Solution to Homework 6:

Problem 1:

Given and Required

7.7-2 A plate ½ × 6½ of A36 steel is used as a tension member as shown in Figure P7 The gusset plate is ⅝-inch-thick and is also of A36 steel. The bolts are 1⅛-i diameter A325. No slip is permitted. Determine the maximum factored load, P_u, can be resisted. *Investigate all possible failure modes.*

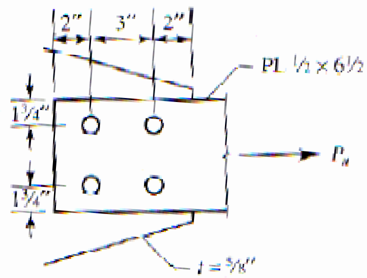


FIGURE P7.7-2

In regards to checking everything, the dimensions of the gusset plate are uncertain, therefore check; (a) gross yielding of plate, (b) net fracture of plate, (c) block shear of plate, (d) shear strength of bolts, (e) bearing strength in gusset, (f) bearing strength in plate.

Solution

$tp := 0.5$ in $\quad tg := \frac{5}{8}$ in

$Lp := 6.5$ in $\quad db := 1.125$ in

$fy := 36$ ksi $\quad fu := 58$ ksi

Gross Yielding of Plate:

$Ap := Lp \cdot tp \qquad Ap = 3.25$ in

$\phi Pny := 0.9 \cdot Ap \cdot fy \qquad \phi Pny = 105.3$ kips

Net Fracture of Plate:

$An := Ap - 2\left(db + \frac{1}{8}\right)tp \qquad An = 2$ in

$U := 0.75 \qquad Ae := U \cdot An$

$\phi Pnf := 0.75 \cdot Ae \cdot fu \qquad \phi Pnf = 65.25$ kips

Shear Strength of Bolts (At factored loads).

$ShearStrength := 4 \cdot 20.9 \rightarrow 83.6$ Table 7-15

Bearing Strength Check, Gusset

$s < sfull$ Therefore, for non edge holes $BSNE := 94.6 \cdot tg$ $BSNE = 59.125$ kips Table 7-12

For Edge Holes $BSE := 73.4 \cdot tg$ $BSE = 45.875$ kips Table 7-13

$\phi Rn := 2 \cdot BSNE + 2 \cdot BSE$ $\phi Rn = 210$ kips ok

Bearing Strength Check, Plate

$s < sfull$ Therefore, for non edge holes $BSNE := 94.6 \cdot tp$ $BSNE = 47.3$ kips Table 7-12

For Edge Holes $BSE := 73.4 \cdot tp$ $BSE = 36.7$ kips Table 7-13

$\phi Rn := 2 \cdot BSNE + 2 \cdot BSE$ $\phi Rn = 168$ kips ok

Block shear strength of plate

$A_{gv} := 2 \cdot 5 \cdot tp$ $A_{gv} = 5$ in^2

$A_{nv} := A_{gv} - \left[3 \cdot \left(db + \frac{1}{8}\right) \cdot tp\right]$ $A_{nv} = 3.125$ in^2

$A_{gt} := 3 \cdot tp$ $A_{gt} = 1.5$ in^2

$A_{nt} := A_{gt} - \left[1 \cdot \left(db + \frac{1}{8}\right) \cdot tp\right]$ $A_{nt} = 0.875$ in^2

$fu \cdot A_{nt} = 50.75$ Kips & $0.6 \cdot fu \cdot A_{nv} = 108.75$ kips

Since, FuAnt < 0.6FuAnv, Equation with fracture shear path governs....

$\phi R_n := 0.75 \cdot (0.6 \cdot fu \cdot A_{nv} + fy \cdot A_{gt})$ $\phi R_n = 122.063$ kips

$\phi R_n := 0.75 \cdot (0.6 \cdot fu \cdot A_{nv} + fu \cdot A_{nt})$ $\phi R_n = 119.625$ kips governs

Therefore, the shear strength of the bolts governs, $\phi Rn = 67$ kips

Problem 2:

Given and Required

7.7-4 A C9 × 20 is used as a tension member and is connected to a ½-inch gusset plate as shown in Figure P7.7-4. A242 steel is used for the tension member and A36 steel is used for the gusset plate. The member has been designed to resist a factored load of 175 kips. If the connection is to be slip critical, how many 1⅜-inch-diameter A325 bolts are needed? Show a sketch with a possible layout. Assume that the member tensile and block shear strengths will be adequate.

