I AM A GRADUATING SENIOR AND MY EXAM MUST BE GRADED EARLY: YES  NO

1) DO NOT put your completed work on the desk next to you or anywhere else where it can be seen. If I come by and see it I will confiscate it and give you zero credit for that problem. Or worse, someone will copy your work and I won’t be able to tell which of you did the copying and accuse the wrong person. Place it face down on your desk under your existing work. Please take this instruction very seriously.

2) Please remove your hat. If it is part of your head, turn it around backwards.

3) Please note that if your work is not legible, if it uses a font size smaller than 12 point, or if I cannot follow your logic at a glance, it will receive zero credit. I will also expect you to solve all problems in the order that I taught you, with a complete explanation of what you are attempting to do, at all times during the solution.

Problem 1) For the bolt group shown, utilizing Ultimate Strength Analysis, I have determined the location of the Instantaneous Center of Rotation (I.C.) as shown. Based on this location, determine the force in the lower left hand bolt, and the angle at which this force is directed, at ultimate load. The force $P = 260$ kips, $x = 2''$ and $y = 3''$.

Problem 2) Design the bolts required to carry the full tensile strength of a 8" wide by ½" thick plate of A242 steel. The plate is gas cut. Use bolts in pairs, centered down the plate, as shown. Note that I have no idea how many bolts will be required, and the number shown is no indication thereof. Not to scale. You may omit block shear rupture and strength of the gusset plate in your calculations. Use 3/4" A490 bolts.

Problem 3) A 20 foot long W12x50 beam-column of A36 steel is symmetrically loaded with a triangular load about the strong axis, as shown. The column loads are 400 kips, and the triangular load is 3 kips per foot. Calculate the LRFD moment amplification factor for this beam-column, and verify it using the iterative method shown in class.

Problem 4) Design the lightest 22 foot long wide flange to carry a factored concentrated load of 100 kips 8 feet from the left end of the beam, and a 50 kip factored load 5 feet from the right end of the beam. The beam is simply supported and laterally braced at the ends only. Use A992 steel and include the weight of the beam. You may omit web crippling, web yielding, shear and local buckling in your design.
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Problem 1) An 18 foot long W12x53 beam column of A992 steel is symmetrically loaded with a triangularly distributed load about the strong axis, as shown. The column loads are 350 kips, and the triangular load is 4 kips per foot. Calculate the LRFD moment amplification factor for this beam-column, and verify it using the iterative method shown in class.

Problem 2) Design the lightest 20 foot long wide flange to carry a concentrated factored 100 kip load 8 feet from the left end of the beam, and a 50 kip factored load 5 feet from the right end of the beam. The beam is simply supported and laterally braced at the ends only. Use A992 steel, and include the weight of the beam. You may omit web crippling, web yielding, shear and local buckling in your design.

Problem 3) For the bolt group shown, utilizing Ultimate Strength Analysis, I have determined the location of the Instantaneous Center of Rotation (I.C.) as shown. Based on this location, determine the force in the lower left hand bolt, and the angle at which this force is directed, at ultimate load. The force P = 260 kips, x = 2” and y = 3”.

Problem 4) Design the bolts required to carry the full tensile strength of an 8” wide by ½” thick plate of A242 steel. The plate is gas cut. Use bolts in pairs, centered down the plate, as shown. Note that I have no idea how many bolts will be required, and the number shown is no indication thereof. Not to scale. You may omit block shear rupture and strength of the gusset plate in your calculations. Use 3/4” A490 bolts.
**Problem Bolt**

Design Bolts

8" x \( \frac{1}{2} " \) PL

A 242 steel

\[ A_e = (8 - 2(\frac{1}{8})) \left( \frac{1}{2} \right) = 3.125 \text{ in}^2 \]

- Bolt
- B.S. 12
- Gage

\[ F_s = 50 \text{ ksi} \]

\[ 0 \leq 70 \text{ ksi} \]

**Shear Strength**

\[ \sigma_s = \frac{V}{A_b} = \frac{F_v}{0.412 \text{ in}^2} = 60 \text{ ksi} \]

\[ \phi = 0.75 \]

**Bolts**

\[ \frac{180^k}{24.84} = 7.06 \text{ kips} \]

\[ \phi A_p = 164 \text{ kips} \]

\[ F_U = 70 \text{ ksi} \]

\[ A_e = 3.125 \text{ in}^2 \]

**Spinning req.**

\[ \left( 2 \frac{3}{8} \right) = 2" \text{ spig} \]

\[ 2(34.94) + 8(37.4) = 368 \text{ kips} \text{ OK} \]

\[ 1.25" \leq 1.5" \text{ OK} \]
Problem 11

\[ A_{242} = F_u \times 50 \quad F_u = 70 \]

\[ \Phi P_n = \Phi F_u A_g = 0.9(60)(8 \times 5) = 180 \text{kN} \]

\[ N_{34F} = \Phi F_u A_n = 0.75(70)(5)(8 - 2(4 + 6)) = 164.1 \text{kN} \]

