CHAPTER

6a

Prentice Hall

Structural Steel Design
LRFD Method

Third Edition

DESIGN OF AXIALLY LOADED COMPRESSION MEMBERS

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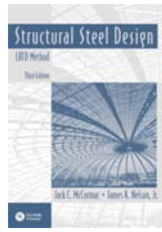
Part II – Structural Steel Design and Analysis

FALL 2002



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ENCE 355 - Introduction to Structural Design

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Introduction

- The members that can be designed for compression include:
  - Single shapes
  - W sections with cover plates
  - Built-up sections constructed with channels
  - Sections whose unbraced lengths in the x and y directions.
  - Lacing and tie plates for built-up sections with open sides.

Introduction

- The Design Process for Columns
  – It is to be noted that the design of columns wit formulas involves a trial-and-error process.
  – The design stress $\phi_c F_{cr}$ is not known until a column size is selected and vice versa.
  – Once a trial section is assumed, the r value for that section can be obtained and substituted into the appropriate column equation to determine its design stress.

Introduction

- The Design Process for Columns
  – In the design of columns, the factored load P_u is computed for a particular column and then divided by an assumed design stress to give an estimated column area A, that is

$$A_{\text{estimated}} = \frac{P_u}{\text{assumed stress}} = \frac{P_u}{\phi_c F_{cr}} \qquad (1)$$

Introduction

- The Design Process for Columns
  - After an estimated column area is determined, a trial section can be selected with approximately that area.
  - The design stress for the selected section can be computed and multiplied by the cross sectional area of the section to obtain the member's design strength.
  - This design strength is compared with the factored load P_u. It must be equal or greater than the load P_u.

Introduction

- General Notes on Column Design
  - The effective slenderness ratio (KL/r) for the average column of **10 to 15 ft** in length will generally fall between **40 and 60**.
  - A value for KL/r in this range can be assumed and substituted into the appropriate column equation.
  - Or instead of the column equation, tables in LRFD manual can be consulted to give the design strength for that particular KL/r value. (KL/r ranges from 1 to 200 in LRFD)

Introduction

- Example 1

  Using F_y = 50 ksi, select the lightest W14 section available for the service column loads P_D = 130 k and P_L = 210 k. Assume KL = 10 ft.

$$P_u = 1.2P_D = 1.2(130) =$$

$$P_u = 1.2P_D + 1.6P_L = 1.2(130) + 1.6(210) = 492\text{ k} \longleftarrow \text{Governs}$$

$$\text{Assume } \frac{KL}{r} = 50$$

Introduction

- Example 1 (cont'd)

$$\phi_c F_{cr} \text{ form Table 3.50 (Part 16 of Manual)} = 35.4\text{ ksi}$$

$$\therefore A_{\text{required}} = \frac{P_u}{\phi_c F_{cr}} = \frac{492}{35.4} = 13.90\text{ in}^2$$

$$\text{Try W14} \times 48 \left(A = 14.1\text{ in}^2, r_x = 5.85\text{ in}, r_y = 1.91\text{ in}\right)$$

$$r_y = 1.91 \longleftarrow \text{controls}$$

$$\frac{KL}{r_y} = \frac{12 \times 10}{1.91} = 62.83$$

$$\phi_c F_{cr} \text{ form Table 3.50 (Part 16 of Manual)}$$
$$\text{and by iterpolation} = 31.85\text{ ksi}$$

Introduction

- LRFD Manual Design Tables (P. 16.I-145)

TABLE 3-50

Design Stress for Compression Members of 50 ksi Specified Yield Stress Steel, $\phi_c = 0.85$[a]

$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi
42.5	41	37.6	81	26.3	121	14.6	161	8.23
42.5	42	37.4	82	26.0	122	14.3	162	8.13
42.5	43	37.1	83	25.7	123	14.1	163	8.03
42.5	44	36.9	84	25.4	124	13.9	164	7.93
42.4	45	36.7	85	25.1	125	13.7	165	7.84
42.4	46	36.4	86	24.8	126	13.4	166	7.74
42.4	47	36.2	87	24.4	127	13.2	167	7.65
42.3	48	35.9	88	24.1	128	13.0	168	7.56
42.3	49	35.7	89	23.8	129	12.8	169	7.47
42.2	50	35.4	90	23.5	130	12.6	170	7.38

Introduction

- LRFD Manual Design Tables (P. 16.I-145)

TABLE 3-50

Design Stress for Compression Members of 50 ksi Specified Yield Stress Steel, $\phi_c = 0.85$[a]

