

2022 MULTI ENGINEER 교육

DESIGN OF MEMBERS FOR COMPRESSION (AISC 360-16 CHAPTER E)

February. 25. 2022

CHAPTER E

DESIGN OF MEMBERS FOR COMPRESSION

This chapter addresses members subject to axial compression.

The chapter is organized as follows:

- E1. General Provisions
- E2. Effective Length
- E3. Flexural Buckling of Members without Slender Elements
- E4. Torsional and Flexural-Torsional Buckling of Single Angles and Members without Slender Elements
- E5. Single-Angle Compression Members
- E6. Built-Up Members
- E7. Members with Slender Elements

User Note: For cases not included in this chapter, the following sections apply:

- H1 – H2 Members subject to combined axial compression and flexure
- H3 Members subject to axial compression and torsion
- I2 Composite axially loaded members
- J4.4 Compressive strength of connecting elements

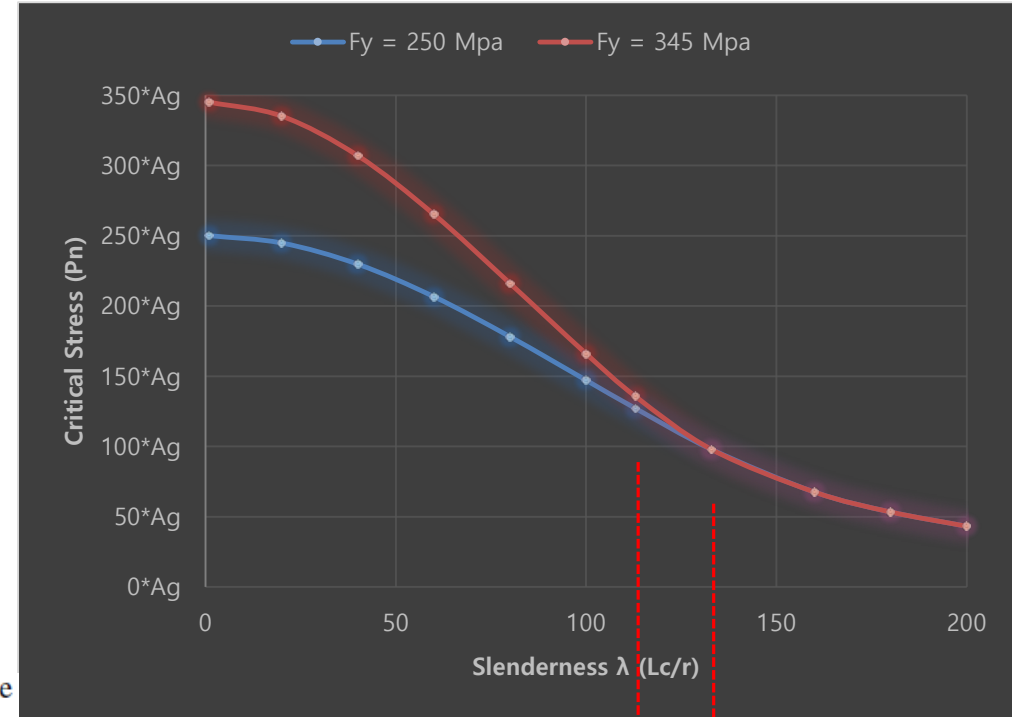
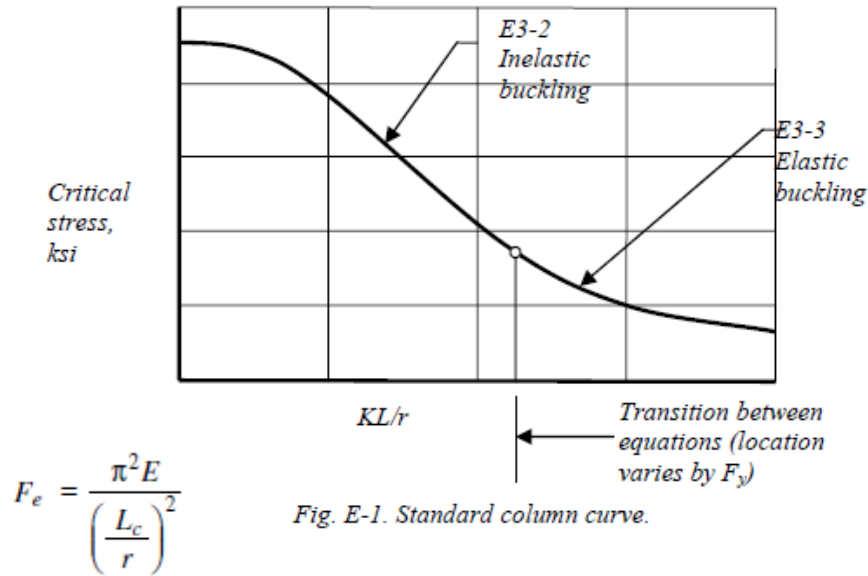
E1. GENERAL PROVISIONS

The design compressive strength, $\phi_c P_n$, and the allowable compressive strength, P_n/Ω_c , are determined as follows.

