Prentice Hall **Structural Steel Design** LRFD Method — Third Edition

CHAPTER

DESIGN OF TENSION MEMBERS

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Part II – Structural Steel Design and Analysis

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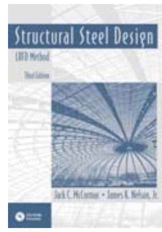

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ENCE 355 - Introduction to Structural Design

Department of Civil and Environmental Engineering

University of Maryland, College Park

Prentice Hall

Selection of Members

- This chapter deals with the design of tension members for external loads.
- In general, the design of tension members should have the following properties:
  1. Compactness
  2. Dimensions that fit into the structure with reasonable relation to other member dimensions.
  3. Minimization of shear blocks and lag.

Selection of Members

- AISC LRFD Specifications

The design strength $\phi_t P_n$ is the lesser of

a) $\phi_t F_y A_g$ (1)

b) $\phi_t F_u A_e$ (2)

c) The block shear strength, $\phi_t R_n$ (3)

Selection of Members

- AISC LRFD Specifications
  - The first expression (Eq. 1) is satisfied if the minimum gross area is at least equal to the following:

$$\min A_g = \frac{P_u}{\phi_t F_y} \quad (4)$$

  - The second expression (Eq. 2) is satisfied if the minimum value of A_e is at least

$$\min A_e = \frac{P_u}{\phi_t F_u} \quad (5)$$

Selection of Members

- AISC LRFD Specifications
  - And since $A_e = U A_n$ for bolted members, the minimum value of A_n is given by

$$\min A_n = \frac{\min A_e}{U} = \frac{P_u}{\phi_t F_u U} \qquad (6)$$

  - Then the minimum A_g for the second expression (Eq. 2) must be at least equal the minimum value of A_n plus the estimated hole area:

$$\min A_g = \frac{P_u}{\phi_t F_u U} + \text{estimated hole areas} \qquad (7)$$

Selection of Members

- AISC LRFD Specifications
  - The third expression (Eq. 3) can be evaluated once a trial shape has been selected, and the other parameters related to the block shear strength are known.
  - The designer can substitute into Eqs. 4 and 7, taking the larger value of A_g so obtained for an initial size estimate.

Selection of Members

- AISC LRFD Specifications
  - The designer also has to check the slenderness ratio that it would not exceed a value of 300, that is

$$\frac{L}{r} = 300 \quad \text{or} \quad \min r = \frac{L}{300} \qquad (8)$$

Selection of Members

- AISC LRFD Specifications
  - If no load involved other than the dead and live loads, then the designer must check the following load factor expressions and take the larger:

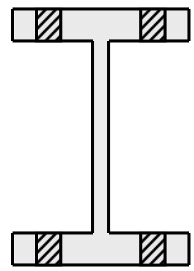
$$P_u = 1.4D \qquad (9)$$

$$P_u = 1.2D + 1.6L \qquad (10)$$

Selection of Members

- Example 1

Select a 30-ft-long W12 section of A992 steel to support a tensile service dead load $P_D = 130$ k and a tensile service load $P_L = 110$ k. As shown in the figure, the member is to have two lines of bolts in each flange for 7/8-in bolts (at least three in a line 4 in on center).



Selection of Members

- Example 1 (cont'd)

Considering the load factor expressions of Eqs. 9 and 10:

$$P_u = 1.4D = 1.4(130) = 182 \text{ k}$$

$$P_u = 1.2D + 1.6L = 1.2(130) + 1.6(110) = 332 \text{ k} \leftarrow \text{Controls}$$

Computing the minimum A_g required using Eqs. 4 and 7:

$$\min A_g = \frac{P_u}{\phi_t F_y} = \frac{332}{0.9(50)} = 7.38 \text{ in}^2$$

Assume U = 0.9 and assume the flange thickness is 0.380 in from the manual for W12.

