis of dog legged staircase

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Design and Analysis of dog-legged staircase	Apply

Teaching Learning Material	Student Activity
Chalk & Talk	listen & practice

Lecture Notes

Types of staircase :-

1. Staircase - definition :

Staircase are used to enable people or goods to be moved from one floor to another floor. It may be provided either with in or outside a building. It is also faciliates an effective means of escape in case of fire. stairs are made to meet the requirements of the Building.

Flight: Flight is an uninterrupted series of steps between two successive floors or between floor and landing, or between two successive landings.

Landing : Flat platform at the head of a series of steps.

Stairwell : The space in which stair / landing are housed.

Types of staircase :-

1. Straight flight
2. Quarter Turn
3. Dog-legged / Half turn
4. open well
5. Geometrical
6. Circular / spiral.
7. Bifurcated.

1. A dog legged stair case is to be designed and detailed with the following particulars.

clear dimension of stair case room = 4.48 x 2.1 m.

The floor to floor height is 3.2 m.

Width of each tread = 250 mm.

Height of each rise = 160 mm.

The finish loads and live loads are 1 kN/m^2 and 5 kN/m^2, respectively. The materials used are M20 grade concrete and Fe500 grade steel. sketch the details of steel. Lower end of flight is supported on ground and the upper end is supported on 230 mm brick masonry wall. Waist slab landing slab are spanning longitudinally.

Solution:

Step1: Dimensioning :—

Rise R = 160mm, Tread T = 250mm.

Floor to floor height H = 3.2m = 3200mm

No. of rise = 3200/R = 20 Each flight has 10 rises.

No. of treads per flight = 10 - 1 = 9

Width of landing slab along flight = (4480 - 9 × 250)/2

= 1115 mm.

Also, width of flight = 1.115 m.

Going of flight = 9 × 250 = 2250 mm.

(b) Effective span and depth of slab:

The landing slab and passage act together with the going (waist slab) as single slab

Effective span = 2250 mm + 1115 mm + $\left[\frac{230}{2}\right]$

= 3480mm = 3.48 m

$D = span/20 = 3480/20 = 174\,mm$

$D \simeq 200\,mm$

ϕ main $= 12\,mm$.

$d' = 20 + \frac{12}{2} = 26\,mm$. (clear cover $= 20\,mm$)

$d = D - d' = 200 - 26 = 174\,mm$.

$\Rightarrow$ overall depth of landing slab $= 200\,mm$.

$d = D - d' = 200 - 26 = 174\,mm$

Step2: Calculation of loads :-

(loads on going Waist slab)

$R = 160\,mm$ $T = 250\,mm$, the inclained length of each step.

$= \sqrt{(160)^2 + (250)^2} = 296.82\,mm$

Self weight of Waist slab $= D \times$ density of reinforced $\times$ (inclined length of step / Tread)

$= (0.2\,m \times 25\,kN/m^3) \times \frac{296.82}{250}$

$= 5.94\,kN/m^2$

Self weight of Waist slab $=$ Density of Brick Masonry $\times$ (Rise /2)

Self weight of steps $= 22\ kN/m^3 \times \left[\frac{0.16m}{2}\right] = 1.76\ kN/m^2$

Weight of finishes $= 1\ kN/m^2$

live load $= 5\ kN/m^2$

$w = 13.70\ kN/m^2$

$W_u = 13.70 \times 1.5 = 20.54\ kN/m^2$

Step 4 : Bending Moment calculation :

$$M = \left[\frac{Wl^2}{8}\right] = \left[\frac{20.54 \times 3.48^2}{8}\right] = 31.10\ kNm$$

Step 5 : Depth check :

$$M_u = 0.155\ f_{ck}\ bd^2$$

$$31.10 \times 10^6 = 0.155 \times 20 \times 1000 \times d^2 \quad (b = 1000)$$

$d_{req} = 100.16\ mm$

$d_{pro} = 174\ mm > d_{req}$. Hence Safe.

