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QUESTION - 01

Explain in detail types of stirrups with figure and also explain ACI codes for shear design.

Ans:-

STIRRUP:-

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

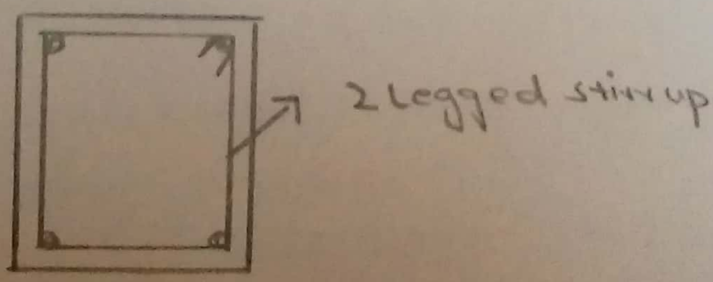
TYPES OF STIRRUPS:-

1- Single Legged stirrup:-

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

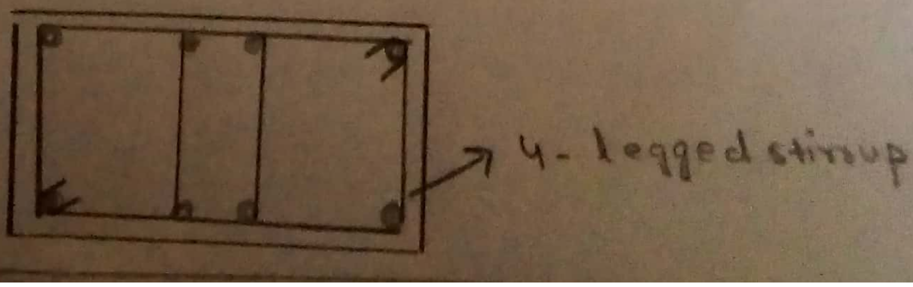
2- Two Legged stirrup:-

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

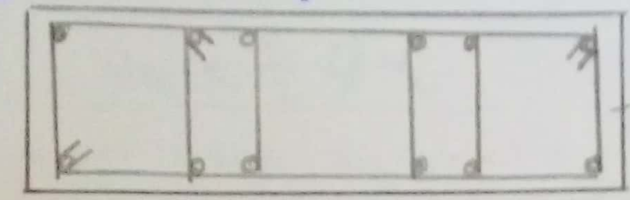


3- Four legged stirrup:-

These stirrups are used of web reinforcement.



4- **Six legged stirrup:-**



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**

$$V_c = 2 \times \sqrt{f'c} \times bw \times d$$

3- **Minimum Web Reinforcement:**

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

$\phi = 0.75$ ⟶ For shear design

(∵ V_u = Total factored shear applied at a given section)

⇒ For minimum Reinforcement Area:-

$$A_{v\,min} = \frac{0.75 \times \sqrt{f'c} \times bw \times s}{f_y} \text{ or } \frac{50 \times bw \times s}{f_y}$$ → [Higher value is selected]

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

$$S_{max} = \frac{A_v \times f_y}{0.75 \times \sqrt{f'c} \times bw} \text{ OR } \frac{A_v \times f_y}{50 \times bw}$$ → [Lesser value is selected]

4- No web-reinforcement is require if

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

=> Between critical section "V_u" and "ϕV_c", spacing b/w web reinforcement can be find 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 stirrup 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.

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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 reinforcement with 7 in² of tensile steel area, If f'c = 4 ksi and fy = 60 ksi, the design the beam for shear.

GIVEN:

Breadth of web of beam (bw) = 14"

Effective depth (d) = 22"

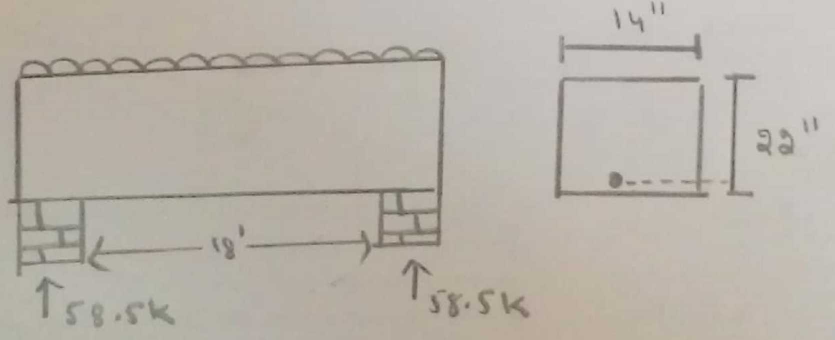
Given load = 6.5 k/ft

Steel area = 7 in²

$F_c' = 4ksi$

$F_y = 60 ksi$

SOLUTION:



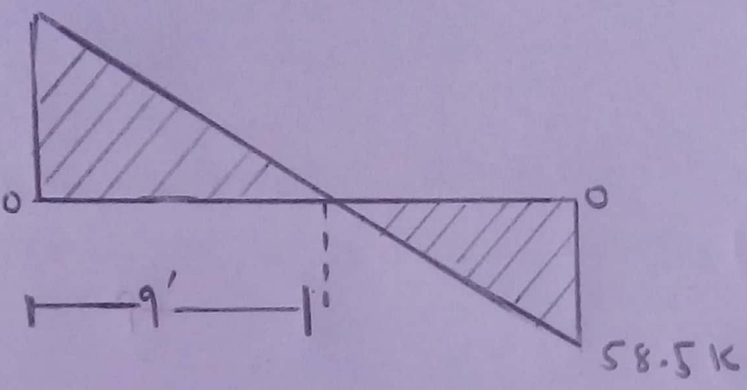
STEP # 1 (Reaction on supports)

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 force diagram will be 58.5k.

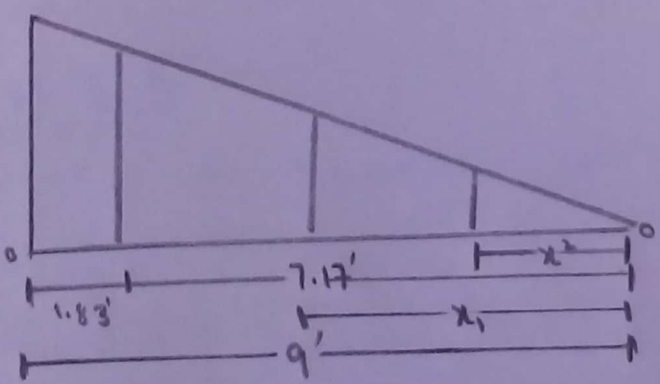


STEP # 3:

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

As we known 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 triangle

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

$$V_u = \frac{58.5 \times 7.17}{9}$$

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

STEP # 4:

Finding the value of "ϕV_c" and "$\frac{1}{2}\phi V_c$" and also its distances from zero shear to right side.

By formula,

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

$$= 0.75 \times 2\sqrt{4600} \times 14 \times 22 = 29219 \text{ kips}$$

$$= 29.21 \text{ kips}$$

⟹ Location of ϕV_c by similar triangles

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

$\Rightarrow$ $x_1 = 4.49'$

$\Rightarrow$ Similarly,

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

$\Rightarrow$ Location of $\frac{1}{2}\phi V_c$ will be,

$$\frac{58.5}{9} = \frac{14.60}{x_2}$$

$\Rightarrow$ $x_2 = 2.24'$

STEP # 5:

Finding the value of ϕV_c

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

$\Rightarrow \phi V_s = V_u - \phi V_c$

$= 46.61 - 29.21$

$\phi V_s = 17.4$ kips

STEP # 6:

Check on section adequacy,

By formula,

$= \phi \times 8 \times \sqrt{f'c} \times bw \times d$

$= 0.75 \times 8 \times \sqrt{4000} \times 14 \times 22 = 116877$ lbs

$= 116.877$ kips

As $\phi \times 8 \times \sqrt{f'c} \times bw \times d > \phi V_s$

So section is Adequate!

STEP # 7:

Check on maximum spacing for stirrups

By formula,

$= \phi \times 4 \times \sqrt{f'c} \times bw \times d$

$= 0.75 \times 4 \times \sqrt{4000} \times 14 \times 22 = 58438$ lbs

$= 58.43$ kips

As

$\phi \times 4 \times \sqrt{f'c} \times bw \times d > \phi Vs$

so maximum will be selected from the following 4 conditions.

