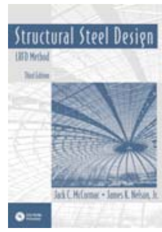
ANALYSIS OF TENSION MEMBERS

A. J. Clark School of Engineering •Department of Civil and Environmental Engineering

Part II – Structural Steel Design and Analysis

3c

FALL 2002



By
Dr. Ibrahim. Assakkaf

ENCE 355 - Introduction to Structural Design

Department of Civil and Environmental Engineering
University of Maryland, College Park

Prentice Hall

Analysis of Bolted Members

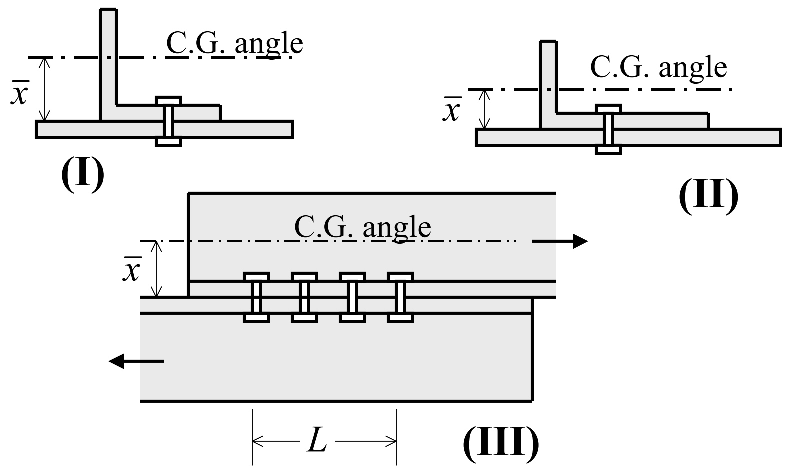
- When tension in a member is transmitted by bolts, A then equal the net area A_n of the member and U is computed as follows:

$$U = 1 - \frac{\bar{x}}{L} \quad \leq 0.9 \qquad (1)$$

- The length L used in above expression is equal to the distance between the first and the last bolts in the line.

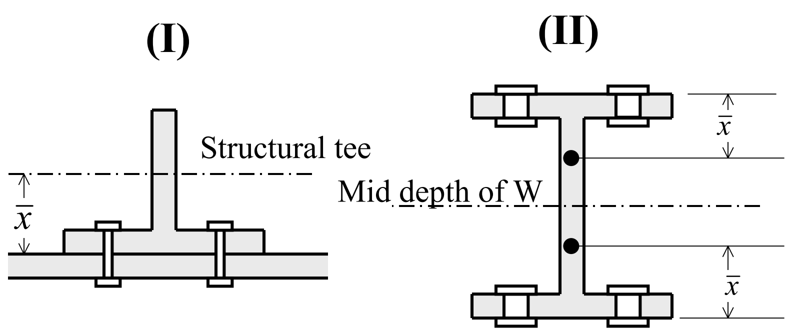
Analysis of Bolted Members

Figure 1a. Values of $\bar{x}$ for Different Shapes



Analysis of Bolted Members

Figure 1b. Values of $\bar{x}$ for Different Shapes



Note $\bar{x} = \bar{y}$ in structural tee tables

Analysis of Bolted Members

- The angle shown in Fig. 1a-I is connected at its ends to only one leg.
- The area effective in resisting tension can be appreciably increased by shortening the width of the unconnected leg and lengthening the width of the connected width (see Fig. 1a-I and II)
- $\bar{x}$ is measured from the plane of the connection to the center of gravity (C.G.) or centroid of the whole section.

Analysis of Bolted Members

- Calculation of U for W Section
  - In order to calculate U for a W section connected by its flange only, it is assumed that the section is split into two structural tees.
  - Then, the value of $\bar{x}$ used will be the distance from the outside edge of the flange to the C.G. of the structural tee as shown in Part II of Fig. 1b.

Analysis of Bolted Members

- Example 1

  Determine the tensile design strength of a W10 × 45 with two lines of ¾-in diameter bolts in each flange using A572 Grade 50 steel with F_y = 50 ksi and F_u = 65 ksi and the LEFD Specification. There are assumed to be at least three bolts in each line 4 in. on center, and the bolts are not staggered with respect to each other.