DESIGN FOR 164.1 kN

**Shear Strength of Bolt**  (Assume threads not engaged)

\[ A_o = \frac{\pi (d_o/2)^2}{4} = 1.42 \text{ in}^2 \quad \Phi P_n = \Phi F_u A_o = 675(60)(.942) = 19.89 \text{ kN/bolt} \]

**Bearing Strength**

**End Holes**

\[ h = d + \frac{h}{4} = \frac{3}{4} + \frac{3}{4} = \frac{13}{4} \quad L_e = L_e - \frac{7}{2} = 1.5 - \frac{13}{2} = 1.094 \]

\[ \Phi P_n = \text{smaller} \left\{ \begin{aligned} \Phi (1.2L_e + t_0) &= 0.75(1.2)(1.094)(70) = 34.92 \text{ k/bolt} \\ \Phi (2.4d_L + t_0) &= 0.75(2.4)(70)(70) = 47.25 \text{ k/bolt} \end{aligned} \right. \]

**Other Holes**

\[ h = d + \frac{h}{6} = \frac{13}{6} \quad L_e - h - 2 + \frac{h}{6} = 12.46 \]

\[ \Phi P_n = \text{smaller} \left\{ \begin{aligned} \Phi (1.2)(1.2)(70)(70) &= 37.40 \quad \text{prescribed} \end{aligned} \right. \]

**Bolts Control**

\[ 164.1 \text{kN} / 19.89 \text{ kN/bolt} = 8.25 \text{ bolts} \quad \text{USE 10 bolts, 2 row of 5} \]
Calculate moment amplification factor

\[ W = 12 \times 53 \quad I_x = 425 \text{ in}^4 \]

\[ S_1 = \frac{W L^3}{6OE I} = \frac{\left(4 \text{ k/ft}\right)(18 \text{ ft})(18 \text{ ft} \times 12\text{ in/ft})^3}{60(29 \times 10^3 \text{k/in}^2)(425 \text{ in}^4)} = 0.491 \text{ in LRFD pgs 162} \]

\[ M_{\text{max}} = \frac{W \ell}{6} = \frac{(4 \text{ k/ft})(18 \text{ ft})(1.8 \text{ ft})}{6} = 108 \text{ kft} \]

\[ \text{Maded axial} = P \delta = \frac{350 \text{k}(0.49 \text{ in})}{12 \text{ in/ft}} = 14.32 \text{ kft} \]

\[ S_2 = 0.491 \left(1 + \frac{14.32}{100}\right) = 0.561'' \]

\[ \text{Maded axial} = P \delta = \frac{350 \text{k}(0.561)}{12 \text{ in/ft}} = 16.37 \text{ kft} \]

\[ S_3 = 0.491 \left(1 + \frac{16.37}{100}\right) = 0.571 \text{ in} \]

\[ \text{Maded} = P \delta = \frac{350 \text{k}(0.571)}{12} = 16.71 \text{ kft} \]

\[ S_4 = 0.491 \left(1 + \frac{16.71}{100}\right) = 0.573 \text{ in} \]

\[ P_a = \frac{\pi^2 E I}{(K L)^2} = \frac{\pi^2(29000)(425)/(18 \times 12)^2}{2607 \text{k}} \]

\[ B_{1x} = \frac{108 \text{ kft} + (0.573 \text{ in/12 in/ft})(350 \text{k})}{108 \text{ kft}} = 1.155 \]

\[ P_{1x} = \frac{1}{(1 - 350/2607)} = 1.155 \]
Amplification Factor

\[ \text{Shape} = \text{W12x53} \]

\[ I \quad \text{about axis of bending (weak or strong)} = 425 \quad \text{In}^4 \]

\[ K = 1 \quad \text{ratio} \]

\[ L = 18 \quad \text{feet} \]

Using LRFD Method:

<table>
<thead>
<tr>
<th>Peuler about axis of bending</th>
<th>2607.229 kips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Moment Amplification Factor</td>
<td>1.15507</td>
</tr>
</tbody>
</table>

Using Iteration Method:

<table>
<thead>
<tr>
<th>Axial load</th>
<th>350 kips</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Mmax 1</td>
<td>108 kip feet</td>
</tr>
</tbody>
</table>

