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Q.No 1

Explain in detail types of stirrups with figures & Also explain ACI codes for shear design.

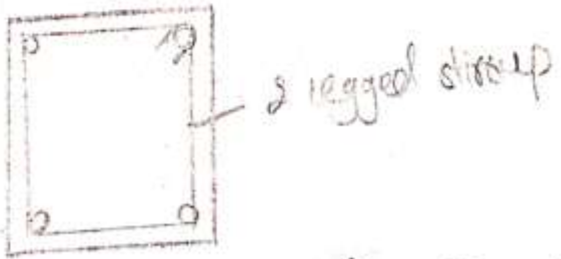
Ans:-

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

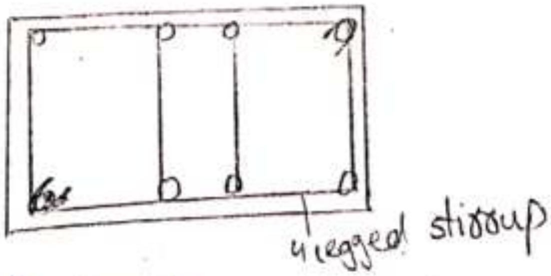
Types of stirrups:-

i. **single legged stirrup:-** The single-leg stirrups have rarely been used because they are mostly used when binding only two rods.

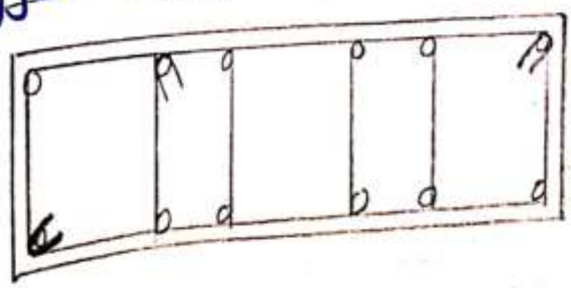
ii. **Two legged stirrup:-** It is most commonly & widely used stirrup. Minimum 4 bars are required for providing this stirrup.



iii. **Four legged stirrup:-** These stirrups are used in case of web reinforcement.



iv. **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° & 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.

$\phi = 0.75 \longrightarrow$ For shear design.

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

For minimum Reinforcement Area:-

$$A_{v\,min} = \frac{0.75 \times \sqrt{f'c} \times b_w \times S}{f_y} \text{ or } \frac{50 \times b_w \times S}{f_y} \rightarrow \left[\begin{array}{l}\text{higher} \\ \text{value is} \\ \text{selected}\end{array}\right]$$

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

$$S_{max} = \frac{A_v \times f_y}{0.75 \times \sqrt{f'c} \times b_w} \text{ or } \frac{A_v \times f_y}{50 \times b_w} \left[\begin{array}{l}\text{lesser value} \\ \text{is selected}\end{array}\right]$$

4- No web-reinforcement is required if

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

$\Rightarrow$ Between critical section "V_u" & "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 stirrups will be the smallest of the following:

i- 24"

ii- $d/2$

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

iv- $S_{max} = \dfrac{A_v \times f_y}{50 \times b_w}$

∵ (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.

Q.No 2

Given data:-

Breadth of web of beam (b_w) = 14"

Effective depth (d) = 22"