Selection of Members

Table 1

Steel Type	ASTM Designation		F_y Min. Yield Stress (ksi)	F_u Tensile Stress[a] (ksi)	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										
		60	60	75										
		65	65	80										
		70	70	90										
	A992		50–65[i]	65										
Corrosion Resistant High-Strength Low-Alloy	A242		42[j]	63[j]										
			46[k]	67[k]										
			50[l]	70[l]										
	A588		50	70										
	A847[f]		50	70										

Selection of Members

- Example 1 (cont'd)

$$\min A_g = \frac{P_u}{\phi_t F_u U} + \text{estimated hole areas}$$

$$= \frac{332}{0.75(65)(0.9)} + 4\left[\left(\frac{7}{8} + \frac{1}{8}\right)(0.380)\right] = 9.09 \text{ in}^2$$

Preferable min r:

$$\min r = \frac{L}{300} = \frac{30 \times 12}{300} = 1.2 \text{ in}$$

Selection of Members

- Example 1 (cont'd)

Try W12 × 35, that has the following properties (P. 1-20 and 1-21, Manual):

$A_g = 10.3\text{ in}^2,\ d = 12.5\text{ in},\ b_f = 6.56\text{ in}$

$t_f = 0.520\text{ in},\ \text{and } r_y = 1.54\text{ in}$

Checking:

$$\phi_t P_n = \phi_t F_u A_g = 0.9(50)(10.3) = 463.5\text{ k} > 332\text{ k}$$ OK

$\bar{x}$ For half W12 × 35 or that is a WT6 × 17.5 :

$\bar{x} = 1.30\text{ in}$ (note it is $\bar{y}$ in P.1-49 of Manual)

Selection of Members

- Example 1 (cont'd)

Checking (cont'd)

$$L = 2(4) = 8\text{ in}$$

$$U = \left(1 - \frac{\bar{x}}{L}\right) \leq 0.90 = \left(1 - \frac{1.30}{8}\right) = 0.84 < 0.90$$

$$A_n = 10.3 - 4\left[\left(\frac{7}{8} + \frac{1}{8}\right)(0.520)\right] = 8.22\text{ in}^2$$

$$\phi_t P_n = \phi_t F_u A_e = 0.75(65)[0.84(8.22)] = 336.6\text{ k} > 332\text{ k}$$ OK

$$\frac{L_y}{r_y} = \frac{30 \times 12}{1.54} = 234 < 300$$ OK

Therefore, USE W12 × 35 Section

Built-up Tension Members

- The LRFD Specification provides a definite set of rules describing how the different parts of built-up tension members are to be connected together:

1. When a tension member is built up from element in continuous contact with each other, such as a plate and a shape, or two plates, the longitudinal spacing of connectors between those elements must not exceed 24 times the thickness of the thinner plate, or 12 in if the member is to be painted.

Built-up Tension Members

2. Should the member consists of unpainted weathering steel elements in continuous contact and be subject to atmospheric corrosion, the maximum permissible connector spacings are 14 times the thickness of the thinner plate, or 7 in.
3. Should a tension member be built up from two or more shapes separated by intermittent filet, the shapes must be connected to each other at intervals such that the slenderness ratio of the individual shapes between fasteners does not exceed 300.

Built-up Tension Members

4. The distance from the center of any bolts to the nearest edge of the connected part under consideration may not be larger than 12 times the thickness of the connected part, or 6 in.

NOTE: refer to Page 105 of the textbook and LRFD Specification *D*2 for more details about the the design of connecting plates.