**Delta 1 (no axial effects)** = 0.491 inches

\[ \text{M add due to Delta 1} = 14.32083 \quad \text{kip feet} \]

\[ \text{Delta 2 with Delta effect} = 0.561315 \quad \text{inches} \]

\[ \text{M add due to Delta 2} = 16.3717 \quad \text{kip feet} \]

\[ \text{Delta 3 with Delta effect} = 0.571385 \quad \text{inches} \]

\[ \text{M add due to Delta 3} = 16.6654 \quad \text{kip feet} \]

\[ \text{Delta 4 with Delta effect} = 0.572827 \quad \text{inches} \]

\[ \text{M add due to Delta 4} = 16.70746 \quad \text{kip feet} \]

\[ \text{Delta 5 with Delta effect} = 0.573034 \quad \text{inches} \]

\[ \text{M add due to Delta 5} = 16.71348 \quad \text{kip feet} \]

\[ \text{Delta 6 with Delta effect} = 0.573063 \quad \text{inches} \]

\[ \text{M add due to Delta 6} = 16.71434 \quad \text{kip feet} \]

\[ \text{Delta 7 with Delta effect} = 0.573067 \quad \text{inches} \]

Final Moment Amplification Factor = 1.154754

*Get from moment tables page 5-162 LRFD Tables.

**Get from deflection tables page 5-162 LRFD Tables.
Calculate moment amplification factor

\[ W = 12 \times 50 \quad I_x = 391 \text{ in}^4 \]

**Iteration**

\[ S_1 = \frac{W L^3}{60EI} = \frac{12}{2} \left( \frac{3K/\text{ft}}{2} \right) \left( 20 \text{ft} \right) \left( 20 \text{ft} \times 391 \text{ in}^4 \right) \]

\[ = 0.61 \text{ in} \quad \text{LRFD pgs 15-162} \]

\[ M_{\text{max}} = \frac{WL}{6} = \frac{12}{2} \left( 20 \text{ft} \right) \left( 20 \text{ft} \right) = 100 \text{ kft} \]

\[ \text{Maddened axial} = P \delta = 400 \text{ k}(0.61 \text{ in}) = 20.33 \text{ kft} \]

\[ S_2 = 0.61 \left( 1 + \frac{20.33}{100} \right) = 0.734" \]

\[ \text{Maddened axial} = P \delta = 400 \text{ k}(0.734") = 24.47 \text{ kft} \]

\[ S_3 = 0.61 \left( 1 + \frac{24.47}{100} \right) = 0.761 \text{ in} \]

\[ \text{Maddened} = P \delta = 400 \text{ k}(0.761 \text{ in}) = 25.31 \text{ kft} \]

\[ S_4 = 0.61 \left( 1 + \frac{25.31}{100} \right) = 0.764 \text{ in} \]

\[ \text{Quit} \]

\[ B_{1x} = \frac{100 \text{ kft} + (0.764 \text{ in}/12 \text{ in/ft})(400 \text{ k})}{100 \text{ kft}} = 1.255 \]

\[ P_n = \frac{\pi^2EI}{(KL)^2} = \frac{\pi^2 (29000)(391)}{(20 \times 12)^2} = 1942 \text{ k} \]

\[ B_{1x} = \frac{1 - 400/1942}{1} = 1.259 \]
**Amplification Factor**

- **Shape**: W12x50
- **I about axis of bending (weak or strong)**: \(391 \text{ in}^4\)
- **K**: 1
- **L**: 20 feet

**Using LRFD Method:**
- Peuler about axis of bending: \(1942.907 \text{ kips}\)
- Final Moment Amplification Factor: \(1.219724\)

**Using Iteration Method:**
- **Axial load**: 350 kips
- **Mmax 1\(^*\)**: 100 kip feet
- Delta 1 (no axial effects)**: 0.61 inches
- Madded due to Delta 1 = 17.79167 kip feet
- Delta 2 with Delta effect = 0.718529 inches
- Madded due to Delta 2 = 20.9571 kip feet
- Delta 3 with Delta effect = 0.737838 inches
- Madded due to Delta 3 = 21.52028 kip feet
- Delta 4 with Delta effect = 0.741274 inches
- Madded due to Delta 4 = 21.62048 kip feet
- Delta 5 with Delta effect = 0.741885 inches
- Madded due to Delta 5 = 21.63831 kip feet
- Delta 6 with Delta effect = 0.741994 inches
- Madded due to Delta 6 = 21.64148 kip feet
- Delta 7 with Delta effect = 0.742013 inches
- Final Moment Amplification Factor: \(1.21692\)

\(^*\) Get from moment tables page 5-162 LRFD Tables.

\(^{**}\) Get from deflection tables page 5-162 LRFD Tables.
The instantaneous center of rotation for the connection below is as shown.