Analysis of Bolted Members

- Example 1 (cont'd)

  The following properties of W10 × 45 section are obtained from LRFD Manual (Page 1-20):

  - $A = A_g = 13.3 \text{ in}^2$, $d = 10.1$ in., $b_f = 8.02$ in., $t_f = 0.62$ in.

  (a) Case I-Yielding of the Section:

$$\phi_t P_n = \phi F_y A_g = 0.90(50)(13.3) = 598.5 \text{ k}$$

  (b) Case II-Net-section Fracture:

$$A_n = 13.3 - 4\left[\frac{3}{4} + \frac{1}{8}\right](0.62) = 11.13 \text{ in}^2 = A$$

Analysis of Bolted Members

- Example 1 (cont'd)

Referring to the tables for half of a W10 × 45 (or WT5 × 22.5), the value of $\bar{x}$ is obtained as

$$\bar{x} = 0.907 \text{ in.} \quad \text{From LRFD, P. 1-49}$$

Then

$$U = 1 - \frac{\bar{x}}{L} = 1 - \frac{0.907}{8} = 0.89 < 0.9$$

$$A_e = UA = 0.89(11.13) = 9.91 \text{ in}^2$$

$$\phi_t P_n = \phi_t F_u A_e = 0.75(65)(9.91) = 483.1 \text{ k}$$

Therefore, design strength = 483.1 k

Connecting Elements for Tension Members

- Splice and gusset plates are usually used as statically loaded tensile connecting elements.
- According to the LRFD Manual, their strength can be determine from
  - For yielding of connection elements:

$$\phi = 0.90 \qquad R_n = A_g F_y \qquad (1)$$

  - For fracture of connection elements:

$$\phi = 0.75 \qquad R_n = A_n F_u \quad \text{with } A_n \le 0.85 A_g \qquad (2)$$

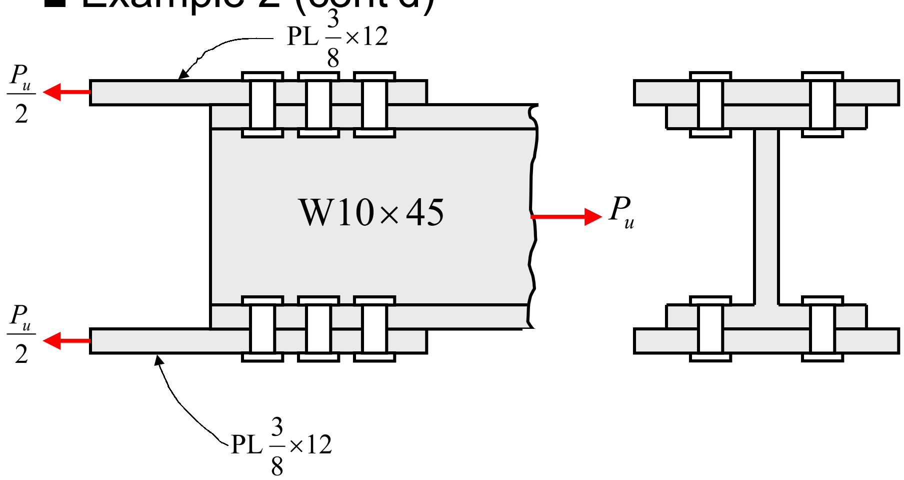
Connecting Elements for Tension Members

- Example 2

  A tension member W10 × 45 with F_y = 50 ksi and F_u = 65 ksi is assumed to be connected at its ends with two 3/8 × 12-in plates as shown. If two lines of ¾-in bolts are used in each plate, determine the design tensile force which the plates can transfer.

