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Section : "B"

Subject : PRCD-I

Semester : "6th"

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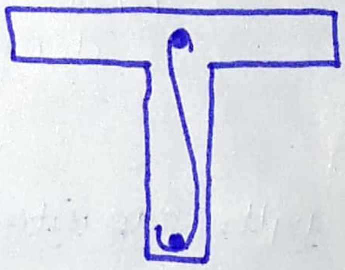
Question no: 01

Explain in detail types of stirrups with figures and also explain ACI codes for Shear Design.

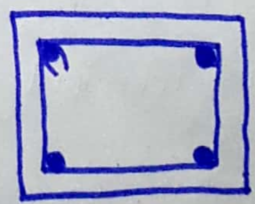
Types of Stirrups: The following are basic types of stirrups used in beams and columns:

1 Single Legged Stirrup:



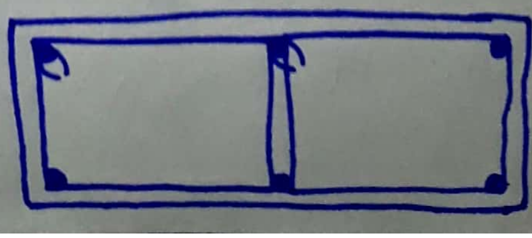
* Rarely used for binding only two rods and this type of binding occured not very commonly.

2 Two-Legged Stirrups:



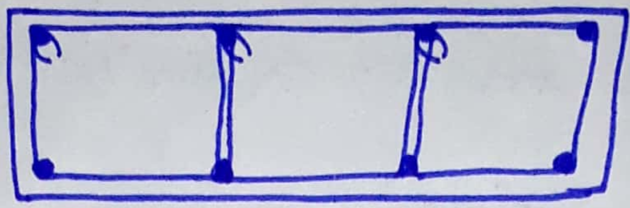
* Widely used for binding of minimum 4 bars.

3 Four-Legged Stirrups:



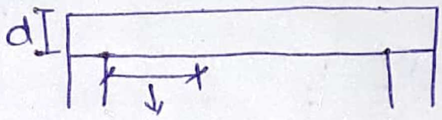
* Web reinforcement are having four-legged stirrups.

4 Six-Legged Stirrups:



ACI codes for Shear Design:

⇒ **Critical Section:** is at a distance "d" from the face of Support.



d = where critical section occurs at 45°.

ⓐ **Shear Strength capacity of Concrete** = $V_c = 2 * \sqrt{f'_c} * b_w * d$

V_u = Total factored Shear Force applied at a given Section.

ⓑ **Mini Web Reinforcement:** if $V_u \leq \varnothing * V_c$, then theoratically no web reinforcement is required. However ACI code require provision of atleast a minimum area of web reinforcement equal to:

⇒ For Shear $\varnothing = 0.75$

⇒ For $A_{Vmin} = 0.75 * \sqrt{f'_c} * \frac{b_w * S}{f_y}$ or $A_{Vmin} = \frac{50 * b_w * S}{f_y}$

⇒ Count max value.

S = Center to Center distance b/w Sterrips

bw = web breadth

fy = tensile Strength

⇒ max. spacing formula $S_{max} = \frac{Av * fy}{0.75 * \sqrt{f'c} * bw}$ or $= \frac{Av * fy}{50 * bw}$

***If $Vu < \frac{1}{2} * \varnothing * Vc$:-** Then no web reinforcement is needed.

⇒ first Sterrip is provided at distance S/2.

⇒ Shear at Critical section is represented by "Vu".

⇒ Between Critical Section "Vu" and "ØVc", spacing b/w web reinforcement can be find by the following formula:

$$S = \frac{\varnothing * Av * fy * d}{Vu - \varnothing Vc}$$

⇒ Preferrably $S \not< 4''$, because of proper compaction vibration and Pouring of Concrete etc.

*** Vs = Shear force carried by web reinforcement:**

According to ACI code:

If $Vs \leq 4 * \sqrt{f'c} * bw * d$, then max-Spacing of Stirrups will be Smallest of following four conditions:

(i) 24″ (ii) d/2 (iii) $S_{max} = \frac{Av * fy}{0.75 * \sqrt{f'c} * bw}$ (iv) $S_{max} = \frac{Av * fy}{50 * bw}$

