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Section B

Semester 6th

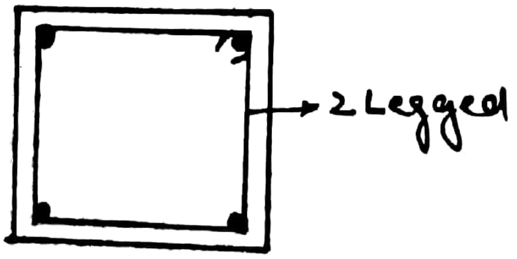
Q1: Explain in details Types of Stirrups with figures and also explain ACI Code for Shear design.

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

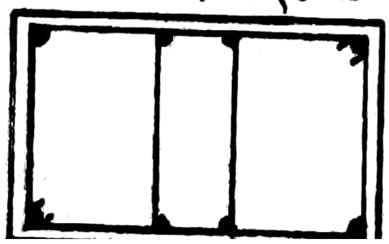
⇒ Types of Structures:

1- Single Legged Stirrup:
The Single-Leg Stirrups have rarely been used b/c are mostly used when binding only two rods.

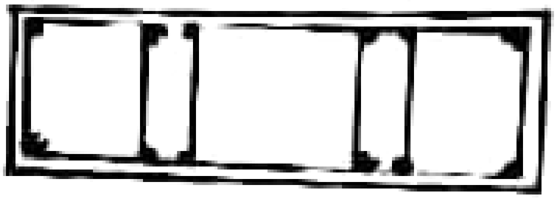
2- Two Legged Stirrups: It is the most commonly and widely used Stirrup. Minimum 4 bars are required for providing the Stirrup.



3- Four Legged Stirrup: These Stirrups are used in Case of web reinforcement



4- Six Legged Stirrups:-



ACI CODES FOR SHEAR Design of a Beams

According to ACI-318 following are the formula used for the shear design of a Beam-

1- Critical Sections: Critical Section occurs at 45° and in 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 $V_u \le \phi V_c$ then theoretically no web reinforcement is required. However ACI Code require provision of at least 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

$$A_{v\,min} = \frac{0.75 \times \sqrt{f_c'} \times b_w \times s}{0.75 \times \sqrt{f_c'} \times b_w} \quad \text{or} \quad \frac{A_v \times f_y}{50 \times b_w}$$

NO web-reinforcement is required if

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

⇒ B/w Critical Section "V_u" and "ϕV_c" Spacing b/w Web reinforcement Can be find by-

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

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-

(∵ V_s = Shear force Carried by Web reinforcement)

① - 24"

② - $d/2$

③ $S_{max} = \dfrac{A_v \times F_y}{0.75 \times \sqrt{F_c'} \times b_w}$

④ $S_{max} = \dfrac{A_v \times F_y}{50 \times b_w}$

⇒ 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 dimension or increase F_c'

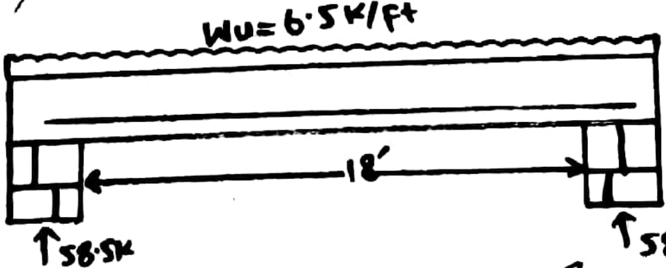
-02:-

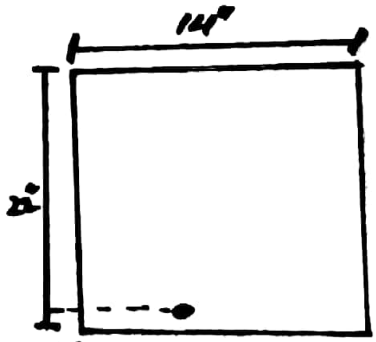
Given data:- Breath of the web of beam = 14"