The nominal compressive strength, P_n , shall be the lowest value obtained based on the applicable limit states of flexural buckling, torsional buckling, and flexural-torsional buckling.

$$\phi_c = 0.90 \text{ (LRFD)} \quad \Omega_c = 1.67 \text{ (ASD)}$$

I. DESIGN OF MEMBERS FOR COMPRESSION



The nominal compressive strength, P_n , shall be determined based on the limit state of flexural buckling:

$$P_n = F_{cr} A_g \quad (\text{E3-1})$$

The critical stress, F_{cr} , is determined as follows:

(a) When $\frac{L_c}{r} \leq 4.71 \sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} \leq 2.25$)

$$F_{cr} = \left(0.658 \frac{F_y}{F_e}\right) F_y \quad (\text{E3-2})$$

(b) When $\frac{L_c}{r} > 4.71 \sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} > 2.25$)

$$F_{cr} = 0.877 F_e \quad (\text{E3-3})$$

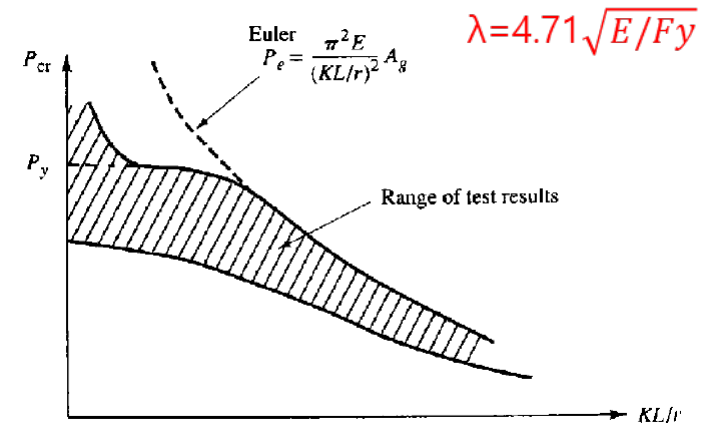
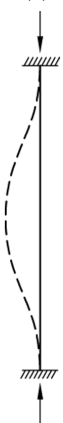
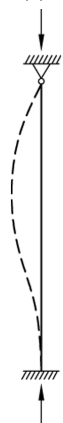
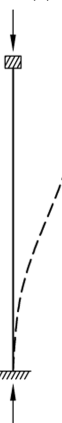

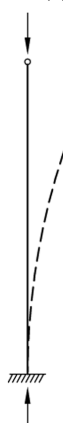













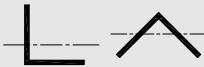

TABLE C-A-7.1
Approximate Values of Effective
Length Factor, *K*

Buckled shape of column is shown by dashed line	(a)	(b)	(c)	(d)	(e)	(f)
						
Theoretical <i>K</i> value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.1	2.0
End condition code	<div> Rotation fixed and translation fixed</div> <div> Rotation free and translation fixed</div> <div> Rotation fixed and translation free</div> <div> Rotation free and translation free</div>					

- 1962). These charts are based on assumptions of idealized conditions, which seldom exist in real structures, as follows:
- (1) Behavior is purely elastic.
 - (2) All members have constant cross section.
 - (3) All joints are rigid.
 - (4) For columns in frames with sidesway inhibited, rotations at opposite ends of the restraining beams are equal in magnitude and opposite in direction, producing single curvature bending.
 - (5) For columns in frames with sidesway uninhibited, rotations at opposite ends of the restraining beams are equal in magnitude and direction, producing reverse curvature bending.
 - (6) The stiffness parameter $L\sqrt{P/EI}$ of all columns is equal.

Chapter B4.1

TABLE USER NOTE E1.1
Selection Table for the Application of
Chapter E Sections

Cross Section	Without Slender Elements		With Slender Elements	
	Sections in Chapter E	Limit States	Sections in Chapter E	Limit States
	Min E3 E4	FB TB	E7	LB FB TB
	E3 E4	FB FTB	E7	LB FB FTB
	E3	FB	E7	LB FB
	E3	FB	E7	LB FB
	E3 E4	FB FTB	E7	LB FB FTB
	E6 E3 E4	FB FTB	E6 E7	LB FB FTB
	E5		E5	
	E3	FB	N/A	N/A
Unsymmetrical shapes other than single angles	E4	FTB	E7	LB FTB

FB = flexural buckling, TB = torsional buckling, FTB = flexural-torsional buckling, LB = local buckling, N/A = not applicable

B4. MEMBER PROPERTIES

1. Classification of Sections for Local Buckling

For members subject to axial compression, sections are classified as nonslender-element or slender-element sections. For a nonslender-element section, the width-to-thickness ratios of its compression elements shall not exceed λ_r from Table B4.1a. If the width-to-thickness ratio of any compression element exceeds λ_r , the section is a slender-element section.

