University Of Technology
Building and Construction Eng. Dept.

Final Exam. / First Attempt — 2013/2014

Subject :Design of Steel Structures
Branch :structural Eng.

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Time : 3 Hours
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Open Books and Notes
Answer four questions

Q_1: Design the member which has a length of 20ft and is carrying a tension service dead load of 50 kip and live load of 100 kip . Section $W_{12 \times w}$ is available. The member is connected through the web only to a gusset plate which has a thickness of 1/2 in . Use A490 bolts with 3/4 in. diameter, threads are excluded from shear plane and the connection is bearing-type. The steel is A572 Gr.42.

Q_2:A) The column shown in Fig.1 below is fabricated by welding a 3⁄4-inch by 8-inch cover plate to the flange of a W16 × 100 section. Steel with Fy = 50 ksi is used for both components. Compute the strength of the column based on flexural buckling only. Assume that the components are connected in such a way that the member is fully effective.

B) A column base plate with N=25in. and B=25in. is resting on 30in. x30in. pedestal. The column section is HP14x117. The column has a total factored load of 1030k. Design the thickness of the base plate using Fy=50ksi and f'c=3.5ksi.

Q_3: the beam AB shown in Fig.2 has steel section $W_{18 \times 143}$. Lateral support at each end and under the concentrated loads are provided. The service load 120kip is 20% due to dead load and 80% due to live load. Check for flexural and shear strengths, deflection and local web yielding at the support. use A992 steel and N=5in.

Q_4: The simply supported member shown in Fig. 3 is subjected to the end couples (bending is about the strong axis) and the axial load. Design this member if these moments and axial loads are from service loads and consist of equal parts dead load and live load. Lateral supports are provided only at the ends. Use F_y=50 ksi, C_b=1 and $W_{12 \times w}$ steel section.

Q_5: A beam-to-column connection is made with a structural tee as shown in the Fig.4 . Eight 1-inch-diameter, A490, fully tightened bearing-type bolts are used to attach the flange of the tee section to the column flange. Compute the maximum allowable factored load of this connection (the tee-to-column connection) at an eccentricity of 3.0 inches. Assume that the bolt threads are in the plane of the shear. The steel is A992.