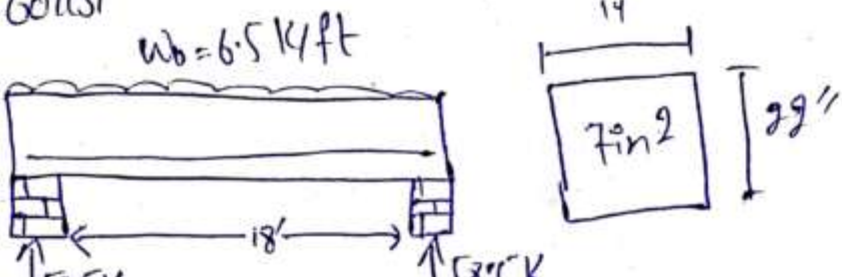
Given load = 6.5K/ft

Steel Area = 7in^2

f'_c = 4ksi

f_y = 60ksi

Sol:-



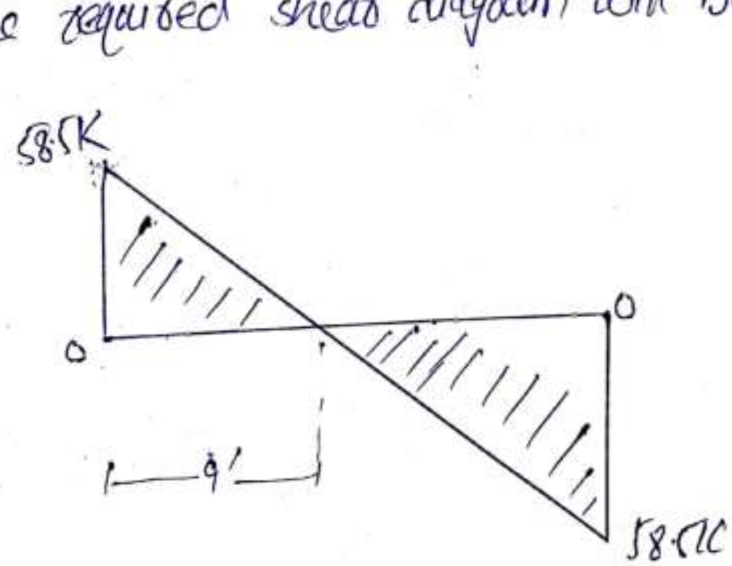
Step#01:- Reactions on supports

Finding the reactions due to applied load

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

Step#02:- Shear Force Diagram

The required shear diagram will be

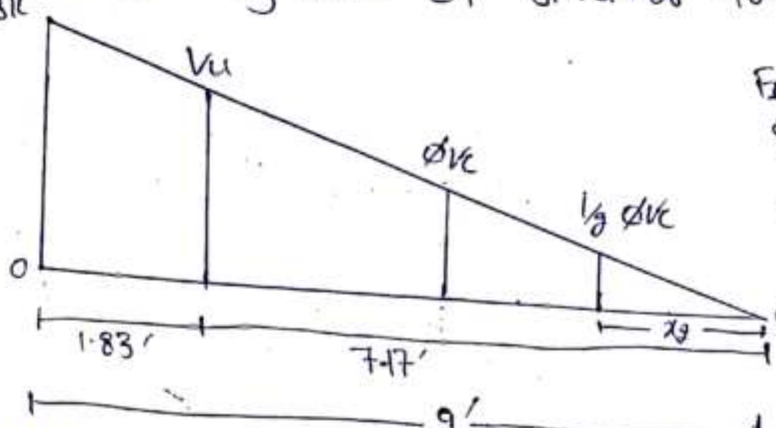


Step #03:-

Finding the value of critical shear 'V_u' & its location.

As we know that critical shear is located at distance 'd' from face to support $(d) = 22'' = 1.83'$

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



From similar Triangles

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

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

$V_u = 46.61$ kips

Step #04:-

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

By formula,

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

$$= 0.75 \times 2 \times \sqrt{4000} \times 14 \times 22$$

$$= 29219 \text{ lbs}$$

$$= 29.21 \text{ kips}$$

=> location of ϕV_c 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 $\frac{1}{2}\phi V_c$ will be

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

Step # 05:-

Finding the value of ϕV_s

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

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

$= 46.61 - 29.21$

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

Step # 06:-

Check on section adequacy,

By formula,

$= \phi \times 8 \times \sqrt{f'_c} \times b_w \times d$

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

$= 116.87 \text{ kips}$

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

So section is Adequate!

