CHAPTER THREE

CONNECTORS

3-1 Overview

The primary structural fasteners used in steel construction have typically been rivets, bolts and pins. These fasteners can be field installed, cheaper and with less problems than welding.

Bolts are generally installed so that they are either perpendicular to the force (i.e. the force causes shear in the fastener) or parallel to the force (i.e. the force causes tension in the fastener) that they are transferring between members. In some cases they have both shear and tension.

Rivets have essentially disappeared from modern steel construction, One thing to note is that rivets provide a very inconsistent clamping force so determining friction capacity for shear transfer is problematic. The capacity of rivet connections is best done considering only the bearing capacity.

Pins are generally smooth large diameter fasteners that are not threaded. These fasteners are not very common. Pins are always placed perpendicular to the load direction and are in shear. Since pins are not threaded, they do not clamp the connected members together and, consequently, do not enable friction based force transfer between the connected members.

Welding is the process of joining two steel pieces (the base metal) together by heating them to the point that molten filler material mixes with the base metal to form one continuous piece.

This chapter will focus principally on the capacity of bolts and welding as they are the preferred structural steel fastener.

3-2 Bolted Connections

Where the load direction is perpendicular to the bolt axis as shown in Figure 3-1-1. In this situation the principle force in the bolt is shear. Less frequently, the bolts are placed such that their axis is parallel to the direction of force as shown in Figure 3-1-2. Here the principle force in the bolts is tension. Then the failure of the connection results either from exceeding the shear capacity of the bolt or one of the bearing limit states discussed with tension members.

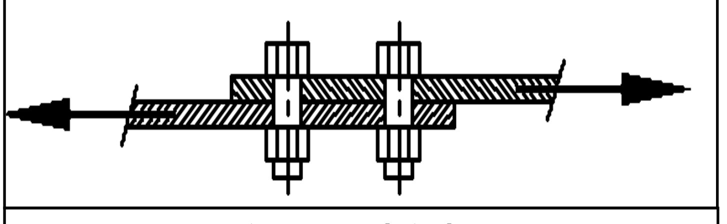


Figure 3-1-1 Bolts in Shear

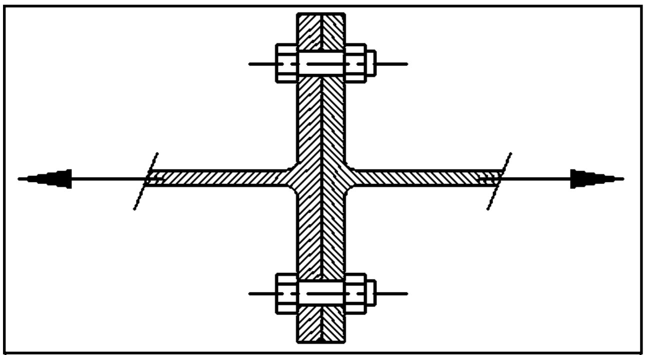


Figure 3-1-2 Bolts in Tension

3-2-1 Design Strength of Bolts in Shear

If the connections are to place in a tension test, shown in Figure 3-1-1, the force vs deformation curve would look something like what is shown in Figure 3-2.

As the load is progressively applied to the connection, the major force transfer between the connected plates would be by friction. The friction capacity is the result of the normal force (N) between the plates created by the bolt tension and the roughness of the contact surfaces (quantified by the friction coefficient, μ). Once the applied force exceeds the friction capacity (i.e. the nominal slip capacity), the connected members slip relative to each other until they bear on the bolts. After slip occurs the force is then transferred by bearing between the edge of the hole and the bolt to the bolt. The bolt carries the force by shear to the adjacent connected plate where it is transferred to the plate by bearing between the bolt and the edge of the hole.