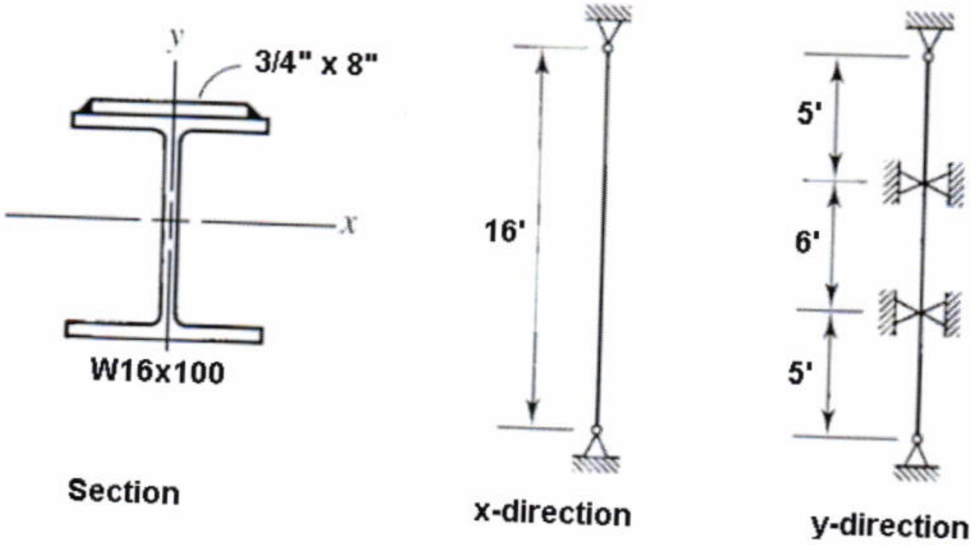


Fig. 1

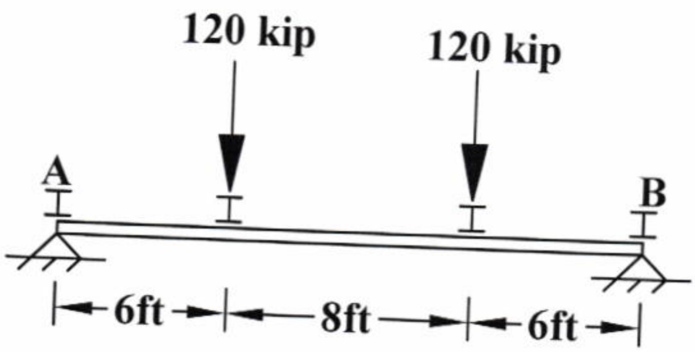


Fig.2

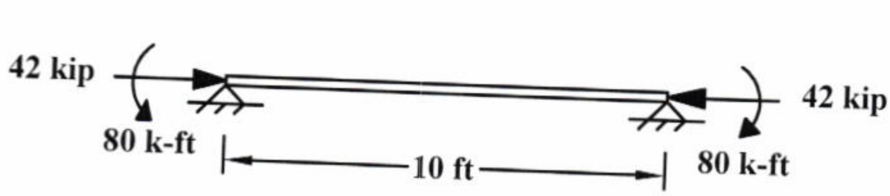


Fig.3

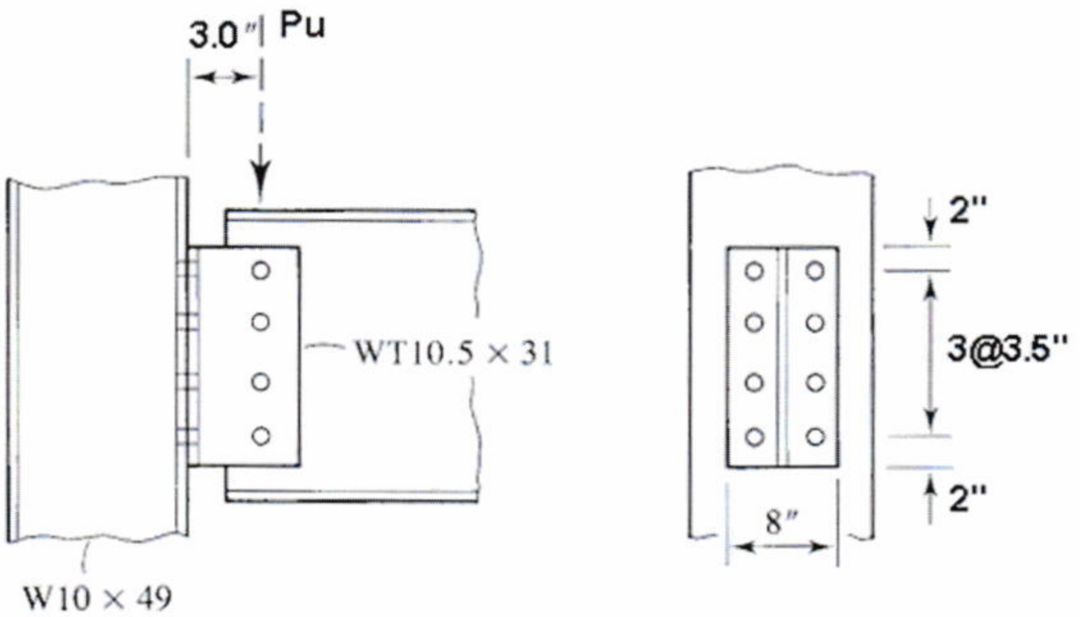


Fig.4

Q1: Solution,

$F_y = 42$, $F_u = 60$

$P_u = 1.2D + 1.6L$

$= 1.2(50) + 1.6(100) = 220$ kip

$A_g = \frac{P_u}{.9 F_y} = \frac{220}{.9 * 42} = 5.82 \text{ in}^2$

$A_e = \frac{P_u}{.75 F_u} = \frac{220}{.75 * 60} = 4.88 \text{ in}^2$

$r_{min} \geq L/300$ & $\frac{20*12}{300} = 0.8$

Try W_{12x22} , $A_g = 6.48$ $d = 12.3$ $t_w = 1/4$ $t_f = 0.425$

$r_x = 4.91$ $r_y = 0.848$ $T = 10\,3/8$

$A = 6.48 > 5.82$ o.k.

