Structure II Recitation 3/29

Concrete Beam Design

Before we start …

Today's Tasks:

Homework Example (Concrete Beam Design)

Lab Session (Reinforcement Placement)

Reminder:

Final Report Due Date: **4/12!!!!!!!!!!**

Architecture 324
Structures II

Prof. Peter von Buelow
Winter 2024

Guidelines for Final Report

After tower testing is over and you begin to write the final reports, here are some guidelines to follow.

1. **Clarity of calculations**: Don't just show numbers but give equations and define variables. Make it legible. Either very neatly by hand or use an equation editor like in Microsoft Word. In Word, go to Insert->Object and select Microsoft Equation. In just a few minutes you should be able to get a hang of producing equations. It's pretty simple to use. If you use Excel make sure you label the equations – don't just show results.

2. **Quality of graphics**. You should have clear line-drawings from programs such as Illustrator, AutoCAD, or similar to produce dimensioned drawings of your models. If using Rhino, use the Make2D function to get clear illustrations. Photographs of your final model before and/or after testing will be required in addition to your drawings.

3. **Submit reports on 8-1/2" x 11" paper only.** Reports on 11x17 paper will not be accepted.

4. **Be clean, polished, and professional.** Write clearly, legibly, and with good grammar. Proofread your report before turning it in. Use appropriate professional language in your report. The mark of a good report is one that is easy to understand by someone not familiar with the project.

5. **Turn in the ORIGINAL graded copy of your Preliminary Report with your Final Report.**

6. In the Revised/Tested Tower section of the Final Report (as listed on the Tower Project Tally Sheet - Final Report Requirements), do all the listed calculations for your tower as tested. That is, you should be analyzing the tower that you actually built and tested. This is not a reiteration of the Preliminary Report. We expect that certain changes were made from the preliminary design in your final design.

7. In calculating the overall tower bucking (buckling of whole tower as opposed to individual member buckling), you should use the Moment of Inertia (I) for the tower as a whole. I is taken from the tower cross-section ignoring any cross bracing (only primary vertical members). Using that value for I, you then apply the Euler Bucking Equation, using K = 1.0 (this assumes the mass of the load has an inertial force that holds the top in place at the moment of buckling).

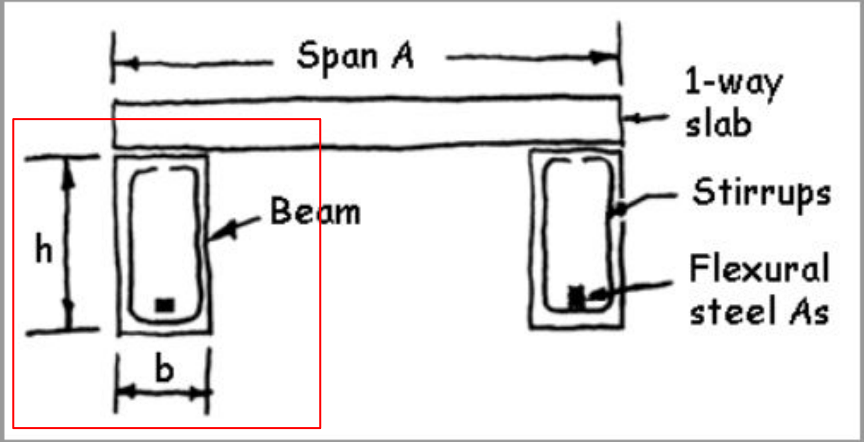
8. Mechanical properties for basswood, are given on the preliminary requirements sheet. If you used materials other than basswood, show what values you used for E, F and density. Cite your sources.

9. Throughout your report, check that your numbers are reasonable. If you get, for example, a predicted load capacity of 70 kips, you probably did something wrong.