Step # 07:-

Check on Maximum spacing for stirrups,

$= \phi \times 4 \times \sqrt{f'_c} \times b_w \times d$

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

$= 58438 \text{ lbs}$

$= 58.43 \text{ kips}$

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,

dia $= (3/8)'' = 0.375''$

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

For 2-legged stirrup

$\Rightarrow$ Area $\times 2$

$\Rightarrow 0.11 \times 2 = 0.22 \text{ in}^2.$

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

4- $S_{max} = \dfrac{A_v \times f_y}{50 \times b_w} = \dfrac{0.22 \times 60000}{50 \times 14} = 18.85''$

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

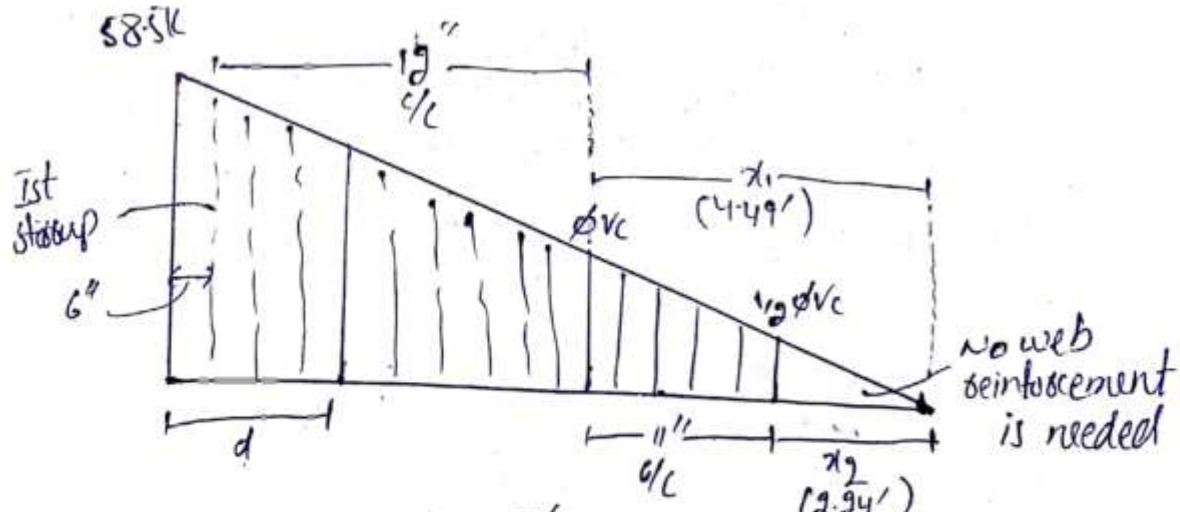
$S = \dfrac{\phi \times A_v \times f_y \times d}{V_u - \phi V_c} = \dfrac{0.75 \times 0.22 \times 60 \times 22}{46.61 - 29.21}$

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

So 12'' c/c

Step #09:-

Final sketch will be



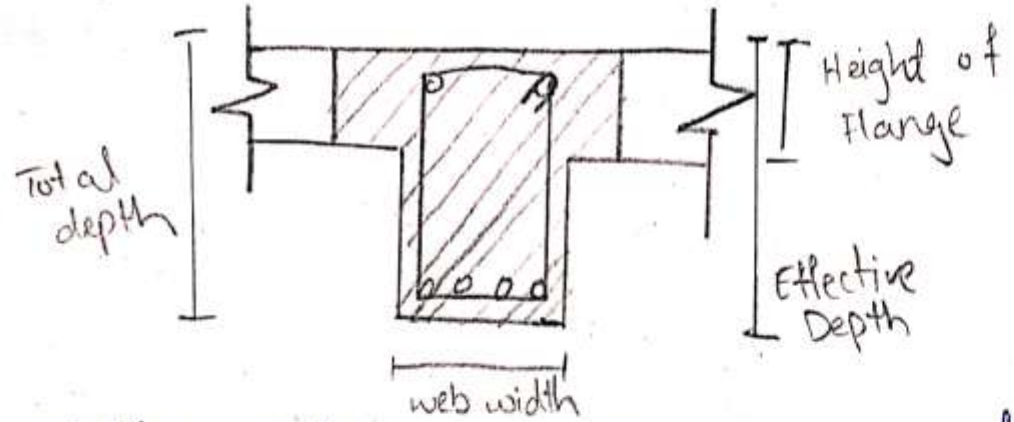
As first stirrup from face of support

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

Q.No 3

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 resists the Loads.