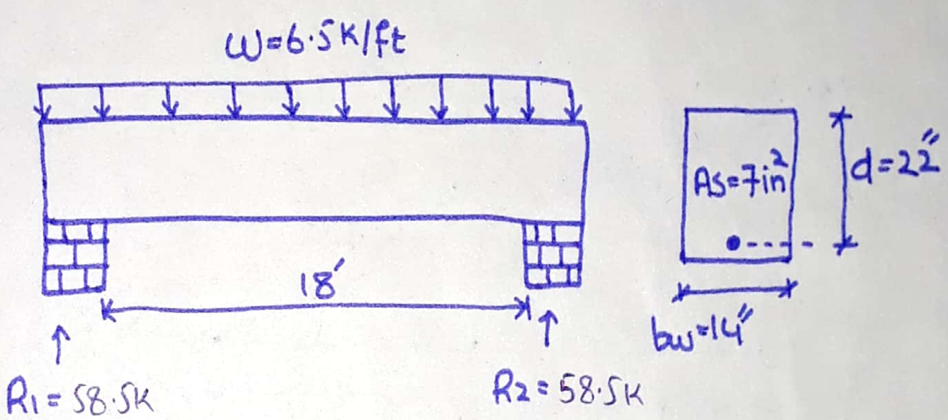
and if $V_s > 4 * \sqrt{f'_c} * b_w * d$ ⇒ Then max. Spacing will be halved.

and if $V_s > 8 * \sqrt{f'_c} * b_w * d$ ⇒ Then either increase cross-sectional dimensions or increase f'_c.

Question no: 02

A Simply Supported rectangular beam 14" wide having an effective depth 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 is 4 ksi and fy is 60 ksi then design a beam for shear.

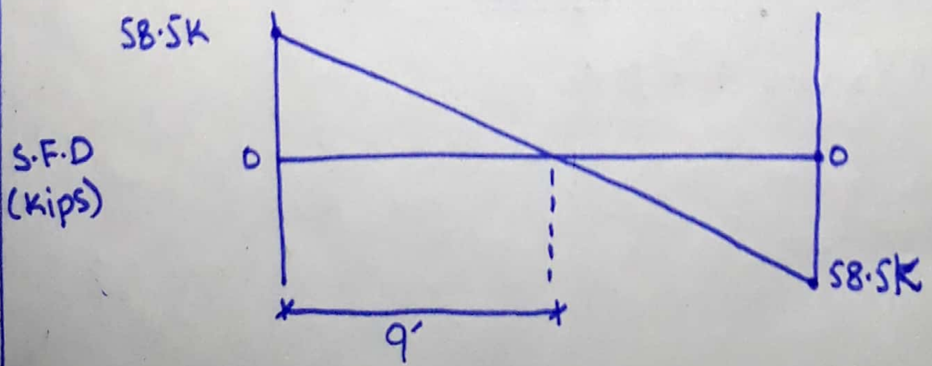
Solution:



Step: 01 Find Values of R_1 and R_2:

$$R_1 = R_2 = \frac{\text{total load}}{2} = \frac{6.5 * 18}{2} = \boxed{58.5 \text{ Kips}}$$

Step: 02 Draw its shear force diagram:

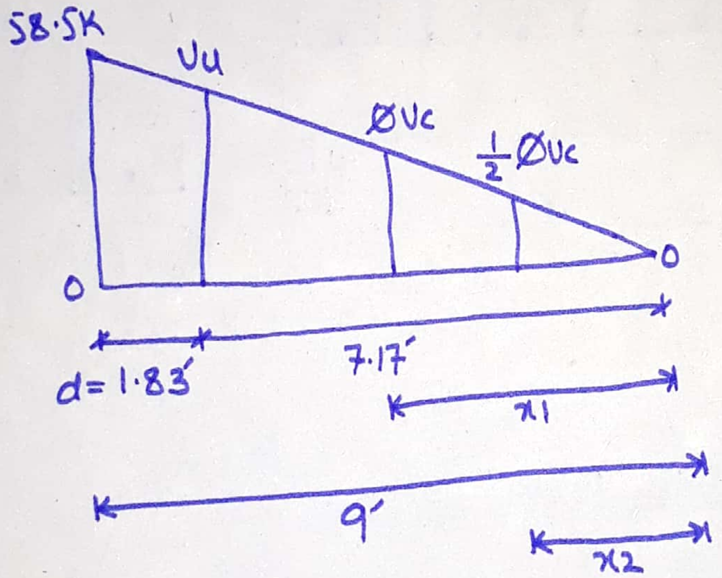


Step: 03 Value of Critical Shear and its location:

⇒ we already know that Critical Section is located at distance 'd' from Support's face

$$d = 22'' = 1.83'$$

⇒ Value of critical shear at distance 'd' by Similarity of triangles:



From Similar Δ's:

$$\frac{58.5}{9} = \frac{Vu}{7.17}$$

$$Vu = 46.61 \text{ Kips}$$

Step: 04 Find value of "ØVc" and "½ ØVc" and its distances from zero shear to right Side:

