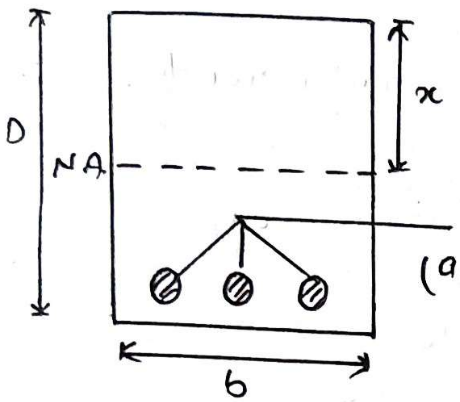
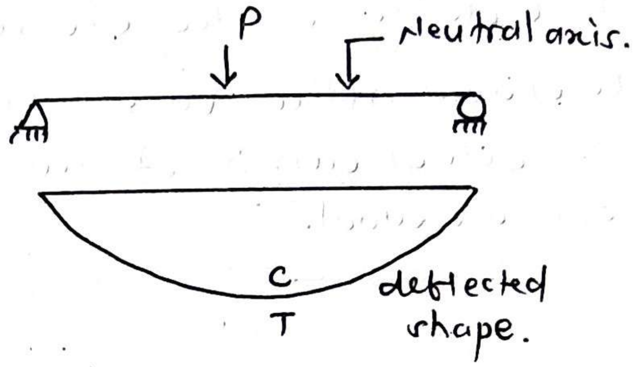
: Structural Engineering:

Introduction:

↳ The composite material consisting of steel and concrete in which compressive force is taken by concrete whereas tension force is taken by steel is known as reinforced cement concrete (RCC).





stress-strain diagram for steel:

- F = Breaking point.
- A = proportionality limit.
- B = Elastic limit
- C = upper yield point
- D = lower yield point
- P = yield plateau
- E = ultimate point

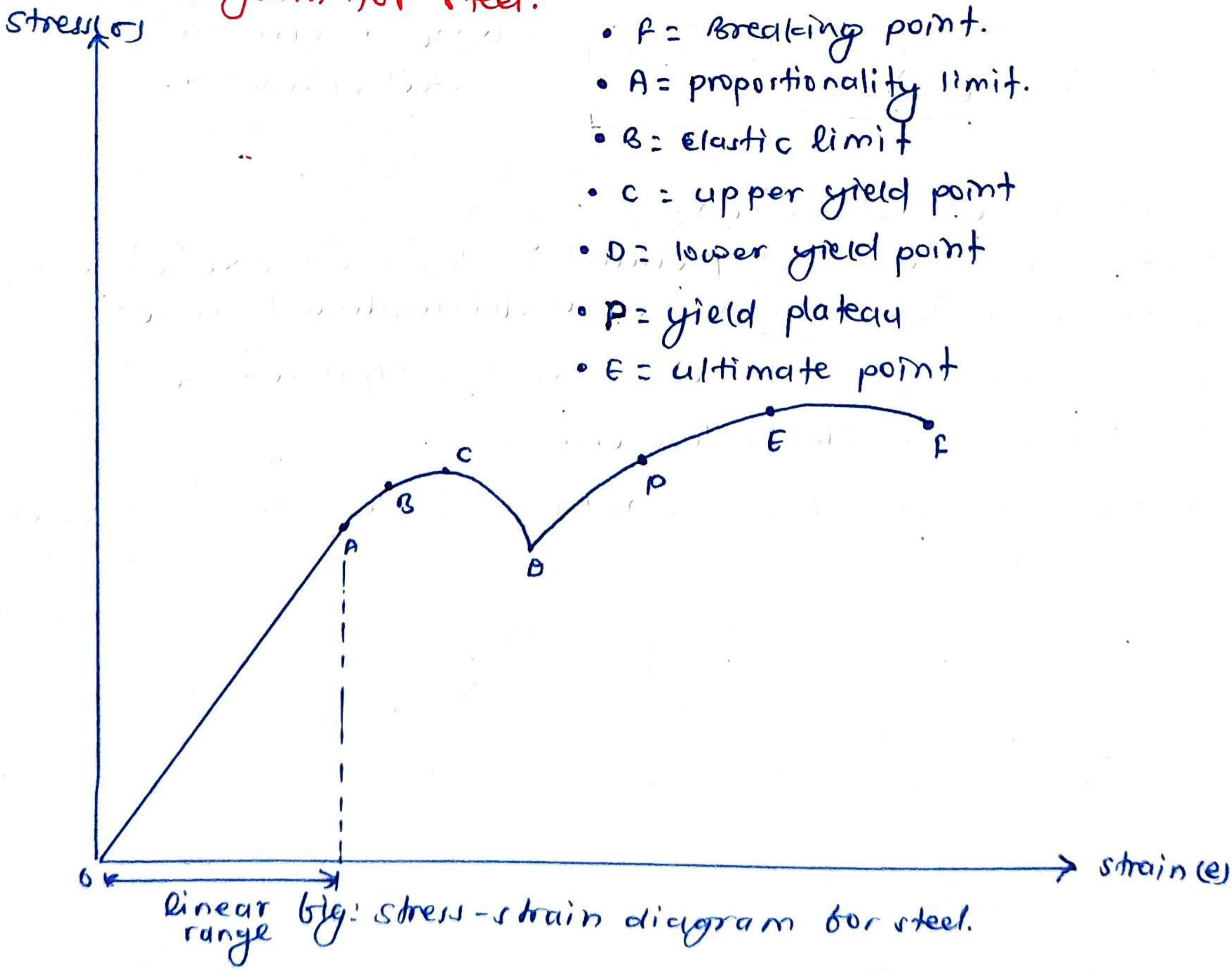


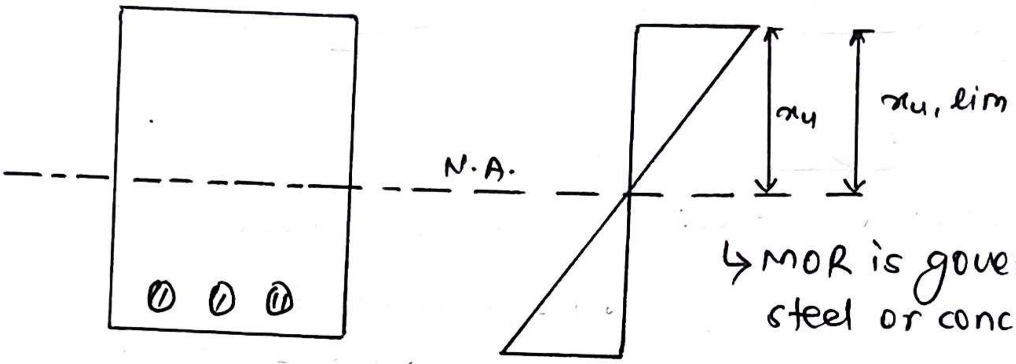
fig: stress-strain diagram for steel.

Q. Describe about the balanced section, under reinforced section and over reinforced section ? [5 marks]

Ans:

a. Balanced section:

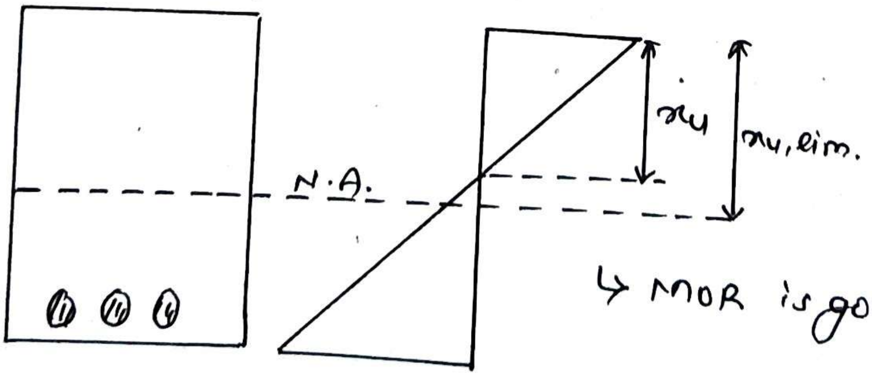
- If area of steel is equal to area of concrete such a section is called balanced section.
- The yielding of steel and concrete occurs simultaneously.
- Balanced / critical failure occurs.
- The actual depth of Neutral axis and critical depth of neutral axis are equal.



- MOR is governed by either steel or concrete.

b. Under reinforced section:

- If the area of steel provided is less than area of concrete, such a section is termed as under-reinforced section.
- The yielding of steel occurs earlier than concrete
- Ductile or tensile failure occurs.
- The actual depth of neutral axis is less than critical depth of neutral axis.



- MOR is governed by steel.

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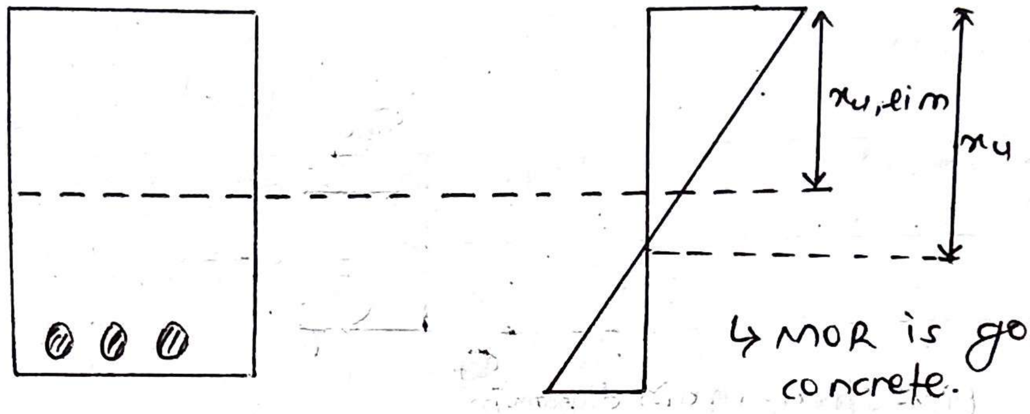
c. Over-reinforced section:

- If area of steel provided is greater than area of concrete, such a section is termed as overreinforced section.
- The crushing of concrete occurs earlier than yielding of steel.
- Brittle or compression failure occurs.
- The actual depth of neutral axis is greater than critical depth of neutral axis.



- MOR is governed by concrete.

*! Methods of Design of RCC structure:

- There are three methods for design of RCC structure:
  - a. Working stress method (WSM).
  - b. Ultimate load method (ULM)
  - c. Limit state method (LSM).

a. Working stress method (WSM):

- Also known as elastic method or modular ratio method.
- It is elastic approach design method.
- It is stress based method of RCC design.
- It is based on working or service load.
- It uses the modular ratio, $m = \frac{280}{3\sigma_{cbc}}$ for design.
- Allowable load doesnot cross the yield point.
- Gives uneconomical section.

Q. ↳ known as deterministic approach since actual load, permissible stress and factor of safety are already known.

A1 a ↳ It doesnot explain about long term effect such as creep, shrinkage, fatigue etc. on structure.

↳ considers factor of safety,

- for steel : 1.78
- for concrete : 3

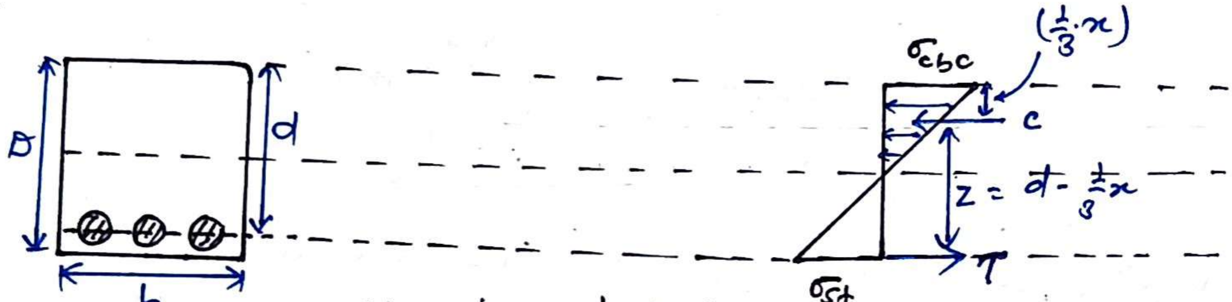


fig: stress-strain diagram.

b. Ultimate load method :(ULM)

b ↳ It is also known as load factor method.

↳ It is plastic approach design method.

↳ It is strain based method of design.

↳ It is based on ultimate load.

↳ It uses safety factor for load.

↳ Allowable load cross the yield point.

↳ Gives economical section.

↳ Also known as deterministic approach.

↳ Doesnot explain about long term effect of creep, shrinkage etc. on structure.

