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Section :- A

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Program :- B.Sc Civil Engineering

Assignment :- Plain & Reinforced Concrete Design - I

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QUESTION - 01

①

Explain in detail types of stirrups with figures and Also explain ACI Codes for shear design.

Ans. -

STIRRUP :-

Stirrups are closed-loop bars tied at regular intervals in beam reinforcement to hold the bars in position.

TYPES OF STIRRUPS :-

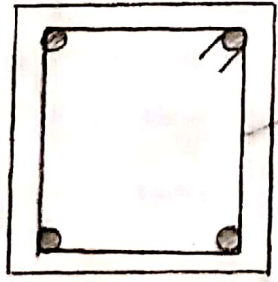
1- Single Legged Stirrup :-

The single-leg stirrups have rarely been used because they are mostly used when binding only two rods.



2- Two Legged Stirrup :-

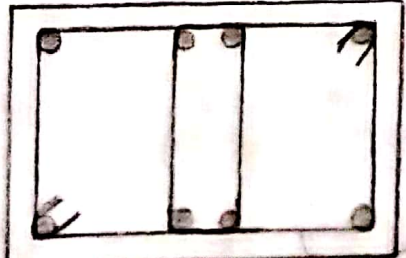
It is most commonly and widely used stirrup. Minimum 4 bars are required for providing this stirrup.



2 legged stirrup

3- Four Legged stirrup :-

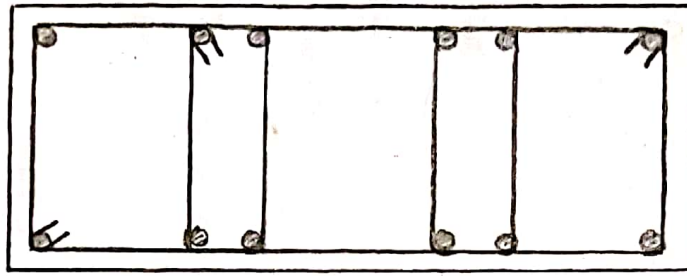
These stirrups are used in case of web reinforcement.



4- legged stirrup

4- Six Legged Stirrup :-

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ACI CODES FOR SHEAR DESIGN OF A BEAM

According to ACI-318, following are the formulas used for the shear design of a beam.

1- Critical Section:- Critical section occurs at 45° and is at distance (d) from the face of support which is equal to effective depth.

2- Shear Strength Capacity of Concrete is

$$V_c = 2 \times \sqrt{f'_c} \times b_w \times d$$

3- Minimum Web Reinforcement:-

If $V_u \leq \phi V_c$, then theoretically no web reinforcement is required. However ACI code require provision of atleast a minimum area of web reinforcement equal to,

$$\phi = 0.75 \longrightarrow \text{For shear design}$$

($\because V_u =$ Total factored shear applied at a given section)

\Rightarrow For Minimum Reinforcement Area:-

$$A_{u\min} = \frac{0.75 \times \sqrt{f'_c} \times b_w \times S}{f_y} \quad \text{or} \quad \frac{S_0 \times b_w \times S}{f_y} \rightarrow \left[\begin{array}{l} \text{Higher} \\ \text{value is} \\ \text{Selected} \end{array} \right]$$

By interchanging the above formulas, we can obtain the formula for maximum spacing.

$$S_{\max} = \frac{A_u \times f_y}{0.75 \times \sqrt{f'_c} \times b_w} \quad \text{or} \quad \frac{A_u \times f_y}{S_0 \times b_w} \rightarrow \left[\begin{array}{l} \text{Lesser value} \\ \text{is} \\ \text{Selected} \end{array} \right]$$

4- No web-reinforcement is required if

$$\underline{V_u < \frac{1}{2} \phi V_c}$$

⇒ Between critical section " V_u " and " ϕV_c ", spacing b/w web reinforcement can be found by,

$$S = \frac{\phi \times A_v \times f_y \times d}{V_u - \phi V_c}$$

5- If $V_s \leq 4 \times \sqrt{f'_c} \times b_w \times d$, then max spacing for stirrups will be the smallest of the following.

1- 24"

2- $d/2$

3- $S_{max} = \frac{A_v \times f_y}{0.75 \times \sqrt{f'_c} \times b_w}$

4- $S_{max} = \frac{A_v \times f_y}{50 \times b_w}$

∴ (V_s = Shear force carried by web reinforcement)

⇒ If $V_s > 4 \times \sqrt{f'_c} \times b_w \times d$



Max. Spacing will be halved

⇒ If $V_s > 8 \times \sqrt{f'_c} \times b_w \times d$



Then either increase cross-sectional dimensions or increase f'_c .

QUESTION - 02

A simply supported rectangular beam 14" wide having an effective depth of 22" to carry a lateral load of 6.5 k/ft on a 18' simple span. It is reinforced with 7 in² of tensile steel area, if $f'_c = 4$ ksi and $f_y = 60$ ksi, then design the beam for shear.