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

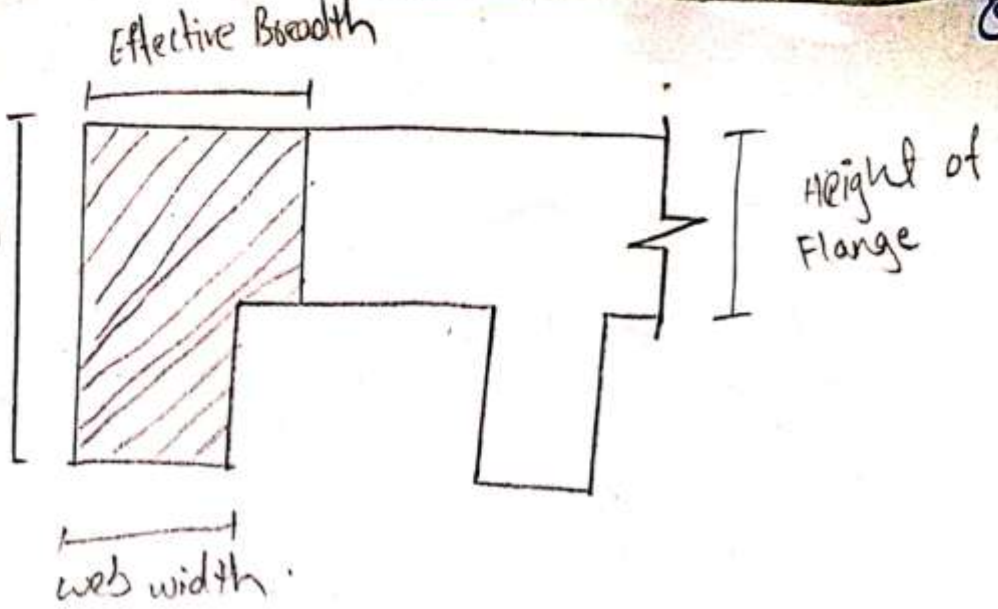
=> The bottom rectangular portion of the beam is called web of the beam.

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

=> L-Beams are also called Edge Beams

=> It is always provided at the corner of the slab.

=> L-Beams are typically 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_e) for T-Beam is calculated as:-

i- $16(h_f) + b_w$ ∴ (h_f = height of flange, CTS = clear transverse span)
ii- c/c distance
iii- span/4
iv- $\frac{CTS}{2} + b_w$

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

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
ht = Height of flange)

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

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

∵ (ϕ = strength Reduction factor
d = Effective depth
a = compression block depth
bw = web width of beam)

5- For checking the range of Reinforcement ratio,

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

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

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

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 accomodation

$$b_{min} = 2(\text{Clear cover}) + 2(\text{dia of stirrup}) + \text{No. of bar}(\text{dia of bar}) + \text{spacing b/w bars}(\text{dia of bar})$$