↳ considers factor of safety,

- for steel : 1.15
- for concrete : 1.5

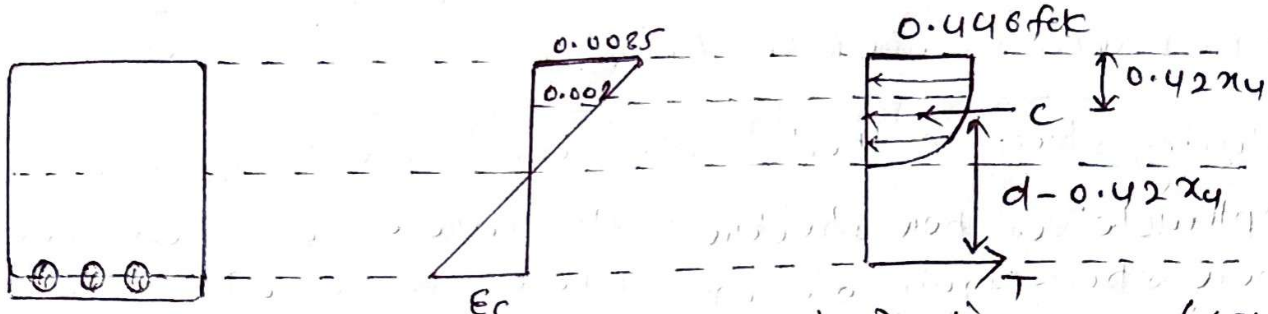


fig: stress-strain diagram. (LSM)

c. Limit state method (LSM):

- It is based on both elastic and plastic approoach design method.
- It is strain based method of design.
- It is also based on ultimate load.
- It uses multiple safety factor and consider limit state of strength and serviceability.
- known as probability approach since it depends on actual data and experience.
- It explain about the long term effects of creep, shrinkage, fatigue etc on structure.
- considers factor of safety.
  - for steel: 1.15
  - for concrete: 1.5

fig: stress strain diagram (top HT E)

Q. Differentiate limit state and working stress method of design. [5 marks]

Ans:: Differences are tabulated below;

S.N.	Working stress Method	S.N.	Limit state method:
I.	Applicable for those structure whose stress-strain diagram is linear.	I.	Applicable for those structure whose stress-strain diagram is non-linear.
II.	It is an elastic approach design method.	II.	It is based on both elastic and plastic analysis of materials.
III.	FOS is considered for materials only.	III.	Partial safety factor is considered for both load and materials.
iv.	It is based on working load or service load.	iv.	It is based on factored load or ultimate load.
V.	Allowable stress doesnot cross the yield point.	V.	Allowable stress cross the yield point.
VI.	Known as deterministic approach of design.	VI.	Known as probabilistic approach of design.
VII.	Tensile stress is considered in WSM of design.	VII.	Tensile stress is ignored in LSM of design.
VIII.	Section appear heavier, so less economical design.	VIII.	Section appear lighter, so more economical design.
ix.	It uses modular ratio $m = \frac{280}{3\sigma_{bc}}$.	ix.	It uses multiple safety factors and consider limit state of strength.

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Q. What is beam? Define its types based on reinforcement. What are the conditions for using doubly reinforced beam? [5 marks]

Ans: Beams are the members that are often subjected to flexure or bending and often supports slab.

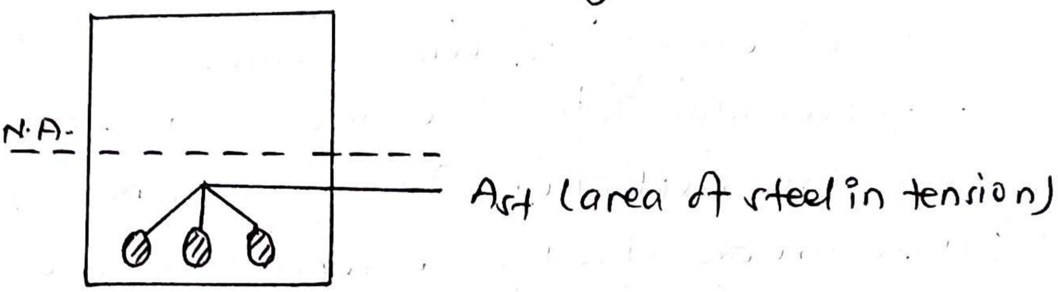
Based on reinforcement, beam is classified as:

a. singly reinforced beam.

b. Doubly reinforced beam.

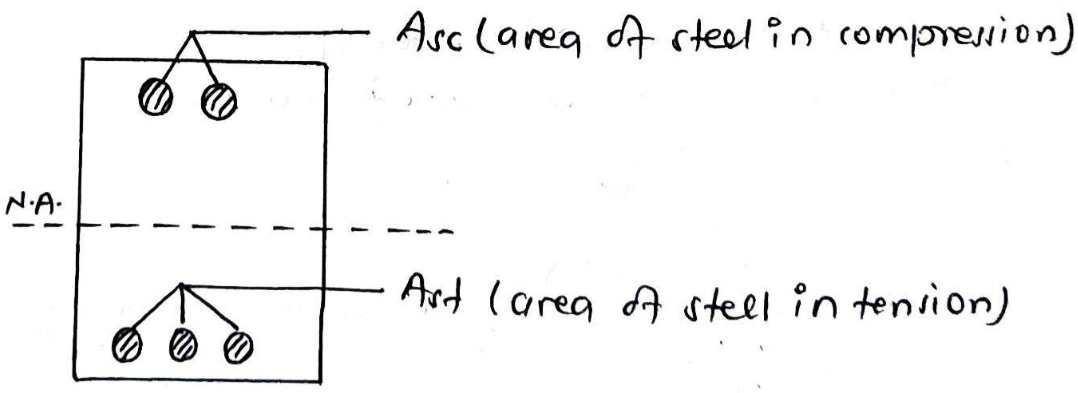
a. Singly reinforced beam:

↳ If the beam is longitudionally reinforced along the tension side only, such beam is termed as singly reinforced beam.



b. Doubly reinforced beam:

↳ If the beam is longitudionally reinforced along compression as well as tension side, the beam is termed as doubly reinforced beam.



*: Necessity for doubly reinforced section:

(i) when the depth or width of beam is restricted due to architectural consideration, aesthetic purpose or head room requirement.

(ii) when external load occurs on either face of member i.e. load is alternating and may cause tension on both faces of member.

(iii) Moment capacity is less than moment due to loading.

(iv) When the loads are eccentric.

(v) when the beam is subjected to sudden lateral loads or dynamic loads.

Advantages of doubly reinforced beam:

(i) enhances ductility at ultimate strength.

(ii) long term deflection of beam are reduced.

(iii) curvature due shrinkage of concrete are also reduced.

Q. Write down the design steps of singly reinforced beams? [5 marks].

Ans: Design steps for singly reinforced beam:

step 1: Deflection control criteria:

↳ calculate the depth of beam.

$$\frac{span}{depth} = \alpha \beta \gamma \delta \lambda$$

for simply supported beam $\frac{span}{depth} = 12$ to 15.

$$\frac{depth}{width} = 1.5 \text{ to } 3 \text{ (for rectangular beam)}.$$

step 2: calculate the loads and factored bending moment:

factored BM,

$$M_u = \frac{wl^2}{8} \quad ; \; l = \text{eff. span.}$$

for SSB. ⟶

w = load on bear (per unit length)

step 3: Depth verification:

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

⇒ calculate d = ---

For $x_{u,max}$: Refer IS-456:2000

pg: 17

$$x_{u,max} = \begin{cases} 0.53d \rightarrow \text{mild steel} \\ 0.48d \rightarrow \text{TOR steel} \\ 0.46d \rightarrow \text{TMT steel.} \end{cases}$$

• IF d < depth adopted in step-I. (OK)

step 4: calculate area of reinforcement:

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

⇒ A_{st} = ----

step 5: check for area of reinforcement:

ⓐ Min^m area of reinforcement,

$$A_{st,min} = \frac{0.85\, bd}{f_y} \quad \text{(IS-456:2000, Pg: 47)}$$

ⓑ Max^m area of reinforcement.

$A_{st,max}$ = 4% or 0.04 bD (IS-456:2000, Pg: 47)

step 6: check for shear

IS-456: 2000 (clause 40.4, Pg: 72)

$$\text{Nominal shear stress } (\tau_v) = \frac{\text{shear force}}{\text{eff. area of beam}}$$

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

Design shear strength of concrete (τ_c) : IS-456: 2000, Pg: (table-19)

$\tau_v < \tau_c$ (OK).

Step 7: Check for deflection:

$$\left(\frac{l}{d}\right)_{actual} \leq \left(\frac{l}{d}\right)_{permissible} \quad (OK)$$

Step 8: Detailing and drawing:

↳ As per codal provision.

Q. Write down the design steps for doubly reinforced beam? [5 marks]:

Ans:

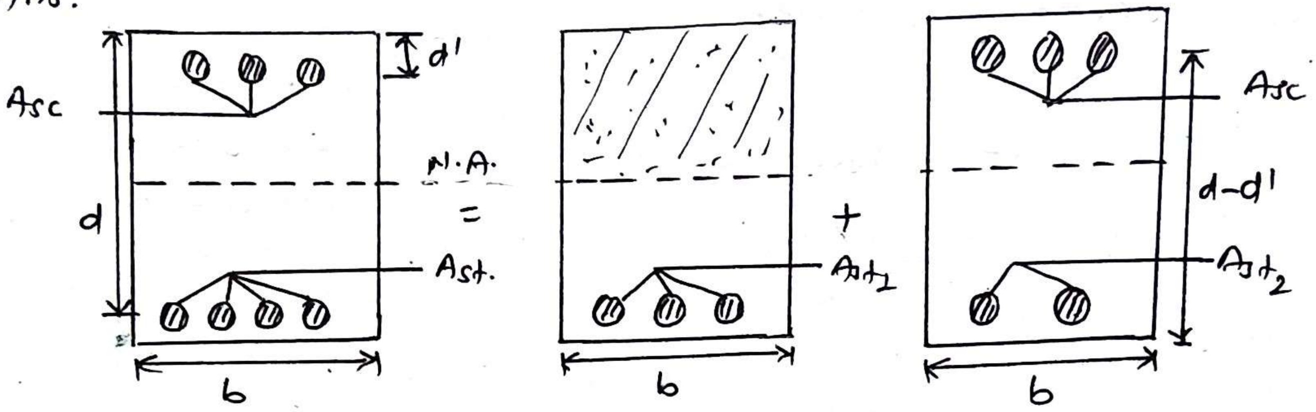


fig: Doubly reinforced section

fig(ii): singly reinforced section

fig:(iii): RCC section corresponding to Asc.

M capacity = 100 kNm

Mu = 150 kNm

; where d' = effective cover for compression bar

d = effective depth.

Given:

- load from super structure.
- size of beam (bxd).

Design procedure:

Step 1: calculate limiting moment capacity

↳ Based on given dimension

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

Here, $x_{u,max}$ depends on types of steel.

$$x_{u\,max} = \begin{cases} 0.53d \rightarrow \text{for mild steel } (f_y = 250\ N/mm^2) \\ 0.48d \rightarrow \text{for TOR } (f_y = 410\ N/mm^2) \\ 0.46d \rightarrow \text{for TMT } (f_y = 500\ N/mm^2) \end{cases}$$

(IS-456:2000 pg:17)

step 2: calculate area of tension reinforcement:

↳ corresponding to $M_{u,lim}$.

$M_{u,lim} = 0.87 f_y A_{st_1} (d - 0.42\, x_{u,max})$

$\Rightarrow A_{st_1} = ----$

step 3: calculate Factored moment

$M_u = \frac{wl^2}{8}$ (for SSB)

compare with $M_{u,lim}$.

if, $M_u > M_{u,lim} \Rightarrow$ doubly reinforced section is required.

i.e compression reinforcement is required.

step 4: calculate additional moment reinforcement:

$M_{add} = M_u - M_{u,lim}$

$M_{add} = f_c \times A_{sc} \times$ lever arm.

$M_{add.} = (f_{sc} - f_{cc}) A_{sc} \times (d - d')$

; Here f_{sc} is calculated based on $\varepsilon_{sc} = 0.0035\left(1 - \frac{d'}{x_{u,max}}\right)$

(IS-456:2000 pg: 96)

$f_{cc} = 0.446\, f_{ck}$.

We can neglect f_{cc} as its value is very small.

$M_{add} = f_{sc} \times A_{sc} \times (d - d')$

$\Rightarrow A_{sc} = ---$

step : Calculate the additional tension reinforcement correspon ding to A_{sc}.

we know,

compression force = tension force

$$f_{sc} \cdot A_{sc} = 0.87 f_y \times A_{st_2}$$

$$\Rightarrow A_{st_2} = \frac{f_{sc} \times A_{sc}}{0.87 f_y} = \text{---}$$

Step 6: calculate total tension reinforcement section:

$$A_{st} = A_{st_1} + A_{st_2}$$

step 7: check for reinforcement,

ⓐ Minimum reinforcement,

$$A_{st,min} = \frac{0.85\, bd}{f_y}$$

ⓑ Maximum reinforcement,

$A_{st,max}$ = 4% of x-section or 0.04 bD.

step 8: check for shear, deflection:

a. Shear force

Nominal shear stress $(\tau_v) = \frac{V_u}{bd}$

Design shear strength of concrete (τ_c)

τ_c = --- from IS-456: 2000, table-19 based on grade of concrete

if $\tau_v < \tau_c$ (ok).

6. Deflection

$$\left(\frac{l}{d}\right)_{actual} \leq \left(\frac{l}{d}\right)_{permissible.} \quad (OK).$$

Step 9: Detailing and drawing:

Additional information:

↳ Actual depth of N.A. for singly reinforced section:

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

↳ Actual depth of N.A. for doubly reinforced section.