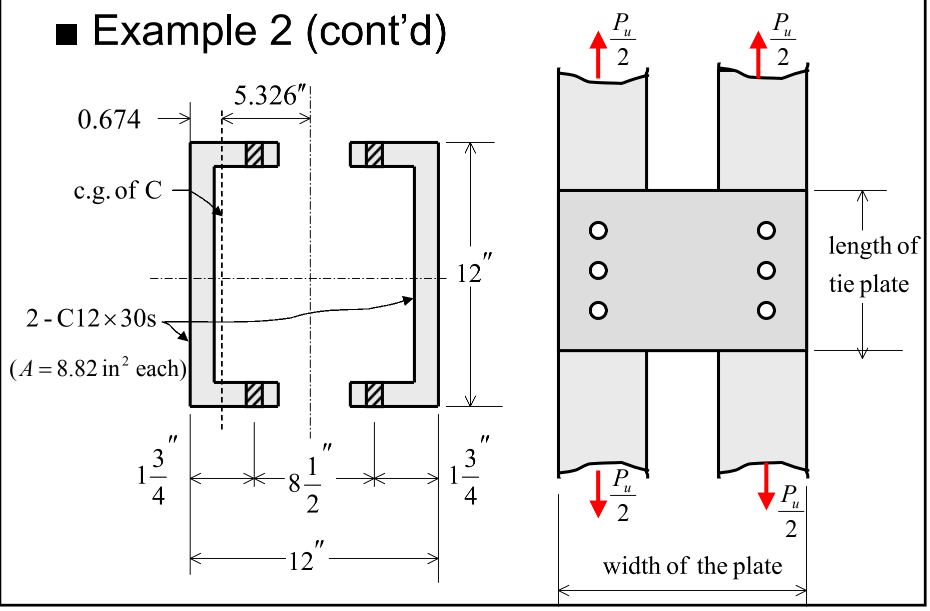
Built-up Tension Members

- Example 2

  Two C12 × 30s, as shown in the figure, have been selected to support a dead tensile working load of 120 k and a 240-k live load tensile working load. The member is 30 ft long consists of A36 steel, and has one line of at least three 7/8-in bolts in each channel flange 3 in on center. Using the LRFD Specification, determine whether the member is satisfactory and design the necessary tie plates. Assume centers of bolt holes are 1.75 in from the backs of the channels.

Built-up Tension Members

- Example 2 (cont'd)



Built-up Tension Members

- Example 2 (cont'd)

Using C12 × 30s, the following properties from the LRFS Manual can be obtained:

A_g = 8.81 in^2 each, t_f = 0.501 in, I_x = 162 in^4 each
I_y = 5.12 in^4 each, y axis 0.674 from back of C, and
r_y = 0.762 in.

Load to be resisted:

$$P_u = 1.4D = 1.4(120) = 168 \text{ k}$$
$$P_u = 1.2D + 1.6L = 1.2(120) + 1.6(240) = 528 \text{ k}$$

← Controls

Built-up Tension Members

■ Example 2 (cont'd)

Design Strengths:

$$\phi_t F_y A_g = 0.9(36)[2(8.81)] = 570.9\text{ k} > 528\text{ k}$$ OK

$$A_n = 2\left[8.81 - 2\left(\frac{7}{8} + \frac{1}{8}\right)(0.501)\right] = 15.62\text{ in}^2$$

$$U = 0.85 \text{ from Table 2 (Table 3-2, Text)}$$

$$\phi_t P_n = \phi_t F_u A_n U = 0.75(58)(15.62)(0.85) = 577.5\text{ k} > 528\text{ k}$$ OK

Selection of Members

Table 1

Steel Type	ASTM Designation		F_y Min. Yield Stress (ksi)	F_u Tensile Stress[a] (ksi)	W	M	S	HP	C	MC	L	HSS Rect.	HSS Round	Steel Pipe
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			50[l]	70[l]										
	A588		50	70										
	A847[f]		50	70										

Built-up Tension Members

- Example 2 (cont'd)

Slenderness Ratio:

$$I_x = 2(162) = 324\ \text{in}^4$$

$$I_y = 2(5.12) + 2(8.81)(5.326)^2 = 511\ \text{in}^4$$

$$r_x = \sqrt{\frac{324}{2(8.81)}} = 4.29\ \text{in}$$

$$r_y = \sqrt{\frac{511}{2(8.81)}} = 5.38\ \text{in}$$

since $r_x = 4.29\ \text{in} < r_y = 5.38\ \text{in}$, r_x controls

$$\frac{L_x}{r_x} = \frac{12 \times 30}{4.29} = 83.9 < 300 \qquad \text{OK}$$

Built-up Tension Members

- Example 2 (cont'd)

