TAUBMAN COLLEGE
ARCHITECTURE & URBAN PLANNING
UNIVERSITY OF MICHIGAN

Arch324
STRUCTURES II

Spring 2025
Recitation

FACULTY: Prof. Peter von Bülow
Mohsen Vatandoost

Arch324: STRUCTURES II

Welcome to Recitation session 03/28

Mohsen Vatandoost {Ph.D., M.Sc., M. Arch}
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Office: Room 3122
hours:
Fri: 11:30 – 12:30
Mon, Wed: 11:00 - 12:00
walk-ins welcome!

Click here to make an appointment

Please feel free to ask questions.

Arch324: STRUCTURES II

Welcome to Recitation session 03/28

Outline:

- Quick **Recap** of the week
- Provide the solution for the assignment **(Homework 9)**
- Answering student's questions
- Lab: **Conc. Beam Design**
- **Tower Project:** Final report by **April 18**

Please feel free to ask questions.

Contact: Mohsenv@umich.edu

Recap of the week

Rectangular Beam Design

Two approaches:

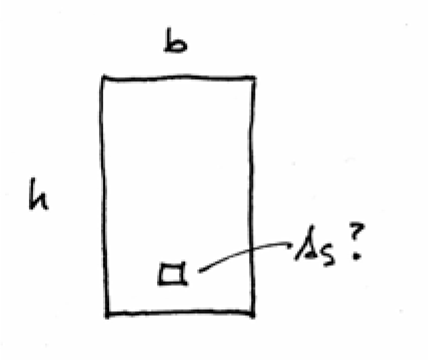
Method 1:

Data:

- Load and Span
- Material properties – f'_c, f_y
- All section dimensions: h and b

Required:

- Steel area – A_s



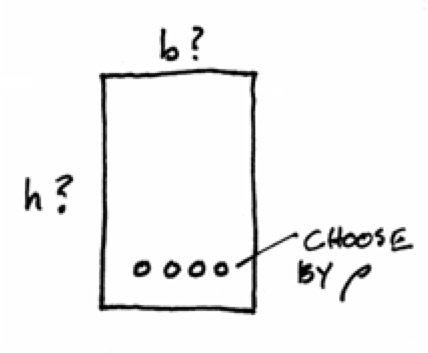
Method 2:

Data:

- Load and Span
- Some section dimensions – h or b
- Material properties – f'_c, f_y
- Choose ρ

Required:

- Steel area – A_s
- Beam dimensions – b and h

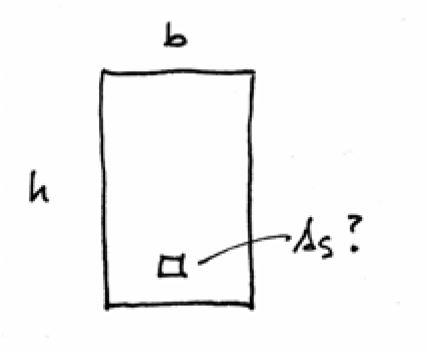


Recap of the week

Rectangular Beam Design – **Method 1**

Data:
- Load and Span
- Material properties – f'_c, f_y
- All section dimensions – b and h

Required:
- Steel area - A_s



1. Calculate the factored load and find factored required moment, M_u
2. Find d = h – cover – stirrup – $d_b/2$
3. Estimate moment arm z = jd, for beams j ≈ 0.9 for slabs j ≈ 0.95
4. Estimate A_s based on estimate of jd.
5. Use As to find a
6. Use a to find A_s (repeat…until **2%** accuracy)
7. Choose bars for A_s and check A_s max & min
8. Check that $\varepsilon_t \geq 0.005$
9. Check $M_u \leq \phi M_n$ (final condition)

10. Design shear reinforcement (stirrups)
11. Check deflection, crack control, rebar development length

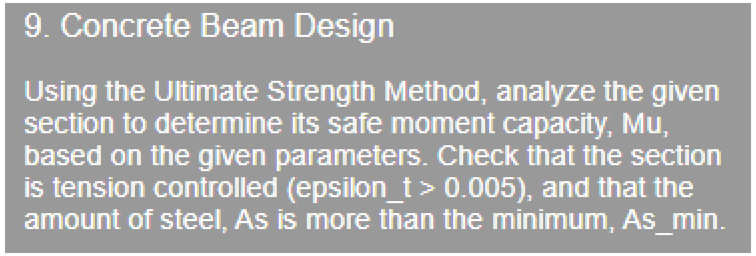
$$\boxed{M_u = \frac{(\gamma_{DL} w_{DL} + \gamma_{LL} w_{LL}) l^2}{8}}$$

$$\boxed{A_s = \frac{M_u}{\varphi f_y \left(d - \frac{a}{2}\right)}}$$

$$\boxed{a = \frac{A_s f_y}{0.85 f'_c b}}$$

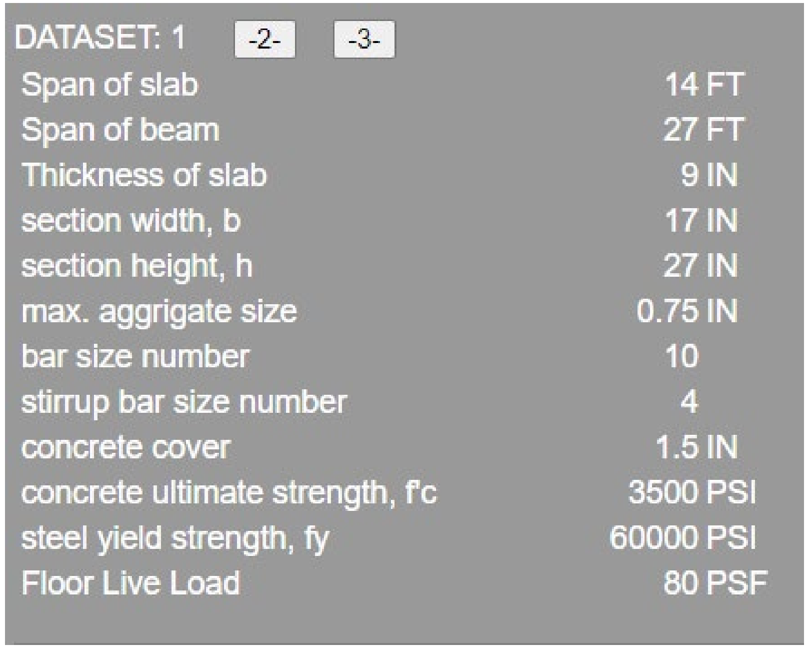
$$\boxed{M_n = A_s f_y \left(d - \frac{a}{2}\right)}$$

Provide the solution for the assignment – **HW9**



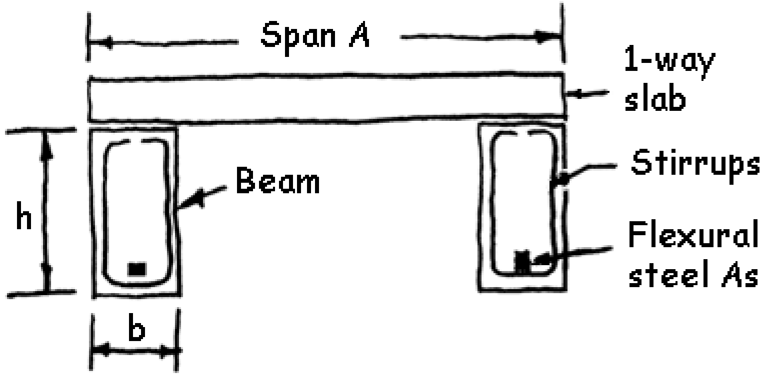
9. Concrete Beam Design

Using the Ultimate Strength Method, analyze the given section to determine its safe moment capacity, Mu, based on the given parameters. Check that the section is tension controlled (epsilon_t > 0.005), and that the amount of steel, As is more than the minimum, As_min.