Step 6 : Ast :-

$$M = 0.87\ f_y\ A_{st}\ d \left[1 - \frac{A_{st}\ f_y}{bd\ f_{ck}}\right]$$

$$31.10 \times 10^6 = 0.87 \times 500 \times A_{st} \times 174 \times \left[1 - \frac{A_{st} \times 500}{1000 \times 174 \times 20}\right]$$

$A_{st} = 438.59\ mm^2$

Minimum Area of steel $= 0.12\ \%.\ bD$

$= 0.12 \times 1000 \times 174$

$= 208.8\ mm^2$

Provide 10mm ϕ.

$$\text{Spacing} = \frac{\text{Area of one rod}}{A_{st}} \times 1000$$

$$= \frac{79}{438.59} \times 1000 = 180.12\text{mm}.$$

Provide 10mm diameter bar at 180mm c/c.

Maximum spacing = 3d (or) 300mm

i) $3d = 3 \times 174 = 522$ mm

ii) 300mm

Spacing Pro < Maximum spacing. Hence Ok.

Provide the same Reinforcement for land slab

Distribution steel area = 0.12% bD

$$= \frac{0.12}{100} \times 1000 \times 174$$

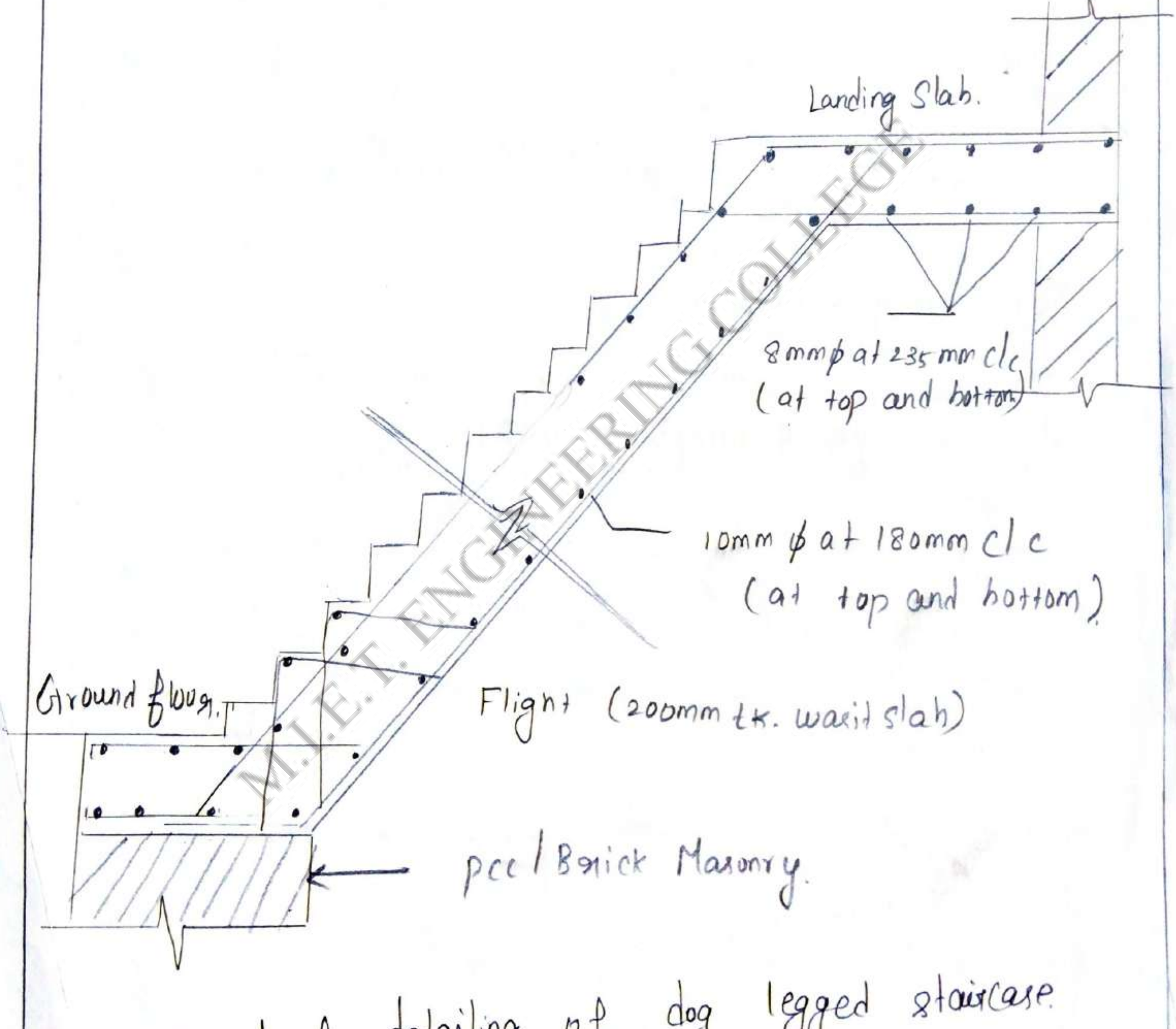
$$= 208.8 \text{ mm}^2$$

Provide 8mm dia. of bar

$$\text{Spacing} = \frac{\text{Area of one rod}}{A_{st}} \times 1000$$

$$= \frac{50}{208.80} \times 1000$$

$$= 239.46\text{mm}$$



Structural detailing of dog legged staircase

Lecture No. 21

Topic(s) to be covered	Dog - legged stair case

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Design and Analysis of dog-legged staircase	Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Apply

Lecture Notes

2. A dog legged stair case is to be designed and detailed with the following particulars:

Clear dimension of stair case rooom = 4.48 x 2.1m

The floor to floor height is 3.2m

Width of each tread = 250mm

Height of each rise = 16mm.

