Appendix F.1 For Immediate Consideration: New Commentary Language

B4.2 Uniformly Compressed Elements with an Edge Stiffener

An edge stiffener is used to provide a continuous support along a longitudinal edge of the compression flange to improve the buckling stress. Even though in most cases, the edge stiffener takes the form of a simple lip, other types of edge stiffeners can also be used for cold-formed steel members.

In order to provide necessary support for the compression element, the edge stiffener must possess sufficient rigidity. Otherwise it may buckle perpendicular to the plane of the element to be stiffened. This mode of buckling first termed "stiffener buckling" by Desmond, Pekoz and Winter (1981a) has come to be termed distortional buckling.

Both theoretical and experimental studies on the local and distortional stability of compression flanges stiffened by edge stiffeners have been carried out in the past. The design requirements included in Section B4.2 of the 1986 AISI *Specification* were based on the investigations on adequately stiffened and partially stiffened elements conducted by Desmond, Pekoz and Winter (1981a), with additional research work of Pekoz and Cohen (Pekoz, 1986b). These design provisions were developed on the basis of the critical buckling criterion and the postbuckling strength criterion.

Specification Section B4.2 recognizes that the necessary stiffener rigidity depends upon the slenderness (w/t) of the plate element being stiffened. Thus, Cases I, II and III each contains different definitions for an adequate stiffener moment of inertia.

The interaction of the plate elements, as well as the degree of edge support, full or partial, is compensated for in the expressions for k, d_s, and A_s (Pekoz, 1986b). In the 1996 edition of the AISI *Specification* (AISI, 1996), the design equations for buckling coefficient were changed for further clarity. In Case II, the equation for $k_a = 5.25\text{-}5\ (D/w) \vee 4.0$ is applicable only for simple lip stiffeners because the term D/w is meaningless for other types of edge stiffeners. It should be noted that the provisions in this section were based on research dealing only with simple lip stiffeners and extension to other types of stiffeners was purely intuitive. The requirement of $140° > \theta > 40°$ for the applicability of these provisions was also decided on an intuitive basis. For design examples, see Part I of the *Manual* (AISI, 1996).

Test data on flexural members to verify the accuracy of the simple lip stiffener design was collected from a number of sources, both university and industry. These tests showed good correlation with the equations in Section B4.2. ~~However, proprietary testing conducted in 1989 revealed that lip lengths with a d/t ratio of greater than 14 gave unconservative results.~~

~~A review of the original research data showed a lack of data for simple stiffening lips with d/t ratios greater than 14. Therefore, pending further research, an upper limit of 14 is recommended.~~

Test data on compression members also showed good overall correlation with the equations in Section B4.2 (Schafer 2000). However, compression members with high web slenderness (approximately h/t > 200) and/or narrow flanges (approximately h/b > 2) may yield unconservative solutions with current methods due to local buckling interaction. Compression members with low web slenderness and wide flanges (shapes approaching square, approximately b/h > 3/4) may yield unconservative solutions due to distortional buckling. In addition, the provisions of

B4.2 may be overly conservative for members with long lips (d/b > 0.25). Current research on beams and columns; Hancock (1985), Hancock et al. (1994, 1996), Schafer and Peköz (1998), Schafer (2000) indicate that more exact calculation of the plate buckling coefficient, k, for both local and distortional buckling may be completed by hand or computational methods.

References

Hancock, G.J. (1985). "Distortional Buckling of Steel Storage Rack Columns". *J. of Structural Eng*., ASCE, 111(12), pp. 2770-2783

Hancock, G.J., Kwon, Y.B., Bernard, E.S. (1994). "Strength Design Curves for Thin-Walled Sections Undergoing Distortional Buckling". *J. of Constructional Steel Research*, Elsevier, 31(2-3), pp. 169-186.

Hancock, G.J., Rogers, C.A., Schuster, R.M. (1996). "Comparison of the Distortional Buckling Method for Flexural Members with Tests." *Proceedings of the Thirteenth International Specialty Conference on Cold-Formed Steel Structures*, St. Louis, MO.