8- Design Moment of given by

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

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

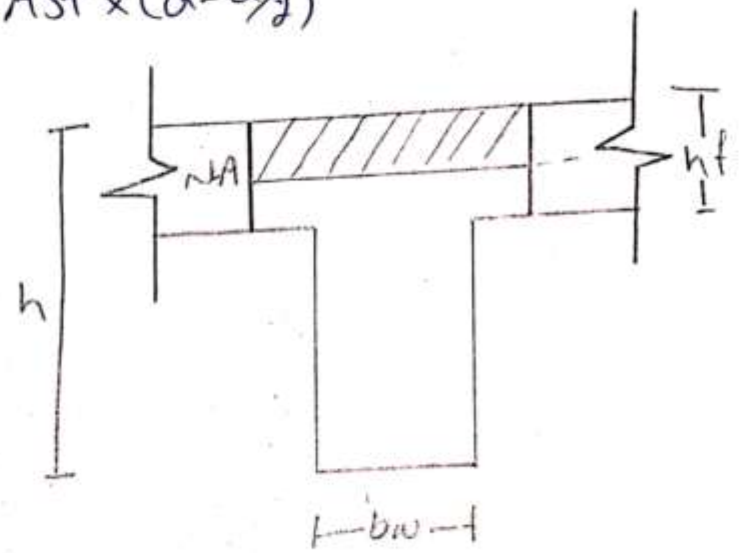
Q.No 4

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

CASE:-01

From the Figure $a < hf$
So in this case, Rectangular Beam Analysis is required.
So, the design Moment formula will be

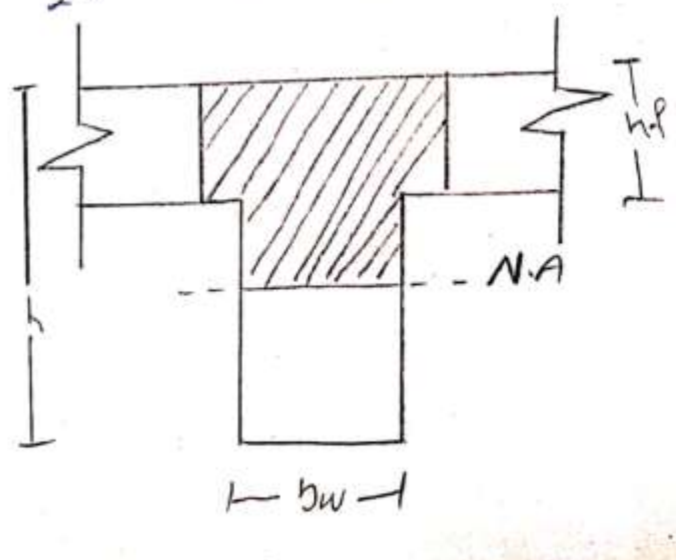
$Md = \phi \times fy \times Ast \times (d - a/2)$



CASE 02:-

From the Figure $a > hf$
So in this, special beam Analysis i.e, T-Beam Analysis is required.
So, the required Design Moment formula will be

$Md = \phi \times [As \times fy \times (d - \frac{hf}{2}) + (As - Ast) + fy \times (d - a/2)]$



Q.No 5

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" & effective depth of 18" & total height is 23". Calculate the necessary flexural reinforcement if the factored applied moment is 5800 kip-inch. Use $f_c' = 3ksi$ & $f_y = 60ksi$

Given:-

Height of flange (h_f) = 3.5"

c/c distance = 9'

length/span of the beam = 16'

web width (b_w) = 10"

Height (h) = 23"

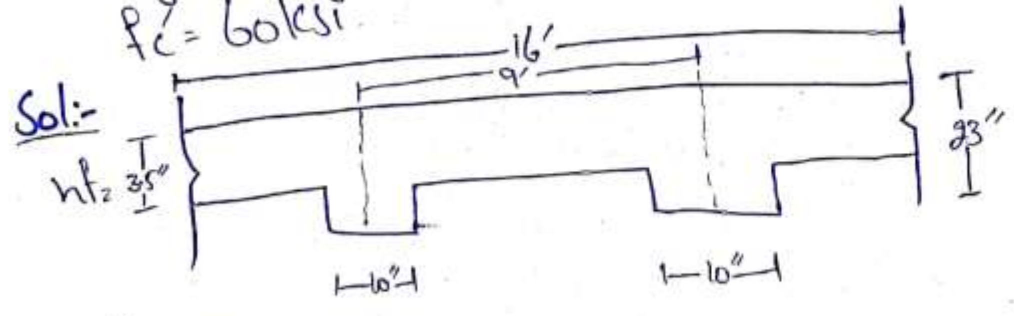
Effective depth (d) = 18"