The finish loads and live loads are $1\ kN/m^2$ and $5\ kN/m^2$, respectively. Both flights are supported at one end on 230mm wall and other end is supported on landing slab 'B'. Landing slab 'A' is supported on beams 'C' and 'D'. Waist slab and landing slab 'B' are spanning longitudinlly. For landing slab 'A' consider only 50% of the estimated load. The materials used are M20 grade concrete and Fe500 grade steel. sketch the details of steel.

Step1: Given data :-

1. Clear dimension of stair case room = 4.48m x 2.1m.
2. The floor to floor height is 3.2m
3. Width of each tread = 250mm.
4. Ht. of each rise = 160mm.
5. Live load = 5 kN/m^2
6. Floor finish = 1 kN/m^2
7. Thickness of support for landing slab B = 230mm.

Landing slab 'A' is supported on 'C' and D.

For landing slab 'A' consider only 50% of estimated load.

M_{20} ; f_{ck} = 20 N/mm^2

~~M~~ Fe415 F_y = 500 N/mm^2

Step2: Dimensioning :

Rise R = 160mm.

Tread T = 250mm.

Floor to floor height H = 3.2 m = 3200mm.

No. of rises = 3200/R = 20 Each flight has 10 rises

No of treads per flight = 10-1 = 9.

Width of landing slab 'B' along flight = (4480 - 9×250)/2
= 1115mm.

Width of passage / Landing slab A = 1115 mm.

Also, width of flight = 1.115m.

Going of flight = 9×250 = 2250mm.

Step3:

Effective span and depth:

For eff. span calculation, consider only half of the width of landing slab 'A' since landing slab 'A' is supported on beams 'C' and 'D'

$$\text{Eff. span} = \left[\frac{1115}{2}\right] mm + 2250\ mm + 1115\ mm + \left[\frac{230\ mm}{2}\right]$$

$$= 4037.50mm = 4.04\ m.$$

Depth of waist slab required = span/20 = 4037.50/20
= 201.88 mm.

D = 250mm.

Diameter of main reinforcement bar = 12mm

$$d' = 20 + \frac{12}{2} = 26mm$$

(Clear cover = 20mm)

Effective depth of waist slab $d = D - d' = 250 - 26 = 224\ mm$

Consider depth D for landing slab $= 200\ mm$.