$r_y = 0.848 > 0.8$ o.k.

assume more than 4 fasteners in direction of loading, ∴ U = 0.7 (Table)

$A_n = A_g - t \sum d + 1/8 + t \sum \frac{S^2}{4g}$

$A_n = 6.48 - .25(.75 + \frac{1}{8}) * 2 = 6.0425$

∴ $A_e = 0.7 * A_n = 4.22 < 4.88$ not. o.k.

Try W_{12x26} , $A_g = 7.65$ $d = 12.2$ $t_w = 1/4$ $r_y = 1.51$

$t_f = 0.38$ $T = 10\,1/8$

$A_e = 0.7[7.65 - 0.25 * 2(.75 + .125)] = 5.04 > 4.88$ o.k.

* $L_{e_{min}} = 1\frac{1}{4}''$ (Table) ⟹ use $2''$

$S = 3d = 3 * \frac{3}{4} = 2.25''$ ⟹ use $2.5''$

* Bolts,

shear, $R_n = \frac{\pi (.75)^2}{4} * 75$ (Table) $= 33.13$ kip, $\phi R_n = .75 * 33.13 = 24.8$ kip

Bearing, use $t = 1/4''$

$h_d = \frac{3}{4} + \frac{1}{16} = \frac{13}{16} = 0.8125$

$R_n = 1.2 L_c t F_u \leq 2.4 d t F_u$

$R_n = 1.2 (2 - \frac{13}{32}) 1/4 * 60 = 28.68$

$2.4 * \frac{3}{4} * 1/4 * 60 = 27$ kip

$28.68 > 27$, ∴ use 27 kip

$R_n = 1.2 (2.5 - \frac{13}{16}) * .25 * 60 = 30.3 > 27$

∴ use 27

∴ $\phi R_n = .75 * 27 = 20.25$ kip

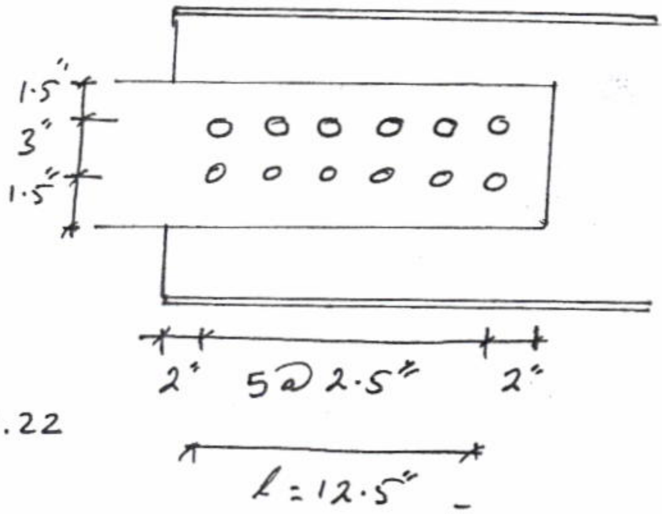
Use the lower of shear & bearing,

∴ No. of bolts $= \frac{220}{20.25} = 10.86$

∴ Use 12 bolts

$$U = 1 - \frac{\bar{x}}{l} = 1 - \frac{0.625}{12.5} = 0.95$$

$0.95 > 0.7$ o.k.



$\therefore P_u = .75 A_e F_u$

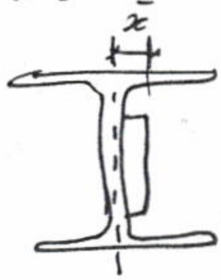
$$A_e = 0.95[7.65 - 0.25 * 2(.75 * .125)] = 7.22$$

$$P_u = 0.75 * 7.22 * 60$$

$$= 324.9 > 220$$

$$P_u = 0.9 A_g F_y = 344.3 > 220$$

$\therefore$ Use $W12 \times 26$



$$\bar{x} = \frac{t_w}{2} + t_{gass.}$$

$$= \frac{1}{8} + \frac{1}{2}$$

$$\bar{x} = 0.625$$

Q2:A

Shape	Area, A	Depth, d		Web			Flange				Distance				
				Thickness, t_w		$\frac{t_w}{2}$	Width, b_f		Thickness, t_f		k		k_1	T	Workable Gage
											k_{des}	k_{det}			
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W16×100	29.5	17.0	17	0.585	9/16	5/16	10.4	10 3/8	0.985	1	1.39	1 7/8	1 1/8	13 1/4	5 1/2