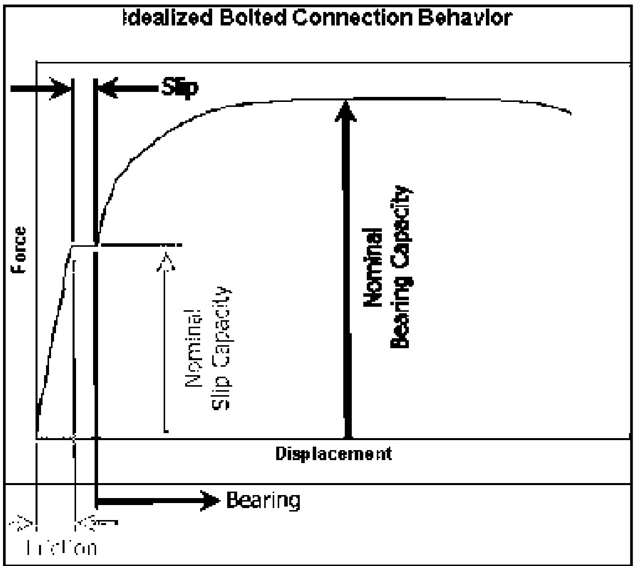


Figure 3-2 Bolt Load/Deformation Curve

As can be seen in Figure 3-2, every connection will have two shear capacities:

- The capacity to carry load without slip and
- The capacity to carry load without shear failure of the bolts

The first is called the **NOMINAL SLIP CRITICAL** capacity.

The second is called the **NOMINAL BEARING** capacity.

In a snug tight connection slip occurs at much smaller loads so the nominal slip capacity is negligible. The only capacity available for a snug tight connection is the nominal bearing capacity.

The location of maximum shear in the bolt is commonly referred to as a **SHEAR PLANE**. The bolt depicted in Figure 3-3-1 is referred to as a "single shear bolt" since it has only one critical shear plane. It is possible to have more than one critical shear plane. Figure 3-3-2 shows a bolt that has two critical shear planes. These bolts are said to be in "double shear" and can transfer twice as much force as a bolt in single shear. It is possible to have even more planes of shear.