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

Moment of resistance:

ⓐ Under reinforced section:

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

ⓑ Over reinforced section:

$$MOR = 0.36\, f_{ck}\, b\, x_u (d - 0.42\, x_u)$$

ⓒ Doubly reinforced section:

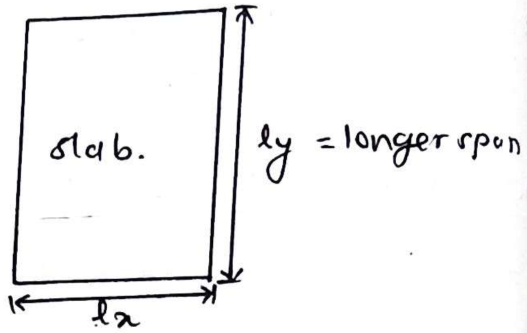
$$MOR = 0.36\, f_{ck}\, b\, x_u (d - 0.42\, x_u) + (f_{sc} - f_{cc}) \cdot A_{sc} \times (d - d')$$

since f_{cc} can be neglected,

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

Slab:

- structural element consisting of two dimensions. i.e. longer span and shorter span.
- area element.



Types of slab:

a. one way slab
b. Two way slab.

a. One way slab:

- If the slab rests on either two sides of wall or beam.
- $\dfrac{\text{longer span}}{\text{shorter span}}, \left(\dfrac{l_y}{l_x}\right) > 2$
- Main bars are provided on shorter side.
- Distribution bars are provided on longer side.

b. Two way slab:

- If the slab rests on four sides either wall or beam.
- $\dfrac{\text{longer span}}{\text{shorter span}} \left(\dfrac{l_y}{l_x}\right) \leq 2$
- Main bars are provided on both directions.
- Distribution bars are not necessary.

Q. Write down the design steps for oneway and two way RCC slab: [5 marks + 5 marks]

*: Design steps for one-way RCC-slab:

step 1: Deflection control criteria:

$$\frac{span}{depth}\left(\frac{l_x}{d}\right) = 30 \text{ to } 35$$

⇒ calculate depth = ?

step 2: calculate effective length:

IS-456 : 2000, pg: 34

l_{eff} = c/c distance
= clear span + d } whichever is less.

step 3: Calculate the load on slab:

- dead load
- floor finish load
- live load
- partition wall load.

step 4: Calculate the factored moment:

$$M_u = \frac{w \times l_e^2}{8}$$; w = load per unit length.

step 5: Depth verification:

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

⇒ d = ---- adopt width b = 1m = 1000 mm

if d < depth calculated in step-1 (ok)

step 6: Calculate the area of reinforcement:

$$M_u = 0.87\, f_y\, A_{st}\left(d - \frac{f_y A_{st}}{f_{ck}\, b}\right)$$ (IS-456 : 2000, pg: 96)

⇒ A_{st} = ---

Step 7: Check for area of reinforcement:

$A_{st} > 0.12\%$ of bD for deformed bar (HYSD)

$A_{st} > 0.15\%$ of bD for plain bar.

Step 8: Check for spacing:

$$\text{spacing} = \frac{\text{width}}{\text{No. of bar}} = \frac{\text{width}}{\frac{A_{st}}{A_\phi}} = \frac{\text{width} \times A_\phi}{A_{st}}$$

; Here A_{st} = Area of reinforcement provided.

A_ϕ = x-section area of individual bar of diameter (ϕ).

a. For main bar.

spacing < 3d or 300 mm whichever is less.

b. For distribution bar

spacing < 5d or 450 mm whichever is less.

Step 9: Check for shear & deflection.

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*! Design steps for two way slab:

step 1: Deflection control criteria:

$$\frac{\text{span}}{\text{depth}} \text{ or } \left(\frac{l_x}{d}\right) = 30 \text{ to } 35$$

⇒ calculate depth = ----

step 2: calculate effective length:

$$\left.\begin{aligned} l_{eff,x} &= \text{c-c distance} \\ &= l_{cx} + d \end{aligned}\right\} \text{whichever is less.}$$

$$\left.\begin{aligned} l_{eff,y} &= \text{c-c distance} \\ &= l_{cy} + d \end{aligned}\right\} \text{whichever is less.}$$

step 3: calculate loads on slab:

- live load
- partition wall load
- dead load
- floor finish load.

step 4: calculate factored moment:

$M_x = \alpha_x w l_x^2$

$M_y = \alpha_y w l_x^2$; where α_x, α_y are moment coefficients.

$$\alpha_x = \frac{l_x}{l_y} = ---$$

$$\alpha_y = \frac{l_y}{l_x} = ---$$

↳ calculate M_x^+, M_x^-, M_y^+, M_y^-

step 5: Depth verification:

↳ Adopt maximum moment and calculate the depth:

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

⇒ $d = ---$ if $d <$ depth calculated in step-I (ok).

Step 6: calculate reinforcement

a. Along x-direction:

$M_{x,max}$ = Higher among (M_x^+ and M_x^-)

$$M_{x,max} = 0.87\, f_y A_{st} \left(d - \frac{f_y A_{st}}{f_{ck} b}\right)$$

b. Along y-direction:

$M_{y,max}$ = Higher among (M_y^+ and M_y^-)

$$M_{y,max} = 0.87\, f_y A_{st} \left(d - \frac{f_y A_{st}}{f_{ck} b}\right)$$

Step 7: Detailing and drawing:

↳ Detailing can be done as per IS-code:

Q. Differentiate between one-way and two-way slab: [5 marks]

S.N.	One way slab	S.N.	Two way slab.
(i)	If $\frac{l_y}{l_x} > 2$, it is one way slab.	(i)	If $\frac{l_y}{l_x} \leq 2$, it is two way slab.
(ii)	Spanning along one direction i.e. moment along one-direction.	(ii)	Spanning along both direction i.e. x and y direction.
(iii)	Crank bars are provided at two sides only.	(iii)	Crank bars are provided at all four sides.
(iv)	Supported on wall or beam on two sides.	(iv)	Supported on wall or beam on four sides.
(v)	Deflected shape is cylindrical. eg: varandah slab	(v)	Deflected shape is dish type. eg: middle room slab.
(vi)	load distribution pattern is linear.	(vi)	load distribution pattern consists of triangular and trapezoidal regions.

:Column:

Q. Define column. Write down the classification of column and also describe about the codal provision for the design of RCC column.

Ans: column:

↳ compressive member subjected to compressive force on its both end is called column.

classification of column:

a. Based on slenderness ratio:

① short column:

↳ $\frac{\text{effective length of column}}{\text{least lateral dimension}} = \frac{l_{eff}}{b} \leq 12$, short column.

↳ crushing failure of materials occurs.

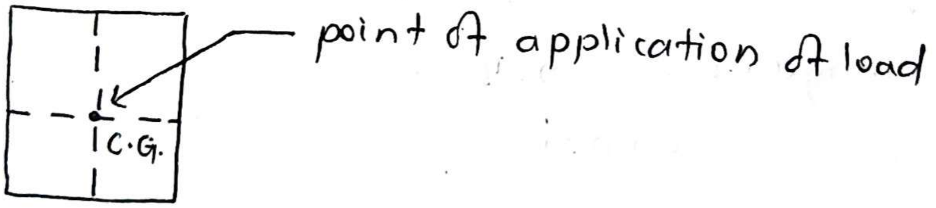
⑪ Long column:

↳ $\frac{\text{effective length of column}}{\text{least lateral dimension}} = \frac{l_{eff}}{b} > 12$, long column.

↳ Buckling failure occurs.

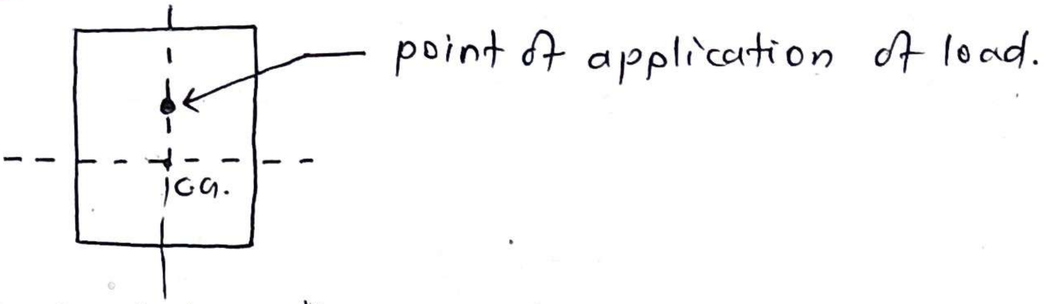
b. Based on loading condition:

① Axially loaded column:



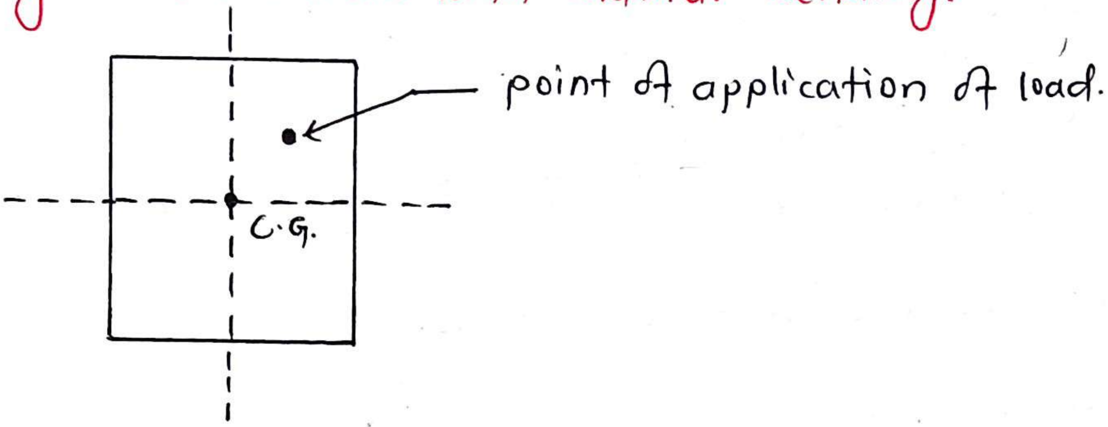
↳ The load is acting at the centroid of the column.

(ii) Axially loaded column with uniaxial bending:



↳ The load is acting apart from C.G. along one direction.

(iii) Axially loaded column with biaxial bending:



Codal Provision for design of RCC column: IS-456:2000

1. For longitudional reinforcement:

a. Min^m diameter of longitudional bar = 12mm.

b. Min^m number of longitudional bar:

↳ At least one bar should be provided at each corner of column.

For example;

→ for rectangular column: 4

→ for square column: 4

→ for circular column: 6

→ for hexagonal column: 6

c. Percentage of reinforcement

Min^m % of reinforcement (longitudional bar) = 0.8 % of gross area.

Max^{m} % of longitudional bar = 4% of gross area (practical purpose)
= 6% of gross area (theoretical purpose)

Note:

- Brittle or buckling failure लाई prevent गर्न at least 0.6% reinforcement provide गर्नु पर्छ!
- compression मा concrete अर्थात् column आफै strong भएतापनि त्यसमा vertical रहेको अरु load आउनाले reinforcement provide गर्नु पर्छ !!!

d. Maximum spacing of longitudional bar = 300 mm.

e. Minimum eccentricity

$$e_{min} = \frac{l}{500} + \frac{D \text{ or } B}{30}$$

or,

$$= 20 \text{ mm}$$

whichever is greater.

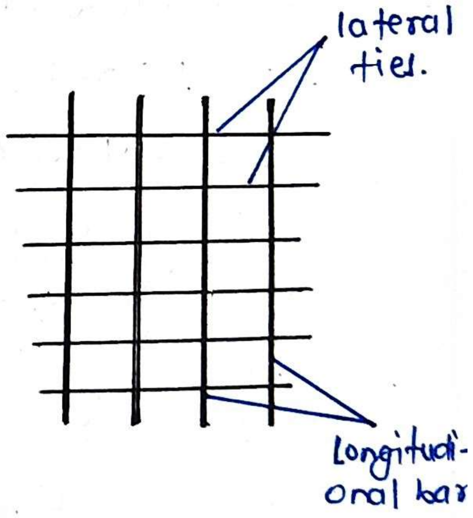
2. For transverse reinforcement:

a. diameter of lateral ties.

$$\phi_t = \frac{\phi_{\text{largest of longitudional bar}}}{4}$$

or

$$= 6 \text{ mm}$$ whichever is greater.



b. Spacing between the lateral ties: (pitch)

- ↳ least lateral dimension of column
- ↳ 16 $\phi_{\text{smallest of longitudional bar}}$
- ↳ 300 mm

whichever is less.

1. Design steps for Axially loaded column:

step 1: Given:

- ↳ factored axial load
- ↳ grade of steel and concrete.

Note:
A_c = Area of concrete
A_{sc} = Area of longitudinal reinforcement.

Assuming short axially loaded column, ($e_{min} < 0.05D$)

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc} \quad (\text{IS-456:2000 pg: 71}) \text{ ----- (i)}$$

step 2: Assume % of steel:

$A_{sc} = P \times A_g$ where; p = % of steel and its range is of value (0.8% - 6%).