Effective depth (d) = 22" Given Load = 6.5 k/ft

Steel area = 7 in² F_c' = 4 ksi F_y = 60 ksi

SOL:-





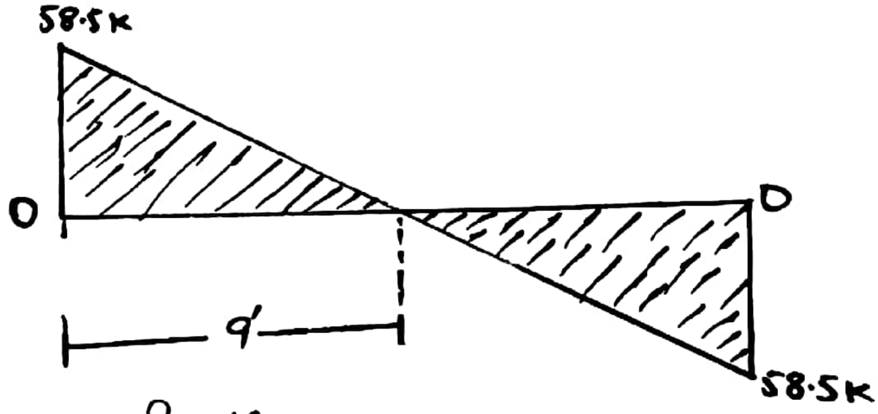
⇒ STEP #01:- (Reactions on Supports)

Finding the reaction due to applied load

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

Step #02:- (Shear Force Diagram)

The required Shear diagram will be

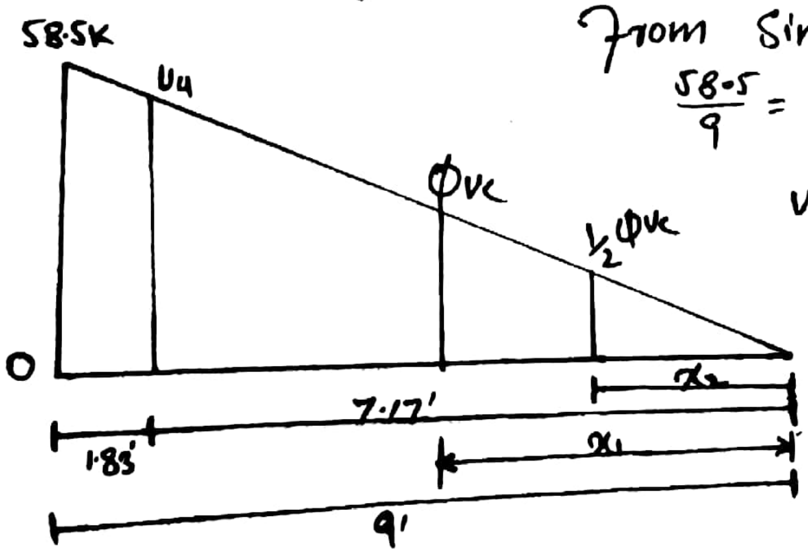


STEP #03:- finding the value of Critical Shear "Vu" and its location

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

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

$V_u = 46.61$ Kips

STEP # 04: 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.

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

$= 0.75 \times 2 \times \sqrt{4000} \times 14 \times 22 = 29219\ lbs$

$= 29.21\ kips$

⇒ Location of ϕV_c by similar triangle

$\frac{58.5}{9} = \frac{\phi V_c}{x_1} \Rightarrow x_1 = 4.49'$

⇒ Similarly:

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

⇒ 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 # 5:

Finding the value of ϕV_s

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

$\Rightarrow \phi V_s = V_u - \phi V_c \Rightarrow 46.61 - 29.21$

$\Rightarrow \phi V_s = 17.4\ kips.$

STEP # 6:

Check on section adequacy.