Eff. depth of landing slab $d = D - d'$

$= 200 - 26 = 174\ mm.$

Step 4 : Calculation for loads:

(i) Loads on going (Waist slab)

with $R = 160\ mm$ and $T = 250\ mm$, the inclined length of each step.

$$= \sqrt{(160)^2 + 250^2} = 296.82\ mm.$$

Self weight of Waist slab = $D \times$ density of reinforced Concrete $\times$ (inclined length of step/Tread)

1. Self weight of Waist slab $= (0.25\ m \times 25\ kN/m^3) \times \frac{296.82}{250}$

$= 7.42\ kN/m^2$

2. Self wt. of Waist slab = (Density of brick masonry $\times$ (Rise /2).

$= 22\ kN/m^3 \times \left(\frac{0.16}{2}\right)$

$= 1.76\ kN/m^2$

3. Weight of finishes $= 1\ kN/m^2$

4. Live load $= 5\ kN/m^2$

5. Total load $W = 15.18\ kN/m^2$

$W_u = 1.5W = 1.5 \times 15.18 = 22.77 \text{ kN/m}^2$

udl along length = $W_u \times$ width of flight

$= 22.77 \times 1.115$

$= 25.39$ kN/m.

Step 5: loads on landing slab 'A'

Self weight of landing slab 'A' $= 0.20\text{m} \times 25 \text{ kN/m}^3$

$= 5 \text{ kN/m}^2$

Weight of finishes $= 1 \text{ kN/m}^2$

Live load $= 5 \text{ kN/m}^2$

$w = 11 \text{ kN/m}^2$

Consider only 50% of the estimated load.

Factored load $W_u = 0.15 \times 1.5 \times w = 0.5 \times 1.5 \times 11$

$= 8.25 \text{ kN/m}^2$

udl along length $= W_u \times$ width of flight

$= 8.25 \times 1.115 = 9.20$ kN/m,

iii) loads on landing slab 'B'

Total load $w = 11 \text{ kN/m}^2$

Factored load $W_u = 1.5 \times w = 1.5 \times 11 = 16.5 \text{ kN/m}^2$

udl along length $= W_u \times$ width of flight

$= 16.5 \times 1.115$

$= 18.40$ kN/m.

c) shear force and Bending moment Calculation.

Figure shows the loading, SF and BM diagram

$$(V_B \times 4.04) = \left[9.2 \times \frac{0.56^2}{2} \right] + (25.39 \times 2.25 \times 1.685) + (18.40 \times 1.23 \times 3.425) \Big]$$

$$V_B = 43.37 \text{ kN}.$$

$$V_A = (9.2 \times 0.56) + (25.39 \times 2.25) + (18.40 \times 1.23) - 43.37$$

$$= 43.37 \text{ kN}.$$

$$V_A = (9.2 \times 0.56) + (25.39 \times 2.25) + (18.40 \times 1.23) - 43.37$$

$$= 41.54 \text{ kN}.$$

Location of maximum BM (SF=0) calculated by similar triangle Principle.

$$\frac{36.39}{x} = \frac{20.74}{(2.25 - x)}$$

$x = 1.43$ m from the starting Point of waist slab (Left end of waist slab)

Maximum BM occurs at a distance of 1.99m $\left(\begin{matrix} 0.56\text{m} + \\ 1.43\text{m} \end{matrix}\right)$ from left support 'A'