Total factored moment (M_u) = 5800 kip-inch

$f_y = 60ksi$

$f_c' = 60ksi$

Sol:-



Step # 01:-

Calculate the effective (be) for T-beam

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

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

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

Selecting the least value of be as,

$b_e = 48"$

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Step# 02:- (13)

Check whether Rectangular or T-beam Analysis is required

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

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

Trial #02:-

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

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

& $A_{st} = 6.55 in^2 \Rightarrow 3.2'' < 3.5''$

So Rectangular Beam Design is required

Trial #03:-

$$a = 3.21''$$

$$\& \; A_{st} = \frac{5800}{0.90 \times 60 (18 - \frac{3.21}{2})} = 6.55 \, in^2$$

So Area of steel is $6.55 in^2$

Step# 03:-

Check ρ_{max} & ρ_{min}

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

$$= 0.85 \times 0.85 \times \frac{3}{60} \left(\frac{0.003}{0.003 + 0.005} \right) = 0.0013$$

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

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

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

$0.003 < 0.036 < 0.013$

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}.

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

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

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

Step # 04:-

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'

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

$$a = 5.72''$$

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

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

As $M_{u2} < M_u$

$1986.67 < 5800$

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

Step # 05:-

Finding difference in moments & Area of steel.

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

$$= 5800 - 1986.67$$

$$M_{u1} = 3813.33 \text{ kip-inch}$$

By formula,

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

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

Step # 06:-

Finding Total steel Area

$$A_s = A_{st} + A'_{st}$$
$$= 2.43 + 4.56 = 6.99 \text{ in}^2$$

Step # 07:-

Selection of Bar:-

In Tension zone

let we use # 8 bar

dia $(8/8) = 1''$, 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 bars

dia $(7/8)''$, 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 # 08:-

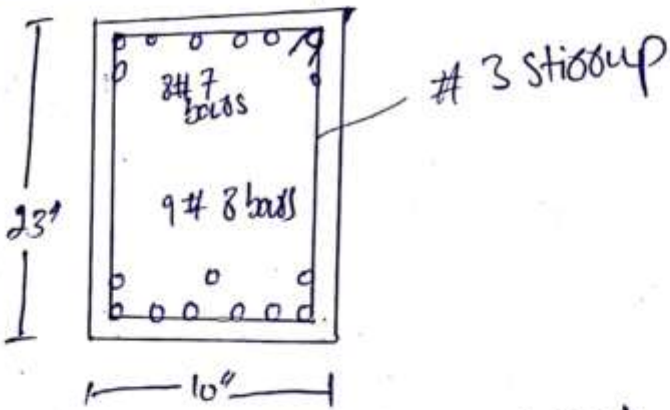
Min width for Accomodation of bars.

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

$= 20.75''$

As $20.75'' > 10''$

So, the bars will be placed in multiple layers.



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

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

Step # 09:-

Finding the Design Moment

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

First $a = \dfrac{(A_s - A'_{st}) \times f_y}{0.85 \times f'_c \times b} = \dfrac{(9 \times 0.785 - 8 \times 0.601) \times 60}{0.85 \times 3 \times 10} = 5.31''$

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

$M_d = 6328.38$

As $6328.38 > 5800$

Design is perfect.

Q.No 6

A beam is revised to developed & ultimate moment of 6000k-inches limited to 14×26 inch size, use f_c' is 4 ksi & fy is 60 ksi. Determine flexural reinforcement assume two rows of tensile reinforcement & effective depth of beam is 22 inch.