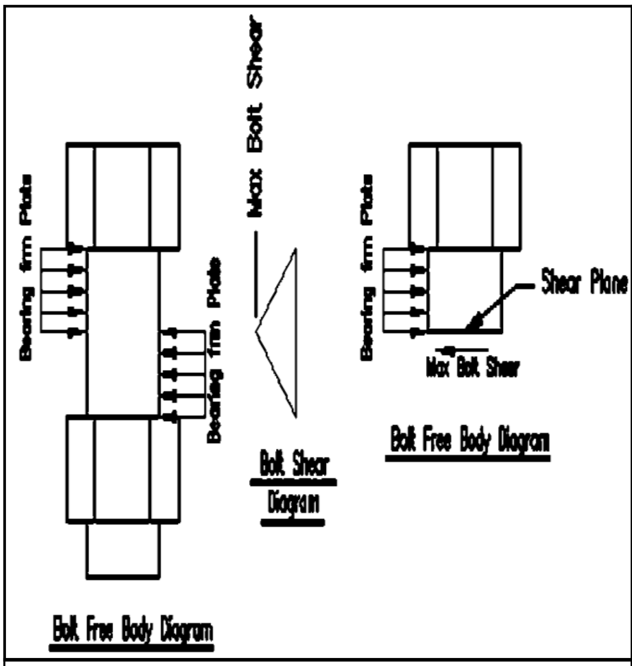


Figure ٣-٣-1Single Shear Bolt

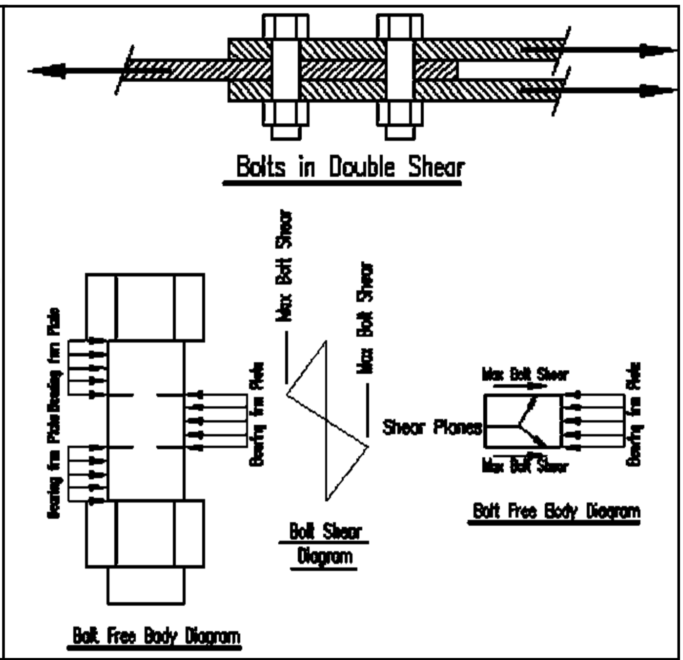


Figure 3-3-2 Double Shear Bolt

In this case R_{nv} is the nominal shear strength *<u>of a shear plane</u>* is computed using the equation:

$$R_{nv} = F_{nv} A_b N_s$$

Where: F_{nv} is obtained from LRFD Table J3.2

A_b is the nominal cross sectional area of the bolt ($\pi d_b^2/4$)

- N_s is the No. of shear planes

$$\varphi R_{nv} = \varphi F_{nv} A_b N_s$$
$$R_{dv} = \varphi R_{nv} N_b$$

Where: φ =0.75

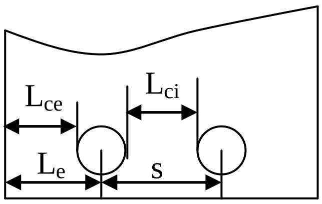
- R_{dv} is design shear strength of connector in joint
- φR_{nv} is design shear strength per bolt

- N_b is the No. of bolts

While R_{nb} is the nominal bearing strength *of a shear plane* is computed using the equation:

$R_{nb} = 1.2\ F_u t\ L_c \leq 2.4\ F_u t\ d_b$

Where: L_c = clear distance — $L_{ce} = L_e - 0.5d_h$ (at edge)
$L_{ci} = s - d_h$ (internal)



- F_u is ultimate tensile stress of member material, ksi
- t is the thickness of member, in
- d_b is the nominal diameter of bolt, in
- d_h is the diameter of hole, in …. $d_h = d_b + 1/16$
- L_e = end distance (Table J3.4, pp107 in LRFDM)

- Min spacing of bolt $s \geq 2\ ⅔d$ a distance of 3*d* is preferred.

$$R_{db} = \varphi R_{nb} * N_b = (\varphi R_{nbe} * N_{be}) + (\varphi R_{nbi} * N_{bi})$$

$$R_d = \min[R_{dv}, R_{db}]$$

Where: $\varphi = 0.75$
- R_{nb} is nominal bearing strength per bolt
- φR_{db} is design bearing strength per bolt
- N_{be} is the No. of external bolts
- N_{bi} is the No. of internal bolts
- R_d is design strength of connector in joint

3-2-2 Design Strength of A Bolt in Tension

The mechanics of a bolt in tension are less complicated than for a bolt in shear. In this case there is no slip to consider. Also there are no shear planes. The capacity of a bolt is the same regardless of the number of plates being connected together. The tensile force is parallel to the bolt axis and is considered to be concentric with the bolt's cross sectional area, resulting in uniform stress across the section as depicted in Figure 3-4.

As tensile load is applied to a connection it will reduce the contact pressure between connected members. The bolts see no tensile force beyond the pretension force until the contact stress between the connected members is overcome.