DATASET: 1 -2- -3-

Span of slab	14 FT
Span of beam	27 FT
Thickness of slab	9 IN
section width, b	17 IN
section height, h	27 IN
max. aggrigate size	0.75 IN
bar size number	10
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	3500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	80 PSF



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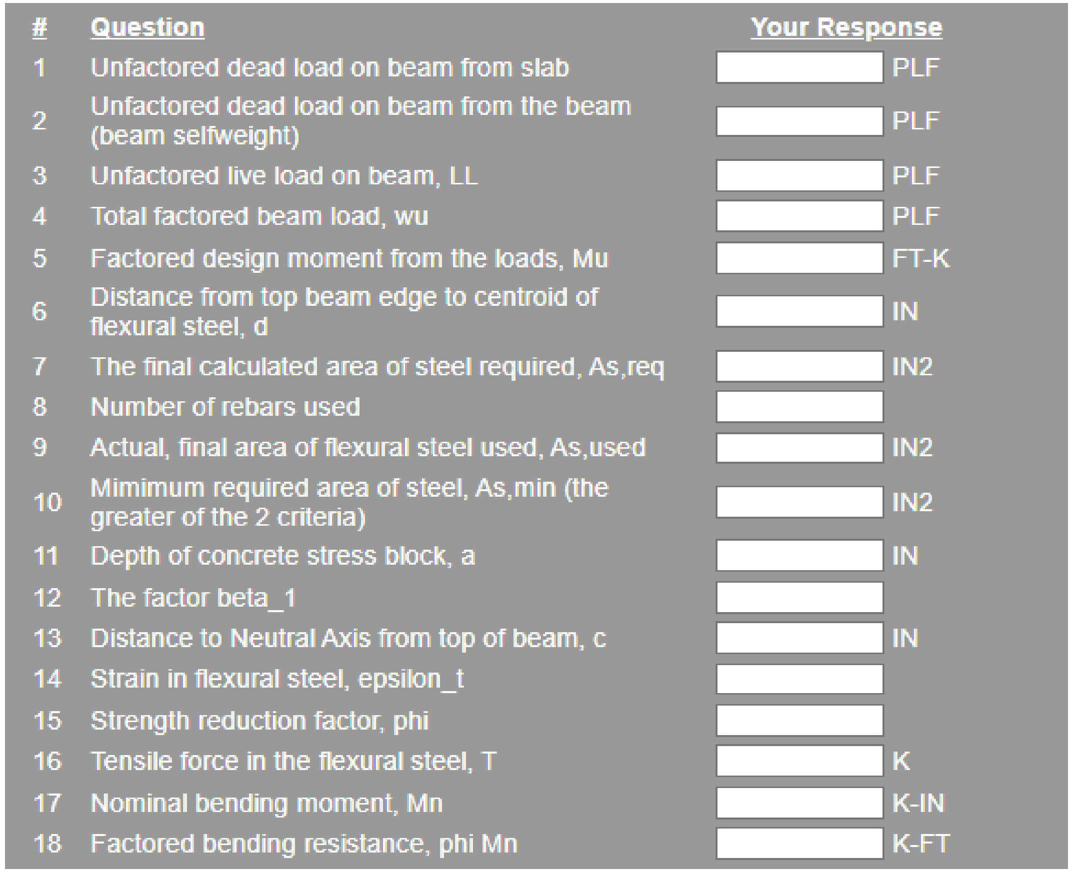
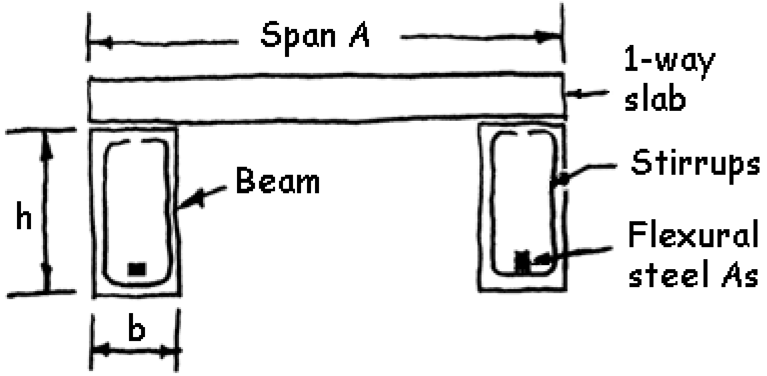


#	Question	Your Response	
1	Unfactored dead load on beam from slab		PLF
2	Unfactored dead load on beam from the beam (beam selfweight)		PLF
3	Unfactored live load on beam, LL		PLF
4	Total factored beam load, wu		PLF
5	Factored design moment from the loads, Mu		FT-K
6	Distance from top beam edge to centroid of flexural steel, d		IN
7	The final calculated area of steel required, As,req		IN2
8	Number of rebars used		
9	Actual, final area of flexural steel used, As,used		IN2
10	Mimimum required area of steel, As,min (the greater of the 2 criteria)		IN2
11	Depth of concrete stress block, a		IN
12	The factor beta_1		
13	Distance to Neutral Axis from top of beam, c		IN
14	Strain in flexural steel, epsilon_t		
15	Strength reduction factor, phi		
16	Tensile force in the flexural steel, T		K
17	Nominal bending moment, Mn		K-IN
18	Factored bending resistance, phi Mn		K-FT



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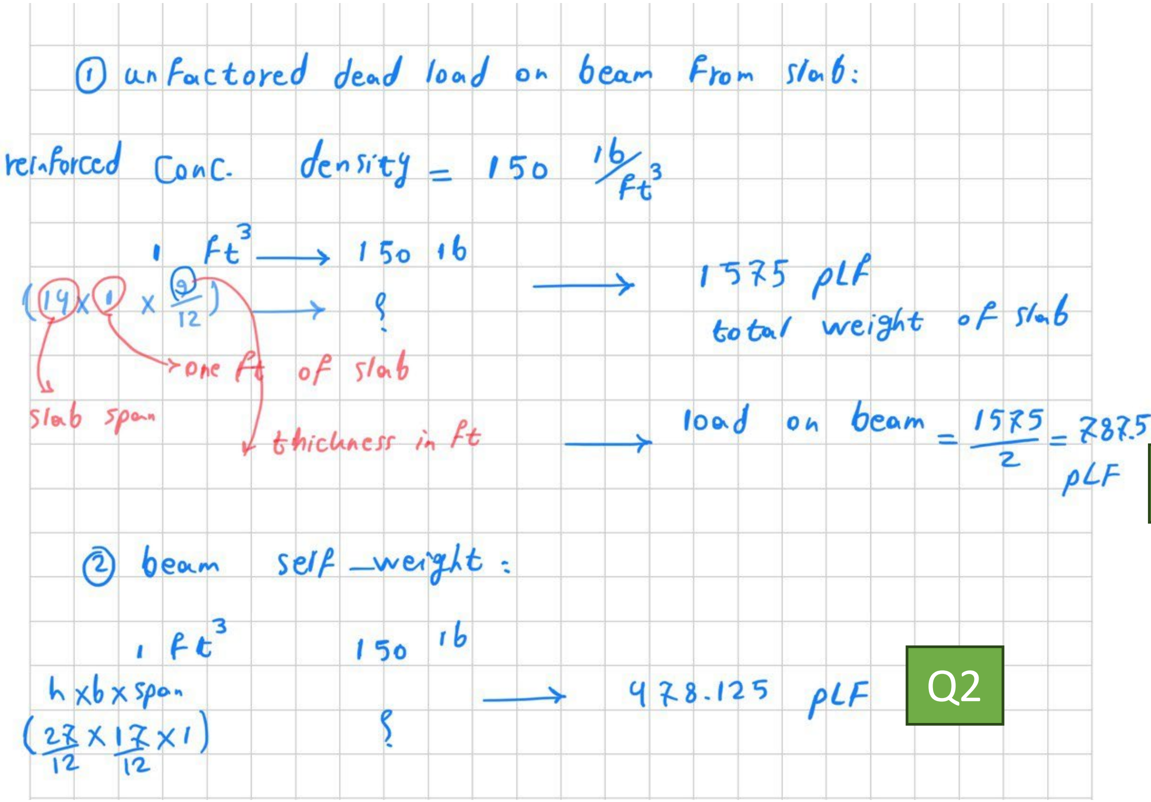