A_g = gross area of column.

$$A_c = A_g - A_{sc}$$

step: 3: Calculate the gross area of column using equⁿ (i) of step-1:

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$

solving we get

A_g = ----

Also,

$$A_g = B \times B \quad (\text{for sq. column})$$
$$= B \times D \quad (\text{for rect. column})$$

Also, $\frac{D}{B} = 1.5$ to 3

step 4: check for column:

$\frac{l_{eff}}{b} \leq 12$ short column, $\quad \frac{l_{eff}}{b} > 12$ long column.

step 5: Calculate area of steel based on assumed % of steel.

$A_{sc} = P \times (B \times B)$ for square column.

$= P \times (B \times D)$ for rectangular column.

step 6: Design of lateral ties:

a. $\phi_{lateral\ ties} = \dfrac{\phi_{largest\ of\ longitudional\ bar}}{4}$

or,

= 6mm whichever is greater.

b. pitch = least lateral dimension of column

= 16 $\phi_{smallest}$ of longitudional bar

= 300 mm

whichever is less.

step 7: Detailing and drawing:

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4. Design of axially loaded column with biaxial bending:

Step 1: Given,

- factored axial load
- factored bending moment (M_{ux}, M_{uy})
- grade of steel and concrete.

Step 2: Assume % of steel:

$A_{sc} = P \times A_g$; where P = % of steel according to codal provision (range 0.8 to 6%)

also, $A_c = A_g - A_{sc}$.

Step 3: calculate size of column:

$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$

$\Rightarrow$ calculate A_g = ----

Also, $A_g = B \times B \rightarrow$ for square.

$A_g = B \times D \rightarrow$ for rectangular.

Step 4: Check for column:

$\frac{l_{eff}}{b} \leq 12$, short column.

$\frac{l_{eff}}{b} > 12$, long column.

- This design steps is for short column:

Step 5: calculate moment due to minimum eccentricity

$M_{u, e\text{-}min, x} = P_u \times e_{min, x}$

$M_{u, emin, y} = P_u \times e_{min, y}$

Design value:

M_{ux} = greater of $M_{u\,emin,x}$ & given M_{ux}.

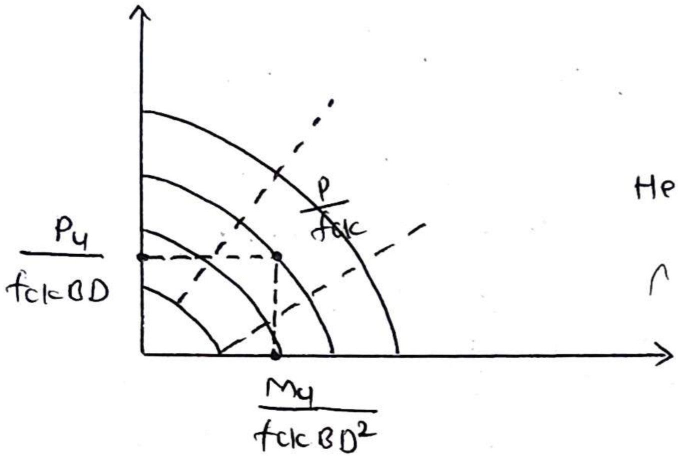
M_{uy} = greater of $M_{u\,emin,y}$ & given M_{uy}.

Step 6: calculate design moment of resistance: (M_{ux_1} & M_{uy_1})

a. Assume % of steel and calculate $\frac{d'}{D}$.

b. Based on $\frac{d'}{D}$, $\frac{P}{f_{ck}}$, assumed % of steel and assuming reinforcement equally distributed on four sides,

From chart of SP-16, calculate M_{ux_1}



Here, $\frac{P}{f_{ck}}$ and $\frac{P_u}{f_{ck}BD}$ are known value.

Also, $\frac{d'}{D}$ = 0.05, 0.10, 0.15 and 0.20 are only permissible

from above chart,

$$\frac{M_{ux_1}}{f_{ck}BD^2} = ---- \Rightarrow M_{ux_1} = (---) \times f_{ck}BD^2$$

Similarly,

$$\frac{M_{uy_1}}{f_{ck}BD^2} = ---- \Rightarrow M_{uy_1} = (---) \times f_{ck}BD^2$$

Step 7: check for the column:

$$\left(\frac{M_{ux}}{M_{ux_1}}\right)^{\alpha_n} + \left(\frac{M_{uy}}{M_{uy_1}}\right)^{\alpha_n} \leq 1$$

- If satisfied, Assumed % of steel is OK.

Here, $\alpha_n = 0.667 + 1.667 \frac{P_u}{P_{uz}}$ (range, $\alpha_n = 1 - 2$)

Here P_u = factored axial load

$P_{uz} = 0.45 f_{ck} A_c + 0.75 f_y A_{sc}$

range of $\frac{P_u}{P_{uz}}$ should be between 0.2 to 0.8.
(must lie in between these two)

step 8: calculate area of longitudional reinforcement:

$A_{sc} = P \times A_g$

step 9: Design the lateral ties:

↳ $\phi_t = \frac{\phi_L}{4}$; ϕ_L = largest of longitudional bar

or

= 6mm whichever is greater.

↳ pitch = least lateral dimension
= 300mm
= 16 $\phi_{smallest}$ of longitudional bar
} whichever is less.

step 10: Detailing and drawing:

In case of long column:-

↳ Additional moment should be considered:

$$M_{ax} = \frac{P_u D}{2000}\left(\frac{l_{ex}}{D}\right)^2$$

$$M_{ay} = \frac{P_u \times B}{2000}\left(\frac{l_{ey}}{B}\right)^2$$

and,

$$M_{ux} = (\text{given } M_{ux}) + M_{ax}$$

$$M_{uy} = (\text{given } M_{uy}) + M_{ay}$$

And then, check:

$$\left(\frac{M_{ux}}{M_{ux_1}}\right)^{\alpha_n} + \left(\frac{M_{uy}}{M_{uy_1}}\right)^{\alpha_n} \leq 1$$

Q. Differentiate between long column and short column:

S.N.	Short column	S.N.	Long column:
(i)	$\frac{l_{eff}}{b} < 12$ & $\frac{l_{eff}}{b} > 3$, then it is short column.	(i)	$\frac{l_{eff}}{b} > 12$, then it is long column.
(ii)	Crushing failure of materials occurs.	(ii)	Buckling failure of materials occurs.

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: Footings :

Introduction:

↳ Footings are the structural member used to support column or wall and transfer their loads to soil below it.

*: Types of footings:

a. Isolated footing
b. combined footing.
c. strip footing
d. strap footing
e. Mat foundation.

a. Isolated footings:

↳ Footing which are used to support isolated column are called isolated footings.

b. Combined footing:

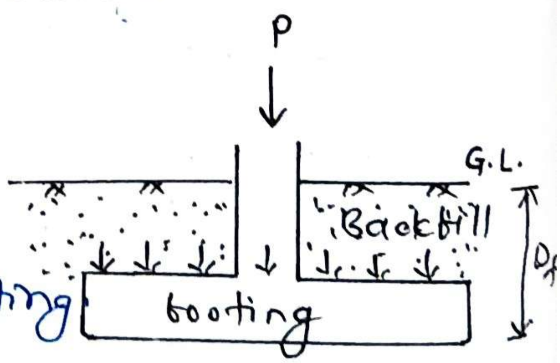
↳ single footing supporting two or more isolated column.

Q. Write down the design steps for axially loaded isolated footings? [5 marks]

Ans: Design steps for isolated footing is given below:

step 1: Given;

↳ load from column (P)
↳ grade of steel and concrete
↳ bearing capacity of soil.



step 2: calculate total weight of footing

total weight = $P + \Delta P$

; where ΔP = 10% of P, load due to self weight of footing & backfill soil.

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step 3: Calculate the area of footing:

$$\text{Area of footing, } A_f = \frac{P + \delta P}{\text{Bearing capacity of soil}}$$

$$\therefore A_f = \frac{P + \delta P}{BCS} = ----$$

Note:

- BCS for kathmandu valley is generally taken as 90 KN/mm².

step 4: calculate the soil resistance at ultimate state:

soil resistance,

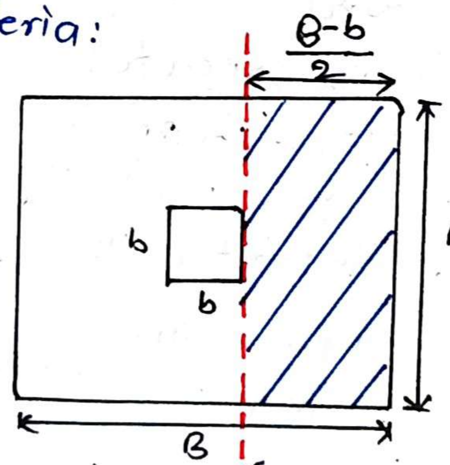
$$q_u = \frac{1.5 \times P}{A_{f\,(adopted)}}$$

step 5: calculate depth of footing:

↳ Depth of footing is based on:

- Bending moment criteria.
- One way shear
- Two way shear.

(i) Bending moment criteria:



critical section for moment.

w [illegible]

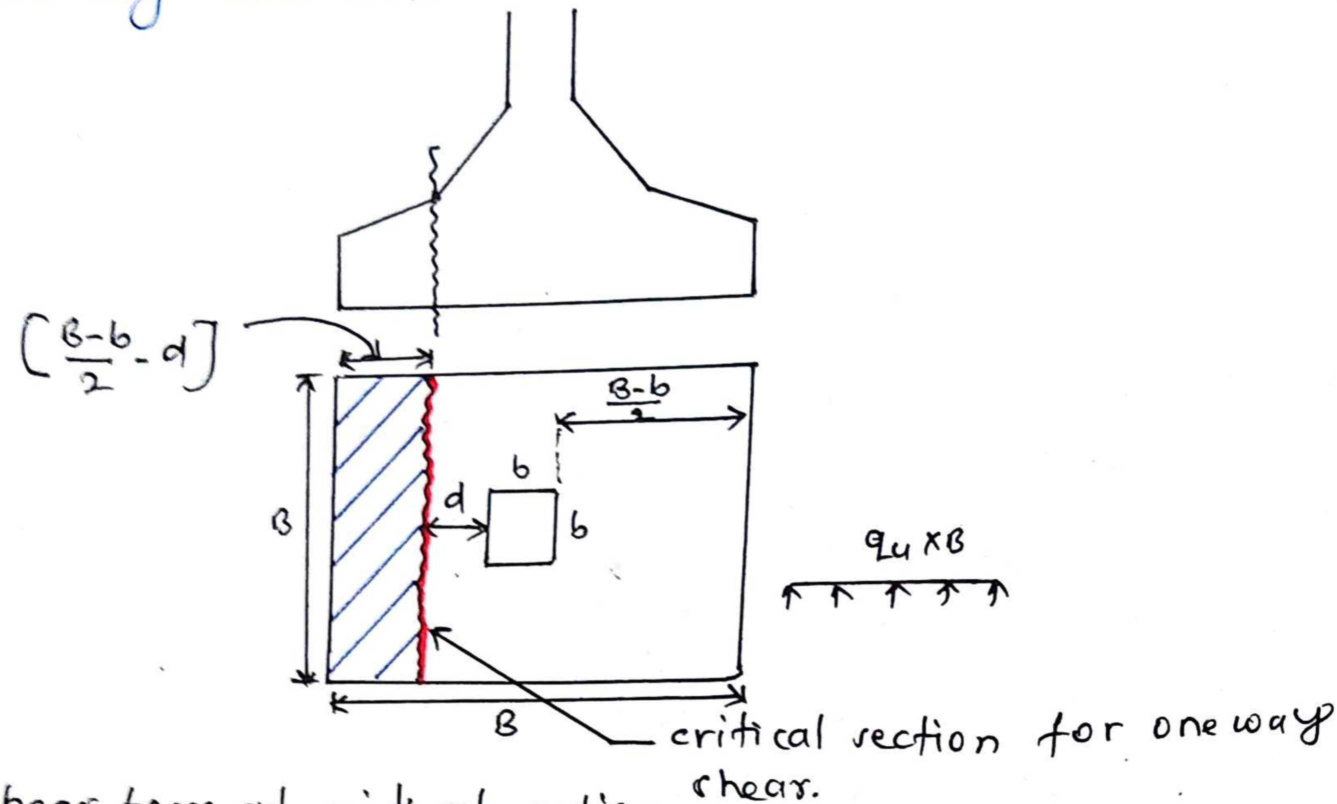
$$M_{x-x} = (\overset{w}{q_u} \times B)\left(\overset{l}{\frac{B-b}{2}}\right)\left(\overset{l/2}{\frac{B-b}{4}}\right)$$

Also,

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

⇒ calculate, d = ---

(ii) One-way shear criteria:



shear force at critical section

$$V_{u1} = (q_u \times B) \times \left[\frac{B-b}{2} - d\right]$$

shear stress $\tau_{v1} = \dfrac{V_{u1}}{b \times d}$

Design shear strength of concrete,

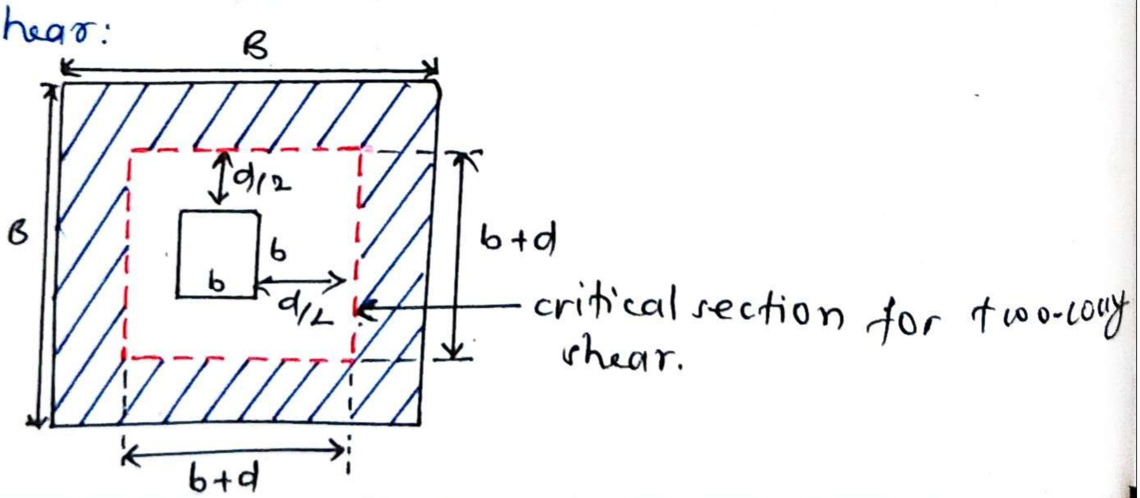
$\tau_c = ---$ IS-456: 2000, pg: 73, table-19
assume % of steel and proceed.
• adopt min^m % of stee = 0.12 % (initially)

Now,

$\tau_{v1} \leq \tau_c$

$\Rightarrow$ calculate, d = ----.