Schafer, B.W. (2000). "Distortional Buckling of Cold-Formed Steel Columns." *Final Report to the American Iron and Steel Institute*, Washington, D.C.

Schafer, B.W., and Peköz, T., (1998). "Laterally Braced Cold-Formed Steel Flexural Members with Edge Stiffened Flanges." *Proceedings of the Fourteenth International Specialty Conference on Cold-Formed Steel Structures*, St. Louis, MO.

Appendix F.2 For Interim Adoption: New Effective Width Method

- Delete all content in existing section B4.2
- New B4.2 section:

B4.2 Uniformly Compressed Elements with an Edge Stiffener

Note, all members that contain elements with an edge stiffener must also be checked for distortional buckling of the member, see provisions of B7.

(a) *Strength Determination*

The effective width, b, shall be determined in accordance with Section B2.1a, except that k shall be taken as 4.0 and w as defined in Figure B4-2.

(b) *Deflection Determination*

The effective width, b_d, used in computing deflection shall be determined as in Section B4.2a, except that f_d is substituted for f.

- New B7 section:

B7 Effective Width of Elements Subject to Distortional Buckling

Elements that form a member which include an edge stiffened element in compression must be checked for distortional buckling. Effective width calculations for **local buckling** should be completed by sections B2 through B5. In addition, effective width calculations for **distortional buckling** should be completing by the guidelines below. The minimum effective area or effective moment of inertia governs the design.

(a) *Strength Determination*

The effective width, b, of all elements that form a member which includes an edge stiffened element in compression, shall be determined in accordance with Section B2.1a, except that k shall be taken as k_d determined below

Determine the elastic distortional buckling stress, f_{ed}, per expressions in Table B7.1. See the commentary for aid in calculation of the section properties for use in the expressions.

Determine the reduced elastic distortional buckling stress

$$f_d = R_d f_{ed} \qquad (Eq.\ \text{B7-11})$$

$$R_d = \min\left(1, \frac{1.17}{\lambda_d + 1} + 0.3\right) \qquad (Eq.\ \text{B7-12})$$

$$\lambda_d = \sqrt{F_n / f_{ed}} \qquad (Eq.\ \text{B7-13})$$

where

F_n is per section C3 for flexural members, and C4 for compression members

Determine k_d for distortional buckling

for elements of width, w, that are a portion of a uniformly compressed member

$$k_d = f_d \frac{12(1-\nu^2)}{\pi^2 E}\left(\frac{w}{t}\right)^2 \qquad (Eq.\ \text{B7-14})$$

for elements of width, w, that are a portion of a flexural member

determine f, the distortional stress at the compression fiber of the element of interest, by using f_d for the distortional stress at the extreme compression fiber of the flexural member (i.e., $f = f_d$ at the extreme compression fiber). then k_d may be calculated as

$$k_d = f \frac{12(1-\nu^2)}{\pi^2 E}\left(\frac{w}{t}\right)^2 \qquad (Eq.\ \text{B7-15})$$

Table B7.1 Calculation of Distortional Buckling Stress (f_{ed})

DISTORTIONAL BUCKLING

$$f_{ed} = \frac{k_{\phi fe} + k_{\phi we}}{\tilde{k}_{\phi fg} + \tilde{k}_{\phi wg}} \qquad (Eq.\ B7\text{-}1)$$

$$L = min\left(L_{cr}, L_m\right) \qquad (Eq.\ B7\text{-}2)$$

Flange Rotational "Stiffness":

$$\left(k_{\phi f}\right)_e = \left(\frac{\pi}{L}\right)^4 \left(EI_{xf}\left(x_o - h_x\right)^2 + EC_{wf} - E\frac{I_{xyf}^2}{I_{yf}}\left(x_o - h_x\right)^2\right) + \left(\frac{\pi}{L}\right)^2 GJ_f \qquad (Eq.\ B7\text{-}3)$$

$$\left(\tilde{k}_{\phi f}\right)_g = \left(\frac{\pi}{L}\right)^2 \left[A_f\left(\left(x_o - h_x\right)^2\left(\frac{I_{xyf}}{I_{yf}}\right)^2 - 2y_o\left(x_o - h_x\right)\left(\frac{I_{xyf}}{I_{yf}}\right) + h_x^2 + y_o^2\right) + I_{xf} + I_{yf}\right] \qquad (Eq.\ B7\text{-}4)$$