① unfactored dead load on beam from slab:

reinforced Conc. density $= 150 \ \text{lb}/\text{ft}^3$

$1 \ \text{ft}^3 \longrightarrow 150 \ \text{lb}$

$\left(14 \times 1 \times \frac{9}{12}\right) \longrightarrow ? \longrightarrow$ 1575 plf

total weight of slab

14 → slab span

1 → one ft of slab

$\frac{9}{12}$ → thickness in ft

$\longrightarrow$ load on beam $= \frac{1575}{2} = 787.5$ plF

Q1

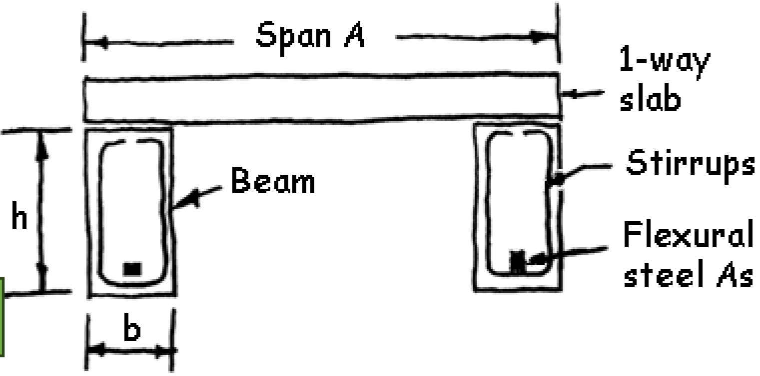
② beam self_weight :

$1 \ \text{ft}^3 \qquad 150 \ \text{lb}$

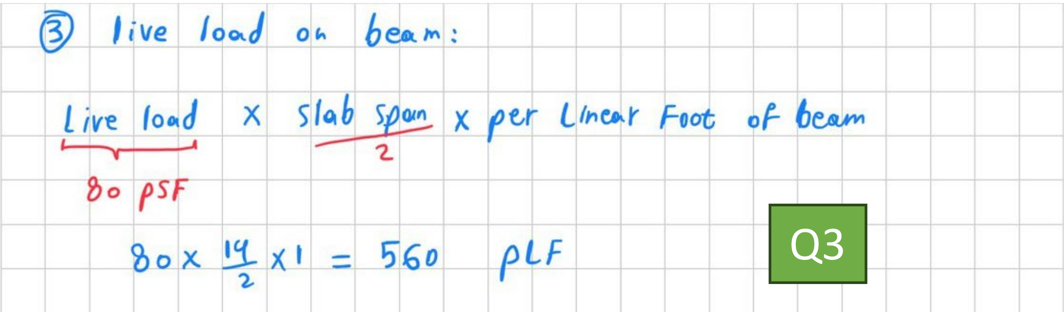
h x b x span

$\left(\frac{27}{12} \times \frac{17}{12} \times 1\right) \qquad ? \longrightarrow$ 478.125 plF

Q2



Provide the solution for the assignment – **HW9**

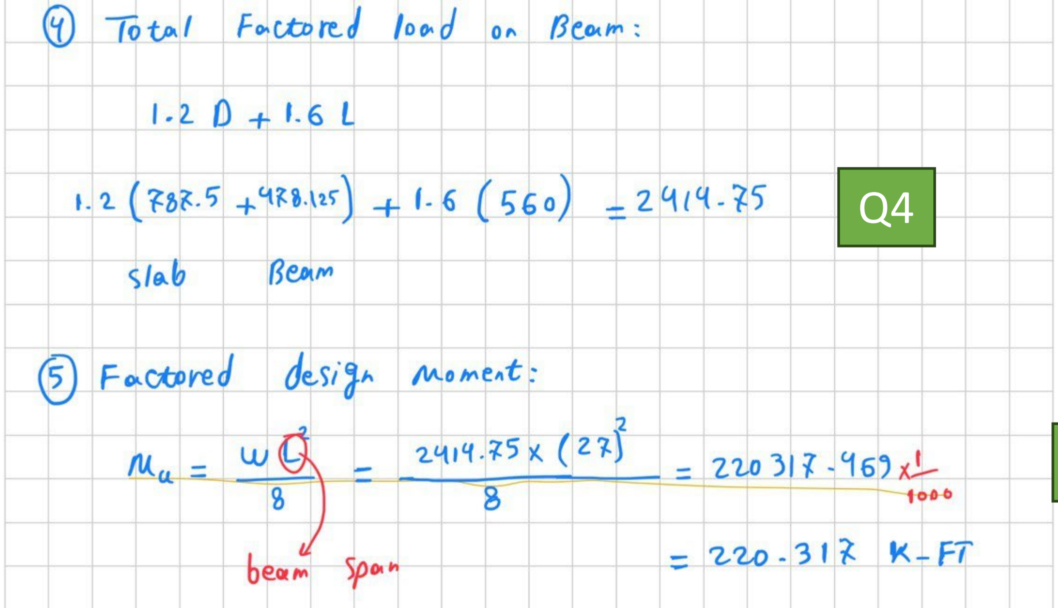


③ live load on beam:

$\underbrace{\text{Live load}}_{80\ \text{PSF}} \times \frac{\text{slab span}}{2} \times \text{per Linear Foot of beam}$

$80 \times \frac{14}{2} \times 1 = 560$ pLF

Q3



④ Total Factored load on Beam:

$1.2\,D + 1.6\,L$

$1.2\,(787.5 + 478.125) + 1.6\,(560) = 2414.75$

slab Beam

Q4

⑤ Factored design moment:

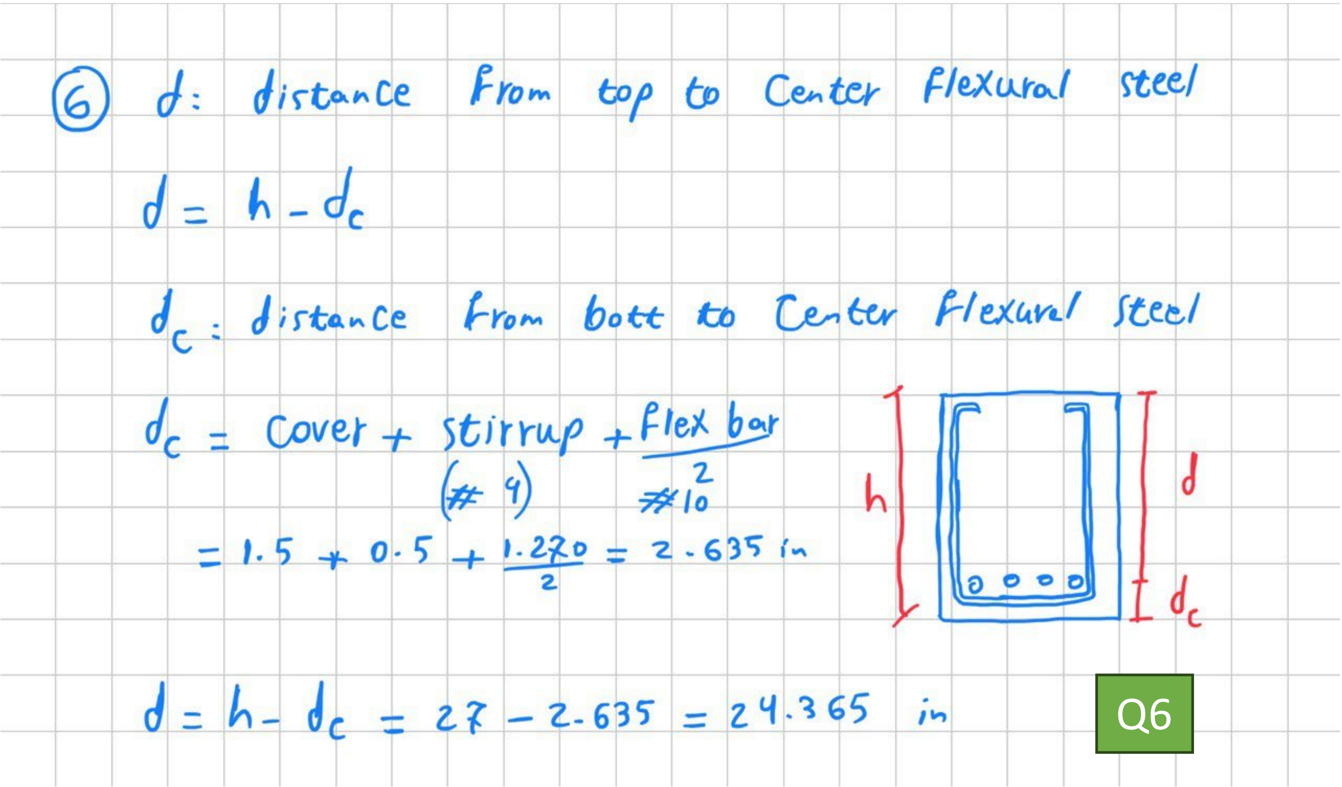
$M_u = \frac{w\,L^2}{8} = \frac{2414.75 \times (27)^2}{8} = 220317.469 \times \frac{1}{1000}$