$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi
41.8	55	34.1	95	22.0	135	11.7	175	6.97
41.7	56	33.8	96	21.7	136	11.5	176	6.89
41.6	57	33.5	97	21.4	137	11.4	177	6.81
41.5	58	33.2	98	21.1	138	11.2	178	6.73
41.4	59	33.0	99	20.8	139	11.0	179	6.66
41.3	60	32.7	100	20.5	140	10.9	180	6.59
41.2	61	32.4	101	20.2	141	10.7	181	6.51
41.0	62	32.1	102	19.9	142	10.6	182	6.44
40.9	63	31.8	103	19.6	143	10.4	183	6.37
40.8	64	31.5	104	19.3	144	10.3	184	6.30

Introduction

■ Example 1 (cont'd)

$$\phi_c P_n = (\phi_c F_{cr})A_g = 31.85(14.1) = 449 \text{ k} < 492 \text{ k} \quad \text{NG}$$

$\therefore$ try next larger W14

Try W14×53 $\left(A = 15.6 \text{ in}^2, r_x = 5.89 \text{ in}, r_y = 1.92 \text{ in}\right)$

$r_y = 1.92 \longleftarrow$ controls

$$\frac{KL}{r_y} = \frac{12 \times 10}{1.92} = 62.5$$

$\phi_c F_{cr}$ form Table 3.50 (Part 16 of Manual)

and by iterpolation = 31.95 ksi

Introduction

■ Example 1 (cont'd)

$$\therefore \phi_c P_n = (\phi_c F_{cr})A_g = 31.95(15.6) = 498 \text{ k} < 492 \text{ k} \quad \text{OK}$$

Checking width-thickness ratio for W14 × 53:

$$\text{W}14 \times 53 \begin{pmatrix} b_f = 8.060 \text{ in}, t_f = 0.660 \text{ in}, \\ k = 1.25 \text{ in}, d = 13.9 \text{ in}, t_w = 0.370 \text{ in} \end{pmatrix}$$

$$\frac{b_f}{2t_f} = \frac{8.060}{2(0.660)} = 6.11 < 0.56\sqrt{\frac{E}{F_y}} = 0.56\sqrt{\frac{29 \times 10^3}{50}} = 13.49 \quad \text{OK}$$

$$\frac{h}{t_w} = \frac{13.9 - 2(1.25)}{0.370} = 30.81 < 1.49\sqrt{\frac{E}{F_y}} = 1.49\sqrt{\frac{29 \times 10^3}{50}} = 35.88 \quad \text{OK}$$

LRFD Design Tables

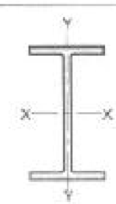
- The LRFD Manual can be used to select various column sections from tables without the need of using a trial-and-error procedures.
- These tables provide axial design strengths $\phi_c P_n$ for various practical effective lengths of the steel sections commonly used as columns.

LRFD Design Tables

- LRFD Manual Design Tables (P. 4-25)

= 50 ksi
= 0.85 $F_{cr} A_g$

Table 4-2 (cont.).
W-Shapes
Design Strength in Axial Compression, $\phi_c P_n$, kips



Shape	W12×										
	106	96	87	79	72	65††	58	53	50	45	40
0	1330	1200	1090	986	897	812	723	663	621	557	497
6	1280	1150	1050	947	861	779	690	623	582	504	450
7	1260	1140	1030	933	848	767	666	610	543	486	434
8	1240	1120	1010	917	834	754	645	594	521	456	416
9	1210	1100	994	900	818	739	631	577	497	445	396
10	1190	1070	973	880	800	723	611	559	472	422	376
11	1160	1050	950	860	781	706	590	539	445	398	354

LRFD Design Tables

- The values are given with respect to the least radii of gyration for W's and WT's with 50 ksi steel.
- Other grade steels are commonly used for other types of sections as shown in the Manual and listed there.
- These include 35 ksi for steel pipe, 36 ksi for L's, 42 ksi for round HSS sections, and 46 ksi for square and rectangular HSS sections.

LRFD Design Tables

- For most columns consisting of single steel shapes, the effective slenderness ratio with respect to the y axis $(KL/r)_y$ is larger than the effective slenderness ratio with respect to the x axis $(KL/r)_x$.
- As a result, the controlling or smaller design stress is for the y axis.
- Because of this, the LRFD tables provide design strengths of columns with respect to their y axis.

LRFD Design Tables

- Example 2

  Using the LRFD column tables with their given yield strengths:

  a. Select the lightest W section available for the loads, steel, and KL of Example 1. Use F_y = 50 ksi.

  b. Select the lightest satisfactory standard (S), extra strong (XS), and double extra strong (XXS) pipe columns described in part (a) of this example. Use F_y = 35 ksi.