Nominal Wt.	Compact Section Criteria		Axis X-X				Axis Y-Y				r_{ts}	h_o	Torsional Properties	
	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	I	S	r	Z	I	S	r	Z			J	C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
100	5.29	24.3	1490	175	7.10	198	186	35.7	2.51	54.9	2.92	16.0	7.73	11900

With the location of the horizontal centroidal axis known, the moment of inertia with respect to this axis can be found

$I_x' = I_x + A(distance)^2$

Component	A	y	Ay	I	distance	I+A(distance)2
Plate	6	0.375	2.25	0.28125	7.375	326.625
W	29.5	9.25	272.875	1490	1.5	1556.375
sum	35.5	7.75	275.125			1883

For the vertical axis,

$$I_y = \frac{1}{12}\left(\frac{3}{4}\right)(8)^3 + 186 = 218 \text{ in.}^4$$

$$r_x = \sqrt{\frac{I_x}{A}} = \sqrt{\frac{1883}{35.5}} = 7.283 \text{ in.}$$

$$r_y = \sqrt{\frac{I_y}{A}} = \sqrt{\frac{218}{35.5}} = 2.478 \text{ in.}$$

$$\frac{K_x L_x}{r_x} = \frac{(16 \times 12)}{7.283} = 26.362$$

$$\frac{K_y L_y}{r_y} = \frac{(6 \times 12)}{2.478} = 29.055$$

$$Maximum\ \frac{KL}{r} = \frac{K_y L_y}{r_y} = 29.055 < 200$$

$$P_0 = F_y A_g = 50 \times 35.5 = 1775 \text{ kip}$$

$$P_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} A_g = 3.1415^2 \times \frac{29000}{29.055^2}(35.5) = 12036.2 \text{ kip}$$

$$\frac{P_e}{P_0} = \frac{12036.2}{1775} = 6.78 > 0.44 \text{ then:}$$

$$P_n = \left[0.658^{\left(\frac{P_0}{P_e}\right)}\right] P_0 = \left[0.658^{\left(\frac{1775}{12036.2}\right)}\right](1775) = 1668.75 \text{ kip}$$

$$P_r = \emptyset_c P_n = 0.9 \times 1668.91 = 1501.88 \text{ kip}$$

Q2:B

Shape	Area, A	Depth, d		Web			Flange				Distance			
				Thickness, t_w		$\frac{t_w}{2}$	Width, b_f		Thickness, t_f		k	k_1	T	Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.
HP14×117[f]	34.4	14.2	14 1/4	0.805	13/16	7/16	14.9	14 7/8	0.805	13/16	1 1/2	1 1/16	11 1/4	5 1/2

Solution:

$N = 25$ in.

Verify $N \geq d + 2(3.00 \text{ in.})$:

$$25\ in. \overset{?}{\geq} 14.2 + 2(3in.) = 20.2\ in. \quad ok$$

$B = 25$ in.

Verify $B \geq b_f + 2(3.00 \text{ in.})$:

$$25 \text{ in.} \overset{?}{\geq} 14.9 + 2(3\text{in.}) = 20.9 \text{ in.} \quad \text{ok}$$

$$P_p = 0.85 f_c' A_1 \sqrt{\frac{A_2}{A_1}}$$

$$P_p = 0.85 \times 3.5 \times 25 \times 25 \sqrt{\frac{30 \times 30}{25 \times 25}} = 2231.25 \text{ kip} \qquad \frac{A2}{A1} = \frac{30 \times 30}{25 \times 25} = 1.44 \quad ok$$