beam span

$= 220.317$ K-FT

Q5

Provide the solution for the assignment – **HW9**



⑥ d: distance from top to Center flexural steel

$d = h - d_c$

d_c: distance from bott to Center flexural steel

$d_c = \text{Cover} + \underset{(\#4)}{\text{stirrup}} + \underset{\#10}{\frac{\text{flex bar}}{2}}$

$= 1.5 + 0.5 + \frac{1.270}{2} = 2.635 \text{ in}$

$d = h - d_c = 27 - 2.635 = 24.365 \text{ in}$

Q6

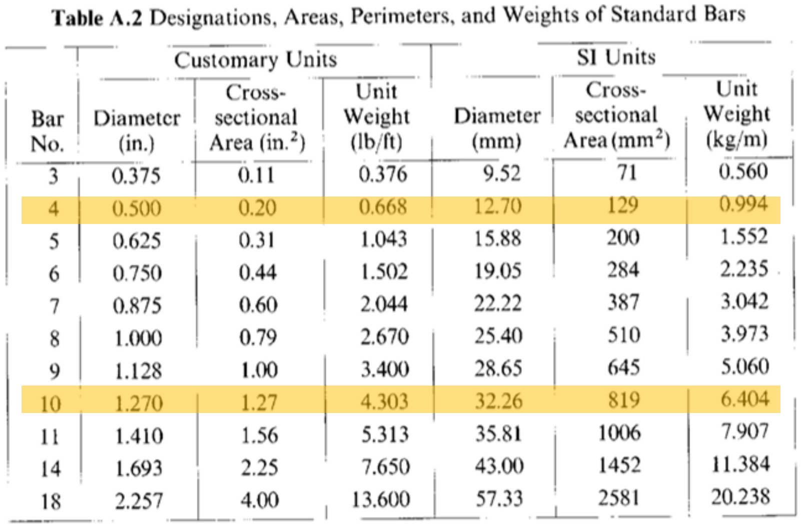
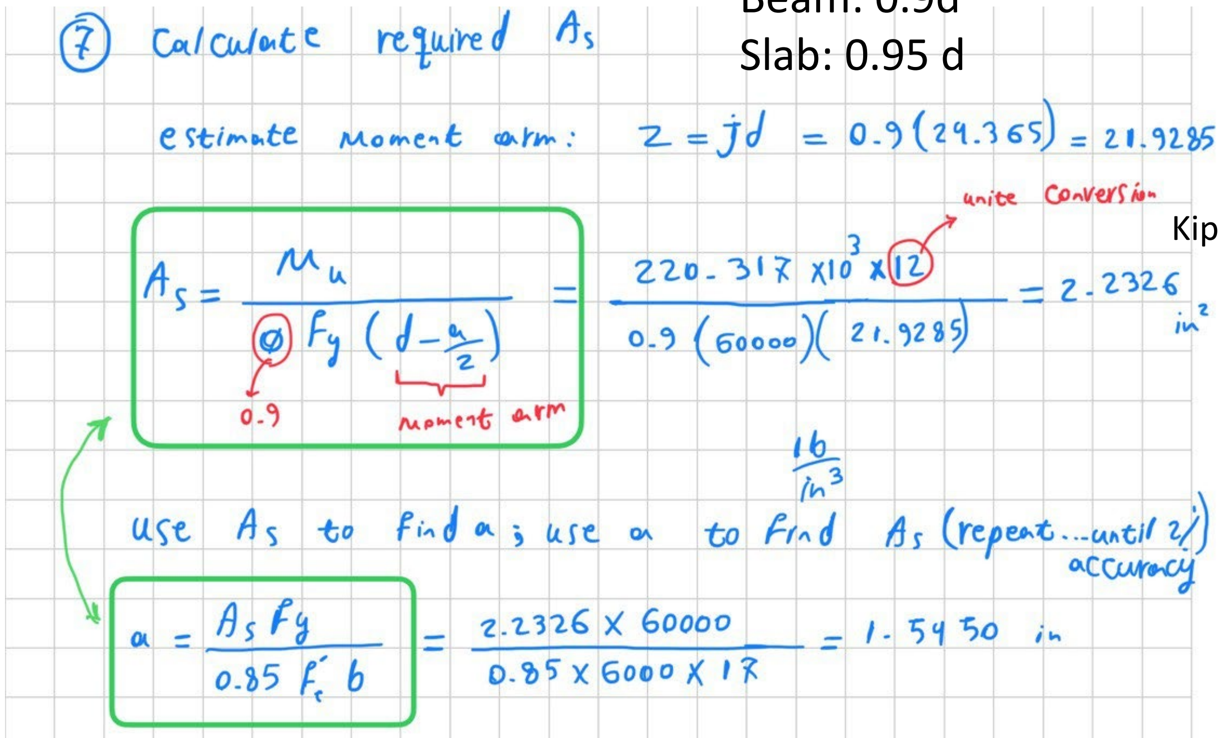


Table A.2 Designations, Areas, Perimeters, and Weights of Standard Bars

	Customary Units			SI Units		
Bar No.	Diameter (in.)	Cross-sectional Area (in.^{2})	Unit Weight (lb/ft)	Diameter (mm)	Cross-sectional Area (mm^2)	Unit Weight (kg/m)
3	0.375	0.11	0.376	9.52	71	0.560
4	0.500	0.20	0.668	12.70	129	0.994
5	0.625	0.31	1.043	15.88	200	1.552
6	0.750	0.44	1.502	19.05	284	2.235
7	0.875	0.60	2.044	22.22	387	3.042
8	1.000	0.79	2.670	25.40	510	3.973
9	1.128	1.00	3.400	28.65	645	5.060
10	1.270	1.27	4.303	32.26	819	6.404
11	1.410	1.56	5.313	35.81	1006	7.907
14	1.693	2.25	7.650	43.00	1452	11.384
18	2.257	4.00	13.600	57.33	2581	20.238

Provide the solution for the assignment – **HW9**

Estimate moment arm:
Beam: 0.9d
Slab: 0.95 d



⑦ Calculate required A_s

estimate Moment arm: $z = jd = 0.9(24.365) = 21.9285$

$$\boxed{A_s = \frac{M_u}{\underset{0.9}{\phi} F_y \underbrace{(d - \frac{a}{2})}_{\text{moment arm}}}} = \frac{220.317 \times 10^3 \times 12}{0.9(60000)(21.9285)} = 2.2326\ in^2$$