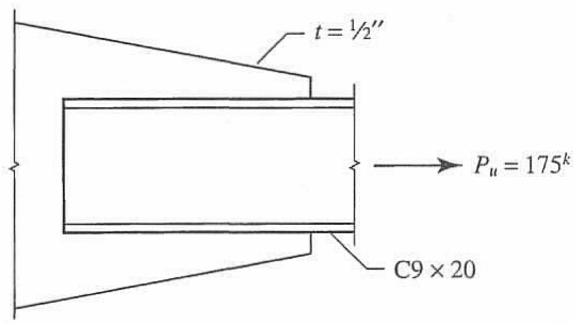


FIGURE P7.7-4

Solution:

$\phi Rn := 31.7$ $\quad \phi Rn = 31.7$ kips

$n := \dfrac{Pu}{\phi Rn}$ $\quad n = 5.521$ $\quad$ Use 6 bolts for Channel Section

Edge Distance $\quad Le := 1.25 \cdot db$ $\quad Le = 1.719$ in $\quad$ Use 2 in. $\quad$ Table J3.4

Spacing $\quad smin := 2.67 \cdot db$ $\quad smin = 3.671$ in $\quad$ Spec J3.3

$spref := 3 \cdot db$ $\quad spref = 4.125$ in $\quad$ Spec J3.3

$sfull := 4 + \dfrac{3}{16}$ $\quad sfull = 4.188$ $\quad$ Table 7-12 $\quad$ Chose $s := 4.25$ in

Bearing Strength Check, Gusset

$s > sfull$ $\quad$ Therefore, for non edge holes $\quad BSNE := 144 \cdot tg$ $\quad BSNE = 72$ kips $\quad$ Table 7-12

For Edge Holes $\quad BSE := 66.9 \cdot tg$ $\quad BSE = 33.45$ kips $\quad$ Table 7-13

$\phi Rn := 4 \cdot BSNE + 2 \cdot BSE$ $\quad \phi Rn = 354.9$ kips $\quad$ ok

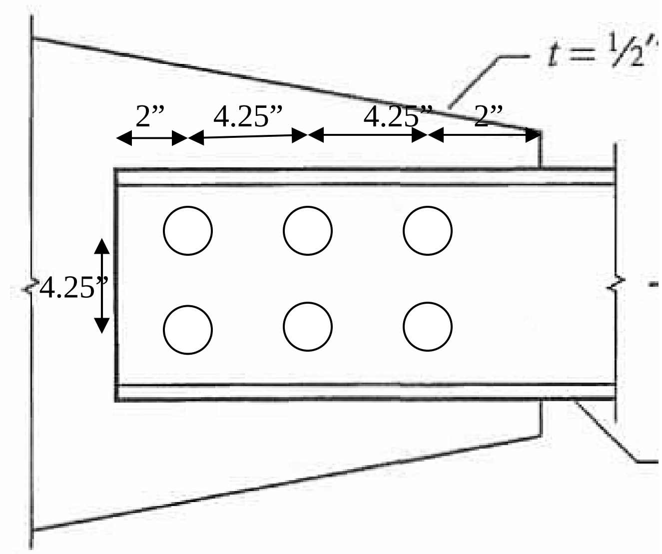
Bearing Strength Check, Channel

$s > sfull$ $\quad$ Therefore, for non edge holes $\quad BSNE := 144 \cdot \dfrac{70}{58} \cdot tw$ $\quad BSNE = 77.859$ kips $\quad$ Table 7-12

For Edge Holes $\quad BSE := 66.9 \cdot \dfrac{70}{58} \cdot tw$ $\quad BSE = 36.172$ kips $\quad$ Table 7-13

$\phi Rn := 4 \cdot BSNE + 2 \cdot BSE$ $\quad \phi Rn = 383.782$ kips $\quad$ ok

Original Number of Bolts ok


t = ½"
2"
4.25"
4.25"
2"
4.25"

Problem 3:

Design a 30 ft. long double angle tension member and its connection for:

- Service dead load of 34 kips and a service live load of 102 kips.
- The member will be connected to a 3/8 in. thick gusset plate.
- Design the connection to be slip critical at service loads.
- Use A325 bolts and A36 (36 ksi) steel for both the angle and the gusset plate.