For	* nonslender - element section	noncompact or
slender	$b/t \leq \lambda_r$	flanges must be
compression		less ratios of its
compression	* slender - element section	ness ratios, λ_p ,
from	$b/t > \lambda_r$	compression ele-
member		the section is
noncompact	the width - to - thickness ratio : b/t	ment exceeds λ_r ,
the	Limiting the width - to - thickness ratio : λ_r	

1a. Unstiffened Elements

For unstiffened elements supported along only one edge parallel to the direction of the compression force, the width shall be taken as follows:

- (a) For flanges of I-shaped members and tees, the width, b , is one-half the full-flange width, b_f .
- (b) For legs of angles and flanges of channels and zees, the width, b , is the full leg or flange width.
- (c) For plates, the width, b , is the distance from the free edge to the first row of fasteners or line of welds.
- (d) For stems of tees, d is the full depth of the section.

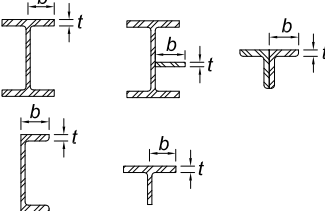
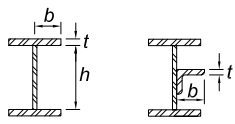
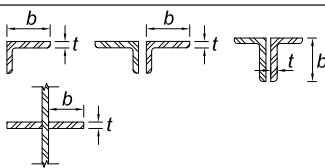

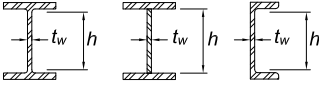

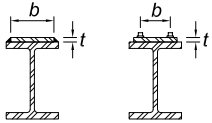

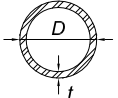
User Note: Refer to Table B4.1 for the graphic representation of unstiffened element dimensions.

1b. Stiffened Elements

For stiffened elements supported along two edges parallel to the direction of the compression force, the width shall be taken as follows:

- (a) For webs of rolled sections, h is the clear distance between flanges less the fillet at each flange; h_c is twice the distance from the centroid to the inside face of the compression flange less the fillet or corner radius.
- (b) For webs of built-up sections, h is the distance between adjacent lines of fasteners or the clear distance between flanges when welds are used, and h_c is twice the distance from the centroid to the nearest line of fasteners at the compression flange or the inside face of the compression flange when welds are used; h_p is twice the distance from the plastic neutral axis to the nearest line of fasteners at the compression flange or the inside face of the compression flange when welds are used.

TABLE B4.1a
Width-to-Thickness Ratios: Compression Elements
Members Subject to Axial Compression

Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio λ_r (nonslender/slender)	Examples
Unstiffened Elements	1 Flanges of rolled I-shaped sections, plates projecting from rolled I-shaped sections, outstanding legs of pairs of angles connected with continuous contact, flanges of channels, and flanges of tees	b/t	$0.56 \sqrt{\frac{E}{F_y}}$	
	2 Flanges of built-up I-shaped sections and plates or angle legs projecting from built-up I-shaped sections	b/t	^[a] $0.64 \sqrt{\frac{k_c E}{F_y}}$	
	3 Legs of single angles, legs of double angles with separators, and all other unstiffened elements	b/t	$0.45 \sqrt{\frac{E}{F_y}}$	
	4 Stems of tees	d/t	$0.75 \sqrt{\frac{E}{F_y}}$	
Stiffened Elements	5 Webs of doubly symmetric rolled and built-up I-shaped sections and channels	h/t_w	$1.49 \sqrt{\frac{E}{F_y}}$	
	6 Walls of rectangular HSS	b/t	$1.40 \sqrt{\frac{E}{F_y}}$	
	7 Flange cover plates and diaphragm plates between lines of fasteners or welds	b/t	$1.40 \sqrt{\frac{E}{F_y}}$	
	8 All other stiffened elements	b/t	$1.49 \sqrt{\frac{E}{F_y}}$	
	9 Round HSS	D/t	$0.11 \frac{E}{F_y}$	

^[a] $k_c = 4\sqrt{h/t_w}$, but shall not be taken less than 0.35 nor greater than 0.76 for calculation purposes.

E2. EFFECTIVE LENGTH

The effective length, L_c , for calculation of member slenderness, L_c/r , shall be determined in accordance with Chapter C or Appendix 7,

where

K = effective length factor

$L_c = KL$ = effective length of member, in. (mm)

L = laterally unbraced length of the member, in. (mm)

r = radius of gyration, in. (mm)

* 200

User Note: For members designed on the basis of compression, the effective slenderness ratio, L_c/r , preferably should not exceed 200.

User Note: The effective length, L_c , can be determined through methods other than those using the effective length factor, K .

E3. FLEXURAL BUCKLING OF MEMBERS WITHOUT SLENDER ELEMENTS

This section applies to nonslender-element compression members, as defined in Section B4.1, for elements in axial compression.

User Note: When the torsional effective length is larger than the lateral effective length, Section E4 may control the design of wide-flange and similarly shaped columns.