Given :-

Breadth of web of beam (b_w) = 14"

Effective depth (d) = 22"

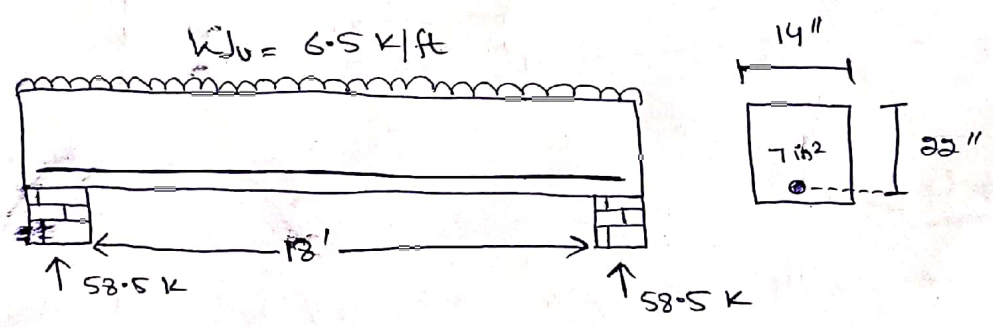
Given load = 6.5 k/ft

Steel Area = 7 in²

$f'_c = 4$ ksi

$f_y = 60$ ksi

Sol :-



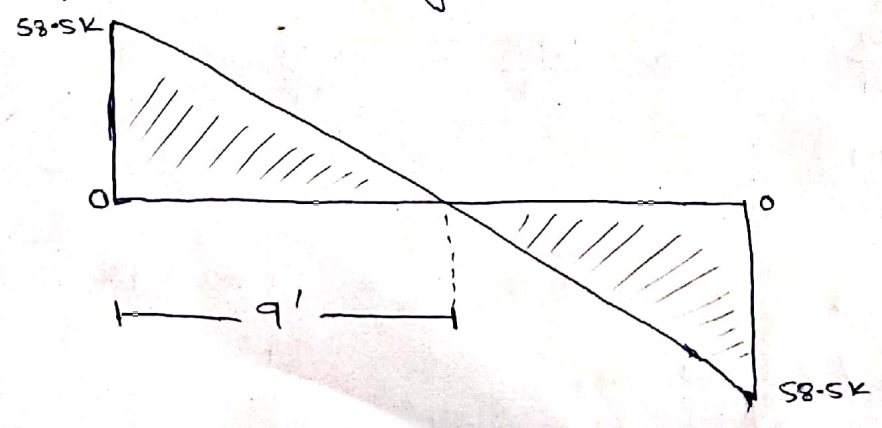
STEP #1 :- (Reactions on Supports)

Finding the reactions due to applied load.

$$\text{Total load} = \frac{6.5 \times 18}{2} = 58.5 \text{ kips}$$

STEP #2 :- (Shear Force Diagram)

The required shear diagram will be.



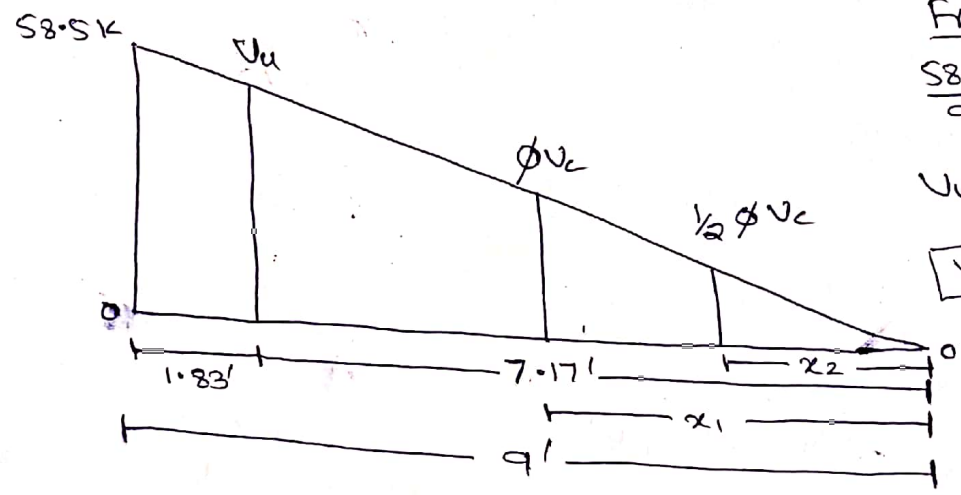
STEP # 3 :-

Finding the value of critical shear "Vu" and its location.

As,

we know that critical shear is located at distance "d" from face of support (d) = 22" = 1.83'

=> we will find the values of critical shear at distance "d" by use of similar triangles.



From Similar Triangles,

$$\frac{58.5}{9} = \frac{V_u}{8.17}$$

$$V_u = \frac{58.5 \times 8.17}{9}$$

$$V_u = 46.61 \text{ kips}$$

STEP # 4 :-

Finding the value of "phi Vc" and "1/2 phi Vc" and also its distances from zero shear to right side.

By formula,

$$\Rightarrow \phi V_c = \phi \times \rho \times \sqrt{f'_c} \times b_w \times d$$

$$= 0.75 \times \rho \times \sqrt{4000} \times 14 \times 22 = 29219 \text{ lbs} = 29.21 \text{ kips}$$

=> Location of phi Vc by similar triangles,

$$\frac{58.5}{9} = \frac{\phi V_c}{x_1} \Rightarrow \frac{58.5}{9} = \frac{29.21}{x_1}$$

$$\Rightarrow x_1 = 4.49'$$

=> Similarly,

$$\frac{1}{2} \phi V_c = \phi V_c / 2 \Rightarrow 29.21 / 2 = 14.60 \text{ kips}$$

=> Location of 1/2 phi Vc will be,

$$\frac{58.5}{9} = \frac{14.60}{x_2} \Rightarrow x_2 = 2.24'$$

STEP #5 :-

Finding the value of ϕV_s

By formula, $V_u = \phi V_s + \phi V_c$

$$\begin{aligned} \Rightarrow \phi V_s &= V_u - \phi V_c \\ &= 46.61 - 29.21 \end{aligned}$$

$$\boxed{\phi V_s = 17.4 \text{ kips}}$$

STEP #6 :-

Check on section adequacy,

By formula,

$$\begin{aligned} &= \phi \times 8 \times \sqrt{f'_c} \times b_w \times d \\ &= 0.75 \times 8 \times \sqrt{4000} \times 14 \times 22 = 116877 \text{ lbs} \\ &= 116.87 \text{ kips} \end{aligned}$$

$$\text{As } \phi \times 8 \times \sqrt{f'_c} \times b_w \times d > \phi V_s$$

So section is Adequate!