1 - $S_{max} = 24''$

2 - $d/2 = 22/2 = 11''$

3 - $S_{max} = \dfrac{Av \times fy}{0.75 \times \sqrt{f'c} \times bw}$

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

4 - $S_{max} = \dfrac{Av \times fy}{50 \times bw} = \dfrac{0.22 \times 60000}{50 \times 14}$

$= 18.85''$

Here we are using #3 stirrup, dia = $(3/8)'' = 0.375''$

So

Area $= \dfrac{\pi}{4}(0.375)^2 = 0.11 in^2$

For 2-legged stirrup

=> Area x 2

=> $0.11 \times 2 = 0.22 in^2$

From above 4 conditions, least value of spacing for #3, 2 legged stirrup will be selected as,

$S_{max} = 11''$

STEP # 8:

stirrup spacing from/at critical section will be,

By formula,

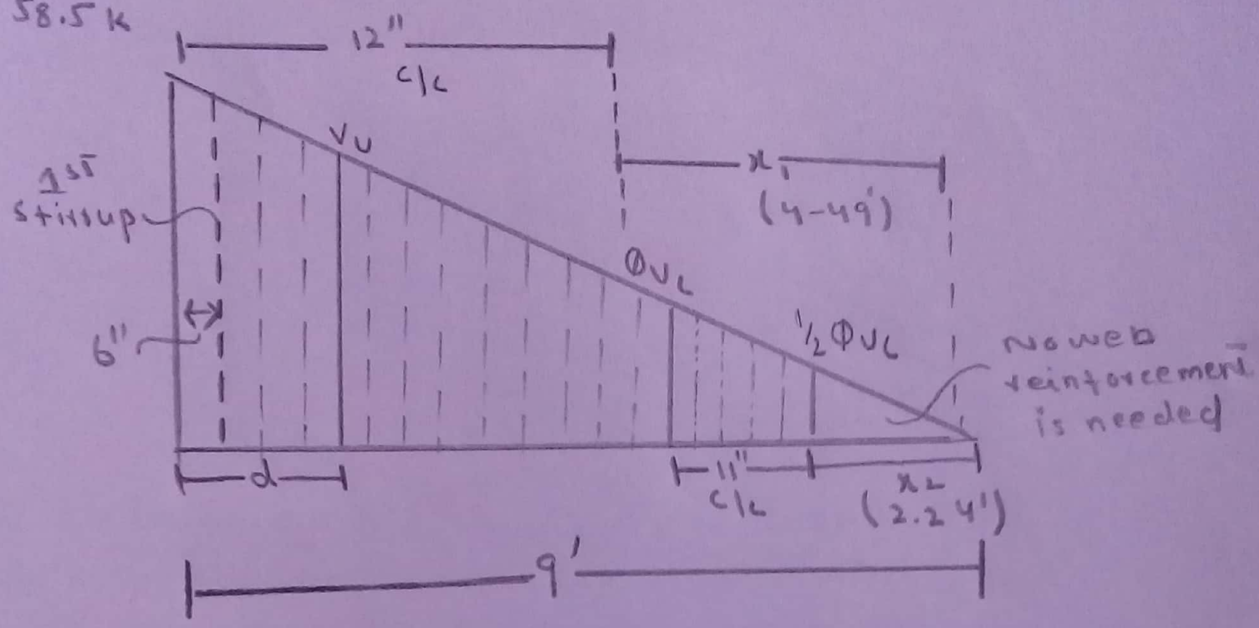
$S = \dfrac{\phi \times Av \times fy \times d}{Vu - \phi Vc} = \dfrac{0.75 \times 0.22 \times 60 \times 22}{46.61 - 29.21}$

$S = 12.5'' \cong 12''$

So $12''$ c/c

STEP # 9:

Final sketch will be,



As

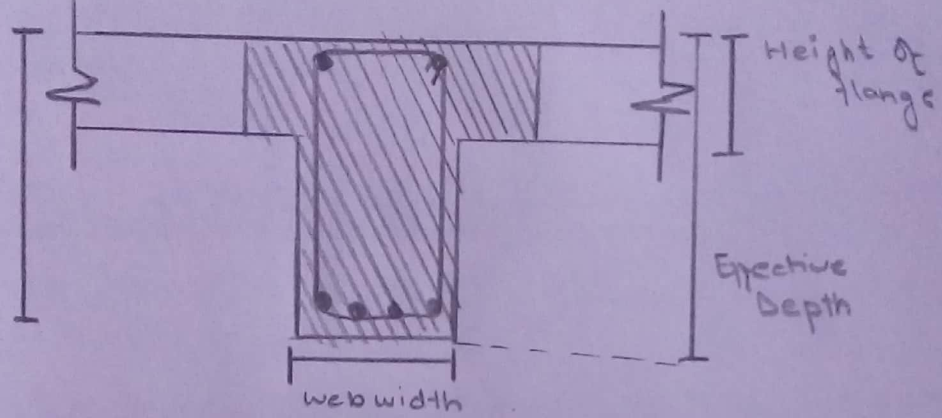
First stirrup from face to support,

$s/2 = 12/2 = 6''$

QUESTION - 03

Define both the T-beam and L-beam with the help of diagrom. Aslo enplain felxural analysis of T-beam.

T-Beam:



=> In most of the required concrete structures, concrete slabs are cost monolitically 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.

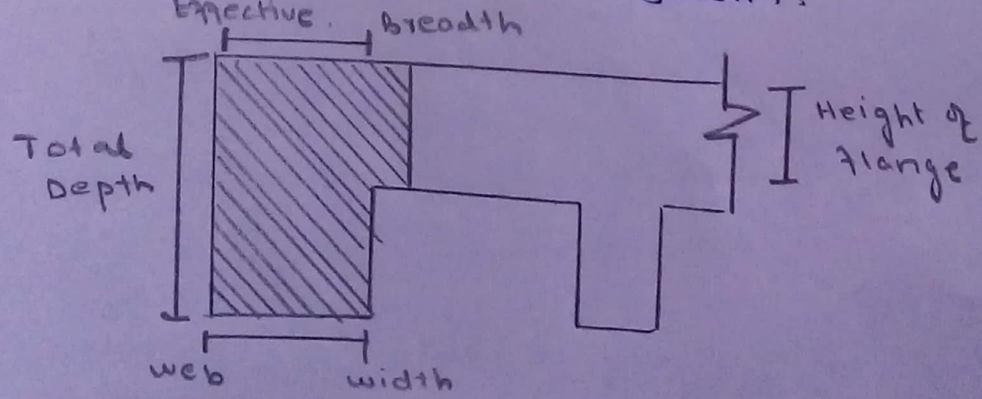
=> It is provided at the center of the slab to resist the loads.

=> The upper most area of the beam attached to the slab is called flange.

=> The button 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 slabs.
=> L-Beams are typical flour beams because of their reduced overall structural depth, the beams are in presstressed or require concrete.

FLEXURAL ANALYSIS OF T-BEAMS

Flexural analysis of T-beam consists of the following steps.

1- For finding the ultimate factured moment, we use the flowing formula,

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

∴ W_u = Total factured load
L = Total span of the beam.

2- Effective width (b_e) for T-Beam is calculated as:

1 - $16(h_f) + b_w$
2 - c/c distance
3 - span/4
4 - $\frac{CT_s}{2} + b_w$

∴ h_f = height of flange
CT_s = Clear transverse span

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

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

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

Where
a = Depth of compression block
h_f = Height of flange

4 - For finding Area of the 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,

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

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

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

6 - Formula for finding No. of bars require is,

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

7 - For checking minimum width for bars accomodation,

$$b_{min} = 2(\text{clear cover}) + 2\left(\text{dia of Stirrup}\right) + \text{No. of bars}\left(\text{dia of bar}\right) + \text{spacing b/w bars}\left(\text{dia of bars}\right)$$