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	18 FT
Span of beam	35 FT
Thickness of slab	11 IN
section width, b	20 IN
section height, h	33 IN
max. aggrigate size	0.75 IN
bar size number	7
stirrup bar size number	3
concrete cover	1.5 IN
concrete ultimate strength, f'c	4500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	95 PSF



Designing the steel bar number and actual area

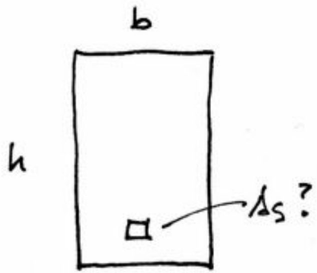
Rectangular Beam Design – **Method 1**

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

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

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

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

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

DL, LL

↓

Required Moment Mu

↓

Required Area A req

↓

Determine Bar Number

↓

Calculate a, β1, c, εt

↓

Calculate final T, M

Q1: Unfactored Dead Load on Beam from Slab

Volume of the Slab x Density / Beam Span

(0.5 x Slab span x Beam span) x Slab Thickness

Density of concrete = 150 pcf

(0.5 x 18 x 35) x (11 / 12) x 150 / 35 = **1237.5 PLF**

Covert Unit (in to ft)

Q2: Unfactored Dead Load on Beam from Beam (Beam Self Weight)

Volume of the Beam x Density / Beam Span

(h x b x Beam Span)

$(33 \times 20 \times 35 / 12^2) \times 150 / 35 =$ **687.5 PLF**

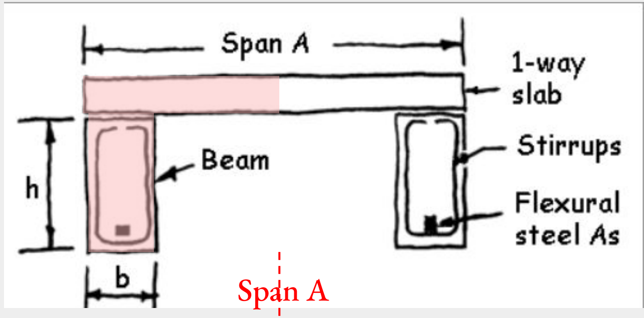
Covert Unit (in to ft)

Q3: Unfactored Live Load on Beam

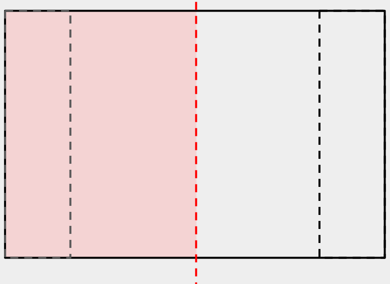
Tributary Area x Floor Live Load / Beam Span

95 x (0.5 x 18 x 35) / 35 = **855 PLF**

DATASET: 1 -2- -3-	
Span of slab	18 FT
Span of beam	35 FT
Thickness of slab	11 IN
section width, b	20 IN
section height, h	33 IN
max. aggrigate size	0.75 IN
bar size number	7
stirrup bar size number	3
concrete cover	1.5 IN
concrete ultimate strength, f'c	4500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	95 PSF



Top View:



Beam Span

Q4: Total Factored Beam Load (wu)

Q1 Q2 Q3

wu
= 1.2 x (DL (Slab) + DL (Beam)) + 1.6 x (LL)
= 1.2 x (1237.5 + 687.5) +1.6 x (855)
= **3678 PLF**

Q5: Factored Design Moment from the Loads (Mu)

Mu = wu x L^2 / 8 = (3678 x 35^2/ 8) / 1000 = **563.19375 ft-k**

Q4 Covert Unit (pounds to kips)

DATASET: 1 -2- -3-

Span of slab	18 FT
Span of beam	35 FT
Thickness of slab	11 IN
section width, b	20 IN
section height, h	33 IN
max. aggrigate size	0.75 IN
bar size number	7
stirrup bar size number	3
concrete cover	1.5 IN
concrete ultimate strength, f'c	4500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	95 PSF

$$1.2w_{DL} + 1.6w_{LL}$$

$$M_u = \frac{(1.2w_{DL} + 1.6w_{LL})l^2}{8}$$

Q6: Distance from Top Beam Edge to Centroid of Flexural Steel (d)

