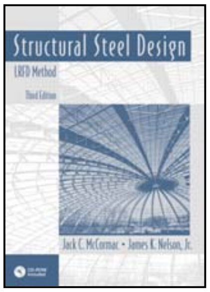
Name: **SAMPLE**

University of Maryland, College Park

Department of Civil & Environmental Engineering

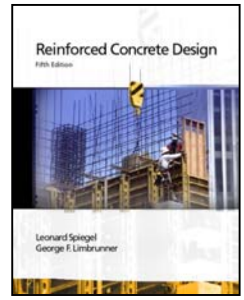
ENCE 355 – Introduction to Structural Design



Honor Pledge Code

"I pledge on my honor that I have not given or received any unauthorized assistance on this assignment/examination."

Signature: ___________________________________



Grading:

Problem 1: ______ / 20

Problem 2: ______ / 20

Problem 3: ______ / 20

Problem 4: ______ / 20

Problem 5: ______ / 20

Problem 6: ______ / 20

Total: ______ / 120

Solution to FINAL EXAM

Friday, December 16, 2002
11:00 AM – 3:00 AM, By DSS

Policies:

1. Write your name on all sheets.
2. Use only the paper provided. Ask for additional sheets, if required.
3. Place only one problem on each sheet (front and back).
4. Draw a box around answers for numerical problems.
5. Give all answers to 3 or 4 significant figures.
6. Include free body diagrams (FBD's) for all equilibrium problems.
7. Closed book / closed notes; ACI and AISC Manuals, and formula sheet are permitted.
8. **SHOW ALL WORK USED TO ARRIVE AT YOUR ANSWER.**

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Problem #1 (20 points)

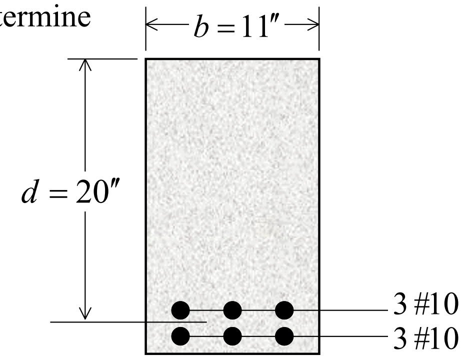
For the reinforced concrete beam cross section shown in the figure, determine

a- The amount of steel required to create the balanced condition.

b- Whether this beam is balanced, underreinforced, or overreinforced? Why?

c- The practical moment capacity ϕM_n of the beam according to the ACI Code.

Use f_y = 40,000 psi for steel and $f'_c = 3{,}000$ psi for concrete.



***** SOLUTION *****

(a) Minimum Width:

If no web reinforcement is to be used, the width must be selected so that the applied shear V_u is no larger than one-half the design shear strength ϕV_c. The calculations are as follows:

$$\text{maximum } V_u = \frac{1}{2}\phi\left(2\sqrt{f'_c}b_w d\right)$$

$$V_u = 1.4(8) + 1.7(11) = 29.9 \text{ kips}$$

Therefore,

$$29.9\times10^3 = \frac{1}{2}\phi\left(2\sqrt{f'_c}b_w d\right) = \frac{1}{2}(0.85)(2)\sqrt{4000}(b)(31)$$

or

$$b = \frac{29.9\times10^3(2)}{(0.85)(2)\sqrt{4000}(31)} = 17.94 \approx \boxed{18 \text{ in.}}$$

Half Dia. of #8 bar

(b) Find b if d = 7.5 in.:

Total depth of beam = 7.5 + 1.5 + 0.5 = 9.5 in. < 10 in, therefore beam is considered shallow and can utilize the full shear strength ϕV_c (ACI Specifications):

$$29.9\times10^3 = \phi\left(2\sqrt{f'_c}b_w d\right) = (0.85)(2)\sqrt{4000}(b)(7.5)$$

or

$$b = \frac{29.9\times10^3}{(0.85)(2)\sqrt{4000}(7.5)} = 37.08 \approx \boxed{37 \text{ in.}}$$

