CHAPTER

Structural Steel Design
LRFD Method

Third Edition

ANALYSIS OF TENSION MEMBERS

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Part II – Structural Steel Design and Analysis

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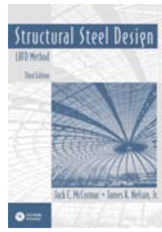

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Prentice Hall

ENCE 355 - Introduction to Structural Design

Department of Civil and Environmental Engineering
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Introduction

- Tension members are found in
  - Bridges and roof trusses
  - Towers
  - Bracing systems
  - Cases where they are used as tie rods
- The design of tension members is very simple and straightforward.
- No buckling problems are encountered as in the case of compression members.

Introduction

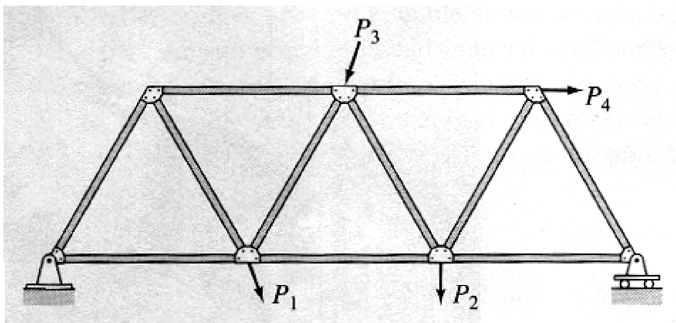
RHINE BRIDGE, COLOGNE-RODENKIRCHEN, (1946-47), SPAN 94.5-378-94.5 m

Introduction

Transmission Towers

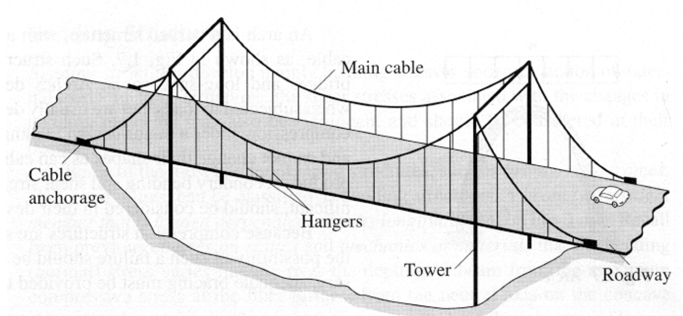
Introduction

- Tension Members
  - Trusses



Introduction

- Tension Members
  - Tension Structures



Introduction

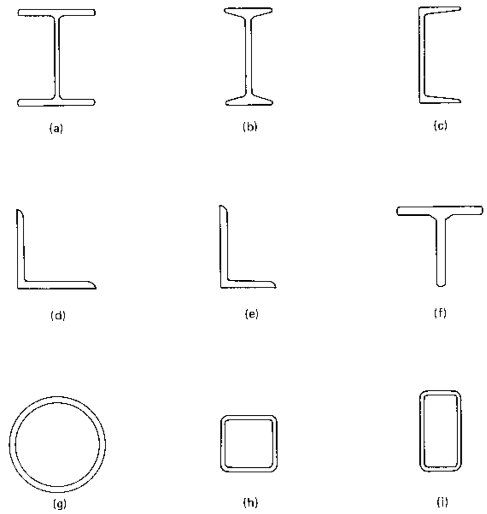
- Rods
  - One of the simplest forms of tension members is the circular rod.
  - The rod has been used frequently in the past, but has only occasional uses nowadays in bracing systems, light trusses, and in timber construction.
  - The problems associated with rods that there is some difficulty connecting them to many structures.

Introduction

- Rolled Shapes (Standard Sections)
  - Today, tension members include
    - Single angles
    - Double angles
    - Tees
    - Channels
    - **W** sections, and
    - Built-up sections
  - These members look better, are stiffer, and are easier to connect to other structures.

Introduction

Steel Sections



Introduction

- Tie Plates (bars)
  - Members consisting of more than one section need to be tied together.
  - Tie plates (also called tie bars) located at various intervals or perforated cover plates serve to hold the various pieces in their correct positions.
  - These plates help correct any an equal distribution of loads between the various parts.

Introduction

- Steel Cables
  - They are made with special steel alloy wire ropes that are cold-drawn to a desired diameter.
  - The resulting wire strengths of about 200,000 to 250,000 psi can be economically used for suspension bridges, cable supported roofs, ski lifts, and other similar applications.