LRFD Design Tables

- Example 2 (cont'd)

  c. Select the lightest satisfactory rectangular and square HSS sections for the situation in part (a). Use F_y = 46 ksi.

  d. Select the lightest round HSS section for part (a). Use F_y = 42 ksi.

---

  a. Enter LRFD tables with K_yL_y = 10 ft., P_u = 492 k, and F_y = 50 ksi.

LRFD Design Tables

- Example 2 (cont'd)

Lightest suitable section in each W series:

$$W14\times 53(\phi_c P_n = 498\text{ k})$$

$$W12\times 53(\phi_c P_n = 559\text{ k})$$

Lightest

Page 4-26 of Manual → $W10\times 49(\phi_c P_n = 520\text{ k})$ ← controls

Therefore, USE W10 × 49

b. Pipe Columns:

S : not available

Page 4-76 of Manual → XS12 × 0.500(65.5 lb/ft) = 549 k

Page 4-76 of Manual → XXS8 × 0.875(72.5 lb/ft) = 575k

LRFD Design Tables

- Example 2 (cont'd)

c. Rectangular and square HSS sections:

Page 4-49 of Manual → $\text{HSS}\,14\times 14\times \frac{5}{16}(57.3\text{ lb/ft}) = 530\text{ k}$

Page 4-51 of Manual → $\text{HSS}\,12\times 10\times \frac{3}{8}(52.9\text{ lb/ft}) = 537\text{ k}$

d. Round HSS section:

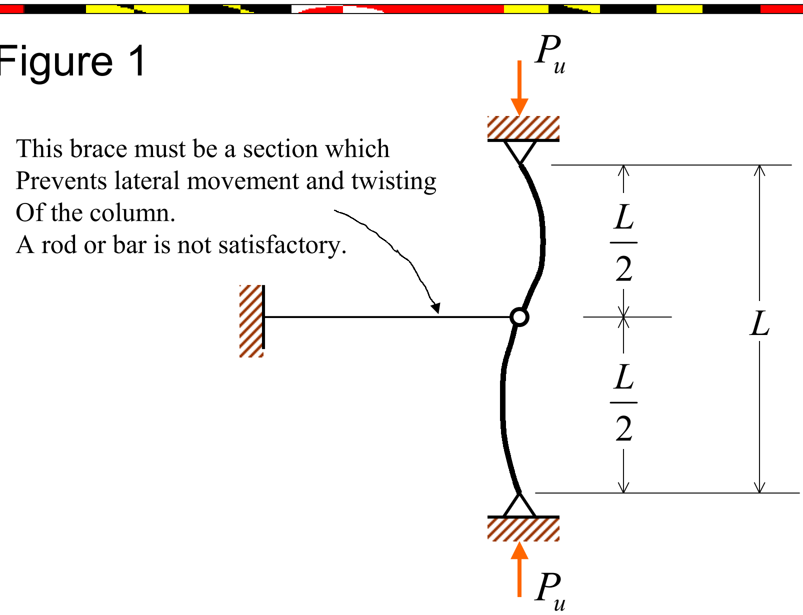
Page 4-66 of Manual → HSS16 × 0.312(52.3 lb/ft) = 500 k

LRFD Design Tables

- How to handle the situation when $(KL/r)_x$ is larger than $(KL/r)_y$?
  - Two methods can be used:
    - Trial-and error method
    - Use of LRFD Tables
  - An axially loaded column is laterally restrained in its weak direction as shown in Figs. 1 and 2

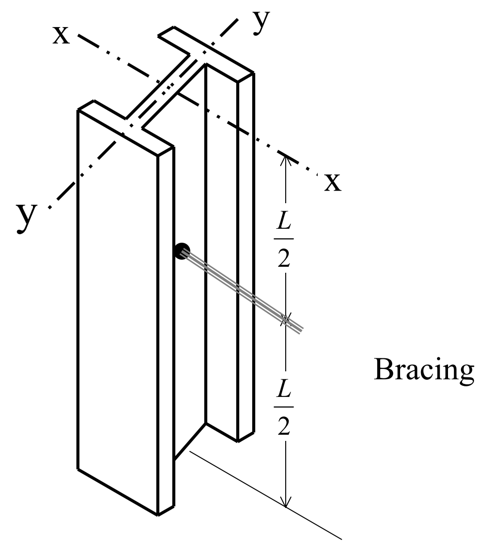
LRFD Design Tables

Figure 1



LRFD Design Tables

- Figure 2



LRFD Design Tables

- How to handle the situation when $(KL/r)_x$ is larger than $(KL/r)_y$?