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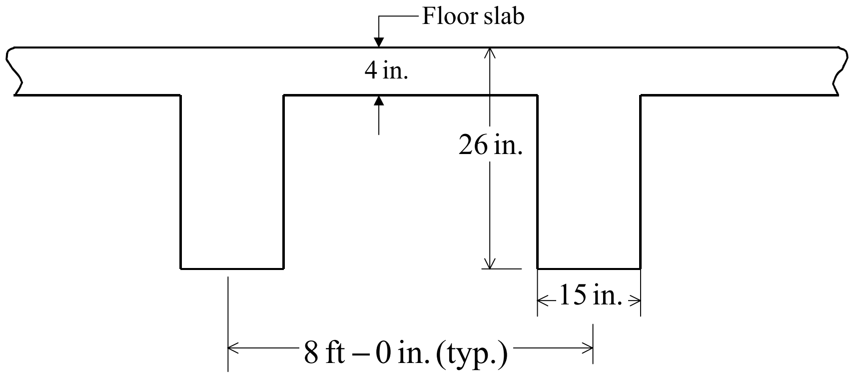
Problem #2 (20 points)
Design a typical interior tension-reinforced T-beam to resist positive moment. A cross section of the floor system is shown. The service loads are 50 $\frac{\text{lb}}{\text{ft}^2}$ dead load (this does not include the weight of the beam and slab) and 325 $\frac{\text{lb}}{\text{ft}^2}$ live load. The beam is on a simple span of 18 ft. Use a compressive strength for concrete $f_c' = 4{,}000$ psi (pound per square inch) and a yield strength for steel f_y = 60,0000 psi.



***** SOLUTION *****

WEIGHT OF SLAB & BEAM

$$\left(\frac{96(4)}{144} + \frac{22(15)}{144}\right)0.150 = 0.74\ k/'$$

$$w_{u(DL)} = 1.4(0.74 + 8(0.05)) = 1.60\ k/'$$

$$w_{u(LL)} = 1.7(8)(0.325) = 4.42\ k/'$$

$$6.02\ k/'$$

(MORE)

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Problem 2 (cnt'd):

$M_u = \frac{6.02(18)^2}{8} = 243.9^{1K}$

ASSUME $d = 26 - 3 = 23''$

DETERMINE b:

$SPAN/4 = \frac{18(12)}{4} = 54''$ ⇐

$16h_f + b_w = 79''$

$SPACING = 96''$

FOR TOTAL EFFECTIVE FLANGE IN COMPRESSION

$\phi M_{n_f} = \frac{0.9(0.85)(4)(54)(4)(23 - \frac{4}{2})}{12} = 1156^{1K}$

$1156^{1K} > 243.9^{1K}$ ∴ RECTANGULAR T-BEAM

REQ'D $\bar{k} = \frac{M_u}{\phi b d^2} = \frac{243.9(12)}{0.9(54)(23)^2} = 0.1138$ KSI

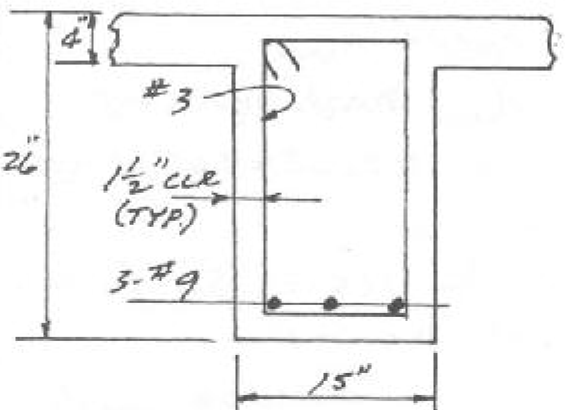
FROM TABLE A-10, REQ'D $\rho = 0.0020$

REQ'D $A_s = 0.0020(54)(23) = 2.48 in^2$ USE 3-#9 ($A_s = 3.0 in^2$)

MIN $b = 9.5''$

ACTUAL $d = 26 - 1.5 - 0.38 - \frac{1.13}{2}$

$= 23.6 > 23.0$ (OK)



CHECK $A_{s,min}$

$A_{s,min} = 0.0033(15)(23.6)$

$= 1.17 in^2 < 3.0 in^2$ (OK)

$A_{s,max} = 0.0425(4)\left[54 + 15\left(\frac{0.503}{4}(23.6) - 1\right)\right] = 14.2 in^2$

$14.2 in^2 > 3.00 in^2$ (OK)

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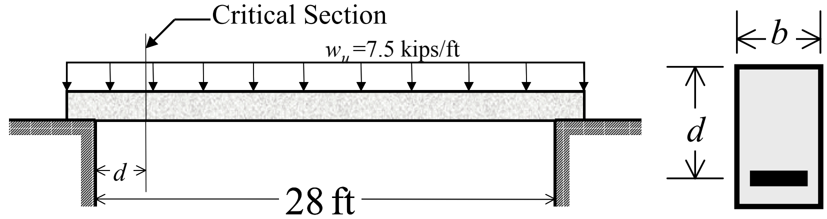
Problem #3 (20 points)
A simply supported, rectangular, reinforced concrete beam having d = 24 in. and b = 15 in. supports a uniformly distributed factored load w_u = 7.5 kips/ft as shown. The given load includes the beam weight. Assume No. 3 single-loop stirrups. Use f_c' = 4000 psi for concrete and f_y = 60,000 psi for steel.