Look at Table A-2 to get the dimensions of the steel bars first,
For my situation:
#7 Flexural Bar, diameter = 0.875 in
#3 Stirrup Bar, diameter = 0.375in

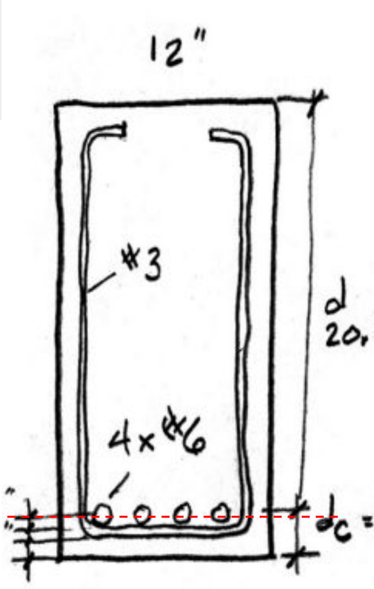
<u>d = Section Height - (Concrete Cover + Stirrup Bar Diameter + Flexural Bar Diameter / 2)</u>

33 - (1.5 + 0.375 + 0.875 / 2) = 33 - 2.3125 = **<u>30.6875 in</u>**

Span of slab	18 FT
Span of beam	35 FT
Thickness of slab	11 IN
section width, b	20 IN
section height, h	33 IN
max. aggrigate size	0.75 IN
bar size number	7
stirrup bar size number	3
concrete cover	1.5 IN
concrete ultimate strength, f'c	4500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	95 PSF

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



Q7: The Final Calculated Area of Steel Required (As req)

Estimate the moment arm z with <u>z = 0.95 x d</u> (slab situation)

z = 0.95 x 30.6875 = 29.153

Mn = Mu / Φ = As x fy x z (Replace z with (d - a/2) to get As)

Q5

Covert Unit (ft-kips to in-pounds)

As = Mu / (Φ x fy x z)

= 563.19375 x 1000 x 12 / (0.9 x 60000 x 29.153)

= 4.293 in^2

Repeat until As is within the 2% accuracy

Use As to get a:

a = As x fy / (0.85 x fc x b) = 4.293 x 60000 / (0.85 x 4500 x 20) = 3.367 in

Q6

Use a to get new As:

As = Mu / (Φ x fy x (d - a/2))

= 563.19375 x 1000 x 12 / (0.9 x 60000 x (30.6875 - 3.367/2))

= 4.315 in

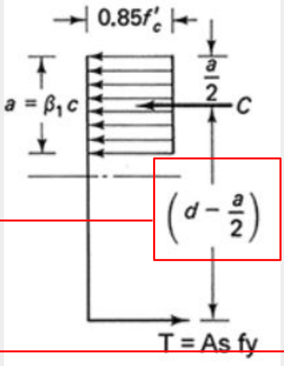
Check if it's within 2% accuracy:

(4.315 - 4.293) / 4.293 = 0.005 < 0.02, It's a pass!

As req = **4.315 in^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

Span of slab	18 FT
Span of beam	35 FT
Thickness of slab	11 IN
section width, b	20 IN
section height, h	33 IN
max. aggrigate size	0.75 IN
bar size number	7
stirrup bar size number	3
concrete cover	1.5 IN
concrete ultimate strength, f'c	4500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	95 PSF



Moment Arm

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

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

Q8: Number of Rebars Used

Use Table A.2 to find the cross sectional area of the flexural bar,

As req / Cross sectional area of the flexural bar = 4.315 / 0.6 = 7.1916

Q7

Round up 7.1916 = **8 rebars**

Q9. Actual, Final Area of Flexural Steel Used (As used)