The nominal compressive strength, P_n , shall be determined based on the limit state of flexural buckling:

$$P_n = F_{cr} A_g \quad (\text{E3-1})$$

The critical stress, F_{cr} , is determined as follows:

(a) When $\frac{L_c}{r} \leq 4.71 \sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} \leq 2.25$)

$$F_{cr} = \left(0.658 \frac{F_y}{F_e} \right) F_y \quad (\text{E3-2})$$

(b) When $\frac{L_c}{r} > 4.71 \sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} > 2.25$)

$$F_{cr} = 0.877 F_e \quad (\text{E3-3})$$

where

A_g = gross cross-sectional area of member, in.² (mm²)

E = modulus of elasticity of steel = 29,000 ksi (200 000 MPa)

F_e = elastic buckling stress determined according to Equation E3-4, as specified in Appendix 7, Section 7.2.3(b), or through an elastic buckling analysis, as applicable, ksi (MPa)

$$F_e = \frac{\pi^2 E}{\left(\frac{L_c}{r}\right)^2} \quad (\text{E3-4})$$

F_y = specified minimum yield stress of the type of steel being used, ksi (MPa)

r = radius of gyration, in. (mm)

User Note: The two inequalities for calculating the limits of applicability of Sections E3(a) and E3(b), one based on L_c/r and one based on F_y/F_e , provide the same result for flexural buckling.

E4. TORSIONAL AND FLEXURAL-TORSIONAL BUCKLING OF SINGLE ANGLES AND MEMBERS WITHOUT SLENDER ELEMENTS

This section applies to singly symmetric and unsymmetric members, certain doubly symmetric members, such as cruciform or built-up members, and doubly symmetric members when the torsional unbraced length exceeds the lateral unbraced length, all without slender elements. These provisions also apply to single angles with $b/t > 0.71\sqrt{E/F_y}$, where b is the width of the longest leg and t is the thickness.

The nominal compressive strength, P_n , shall be determined based on the limit states of torsional and flexural-torsional buckling:

$$P_n = F_{cr} A_g \quad (\text{E4-1})$$

The critical stress, F_{cr} , shall be determined according to Equation E3-2 or E3-3, using the torsional or flexural-torsional elastic buckling stress, F_e , determined as follows:

- (a) For doubly symmetric members twisting about the shear center

(For H 형강)

$$F_e = \left(\frac{\pi^2 E C_w}{L_{cz}^2} + GJ \right) \frac{1}{I_x + I_y} \quad (\text{E4-2})$$

- (b) For singly symmetric members twisting about the shear center where y is the axis of symmetry

(For C, T, Double Angle)

$$F_e = \left(\frac{F_{ey} + F_{ez}}{2H} \right) \left[1 - \sqrt{1 - \frac{4F_{ey}F_{ez}H}{(F_{ey} + F_{ez})^2}} \right] \quad (\text{E4-3})$$

User Note: For singly symmetric members with the x -axis as the axis of symmetry, such as channels, Equation E4-3 is applicable with F_{ey} replaced by F_{ex} .

- (c) For unsymmetric members twisting about the shear center, F_e is the lowest root of the cubic equation

$$(F_e - F_{ex})(F_e - F_{ey})(F_e - F_{ez}) - F_e^2(F_e - F_{ey})\left(\frac{x_o}{\bar{r}_o}\right)^2 - F_e^2(F_e - F_{ex})\left(\frac{y_o}{\bar{r}_o}\right)^2 = 0 \quad (\text{E4-4})$$

where

C_w = warping constant, in.⁶ (mm⁶)

$$F_{ex} = \frac{\pi^2 E}{\left(\frac{L_{cx}}{r_x}\right)^2} \quad (\text{E4-5})$$

$$F_{ey} = \frac{\pi^2 E}{\left(\frac{L_{cy}}{r_y}\right)^2} \quad (\text{E4-6})$$

$$F_{ez} = \left(\frac{\pi^2 E C_w}{L_{cz}^2} + GJ \right) \frac{1}{A_g \bar{r}_o^2} \quad (\text{E4-7})$$

G = shear modulus of elasticity of steel = 11,200 ksi (77 200 MPa)

H = flexural constant

$$= 1 - \frac{x_o^2 + y_o^2}{\bar{r}_o^2} \quad (\text{E4-8})$$

I_x, I_y = moment of inertia about the principal axes, in.⁴ (mm⁴)

J = torsional constant, in.⁴ (mm⁴)

K_x = effective length factor for flexural buckling about x -axis

K_y = effective length factor for flexural buckling about y -axis

K_z = effective length factor for torsional buckling about the longitudinal axis

$L_{cx} = K_x L_x$ = effective length of member for buckling about x -axis, in. (mm)

$L_{cy} = K_y L_y$ = effective length of member for buckling about y -axis, in. (mm)

$L_{cz} = K_z L_z$ = effective length of member for buckling about longitudinal axis, in. (mm)

L_x, L_y, L_z = laterally unbraced length of the member for each axis, in. (mm)

\bar{r}_o = polar radius of gyration about the shear center, in. (mm)

$$\bar{r}_o^2 = x_o^2 + y_o^2 + \frac{I_x + I_y}{A_g} \quad (\text{E4-9})$$

r_x = radius of gyration about x -axis, in. (mm)

r_y = radius of gyration about y -axis, in. (mm)

x_o, y_o = coordinates of the shear center with respect to the centroid, in. (mm)

User Note: For doubly symmetric I-shaped sections, C_w may be taken as $I_y h_o^2/4$, where h_o is the distance between flange centroids, in lieu of a more precise analysis. For tees and double angles, omit the term with C_w when computing F_{ez} and take x_o as 0.