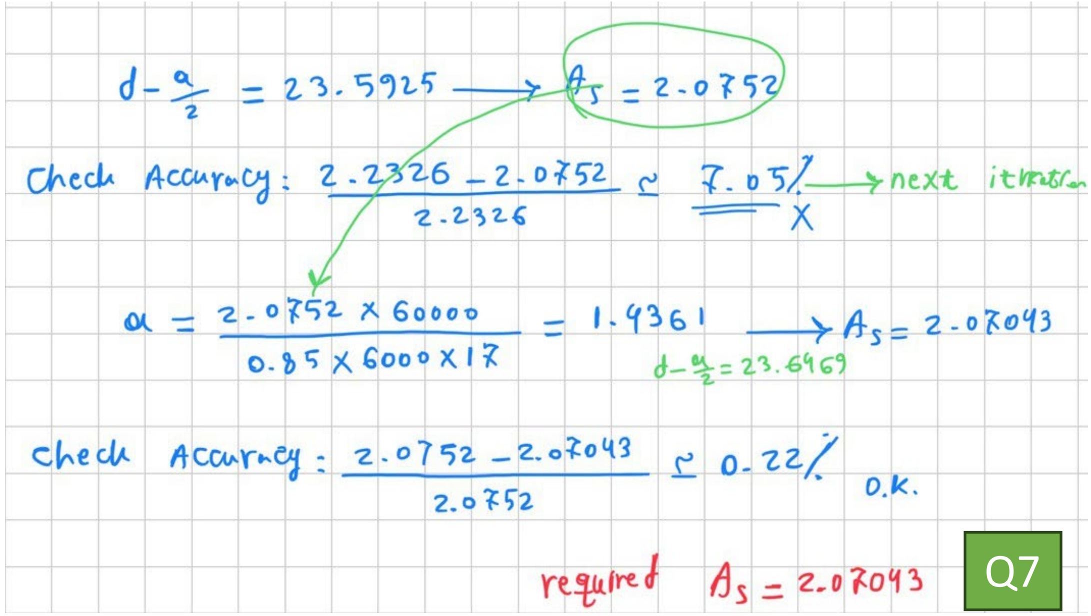
unite Conversion

$\frac{lb}{in^3}$

use A_s to find a; use a to find A_s (repeat...until 2% accuracy)

$$\boxed{a = \frac{A_s F_y}{0.85 f'_c b}} = \frac{2.2326 \times 60000}{0.85 \times 6000 \times 17} = 1.5450\ in$$

Kip-fit to Lb-in



$d - \frac{a}{2} = 23.5925 \longrightarrow A_s = 2.0752$

Check Accuracy: $\frac{2.2326 - 2.0752}{2.2326} \approx 7.05\% \longrightarrow$ next iteration
X

$a = \frac{2.0752 \times 60000}{0.85 \times 6000 \times 17} = 1.4361 \longrightarrow A_s = 2.07043$

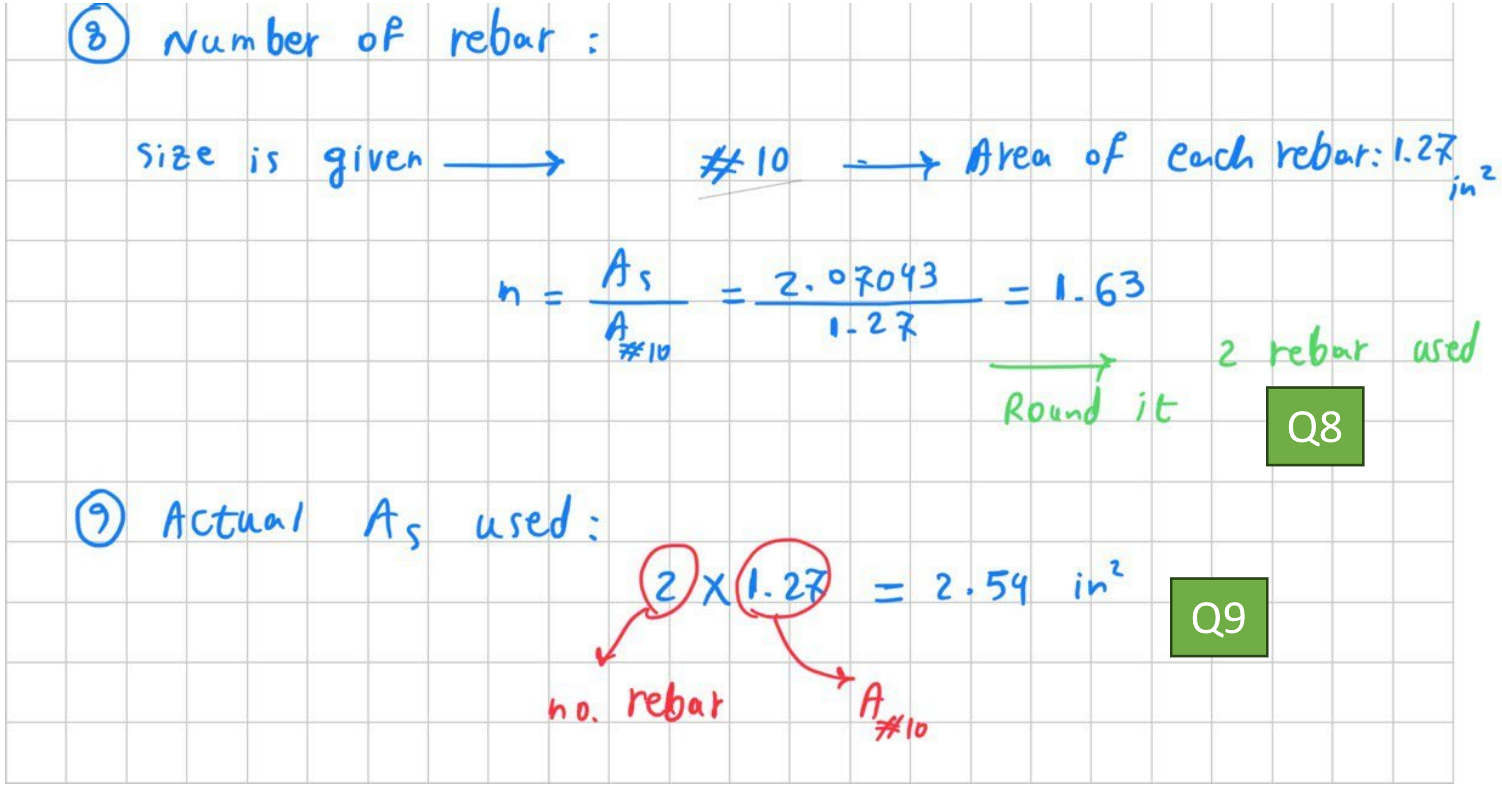
$d - \frac{a}{2} = 23.6469$

Check Accuracy: $\frac{2.0752 - 2.07043}{2.0752} \approx 0.22\%$ O.K.