STEP #7 :-

Check on Maximum Spacing for stirrups,

By formula,

$$\begin{aligned} &= \phi \times 4 \times \sqrt{f'_c} \times b_w \times d \\ &= 0.75 \times 4 \times \sqrt{4000} \times 14 \times 22 = 58438 \text{ lbs} \\ &= 58.43 \text{ kips} \end{aligned}$$

$$\text{As } \phi \times 4 \times \sqrt{f'_c} \times b_w \times d > \phi V_s$$

So Maximum will be Selected from the following 4 conditions,

- 1- $S_{max} = 24''$
- 2- $d/2 = 22/2 = 11''$
- 3- $S_{max} = \frac{A_v \times f_y}{0.75 \times \sqrt{f'_c} \times b_w}$

Here we are using #3 stirrup,
 $d_{\text{dia}} = (3/8)'' = 0.375''$

$$\text{So Area} = \frac{\pi}{4} (0.375)^2 = 0.11 \text{ in}^2$$

For 2-legged stirrup

$$\begin{aligned} \Rightarrow \text{Area} \times 2 \\ \Rightarrow 0.11 \times 2 &= 0.22 \text{ in}^2 \end{aligned}$$

$$3 - S_{max} = \frac{0.22 \times 60000}{0.75 \times \sqrt{4000} \times 14} = 19.87''$$

$$4 - S_{max} = \frac{A_v \times f_y}{S_o \times b_w} = \frac{0.22 \times 60000}{S_o \times 14} = 18.85''$$

From above 4 conditions, Least value of Spacing for #3, 2 legged stirrup will be Selected as,

$$S_{max} = 11''$$

STEP # 8 :-

Stirrups spacing from/at critical section will be,

By formula,

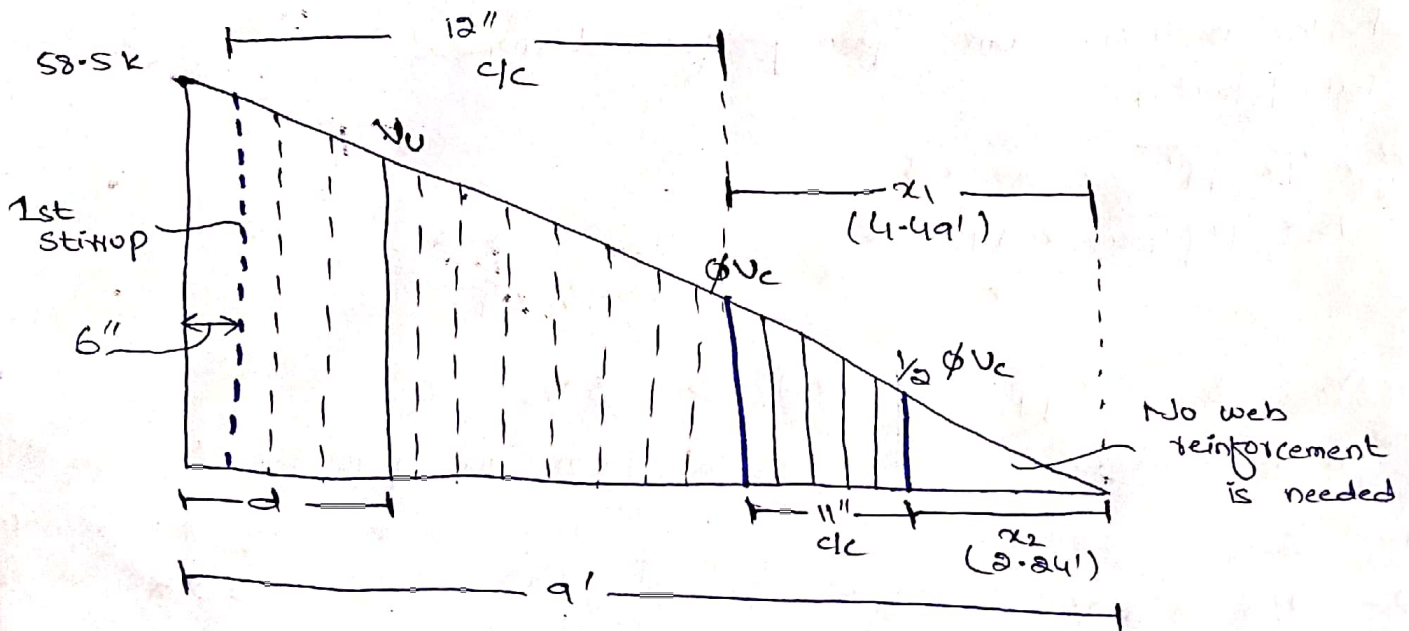
$$S = \frac{\phi \times A_v \times f_y \times d}{V_u - \phi V_c} = \frac{0.75 \times 0.22 \times 60000 \times 22}{46.61 - 29.91}$$