By formula

$= \phi \times 8 \times \sqrt{f'_c} \times b_w \times d \Rightarrow 0.75 \times 8 \times \sqrt{4000} \times 14 \times 22$

$= 116877\ lbs = 116.87\ kips$

As $\phi \times 8 \times \sqrt{F'c} \times bw \times d > \phi Vs$

So Section is Adequate!

STEP:07 Check Maximum Spacing for Stirrups

By formula-

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

$= 0.75 \times 4 \sqrt{4000} \times 14 \times 22 \Rightarrow 58438$ lbs $\Rightarrow 58.43$ 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- $\frac{d}{2} = \frac{22}{2} = 11''$

3- $\frac{Av \times fy}{0.75 \times \sqrt{F'c} \times bw}$ Here we are using #3

Stirrups dia $= \left(\frac{3}{8}\right)'' = 0.375''$

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

STEP #8: Stirrups Spacing from/at Critical Section will be By formula.

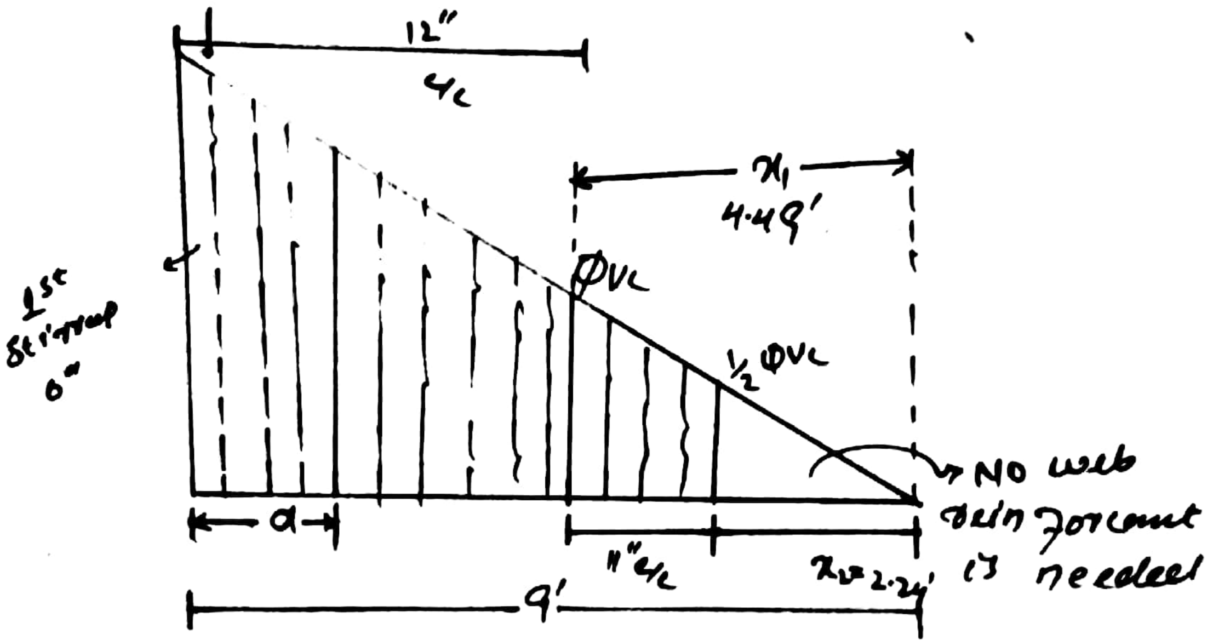
$S = \frac{\phi \times Av \times Fy \times d}{Vu - \phi Vc} = \frac{0.75 \times 0.22 \times 60 \times 22}{46.61 - 29.21}$