PROBLEM 2 DESIGN A 30-FT LONG DOUBLE ANGLE TENSION MEMBER AND ITS CONNECTION FOR:

- A SERVICE DEAD LOAD OF 34 Kips AND A SERVICE LIVE LOAD OF 102 Kips
- THE MEMBER WILL BE CONNECTED TO A 3/8-IN THICK GUSSET PLATE.
- DESIGN THE MEMBER TO BE SLIP CRITICAL AT SERVICE LOADS.
- USE A36 STEEL FOR ANGLES AND GUSSET PLATE, A325 BOLTS

$F_y = 36\text{ksi}$
$F_u = 58\text{ksi}$

FIRST, FIND FACTORED LOAD COMB.

- $1.4D$
- $1.2D + 1.6L = 1.2(34\text{ Kips}) + 1.6(102\text{ Kips}) = 204\text{ Kips}$

**

- Although the member is a tension member, the section was selected with slenderness $(KL/r < 200)$ in mind, since it's possible that unpredicted loading could create a compressive condition on the member. For tension members, $KL/r < 300$ may be used, but a more conservative approach was taken.
- Thus, from Table 4-10 and Table 3-7, a 2L8x6x3/4 section was selected. The design process was facilitated with the attached spreadsheet I created for the design project in order to avoid redesign steps.

* Verify $\frac{KL}{r_x} = \frac{(30\text{ft})(12\text{in/ft})}{2.52\text{in}} = 142.9 < 200$

Verify $\frac{KL}{r_y} = \frac{(30\text{ft})(12\text{in/ft})}{2.47\text{in}} = 145.75 < 200$

① SELECT SIZE AND NUMBER OF BOLTS:

DESIGN SLIP RESISTANCE ϕR_n FOR SLIP CRITICAL AT SERVICE LOAD:

FROM TRIAL AND ERROR USING SPREADSHEET AND TABLE 7-16,

SELECTED $d_{bolt} = 1.5\text{in.}$

From Table 7-16, FOR DOUBLE SHEAR CONDITION, $\phi R_n = 60.1$ kips/bolt

Service Load $= 34^k + 102^k = 136^k$!! must be used here.

TO FIND N_b, NUMBER OF BOLTS,

$$N_b = \frac{P_u}{\phi R_n} = \frac{\cancel{(204\text{ Kips})}}{60.1} = \cancel{3.39} \sim 2.29\text{ bolts.}$$

So select 4 bolts (A325, 1-in diameter) ok → 4 bolts are more than enough.

BOLT SHEAR $\phi R_n = (60.1\text{ kip/bolt})(4\text{ bolts}) = 240.4\text{ kips} > \cancel{204\text{ kips}}$ 136 kips OK

② DESIGN EDGE DISTANCE AND BOLT SPACING

FROM TABLE J3.4:

- For 1-in diameter bolts (rolled edges), min. edge distance = 1.25 in.
- Select $L_e = 4$ in. ✓
- Check max. $L_e = 12t \le 6$ in.
  $= 12(3/4) \le 6$ in.
  $= 6$ in. ok

FROM SPEC. J3.3:

- MIN. $s = 2\tfrac{2}{3} d_{bolt} = (2\tfrac{2}{3})(1.5\text{ in}) = 4$ in.
- PREFERRED $s = 3d_{bolt} = (3)(1.5\text{in}) = 4.5$in
- CHOOSE $s = 4.5$in ✓

THUS, CONNECTION LENGTH, $L = 3s = 3(4.5\text{in}) = 13.5$ in ✓
(Assume 1 row of 4 bolts)

③ VERIFY TENSION YIELDING STRENGTH FOR MEMBER

FROM TABLE 1-7, $A_g = (2\text{ angles})(9.99\text{in}^2/\text{angle}) = 19.98\text{ in}^2$

$$\phi R_n = (0.9)A_g F_y = (0.9)(19.98\text{ in}^2)(36\text{ ksi}) = 647.35\text{ kips} > 204\text{ kips} \quad \text{OK}$$

④ VERIFY TENSION RUPTURE STRENGTH FOR MEMBER

FROM TABLE 1-7, $\bar{x} = 1.56$ in.

$$U = 1 - \frac{\bar{x}}{L} = 1 - \frac{1.56\text{ in}}{13.5\text{ in}} \le 0.9$$

$$U = 0.884$$

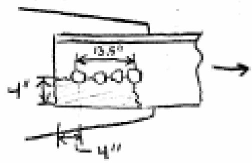
1 bolt
2 angles

$$A_n = A_g - 2(1.5\text{in} + 1/8\text{ in})(\underbrace{3/4\text{ in.}}_{t}) = 17.54\text{ in}^2$$

$$A_e = UA_n = (0.884)(17.54\text{ in}^2) = 15.52\text{ in}^2$$

$$\phi R_n = (0.75)A_e F_u = (0.75)(15.52\text{ in}^2)(58\text{ ksi}) = 675\text{ kips} > 204\text{ kips} \quad \text{OK}$$