$$S = 12.5'' \approx 12''$$

So 12" c/c

STEP # 9 :-

Final sketch will be,



As First stirrup from face of support,

$$S/2 = 12/2 = 6''$$

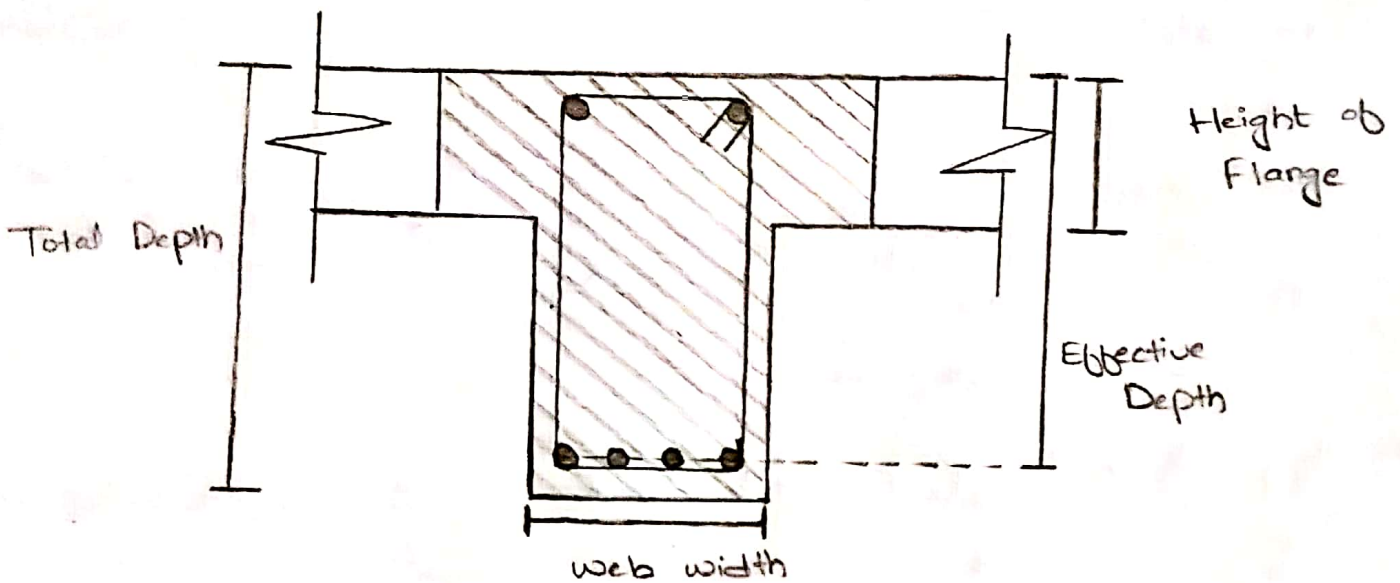
QUESTION-03

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Define both the T-Beam and L-Beam with the help of diagram. Also explain flexural analysis of T-Beam.

T-BEAM :-

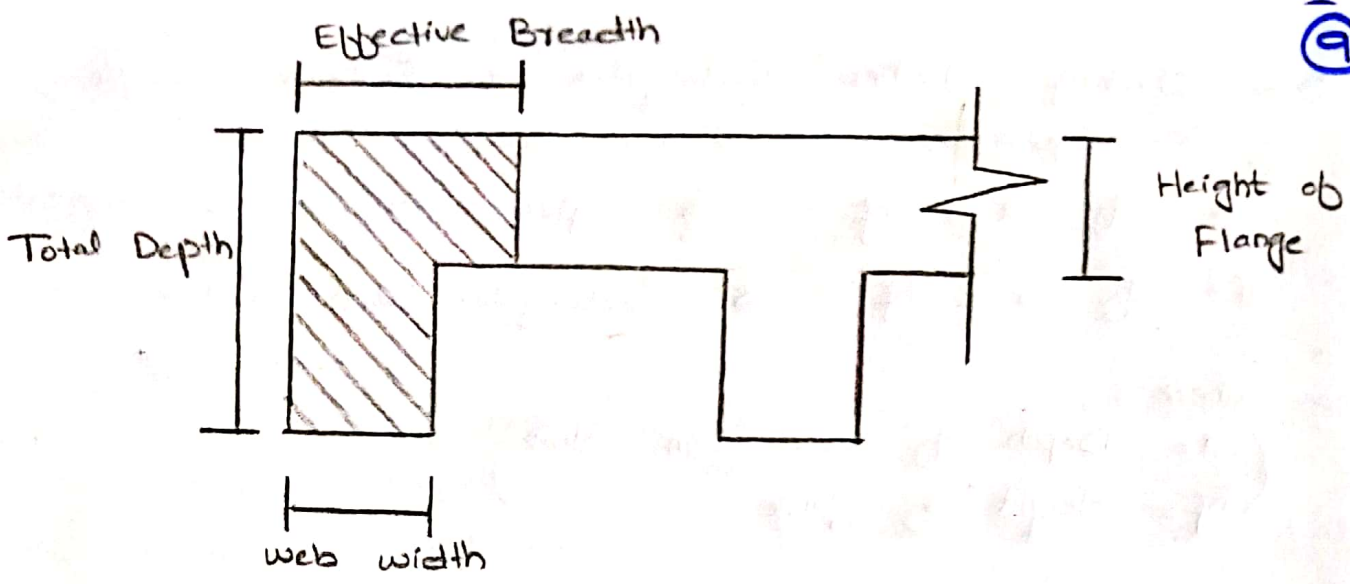
⇒ In most of the reinforced concrete structures, concrete slabs are cast monolithically with the slab so, in this case the beam that act as an intermediate beam are called T-Beams.



- ⇒ Because of their T-shape, these beams are called T-Beams.
- ⇒ It is provided at the center of the slab to resist the loads.
- ⇒ The upper most area of the the beam attached to the slab is called Flange.
- ⇒ The bottom rectangular portion of the beam is called web of the beam.

L-BEAM :-

⇒ L-shaped structure that is in contact with the slab and present at the corner of the floor is called L-Beam.



- => L-Beams are also called Edge Beams.
- => It is always provided at the corners of the slab.
- => L-Beams are typical floor beams because of their reduced overall structural depth, the beams are in Prestressed or reinforced concrete.