$\emptyset_c P_p \geq P_u$

$0.6 \times 2231.25\text{kip} \geq 1030\text{kip}$

$1338.75\text{kip} > 1030 \text{ kip} \quad \text{ok}$

$$m = \frac{N - 0.95d}{2} = \frac{25 - 0.95 \times 14.2}{2} = 5.755 \text{ in.}$$

$$n = \frac{B - 0.8b_f}{2} = \frac{25 - 0.8 \times 14.9}{2} = 6.54 \text{ in.}$$

$$n' = \frac{\sqrt{db_f}}{4} = \frac{\sqrt{14.2 \times 14.9}}{4} = 3.636 \text{ in.}$$

$$x = \left(\frac{4db_f}{(d + b_f)^2}\right)\frac{P_u}{\emptyset_c P_p} \leq 1.0$$

$$x = \left(\frac{4 \times 14.2 \times 14.9}{(14.2 + 14.9)^2}\right)\frac{1030}{1338.75} \leq 1.0$$

$x = 0.769 < 1 \quad \text{use } x = 0.769$

$$\lambda = \frac{2\sqrt{x}}{1 + \sqrt{1 - x}} \leq 1.0$$

$$\lambda = \frac{2\sqrt{0.769}}{1 + \sqrt{1 - 0.769}} \leq 1.0$$

$\lambda = 1.184 \leq 1.0 \qquad \text{use } \lambda = 1.0$

$\lambda n' = 1.0 \times 3.636 = 3.636 \text{ in.}$

$$t_{min} = l\sqrt{\frac{2P_u}{0.9F_yBN}} = 6.54 \times \sqrt{\frac{2 \times 1030}{0.9 \times 50 \times 25 \times 25}} = 1.77\ in.$$

Use $t = 2$ in.

Use plate 25 in. x 25 in. x 2 in.

Q3: Solution,

$F_y = 50 \quad F_u = 65$ ksi

$P_u = 1.2(.2*120) + 1.6(.8*120) = 1.2*24 + 1.6*96$

$P_u = 182.4$ kip

$M_u = P_u * 6 = 1094.4$ k-ft

$L_b = 8'$

W18x143, $A = 42.1 \quad d = 19.5 \quad t_w = 0.73 \quad k = 1.72 \quad \frac{b_f}{2t_f} = 4.25$

$h/t_w = 22 \quad I_x = 2750 \quad S_x = 282 \quad Z_x = 322$

$r_y = 2.72$

* $L_p = 1.76 * 2.72\sqrt{\frac{29000}{50}} = 9.6'$

$L_b < L_p \quad \therefore$ laterally supported beam

$\frac{b_f}{2t_f} \leq 0.38\sqrt{\frac{29000}{50}}$, $\quad h/t_w \leq 3.76\sqrt{\frac{29000}{50}}$

$4.25 < 9.15 \quad\quad 22 < 90.5$

$\therefore$ Compact section.

$M_n = Z_x F_y = \frac{322*50}{12} = 1341.66$ kip-ft

$\phi M_n = 0.9 * 1341.66 = 1207.5 > M_u = 1094.4$ o.k.

* $h/t_w \leq 2.24\sqrt{\frac{29000}{50}}$

$22 < 53.93$

$\therefore C_v = 1$ & $\Phi_v = 1$

$V_n = 0.6 F_y A_w C_v$

$= 0.6 * 50 (19.5 * 0.73) * 1$

$= 427.05$

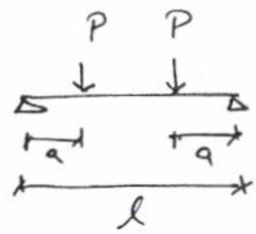
$\Phi V_n = 427 > V_u = 182.4$ o.k.

* $R_n = (2.5k + N) F_{yw} t_w$

$= (2.5 * 1.72 + 5) 50 * 0.73 = 339.45$ kip

$\Phi R_n = 339.45 > 182.4$ o.k.

* $L/360 = \frac{20 * 12}{360} = 0.66$ in



$P = 96$ kip $l = 20 * 12 = 240''$ $a = 6 * 12 = 72''$

$I_x = 2750$

$\Delta_{\substack{max \\ center}} = \frac{Pa}{24EI}(3l^2 - 4a^2) = 0.549'' < 0.66''$ o.k.