⑤ VERIFY BLOCK SHEAR RUPTURE OF MEMBER



1 block × 2 angles = 2 blocks

v plane is ab , t plane is bc

$A_{gv} = (13.5\,in + 4\,in)(3/4\,in)(2\,blocks) = 26.25\,in^2$

$A_{nv} = A_{gv} - (2\,blocks)(3.5\,holes)(\underbrace{1.5\,in}_{d_{bolt}} + 1/8\,in)(\underbrace{3/4\,in}_{t}) = 17.72\,in^2$

$A_{gt} = (4\,in)(3/4\,in)(2\,blocks) = 6\,in^2$

$A_{nt} = A_{gt} - (2\,blocks)(1/2\,hole)(1.5\,in + 1/8\,in)(3/4\,in) = 4.78\,in^2$

Find governing equation:

$0.6 F_u A_{nv} = (0.6)(58\,ksi)(17.72\,in^2) = 616.61\,kips$

$F_u A_{nt} = (58\,ksi)(4.78\,in^2) = 277.31\,in^2$

The larger value dictates the equation used

$\phi R_n = 0.75(0.6 F_u A_{nv} + F_y A_{gt}) \le 0.75[0.6 F_u A_{nv} + F_u A_{nt}] = 0.75[(0.6)(58)(17.72) + (58)(4.78)]$

$= 0.75((0.6)(58\,ksi)(17.72\,in^2) + (36\,ksi)(6\,in^2)) \le 670.42$

$= 624.46\,kips > 204\,kips$ OK

⑥ DESIGN GUSSET PLATE

GIVEN: $t = 3/8$ in. , A36 steel

$A_g = Lt$

Since $\phi R_n \geq 204$ kips , choose L based on yielding strength:

$$\phi R_n = (0.9) A_g F_y = 0.9 L t F_y$$

$$L \geq \frac{\phi R_n}{0.9 t F_y} = \frac{204 \text{ kips}}{(0.9)(3/8 \text{ in})(36 \text{ ksi})} = 16.79 \text{ in.}$$ • Select L = 17 in.

⑦ GUSSET PLATE YIELDING STRENGTH

$$\phi R_n = (0.9)(17 \text{ in.})(3/8 \text{ in})(36 \text{ ksi}) = 206.55 \text{ kips} \quad \underline{\text{OK}}$$

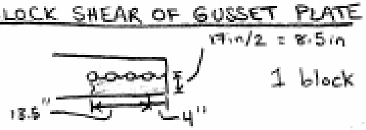
⑧ GUSSET PLATE RUPTURE STRENGTH

$$A_n = A_g - (1 \text{ bolt})(d_{bolt} + 1/8 \text{ in})(3/8 \text{ in})$$
$$= (17 \text{ in})(3/8 \text{ in}) - (1.5 \text{ in} + 1/8 \text{ in})(3/8 \text{ in}) = 5.77 \text{ in}^2 \leq 0.85 A_g = \underline{5.42 \text{ in}^2}$$

use this one

$$\phi R_n = 0.75 A_n F_u = (0.75)(5.42 \text{ in}^2)(58 \text{ ksi}) = 235.77 \text{ kips} > 204 \text{ kips} \quad \underline{\text{OK}}$$

⑨ BLOCK SHEAR OF GUSSET PLATE



1 block

$$A_{gv} = (13.5 \text{ in} + 4 \text{ in.})(\underset{t}{3/8 \text{ in}})(1 \text{ block}) = 6.56 \text{ in}^2$$

$$A_{nv} = A_{gv} - (3.5 \text{ holes})(\underset{d_{bolt}}{1.5 \text{ in}} + 1/8 \text{ in})(\underset{t}{3/8 \text{ in}})(1 \text{ block}) = 4.43 \text{ in}^2$$

$$A_{gt} = (8.5 \text{ in})(3/8 \text{ in})(1 \text{ block}) = 3.19 \text{ in}^2$$

$$A_{nt} = A_{gt} - (1/2 \text{ hole})(1.5 \text{ in} + 1/8 \text{ in})(3/8 \text{ in})(1 \text{ block}) = 2.88 \text{ in}^2$$