In this case R_{nt} the nominal tensile strength *of a bolt* is computed using the equation:
$R_{nt} = F_{nt} A_b$

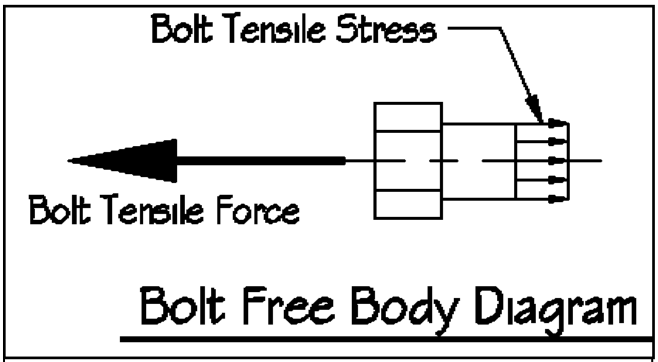


Figure 3-4 Bolt in Tension

Where: F_{nt} = nominal tensile strength per unit area, obtained from ASIC-LRFD manual, Table J3.2 (p. 6-81), as:

- F_{nt} = 90 ksi for A325 bolts
  113 ksi for A490 bolts
- A_b is the nominal cross sectional area of the bolt ($\pi d_b^2/4$)

$$\varphi R_{nt} = \varphi F_{nt} . A_b$$

$$R_{dt} = \varphi R_{nt} * \text{No. of bolt}$$

Where: φ =0.75 and R_{dt} is design tensile strength of a connector

3-2-3 Design Strength of A Bolt in Combined Shear and Tension

The bolts in wind bracing connections are often subjected to both shear and tension under applied loads. The interaction of applied shear and tension creates a situation where the principle stress is neither perpendicular nor parallel to the axis of the fastener. Figure 3-5 shows a connection where the bolts see both shear and tension.

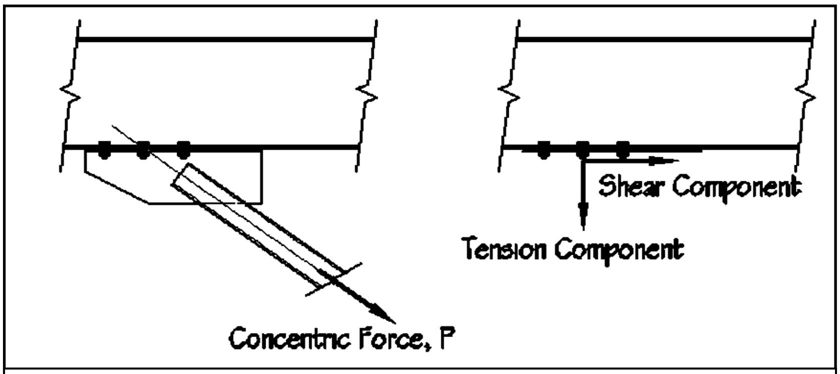


Figure 3-5 Connection with Combined Shear and Tension

The elliptic interaction formula approach can be used:

$$\left(\frac{T_u}{\phi R_{nt}}\right)^2 + \left(\frac{V_u}{\phi R_{nv}}\right)^2 \le 1.0$$

Where: T_u is the factored tensile load in bolt

- φR_{nt} is design tensile strength of a high-strength bolt
- V_u is the factored shear load in bolt
- φR_{nv} is design shear strength per bolt
- T_u is the factored tensile load in bolt

For combined shear and tension, equations for tension stress limit are given in the ASIC-LRFD manual, Table J3.5 (p. 6-84), as:

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

***Example Problem* 3-1:** Determine the max. axial tensile load P (30% dead load & 70% live load) that can be transmitted by the bolts in the butt splice shown in Figure 3–6. . The main plates are ½-in. thick, and the cover plates are ⅜-in. thick. Assume 1-in. dia. A 490 bolts in standards holes with threads eXcluded from shear planes . The plates are of A572 Gr 55 steel.