(iii) Two-way shear:



shear force at critical section:

$$V_{u_2} = q_u \times [B \times B - (b+d)(b+d)]$$

$$= q_u \times [B^2 - (b+d)^2]$$

shear stress

$$\tau_{v_2} = \frac{V_{u_2}}{b_o \times d}$$; where b_o = perimeter of critical section $= 4(b+d)$

Design shear strength for two way shear:
IS-456 : 2000, pg: 58 & 59

$$\tau_{c_2} = K_s \times 0.25\sqrt{f_{ck}}$$

; where $K_s = 0.5 + \beta_c \not> 1$

and $\beta_c = \dfrac{\text{shorter side of column.}}{\text{longer side of column.}}$

Now,

$\tau_{v_2} \leq \tau_{c_2}$

⇒ calculate, depth, d = ...

↳ Adopt depth of footing = larger of above three depth calculated

step 5: calculate area of reinforcement:

↳ using maximum bending moment,

$$M_{max} = M_{x-x} = 0.87 f_y A_{st}\left(d - \frac{f_y A_{st}}{f_{ck} b}\right)$$

⇒ calculate, A_{st} = ---

step 6: check for area of steel and spacing

↳ According to codal provision IS-456 : 2000

step 7: check for development length

$$l_d \geq \frac{\sigma_s \phi}{4\tau_{bd}}$$

step 8: Detailing and drawing:

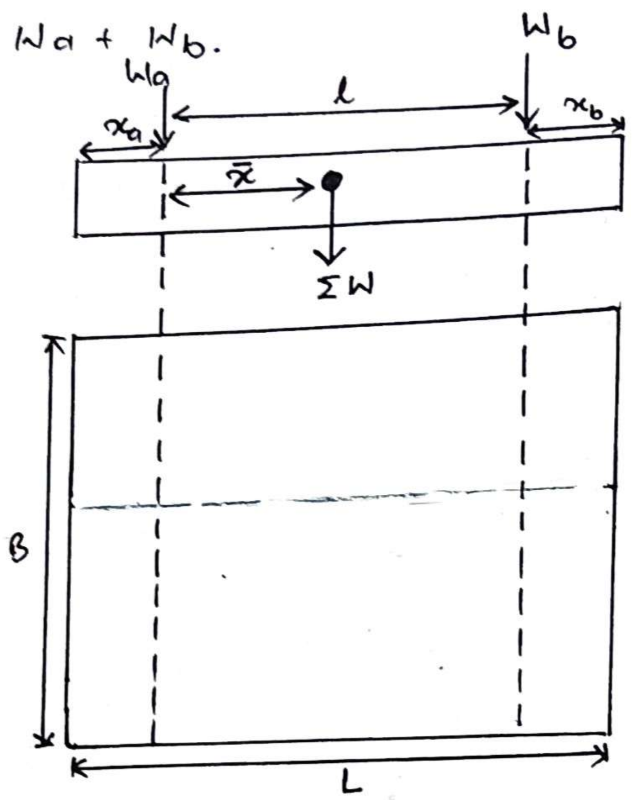
Q. Write down the design steps for combined footings? [10 marks]

Ans: The footing provided for two or more column in a single row is called combined footing.

Design steps for combined footing:-

step 1: calculate total load from column:

$$\Sigma W = W_a + W_b.$$



step 2: Area of footing:

$$\text{Area of footing},\ A_f = \frac{\Sigma W + 10\% \text{ of } \Sigma W}{BCS}$$

step 3: calculate C.G. of resultant load:

$$W_a \times 0 + W_b \times l = \Sigma W \times \bar{x}$$

$$\bar{x} = \frac{W_b \times l}{\Sigma W} \text{ from column A.}$$

step 4: calculate the size ($L \times B$) of footing:

$$\frac{L}{2} = (x_a + \bar{x})$$ ($\because$ CG of resultant load must coincide CG of footings).

$$\therefore L = 2(x_a + \bar{x})$$

step 5: Calculate ultimate pressure of soil:

$$q_u = \frac{\text{factored load}}{A_{f(\text{adopted})}}$$

step 6: calculation of foundation depth:

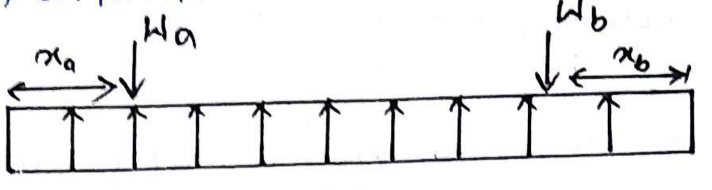
↳ By using following criteria:

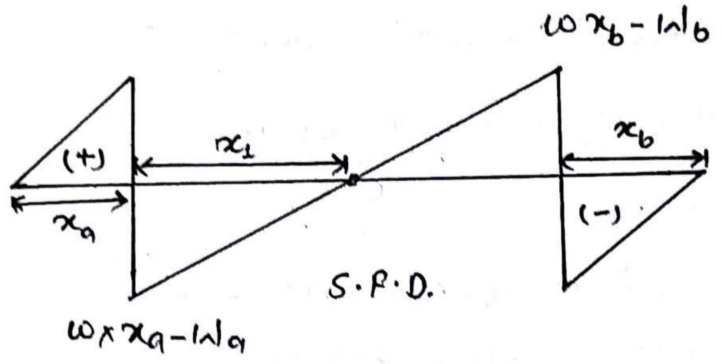
a. Bending moment criteria.

b. one-way shear criteria.

c. two-way shear criteria.

a. Bending moment criteria:





S.F.D.

ω = load per unit length.

↳ x_1 can be calculated similar Δ.

↳ Maximum moment at a distance $(x_a + \bar{x}_1)$

$$M_{max} = \omega (x_a + \bar{x}_1) \frac{(x_a + \bar{x}_1)}{2} - W_a \times \bar{x}_1$$

↳ Maximum moment at face of column

$$M_{max} = \omega \times \left(x_a - \frac{a_1}{2}\right) \frac{\left(x_a - \frac{a_1}{2}\right)}{2}$$

$$= \frac{\omega \left(x_a - \frac{a_1}{2}\right)^2}{2}$$

or

$$= \frac{\omega \left(x_b - \frac{a_2}{2}\right)^2}{2}$$

∴ Adopt max^m B.M. among the two value.

↳ calculate depth by

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

⇒ calculate, d = ---

b. one way shear:

↳ same as Isolated footing.

c. Two way shear:

↳ same as Isolated footing.

∴ Adopt max^m depth among all three cases.

step 7: calculate area of reinforcement:

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

⇒ Ast = ----

step 8: check area of reinforcement and spacing according to codal provision (IS-456:2000)

step 9: check for development length.

step 10: Detailing and drawing.

: Steel and Timber structure:

Steel structure:

Q. Write down the design specification for the design of steel structure by bolted connection? [5 marks]

Ans: Design specification for bolted connection: IS-800 : 2007.

a. Nominal diameter of bolt = diameter of shank.

For eg: M_{16} bolt.
↳ Nominal diameter of bolt.

b. Diameter of hole (d_o):

d_o = Nominal diameter of bolt + standard clearance.

; where standard clearance is given as:

- 12 - 14 ϕ = 1 mm clearance
- 14 - 24 ϕ = 2 mm clearance
- > 24 ϕ = 3 mm clearance.

} IS-800 : 2007 Pg: 75, table-19

c. Pitch / gauge / edge / end distance:

- **Pitch:** centre to centre distance between two bolt along the direction of load.

  Min^m pitch = $2.5 \times \phi_{bolt}$

  Max^m pitch = $32t$ or 300 mm whichever is less.

  ; where t = thickness of thinner plate.

- **Gauge:**

  ↳ centre to centre distance between two bolts along the transverse direction of load.

  gauge distance = min^m of [• 100 mm + 4t • 200 mm.

- **End distance:** Distance of bolt from the edge of plate along the direction of load.

  • Min^m end distance, e_{min} = $1.7\, d_o$ → hand made
  = $1.5\, d_o$ → machine made

• Max^m end distance, $e_{max} = 12 t\epsilon$

$$; \epsilon = \left(\frac{250}{f_y}\right)^{1/2}$$

• Edge distance:

↳ Distance of bolt from edge of plate along the transverse direction of load.

d. No. of bolts:

$$n = \frac{\text{factored load}}{\text{bolt value (design strength of bollt)}}$$

e. Bolt value (design strength of bolt)

① Design shear strength of bolt (V_{dsb}):

$$V_{dsb} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}}(n_n A_{nb} + n_s A_{sb})$$

; where

f_{ub} = ultimate strength of bolt

for eg: for 4.6 grade of bolt

$f_{ub} = 4 \times 100 = 400\ N/mm^2$

$f_{yb} = 0.60 \times f_{ub} = 240\ N/mm^2$

γ_{mb} = partial safety factor for bolt.

A_{sb} = area of shank of bolt.

A_{nb} = area of thread of bolt. $(0.78 A_{sb})$

n_n = no. of shear plane in which thread of bolt lies.

n_s = no. of shear plane in which shank of bolt lies.

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⑪ Design bearing strength of bolt:

$$V_{dpb} = \frac{2.5 K_b d t f_u}{\gamma_{Mb}}$$

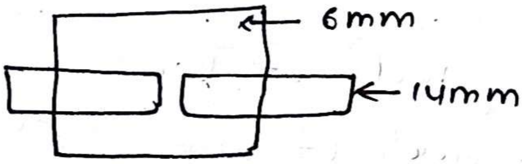
; where

d = diameter of bolt

f_u = ultimate strength of plate

t = thickness of thinner plate

= min^m thickness of summation of cover plate and main plate.



$t = 6 + 6 = 12mm$

for K_b ;

↳ adopt K_b = min^m of $\left(\frac{e}{3d_0}, \frac{p}{3d_0} - 0.25, \frac{f_{ub}}{f_u}, 1\right)$

γ_{Mb} = partial safety factor for bolt.

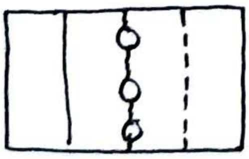
↳ Adopt bolt value = min^m of V_{dsb} & V_{dpb}.

f. Efficiency of joint:

$$\eta_{joint} = \frac{\text{strength of bolt (bolt value)}}{\text{strength of solid plate}} \times 100\%.$$

; where, strength of solid plate = $\frac{f_y A_g}{\gamma_{M0}}$; $\gamma_{M0} = 1.1$.

g. check for rupture strength and block shear strength:



$$T_{dn} = \frac{0.9 A_n f_u}{\gamma_{M1}}$$

; where A_n = net area = $(b - nd_0) \times t$

$\gamma_{M1} = 1.25$

f_u = ultimate strength of plate.

Q. Write down the assumptions of bolted connection:

Ans: Assumptions made in bolted connection are:

1. The grade of steel for plate:

→ Fe 410 grade of steel.

- $f_u = 410\ N/mm^2$

$f_y = \frac{f_u}{\sqrt{3}}$

2. The grade of bolt:

4.6 grade of bolt } for normal bolt.
5.6 grade of bolt

8.8 grade of bolt } for high strength friction grip bolt.
>6.6 grade of bolt

3. The partial safety factor for bolt:

$\gamma_{mb} = 1.25$

$\gamma_{m0} = 1.10$ (for yieldings)

4. For calculation of shear strength:

Assuming thread lies on shear plane.

5. Assume nominal diameter of bolt:

(M_{16}, M_{20}, M_{24}) → generally

Q: Write down the failure criteria of bolted connection?