FLEXURAL ANALYSIS OF T-BEAM :-

Flexural Analysis of T-Beam consists of the following steps:-

- 1 - For Finding the Ultimate Factored moment, we use the following formula;

$$M_u = \frac{W_u \times L^2}{8}$$

(W_u = Total Factored Load)
(L = Total span of the beam)

- 2 - Effective width (b_{ef}) for T-Beam is calculated as :-
 - 1 - $16(h_f) + b_w$
 - 2 - c/c distance
 - 3 - $\text{span} / 4$
 - 4 - $\frac{CTS}{2} + b_w$

\therefore (h_f = height of flange)
(CTS = clear transverse span)

- We have to select the least value from above formulas
- If c/c distance is given, then there is no need of " $\frac{CTS}{2} + b_w$ "

3 - Checking whether Rectangular or T-Beam Analysis is required

- i - If $a > hf$ → special Analysis is required
- ii - If $a < hf$ → Rectangular beam Analysis is required

where

(a = Depth of Compression block)
 (hf = Height of flange)

4 - For Finding Area of steel, we have to use

$$A_{st} = \frac{M_u}{\phi \times f_y \times (d - a/2)}$$

where

$$a = \frac{A_{st} \times f_y}{0.85 \times f'_c \times b_w}$$

∴ ϕ = strength Reduction factor
 d = Effective depth
 a = Compression block depth
 b_w = web width of beam

5 - For checking the range of Reinforcement Ratio,

$$\rho_{max} = 0.85 \times \beta \times \frac{f'_c}{f_y} \times \left(\frac{E_u}{E_u + E_y} \right)$$

$$\rho_{min} = \frac{200}{f_y}$$

$$\rho = \frac{A_{st}}{b \times d}$$

6 - Formula for Finding No. of bars required is,

$$\text{No. of bars} = \frac{\text{Area of steel}}{\text{Area of single bar}}$$

7 - For checking Minimum width for bars accommodation,

$$b_{min} = 2(\text{clear cover}) + 2(\text{dia of stirrup}) + \text{No. of bars} \left(\frac{\text{dia of bar}}{\text{bar}} \right) + \text{Spacing} \left(\frac{\text{dia of bar}}{\text{bar}} \right)$$

8 - Design Moment is given by,

$$M_d = \phi \times f_y \times A_{st} \times (d - a/2) \rightarrow \text{if } a < hf$$

$$M_d = \phi \times [A_s \times f_y \times (d - hf/2) + (A_s - A_{st}) \times f_y \times (d - a/2)] \rightarrow \text{if } a > hf$$

QUESTION - 04

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What is the difference b/w. CASE-1 and CASE-2 in the design of T-Beam?

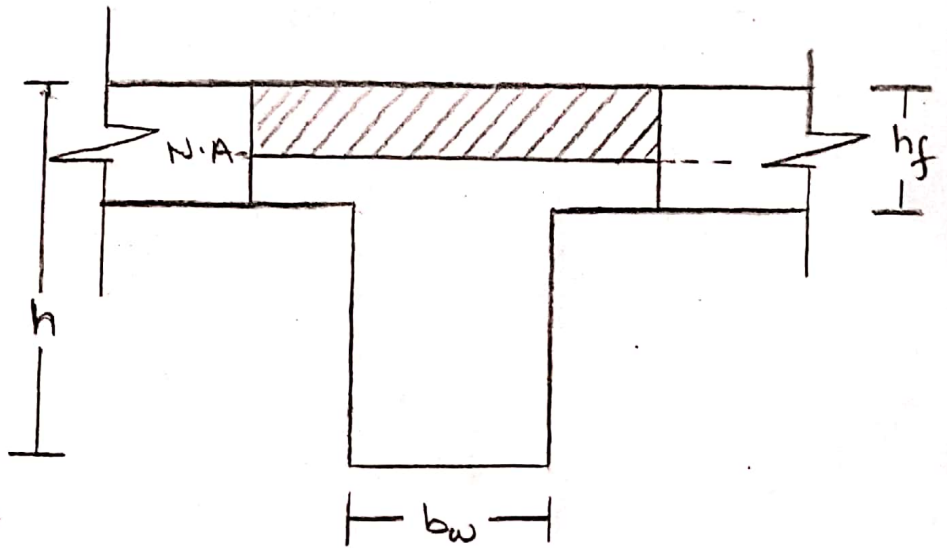
CASE - I :-

From the figure

$$a < h_f$$

So in this case,
Rectangular Beam
Analysis is Required.

So,
The Design Moment
formula will be



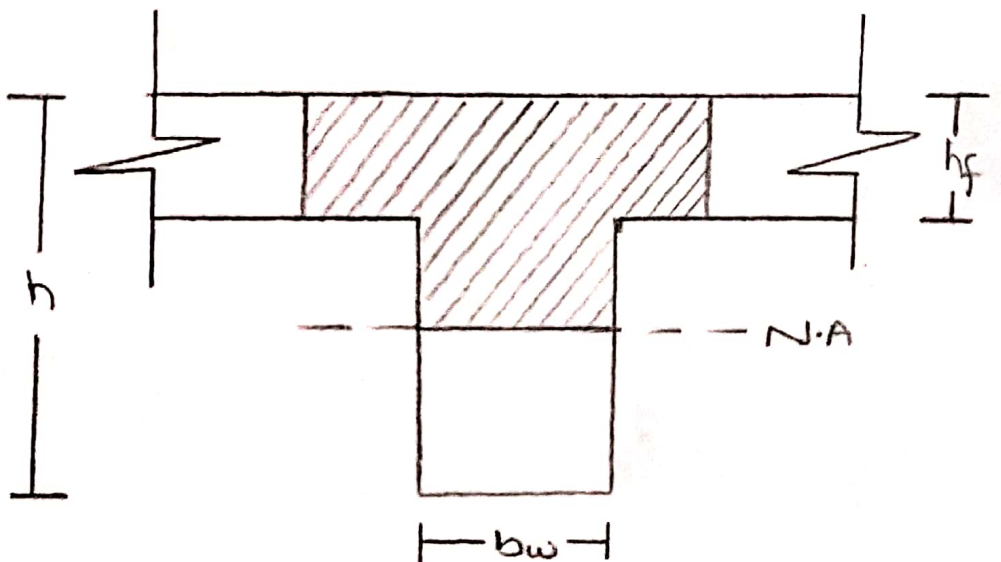
$$M_d = \phi \times f_y \times A_{st} \times (d - a/2)$$

CASE - II :-

From the figure,

$$a > h_f$$

So in this, Special
beam analysis i.e.,
T-Beam Analysis
is required.