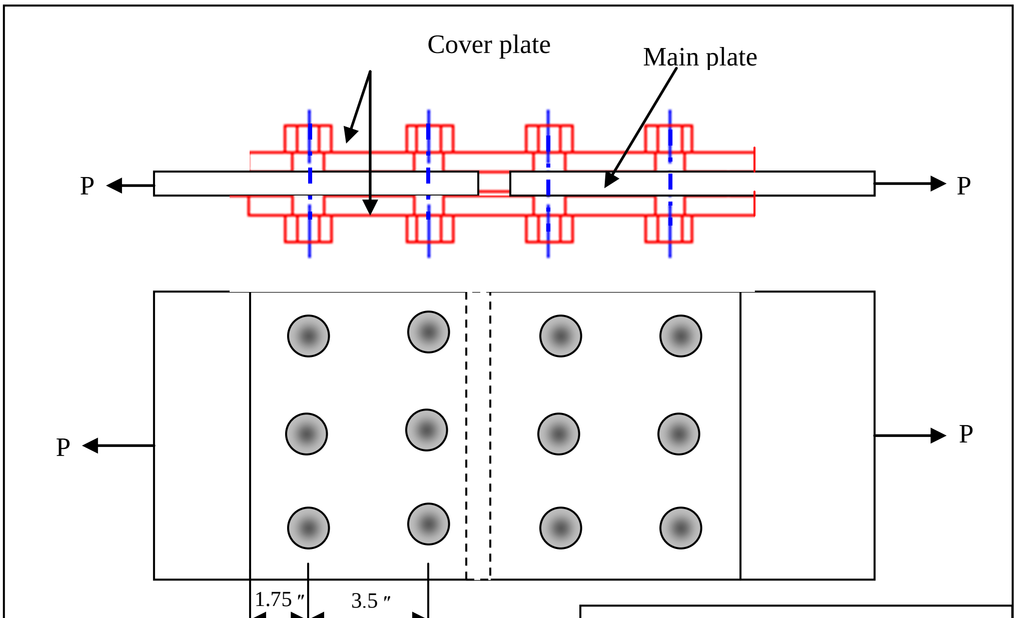


Figure 3-6 Example problem 3-1

Solution: - Design shear strength

From table **J 3.2** the value of F_{nv} for A490 bolt with eXcluded threads is 84.0 ksi

$\varphi R_{nv} = \varphi F_v A_b N_s = 0.75 * 75 * \pi(1)^2/4 * 2 = 88.4$ kips

$R_{dv} = \varphi R_{nv} N_b = 88.4 * 6 = 530.4$ kips

- Design bearing strength

@ edge bolt: $L_{ce} = L_e - 0.5\, d_h = 1.75 - 0.5(1 + 1/16) = 1.22$ in.

$\varphi R_{nbe} = 0.75(1.2\, F_u t\, L_c) = 0.75*1.2*70*1.22*1/2 = 38.4$ kips

@ interior bolt: $L_{ci} = s - d_h = 3.5 - (1 + 1/16) = 2.44$ in.

$\varphi R_{nbi} = 0.75(1.2\, F_u t\, L_c) = 0.75*1.2*70*2.44*1/2 = 76.9$ kips $> 0.75(2.4\, F_u t\, d_b) = 0.75*2.4*70*½*1 = 63$ kips

Take $\varphi R_{nbi} = 63$ kips

$R_{db} = (N_{be} * \varphi R_{nbe}) + (N_{bi} * \varphi R_{nbi}) = (3*38.4) + (3*63) = 304.2$ kips

$R_d = \min(R_{dv}, R_{db})$ .... $R_d = 304.2$ kips $\geq P_u$

$P_u = 1.2DL + 1.6LL = 1.2(0.3\, P_s) + 1.6(0.7\, P_s) \leq 478$ kips

$P_{s,\,max} = 205.5$ kips

***Example Problem* 3-2:** A lap joint connecting two ½-in. plates transmits axial service tensile loads $P_D = 60$ kips and $P_L = 60$ kips using 1-in. dia. A325 high-strength bolts in standard holes with threads iNcluded in the shear plane. Assume A572 Gr 50 steel. Determine the No. of bolt required for a bearing type joint.