Connecting Elements for Tension Members

- Example 2 (cont'd)



Connecting Elements for Tension Members

- Example 2 (cont'd)

$$\phi_t F_y A_g = 0.9(50)\left[2\left(\frac{3}{8}\right)(12)\right] = 405 \text{ k}$$

$$A_n \text{ of 2 plates} = (2)\left[\left(\frac{3}{8}\right)(12) - \left(\frac{3}{4} + \frac{1}{8}\right)(2)\left(\frac{3}{8}\right)\right] = 7.69 \text{ in}^2$$

$$0.85 A_g = 0.85\left[2\left(\frac{3}{8}\right)(12)\right] = 7.65 \text{ in}^2 < 7.69$$

$$\therefore A_n = 7.65 \text{ in}^2$$

$$\phi_t P_n = \phi_t F_u A_n = 0.75(65)(7.65) = 372.9 \text{ k} \quad \text{controls}$$

Therefore,

$$\phi_t P_n = 372.9 \text{ k}$$

Block Shear

- The design strength of a tension member is not always controlled by

$$\phi_t F_y A_g \qquad \text{or} \qquad \phi_t F_u A_g$$

  or by the strength of the bolts or welds with which the member is connected.

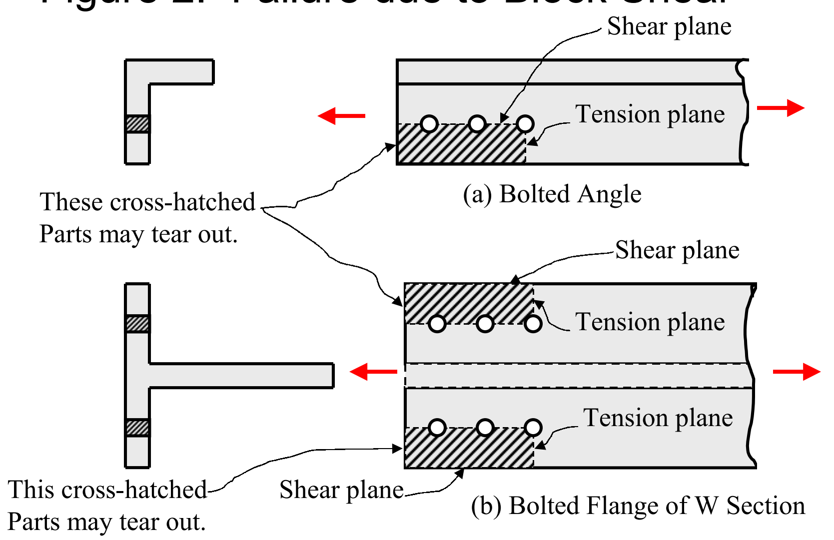
- It may instead be controlled by its ***block shear*** strength as will be described.

Block Shear

- Failure due to Block Shear
  - The failure of a member may occur along a path involving tension on one plane and shear on a perpendicular plane as shown in Fig. 2.
  - In this figure, several possible block shear failures are shown.
  - For these situations, it is possible for a "block" to tear out.

Block Shear

Figure 2. Failure due to Block Shear



Block Shear

- Failure due to Block Shear
  - When a tensile load applied to a particular connection is increased, the fracture strength of the weaker plane will be approached.
  - That plane will not fall because it is restrained by the stronger plane.
  - The load can be increased until the fracture strength of the stronger plane is reached.

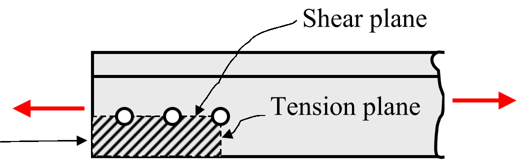
Block Shear

- Failure due to Block Shear
  - During this time, the weaker plane is in yielding.
  - The total strength of the connection equals the fracture strength of the stronger plane plus the yield strength of the weaker plane.
  - However, it is not realistic to add the fracture strength of one plane to the fracture strength of the plane to determine the block shear capacity of a particular member.

Block Shear

■ Failure due to Block Shear

Block shear failure can be thought of as being a tearing or rupture failure and not a yielding failure at bolt holes.



This cross-hatched
Parts may tear out.