So
the required Design Moment
will be,

$$M_d = \phi \times \left[A_s \times f_y \times (d - \frac{h_f}{2}) + (A_s - A_{st}) \times f_y \times (d - a/2) \right]$$

QUESTION - 05

A floor system consists of 3.5" concrete slab supported by 16' simple span spaced at 9' c/c, the beam having a web width of 10" and effective depth of 18" and total height is 23". Calculate the necessary flexural reinforcement if the factored applied moment is 5800 kip-inch. Use $f'_c = 3$ ksi and $f_y = 60$ ksi

Given :-

Height of flange (h_f) = 3.5"

c/c distance = 9'

Length / span of the beam = 16'

web width (b_w) = 10"

Effective depth (d) = 18"

Height (h) = 23"

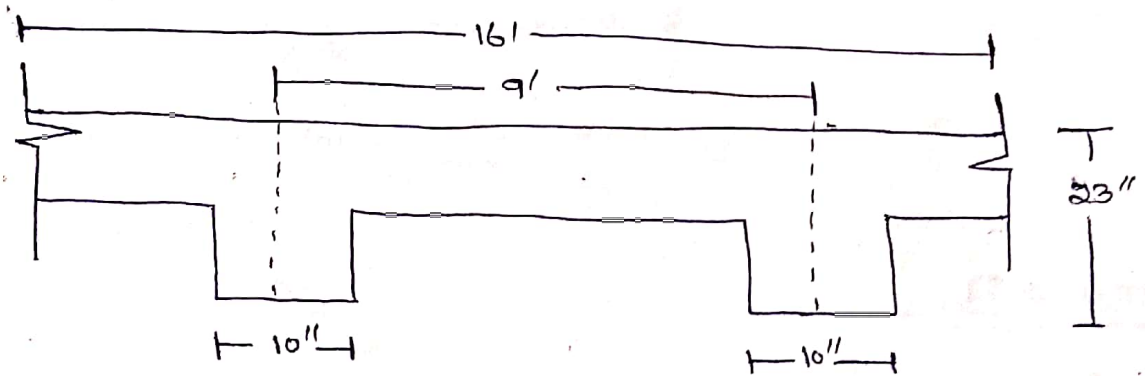
Total factored moment (M_u) = 5800 kip-inch

$f'_c = 3$ ksi

$f_y = 60$ ksi

Sol :-

$h_f = 3.5"$



STEP #1 :-

Calculate the effective width (b_e) for T-beam.

$$1 - 16(h_f) + b_w = 16(3.5) + 10 = 66"$$

$$2 - \text{c/c distance} = 9 \times 12 = 108"$$

$$3 - \text{Span}/4 = \frac{16}{4} \times 12 = 48"$$

Selecting the least value of b_e as,

$$b_e = 48"$$

STEP #2:-

check whether Rectangular or T-beam Analysis is required.

Trial # 01 :- Let $a = hf = 3.5''$

$$A_{st} = \frac{M_u}{\phi \times f_y \times (d - a/2)} = \frac{5800}{0.90 \times 60 \times (18 - 3.5/2)} = 6.61 \text{ in}^2$$

Trial # 02 :-

$$a = \frac{A_{st} \times f_y}{0.85 \times f'_c \times b_e}$$

$$a = \frac{6.61 \times 60}{0.85 \times 3 \times 48} = 3.2''$$

$$\Rightarrow 3.2'' < 3.5''$$

and $A_{st} = 6.55 \text{ in}^2$

So Rectangular Beam Design is Required!

Trial # 03 :-

$$a = 3.21''$$

$$\text{and } A_{st} = \frac{5800}{0.90 \times 60 \left(18 - \frac{3.21}{2}\right)} = 6.55 \text{ in}^2$$

So Area of steel is 6.55 in².

STEP #3:-

check f_{max} and f_{min} .

$$\begin{aligned} \Rightarrow f_{max} &= 0.85 \times \beta \times \frac{f'_c}{f_y} \left(\frac{\epsilon_u}{\epsilon_u + \epsilon_t} \right) \\ &= 0.85 \times 0.85 \times \frac{3}{60} \left(\frac{0.003}{0.003 + 0.005} \right) = 0.013 \end{aligned}$$

$$\Rightarrow f_{min} = \frac{200}{f_y} = \frac{200}{60000} = 0.003$$

$$\Rightarrow f = \frac{A_{st}}{b \times d} = \frac{6.55}{10 \times 18} = 0.036$$

$$f_{min} < f < f_{max}$$

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$$0.003 < 0.036 < 0.013$$



As the value of f_{max} is less than f , so we have to design it as "Doubly Reinforced Beam."