required $A_s = 2.07043$

Q7

Provide the solution for the assignment – **HW9**



⑧ Number of rebar :

size is given ⟶ #10 ⟶ Area of each rebar: 1.27 in²

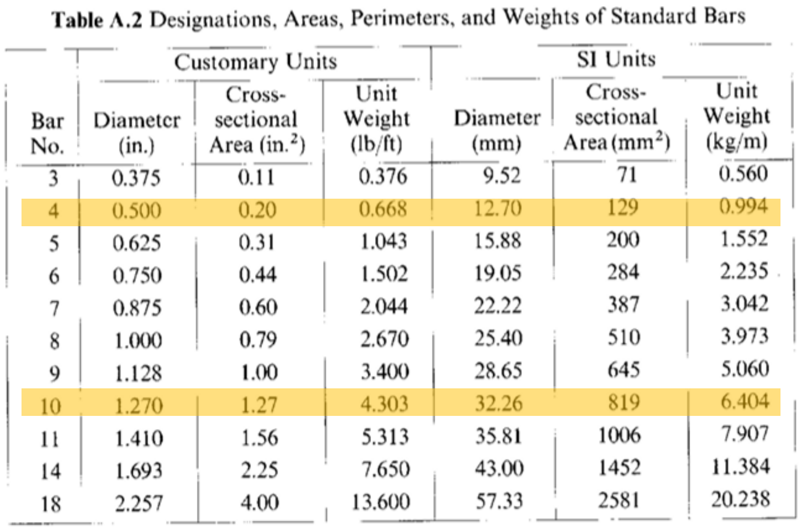
$$n = \frac{A_s}{A_{\#10}} = \frac{2.07043}{1.27} = 1.63 \xrightarrow[\text{Round it}]{} 2 \text{ rebar used}$$

Q8

⑨ Actual A_s used:

$$\underbrace{2}_{\text{no. rebar}} \times \underbrace{1.27}_{A_{\#10}} = 2.54 \text{ in}^2$$

Q9



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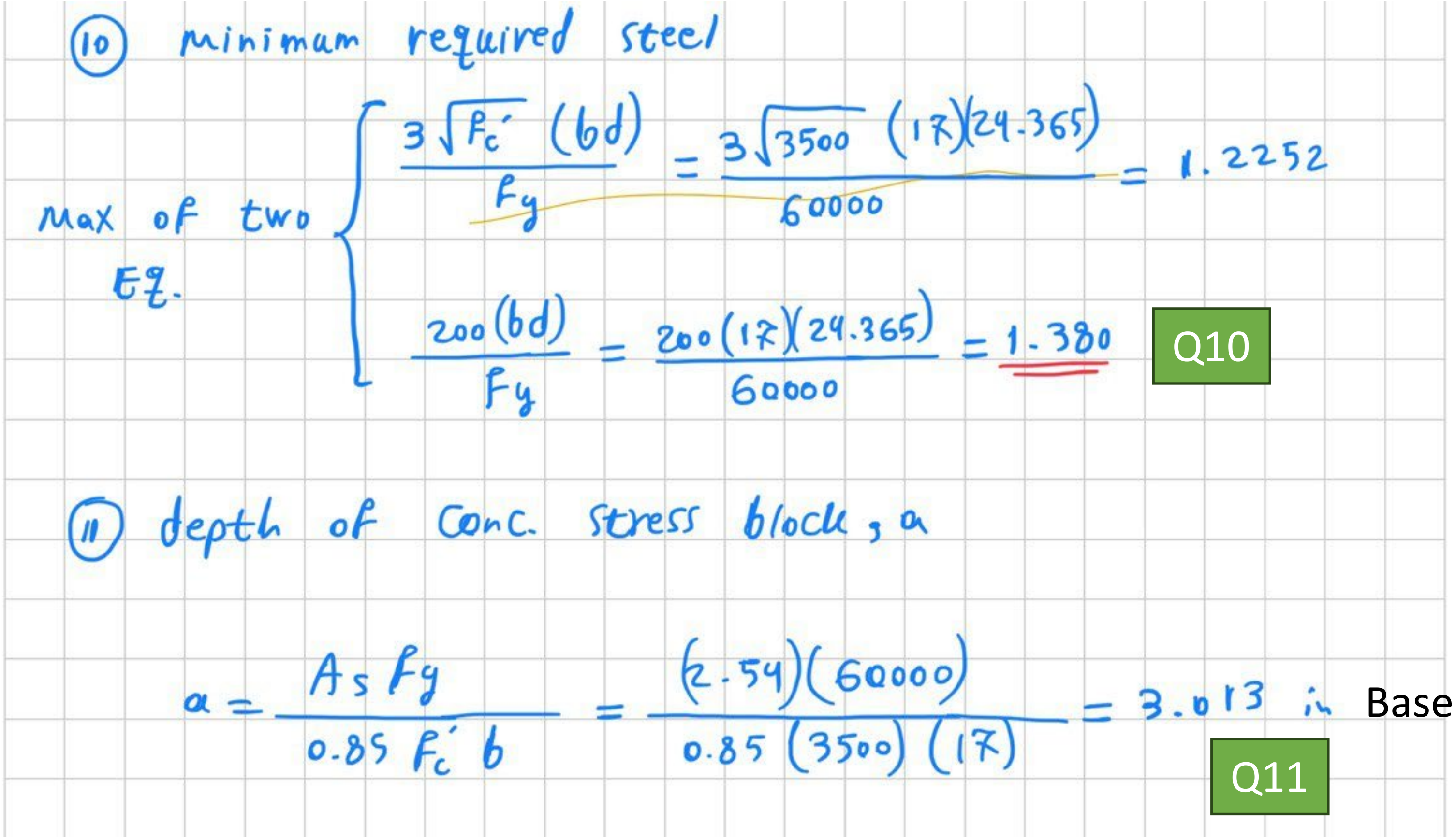


⑩ minimum required steel

Max of two Eq.

$$\frac{3\sqrt{f_c'}\,(bd)}{f_y} = \frac{3\sqrt{3500}\,(17)(24.365)}{60000} = 1.2252$$