Design Strength of Tension Members

- Nominal Strength
  - The strength of a tension member may be described in terms of the "limit states" that govern.
  - The controlling strength limit state for a tension member can either
    - Yielding of the gross cross-section of the member away from the connection, or
    - Fracture of the effective net area (i.e., through the holes) at the connection

Design Strength of Tension Members

- LRFD Specification

  When the limit state is general ***yielding*** of the gross section over the member length, as for a tension member without holes (i.e., with welded connection), the nominal strength P_n is expressed as

$$\boxed{\begin{aligned} &P_n = F_y A_g \\ &P_u \leq \phi_t F_y A_g \quad \text{with } \phi_t = 0.90 \end{aligned}} \qquad (1)$$

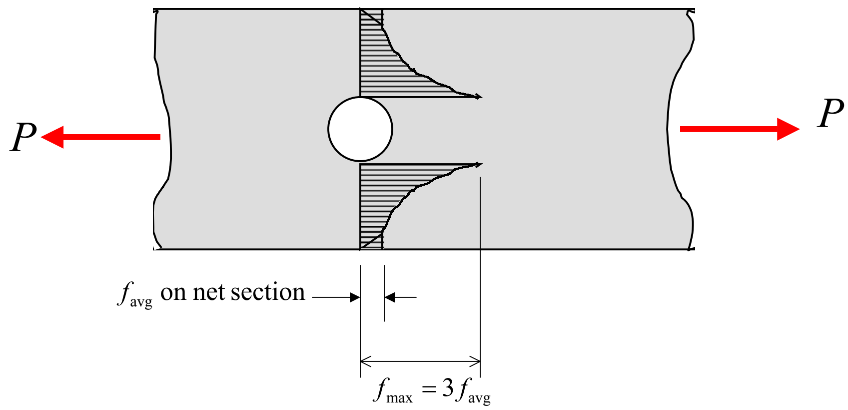
F_y = yield stress
A_g = gross cross-sectional area

Design Strength of Tension Members

- LRFD Specification
  - For tension members having ***holes***, such as for rivet or bolts, the reduced cross section is referred to as the ***net area***.
  - Holes in member cause stress concentration (nonuniform stresses).
  - For example, a hole in a plate with a tensile service force P produces a stress distribution at service load as shown in Fig. 1

Design Strength of Tension Members

- Figure 1. Elastic Stress Distribution with Holes Present

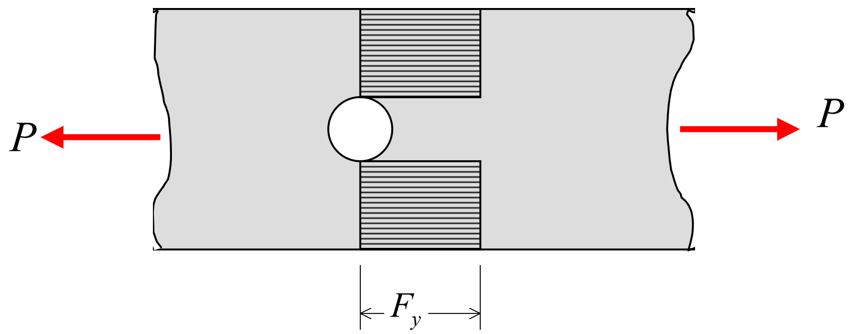


Design Strength of Tension Members

- LRFD Specification
  – Theory of elasticity shows that tensile stress adjacent to the hole will about three times the average stress on the net area.
  – However, as each fiber reaches yield strain, that is $\varepsilon_y = F_y/E_s$, its stress then becomes a constant F_y with deformation continuing with increasing load until finally all fibers have achieved or exceeded the strain ε_y (see Fig. 2)

Design Strength of Tension Members

- Figure 2. Ultimate Condition - Stress Distribution with Holes Present



Design Strength of Tension Members

- LRFD Specification

When the limit state is a localized yielding resulting in a fracture through the effective net area of a tension member having holes, the nominal strength P_n is expressed as

$$\boxed{\begin{aligned} P_n &= F_u A_e \\ P_u &\leq \phi_t F_u A_e \quad \text{with } \phi_t = 0.75 \end{aligned}} \qquad (2)$$

F_u = tensile strength
A_e = effective net area = UA_n
A_n = net area
U = efficiency factor

Design Strength of Tension Members

Table 1

Steel Type	ASTM Designation		F_y Min. Yield Stress (ksi)	F_u Tensile Stress[a] (ksi)	Applicable Shape Series: W	M	S	HP	C	MC	L	HSS: Rect.	HSS: Round	Steel Pipe
Carbon	A36		36	58–80[b]										
	A53 Gr. B		35	60										
	A500	Gr. B	42	58										
			46	58										
		Gr. C	46	62										
			50	62										
	A501		36	58										
	A529[c]	Gr. 50	50	65–100										
		Gr. 55	55	70–100										
High-Strength Low-Alloy	A572	Gr. 42	42	60										
		Gr. 50	50	65[d]										
		Gr. 55	55	70										
		Gr. 60[e]	60	75										
		Gr. 65[e]	65	80										
	A618[f]	Gr. I & II	50[g]	70[g]										
		Gr. III	50	65										
	A913	50	50[h]	60[i]										
		60	60	75										
		65	65	80										
		70	70	90										
	A992		50–65[j]	65[i]										
Corrosion Resistant High-Strength Low-Alloy	A242		42[l]	63[l]										
			46[k]	67[k]										
			50[l]	70[l]										
	A588		50	70										
	A847[l]		50	70										