Ans: Failure of bolted connection can be classified into: ~~two types~~

a. Shear failure of bolt

b. Shear failure of plate (Block shear failure)

c. Tension failure of bolt

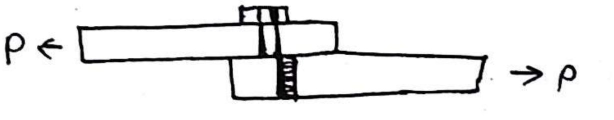
d. Tension failure of plate

e. Bearing failure of bolt

f. Bearing failure of plate.

a. Shear failure of bolt:

↳ This type of failure occurs when the factored shear force generated on bolt due to applied load exceeds the shear strength capacity of bolt.



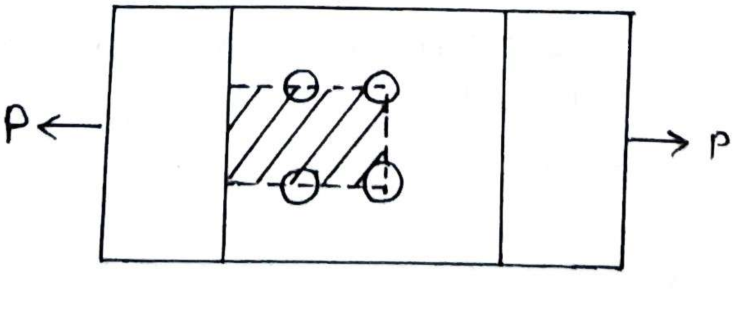
b. Shear failure of plate (Block shear failure):

↳ When the strength of plate is less than shearing strength of bolt, block shear failure occurs.

↳ In this failure, the block of material within the bolted area breaks away.

↳ to prevent it, minimum edge distance should be provided.

~~c. Tensio~~

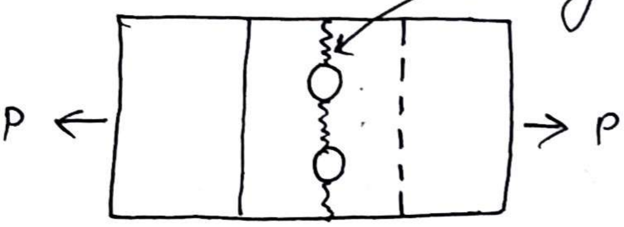


c. Tension failure of bolt:

↳ This type of failure occurs if applied factored tensile force is greater than tensile strength of bolt.

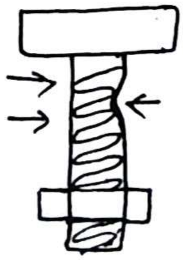
d. Tension failure of plates.

↳ This type of failure occurs when bolt is strong and plate is weak.



e. Bearing failure of bolt:

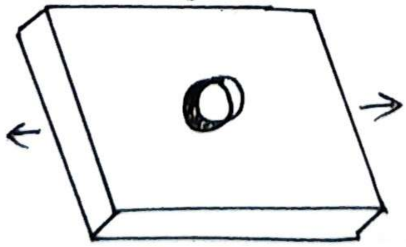
↳ When the plate is strong and bolt is weak, the bolt may crush around the bolt circumference which is known as bearing failure of bolt.



f. Bearing failure of plates:

↳ occurs when bolt is strong and plate is weak in bearing.

↳ weaker plate material get crushed when bearing stress in plate exceeds bearing strength.



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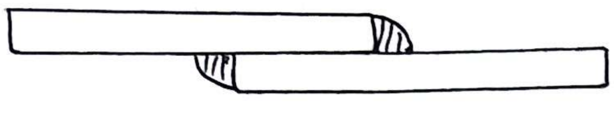
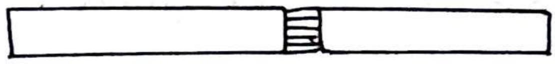
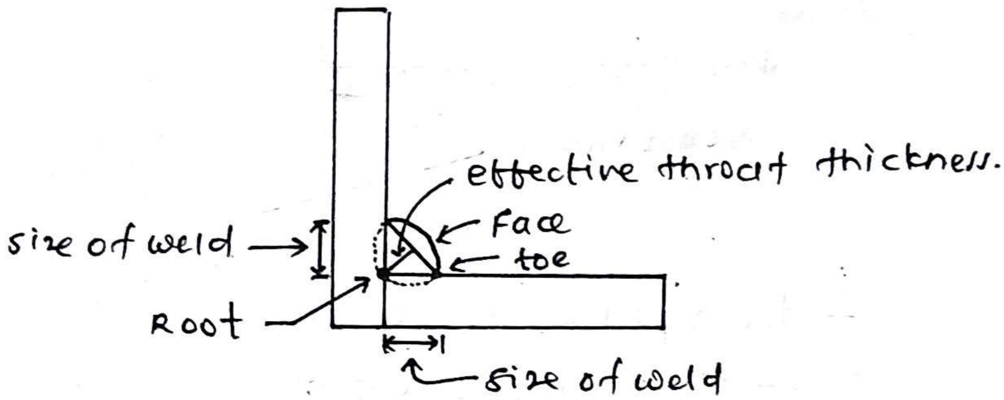
Welded connection:-

Q. Describe about the design provision / guidelines / specification for the design of steel structure by welded connection. [5marks]

Ans:







a. Size of weld:

Maximum size of weld = thickness of thinner plate - 1.5 (when two plate are connected)

or

" " " " (S) = $\frac{3}{4} \times t$; t= thickness of rolled section at toe.

Minimum size of weld:

↳ calculated based on thickness of thicker plate.

- Table 22, pg: 78 (IS-800:2007)

b. Effective throat thickness: (t_e)

↳ effective throat thickness, $t_e = KS$

; K depends on fusion angle and, K = 0.70 (for 60 - 90° fusion angle)

S = size of weld.

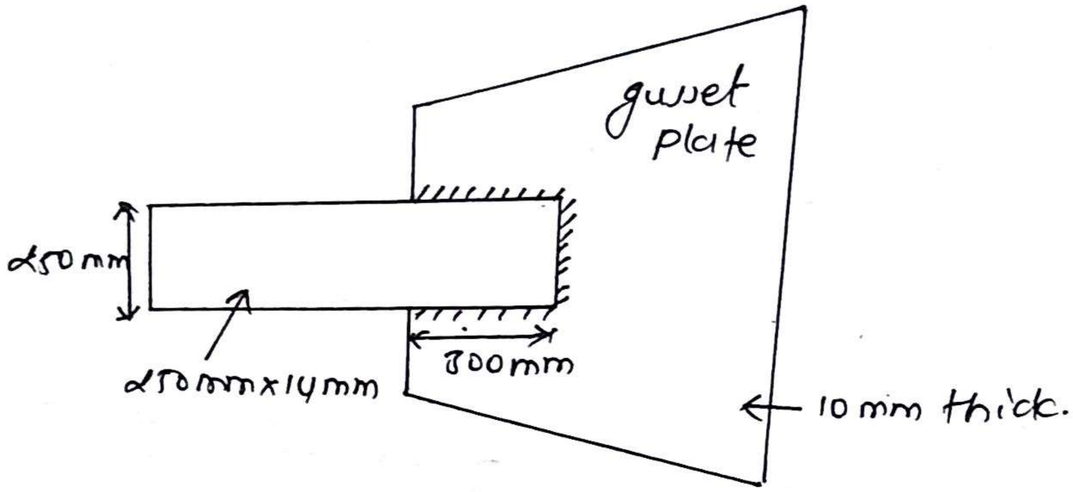
But, $t_e \nless 3mm$ &

$t_e \ngtr 0.7t$; t= thickness of thinner plate.

Numerical:

A tie member in a truss girder is 250mm x 14mm is welded with 10mm thick gusset plate by fillet weld. The overlap is 300mm and size of weld is 6mm. Determine the design strength of the weld. [5marks]

Solution:



Given,

width of tie member = 250mm.

thickness of tie member = 14mm

thickness of gusset plate = 10mm

size of weld (s) = 6mm

overlap distance = 300mm.

$\therefore$ Total length of weld (l_w) = 300+250+300 = 850 mm

effective length of weld $(l_{we}) = l_w - 2s$

$= 850 - 2\times6$

$= 838$ mm.

Effective throat thickness $(t_e) = k.s$

$= 0.70\times s$

$= 0.70\times 6$

$= 4.2$mm.

Now

strength of weld is given by;

$$P_u = \frac{f_u}{\sqrt{3}\,\gamma_{mw}}\,(l_{we}\times t_e)$$

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Assuming grade of steel : Fe410

$f_u = 410\ N/mm^2$

$\gamma_{mw} = 1.5 \rightarrow$ field

$= 1.25 \rightarrow$ shop

Adopting $\gamma_{mw} = 1.25$

Now

$$P_u = \frac{410}{\sqrt{3} \times 1.25} \times (888 \times 4.2)$$

$$= 666.51\ kN$$

∴ The design strength of the weld = 666.51 kN.

Design of Axially loaded columns:

Q. Write down the design steps for axially loaded column. [5 marks]

Ans: Design steps for axially loaded steel column are given below:

Step 1: Assume the slenderness ratio based on the length of the column.

Step 2: Based on the assumed slenderness ratio, yield stress and buckling class, calculate the design compressive stress (f_{cd}):

Pg: 42, 43, 44, 45.... (IS-800:2007)

for channel section → buckling class c

(Pg: 44 IS-800:2007)

Step 3: Calculate the appropriate area of section.

$$\text{Area, } A = \frac{\text{factored compressive load } (P_u)}{\text{design compressive stress } (f_{cd})}$$

$$A = \frac{P_u}{f_{cd}}$$

step 4: choose the suitable section having an area equal or greater than area calculated in step-3.

step 5: Calculate the design compressive stress based on section adopted (f_{cd}).

step 6: Calculate the design strength of compression member

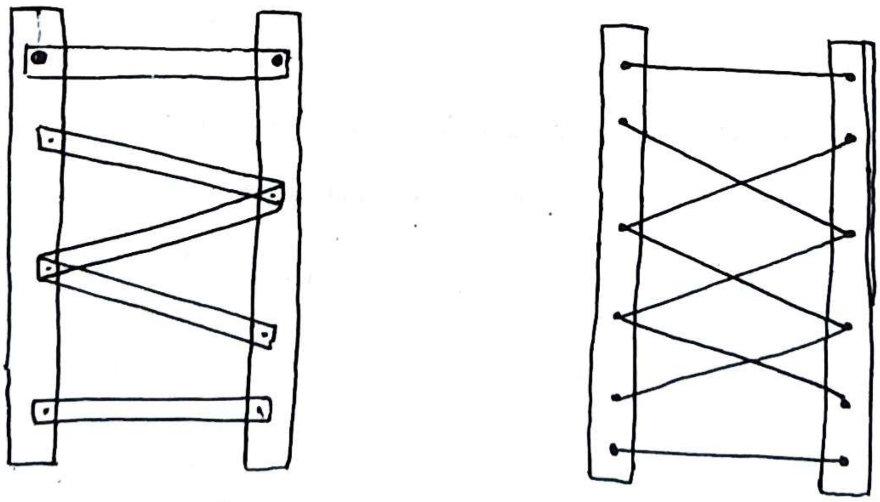
$$P_d = A \times f_{cd}$$

step 7: check:

- if $P_d >$ factored given load (applied load)
  section is safe.
- if $P_d <$ factored given load (applied load)
  Revise the section followed from step-4.

Built up column:

↳ composite column consisting of lacing system and batten system is called built up column.



single lacing system   double lacing system.

fig: builtup column consisting of lacing system.

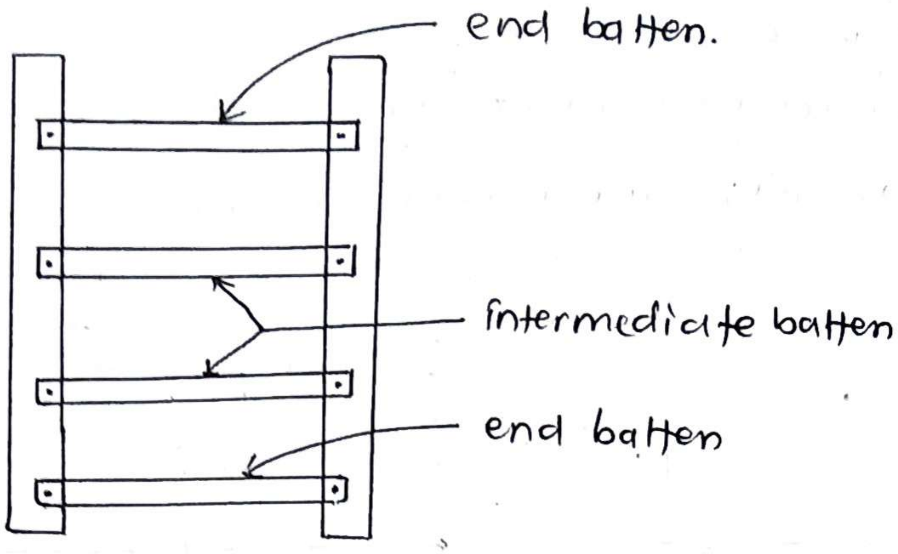


fig: builtup column consisting of batten system.