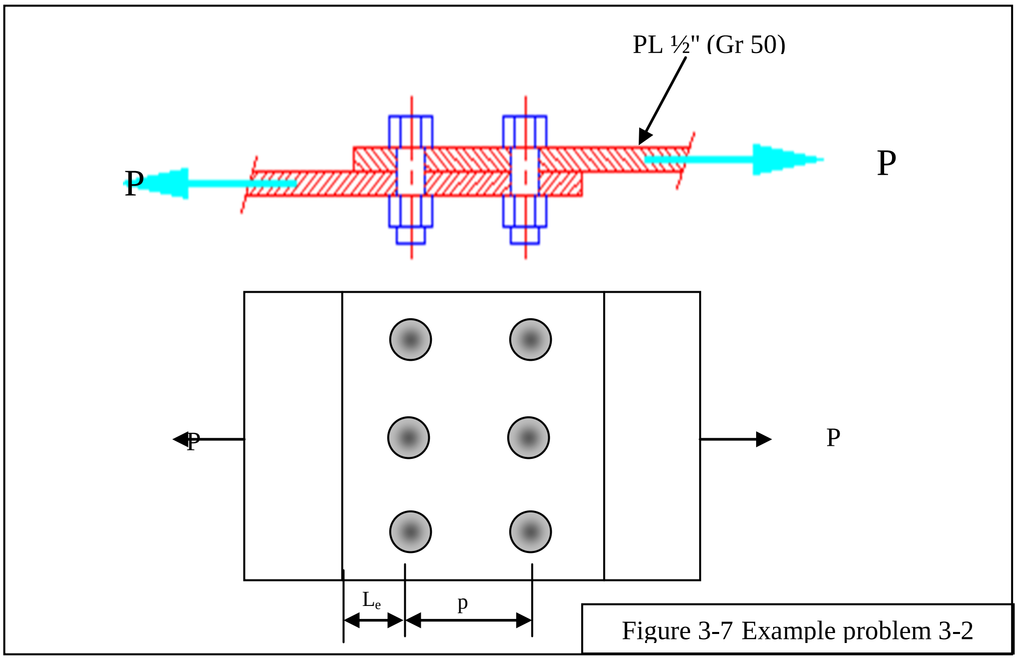


Figure 3-7 Example problem 3-2

Solution: -

P_u= 1.2DL + 1.6LL = 1.2(60) + 1.6(60) = 168 kips

$\varphi R_{nv} = \varphi F_{nv} A_b N_s = 0.75*48*\pi(1)^2/4*1 = 28.3$ kips

$\varphi R_{nbi} = \varphi R_{nbe} = 0.75(2.4\ F_u t\ d) = 0.75*2.4*65*1*½ = 58.5$ kips

R_d = min. (R_{dv}, R_{db}) = min. ($N_b\ \varphi R_{nv}$, $N_b \varphi R_{nb}$) .... 28.3 N_b kips $\geq P_u$

No. of bolts (N_b) = 168/28.3 = 5.9

Provide 6 bolts. That is 3 bolts in each vertical row.

***Example Problem* 3-3:** Determine the required number of ¾ in. diameter A490 bolts for the connection below. It subjected to axial service tensile loads P_D = 14 kips and P_L=126 kips.