Q3

Q_4 : Solution,

$P_u = 1.2\,(21) + 1.6\,(21) = 58.8$ kip

$M_{nt} = 1.2\,(40) + 1.6\,(40) = 112$ kip-ft

$l_x = l_y = 10'$.

$k_x = k_y = 1$

$(kl)_y = 10$

$(kl)_{y_{eq.}} = \frac{(kl)_x}{r_x/r_y} = \frac{10}{1.8} = 5.5$

$\therefore\ KL = 10$

assume $p = 1.18$

$pP_u = \frac{1.18}{1000}\,58.8 = 0.069 < 0.2$, $H_{1-1}b$ applied

$\frac{1}{2} pP_u + \frac{9}{8}\,(b_x M_{ux}) \leq 1$

$\frac{1}{2} * \frac{1.18}{1000} * 58.8 + \frac{9}{8}\left(\frac{b_x}{1000} * 112\right) = 1$

$b_x = 7.66$

with $KL = 10$ and from Table 6-1 Choose,

$W_{12\times 26}$, $p = 4.64$, $b_x = 7.78$

$pP_u = \frac{4.64}{1000} * 58.8 = 0.27 > 0.2$, use $H_{1-1}a$

$\frac{4.64}{1000} * 58.8 + \frac{7.78}{1000} * 112 < 1$

$1.14 > 1.0$ not o.k.

Try larger Section

$W_{12\times30}$, $P = 3.99$ $b_x = 6.62$

$$\frac{3.99}{1000} * 58.8 = 0.23 > 0.2 \quad , \quad H_{1-1a}$$

$$0.23 + \frac{6.62}{1000} * 112 < 1$$

$$0.97 < 1 \quad \text{o.k.}$$

$W_{12\times30}$, $A = 8.79$ $b_f/2t_f = 7.41$ $h/t_w = 41.8$

$$b_f/2t_f < 0.56\sqrt{\frac{29000}{50}} \quad , \quad h/t_w < 1.49\sqrt{\frac{E}{F_y}}$$

$7.41 < 13.48$ ✓ $41.8 \not< 35.87$ not. ok.

Try $W_{12\times40}$, $A = 11.7$ $r_x = 5.13$ $r_y = 1.94$

$\frac{b_f}{2t_f} = 7.77$ $h/t_w = 33.6$ $Z_x = 57$ $S_x = 51.1$

$r_{ts} = 2.21$ $h_o = 11.4$ $J = .906$

* $7.77 < 13.48$ ✓ $33.6 < 35.87$ ✓ o.k.

$$(kl/r)_x = \frac{10*12}{5.13} = 23.4$$

$$(kl/r)_y = \frac{10*12}{1.94} = 61.8 < 300 \quad \text{o.k.}$$

$$kl/r \leqslant 4.71\sqrt{\frac{E}{F_y}}$$

$$61.8 < 113.4$$

$$\therefore F_{cr} = [0.658^{F_y/F_e}] F_y$$

$$F_e = \frac{\pi^2 29000}{(61.8)^2} = 74.9$$

$$F_{cr} = [.658^{50/74.9}]50 = 37.8 \text{ ksi}$$

$$P_n = F_{cr} A = 442.26$$

$$\phi_c P_n = 398 \text{ kip} \quad , \quad \frac{P_u}{\phi P_n} = \frac{58}{398} = .147 < .2 \quad \therefore \text{use } H_{1-1b}$$

* $L_b =$

$$L_p = 1.76 * 1.94 \sqrt{\frac{29000}{50}} = 6.85'$$

$$L_r = 1.95 * 2.21 * \frac{29000}{35} \sqrt{\frac{0.906}{51.1 * 11.4}} \sqrt{1 + \sqrt{1 + 6.76 \left(\frac{35 * 51.1 * 11.4}{29000 * .906}\right)}}$$

$$L_r = 21.9'$$

$$L_r > L_b > L_p$$

$$M_p = 50 * 57 = 2850 \text{ ksi} = 237.5 \text{ k-ft}$$

$$\therefore M_n = 1\left[237.5 - \left(237.5 - \frac{35 * 51.1}{12}\right)\left(\frac{10 - 6.85}{21.9 - 6.85}\right)\right] \leq M_p$$