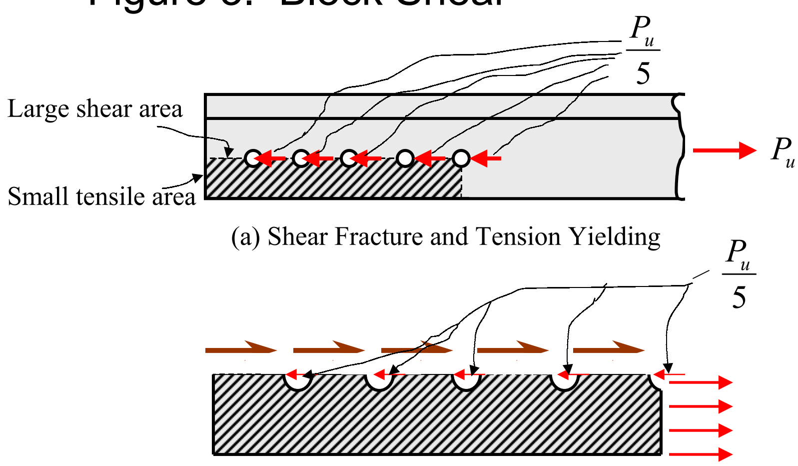
Block Shear

■ Failure due to Block Shear

- The member shown in Fig. 3a has a larger shear area and a small tensile area.
- Therefore, the primary resistance to a block shear failure is shearing and not tensile.
- The LRFD Specification states that it is logical to assume that when shear fracture occurs on this large shear-resisting area, the small tensile area has yielded.

Block Shear

Figure 3. Block Shear



(a) Shear Fracture and Tension Yielding

(b) Free body of "block" that tends to shear out in angle of part a.

Block Shear

- Failure due to Block Shear
  - Part (b) of Fig. 3 shows a free body of the block that tends to tear out the angle of Part a. This block shear is caused by the bolts bearing on the back of the bolts holes.
  - When a member has a large tensile area and a small shear area, the block shear failure will be tensile and not shearing.

Block Shear

- LRFD Specification on Block Shear
  - The block shear design strength of a member is to be determined by
    1. Computing the tensile fracture strength on the net section in one direction and adding to that value the shear yield strength on the gross area on the perpendicular segment.
    2. Computing the shear fracture strength on the gross area subject to tension and adding it to the tensile yield strength on the net area subject to shear on the perpendicular segment.
  - The expression to use is the one with larger rupture value.

Block Shear

- LRFD Specification on Block Shear

1. If $F_u A_{nt} \geq 0.6\, F_u\, A_{nv}$, then shear yielding and tension fracture, and the following Eq. is used:

$$\phi R_n = \phi\left[0.6 F_y A_{gv} + F_u A_{nt}\right] \leq \phi\left[0.6 F_u A_{nv} + F_u A_{nt}\right] \qquad (3)$$

2. If $F_u A_{nt} < 0.6\, F_u\, A_{nv}$, then shear yielding and tension fracture, and the following Eq. is used:

$$\phi R_n = \phi\left[0.6 F_u A_{nv} + F_y A_{gt}\right] \leq \phi\left[0.6 F_u A_{nv} + F_u A_{nt}\right] \qquad (4)$$

in which $\phi = 0.75$, and

Block Shear

- LRFD Specification on Block Shear

A_{gv} = gross area subjected to shear, in^2

A_{gt} = gross area subjected to tension, in^2

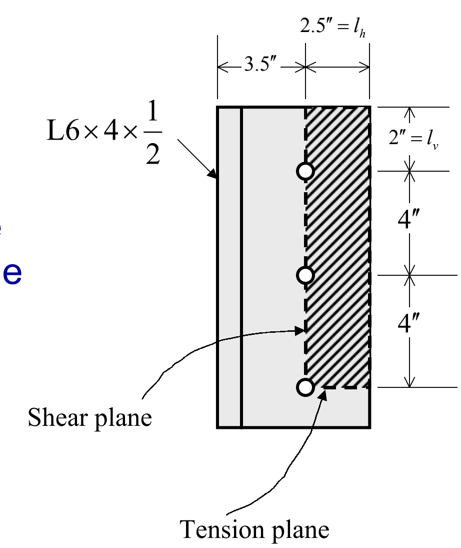
A_{nv} = net area subjected to shear, in^2

A_{nt} = net area subjected to tension, in^2

Block Shear

- Example 3

The A572 Grade 50 (F_u = 65 ksi) tension member shown is connected with three ¾-in bolts. Determine the block shearing strength of the member and its tensile strength.