8 - Design moment is given by,

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

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

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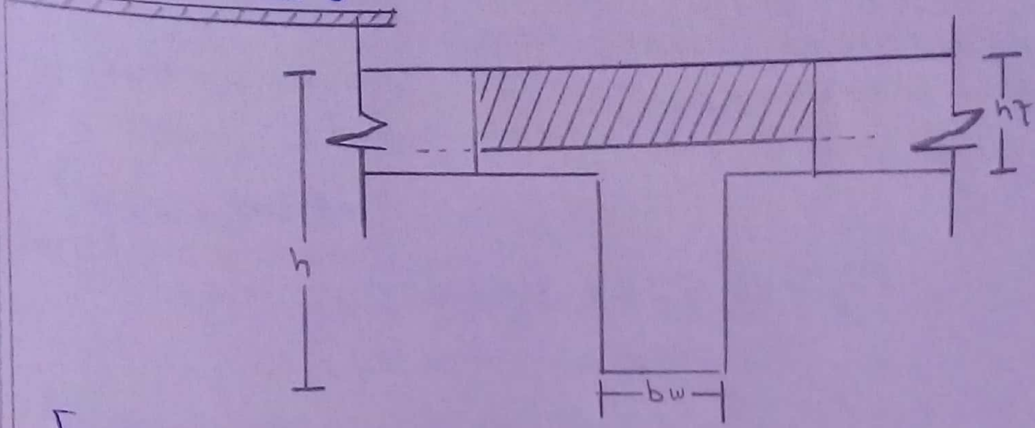
QUESTION - 04

What is difference between CASE-I and CASE-2 the design of Beam?

CASE-I :



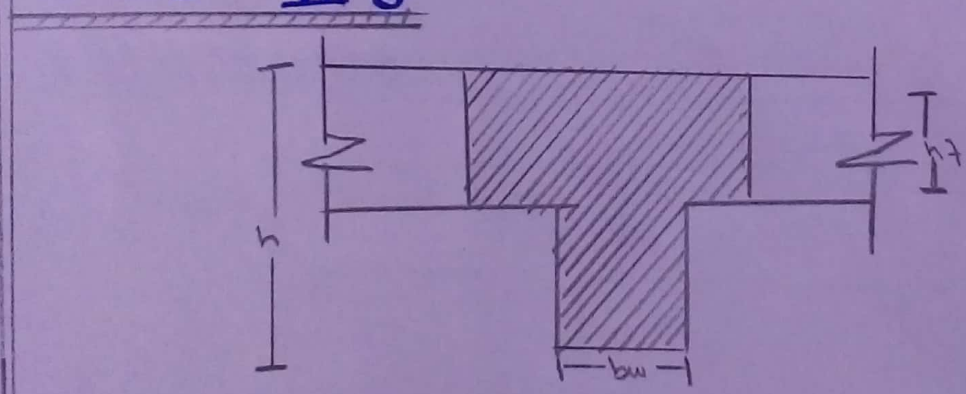
From the figure.

$$a < h_f$$

So in this case, Rectangular Beam Anaylysis 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 Analysic is required
So,
the required Design moment will be,

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

QUESTION - 05

A flour 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 factured applied moment is 5800 kip-inch. use $f'c = 3ksi$ and $fy = 60ksi$

GIVEN:-

Height of flange $(hf) = 3.5"$

c/c distance $= 9'$

Length /span of the beam $= 16'$

web width $(bw) = 10"$

Effective depth $(d) = 18"$

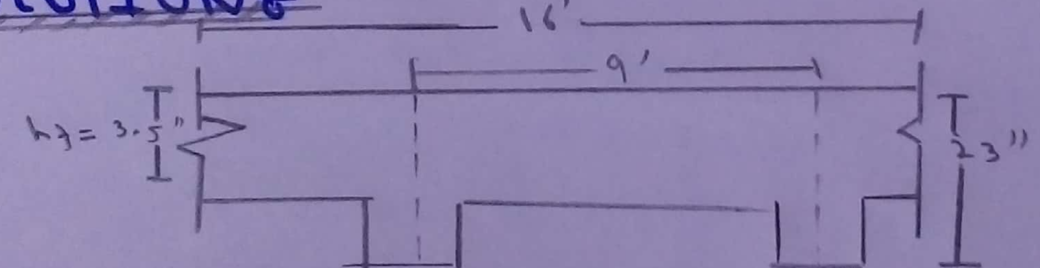
Height $(h) = 23"$

Total factored moment $(Mu) = 5800$ kipinch.

$f'c = 3ksi$

$fy = 60ksi$

SOLUTION:-



STEP # 1:-

Calculate the effective width (bc) for T-beam

1 - $16(hf)+bw = 16(3.5)+10 = 66"$

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

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

selecting the least value of be as,

$$bc = 48"$$

STEP # 2 :

Check whether Rectangular or T-beam Analysis is required

Trial # 01 :

Let $a = h_f = 3.5''$

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

Trial # 02 :-

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

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

and $A_{st} = 6.55\,in^2$ ⟹ $3.2'' < 3.5''$

So rectangular Beam Design is Required

Trial # 03 :

$a = 3.21''$

and $A_{st} = \dfrac{5800}{0.90 \times 60 \left(18 - \frac{3.2}{2}\right)} = 6.55\,in^2$

So area of steel is $6.55\,in^2$.