$$M_n = 219 < M_p$$

$$\phi M_n = .9 * 219 = 197.1 \text{ k-ft}$$

$$B_1 = \frac{C_m}{1 - \frac{P_u}{P_{e1}}} \geq 1$$

$$C_m = 0.6 - 0.4(-1) = 1$$

$$B_1 = \frac{1}{1 - \frac{58.8}{\frac{\pi^2 E A}{\left(\frac{K_1 l}{r}\right)^2}}} = \frac{1}{1 - \frac{58.8}{\frac{\pi^2 29000 * 11.9}{(23.4)^2}}} = 1.004$$

$$M_u = M_{nt} * B_1 = 113$$

$$\frac{P_u}{2\,\phi_c P_n} + \frac{M_{ux}}{\phi_b M_{nx}} \leq 1$$

$$\frac{58.8}{2 * 398} + \frac{113}{197.1} < 1$$

$$0.646 < 1 \qquad o.k.$$

∴ Use W12x40

Q5:

Shape	Area, A	Depth, d		Stem Thickness, t_w		Stem $\frac{t_w}{2}$	Stem Area	Flange Width, b_f		Flange Thickness, t_f		Distance k		Distance Workable Gage
	in.^{2}	in.		in.		in.	in.^{2}	in.		in.		in.	in.	in.
WT10.5×31[c]	9.13	10.5	10½	0.400	3/8	3/16	4.20	8.24	8¼	0.615	5/8	1.12	1 5/16	5½

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k_{des}	Distance k_{det}	Distance k_1	Distance T	Distance Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W1(×49	14.4	10.0	10	0.340	5/16	3/16	10.0	10	0.560	9/16	1.06	1¼	13/16	▼	5½

Determine the bearing and shear nominal strengths. For the strength in bearing, use a hole diameter of

$$h = d + \frac{1}{16} = 1 + \frac{1}{16} = 1.0625\ in.$$

$L_e = 2$ in.

$$L_c = L_e - \frac{h}{2} = 2 - \frac{1.0625}{2} = 1.46875 \text{ in.}$$

$R_n = 1.2L_ctF_u = 1.2 \times 1.46875 \times 0.56 \times 65 = 64.155$ kip

Upper limit $= 2.4dtF_u = 2.4 \times 1 \times 0.56 \times 65 = 87.36$ kip

$\therefore$ for this bolt $R_n = 64.155$ kip

For the other holes, use s $=$ 3.5 in. Then,

$$L_c = S - h = 3.5 - 1.0625 = 2.4375$$

$R_n = 1.2L_ctF_u = 1.2 \times 2.4375 \times 0.56 \times 65 = 106.47$ kip

Upper limit $= 2.4dtF_u = 2.4 \times 1 \times 0.56 \times 65 = 87.36$ kip

$\therefore$ for this bolt $R_n = 87.36$ kip

TABLE J3.2
Nominal Stress of Fasteners and Threaded Parts, ksi (MPa)

Description of Fasteners	Nominal Tensile Stress, F_{nt}, ksi (MPa)	Nominal Shear Stress in Bearing-Type Connections, F_{nv}, ksi (MPa)
A307 bolts	45 (310) [a][b]	24 (165) [b][c][f]
A325 or A325M bolts, when threads are not excluded from shear planes	90 (620) [e]	48 (330) [f]
A325 or A325M bolts, when threads are excluded from shear planes	90 (620) [e]	60 (414) [f]
A490 or A490M bolts, when threads are not excluded from shear planes	113 (780) [e]	60 (414) [f]
A490 or A490M bolts, when threads are excluded from shear planes	113 (780) [e]	75 (520) [f]
Threaded parts meeting the requirements of Section A3.4, when threads are not excluded from shear planes	0.75 F_u [a][d]	0.40 F_u
Threaded parts meeting the requirements of Section A3.4, when threads are excluded from shear planes	0.75 F_u [a][d]	0.50 F_u

[a] Subject to the requirements of Appendix 3.

[b] For A307 bolts the tabulated values shall be reduced by 1 percent for each 1/16 in. (2 mm) over 5 diameters of length in the grip.