Block Shear

■ Example 3 (cont'd)

For L6 × 4 × ½, the LRFD Manual gives the following properties (P. 1-34 & 1-35):

A = 4.72 in^2, and x in unconnected leg = 0.986 in.

The following areas can be computed:

$$A_{gv} = (10)\left(\frac{1}{2}\right) = 5.0\text{ in}^2$$

$$A_{gt} = (2.5)\left(\frac{1}{2}\right) = 1.25\text{ in}^2$$

$$A_{nv} = \left[10 - 2.5\left(\frac{3}{4} + \frac{1}{8}\right)\right]\left(\frac{1}{2}\right) = 3.91\text{ in}^2$$

$$A_{nt} = \left[2.5 - \frac{1}{2}\left(\frac{3}{4} + \frac{1}{8}\right)\right]\left(\frac{1}{2}\right) = 1.03\text{ in}^2$$

Block Shear

■ Example 3 (cont'd

$$F_u A_{nt} = (65)(1.03) = 66.9\text{ k} < 0.6\,F_u A_{nv} = 0.6(65)(3.91) = 152.5\text{ k}$$

Therefore, use Eq. 4

$$\phi R_n = \phi\left[0.6F_u A_{nv} + F_y A_{gt}\right] \le \phi\left[0.6F_u A_{nv} + F_u A_{nt}\right]$$

$$\phi R_n = 0.75[0.6(65)(3.9) + 50(1.25)] = 161\text{ k}$$ ← Controls

$$< 0.75[0.6(65)(3.9) + 65(1.03)] = 164\text{ k}$$

– Tensile strength of angle:

(a) Yieding Criterion:

$$\phi_t P_n = \phi_t F_y A_g = 0.9(50)(4.72) = 212.4\text{ k}$$

Block Shear

- Example 3 (cont'd

(a) Fracture Criterion :

$$A_n = 4.72 - (1)\left[\frac{3}{4} + \frac{1}{8}\right]\left(\frac{1}{2}\right) = 4.28\ \text{in}^2 = A$$

$$U = 1 - \frac{\bar{x}}{L} = 1 - \frac{0.986}{8} = 0.88 \leq 0.9$$

$$A_e = UA = 0.88(4.28) = 3.77\ \text{in}^2$$

$$\phi_t P_n = \phi_t F_u A_e = 0.75(65)(3.77) = 183.8\ \text{k}$$

Therefore,

$$\phi_t P_n = 161\ \text{k}$$

Block Shear

- Use of Tables in LRFD Manual
  - Tables are available in Part 9 of the LRFD Manual, 2nd Edition with which block shear strengths of W beams can be determined .
  - In Table 9.3, values of $\phi F_u A_{nt}$ are tabulated per inch of material thickness, and then in Table 9.4 values of $\phi\,(0.6F_y A_{gv})$ per inch of material thickness are given.

Computer Example

- Example 4

  Using the program INSTEP32, determine the design tensile strength of a 12-ft long W12 × 136 consisting of A572 Grade 50 steel if the net area is assumed to be 35.52 in^2 and U = 0.9.

Input:

P_u = 0 kips
Net Area = 35.52 in^2
Length = 12 × 12 = 144 in
U = 0.9

Computer Example

- Example 4 (cont'd)

Instep32--Structural Steel Design with AISC LRFD Procedures
Clemson University Department of Civil Engineering

Client: Project: Topic:	Designed by: Checked by: Date:

Design of a Member in Axial Tension

Properties for Specified Material
F_y = 50 ksi
F_u = 65 ksi

Specified Design Data
P_u = 0 kips
Net Area = 35.52 sq.in.
L = 144 in.
U = 0.9

Trial Section: W12X136

Computer Example

■ Example 4 (cont'd)

```
Check Yield Criteria
Pn = 50(39.9) = 1995 kips
0.9Pn = 0.9(1995) = 1795.5 kips

Check Fracture Criteria
Pn = 0.9(35.52)(50) = 2077.92 kips
0.75Pn = 0.75(2077.92) = 1558.44 kips

Check Slenderness Criteria
L/R = 144/3.16 = 45.5696

This member is adequate
```