$$\frac{200\,(bd)}{f_y} = \frac{200(17)(24.365)}{60000} = \underline{1.380}$$

Q10

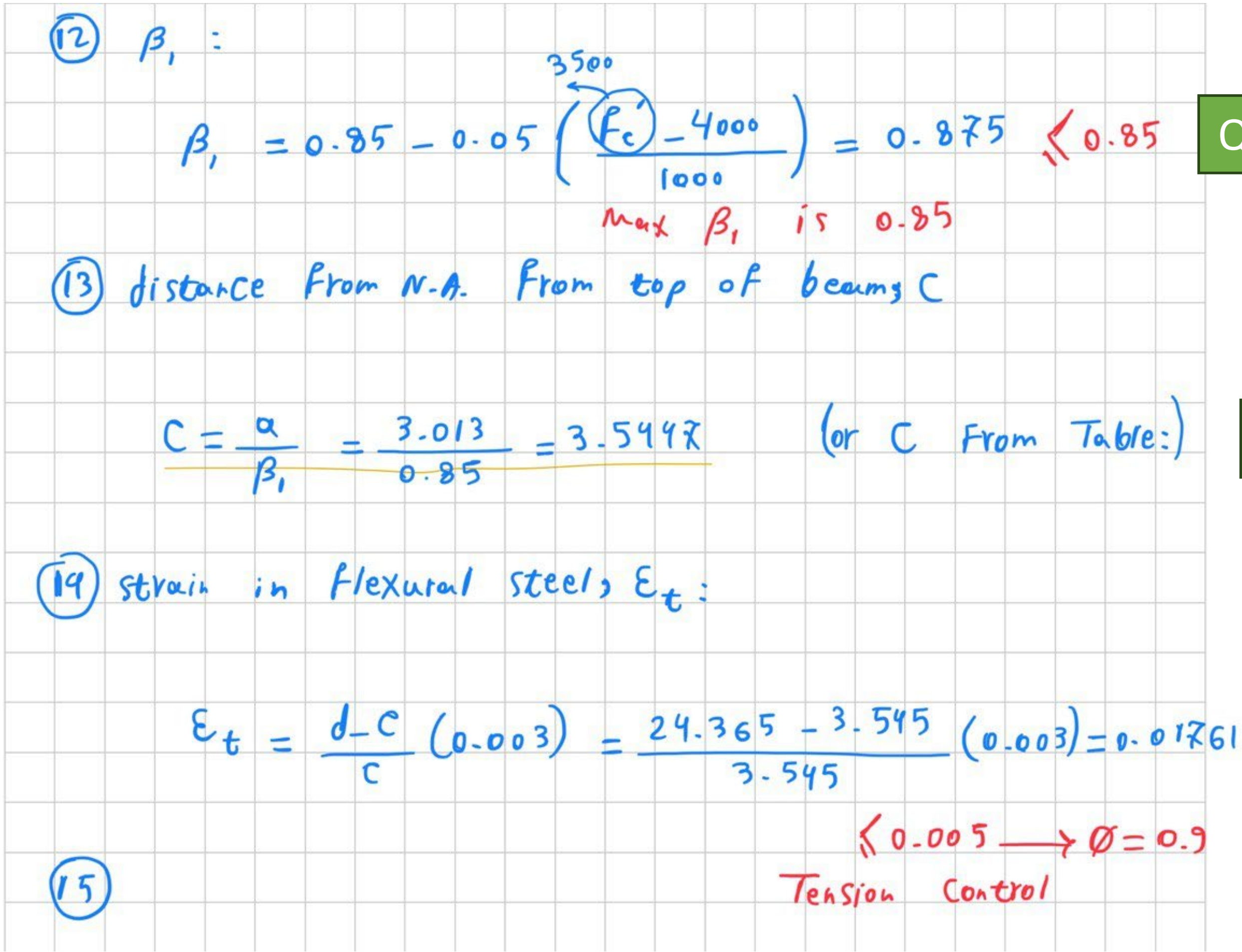
⑪ depth of conc. stress block, a

$$a = \frac{A_s f_y}{0.85 f_c' b} = \frac{(2.54)(60000)}{0.85\,(3500)\,(17)} = 3.013 \text{ in}$$

Based on the Actual As

Q11

Provide the solution for the assignment – **HW9**



⑫ β_1 :

$$\beta_1 = 0.85 - 0.05\left(\frac{\overset{3500}{f'_c} - 4000}{1000}\right) = 0.875 \not< 0.85$$

Max β_1 is 0.85

⑬ distance from N.A. from top of beams C

$$C = \frac{a}{\beta_1} = \frac{3.013}{0.85} = 3.5447$$

(or C From Table:)

⑭ strain in flexural steel, ε_t :

$$\varepsilon_t = \frac{d-c}{c}(0.003) = \frac{24.365 - 3.545}{3.545}(0.003) = 0.01761$$

$\not< 0.005 \longrightarrow \phi = 0.9$

Tension Control

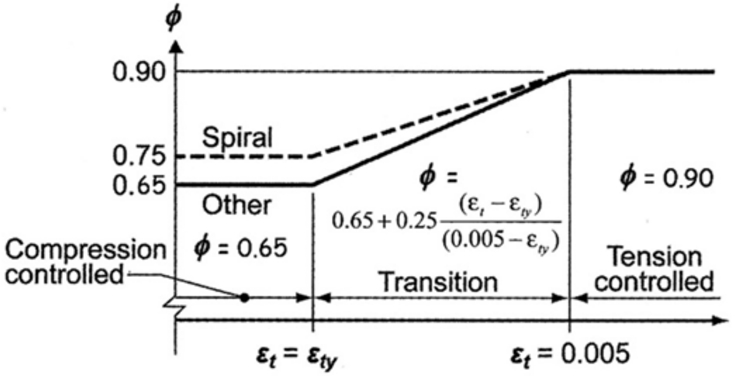
⑮

Q12

Q13

Q14

>0.005



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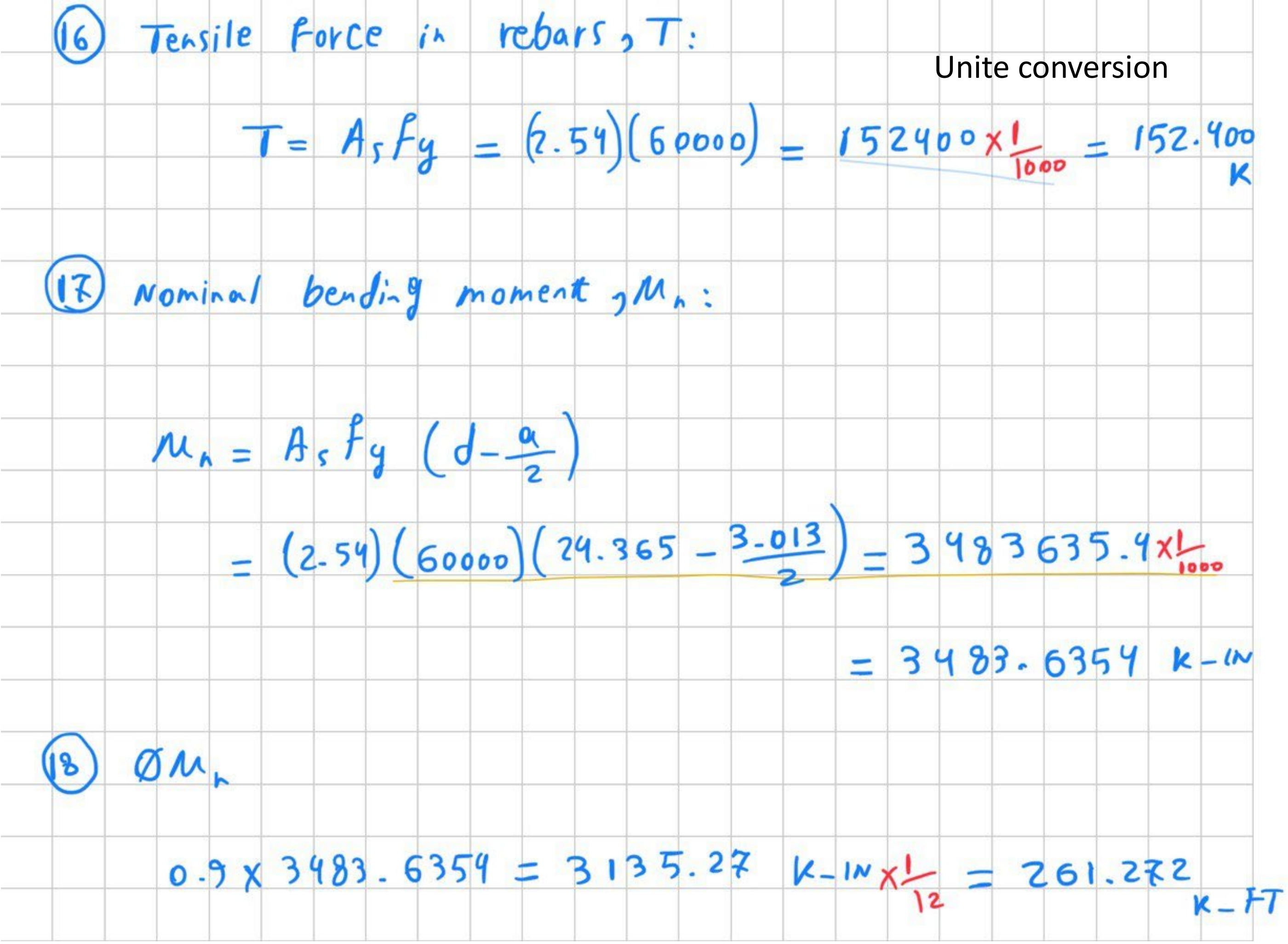


⑯ Tensile Force in rebars, T:

Unite conversion

$$T = A_s f_y = (2.54)(60000) = \underline{152400 \times \frac{1}{1000}} = 152.400\ K$$