As used

= Cross sectional area of flexural steel x number of rebars

= 0.6 x 8 = **4.8 in^2**

Q8

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

Bar No.	Customary Units			SI Units		
	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

Q10: Minimum Required Area of Steel (As min)

Calculate the two formulas and choose the bigger one:

(3 x (fc')$^{0.5}$/ fy) x b x d = 3 x 4500$^{0.5}$ / 60000 x 20 x 30.6875 = 2.0586

Q6

200 / fy x b x d = 200 / 60000 x 20 x 30.6875 = 2.0458

Since 2.0586 > 2.0458, **As min = 2.0586 in^2**

DATASET: 1 -2- -3-

Span of slab	18 FT
Span of beam	35 FT
Thickness of slab	11 IN
section width, b	20 IN
section height, h	33 IN
max. aggrigate size	0.75 IN
bar size number	7
stirrup bar size number	3
concrete cover	1.5 IN
concrete ultimate strength, f'c	4500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	95 PSF

As_{min}:

greater of (a) and (b)

(a) $$\frac{3\sqrt{f'_c}}{f_y} b_w d$$

(b) $$\frac{200}{f_y} b_w d$$

Q11: Depth of Concrete Stress Block (a)

Q9

a = (As x fy) / (0.85 x fc' x b)
= (4.8 x 60000) / (0.85 x 4500 x 20)
= **3.7647 in**

Q12: Factor Beta 1 (β1)

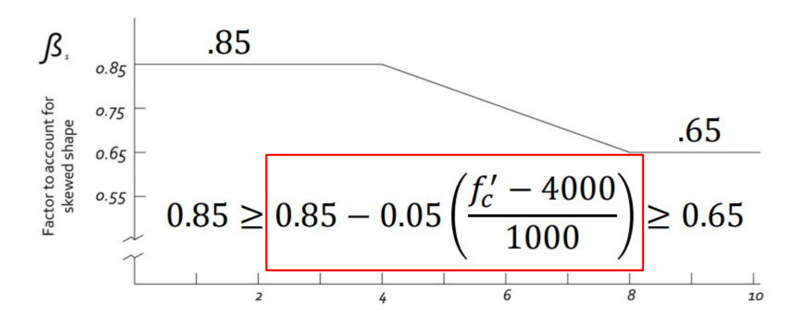
β1 = 0.85 - 0.05 x ((fc' - 4000) / 1000)
= 0.85 - 0.05 x ((4500 - 4000) / 1000) = **0.825**

Q13: Distance to Neutral Axis from Top of the Beam (c)

c = a / β1 = 3.7647 / 0.825 = **4.5633 in**

f'_c	β_1
0	0.85
1000	0.85
2000	0.85
3000	0.85
4000	0.85
5000	0.8
6000	0.75
7000	0.7
8000	0.65
9000	0.65
10000	0.65

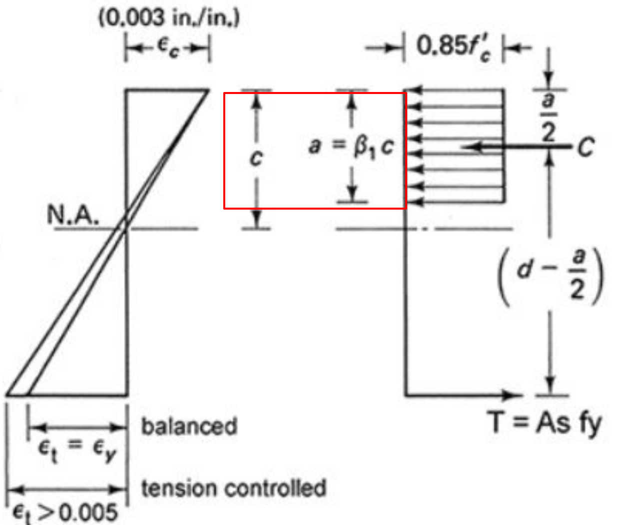
DATASET: 1	-2- -3-
Span of slab	18 FT
Span of beam	35 FT
Thickness of slab	11 IN
section width, b	20 IN
section height, h	33 IN
max. aggrigate size	0.75 IN
bar size number	7
stirrup bar size number	3
concrete cover	1.5 IN
concrete ultimate strength, f'c	4500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	95 PSF



$$0.85 \geq 0.85 - 0.05\left(\frac{f'_c - 4000}{1000}\right) \geq 0.65$$

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

$$a = \beta_1 c$$



Q14: Strain in Flexural Steel (εt)