⇒ First we have to find the Area of steel against f_{max} .

$$f_{max} = \frac{A_{st}}{b \times d} \Rightarrow A_{st} = f_{max} \times (b \times d)$$

$$A_{st} = 0.013 \times (10 \times 18)$$

$$A_{st} = 2.34 \text{ in}^2$$

STEP # 4 :-

Finding the value of M_{u2} :-

By formula,

$$M_{u2} = \phi \times A_{st} \times f_y \times (d - a/2)$$

First Finding the value of "a"

$$\Rightarrow a = \frac{A_{st} \times f_y}{0.85 \times f'_c \times b} = \frac{2.43 \times 60}{0.85 \times 3 \times 10}$$

$$a = 5.72''$$

$$\Rightarrow M_{u2} = 0.90 \times 2.43 \times 60 \times (18 - 5.72/2)$$

$$M_{u2} = 1986.67 \text{ kip-inch}$$

$$\begin{array}{l} \text{As } M_{u2} < M_u \\ 1986.67 < 5800 \end{array}$$

So we have to design the beam in such way that it can resist more bending moment than the applied external moment.

STEP # 5 :-

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Finding Difference in moments and Area of steel.

$$\begin{aligned} M_{U1} &= M_{U0} - M_{U2} \\ &= 5800 - 1986.67 \end{aligned}$$

$$M_{U1} = 3813.33 \text{ kip-inch}$$

By formula,

$$A'_s = \frac{M_{U1}}{\phi \times f_y \times (d-d')} = \frac{3813.33}{0.90 \times 60 \times (18-2.5)}$$

$$A'_s = 4.56 \text{ in}^2$$

STEP # 6 :-

Finding Total Steel Area.

$$\begin{aligned} A_s &= A_{st} + A'_s \\ &= 2.43 + 4.56 = 6.99 \text{ in}^2 \end{aligned}$$

STEP # 7 :-

Selection of Bar :-

In Tension Zone :-

Let we use # 8 bar

$$\text{dia} = (8/8) = 1'' \quad , \quad \text{Area} = \frac{\pi}{4} (1)^2 = 0.785 \text{ in}^2$$

By formula

$$\text{No. of bars} = \frac{\text{Area of steel}}{\text{Area of single bar}} = \frac{6.99}{0.785} = 8.9 \approx 9$$

So 9 # 8 bars

In Compression Zone :-

Let we use # 7 bar

$$\text{dia} = (7/8)'' \quad , \quad \text{Area} = \frac{\pi}{4} (7/8)^2 = 0.601 \text{ in}^2$$

By formula,

$$\text{No. of bars} = \frac{\text{Area of steel}}{\text{Area of single bar}} = \frac{4.56}{0.601} = 7.5 \approx 8$$

So 8 # 7 bars

STEP # 8 :-

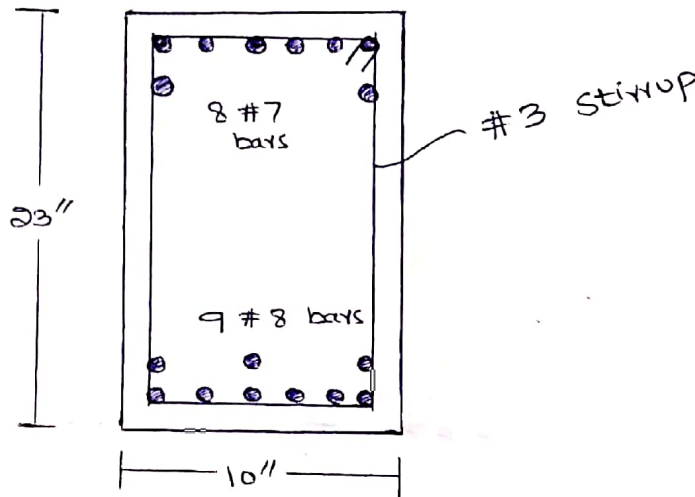
Minimum width for Accomodation of bars.

$$b_{min} = (2 \times 1.5) + (2 \times 3/8) + 9(8/8) + 8(8/8)$$

$$= 20.75''$$

As 20.75'' > 10''

So, the bars will be placed in multiple layers.



$$\text{Effective depth } (d) = 23 - 1.5 + \frac{3}{8} + \frac{8}{8} + \frac{1}{2}(\frac{8}{8}) = 19.6''$$

$$\text{Effective cover } (d') = 1.5 + \frac{3}{8} + \frac{7}{8} + \frac{1}{2}(\frac{7}{8}) = 3.18''$$

STEP # 9 :-

Finding the Design Moment.

$$M_d = \phi [A_s \times f_y \times (d - d') + (A_s - A_{s'}) \times f_y \times (d - a/2)]$$

$$\text{First } a = \frac{(A_s - A_{s'}) \times f_y}{0.85 \times f'_c \times b} = \frac{(9 \times 0.785 - 8 \times 0.601) \times 60}{0.85 \times 3 \times 10} = 5.31''$$

$$\Rightarrow M_d = 0.90 \left[(8 \times 0.601) \times 60 \times (19.6 - 3.18) + (9 \times 0.785 - 8 \times 0.601) \times 60 \times (19.6 - \frac{5.31}{2}) \right]$$

$$M_d = 6328.38$$

As 6328.38 > 5800 → So design is OK!

QUESTION - 06

A beam is revised to developed and ultimate moment of 6000 kip-inches limited to 14 x 26 inch size, use $f'_c = 4$ ksi and $f_y = 60$ ksi. Determine flexural reinforcement assume two rows of tensile reinforcement and effective depth of beam is 22 inches.