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

So $12''$ c/c

STEP # 09:-

Final Sketch will be,



As first Stirrup from face of Support

$$S/2 = \frac{12}{2} = 6''$$

Q NO 2

Given:-

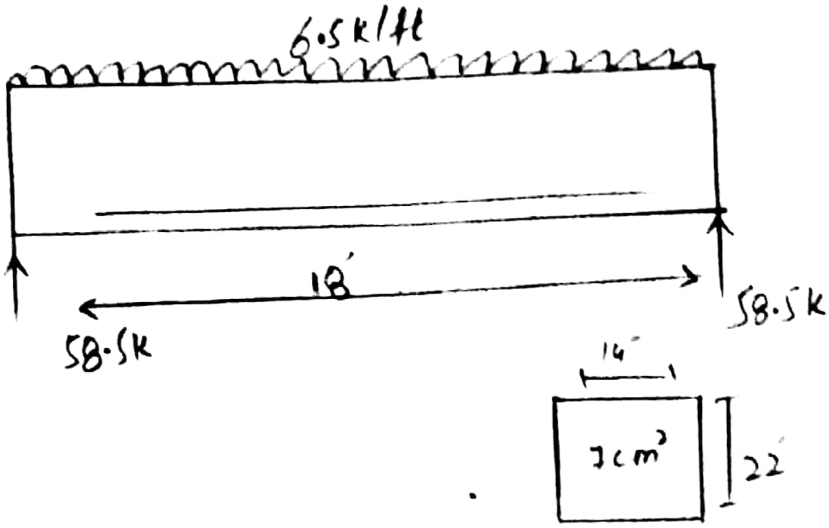
Brealth of web of beam (bw) = 14"

Effective depth d = 22"

load = 6.5k/ft

f'c = 4ksi

fy = 60ksi



Step: 2

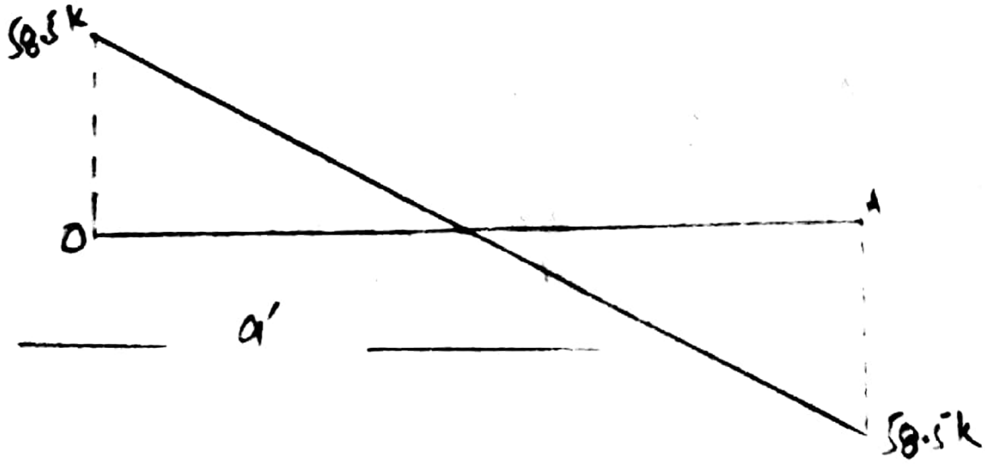
Rxn on Supports

$$\frac{6.5\times18}{2} = 58.5\ \text{kips}$$

Step. 2

SFD

The realwise Shear force Diagram is



Similarly

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

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

$\frac{58.5}{9} = \frac{14.60}{x_3}$

=> $x_3 = 2.24'$

Step:05

finding the value of ϕV_s

By formula

$\phi V_s = V_u - \phi V_c$

$= 46.61 - 29.21$

$\phi V_s = 17.4$ kips

Step:06

Check on section adequacy

By formula

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

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

$= 116877$ lbs

$= 116.87$ kips

For 2-legged stirrup

Area × 2

$0.11 \times 2 = 0.22$ in²

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

4- $S_{max} = \frac{A_v \times f_y}{50 \times b_w} = \frac{0.22 \times 60{,}000}{50 \times 14} = 18.85''$