Based on this fact, determine the force in the lower left bolt, and the angle at which the force is directed.

\[
\frac{\delta_1}{\delta_2} = \frac{R_1}{R_2}
\]

\[
\delta_2 = \frac{R_2}{R_1} \delta_1 = \frac{8.544''}{13.416''} (0.34'') = 0.2165'' = \Delta \text{ of bolt #2}
\]

So, force in bolt 2 = \( F_{2} = \text{Rust} (1 - e^{-10\Delta \times 0.55}) \)

\[
F_2 = 74K (1 - e^{-10 \times 0.2165 \times 0.55})
\]

\[
F_2 = 69.20K
\]

If used Elastic Analysis

Angle as shown above
Beam Design

Checked by: 
Date: 
Job No.

Final Check: 
Date: 
Sheet: ___ of ___

Project

By: 
Date: 

Load: 50 kN
Load: 20 kN

\[ R_A + R_B = 150 \text{kN} \]
\[ R_B = 75 \text{kN} \]
\[ R_A = 75 \text{kN} \]

\[ R_B = 77.5 \text{kN} \]
\[ R_A = 72.5 \text{kN} \]

\[ V = -75 \text{kN} \]
\[ M = -75 \text{kN} \cdot \text{m} \]

\[ M_A = 5.5 \times 75 = 412.5 \text{kN} \cdot \text{m} \]
\[ M_B = 18.5 \times 75 - 3.0 (100) = 525 \text{kN} \cdot \text{m} \]
\[ M_C = 18.5 \times 75 - 8.5 (100) = 387.5 \text{kN} \cdot \text{m} \]

\[ C_B = \frac{12.5 (600)}{2.5 (600) + 3(412.5) + 4(525) + 3(387.5)} = 1.25 \]

\[ M_V = \frac{480 \text{kN} \cdot \text{m}}{1.25} = 384 \text{kN} \cdot \text{m} \]

\[ M_{LRF} = 927 \times 84 \]

Temp: 97°C

\[ M_{LRF} = 637 \text{kN} \cdot \text{m} \]

\[ M_{\text{max}} = 607.2 \text{kN} \cdot \text{m} \]

New max moment:

\[ R_A = R_B = 75.92 \text{kN} \]

\[ \phi M_{\text{u}} = 63 \text{kN} \cdot \text{m} \]

\[ \phi M_{\text{p}} = 915 \text{kN} \cdot \text{m} \]

\[ Om_{\text{u}} > M_{\text{LRF}} \text{ OK.} \]

Add weight? OK!
L = 20 ft
W-shape

\[ \varepsilon M_k = 0 = 100(8) + 50(10) - D(20) \]
\[ D = 77.5 k \]
\[ \varepsilon F_y = 0 = -100 - 50 + 77.5 + A \]
\[ A = 72.5 k \]

\\* Ignore beam weight for now \\

\\* M_{max} occurs at B \\

\[ \sum M_B = 0 = -72.5(8) + M_{max} \]
\[ M_{max} = 580 \text{k-ft} \rightarrow M_u \]

\\* Calculate C_b:

\[ M_{y_1} = 72.5(8) = 362.5 \text{k-ft} \]
\[ M_{y_2} = 72.5(10) - 100(2) = 525 \text{k-ft} \]
\[ M_{3/4} = 77.5(5) = 387.5 \text{k-ft} \]
\[ M_{max} = 580 \text{k-ft} \]
\[ C_b = \frac{12.5 M_{max}}{2.5 M_{max} + 3 M_{y_1} + 4 M_{y_2} + 3 M_{3/4}} \]
\[ C_b = \frac{12.5(580)}{2.5(580) + 3(362.5) + 4(525) + 3(387.5)} = 1.25 \]
Use of beam design charts, divide \( m_u \) by \( c_b \)

\[
\frac{580}{1.25} = 464 \text{ ft} \cdot \text{k}
\]

\( L_b = 20' \)

\[ \Phi_b M_u = 464 \text{ ft} \cdot \text{k} \]

Try a W18x76, \( \Phi_b M_p > \frac{(M_u)}{(0.2k)} \)

(Heaviest acceptable) \( \Phi_b M_p \approx 49.2 \text{ ft} \cdot \text{k} \leq (L15 \text{ ft} \cdot \text{k}) \) (w/cb = 1.0)

(OK)

\[ (w/cb = 1.25) > 580 \]

(w/cb = 1.25) (OK)

Add beam weight \( \Phi_b M_u \approx 49.2 \text{ ft} \cdot \text{k} \)

\[
W_u = 1.2(0.074) = 0.0912
\]

\[ \Sigma M_A = 0 \]

\[ 100(8) + 50(15) + 0.912(80^2) \]

\[ -20(D) = 0 \]

\( D = 78.412 \)

\[ \Sigma F_y = 0 \]

\[ A - 100 - 50 - 0.912(20) + \]

\[ 78.412 \]

\( A = 73.412 \)

\[ M_{max} = 584.378 \text{ ft} \cdot \text{k} < L15 < L11 \] (OK)

\[ \rightarrow \text{Use a W18x76} \]