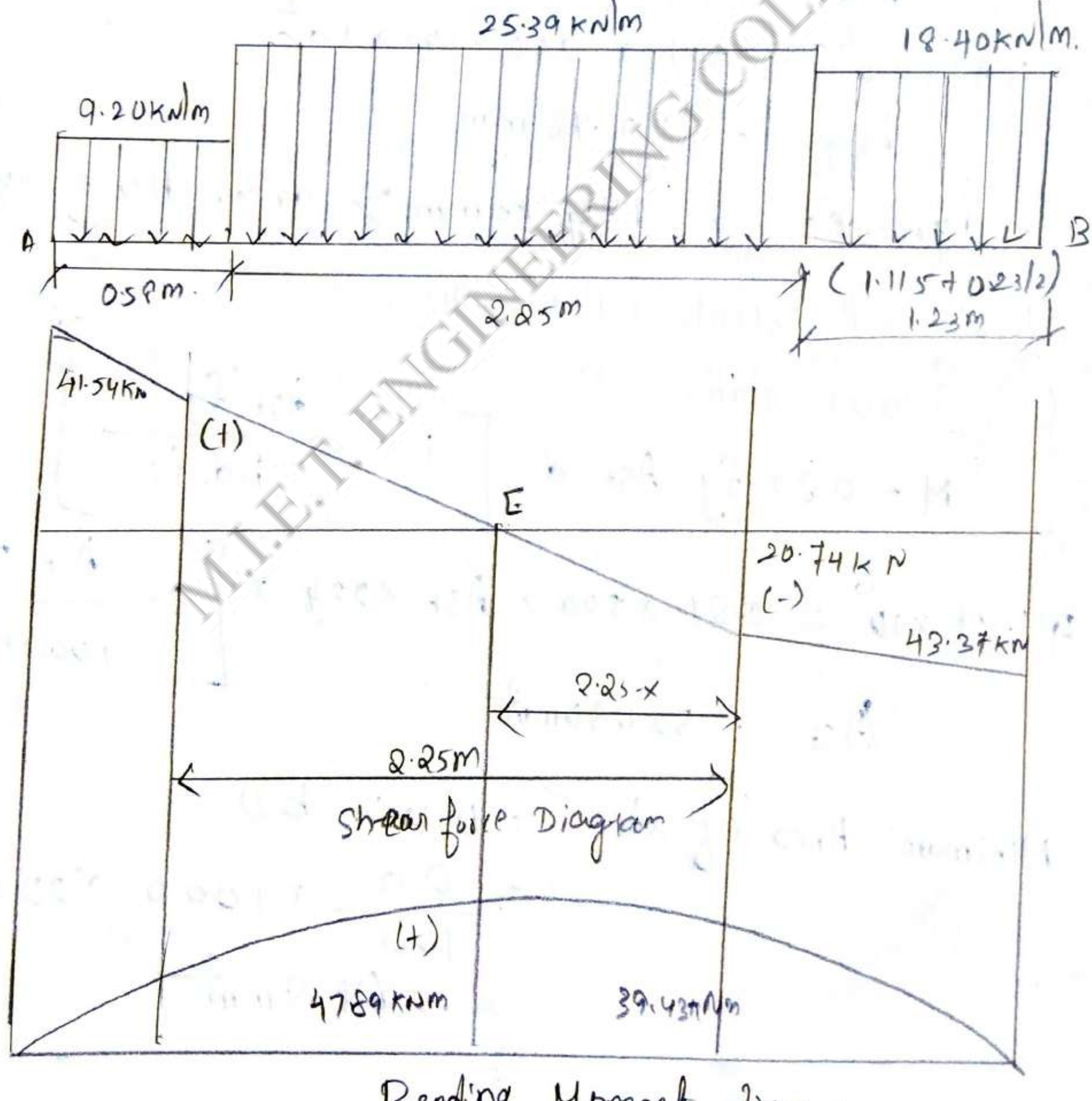
$$\text{Max. BM} = (41.54 \times 1.99) - (9.20 \times 0.56 \times 1.71) - \left(25.39 \times 1.43 \times \frac{1.43}{2}\right)$$

$$\boxed{M_{max} = 47.89 \text{ kNm.}}$$

BM at the right side end of Waist slab = M_{End} of waist slab.

$$= (43.37 \times 1.23) - \left(18.40 \times 1.23 \times \frac{1.23}{2}\right)$$

$$= 39.43 \text{ kNm.}$$



Bending Moment diagram

Step 6: Depth of slab check :-

(i) Waist slab:

For Fe500 $M_u = 0.155\,bd^2 f_{ck}$.

$47.89 \times 10^6 = 0.155 \times 20 \times 1000 \times d^2$

$d_{req} = 124.29\,mm$.

$d_{prov} = 224\,mm > d_{req}$. Hence safe

Landing slab 'B'

$M_u = 0.155\,f_{ck}\,bd^2$

$39.43 \times 10^6 = 0.155 \times 20 \times 1000 \times d^2$

$d_{req} = 112.78\,mm$

$d_{provided} = 174.78\,mm > d_{req}$. Hence safe.