⇒ $Ø * 2 * \sqrt{fc'} * bw * d = ØVc$

$$ØVc = \frac{0.75 * 2 * \sqrt{4000} * 14 * 22}{1000}$$

$$ØVc = 29.22 \text{ Kips}$$

⇒ Location of ϕV_c by Similarity of Δ's:

$$\frac{58.5}{9} = \frac{29.22}{x_1}$$

$$\boxed{x_1 = 4.5'}$$

⇒ Now "$\frac{1}{2}\phi V_c$"

$$= \frac{29.22}{2}$$

$$\boxed{= 14.61 \text{ Kips}}$$

⇒ Location of $\frac{1}{2}\phi V_c$ by Similarity of Δ's:

$$\frac{58.5}{9} = \frac{14.61}{x_2}$$

$$\boxed{x_2 = 2.25'}$$

Step: 05 Value of ϕV_s:

$$(V_u = \phi V_s + \phi V_c)$$

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

$$\phi V_s = 46.61 - 29.22$$

$$\boxed{\phi V_s = 17.39 \text{ Kips}}$$

Step: 06 Check on Section adequacy:

$$\phi * 8 * \sqrt{f'c} * bw * d \Rightarrow \frac{0.75 * 8 * \sqrt{4000} * 14 * 22}{1000} \boxed{= 116.88K}$$

So $[\phi V_s] < [\phi * 8 * \sqrt{f'c} * b_w * d]$.

hence it means section is adequate.

Step: 07 Check on max. spacing for stirrups:

$\phi * 4 * \sqrt{f'c} * b_w * d$

$$\frac{0.75 * 4 * \sqrt{4000} * 14 * 22}{1000}$$

$= 58.44$ Kips

⇒ As $(\phi * 4 * \sqrt{f'c} * b_w * d) > (\phi V_s)$

So max. spacing will be selected from following conditions:

① $S_{max} = 24''$

② $\frac{d}{2} = \frac{22}{2} = 11''$

③ $S_{max} = \frac{A_v * f_y}{0.75 * \sqrt{f'c} * b_w}$

$S_{max} = \frac{0.22 * 60000}{0.75 * \sqrt{4000} * 14}$

$S_{max} = 19.88''$

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

$S_{max} = \frac{0.22 * 60,000}{50 * 14}$

$S_{max} = 18.86''$

⇒ least value of spacing for #3, 2 legged sterip will be selected.

So $S_{max} = 11''$

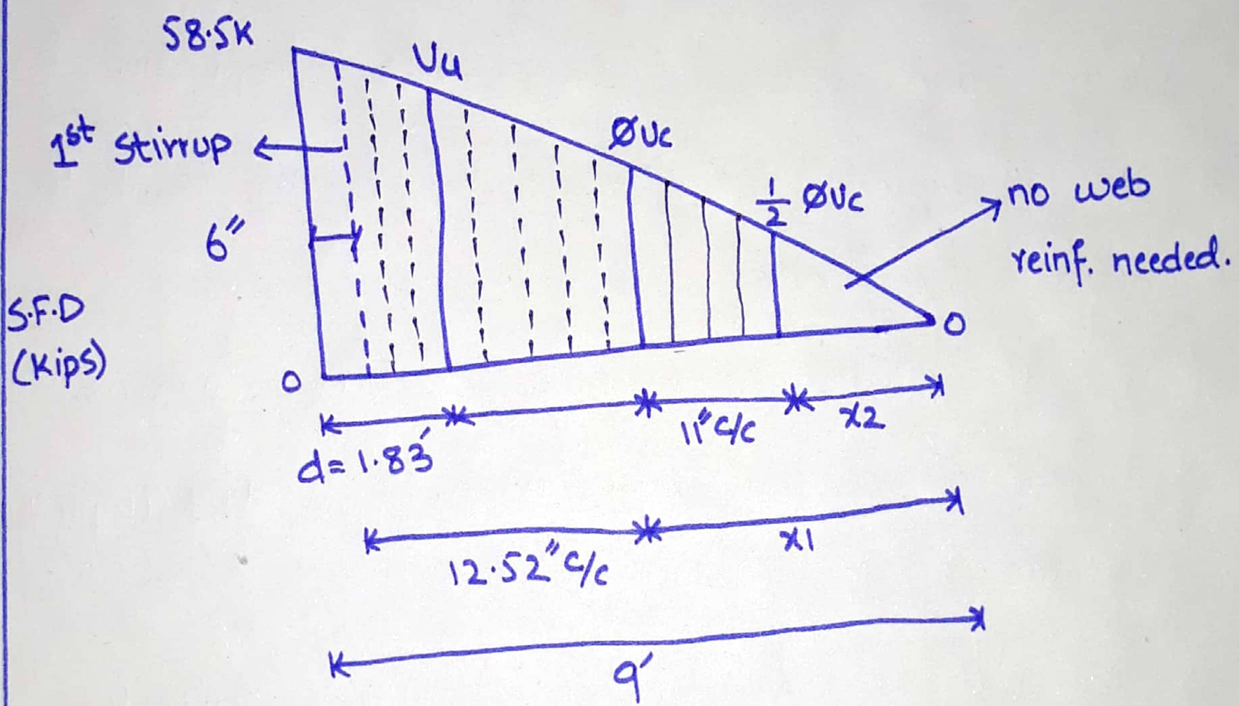
Step: 08 Spacing of Stirrup from Critical section:

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

$$S = \frac{0.75 * 0.22 * 60 * 22}{46.61 - 29.22}$$

$$\boxed{S = 12.52'' \text{ c/c}}$$

Step: 09 Final Sketch:



First Stirrup From Support Face: $\frac{S}{2}$

$$= \frac{12.52}{2}$$

$$\boxed{= 6.26'' \approx 6.00''}$$

Question no: 03

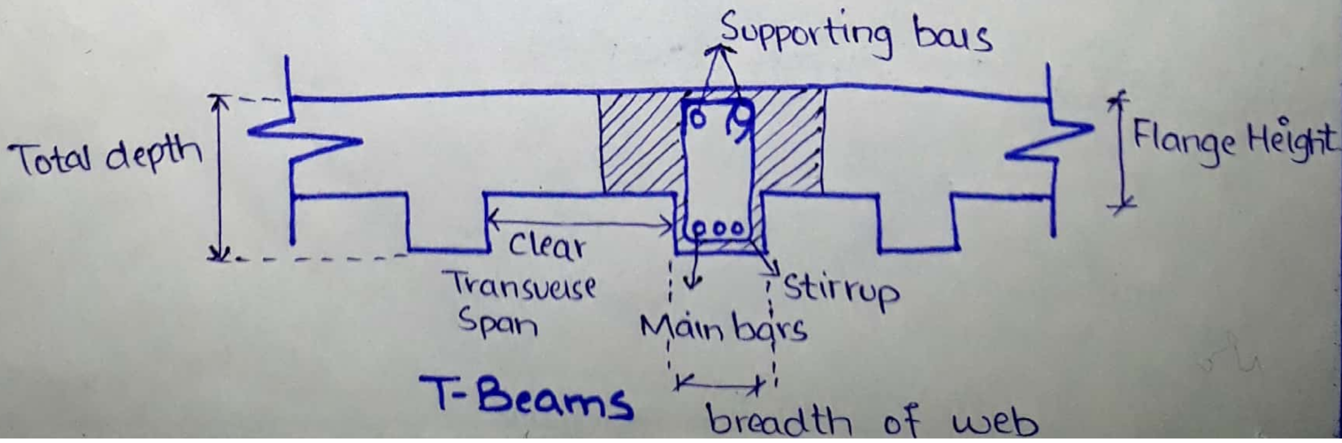
Define both T-Beams and L-Beams with the help of diagram. Also explain flexural strength analysis for T-Beam.

T-Beams: T-Beams are that type of beams whose cross-section is in T-form. These types of beams are casted monolithically with slabs in a positive moment zone, part of the slab act as part of the beam and resist the longitudinal compression.

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

⇒ The top of the t-shaped cross-section serves as flange or compression member. in resisting compressive stresses.

⇒ The web of the beam below flange serves to resist shear stress.

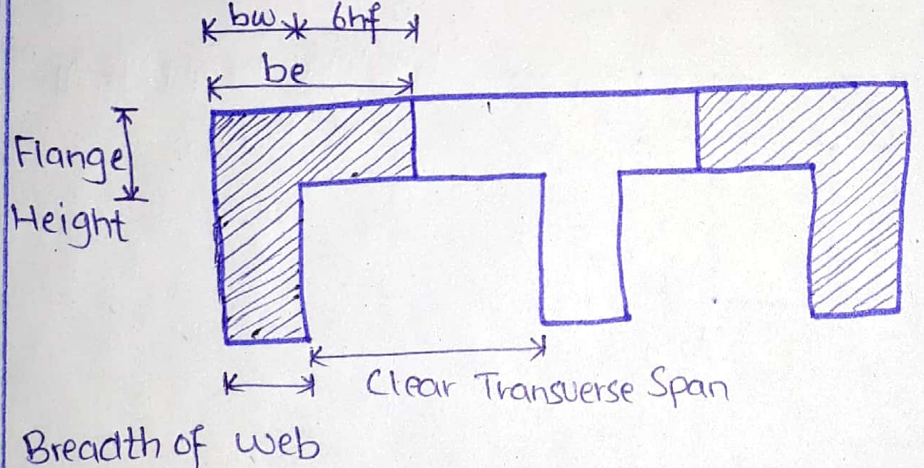


T-Beams

L-Beams: The beams having cross-section as that of inv. L-Shape is called L-Beams. These concrete beams are Poured monolithically with slabs to form the floor of buildings. It is always provided at the corners of the Slabs.