$\varepsilon t = (d - c) / c \times (0.003)$ = (30.6875 - 4.5633) / 4.5633 x 0.003 = **0.01717**

Q6 Q13

Q15: Strength Reduction Factor (Φ)

Check if εt is bigger than 0.005,

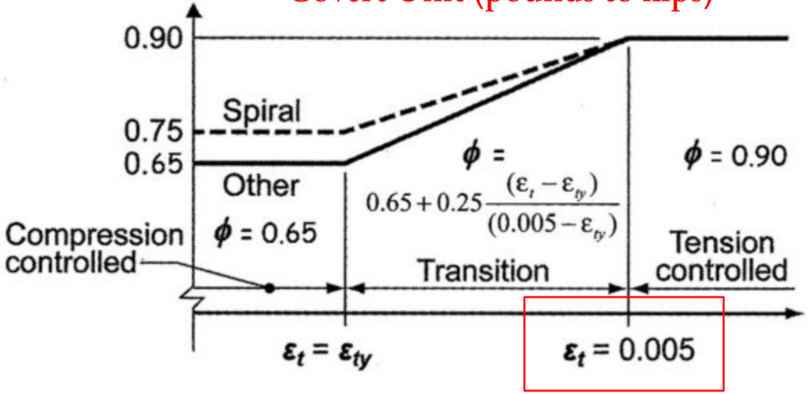
Since my εt is bigger, its tension - controlled, **Φ = 0.9**

Q16: Tensile Force in the Flexural Steel (T)

T = As x fy = 4.8 x 60000 / 1000 = **288 k**

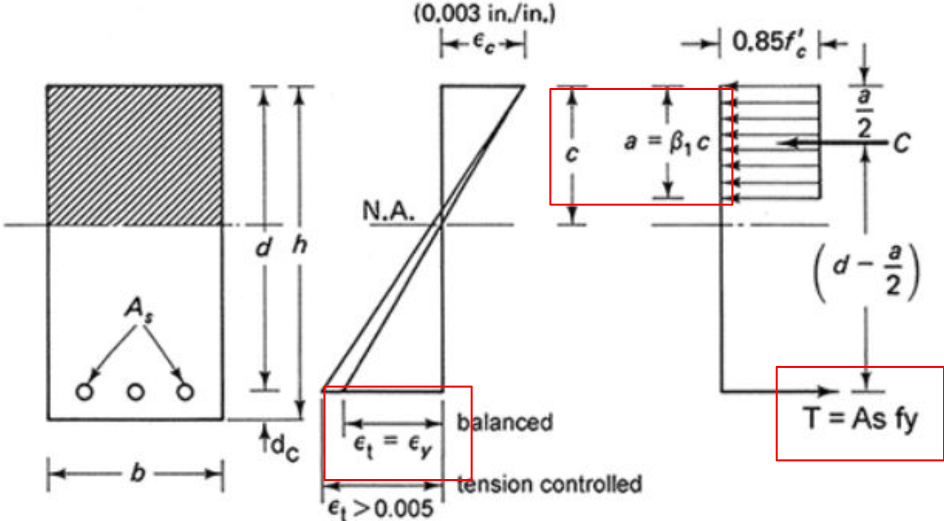
Q9

Covert Unit (pounds to kips)



DATASET: 1	-2- -3-
Span of slab	18 FT
Span of beam	35 FT
Thickness of slab	11 IN
section width, b	20 IN
section height, h	33 IN
max. aggrigate size	0.75 IN
bar size number	7
stirrup bar size number	3
concrete cover	1.5 IN
concrete ultimate strength, f'c	4500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	95 PSF