Area of steel calculation:

(i) Waist slab:

$$M = 0.87\,f_y\,A_{st}\,d\left[1 - \frac{A_{st}\,f_y}{bd\,f_{ck}}\right]$$

$$47.89 \times 10^6 = 0.87 \times 500 \times A_{st} \times 224 \times \left[1 - \frac{A_{st} \times 500}{1000 \times 224 \times 20}\right]$$

$A_{st} = 521.90\,mm^2$

Minimum Area of steel $= 0.12\%\,bD$

$= \frac{0.12}{100} \times 1000 \times 224$

$= 268.8\,mm^2$

$=$

Provide 10mm diameter bar,

$$\text{Spacing} = \frac{\text{Area of one rod}}{A_{st}} \times 1000 = \frac{79}{521.90} \times 1000$$

Provide 10mm diameter main $= 151.37$ mm

steel bar 150mm c/c.

Maxmum spacing = 3d (or) 300 mm whichever is less

3d = 3 X 174 = 522mm or 300mm

Spacing provided < Max. spacing.

Calculated bending moments for the design of waist slab and landing slab B are 44.07 kNm and 40.02 kNm. respectively. Not much variation between those bending moments and hence provide the same reinforcement for landing slab 'B' also.

Distribution steel area $= 0.12\%\ bD = \frac{0.12}{100} \times 1000 \times 224$

Provide 8mm dia. bar $= 2688\ mm^2$

$$\text{Spacing} = \frac{\text{Area of one bar}}{A_{st}} \times 1000 = \frac{50}{1000} = 186.01\ mm$$

Provide 8 mm diameter distribution steel barat 185mm c/c.

—x— x

Lecture No. 16.

Topic(s) to be covered	Continuous slabs, and supporting beams.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Analysis and design of continuous slab	Apply.

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Practice.

Lecture Notes

Problems Solved on Continuous slab :-

1. Design a continuous one way slab as shown in figure. It is subjected to a live load of 4 kN/m^2 and floor finish of 1.25 kN/m^2. Consider concrete of grade M20 and steel of grade Fe415. Assume width of beam as 300mm.

Given data :

1. live load = 4 kN/m^2
2. Floor Finish load = 1.25 kN/m^2

Width of support = 300mm.

M20 ; f_{ck} = 20 N/mm^2

Fe 415 f_y = 415 N/mm^2

Step 2 : load calculation :

Consider end span for depth calculation.

For simply supported slab, $d = \frac{l_x}{25}$

continuous slab $d = l_x/25 \times 1.3$

one end of the slab is continuous while the other end is discontinuous ; hence take average value for depth calculation.

$$d = \frac{l_x}{25 \times \left[\frac{1+1.3}{2}\right]} = \frac{l_x}{28.75} \simeq \frac{l_x}{29}.$$

$$d_{req} = \frac{3500}{29} = 121\,mm.$$

$$D = 121 + 15 + \frac{8}{2} = 140\,mm.$$

Provid 140mm overall depth.

Step4 : Ast Main :—

From Annex - G, clause G-1.1 b IS456-2000

$$M = 0.87\, f_y\, A_{st}\, d \left[1 - \frac{A_{st}\, f_y}{b d\, f_{ck}}\right]$$

i) at support C,

$$15.44 \times 10^6 = 0.87 \times 415 \times A_{st} \times 121 \left[1 - \frac{A_{st} \times 415}{1000 \times 121 \times 20}\right]$$

$$A_{st} = 5454.811\ mm\ (or)$$

Moment calculation :

portion.	Support A	Span between A & B	support B	Span b/w B & C and C/C	support C.
D.L Moment Co-efficient α_d.	$-\frac{1}{24}$	$\frac{1}{12}$	$-\frac{1}{10}$	$\frac{1}{16}$	$-\frac{1}{12}$
Moment due to D.L, $M_{ud} = \alpha_d W_{ud} l^2 = \alpha_d \times 7.125 \times 3.5^2$	−3.64	7.27	−8.73	5.46	−7.27
L.L moment co-efficient α_L	$-\frac{1}{24}$	$\frac{1}{10}$	$-\frac{1}{9}$	$\frac{1}{12}$	$-\frac{1}{9}$
Moment due to L.L $M_{ul} = \alpha_l W_{ul} l^2 = \alpha_l \times 7.125 \times 3.5^2$	−3.06	7.35	−8.17	6.13	−8.17
Total Moment $M_u = M_{ud} + M_{ul}$	−6.70	14.62	−16.9	−11.59	−15.44