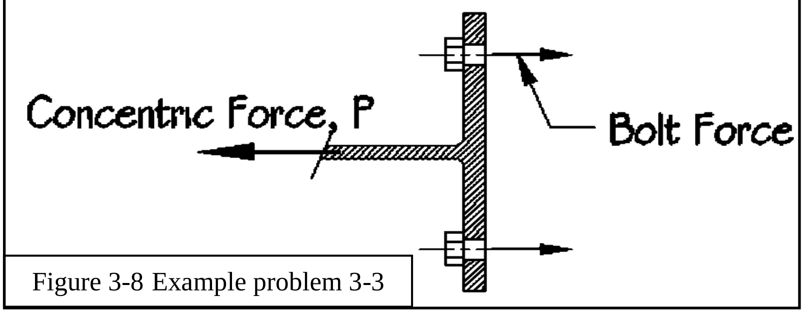


Figure 3-8 Example problem 3-3

Solution: -

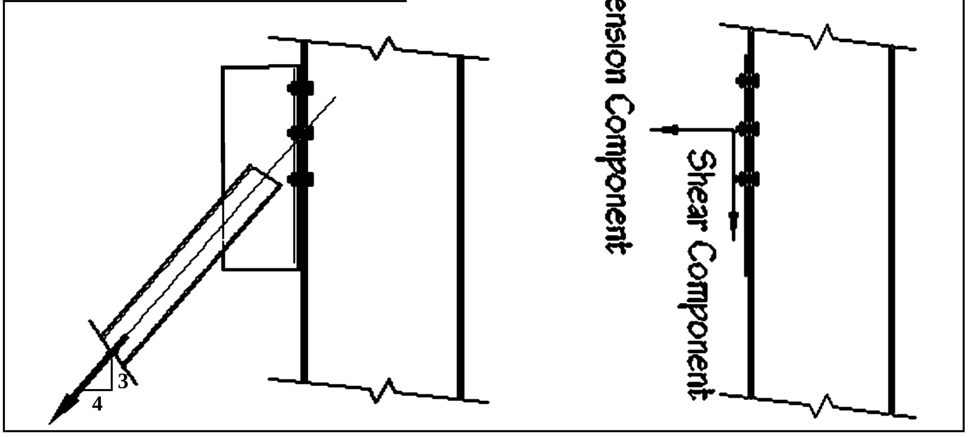
P_u= 1.2DL + 1.6LL = 1.2(14) + 1.6(126) = 218.4 kips

$\varphi R_{nt} = \varphi F_{nt} A_b = 0.75 * 113 * \pi(¾)^2/4 = 37.5$ kips

No. of bolts = $P_u / \varphi R_{nt}$ = 5.8 say 6 bolts

Example Problem 3-4: A WT10.5×31 A36 Gr.36 is used as a bracket to transmit axial service tensile loads P_D = 15 kips and P_L=45 kips. Determine the adequacy of the ⅞ in. diameter A325bolts with threads in shear plan for the connection below.

Figure 3-9 Example problem 3-4



Solution: -

P_u= 1.2DL + 1.6LL = 1.2(15) + 1.6(45) = 90 kips

– The bolts in shear:

$V_{u,\ total}$ = 3/5 * 90 = 54 kips

- Shear strength:

$\varphi R_{nv} = \varphi F_{nv} A_b N_s = 0.75 * 48 * \pi(⅞)^2/4 = 21.7$ kips

$R_{dv} = \varphi R_{nv}\ N_b = 21.7 * 3 = 64.95$kips

- Bearing strength: the flange of TW-section controls

t_f = 0.615 "

φR_{nb} = 0.75(2.4 F_u d_bt) = 0.75*2.4*58* ⅞ * 0.615= 56.18 kips

$R_{db} = N_b * \varphi R_{nb}$ = 3 * 56.18 = 168.54 kips

R_d = min(R_{dv}, R_{db}) .... R_d = 64.95 kips > V_u = 54 kips O.K.

– The bolts in tension:

$T_{u,\ total}$ = 4/5 * 90 = 72 kips,

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

$f_v = V_u/(A_b$* No. of bolts) = 54/(0.6016*3) = 22.45 ksi

$$F'_{nt} = 1.3(90) - \frac{90}{0.75(54)} 22.45 = 67.11\text{ksi} < 90 \text{ ksi} \quad \text{O.K.}$$

$\varphi R_{nt} = \varphi F'_{nt} A_b$ = 0.75 * 67.11* $\pi(⅞)^2/4$ = 30.3 kips

$R_{dt} = \varphi R_{nt}$ * No. of bolts = 3*30.3 = 90.9 kips >T_u = 72 kips O.K.