- (d) For members with lateral bracing offset from the shear center, the elastic buckling stress, F_e , shall be determined by analysis.

User Note: Members with lateral bracing offset from the shear center are susceptible to constrained-axis torsional buckling, which is discussed in the Commentary.

E4. TORSIONAL AND FLEXURAL-TORSIONAL BUCKLING OF MEMBERS WITHOUT SLENDER ELEMENTS

This section is most commonly applicable to double angles and WT sections, which are singly-symmetric shapes subject to torsional and flexural-torsional buckling. The available strengths in axial compression of these shapes are tabulated in Part 4 of the *AISC Manual* and examples on the use of these tables have been included in this chapter for the shapes with $KL_z = KL_y$.

E5. SINGLE-ANGLE COMPRESSION MEMBERS

The nominal compressive strength, P_n , of single-angle members shall be the lowest value based on the limit states of flexural buckling in accordance with Section E3 or Section E7, as applicable, or flexural-torsional buckling in accordance with Section E4. Flexural-torsional buckling need not be considered when $b/t \leq 0.71\sqrt{E/F_y}$.

The effects of eccentricity on single-angle members are permitted to be neglected and the member evaluated as axially loaded using one of the effective slenderness ratios specified in Section E5(a) or E5(b), provided that the following requirements are met:

- (1) Members are loaded at the ends in compression through the same one leg.
- (2) Members are attached by welding or by connections with a minimum of two bolts.
- (3) There are no intermediate transverse loads.
- (4) L_c/r as determined in this section does not exceed 200.
- (5) For unequal leg angles, the ratio of long leg width to short leg width is less than 1.7.

Single-angle members that do not meet these requirements or the requirements described in Section E5(a) or (b) shall be evaluated for combined axial load and flexure using the provisions of Chapter H.

- (a) For angles that are individual members or are web members of planar trusses with adjacent web members attached to the same side of the gusset plate or chord

- (1) For equal-leg angles or unequal-leg angles connected through the longer leg

- (i) When $\frac{L}{r_a} \leq 80$

$$\frac{L_c}{r} = 72 + 0.75 \frac{L}{r_a} \quad (\text{E5-1})$$

- (ii) When $\frac{L}{r_a} > 80$

$$\frac{L_c}{r} = 32 + 1.25 \frac{L}{r_a} \quad (\text{E5-2})$$

- (2) For unequal-leg angles connected through the shorter leg, L_c/r from Equations E5-1 and E5-2 shall be increased by adding $4[(b_1/b_s)^2 - 1]$, but L_c/r of the members shall not be taken as less than $0.95L/r_z$.

- (b) For angles that are web members of box or space trusses with adjacent web members attached to the same side of the gusset plate or chord

- (1) For equal-leg angles or unequal-leg angles connected through the longer leg

- (i) When $\frac{L}{r_a} \leq 75$

$$\frac{L_c}{r} = 60 + 0.8 \frac{L}{r_a} \quad (\text{E5-3})$$

(ii) When $\frac{L}{r_a} > 75$

$$\frac{L_c}{r} = 45 + \frac{L}{r_a} \quad (\text{E5-4})$$

- (2) For unequal-leg angles with leg length ratios less than 1.7 and connected through the shorter leg, L_c/r from Equations E5-3 and E5-4 shall be increased by adding $6[(b_l/b_s)^2 - 1]$, but L_c/r of the member shall not be taken as less than $0.82L/r_z$

where

L = length of member between work points at truss chord centerlines, in. (mm)

L_c = effective length of the member for buckling about the minor axis, in. (mm)

b_l = length of longer leg of angle, in. (mm)

b_s = length of shorter leg of angle, in. (mm)

r_a = radius of gyration about the geometric axis parallel to the connected leg, in. (mm)

r_z = radius of gyration about the minor principal axis, in. (mm)

E6. BUILT-UP MEMBERS

1. Compressive Strength

This section applies to built-up members composed of two shapes either (a) interconnected by bolts or welds or (b) with at least one open side interconnected by perforated cover plates or lacing with tie plates. The end connection shall be welded or connected by means of pretensioned bolts with Class A or B faying surfaces.

User Note: It is acceptable to design a bolted end connection of a built-up compression member for the full compressive load with bolts in bearing and bolt design based on the shear strength; however, the bolts must be pretensioned. In built-up compression members, such as double-angle struts in trusses, a small relative slip between the elements can significantly reduce the compressive strength of the strut. Therefore, the connection between the elements at the ends of built-up members should be designed to resist slip.