STEP # 03 :

Check ρ_{max} and ρ_{min}.

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

$$= 0.85 \times 0.85 \times \frac{3}{60} \left(\frac{0.003}{0.003 + 0.005}\right) = 0.013$$

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

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

$$\rho_{min} < \rho < \rho_{max}$$

$$0.003 < 0.036 < 0.013$$

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

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

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

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

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

STEP # 04 :

Finding the value of Mu_2 :-

By formula

$$Mu_2 = \phi \times A_{st} \times f_y \times (d - a/2)$$

First finding the value of "a"

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

$$a = 5.72''$$

$$\Rightarrow Mu_2 = 0.90 \times 2.43 \times 60 \times (18.5.72/2)$$

$$\boxed{Mu_2 = 1986.67 \text{ kip-inch}}$$

As $Mu_2 < Mu$

$$1986.67 < 5800$$

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

STEP # 05 :-

Finding Difference in moments and Area of steel.

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

$= 5800 - 1986.67$

$M_{u1} = 3813.33$ kip-inch

By formula,

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

$A'st = 4.56 in^2$

STEP # 06 :-

Finding total steel Area.

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

$= 2.43 + 4.56 = 6.99 in^2$

STEP # 07 :-

Selection of Bars :-

In tension zone :-

let we use # 8 bars

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

By formula

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 bars.

dia = (7/8)", Area = $\frac{\pi}{4}(7/8)^2$ = 0.601 in²

By formula,

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

So 8 # 7 bars.

Step # 8:

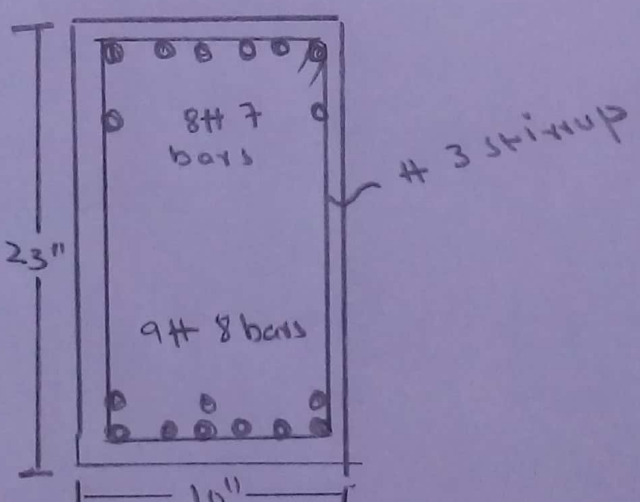
Minimum width for accomodation of bars.

bmin = (2×1.5) + (2×3/8) + 9(8/8) + 8(8/8)

= 20.75"

As 20.75" > 10"

So, the bars will be placed in multiple layyers.



Effective depth (d) = $23 - 1.5 + \frac{3}{8} + \frac{3}{8} + \frac{1}{2}\left(\frac{8}{8}\right)$

= 19.6"

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

3.18"

Step # 9:

Finding the Design moment

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

First $a = \frac{(A_s - A'_{st}) \times f_y}{0.85 \times f'_c \times b} = \frac{(9 \times 0.785 - 8 \times 0.601) \times 60}{0.85 \times 3 \times 10}$

$= 5.31''$

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

$M_d = 6328.38$

As $6328.38 > 5800 \rightarrow$ so design is ok!

QUESTION - 06

A beam is revised to developed and ultimate moment of 6000 kip-inchs limited to 14x26 inch size, use f'_c = 4ksi and f_y = 60ksi. Determine flexural reinforcement assume two rows of tensile reinforcement and effective depth of beam is 22 inches.

GIVEN:

Breadth (b) = 14"

Height (h) = 26"

concrete compression strength (f'_c) = 4ksi

Steel tensile Strength (f_y) = 60ksi

ultimate factored Moment (M_u) = 6000 kip-inches.