Sol:-

Concrete compression strength $(f_c') = 4\,ksi$

Steel Tensile strength $(f_y) = 60\,ksi$

Breadth (b) 14"

Height (h) = 26"

Ultimate Factored Moment $(M_u) = 6000$ kip-inch

Effective depth of beam (d) = 22"

Assume effective cover (d') = 2.5"

Step # 01:- (Reinforcement ratio)

By formula

$$\rho_{max} = 0.85 \times \beta \times \frac{f_c'}{f_y}\left(\frac{\varepsilon_u}{\varepsilon_u + \varepsilon_t}\right)$$

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

$\rho_{max} = 0.0180$

Step # 02 :- Area of steel

As we know that

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

$A_{st} = 0.0180 \times (14 \times 22)$

$A_{st} = 5.54\,in^2$

Step # 03 Design Moment

By Using formula

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

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

$a = 6.98''$

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

$= 5537.41 \text{ kip-inch}$

As; $5537.4 < 6000$

So, we have to design a section as doubly reinforced

Step # 04 (Difference in Moments)

$Mu_1 = Mu - Mu_2$

$= 6000 - 5537.4$

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

Step # 05:- Area of steel

$Mu_1 = \phi \times A's t \times fy \times (d - d')$

compression zone area,

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

$A'st = 0.44 in^2$

Step # 06 Total Steel Area

$As = Ast + A'st$

$= 5.54 + 0.44$

$As = 5.98 in^2$

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Step # 07 Selection of bars & No. of bars

① Steel in Tension zone:-

we use # 7 bars

dia $(7/8)'' = 0.875$

$$Area = \frac{\pi}{4} (0.875)^2$$

$$A = 0.601 \, in^2$$

So, $\text{No. of bars} = \frac{As}{\text{Area of single bar}}$

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

So, 10 # 7 bars

② steel in compression zone:-

we use # 5 bars

dia $= (5/8)'' = 0.625''$

$$Area = \frac{\pi}{4} (0.625)^2$$

$$A = 0.306 \, in^2$$

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

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

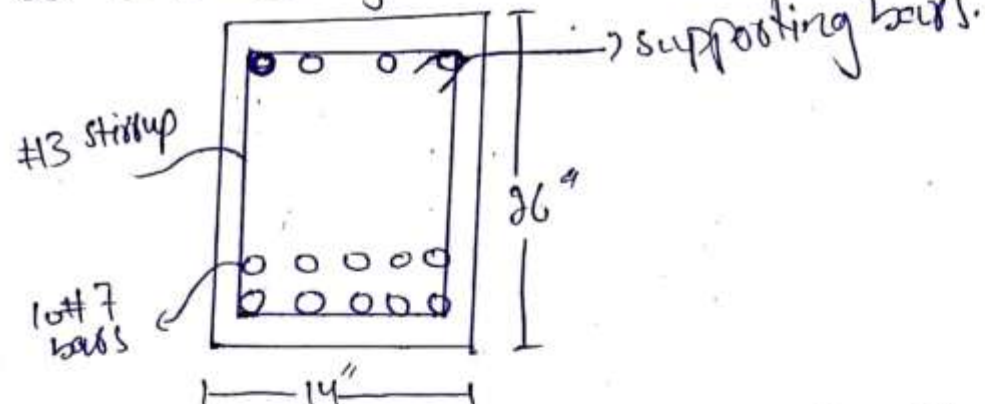
So, 2 # 5 bars

Step # 8:- Minimum width of beam

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

$b_{min} = 20.39 > 14$

So it is not good in one layer.



$\Rightarrow$ effective depth $(d) = 26 - 1.5 - 3/8 - 7/8 - 1/2\,(7/8)$

$= 22.82''$

$\Rightarrow$ effective cover $(d') = 1.5 + \frac{3}{8} + 1/2\,(5/8)$

$= 2.18$

Step # 9:- Design Moment

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

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

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

$d = 0.90[(2 \times 0.306) \times 60 \times (22.82 - 2.18) + (10 \times 0.601 - 2 \times 0.3 \times 60$
$\times 60 \times (22.82 - 6.80/2)]$

$M_d = 7047.6$ kip-inch

$= 7047.6 > 6000$

Design is OK.