Design of tie plates:

$$\text{Distance between lines of bolts} = 12 - 2\left(1\frac{3}{4}\right) = 8.5\ \text{in}$$

$$\text{Min. length of tie plates} = \frac{2}{3}(8.5) = 5.67\ \text{in (say 6 in)}$$

$$\text{Min. thickness of tie plates} = \frac{1}{50}(8.5) = 0.17\ \left(\text{say } \frac{3}{16}\ \text{in}\right)$$

$$\text{Min. width of tie paltes} = 8.5 + 2\left(1\frac{1}{2}\right) = 11.5\ \text{in (say 12 in)}$$

Max. preferable spacing of tie plates:

Least r of C = 0.762 in

$$\text{Max. preferable } \frac{L}{r} = 300 \Rightarrow \frac{L}{0.762} = 300 \Rightarrow L = 228.6\ \text{in} = 19.05\ \text{ft}$$

USE 3/16 × 6 × 1 ft

Rods and Bars

- When rods and bars are used as tension members, they may be simply welded at their ends, or they may be threaded and held in place with nuts.
- The LRFD nominal tensile design stress for threaded rods is given in their table J3.2 and equals $\phi 0.75\,F_u$, and is to be applied to the gross area of the rod A_D computed with the major thread diameter.

Rods and Bars

- The area required for a particular tensile load can then be calculated from the following expression:

$$A_D \geq \frac{P_u}{\phi 0.75 F_u} \quad \text{with } \phi = 0.75 \qquad (11)$$

Rods and Bars

■ Example 3

Using A36 steel and LRFD Specification, select a standard rod of A36 steel to support a tensile working dead load of 10 k and a tensile working live load of 20 k.

$$P_u = 1.4D = 1.4(10) = 14 \text{ k}$$

$$P_u = 1.2D + 1.6L = 1.2(10) + 1.6(20) = 44 \text{ k}$$ ← Controls

$$\text{Eq.11:} \quad A_D = \frac{P_u}{\phi 0.75 F_u} = \frac{44}{0.75(0.75)(58)} = 1.35 \text{ in}^2$$

$$\text{USE } 1\frac{3}{8}\text{-in-diameter rod } (A_D = 1.49 \text{ in}^2)$$

Design for Fatigue Loads

■ The AISC has provisions for fatigue design as outlined by the following procedure:

1. The design stress range determined in accordance with the AISC requirements is only applicable for the following situations:
   a. Structures for which the steel has adequate corrosion protection for the conditions expected in that locality.
   b. Structures for temperatures do not exceed 300^0 F.

Design for Fatigue Loads

2. The provisions of the Specification apply to stresses which are calculated with unfactored loads and the maximum permitted stress due to these loads is 0.66 F_y.

   Formulas are given in Appendix K.3 of the Specification for computing the design stress range.

Design for Fatigue Loads

- The stress range, for most cases, can be calculated from

$$F_{SR} = \left(\frac{C_f}{N}\right)^{0.333} \geq F_{TH} \qquad (12)$$

Where
F_{SR} = design stress range, ksi
C_f = constant from Table A-K3.1 in LRFD Appendix
N = number of stress fluctuations in design life
F_{TH} = threshold fatigue stress range from Table A-K3.1 in LRFD Appendix, Ksi.

Design for Fatigue Loads

- Example 4

  A tension member is to consist of a W12 section (F_y = 50 ksi) with fillet-welded end connections. The service dead load is 40 k, while it is estimated that the service live load will vary from a compression of 20 k to a tension of 90 k fifty times per day for an estimated design life of 25 years. Select the section.

See Solution on Page 116, Textbook.