⇒ The top of L-Shape beam crossection is known as Flange or Slab Thickness.

⇒ The bottom of L-Shape beam cross section is known as web of beam.



be = Effective Breadth

bw = Breadth of web

hf = Height of Flange.

L-Beams

Flexural Strength Analysis of T-Beam:

There are two cases in T-Beam analysis. which are the following:

Case 01):- when $a \leq hf$, then we will do rectangular beam analysis.

Case 02):- when $a > hf$, then we will do T-Beam analysis.

where a = height of compression block.

hf = height of flange.

bw = breadth of web.

* The following steps are considered for flexural strength analysis of T-Beam.

(i) Ultimate factored moment, Mu:

$$Mu = \frac{Wu * L^2}{8}$$ where Wu = Total factored load

L = length of beam (total)

(ii) Effective width/breadth (be):

be ⇒ least value in below formulas.

* 16(hf) + bw
* c/c distance
* Span/4
* CTS/2 + bw

(iii) Checking whether Case-I or Case-II analysis required:

* if $a > h_f \Rightarrow$ T-Beam analysis $\Rightarrow$ Case-II

if $a \le h_f \Rightarrow$ Rectangular beam analysis $\Rightarrow$ Case-I

(iv) Area of Steel (Ast):

$$A_{st} = \frac{M_u}{\phi * f_y * (d - a/2)} \quad \text{where} \quad a = \frac{A_{st} * f_y}{0.85 * f_c' * b_w}$$

(v) $$* \; \rho_{max} = 0.85 * \beta * \frac{f_c'}{f_y} * \left(\frac{\varepsilon_u}{\varepsilon_u + \varepsilon_y}\right)$$

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

$$* \; \rho = \frac{A_{st}}{b * d}$$

(vi) No. of bars:

$$\# \text{bars} = \frac{\text{Area of steel}}{\text{area of one steel bar}}$$

(vii) b_{min} = 2(clear cover) + 2(Stirrup dia) + (no of bars)(dia of bar) + (Spacing b/w bars)(dia of bar).

(viii) Design moment:

$$M_D = \phi * f_y * A_{st} * (d - a/2) \Rightarrow (\text{Case-I})$$

$$M_D = \phi * [A_s * f_y * (d - h_f/2) + (A_s - A_{st}) * f_y * (d - a/2)$$

⇓

(case-II).

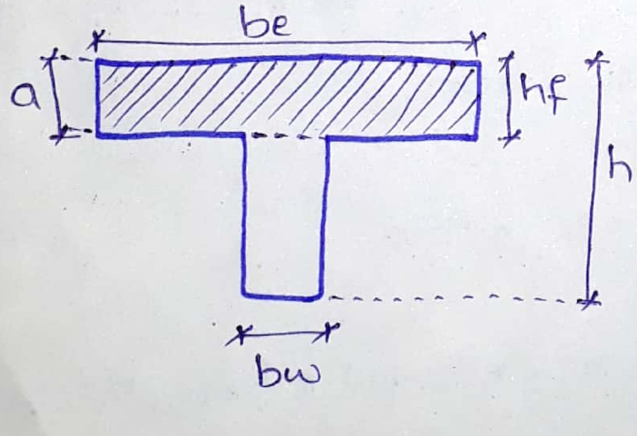
Question no: 04

what is the difference between Case-I and Case-II in the design of T-Beam?

Case-I

(1) In case-I ($a \le hf$), which shows that the height of compression block is less then or upto flange level. Its indication is that the beam is rectangular. and it will be analysed by Rectangular Beam analysis method

(2)

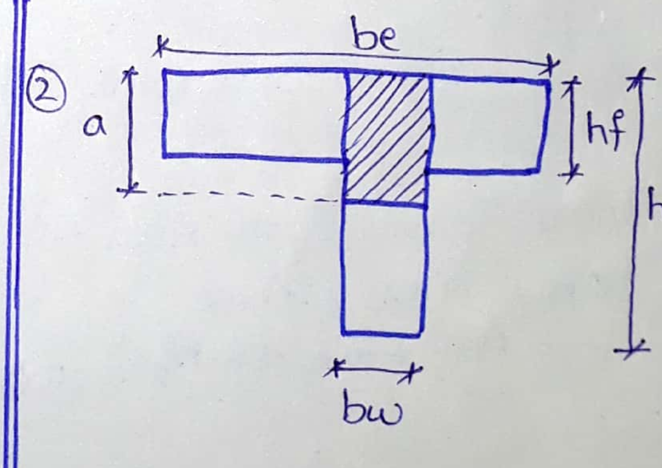


(3) Moment $Md = \phi * Ast * fy * (d - \frac{a}{2})$

Case-II

(1) In case-II ($a > hf$), which shows that the height of compression block is more then the flange level and it indicates that the beam will be analysed by T-Beam analysis method.