Q. Write down the design steps for built up lacing system:

1. Assume design compressive stress (f_{cd}).
↳ Normally 100 to 175 MPa.

2. Calculate the approximate area required for builtup column

$$\text{Area}(A) = \frac{\text{factored compressive load}}{\text{design compressive stress}}$$

$$A = \frac{P_u}{f_{cd}}$$

3. Choose the suitable section having area equal or greater than calculated area.

4. Calculate the design strength of column

$$P_d = f_{cd} \times A > P_u \text{ (ok) safe.}$$

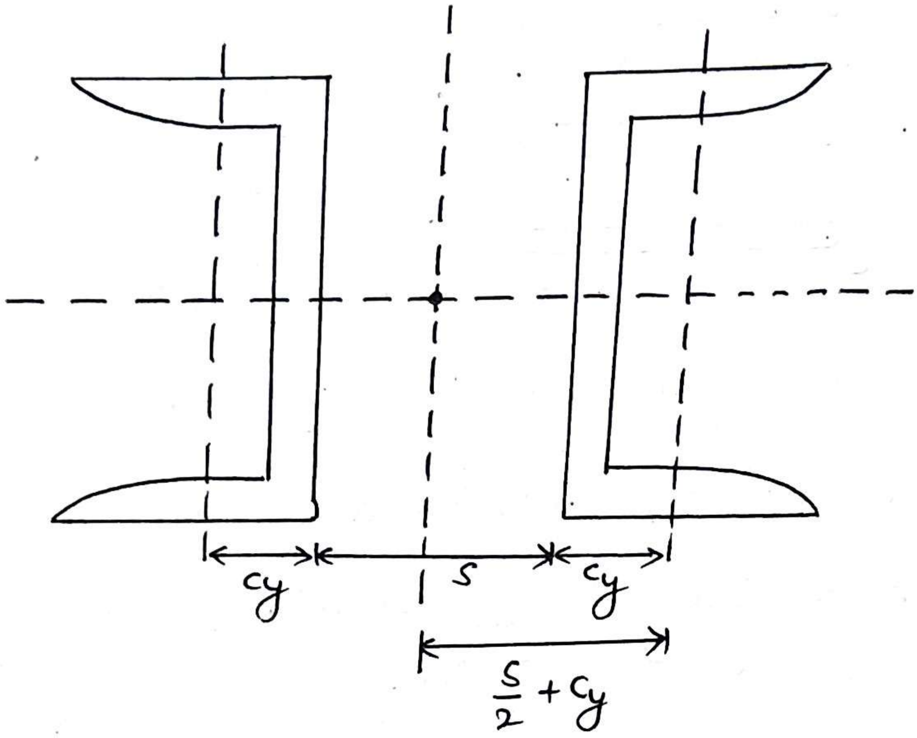
Here A = 2 times area required (from code)

P_u = factored axial compressive load.

5. Spacing of column:

↳ Based on type of connection:

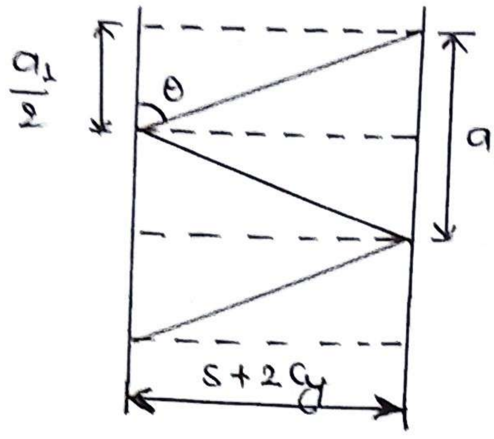
For example; two channel section connected back to back:



Here,

$$I_y = I_{y(centroid)} + A\left(\frac{s}{2} + c_y\right)^2$$

6. Assume lacing angle between 40° to 70°.



7. Spacing of lacing bar

$$\tan\theta = \frac{s+2c_y}{a_1/2}$$

$$\Rightarrow a_1 = 2(s+2c_y) \times \cot\theta$$

↳ check for spacing

$$\frac{a_1}{r_y} \leq 0.7\left(\frac{kl}{r}\right)_{eff}$$

or,

$$\frac{a_1}{r_y} \leq 50 \quad \text{whichever is less.}$$

; where $\left(\frac{kl}{r}\right)_{eff} = 1.05 \times \left(\frac{kl}{r}\right)_{actual}$.

8. Design of lacing bar:

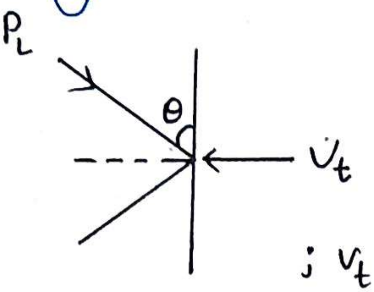
a. Dimension of lacing bar:

- width of lacing bar ≮ 3 × nominal diameter of bolt.
- thickness of lacing bar

$$t_e = \frac{\text{eff. length of lacing bar}}{40}, \text{ for single lacing system}$$

$$t_e = \frac{l_{eff}}{60}, \text{ for double lacing system}$$

b. load on lacing bar:



; $V_t = 2.5\%$ of axial load.

$$P_L \sin\theta = \frac{V_t}{N}$$

$$\Rightarrow P_L = \frac{V_t}{N} \times \operatorname{cosec}\theta.$$

- for single lacing system.

$$P_L = \frac{V_t}{N} \operatorname{cosec}\theta$$

- for double lacing system

$$P_L = \frac{V_t}{2N} \operatorname{cosec}\theta$$

c. check for lacing:

capacity of lacing bar

$$P_d = A \times f_{cd}$$

; where f_{cd} can be calculated as:

↳ $\min^m$ radius of gyration is required given by

$$r_{min} = \frac{t}{\sqrt{12}} \text{ ; } t = \text{thickness of lacing bar.}$$

↳ Based on $\frac{kl}{r_{min}}$, f_y and buckling class,

calculate f_{cd}.

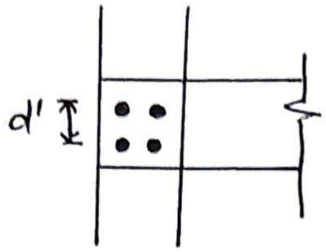
- To be safe,

$$P_d > P_L$$

if not revise the section.

9. Design of connection:
↳ connection is designed as per requirements.
- Bolted connection.
- welded connection.

10. Design of tie plate: (batten)



length of batten = $S + 2B$ where B = flange width.

effective depth of batten = distance between centroid of the main compression member

$d' = S + 2C_y$

overall depth of batten, $D = d' + 2 \times$ end distance

$D = d' + 2 \times$ end distance.

thickness of batten, $t_e = \dfrac{\text{eff. length of batten}}{50}$

*: Battens:

↳ All steps upto step no. 5 are same as lacing.

6. Effective slenderness ratio $\left(\frac{kl}{r}\right)_{eff} = 1.10 \times \left(\frac{kl}{r}\right)_{actual}$.

7. Spacing of batten (c):

$$\frac{c}{r_y} \leq 50$$

$$\leq 0.70 \left(\frac{kl}{r}\right)_{eff}$$

8. Length of batten $= s + 2B$

thickness of batten $= \frac{l_{eff}}{50}$

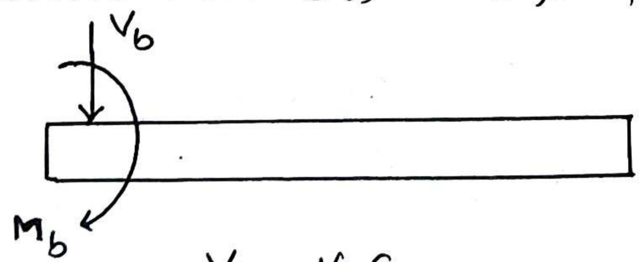
effective depth of end batten $= s + 2C_y$

For intermediate battens

effective depth $= \frac{3}{4} \times$ eff. depth of end battens.

9. Design of battens:

Transverse shear $(V_t) = 2.5\%$ of axial load.



$$V_b = \frac{V_t C}{NS}$$

$$M_b = \frac{V_t C}{2N}$$

10. Check

↳ Direct shear stress $= \frac{V_b}{dt} < \frac{F_y}{\sqrt{3}\,\gamma_{m0}}$

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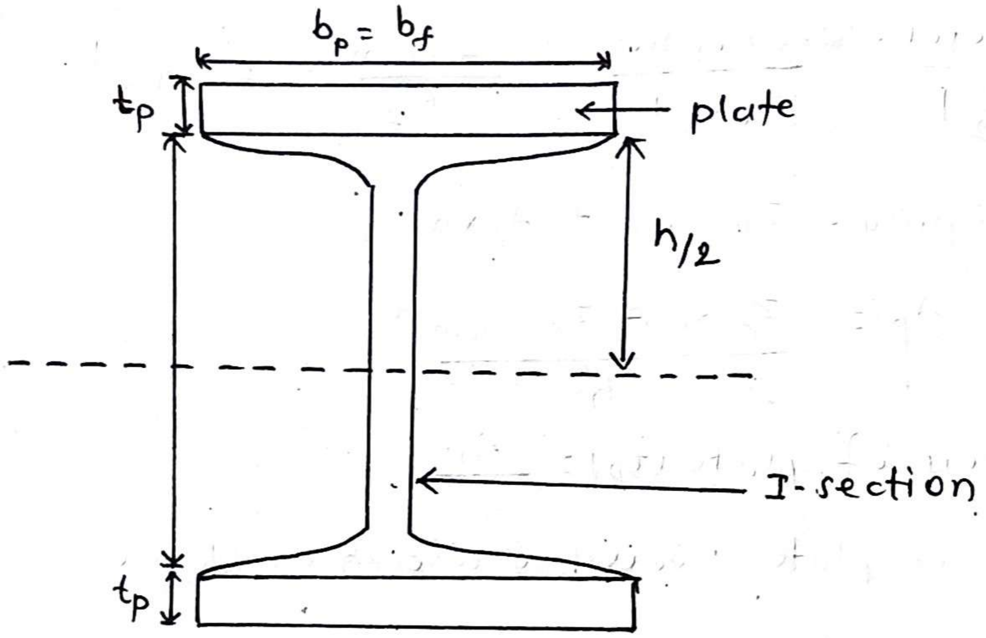
↳ Bending stress $= \frac{6 M_b}{t d^2} < \frac{f_y}{\gamma_{m0}}$

Built up Beam:

↳ When depth of beam is limited due to headroom requirement then built up section is to be provided.

↳ When the beam is subjected to heavy loading i.e. high bending moment, in such case built up section is to be needed.



Design of beam:

1. Calculate the shear force and bending moment due to different loading.

2. Section modulus required

$$Z_{p,req} = \frac{M_u \gamma_{m0}}{f_y} \; ; \; M_u = \text{factored bending moment.}$$

3. Choose the suitable section having section modulus equal to $Z_{p,req}$ or greater.

4. Calculate the capacity of section
   - If $M_{capacity} > M_u$ (safe)

5. Design of connection.

*: Design of plate:

$$I_{total} = I_{beam} + I_{plate} \quad \text{——} \quad ①$$

$$I_{plate} = 2\left[\cancel{I_0}^{0} + A_p \times \left(\frac{h}{2}\right)^2\right]$$ ($\because$ CG of compression side is acting at junction of plate and beam].

$$I_{plate} = I_{beam} + 2A_p\left(\frac{h}{2}\right)^2$$

$$\frac{I_{total}}{\left(\frac{h}{2}\right)} = \frac{I_{required}}{(h/2)} = \frac{I_{beam}}{h/2} + 2A_p\left(\frac{h}{2}\right)$$

$$Z_{p,req} = Z_{p,beam} + A_p \times h$$

$$A_p = \frac{Z_{p,req} - Z_{p,beam}}{h}$$

↳ thickness of plate $(t_p) = \frac{A_p}{b_p}$

↳ width of plate is equal to width of flange of beam.

Base plate:

↳ The plate provided at bottommost part of the column is called base plate.

Numerical:

Design the slab base (base plate) for a column section ISSC 200 which carries factored axial load (compressive) 1000 kN. Use M_{20} grade of concrete and thickness of flange is 15mm.

Solution:

Bearing strength of concrete $= 0.6 f_{ck}$.

$= 0.6 \times 20$

$= 12$ Mpa.

Area of base plate $= \dfrac{\text{factored load}}{\text{bearing strength}}$

$= \dfrac{1000 \times 10^3}{12}$

$= 83333.33 \text{ mm}^2$

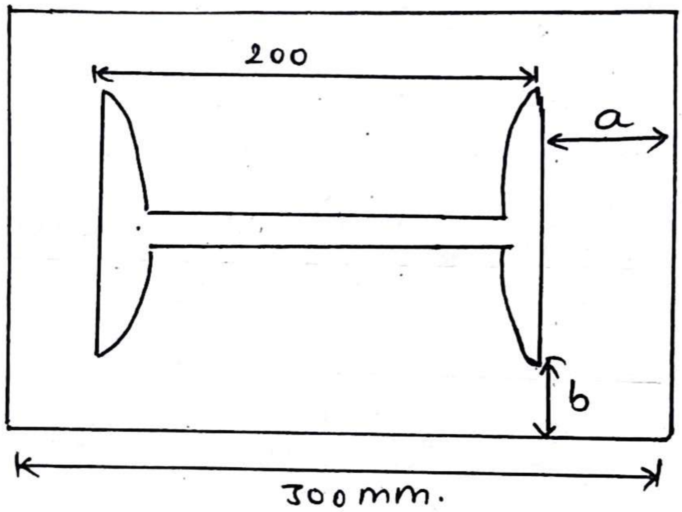
Provide square base plate;

$B \times B = 83333.33$

$B \approx 288.67 \text{ mm}$

$B \approx 300 \text{ mm}.$

$\therefore$ Provide base plate of 300mm x 300mm.