[c] Threads permitted in shear planes.

[d] The nominal tensile strength of the threaded portion of an upset rod, based upon the cross-sectional area at its major thread diameter, A_D, which shall be larger than the nominal body area of the rod before upsetting times F_y.

[e] For A325 or A325M and A490 or A490M bolts subject to tensile fatigue loading, see Appendix 3.

[f] When bearing-type connections used to splice tension members have a fastener pattern whose length, measured parallel to the line of force, exceeds 50 in. (1270 mm), tabulated values shall be reduced by 20 percent.

For the strength in shear,:

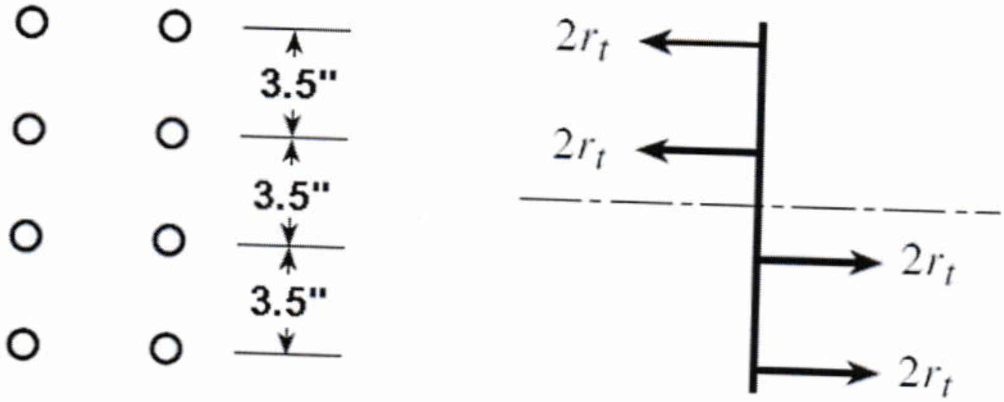
$$R_n = F_{nv}A_b = 60 \times \left(\frac{\pi \times 1}{4}\right) = 47.12\ kip$$

$$R_{n_{bearing_{total}}} = 2 \times 64.155 + 6 \times 87.36 = 652.47\ kip$$

$R_{n_{shear\,total}} = 8 \times 47.12 = 376.96\ kip$

$R_{r_{total}} = 0.75 \times 376.96 = 282.743\ kip$

Compute the tensile force per bolt and then check the tension–shear interaction. Because of symmetry, the centroid of the connection is at middepth. Figure below shows the bolt areas and the distribution of bolt tensile forces.



The moment of the resisting couple is found by summing moments about the neutral axis:

$\sum M_{NA} = 2r_t(1.75 + 5.25 + 5.25 + 1.75) = 28r_t$

The applied moment is:

$M_u = P_u e = 3P_u$

Equating the resisting and applied moments, we get:

$3P_u = 28r_t$

The factored load shear stress is:

$$f_v = \frac{P_u}{N \times A_b} = \frac{P_u}{8 \times 0.785}$$

$$F'_{nt} = 1.3F_{nt} - \frac{F_{nt}}{\emptyset F_{nv}} f_v \le F_{nt}$$

$$F'_{nt} = 1.3 \times 113 - \frac{113}{0.75 \times 60} \frac{P_u}{(8 \times 0.785)} \le F_{nt}$$

$146.9 - 0.316P_u = 113$

$P_u = 107.28\ kip$

The design tensile strength is:

$$R_r = \emptyset F'_{nt} A_b = 0.75\left(1.3 \times 113 - \frac{113}{0.75 \times 60} \frac{P_u}{8 \times 0.785}\right) \times 0.785\ \ge r_t$$

$$0.75\left(1.3 \times 113 - \frac{113}{0.75 \times 60} \frac{P_u}{8 \times 0.785}\right) \times 0.785\ \ge \frac{3P_u}{28}$$

$$\left(1.3 \times 113 - \frac{113}{0.75 \times 60} \frac{P_u}{8 \times 0.785}\right) = \frac{P_u}{5.495}$$

$146.9 = 0.497P_u$

$P_u = 295.573\ kip$

$P_u = 107.28\ kip$