Step:08

Stirrup spacing from/at Critical section will be by formula

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

$$= \frac{0.75 \times 0.22 \times 60 \times 22}{46.61 - 29.21}$$

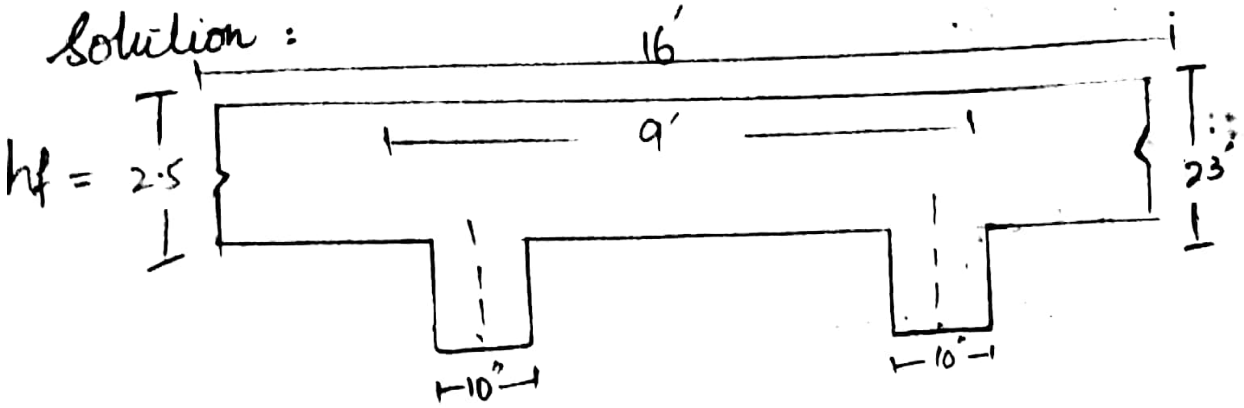
$S = 12.5'' \cong 12''$

so 12 c/c

$f'_c = 3\,ksi$

$f_y = 60\,ksi$

Solution :



Step. 01

Calculate the effective width (b_e) for T- beams

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

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

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

Selecting the least value of be as,

$b_e = 48'$

Step. 2

Check whether Rectangular or T-beam Analysis is required

Trial 01 :

Let $a = h_f = 3.5'$

Step. 03

Check ρ_{max} and ρ_{min}

$$\rho_{max} = 0.85 \times \beta_1 \times \frac{f'_c}{f_y} \left(\frac{\epsilon_u}{\epsilon_u + \epsilon_t}\right)$$

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

$$\Rightarrow \rho_{min} = \frac{200}{f_y} = \frac{200}{60,000} = 0.003$$

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

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

$$0.003 < 0.036 < 0.013$$

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}

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

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

(11)

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

step: 05

finding differece in moments and Area of steel

$$M_{U1} = M_U - M_{U2}$$
$$= 5800 - 1986.67$$
$$= 3813.33 \text{ Kip-inch}$$

By formula

$$A_{st} = \frac{M_U}{\phi \times f_y \times (d-d')}$$

$$A_{st} = 4.56 in^2$$

step: 06

finding total steel Area

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

step: 07

Selection of Bar:-

In Compression zone

Let use no 7 bar

$Area = \frac{\pi}{4} d^2 = 7/8 \times \pi/4$

$= 0.60 \, in^2$

By formula

$= \frac{\text{Area of steel}}{\text{Area of single bar}} = \frac{6.99}{0.78} =$

$4.56 = 7.5 \approx 8$

So 8# 7 bars

Step: 08

Maximum width for Accomodation of bars

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

$= 20.75''$

As

$20.75'' > 10$

bars will be place in multiple layers

Question No : 06 (15)

Solution

Breadth (b) = 14"

Height (h) = 26"

Concrete Compression Strength f'_c = 4ksi

Steel Tensile Strength (f_y) = 60 ksi

Mu = 6000 Kip - inch

Effective depth of beam (d) = 22"