Sol:-

Given :-

Breadth (b) = 14"

Height (h) = 26"

Concrete Compression strength (f'_c) = 4 ksi

Steel Tensile strength (f_y) = 60 ksi

Ultimate Factored Moment (M_u) = 6000 kip-inches

Effective depth of beam (d) = 22"

Assume Effective cover (d') = 2.5"

STEP #1 (Reinforcement Ratio)

By formula,

$$\rho_{max} = 0.85 \times \beta \times \frac{f'_c}{f_y} \times \left(\frac{\epsilon_u}{\epsilon_u + \epsilon_y} \right)$$

$$= 0.85 \times 0.85 \times \frac{4}{60} \times \left(\frac{0.003}{0.003 + 0.005} \right)$$

$\rho_{max} = 0.0180$

STEP #2 i- (Area of Steel)

As we know that,

$$\rho_{max} = \frac{A_{st}}{b \times d} \Rightarrow A_{st} = \rho_{max} \times (b \times d)$$

$$\Rightarrow A_{st} = 0.0180 \times (14 \times 22) = 5.54 \text{ in}^2$$

STEP #3 :- (Design Moment) :-

By Using formula

$$M_{u2} = \phi \times A_{st} \times f_y \times (d - a/2)$$

$$\Rightarrow a = \frac{A_{st} \times f_y}{0.85 \times f'_c \times b} = \frac{5.54 \times 60}{0.85 \times 4 \times 14} = \boxed{6.98''}$$

So,

$$M_{u2} = 0.90 \times 5.54 \times 60 \times (22 - \frac{6.98}{2}) = 5537.4 \text{ kip-inch}$$

As,

$$5537.4 < 6000$$

So we have to design a section as doubly reinforced.

STEP # 4 :- (Difference In Moments)

$$M_{u1} = M_u - M_{u2} = 6000 - 5537.4$$

$$M_{u1} = \boxed{462.6 \text{ kip-inches}}$$

STEP # 5 :- (Area of Steel)

$$M_{u1} = \phi \times A'_{st} \times f_y \times (d - d')$$

So Area of steel in compression zone will be,

$$\Rightarrow A'_{st} = \frac{M_{u1}}{\phi \times f_y \times (d - d')} = \frac{462.6}{0.90 \times 60 \times (22 - 2.5)}$$

$$\Rightarrow \boxed{A'_{st} = 0.44 \text{ in}^2}$$

STEP # 6 :- (TOTAL Steel Area)

$$A_s = A_{st} + A'_{st}$$

$$= 5.54 + 0.44 = 5.98 \text{ in}^2$$

STEP # 7 :- (Selection of No. of bars used)

1 - Steel in Tension Zone :-

we use # 7 bar ,

$$\text{dia} = (7/8)'' = 0.875'' \quad , \quad \text{Area} = \frac{\pi}{4} (0.875)^2$$

$$= 0.601 \text{ in}^2$$

So,

$$\text{No. of bars} = \frac{A_s}{\text{Area of single bar}}$$

$$= \frac{5.98}{0.601} = 9.9 \approx 10 \text{ bars}$$

So 10 #7 bars .

2 - Steel in Compression Zone :-

we use # 5 bar ,

$$\text{dia} = (5/8)'' = 0.625'' \quad , \quad \text{Area} = \frac{\pi}{4} (0.625)^2$$

$$= 0.306 \text{ in}^2$$

So,

$$\text{No. of bars} = \frac{A'_{st}}{\text{Area of single bar}}$$

$$= \frac{0.44}{0.306} = 1.43 \approx 2 \text{ bars}$$

So 2 #5 bars

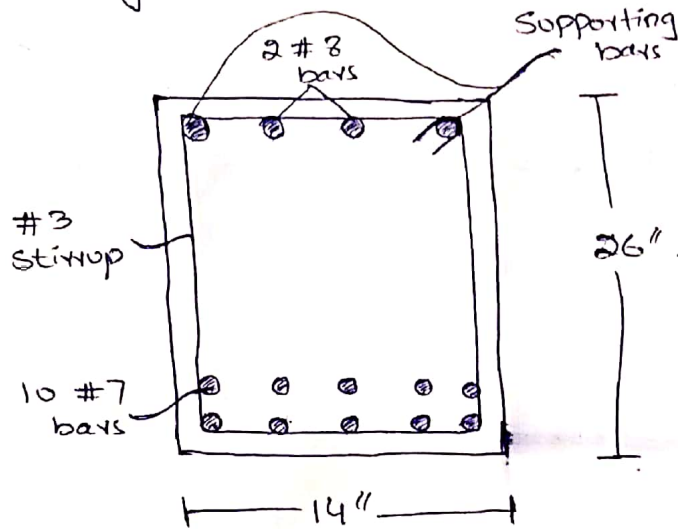
STEP # 8 :- (Minimum Width of Beam)

20

$$b_{min} = 2(1.5) + 2(3/8) + 10(7/8) + 9(7/8)$$

$$b_{min} = 20.37 > 14''$$

So not good in one layer.



Now,

$$\Rightarrow \text{Effective depth } (d) = 26 - 1.5 - 3/8 - 7/8 - 1/2(7/8) \\ = 22.82''$$

$$\Rightarrow \text{Effective Cover } (d') = 1.5 + 3/8 + 1/2(5/8) \\ = 2.18''$$

STEP # 9 :- (Design Moment)

$$M_d = \phi \times [A_{st}' \times f_y \times (d - d') + (A_{st} - A_{st}') \times f_y \times (d - a/2)]$$

$$a = \frac{(A_{st} - A_{st}') \times f_y}{0.85 \times f_c \times b}$$

$$= \frac{(10 \times 0.601 - 2 \times 0.306) \times 60}{0.85 \times 4 \times 14} = 6.80''$$

$$M_d = 0.90 \left[(2 \times 0.306) \times 60 \times (22.82 - 2.18) + (10 \times 0.601 - 2 \times 0.306) \times 60 \times (22.82 - 6.80/2) \right]$$

$$M_d = 7047.6 \text{ kip-inches}$$

$$As \quad 7047.6 > 6000$$

Design is OK!