Flexural Member: Critical Length and Web Rotational Stiffness

$$L_{cr} = \left(\frac{4\pi^4 h\left(1-\nu^2\right)}{t^3}\left(I_{xf}\left(x_o - h_x\right)^2 + C_{wf} - \frac{I_{xyf}^2}{I_{yf}}\left(x_o - h_x\right)^2\right) + \frac{\pi^4 h^4}{720}\right)^{1/4} \qquad (Eq.\ B7\text{-}5)$$

$$k_{\phi we} = \frac{Et^3}{12\left(1-\nu^2\right)}\left(\frac{3}{h} + \left(\frac{\pi}{L}\right)^2\frac{19h}{60} + \left(\frac{\pi}{L}\right)^4\frac{h^3}{240}\right) \qquad (Eq.\ B7\text{-}6)$$

$$\tilde{k}_{\phi wg} = \frac{ht\pi^2}{13440}\left(\frac{\left(45360\left(1-\xi_{web}\right) + 62160\right)\left(\frac{L}{h}\right)^2 + 448\pi^2 + \left(\frac{h}{L}\right)^2\left(53 + 3\left(1-\xi_{web}\right)\right)\pi^4}{\pi^4 + 28\pi^2\left(\frac{L}{h}\right)^2 + 420\left(\frac{L}{h}\right)^4}\right) \qquad (Eq.\ B7\text{-}7)$$

Compression Member: Critical Length and Web Rotational Stiffness

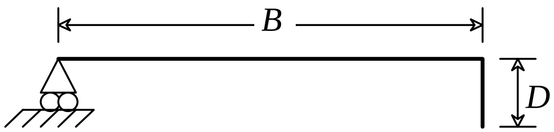
$$L_{cr} = \left(\frac{6\pi^4 h\left(1-\nu^2\right)}{t^3}\left(I_{xf}\left(x_o - h_x\right)^2 + C_{wf} - \frac{I_{xyf}^2}{I_{yf}}\left(x_o - h_x\right)^2\right)\right)^{1/4} \qquad (Eq.\ B7\text{-}8)$$

$$k_{\phi we} = \frac{Et^3}{6h\left(1-\nu^2\right)} \qquad (Eq.\ B7\text{-}9)$$

$$\tilde{k}_{\phi wg} = \left(\frac{\pi}{L}\right)^2\frac{th^3}{60} \qquad (Eq.\ B7\text{-}10)$$

E = Modulus of Elasticity
G = Shear Modulus
ν = Poisson's Ratio
t = plate thickness
h = web depth
$\xi = (f_1 - f_2)/f_1$ stress gradient in the web
L_m = Distance between restraints which limit rotation of the flange about the flange/web junction

A_f, I_{xf}, I_{yf}, C_{wf}, J_f = Section properties of the compression flange (flange and edge stiffener) about x, y axes respectively, where the x, y axes are located at the centroid of flange with x-axis parallel with flat portion of the flange
x_o = x distance from the flange/web junction to the centroid of the flange.
h_x = x distance from the centroid of the flange to the shear center of the flange