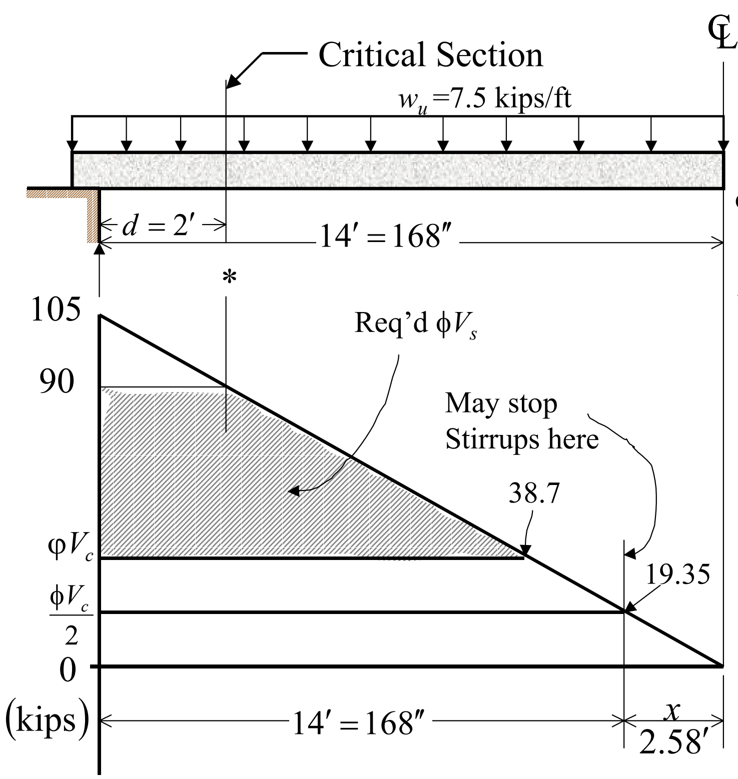
(a) Draw the complete shear (V_u) diagram showing all-important points for stirrup designs (**Hint**: make use of the symmetry of the beam about its mid span).

(b) Using the V_u diagram, select the stirrup spacing to use at the critical section (d distance from the face of the left support), and the location along the beam where stirrups may be stopped.



***** SOLUTION *****

(a) Complete shear diagram:



$$V_u = \frac{w_u L}{2} = \frac{7.5(28)}{2} = 105\text{ k}$$

$$\phi V_c = \phi 2\sqrt{f_c'}bd = \frac{0.85(2)\sqrt{4000}(15)24}{1000}$$

$$= 38.7\text{ k}$$

$$\frac{\phi V_c}{2} = 19.35\text{ k}$$

$$V_u^* = 105 - 2(7.5) = 90\text{ k}$$

$$V_u^* > \frac{\phi V_c}{2}, \therefore \text{stirrups req'd}$$

$$x = \frac{19.35}{7.5} = 2.58\text{ ft}$$

#3 stirrups ($A_v = 0.22\text{ in}^2$)

(b) Stirrups spacing and location of not needed stirrups:

$$s = \frac{\phi A_v f_y d}{\text{req'd}\phi V_s^*} = \frac{0.85(0.22)(60)(24)}{90 - 38.7} = \boxed{5.25\text{ in.}}$$

Location along the beam where stirrups may be stopped = 14 - 2.58 = **11.42 ft from left f.o.s**

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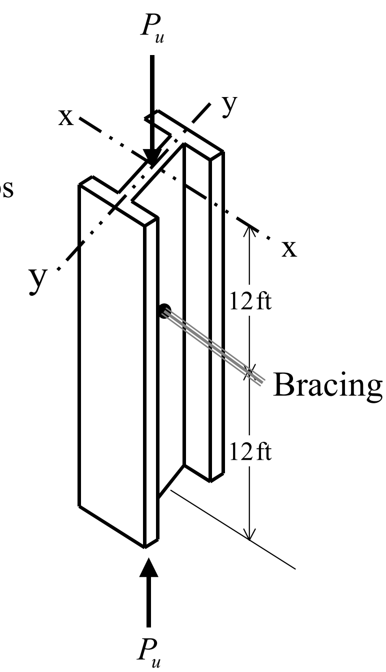
Problem #4 (20 points): A steel W section is to be selected to support axial compressive dead and live loads of P_D = 400 kips and P_L = 700 kips, respectively. The member, which is to be 24 ft long and to be pinned top and bottom, has lateral support (pinned) supplied in the weak direction at middepth as shown. Select the lightest W12 section using the LRFD Manual and A572 Grade 50 steel.