  Trial-and-error Procedure:
  - A trial section can be selected as described previously.
  - Then the slenderness values $(KL/r)_x$ and $(KL/r)_x$ are computed.
  - Finally, $\phi_c F_{cr}$ is determined for the larger value of $(KL/r)_x$ and $(KL/r)_x$ and multiplied by A_g to obtained $\phi_c P_n$.
  - Then if necessary, another size can be tried, and so on.

LRFD Design Tables

- How to handle the situation when $(KL/r)_x$ is larger than $(KL/r)_y$?
  - It is assumed that K is the same in both directions. Then, if equal strengths about the x and y axis to be obtained, the following relation must hold:

$$\frac{L_x}{r_x} = \frac{L_y}{r_y} \qquad (2)$$

LRFD Design Tables

- How to handle the situation when $(KL/r)_x$ is larger than $(KL/r)_y$?
  - For L_y to be equivalent to L_x, the following relation would hold true:

$$L_x = L_y \frac{r_x}{r_y} \qquad (3)$$

- If $L_y\,(r_x/r_y)$ is less than L_x, then L_x controls.
- If $L_y\,(r_x/r_y)$ is greater than L_x, then L_y controls.

LRFD Design Tables

- How to handle the situation when $(KL/r)_x$ is larger than $(KL/r)_y$?

  Use of LRFD Tables:

  - Based on the preceding information, the LRFD Manual provides a method with which a section can be selected from tables with little trial and error when the unbraced lengths are different.
  - The designer enters the appropriate table with K_yL_y, selects a shape, takes r_x/r_y value in the table for that shape, and multiplies it by L_y.
  - If the result is larger than K_xL_x, then K_yL_y controls and the shape initially selected is the correct one.

LRFD Design Tables

- How to handle the situation when $(KL/r)_x$ is larger than $(KL/r)_y$?

  Use of LRFD Tables (cont'd):

  - If the result of the multiplication is less than K_xL_x, then K_xL_x controls and the designer will reenter the tables with a larger K_yL_y equal to $K_xL_x/(r_x/r_y)$ and select the final section.

LRFD Design Tables

- Example 3

Select the lightest satisfactory W12 for the following conditions: F_y = 50 ksi, P_u = 900 k, K_xL_x = 26 ft, and K_yL_y = 13 ft.

a. By trial and error
b. Using LRFD tables

---

a. Using trial and error:

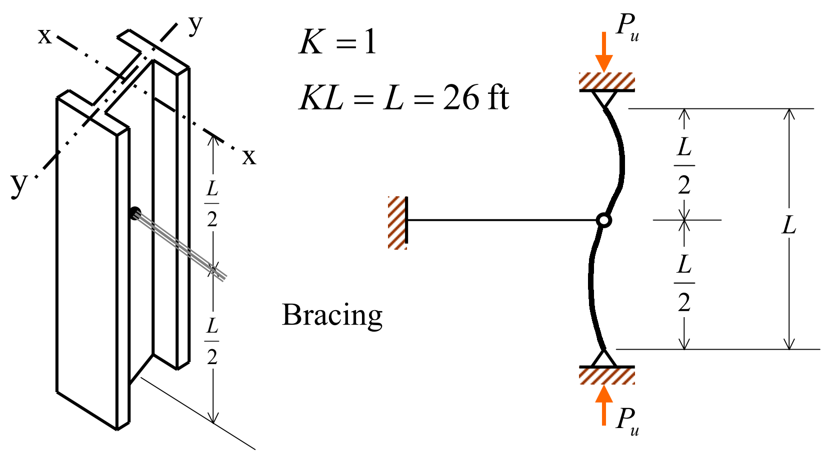
$$\text{Assume}\ \frac{KL}{r} = 50$$

LRFD Design Tables

- Example 3 (cont'd)

$K = 1$

$KL = L = 26\ \text{ft}$



LRFD Design Tables

- Example 3 (cont'd)

$\phi_c F_{cr} = 35.40$ ksi (from Table 3.50 of Manual)

$$A_{\text{required}} = \frac{P_u}{\phi_c F_{cr}} = \frac{900}{35.40} = 25.42 \text{ in}^2$$

Try W12×87$\left(A = 25.6 \text{ in}^2, r_x = 5.38 \text{ in}, r_y = 3.07 \text{ in}\right)$

$$\left(\frac{KL}{r}\right)_x = \frac{12 \times 26}{5.38} = 57.99 \approx 58 \longleftarrow \text{controls}$$

$$\left(\frac{KL}{r}\right)_y = \frac{12 \times 13}{3.07} = 50.81$$

$\phi_c F_{cr} = 33.2$ ksi $\quad \therefore \varphi_c P_n = 33.2(25.6) = 850 \text{ k} < 900 \text{ k}$ NG

A subsequent check of the next larger W section (W12 × 96) shows it will work.