Q16

⑰ Nominal bending moment, M_n:

$$M_n = A_s f_y \left(d - \frac{a}{2}\right)$$

$$= (2.54)(60000)\left(24.365 - \frac{3.013}{2}\right) = 3483635.4 \times \frac{1}{1000}$$

$$= 3483.6354\ K\text{-}IN$$

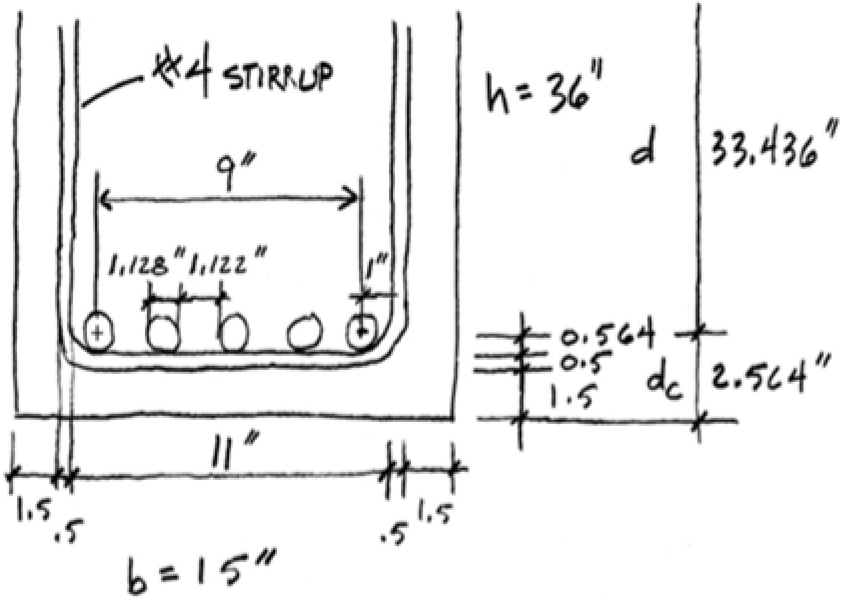
Q17

⑱ $\emptyset M_n$

$$0.9 \times 3483.6354 = 3135.27\ K\text{-}IN \times \frac{1}{12} = 261.272\ K\text{-}FT$$

Q18

Lab : Reinforcement Placement



Flexture rebars #9
Stirrup #4

Description

This project produces a graphic representation of the reinforcing layout of a concrete beam.

Goals

To determine bar diameters and horizontal spacing
To find the placement and dimensions of a shear stirrup.
To establish proper cover for reinforcement.
To draw all beam elements in the proper scale and location.

Lab : Reinforcement Placement

fc = 3000 PSI
fy = 60000 PSI
Stirrup #4
Flexural rebar: five rebar #8
B = 15 in
H = 36 in
Cover = 1.5 in

Procedure

1. For the example beam worked in class, determine the required spacing, s_v and s_h, for the bar size used.
2. For the given stirrup size determine the bend radius for a 90° bend.
3. Make a sketch showing the proper locations of bars and the stirrup including cover.
4. Draw and dimension the depth of the stress block, "a" and the distance to the N.A. from the top of the beam, "c".
5. Dimension and label "d" and "d_c".

ACI 318 Chapter 25.2
Placement of Reinforcement

- Cover (ACI 20.6.1)
- Horizontal spacing in beams, s_h (ACI 25.2.1)
  1 inch
  d_b
  4/3 $d_{agg,max}$
- Vertical spacing in beams (ACI 25.2.2)
  Min 1 inch

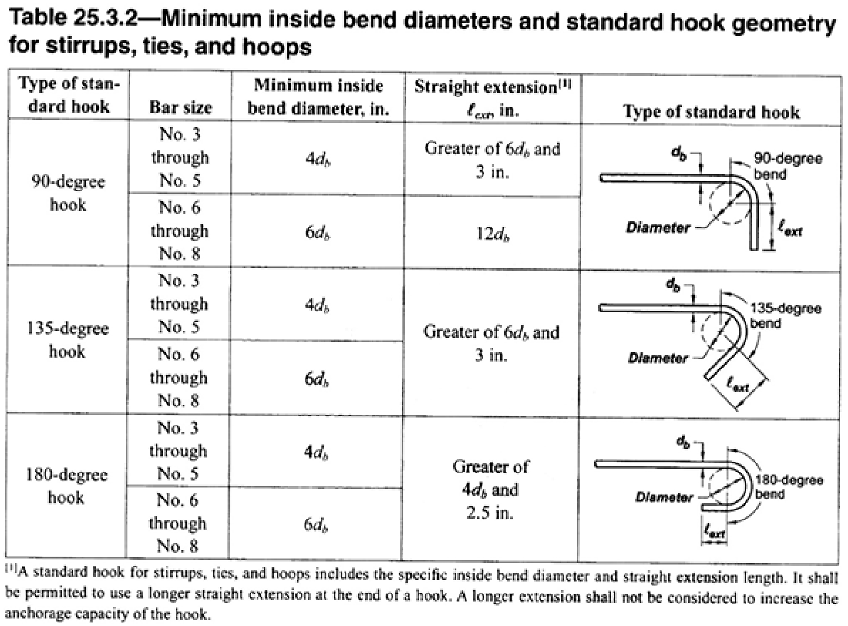
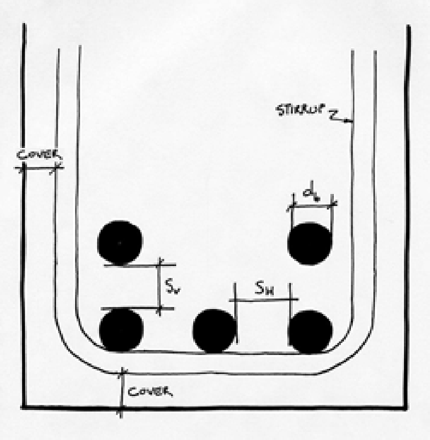


Table 25.3.2—Minimum inside bend diameters and standard hook geometry for stirrups, ties, and hoops

Type of standard hook	Bar size	Minimum inside bend diameter, in.	Straight extension[1] ℓ_{ext}, in.	Type of standard hook
90-degree hook	No. 3 through No. 5	$4d_b$	Greater of $6d_b$ and 3 in.	
	No. 6 through No. 8	$6d_b$	$12d_b$	
135-degree hook	No. 3 through No. 5	$4d_b$	Greater of $6d_b$ and 3 in.	
	No. 6 through No. 8	$6d_b$		
180-degree hook	No. 3 through No. 5	$4d_b$	Greater of $4d_b$ and 2.5 in.	
	No. 6 through No. 8	$6d_b$		

[1] A standard hook for stirrups, ties, and hoops includes the specific inside bend diameter and straight extension length. It shall be permitted to use a longer straight extension at the end of a hook. A longer extension shall not be considered to increase the anchorage capacity of the hook.

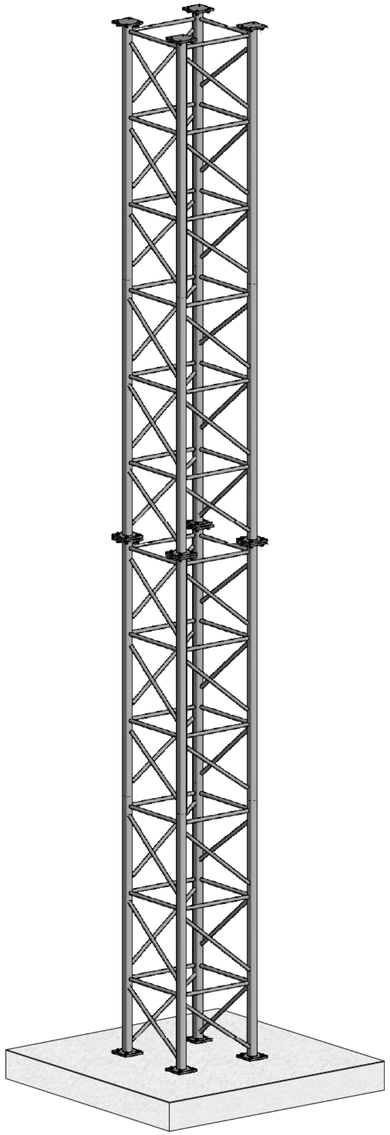


Horizontal Spacing in Beams
ACI 25.2.1
1 inch
db
4/3 max aggregate

Tower Project:

Tower Project final report:

April, 18



Thank you.

Any question?

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