(2)



(3) Moment $Md = Md_1 + Md_2$

$Md_1 = Asf * fy * (dy - \frac{hf}{2})$

$Md_2 = ASw * fy * (d - \frac{a}{2})$

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

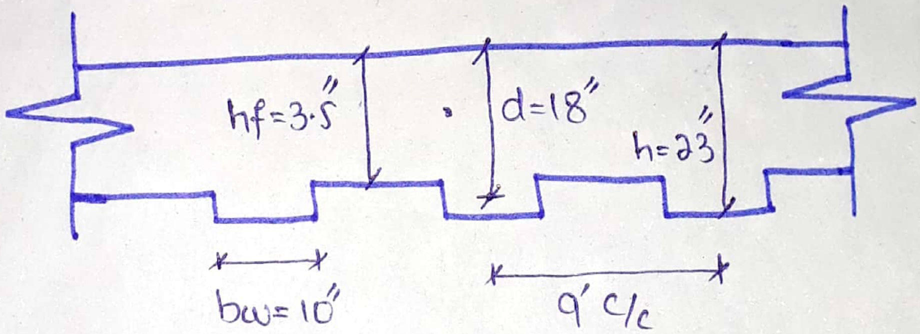
Question no: 05

A floor System consist of 3.5 in concrete slab Supported by 16′ Simple Span beam Spaced at 9′ Center to Center. the beam have a web width of 10″ and effective depth if 18″ and total height is 23″. Calculate the necessary flexural reinforcement if the factored applied moment is 5800 K-inch.

Use f'_c = 3 Ksi or 3000 Psi

f_y = 60 Ksi or 60,000 Psi

Solution:



Step: 01 To find effective breadth "be":

ⓐ $16 * hf + bw = 16 * 3.5 + 10 = 66''$

ⓑ c/c distance $= 9 * 12 = 108''$

ⓒ $\frac{\text{Span of Beam}}{4} = \frac{16*12}{4} = 48''$

hence $be = 48''$

Step:02 Check for Rectangular or T-Beam analysis:

Trial : 01 ⇒ Let $a = h_f = 3.5''$

$$\Rightarrow A_S = \frac{M_u}{\phi * f_y * (d - \frac{a}{2})} = \frac{5800}{0.90 * 60 * (18 - \frac{3.5}{2})}$$

$$A_S = 6.61 \text{ in}^2$$

Trial : 02

$$\Rightarrow a = \frac{A_S * f_y}{0.85 * f'_c * b_e} = \frac{6.61 * 60}{0.85 * 3 * 48}$$

$$a = 3.24'' < h_f = 3.5''$$

⇒ Hence Rectangular beam analysis.

$$\Rightarrow A_S = \frac{M_u}{\phi * f_y * (d - \frac{a}{2})} = \frac{5800}{0.90 * 60 * (18 - \frac{3.24}{2})}$$

$$A_S = 6.56 \text{ in}^2$$

Trial : 03 ⇒ $a = \frac{6.56 * 60}{0.85 * 3 * 48}$

$$a = 3.22''$$

$$\Rightarrow A_S = \frac{M_u}{\phi * f_y * (d - \frac{a}{2})} = \frac{5800}{0.90 * 60 * (18 - \frac{3.22}{2})}$$

$$A_S = 6.55 \text{ in}^2$$

Trial : 04 $\Rightarrow$ $a = \dfrac{6.55 * 60}{0.85 * 3 * 48}$

$$\boxed{a = 3.21''}$$

$$AS = \frac{5800}{0.90 * 60 * \left(18 - \frac{3.21}{2}\right)}$$

$$\Rightarrow \boxed{AS = 6.55\,in^2}$$

Step: 03 ρ_{max} and ρ_{mini} :

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

$$\rho_{max} = 0.85 * 0.85 * \frac{3}{60} * \left(\frac{0.003}{0.003 + 0.005}\right)$$

$$\boxed{\rho_{max} = 0.0135}$$

$$\Rightarrow \rho_{mini} = \frac{200}{f_y} = \frac{200}{60{,}000}$$

$$\boxed{\rho_{mini} = 0.0033}$$

$$\Rightarrow \rho_{provided} = \frac{Ast}{bw * d} = \frac{6.55}{10 * 18}$$

$$\boxed{\rho_{provided} = 0.036}$$

$$\boxed{\rho_{mini} < \rho_{provided} > \rho_{max}}$$

$\Rightarrow$ Hence designing it as Doubly Reinforced Beam.