Therefore, USE W12 × 96

LRFD Design Tables

- LRFD Manual Design Tables (P. 16.I-145)

TABLE 3-50

Design Stress for Compression Members of 50 ksi Specified Yield Stress Steel, $\phi_c = 0.85$[a]

$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi
42.5	41	37.6	81	26.3	121	14.6	161	8.23
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42.5	44	36.9	84	25.4	124	13.9	164	7.93
42.4	45	36.7	85	25.1	125	13.7	165	7.84
42.4	46	36.4	86	24.8	126	13.4	166	7.74
42.4	47	36.2	87	24.4	127	13.2	167	7.65
42.3	48	35.9	88	24.1	128	13.0	168	7.56
42.3	49	35.7	89	23.8	129	12.8	169	7.47
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LRFD Design Tables

- LRFD Manual Design Tables (P. 16.I-145)

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$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi	$\frac{Kl}{r}$	$\phi_c F_{cr}$ ksi
41.8	55	34.1	95	22.0	135	11.7	175	6.97
41.7	56	33.8	96	21.7	136	11.5	176	6.89
41.6	57	33.5	97	21.4	137	11.4	177	6.81
41.5	58	33.2	98	21.1	138	11.2	178	6.73
41.4	59	33.0	99	20.8	139	11.0	179	6.66
41.3	60	32.7	100	20.5	140	10.9	180	6.59
41.2	61	32.4	101	20.2	141	10.7	181	6.51
41.0	62	32.1	102	19.9	142	10.6	182	6.44
40.9	63	31.8	103	19.6	143	10.4	183	6.37
40.6	64	31.5	104	19.3	144	10.3	184	6.30

LRFD Design Tables

- Example 3 (cont'd)

See P. 4-25 of Manual

b. Using LRFD tables:

Enter tables with $K_y L_y$ = 13 ft, F_y = 50 ksi, and P_u = 900 k.

$$\text{Try W}12\times 87\left(\frac{r_x}{r_y}=1.75\right)\text{ with } \phi_c P_n \text{ based on } K_y L_y$$

$$\text{Equivalent } K_y L_y = \frac{K_x L_x}{r_x / r_y} = 13(1.75) = 22.75 \text{ ft} < K_x L_x$$

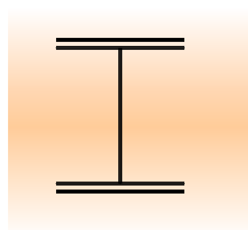
Therefore, $K_x L_x$ controls.

$$\text{Reenter tables with } K_y L_y = \frac{K_x L_x}{r_x / r_y} = \frac{26}{1.75} = 14.86$$

$\boxed{\text{USE W}12\times 96}$ $\phi_c P_n = P_u = 935 \text{ k}$ **OK**

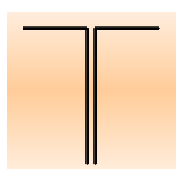
Built-up Columns

- Compression members may be constructed with more shapes built-up into a single member.
- They may consist of parts in contact with each other, such as cover-plated sections:



Built-up Columns

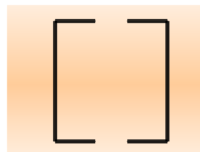
- Or they may consist of parts in near contact with each other, such as pair of angles:



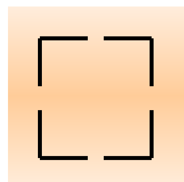
- These pairs of angles may be separated by a small distance from each other equal the thickness of the end connection or gusset plates between them.

Built-up Columns

- They may consist of parts that are spread well apart, such as pairs of channels:



- Or four angles, and so on.



Built-up Columns

- Two-angle sections probably are the most common type of built-up members. They are frequently used as the members of light trusses.
- When a pair angles are used as a compression member, they need to be fastened together so they will act as a unit.
- Welds may be used at intervals or they may be connected with bolts.

Built-up Columns

- For long columns, it may be suitable to use built-up sections where the parts of the columns are spread out or widely separated from each other.
- These types of built-up columns are commonly used for crane booms and for compression members of various kinds of towers.
- The widely spaced parts of these types must be carefully laced or tied together.