The nominal compressive strength of built-up members composed of two shapes that are interconnected by bolts or welds shall be determined in accordance with Sections E3, E4 or E7, subject to the following modification. In lieu of more accurate analysis, if the buckling mode involves relative deformations that produce shear forces in the connectors between individual shapes, L_c/r is replaced by $(L_c/r)_m$, determined as follows:

- (a) For intermediate connectors that are bolted snug-tight

$$\left(\frac{L_c}{r}\right)_m = \sqrt{\left(\frac{L_c}{r}\right)_o^2 + \left(\frac{a}{r_i}\right)^2} \quad (\text{E6-1})$$

- (b) For intermediate connectors that are welded or are connected by means of pretensioned bolts with Class A or B faying surfaces

(1) When $\frac{a}{r_i} \leq 40$

$$\left(\frac{L_c}{r}\right)_m = \left(\frac{L_c}{r}\right)_o \quad (\text{E6-2a})$$

(2) When $\frac{a}{r_i} > 40$

$$\left(\frac{L_c}{r}\right)_m = \sqrt{\left(\frac{L_c}{r}\right)_o^2 + \left(\frac{K_i a}{r_i}\right)^2} \quad (\text{E6-2b})$$

where

$\left(\frac{L_c}{r}\right)_m$ = **modified slenderness ratio** of built-up member

$\left(\frac{L_c}{r}\right)_o$ = slenderness ratio of built-up member acting as a unit in the buckling direction being addressed

L_c = effective length of built-up member, in. (mm)

K_i = 0.50 for angles back-to-back
 = 0.75 for channels back-to-back
 = 0.86 for all other cases

a = **distance between connectors**, in. (mm)

r_i = minimum radius of gyration of individual component, in. (mm)

2. Dimensional Requirements

Built-up members shall meet the following requirements:

- (a) Individual components of compression members composed of two or more shapes shall be connected to one another at intervals, a , such that the slenderness ratio, a/r_i , of each of the component shapes between the fasteners does not exceed three-fourths times the governing slenderness ratio of the built-up member. The least radius of gyration, r_i , shall be used in computing the slenderness ratio of each component part.
- (b) At the ends of built-up compression members bearing on base plates or finished surfaces, all components in contact with one another shall be connected by a weld having a length not less than the maximum width of the member or by bolts spaced longitudinally not more than four diameters apart for a distance equal to $1\frac{1}{2}$ times the maximum width of the member.

Along the length of built-up compression members between the end connections required in the foregoing, longitudinal spacing of intermittent welds or bolts shall be adequate to provide the required strength. For limitations on the longitudinal spacing of fasteners between elements in continuous contact consisting of a plate and a shape, or two plates, see Section J3.5. Where a component of a built-up compression member consists of an outside plate, the maximum spacing shall not exceed the thickness of the thinner outside plate times $0.75\sqrt{E/F_y}$, nor 12 in.

(300 mm), when intermittent welds are provided along the edges of the components or when fasteners are provided on all gage lines at each section. When fasteners are staggered, the maximum spacing of fasteners on each gage line shall not exceed the thickness of the thinner outside plate times $1.12\sqrt{E/F_y}$ nor 18 in. (460 mm).

- (c) Open sides of compression members built up from plates or shapes shall be provided with continuous cover plates perforated with a succession of access holes. The unsupported width of such plates at access holes, as defined in Section B4.1, is assumed to contribute to the available strength provided the following requirements are met:

- (1) The width-to-thickness ratio shall conform to the limitations of Section B4.1.

User Note: It is conservative to use the limiting width-to-thickness ratio for Case 7 in Table B4.1a with the width, b , taken as the transverse distance between the nearest lines of fasteners. The net area of the plate is taken at the widest hole. In lieu of this approach, the limiting width-to-thickness ratio may be determined through analysis.

- (2) The ratio of length (in direction of stress) to width of hole shall not exceed 2.
- (3) The clear distance between holes in the direction of stress shall be not less than the transverse distance between nearest lines of connecting fasteners or welds.
- (4) The periphery of the holes at all points shall have a minimum radius of $1\frac{1}{2}$ in. (38 mm).
- (d) As an alternative to perforated cover plates, lacing with tie plates is permitted at each end and at intermediate points if the lacing is interrupted. Tie plates shall be as near the ends as practicable. In members providing available strength, the end tie plates shall have a length of not less than the distance between the lines of fasteners or welds connecting them to the components of the member. Intermediate tie plates shall have a length not less than one-half of this distance. The thickness of tie plates shall be not less than one-fiftieth of the distance between lines of welds or fasteners connecting them to the segments of the members. In welded construction, the welding on each line connecting a tie plate shall total not less than one-third the length of the plate. In bolted construction, the spacing in the direction of stress in tie plates shall be not more than six diameters and the tie plates shall be connected to each segment by at least three fasteners.
- (e) Lacing, including flat bars, angles, channels or other shapes employed as lacing, shall be so spaced that L/r of the flange element included between their connections shall not exceed three-fourths times the governing slenderness ratio for the member as a whole. Lacing shall be proportioned to provide a shearing strength normal to the axis of the member equal to 2% of the available compressive strength of the member. For lacing bars arranged in single systems, L/r shall not exceed 140. For double lacing, this ratio shall not exceed 200. Double lacing bars shall be joined at the intersections. For lacing bars in compression, L is permitted to be

taken as the unsupported length of the lacing bar between welds or fasteners connecting it to the components of the built-up member for single lacing, and 70% of that distance for double lacing.