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



Q17: The Nominal Bending Moment (Mn)

Mn = T x (d - (a / 2)) = 288 x (30.6875 - 3.7647 / 2) = **<u>8295.88 k-in</u>**

Q16 Q6 Q11

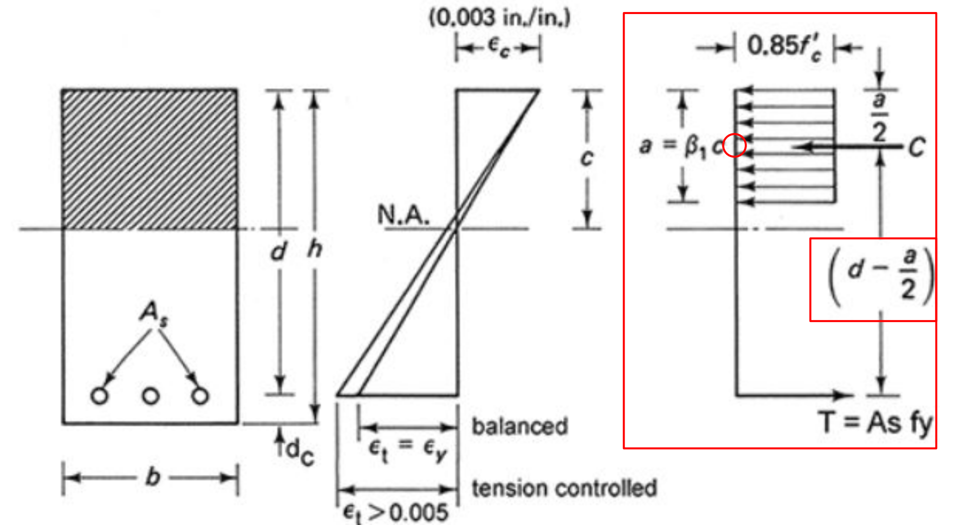
Q18: The Factored Bending Resistance (ΦMn)

ΦMn = 0.9 x 8295.88 / 12 = **<u>622.19 k-ft</u>**

Q15 Q17

Covert Unit (in to ft)

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




Woah, deja vu

Reinforcement Placement

Description

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

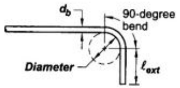
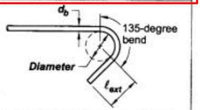
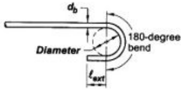
Goals

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.

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".

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.

Lab Sessions:

Goal:

1. Determine minimum spacings (S_H, S_V)
2. Determine bend radius (90 degree)
3. Calculate d & dc
4. Calculate a & c
5. Make a sketch of the beam section

Fc’ = 3000 psi
Fy = 60000 psi
d, agg max = 3/4 in

Stirrup = #4
Flexural Bar = #9
Steel Bar Number = 4

Concrete Cover = 1.5in
Section Width = 15 in
Section Height = 36 in

f'_c	β_1
0	0.85
1000	0.85
2000	0.85
3000	0.85
4000	0.85
5000	0.8
6000	0.75
7000	0.7
8000	0.65
9000	0.65
10000	0.65

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

$$c = \frac{a}{\beta_1}$$

Details of Reinforcement

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

Bar size designation	Nominal cross section area, sq. in.	Weight, lb per ft	Nominal diameter, in.
#3	0.11	0.376	0.375
#4	0.20	0.668	0.500
#5	0.31	1.043	0.625
#6	0.44	1.502	0.750
#7	0.60	2.044	0.875
#8	0.79	2.670	1.000
#9	1.00	3.400	1.128
#10	1.27	4.303	1.270
#11	1.56	5.313	1.410
#14	2.25	7.650	1.693
#18	4.00	13.600	2.257