Step: 04 Ast against ρ_{max}:

$$\rho_{max} = \frac{Ast}{b*d} \Rightarrow Ast = 0.0135*10*18$$

$$\boxed{Ast = 2.43 in^2}$$

Step: 05 Finding Value of MU2:

$$MU_2 = \emptyset * Ast * fy * (d - \frac{a}{2})$$

$$MU_2 = 0.90 * 2.43 * 60 * (18 - \frac{5.72}{2})$$

$$\boxed{MU_2 = 1986.67 K''}$$

finding $a = \frac{Ast * fy}{0.85 * f'c * b} = \frac{2.43 * 60}{0.85 * 3 * 10}$

$$\boxed{a = 5.72''}$$

$$\boxed{MU_2 = 1986.67 Kip''} < \boxed{MU = 5800 Kip''}$$

⇒ Show doobly Reinforced Beam analysis.

Step: 06 Finding Value of MU1:

$$MU_1 = MU - MU_2 \Rightarrow MU_1 = 5800 - 1986.67$$

$$\boxed{MU_1 = 3813.33 Kip''}$$

$$MU_1 = \emptyset * A's * fy * (d - d')$$

$$A's = \frac{3813.33}{0.90 * 60 * (18 - 2.5)}$$

$$\boxed{A's = 4.556 in^2}$$

Step: 07 Total Steel Area:

$AS = Ast + A's$

$AS = 2.43 + 4.556$

$AS = 6.986\ in^2$

Step: 08 Selection of Bars:

⇒ For Tension Zone:-

* Using bar #8
* Area of 1#8 bar = $0.785\ in^2$
* # of bars = $\frac{6.986}{0.785}$

# of bars = 8.89 ≈ 9 bars

⇒ For Compression Zone:-

* Using bar #6
* Area of 1#6 bar = $0.44\ in^2$
* # of bars = $\frac{4.556}{0.44}$

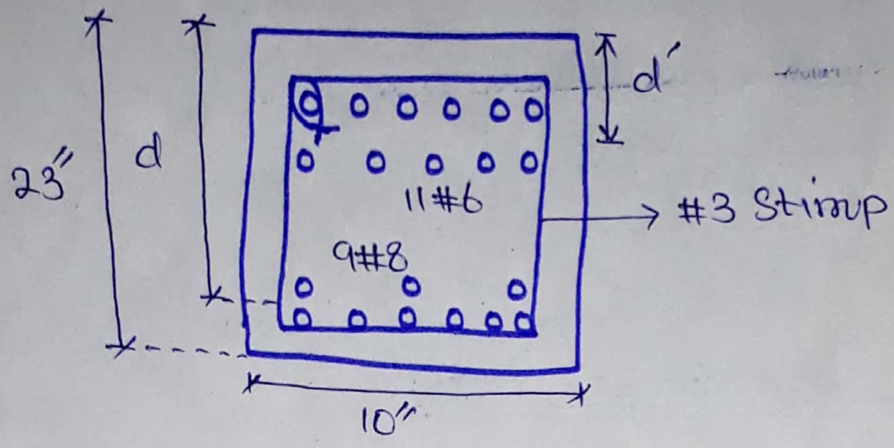
# of bars = 10.35 ≈ 11 bars

Step: 09 Check on mini width of Beam:

$b_{mini} = (2*1.5) + (2*3/8) + (9*8/8) + (8*8/8)$

$b_{mini} = 20.75'' > 10''$ ⇒ Hence reinforcement is not good in one layer. Doubly layered.

Cross Section of Beam:



$d = (23) - (1.5 + 3/8 + 8/8 + (8/8 * 0.5)) = 19.625''$

$d' = 1.5 + 3/8 + \frac{6}{8} + (\frac{6}{8} * 0.5) = 3''$

Step: 10 Design Moment:

$a = \frac{(As - As') * fy}{0.85 * f'c * b} = \frac{(9 * 0.785 + 11 * 0.44) * 60}{0.85 * 3 * 10}$

$a = 5.24''$

$Md = \varnothing [As' * fy * (d - d') + (As - As') * fy * (d - a/2)]$

$Md = 0.90 [(11 * 0.44) * 60 * (19.625 - 3) + (2.225) * 60 * 17.005]$

$Md = 6388.26 \text{ Kip''} > Mu = 5860 \text{ Kip''}$

Design is O.K!