Design Strength of Tension Members

- Net Areas, A_n
  - Whenever a tension member is to be fastened by means of bolts or rivets, holes must be provided at the connection.
  - Therefore, the member cross sectional area is reduced and the strength of the member may also be reduced depending on the size and location of the holes.
  - The term "*net cross-sectional area*" or "*net area*" refers to the gross sectional area of the member minus the holes, notches, or other indentations.

Design Strength of Tension Members

- Net Areas, A_n (cont'd)
  - Methods for Cutting Holes
    1. The most common and least expensive method is to punch standard holes 1/16 in. (1.6 mm) larger than the diameter of the rivet or bolt.

       In general the plate thickness is less than the punch diameter. This is accounted in design by assuming that the extend of the damage is limited to a radial distance of 1/32 in. (0.8 mm) around the hole.

Design Strength of Tension Members

- Net Areas, A_n (cont'd)
  - Methods for Cutting Holes
    2. A second method of cutting holes consists of subpunching them 3/16 in. (4.8 mm) diameter undersize and them reaming the holes to the finished size after the pieces being joined are assembled.

       This method is more expensive, but offers the advantage of accurate alignment.

       This method produces better strength.

Design Strength of Tension Members

- Net Areas, A_n (cont'd)
  - Methods for Cutting Holes
    3. A third method consists of drilling holes to a diameter of the rivet or bolt plus 1/32 in. (0.8 mm).

       This method is used to join thick pieces, and is the most expensive of the all common methods.

Design Strength of Tension Members

- Net Areas, A_n (cont'd)

  How to find the area of the hole?

  The area f the hole is considered a rectangular area, and is computed as follows:

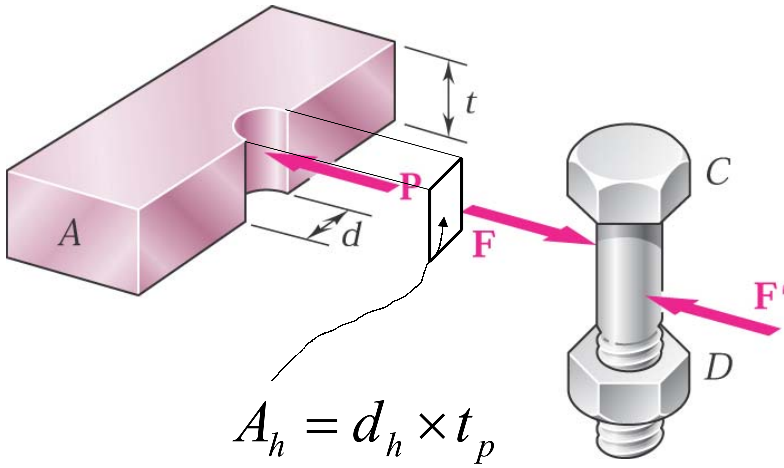
$$\boxed{A_h = d_h \times t_p} \qquad (3)$$

For fastener in standard holes,

d_h = diameter of fastener + 1/8 in. (3.2 mm)

t_p = thickness of plate or metal used

Design Strength of Tension Members



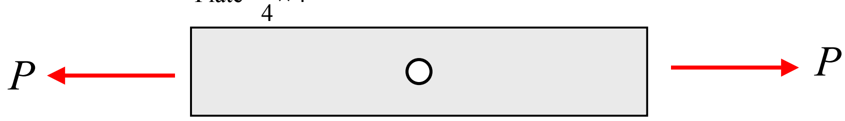
$$A_h = d_h \times t_p$$

Design Strength of Tension Members

- Example 1

  What is the net area A_n for the tension member shown?