User Note: The inclination of lacing bars to the axis of the member shall preferably be not less than 60° for single lacing and 45° for double lacing. When the distance between the lines of welds or fasteners in the flanges is more than 15 in. (380 mm), the lacing should preferably be double or made of angles.

For additional spacing requirements, see Section J3.5.

E7. MEMBERS WITH SLENDER ELEMENTS

This section applies to slender-element compression members, as defined in Section B4.1 for elements in axial compression.

The nominal compressive strength, P_n , shall be the lowest value based on the applicable limit states of flexural buckling, torsional buckling, and flexural-torsional buckling in interaction **with local buckling.**

$$P_n = F_{cr} A_e \quad (\text{E7-1})$$

where

A_e = summation of **the effective areas of the cross section based on reduced effective widths**, b_e , d_e or h_e , or the area as given by Equations E7-6 or E7-7, in.² (mm²).

F_{cr} = **critical stress determined in accordance with Section E3 or E4,** ksi (MPa).

For single angles, determine F_{cr} in accordance with Section E3 only.

User Note: The effective area, A_e , may be determined by deducting from the gross area, A_g , the reduction in area of each slender element determined as $(b - b_e)t$.

1. Slender Element Members Excluding Round HSS

The effective width, b_e , (for tees, this is d_e ; for webs, this is h_e) for slender elements is determined as follows:

$$(a) \text{ When } \lambda \leq \lambda_r \sqrt{\frac{F_y}{F_{cr}}}$$

$$b_e = b \quad (\text{E7-2})$$

$$(b) \text{ When } \lambda > \lambda_r \sqrt{\frac{F_y}{F_{cr}}}$$

$$b_e = b \left(1 - c_1 \sqrt{\frac{F_{el}}{F_{cr}}} \right) \sqrt{\frac{F_{el}}{F_{cr}}} \quad (\text{E7-3})$$

TABLE E7.1
Effective Width Imperfection Adjustment Factors,
 c_1 and c_2

Case	Slender Element	c_1	c_2
(a)	Stiffened elements except walls of square and rectangular HSS	0.18	1.31
(b)	Walls of square and rectangular HSS	0.20	1.38
(c)	All other elements	0.22	1.49

where

b = width of the element (for tees this is d ; for webs this is h), in. (mm)
 c_1 = effective width imperfection adjustment factor determined from Table E7.1

$$c_2 = \frac{1 - \sqrt{1 - 4c_1}}{2c_1} \tag{E7-4}$$

λ = width-to-thickness ratio for the element as defined in Section B4.1

λ_r = limiting width-to-thickness ratio as defined in Table B4.1a

$$F_{el} = \left(c_2 \frac{\lambda_r}{\lambda} \right)^2 F_y \tag{E7-5}$$

= elastic local buckling stress determined according to Equation E7-5 or an elastic local buckling analysis, ksi (MPa)

2. Round HSS

The effective area, A_e , is determined as follows:

(a) When $\frac{D}{t} \leq 0.11 \frac{E}{F_y}$

$$A_e = A_g \tag{E7-6}$$

(b) When $0.11 \frac{E}{F_y} < \frac{D}{t} < 0.45 \frac{E}{F_y}$

$$A_e = \left[\frac{0.038E}{F_y (D/t)} + \frac{2}{3} \right] A_g \tag{E7-7}$$

where

D = outside diameter of round HSS, in. (mm)
 t = thickness of wall, in. (mm)

AISC 360 - 10 al spacing requirements, see Section J3.5.

E7. MEMBERS WITH SLENDER ELEMENTS

This section applies to slender-element compression members, as defined in Section B4.1 for elements in uniform compression.

The *nominal compressive strength*, P_n , shall be the lowest value based on the applicable *limit states* of *flexural buckling*, *torsional buckling*, and *flexural-torsional buckling*.

$$P_n = F_{cr} A_g \quad (\text{E7-1})$$

The critical *stress*, F_{cr} , shall be determined as follows:

$$\begin{aligned} \text{(a) When } \frac{KL}{r} \leq 4.71 \sqrt{\frac{E}{QF_y}} \quad \left(\text{or } \frac{QF_y}{F_e} \leq 2.25 \right) \\ F_{cr} = Q \left[0.658 \frac{QF_y}{F_e} \right] F_y \end{aligned} \quad (\text{E7-2})$$

$$\begin{aligned} \text{(b) When } \frac{KL}{r} > 4.71 \sqrt{\frac{E}{QF_y}} \quad \left(\text{or } \frac{QF_y}{F_e} > 2.25 \right) \\ F_{cr} = 0.877 F_e \end{aligned} \quad (\text{E7-3})$$

where

F_e = elastic *buckling stress*, calculated using Equations E3-4 and E4-4 for doubly symmetric members, Equations E3-4 and E4-5 for singly symmetric members, and Equation E4-6 for unsymmetric members, except for single angles with $b/t \leq 20$, where F_e is calculated using Equation E3-4, ksi (MPa)

Q = **net reduction factor** accounting for all slender compression elements;

= 1.0 for members without slender elements, as defined in Section B4.1, for elements in uniform compression

= $Q_s Q_a$ for members with *slender-element sections*, as defined in Section B4.1, for elements in uniform compression.