$d_{pro} = 121\,mm.$

Live load $= 4\ kN/m^2$

self-wt of slab $= 0.14 \times 25\ kN/m^3 = 3.5\ kN/m^2$

Floor finish $= 1.25\ kN/m^2$

Total load $= 4.75\ kN/m^2$

Factored Dead load $W_{ud} = 4.75 \times 1.5$

$= 7.125\ kN/m^2$

Factored live load $W_{ul} = 4 \times 1.5$

$= 6\ kN/m^2$

Effective l_e = c/c distance b/w supports

$= 3.50\,m.$

Step 4 : Thickness of slab calculation :

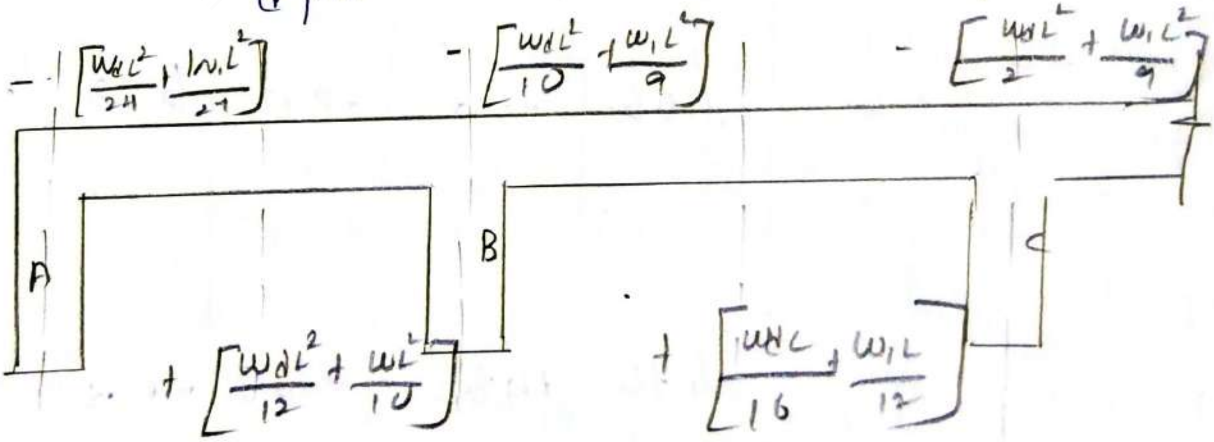
For Fe 415, $M_u = 0.138\, f_{ck}\, b d^2$

$15.44 \times 10^6 = 0.138 \times 20 \times 1000 \times d^2$

$(\because b = 1m\ \text{strip})$

$d_{req} = 71.12\,mm.$

$d_{pro} = 121\,mm > d_{req}$. Hence.



Bending moment co-efficient for a continuous beam/slab

ii) at support A,

$6.70 \times 10^6 = A_{st}^2 - 5832.72 A_{st} + 8945260.3 = 0$

$$A_{st} = \frac{5832.72 - 5517.47}{2} = 157.62\ mm^2$$

iii) at mid span between A & B.

$14.62 \times 10^6 = A_{st}^2 - 5832.72 A_{st} + 1951935.20 = 0$

$$A_{st} = \frac{5832.72 - 5119.85}{2} = 356.43\ mm^2$$

iv) at Support B.

$16.9 \times 10^6 = 4368.05 A_{st} - 7.49 A_{st}^2$

$A_{st}^2 - 5832.72 A_{st} + 2256341.789 = 0$

$$A_{st} = \frac{5832.72 - 4999.53}{2} = 416.62\ mm^2$$

v) at mid span between B & C and C/C :-

$11.59 \times 10^6 = A_{st}^2 - 5832.72 A_{st} + 1304405.675 = 0$

$$A_{st} = \frac{5832.72 - 5517.47}{2} = 157.62\ mm^2$$