Plate - $\frac{1}{4} \times 4$



Standard hole for a - $\frac{3}{4}$ – in - diam. bolt

Design Strength of Tension Members

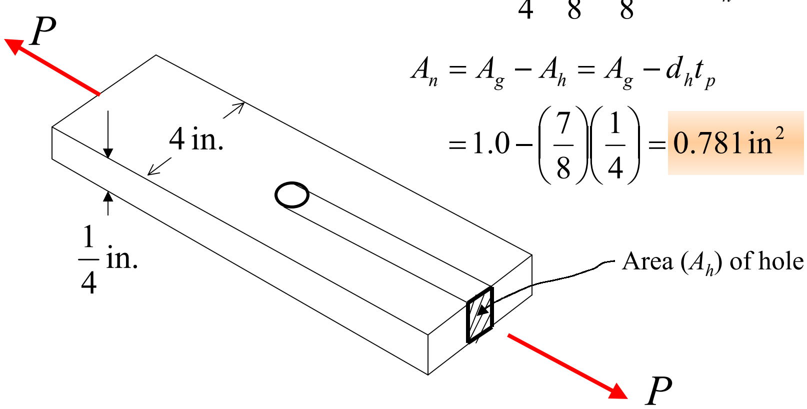
- Example 1 (cont'd)

$$A_g = 4(0.25) = 1.0\ \text{in}^2$$

$$\text{width to be deducted for hole} = \frac{3}{4} + \frac{1}{8} = \frac{7}{8}\ \text{in.} = d_h$$

$$A_n = A_g - A_h = A_g - d_h t_p$$

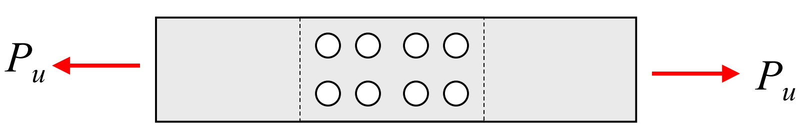
$$= 1.0 - \left(\frac{7}{8}\right)\left(\frac{1}{4}\right) = 0.781\ \text{in}^2$$

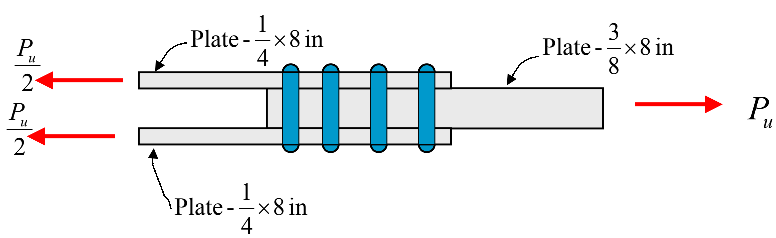


Design Strength of Tension Members

- Example 2

Determine the net area of the 3/8 × 8-in plate shown. The plate is connected at its ends with two lines of ¾-in bolts.





Design Strength of Tension Members

- Example 2 (cont'd)

$$A_g = \left(\frac{3}{8}\right)(8) = 3\text{ in}^2$$

$$\text{width to be deducted for one hole} = \frac{3}{4} + \frac{1}{8} = \frac{7}{8}\text{ in.} = d_h$$

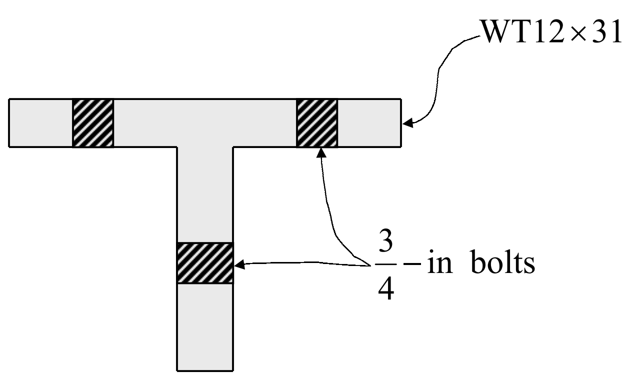
$$A_n = A_g - 2A_h = A_g - 2d_h t_p$$

$$= 3.0 - 2\left[\frac{7}{8} \times \frac{3}{8}\right] = 2.34\text{ in}^2$$

Design Strength of Tension Members

- Example 3

Compute the net area for the member shown in the figure.



Design Strength of Tension Members

- Example 3 (cont'd)
  - Using a **WT12 × 31**, the following properties can be obtained from the AISC Steel Manual (Page 1-44):

$$A = 9.16 \text{ in}^2$$
$$t_w = 0.430 \text{ in}$$
$$t_f = 0.59 \text{ in}$$

Therefore,

$$A_g = A = 9.16 \text{ in}^2$$

Design Strength of Tension Members

- Example 3 (cont'd)

$$\text{width to be deducted for one hole} = \frac{3}{4} + \frac{1}{8} = \frac{7}{8} \text{ in.} = d_h$$

$$\begin{aligned} A_n &= A_g - 2(A_h)_{\text{Flange}} - (A_h)_{\text{Web}} \\ &= A_g - 2(d_h t_p)_{\text{Falnge}} - (d_h t_p)_{\text{Web}} \\ &= A_g - 2d_h t_f - d_h t_w \\ &= 9.16 - 2\left(\frac{7}{8}\right)(0.59) - \frac{7}{8}(0.430) = 7.75 \text{ in}^2 \end{aligned}$$