Thickness of base plate

$$t = \sqrt{\frac{2.5\, w\,(a^2 - 0.3 b^2)\, \gamma_{m_0}}{f_y}}$$ (Pg: 47 IS800: 2007)

; w = uniform pressure

$= \dfrac{P}{A}$

$= \dfrac{1000 \times 10^3}{300 \times 300} = 11.11 \text{ N/mm}^2$

a = longer projection $= \dfrac{300-200}{2} = 50\text{mm}.$

b = smaller projection $= \dfrac{300-200}{2} = 50\text{mm}.$

$$t = \sqrt{\frac{2.5 \times 11.11 \times (50^2 - 0.3 \times 50^2) \times 1.10}{250}}$$; $\gamma_{mo} = 1.10$ pg: 30 table-5.

$t = 14.62\,mm.$

Since $t \propto t_f$

$\therefore$ provide $t_{min} = 15\,mm.$

Hence provide (500mm x 500mm x 15mm) base plate.

Design principle of Timber structure:

Q. Write down the assumptions and design principles of Timber column? [1+4=5marks]

Ans: Assumptions:

① Assume grade of timber

↳ Grade II, the permissible stress should be multiplied by 0.84.

↳ select grade, the permissible stress should be multiplied by 1.16.

② Assume permissible stress for timber.

↳ take permissible stress parallel to grain.

③ Assume use of timber.

↳ outside location

↳ inside location

↳ wet condition.

Design principles:

① Assume dimension of column.

② select the type of column.

③ select the safe compressive stress on column.

④ check for permissible loads for column.

↳ If permissible load > axial applied load (ok).

otherwise redesign the column.

Types of timber column:

(i) solid column.

(ii) Box and built up column.

(iii) spaced column.

Note:

Each types of column is again sub-divided into

a. short column

b. Intermediate column

c. Long column.

Design principles for solid column:

Solid column:

↳ column consisting single piece of woods is called solid column.

Design steps:

a. Assume dimension of column 300mm x 300mm.

b. Types of column:

(i) Short column:

$$\frac{\text{length of column}}{\text{least dimension}} \leq 11$$

↳ Safe compressive stress (σ_c) = σ_{cp} (from table-2)

; where σ_{cp} = permissible stress parallel to grain.

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(ii) Intermediate column:

$11 < \frac{l}{d} < K_8$

; where $K_8 = 0.702\sqrt{\frac{E}{\sigma_p}}$

; E = modulus of elasticity

↳ safe compressive stress (σ_c) = $\sigma_p\left[1 - \frac{1}{3}\left(\frac{l}{dK_8}\right)^4\right]$

(iii) long column:

$\frac{l}{d} > K_8$

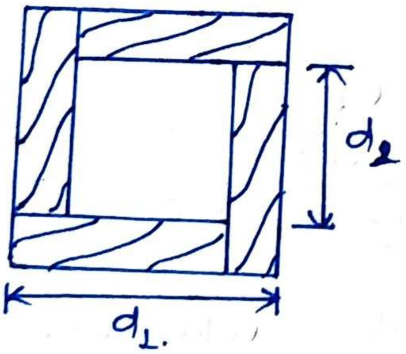
↳ safe compressive stress (σ_c) = $\frac{0.329E}{(l/d)^2}$

c. safe permissible load (P_c) = A × safe compressive stress

if P_c > Axial load of column. (OK).

if P_c < Axial load of column (Revise the section.)

Design principles for box and builtup column:



d_1 = outer dimension of column

d_2 = inner dimension of column.

Design steps:

a. Assume size of column.

b. select types of column.

① short column:

$$\frac{l}{\sqrt{d_1^2+d_2^2}} \leq 8$$

↳ safe compressive stress $(\sigma_c) = q \times \sigma_{cp}$.

; where q = constant which depends on plank's thickness.

(II) Intermediate column:

$$8 < \frac{l}{\sqrt{d_1^2+d_2^2}} \leq k_g$$

; where $k_g = \frac{\pi}{2}\sqrt{\frac{UE}{5q\,\sigma_{cp}}}$

; U = constant value which depend on plank's thickness.

↳ safe compressive stress $(\sigma_c) = q \times \sigma_{cp} \times \left[1 - \frac{1}{3}\left(\frac{l}{\sqrt{d_1^2+d_2^2}} \times \frac{1}{k_g}\right)^4\right]$

(III) long column:

$$\frac{l}{\sqrt{d_1^2+d_2^2}} > k_g$$

↳ safe compressive stress $(\sigma_c) = \frac{0.329\,UE}{\left(\frac{l}{\sqrt{d_1^2+d_2^2}}\right)^2}$

; U is constant value which depends upon plank thickness.

c. safe compressive load

$(P_c) = A \times \sigma_c > P$. (axial load) (OK).

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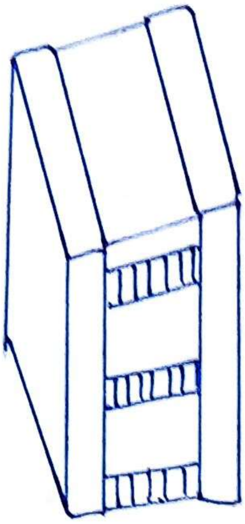
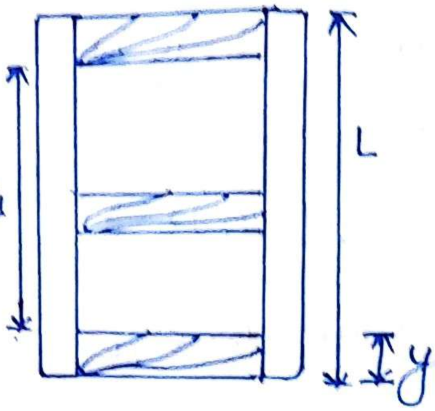
Design principles of spaced column:





y = end distance
$= l - 2y$

if $y = \frac{l}{20}$ then

$$l_{eff} = \frac{l_1}{\sqrt{2.5}}$$

$y = l/10$ to $l/20$

$$l_{eff} = \frac{l_1}{\sqrt{3}}$$

a. select types of column:

① short column

$$\frac{l}{d} < 11$$

↳ safe compressive stress $(\sigma) = \sigma_p$

⑪ intermediate column

$$11 < \frac{l}{d} \leq K_{10}$$

; where $K_{10} = 0.702 \sqrt{\frac{2.5E}{\sigma_{cp}}}$

↳ safe compressive stress $(\sigma) = \sigma_p \left[1 - \frac{1}{3}\left(\frac{l}{dK_{10}}\right)^4\right]$

(iii) long column:

$\frac{l}{d} > K_{10}$

↳ safe compressive stress (σ_c) =

b. safe compressive load (P_c) = $\sigma_c \times A$

if P_c > axial load (ok)

otherwise revise the section.

Timber beam:

Design steps:

step: 1 calculate maximum B.M. based on loading condition:

step: 2 Adopt the permissible bending stress (σ_b) depending upon the types of woods.

Table-I [IS-883 : 1994]

- for select grade, σ_b should be multiplied by 1.16
- for grade-II, σ_b should be multiplied by 0.84.

step: 3 calculate the section modulus.

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R} \Rightarrow Z = \frac{M}{\sigma} = \frac{\text{moment (maximum)}}{\text{permissible bending stress}}$$

step: 4 calculate the dimension of beam.

For eg: rectangular beam.

$$Z = \frac{bd^2}{6}$$

assume, $d = 3b$ (according to codal provision)

calculate, $b = ---$

$b \nless 50\text{mm}$ } whichever is greater.
$\nless \frac{\text{span}}{50}$

∴ bxd is obtained.

step:5 check for bending stress; shear stress and deflection:

a. check for bending stress:

$$(\sigma_b)_{actual} = \frac{M_{max}}{Z} \; ; \; Z = \frac{bd^2}{6} \text{ (adopted)}.$$

$(\sigma_b)_{permissible} = (\sigma_b)_{from\ code} \times$ grade factor $\times$ form factor (K_3)

↳ if depth of beam exceeds 800 mm

$$K_3 = 0.81 \left(\frac{D^2 + 89400}{D^2 + 55000} \right)$$

where D = depth of beam in mm.

↳ if $(\sigma_b)_{actual} < (\sigma_b)_{permissible}$ (safe).

b. check for shear stress (τ):

↳ $\tau_{actual} \leq \tau_{permissible}$.

- Actual shear stress depends upon the type of loading and adopted according to code IS-883:1994.

- $\tau_{permissible}$ depends on types of wood and adopted from codal provision IS-883:1994.

c. check for deflection:

$\Delta_{actual} \leq \Delta_{permissible}$

; where $\Delta_{actual} = \frac{KWl^4}{EI}$; W = load in KN/m.

$K = \frac{5}{384}$ for SSB subjected to UDL in whole span.

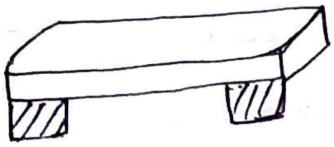
$K = \frac{1}{48}$ for SSB subjected to point load at mid span.

$K = \frac{1}{3}$ for cantilever beam subjected to point load at free span.

$\Delta_{permissible} = \frac{span}{240}$ (for all type of beam)

$\Delta_{permissible} = \frac{span}{150}$ (for cantilever beam)

d. Check for bearing:



Bearing area = Bearing width x width of beam.

$\text{Bearing stress} = \frac{\text{support reaction}}{\text{bearing area}}$

↳ Actual bearing stress ≤ permissible bearing stress

IS-code : 883 : 1994.

Tension member:

↳ Members subjected to tension force are called tension members.

eg: ties

Design steps:

1. Tension force i.e. T is known.
2. calculate the area of tension member.

$$A_{g,req} = \frac{T \times \gamma_{m0}}{f_y}$$

3. choose the suitable section having area equal to or greater than $A_{g,req}$.
4. Design the connection as per requirement.
   - ↳ Bolted connection
   - ↳ welded connection
5. check for adopted member.

(i) check for yielding

$$T_{dg} = \frac{A_g \times f_y}{\gamma_{m0}} > T$$

(ii) check for rupture

$$T_{dn} = \frac{0.9 A_n f_y}{\gamma_{m1}}$$; A_n = net area

$= b \times t - n \times (d_h \times t)$

$= (b - n d_h)t$ → for bolting

; d_h = dia. of hole.

$\gamma_{m1} = 1.25$, pg: 30 table-5;

(iii) check for block shear failure:

↳ According to codal provision.

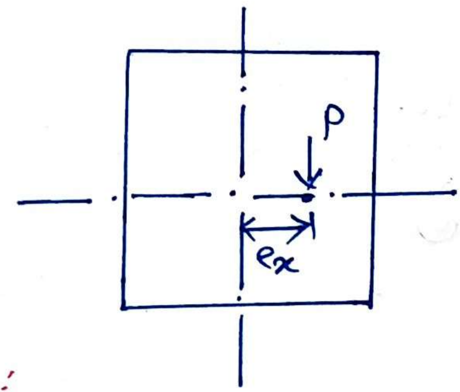
↳ Minimum of above value should be greater than applied tension load.

6. For the member to be safe, the design strength of tension member i.e.

- if (T_{dg}, T_{dn}, T_{db}) > T (factored tension force)
- if (T_{dg}, T_{dn}, T_{db}) < T, Revise the section and follow the step-3 onwards.

Eccentric column:

↳ column subjected to bending moment due to eccentricity is called as eccentric column.



Design steps:

① Assume the design compressive stress (fcd).

fcd = 100 to 150 MPa (as per requirement)

② calculate the area required

$$A_{g,req} = \frac{\text{factored load (compressive)}}{\text{design compressive stress (fcd)}}$$

$$A_{g,req} = \frac{P_u}{f_{cd}}$$

③ Choose the suitable section having area greater than $A_{g,req}$. (in general increase by 25% to 40% to resist the BM also.)

④ Take the relevant properties of adopted section based on codal provision of IS:800:2007

⑤ Classify the section according to codal provision IS-800:2007

⑥ Check for design compressive stress (P_d)

$$P_d = A \times f_{cd}$$

⑦ Check for local yielding.

$$\frac{N}{N_d} + \frac{M_y}{M_{dy}} + \frac{M_z}{M_{dz}} \leq 1 \text{ (Pg:70)}$$

where N = factored applied compressive load.

N_d = design strength of member in compression due to yielding

$$= \frac{A_g f_y}{\gamma_{mo}}$$

M_y, M_z = factored applied load

M_{dy}, M_{dz} = design bending strength.

$$\left.\begin{array}{l} M_{dy} = \beta_b \times Z_{py} \times f_{bd} \\ M_{dz} = \beta_b \times Z_{pz} \times f_{bd} \end{array}\right\} \text{Pg:54}$$

↳ If the above condition satisfies, design is ok.