Assume effective cover (d') = 2.5"

Step: 01 (Reinforcement Ratio

By formula

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

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

ρ_{max} = 0.0180

Step: 2 (Area of steel)

As we know that

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

Step :05 : (Area of steel)

$Mu_1 = \phi \times Ast \times fy \times (d-d')$

So Area of steel in compressive zone will be

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

$\Rightarrow Ast = 4.44 \, in^2$

Step #06
(Total steel Area)

$A_s = Ast + Ast$
$= 5.54 + 0.44$
$= 5.98 \, in^2$

Step :07

1- Steel in tention zone:-
we use #7 bars

dia = (7/8) = 0.875"

$Area = \frac{\pi}{4}(0.875)^2$
$= 0.601 \, in^2$

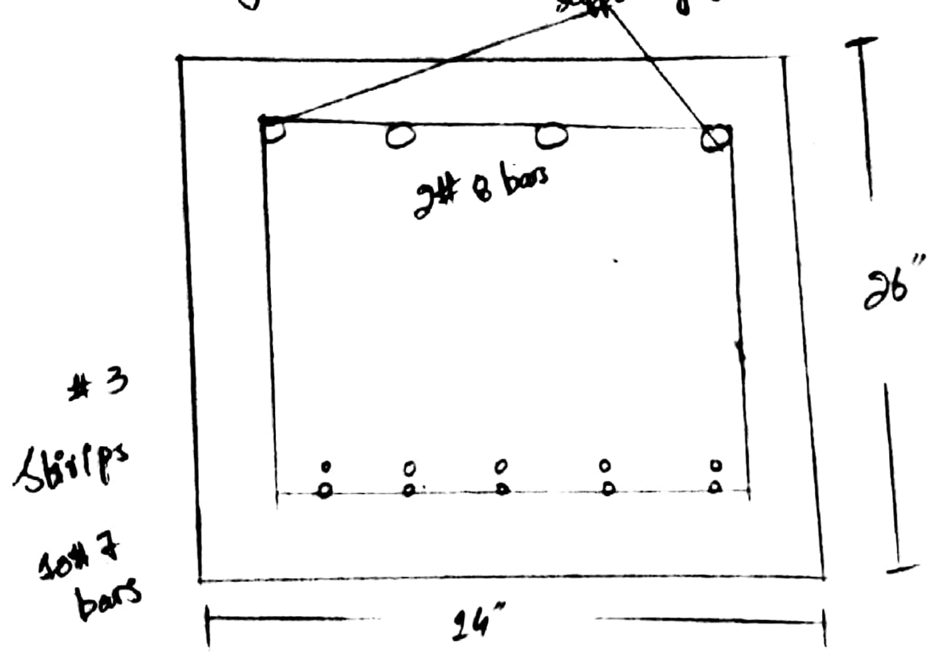
Step:08

(Minimum width of Beam)