***** SOLUTION *****



Trying W12's:
P_u = 1.4 (400) = 560 kips
P_u = 1.2 (400) + 1.6 (700) = 1600 kips ← controls
Entering LRFD tables with K_yL_y = 12 ft, F_y = 50 ksi and P_u = 1600 kips

Try W12 × 152 ($\frac{r_x}{r_y} = 1.77$)

Equivalent $K_yL_y = \frac{K_xL_x}{\frac{r_x}{r_y}} = \frac{24}{1.77} = 13.56 \text{ ft} > K_yL_y = 12$ ft

Therefore,
Reenter tables with K_yL_y = 13.56 ft and P_u = 1600 kips
And hence,

Select W12 ×170

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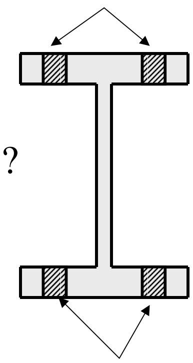
Problem #5 (20 points): Neglecting block shear, select the lightest steel W14 section available to support a factored tensile load P_u of 664 kips. The member is to be 30 ft long and is assumed to have two lines of holes for 1-in. standard bolts in each flange as shown. There will be at least three bolts in each line 4 inch on center. Use F_y = 50 ksi and F_u = 65 ksi. (Note that $U = 1 - \frac{\bar{x}}{L} \le 0.90$)

***** SOLUTION *****



$$\min A_g \text{ required} = \frac{P_u}{\phi_t F_y} = \frac{664}{0.9(50)} = 14.76 \text{ in}^2$$

Assume $U = 0.9$

$$\min A_g = \frac{P_u}{\phi_t F_u U} + \text{estimated area of holes}$$

$$= \frac{664}{0.75(65)(0.9)} + 4\left(1 + \frac{1}{8}\right)(0.72) = 18.37 \text{ in}^2 \Leftarrow$$

$$\min r = \frac{L}{300} = \frac{12(30)}{300} = 1.20 \text{ in}$$

Try W14 × 68 (A_g = 20.0 in^2, t_f = 0.720 in, r_y = 2.46 in)

Checking:

$\phi_t P_n = 0.9(50)(20) = 900 \text{ kips} > 664 \text{ kips}$ OK

$A_n = 20 - 4\left(1 + \frac{1}{8}\right)(0.72) = 16.76 \text{ in}^2$

$\bar{x} = \bar{y}$ for a WT7 × 34 = 1.29 in

$U = 1 - \frac{\bar{x}}{L} = 1 - \frac{1.29}{8} = 0.839 < 0.9$ OK

$\phi_t P_n = 0.75(65)(0.839)(16.76) = 685.5 \text{ kips} > 664 \text{ kips}$ OK

$\frac{L}{r} = \frac{12(30)}{2.46} = 146.3 < 300$ OK

Therefore,

Select W14 ×68

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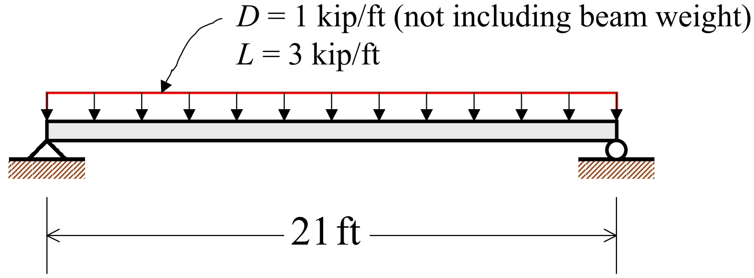
Problem #6 (20 points): Using the LRFD Manual, select the lightest steel W beam section for the span and loading shown in the figure, assuming full lateral support is provided for the compression flange by the floor slab above (i.e., $L_b = 0$) and yield strength of steel $F_y = 50$ ksi.



***** SOLUTION *****

Beam weight estimate:

$$w_u(\text{beam weight excluded}) = 1.2(1.0) + 1.6(3.0) = 6.0\,\frac{\text{kips}}{\text{ft}}$$

$$M_u = \frac{w_u L^2}{8} = \frac{6(21)^2}{8} = 330.75\text{ ft-kips}$$

$$Z_{\text{required}} = \frac{M_u}{\phi_t F_y} = \left(\frac{330.75}{0.90(50)}\right)\times 12 = 88.2\text{ in}^3$$

Referring to Table 5-3 in Part 5 of the LRFD Manual, a W21 × 44 ($Z_x = 95.8$ in^3) is the lightest section available.

Assume beam weight = 44 lb/ft, therefore the design distributed load w_u will be revised as follows:

$$w_u = 1.2(1.044) + 1.6(3) = 6.05\,\frac{\text{kips}}{\text{ft}}$$

$$M_u = \frac{w_u L^2}{8} = \frac{6.05(21)^2}{8} = 333.5\text{ ft-kips}$$

$$Z_{\text{required}} = \left(\frac{333.5}{0.90(50)}\right)\times 12 = 88.9\text{ in}^3 < Z = 95.8\text{ in}^3 \quad \text{OK}$$

Therefore,

USE W21 × 44 with F_y = 50 ksi