User Note: For cross sections composed of only unstiffened slender elements, $Q = Q_s$ ($Q_a = 1.0$). For cross sections composed of only stiffened slender elements, $Q = Q_a$ ($Q_s = 1.0$). For cross sections composed of both stiffened and unstiffened slender elements, $Q = Q_s Q_a$. For cross sections composed of multiple unstiffened slender elements, it is conservative to use the smaller Q_s from the more slender element in determining the member strength for pure compression.

1. Slender Unstiffened Elements, Q_s

The reduction factor, Q_s , for slender *unstiffened elements* is defined as follows:

- (a) For flanges, angles and plates projecting from rolled *columns* or other compression members:

I. DESIGN OF MEMBERS FOR COMPRESSION

공칭 압축강도 P_n

1. 세장비 ≤ 200
($\lambda = KL/r$)
2. 비세장판 단면 / 세장판 단면 판별
(Table B4.1a)

Non-Slender : $b/t \leq \lambda_r$

Slender : $b/t > \lambda_r$

3. Table User Note E1.1 – 해당 Chapter 적용

Non-slender elements,

E3 (힘좌굴) & E4 (비틀림좌굴) 중 작은 값

(a) When $\frac{L_c}{r} \leq 4.71 \sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} \leq 2.25$)

$$F_{cr} = \left(0.658 \frac{F_y}{F_e} \right) F_y \quad (E3-2)$$

(b) When $\frac{L_c}{r} > 4.71 \sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} > 2.25$)

$$F_{cr} = 0.877 F_e \quad (E3-3)$$

$$(E3-4) \quad F_e = \frac{\pi^2 E}{\left(\frac{L_c}{r} \right)^2}$$

(E4-2) For doubly symmetric members twisting about the shear center

(For H 형강)
$$F_e = \left(\frac{\pi^2 E C_w}{L_{cz}^2} + GJ \right) \frac{1}{I_x + I_y}$$

(E4-3) For singly symmetric members twisting about the shear center where y is the axis of symmetry

(For C, T, Double Angle)

$$F_e = \left(\frac{F_{ey} + F_{ez}}{2H} \right) \left[1 - \sqrt{1 - \frac{4F_{ey} F_{ez} H}{(F_{ey} + F_{ez})^2}} \right]$$

Slender elements,

E7 (힘, 비틀림, 국부좌굴)

$$P_n = F_{cr} A_e$$

(a) When $\lambda \leq \lambda_r \sqrt{\frac{F_y}{F_{cr}}}$

$$b_e = b \quad (E7-2)$$

(b) When $\lambda > \lambda_r \sqrt{\frac{F_y}{F_{cr}}}$

$$b_e = b \left(1 - c_1 \sqrt{\frac{F_{el}}{F_{cr}}} \right) \sqrt{\frac{F_{el}}{F_{cr}}} \quad (E7-3)$$

CHAPTER H

DESIGN OF MEMBERS FOR COMBINED FORCES AND TORSION

This chapter addresses members subject to axial force and flexure about one or both axes, with or without torsion, and members subject to torsion only.

The chapter is organized as follows:

- H1. Doubly and Singly Symmetric Members Subject to Flexure and Axial Force
- H2. Unsymmetric and Other Members Subject to Flexure and Axial Force
- H3. Members Subject to Torsion and Combined Torsion, Flexure, Shear, and/or Axial Force
- H4. Rupture of Flanges with Holes Subjected to Tension

User Note: For composite members, see Chapter I.

H1. DOUBLY AND SINGLY SYMMETRIC MEMBERS SUBJECT TO FLEXURE AND AXIAL FORCE

1. Doubly and Singly Symmetric Members Subject to Flexure and Compression

The interaction of flexure and compression in doubly symmetric members and singly symmetric members constrained to bend about a geometric axis (x and/or y) shall be limited by Equations H1-1a and H1-1b.

User Note: Section H2 is permitted to be used in lieu of the provisions of this section.

(a) When $\frac{P_r}{P_c} \geq 0.2$

$$\frac{P_r}{P_c} + \frac{8}{9} \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1.0 \quad (\text{H1-1a})$$

(b) When $\frac{P_r}{P_c} < 0.2$

$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1.0 \quad (\text{H1-1b})$$

where

P_r = required axial strength, determined in accordance with Chapter C, using LRFD or ASD load combinations, kips (N)

P_c = available axial strength determined in accordance with Chapter E, kips (N)

M_r = required flexural strength, determined in accordance with Chapter C, using LRFD or ASD load combinations, kip-in. (N-mm)