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

$b_{min} = 20.37 > 14"$

So not good in one layer



Now

Effective depth $(d) = 26 - 1.5 - 3/8 - 7/8 - \frac{1}{2}(7/8)$

$= 22.82"$

Effective cover $(d') = 1.5 + \frac{3}{8} + \frac{1}{2}\left(\frac{5}{8}\right)$

$= 2.18"$

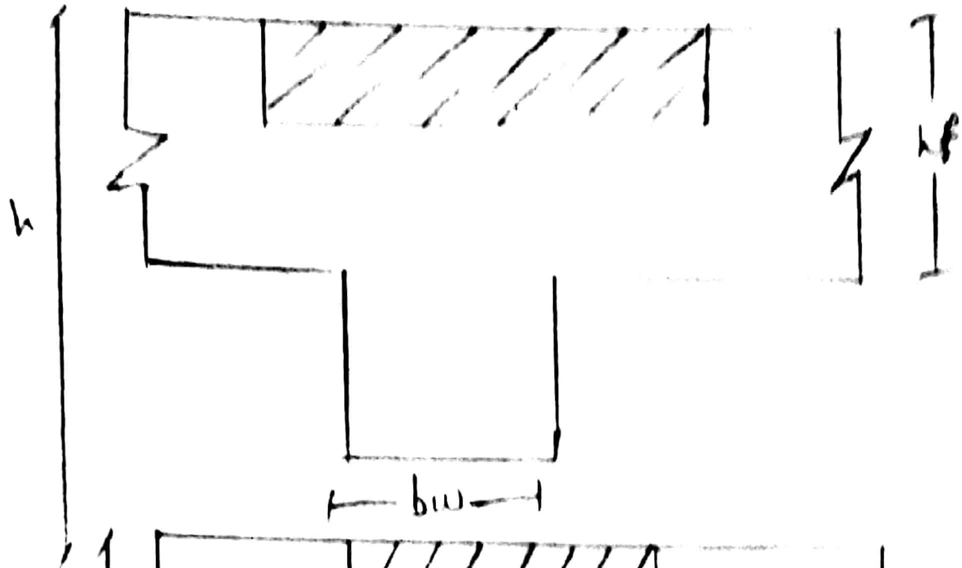
Step: 9 (Design Moment)

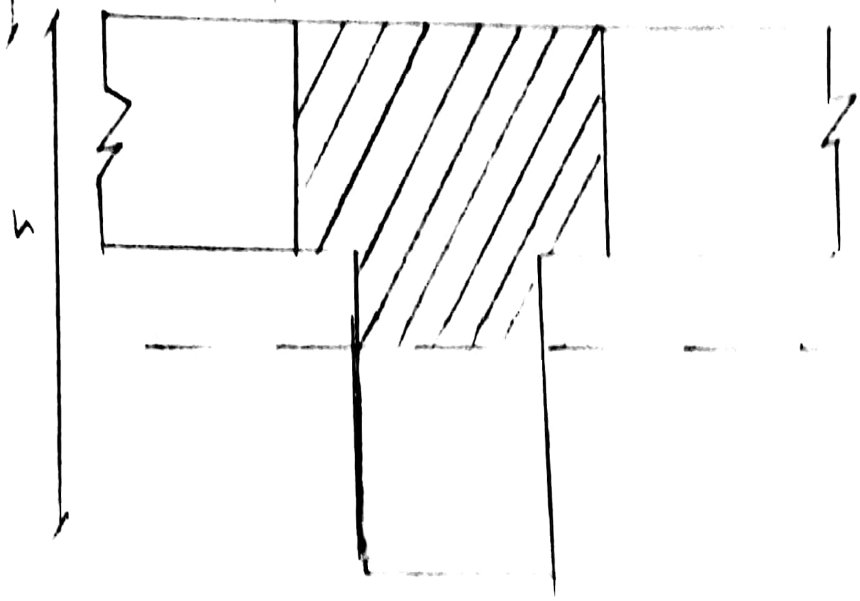
$M_d = \phi\left[A_{st} \times f_y \times (d - d') + (A_{st} - A'_{st}) \times f_y \times \left(d - \frac{a}{2}\right)\right]$

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

The Design moment formula will be

$$Md = \emptyset \times fy \times Ast \times (d - \frac{a}{2})$$





Case - II

From figure

$a > hf$

So in this Special beam analysis is required

So

the required Design moment

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

1 - 16 (hf) + bw

2. L/6 . distance

3- Span 4

4 - $\frac{CTs}{2}$ + bw

3 - Checking Whether Rectangular or T-Beam Analysis

i, If a > hf → Special Analysis Required

(ii, If a < hf → Rectangular beam analysis is required

a = Depth of Compression block

hf = Height of flange

4, For finding Area of Steel, we have to use

$$Ast = \frac{Mu}{\phi \times fy \times (d - a/2)}$$

Where

$$a = \frac{Ast \times fy}{0.85 \times f'c \times bw}$$