Question no: 06

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

Solution:

breadth = b = 14"

height = h = 26"

MU = 6000 K-inch

f'_c = 4ksi

f_y = 60ksi

d = 22"

d' = 2.5"

Step: 01 Capacity of Section as Singly reinforced beam:

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

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

$$\boxed{\rho_{max} = 0.0181}$$

Step: 02 Steel Area (Ast):

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

$$A_{st} = (0.0181 * 14 * 22) \Rightarrow \boxed{A_{st} = 5.57\, in^2}$$

Step: 03 finding M_{u2} value:

$$M_{u2} = \phi * A_{st} * f_y * \left(d - \frac{a}{2}\right)$$

⇒ Firstly finding value of "a":-

$$a = \frac{A_{st} * f_y}{0.85 * f'_c * b} = \frac{5.57 * 60}{0.85 * 4 * 14}$$

$$\boxed{a = 7.02''}$$

So $M_{u2} = 0.90 * 5.57 * 60 * \left(22 - \frac{7.02}{2}\right)$

$$\boxed{M_{u2} = 5561.42 \text{ Kip}'' < 6000}$$

⇒ Hence Design a section as Doubly Reinforced Beam.

Step: 04 Finding value of M_{u1}:

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

$$M_{u1} = 6000 - 5561.42$$

$$\boxed{M_{u1} = 438.58 \text{ Kip}''}$$

Step: 05 Area of Steel:

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

$$A'_s = \frac{M_{u1}}{\phi * f_y * (d - d')} = \frac{438.58}{0.90 * 60 * (22 - 2.5)}$$

$$\boxed{A'_s = 0.42 \text{ in}^2}$$

Step: 06 Total Steel Area (AS):

$AS = Ast + A's$

$AS = 5.57 + 0.42$

$\boxed{AS = 5.99\ in^2}$

Step: 07 Selection of Bars:

* For Tensile Zone:

* Using bar #9
* area of one bar = $0.994\ in^2$
* # of bars = $\frac{5.99}{0.994}$

$= 6.02 \approx 7$ bars

* For Compression Zone:

* Using bar #7
* area of one bar = $0.601\ in^2$
* # of bars = $\frac{0.42}{0.601}$

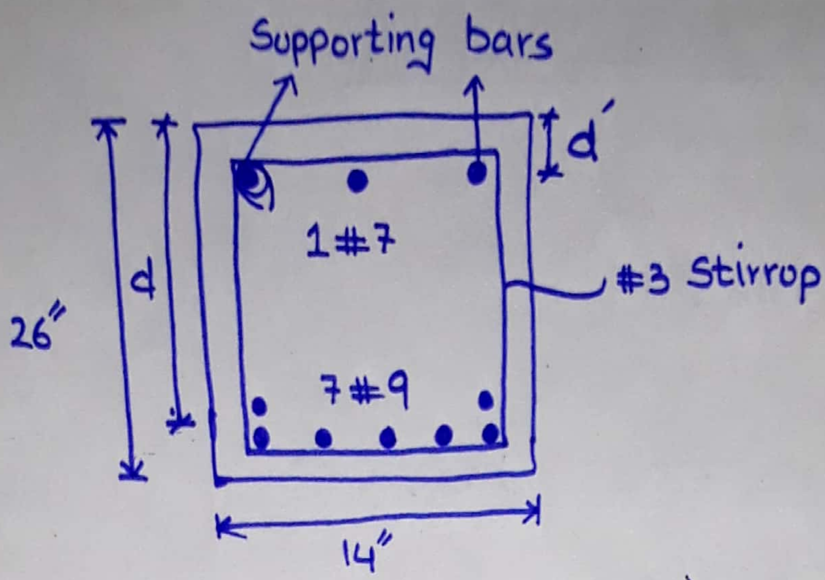
# of bars $= 0.698 \approx 1$ bar

Step: 08 Checking mini. width of beam:

$b_{min} = (2*1.5)+(2*3/8)+(7*9/8)+(6*9/8)$

$\boxed{b_{min} = 18.375'' > 14''}$

⇒ Hence not good in one layer so bars (main) should be Provided in two layers.



$d = 26 - (1.5 + 3/8 + 9/8 + (9/8 * 0.5))$

$d = 22.44''$

$d' = 1.5 + 3/8 + \frac{1}{2}(7/8)$

$d' = 2.31''$

Step: 09 Design Moment (MD):

⇒ Firstly finding value of "a".

$a = \frac{(As - A's) * fy}{0.85 * f'c * b} = \frac{(7 * 0.994 - 1 * 0.601) * 60}{0.85 * 4 * 14}$

$a = \frac{6.357 * 60}{47.6} \Rightarrow a = 8.013''$

Now ⇒ $MD = 0.90[A's * fy * (d - d') + (As - A's) * fy * (d - a/2)]$

$MD = 0.90[(1 * 0.601) * 60 * (22.44 - 2.31) + (6.357) * 60 * (18.43)]$

$MD = 0.90[725.8878 + 7029.5706]$

$MD = 6979.91 K'' > 6000 K''$ Design is OK!