Effective depth of beam (d) = 22"

Assume effective cover (d') = 2.5"

SOLUTION:

STEP # 01: (Reinforcement Ratio)

By formula

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

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

STEP # 02 (Area of steel)

As we know that,

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

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

STEP # 3 : (Design Moment)

By using formula

$Mu_2 = \phi \times Ast \times fy \times (d - a/2)$

$\Rightarrow a = \frac{Ast \times fy}{0.85 \times f'c \times b} = \frac{5.54 \times 60}{0.85 \times 4 \times 14} = \boxed{6.98''}$

So,

$Mu_2 = 0.90 \times 5.54 \times 60 \times (22 - \frac{6.98}{2})$

$= 5537.4$ kip-inch

As

$5537.4 < 6000$

So we have to design a section as doubly reinforced.

STEP # 4 (Difference In Moment)

$Mu_1 = Mu - Mu_2$

$= 6000 - 5537.4$

$\boxed{Mu_1 = 462.6 \text{ kip-inches}}$

STEP # 5 (Area of Steel)

$Mu_1 = \phi \times A'st \times Fy \times (d - d')$

So Area of steel in compression zone will be,

$\Rightarrow A'st = \frac{Mu_1}{\phi \times fy \times (d - d')} = \frac{462.6}{0.90 \times 60 \times (22 - 2.5)}$

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

STEP # 06 (Total steel Area)

$As = Ast + A'st$

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

STEP # 07 (Section & No. of bars used)

1- Steel in tension zone:-

we use # 7 bars.

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

$= 0.601 in^2$

So

No of bars $= \frac{Ast}{\text{Area of single bars}}$

$= \frac{5.98}{0.601} = 9.9 \simeq 10$ bars.

So 10 # 7 bars.

2- steel in compression zone:-

we use # 5 bars,

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

$= 0.306 in^2$

So,

No of bars $= \frac{A's}{\text{Area of singlebars}}$

$= \frac{0.44}{0.306} = 1.43 \simeq 2$ bars

So 2 # 5 bars.

STEP # 8 :- (Minimum width of Beam)

bmin $= 2(1.5) + 2(3/8) + 10(7/8) + 9(7/8)$

bmin $= 20.37 > 14''$

so not good in one layer.

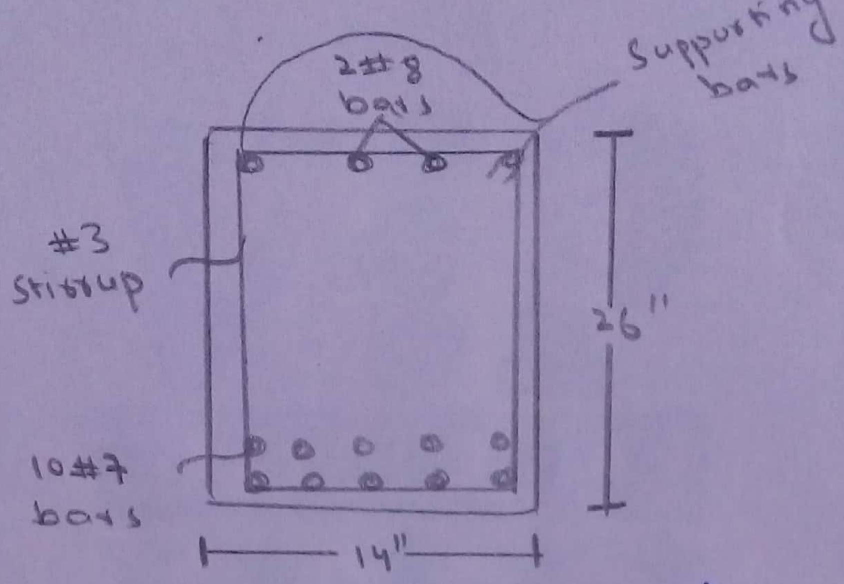
Now,

=> Effective depth (d) $= 26 - 1.5 - 3/8 - 7/8 - 1/2(7/8)$

$= 22.82''$

=> Effective cover (d') $= 1.5 + 3/8 + 1/2(5/8)$

$= 2.18''$



Step # 9 g (Design Moment)

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

$$a = \frac{(A_{st} - A'_{st}) \times f_y}{0.85 \times f'_c \times b}$$

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

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

M_d = 7047.6 kip-inches

As 7047.6 > 6000

Design is okay!