$$A = (B + D)t$$

$$J = \tfrac{1}{3} Bt^3 + \tfrac{1}{3} Dt^3$$

$$I_x = \frac{t\left(t^2 B^2 + 4BD^3 + t^2 BD + D^4\right)}{12(B + D)}$$

$$I_y = \frac{t\left(B^4 + 4DB^3\right)}{12(B + D)}$$

$$I_{xy} = \frac{tB^2 D^2}{4(B + D)}$$

$$I_o = \frac{tB^3}{3} + \frac{Bt^3}{12} + \frac{tD^3}{3}$$

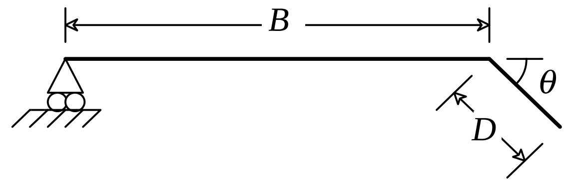
$$x_o = \frac{B^2}{2(B + D)}$$

$$h_y = y_o = \frac{-D^2}{2(B + D)}$$

$$h_x = \frac{-\left(B^2 + 2DB\right)}{2(B + D)}$$

$$x_o - h_x = B$$

$$C_w = 0$$



$$A = (B + D)t$$

$$J = \tfrac{1}{3} Bt^3 + \tfrac{1}{3} Dt^3$$

$$I_x = \frac{t\left(t^2 B^2 + 4BD^3 - 4BD^3 \cos^2(\theta) + t^2 BD + D^4 - D^4 \cos^2(\theta)\right)}{12(B + D)}$$

$$I_y = \frac{t\left(B^4 + 4DB^3 + 6D^2 B^2 \cos(\theta) + 4D^3 B \cos^2(\theta) + D^4 \cos^2(\theta)\right)}{12(B + D)}$$

$$I_{xy} = \frac{tBD^2 \sin(\theta)\left(B + D\cos(\theta)\right)}{4(B + D)}$$

$$I_o = \frac{tB^3}{3} + \frac{Bt^3}{12} + \frac{tD^3}{3}$$

$$x_o = \frac{B^2 - D^2 \cos(\theta)}{2(B + D)}$$

$$h_y = y_o = \frac{-D^2 \sin(\theta)}{2(B + D)}$$

$$h_x = \frac{-\left(B^2 + 2DB + D^2 \cos(\theta)\right)}{2(B + D)}$$

$$x_o - h_x = B$$

$$C_w = 0$$

Figure C-B7-1 Element Properties for a Simple Lip Stiffener

Appendix F.3 For Long-term Adoption and Interim Adoption as an Alternative Procedure: Direct Strength

An outline of the Direct Strength method (methods C2 and C3 in this report) follows:

G. Alternative Design Procedure: Direct Strength

G1 Columns

G1.1 Nominal long column buckling load

$P_{ne} = \left(0.658^{\lambda_c^2}\right)P_y$ for $\lambda_c \le 1.5$ and (*Eq*. G1.1-1)

$= \left[\frac{0.877}{\lambda_c^2}\right]P_y$ for $\lambda_c > 1.5$ (*Eq*. G1.1-2)

$\lambda_c = \sqrt{P_y/P_{cre}}$ (*Eq*. G1.1-3)

$P_y = A_g F_y$ (*Eq*. G1.1-4)

$P_{cre} = A_g F_e$ (*Eq*. G1.1-5)

F_e = the least of the elastic flexural, torsional and torsional-flexural buckling stress determined according to Section C4.1 through C4.3

G2.1 Local buckling strength

$P_{nl} = P_{ne}$ for $\lambda_l \le 0.776$ and (*Eq*. G1.2-1)

$= \left(1-0.15\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right)\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne}$ for $\lambda_l > 0.776$ (*Eq*. G1.2-2)

$\lambda_l = \sqrt{P_{ne}/P_{crl}}$ (*Eq*. G1.2-3)

P_{crl} = Elastic local column buckling load*

G3.1 Distortional buckling strength

$P_{nd} = P_{ne}$ for $\lambda_d \le 0.561$ and (*Eq*. G1.3-1)

$= \left(1-0.25\left(\frac{P_{crd}}{P_{ne}}\right)^{0.6}\right)\left(\frac{P_{crd}}{P_{ne}}\right)^{0.6} P_{ne}$ for $\lambda_d > 0.561$ (*Eq*. G1.3-2)

$\lambda_d = \sqrt{P_{ne}/P_{crd}}$ (*Eq*. G1.3-3)

P_{crd} = Elastic distortional column buckling load*

G4.1 Nominal Capacity

P_n = minimum of P_{nl} , P_{nd} (*Eq*. G1.4-1)

$\Omega = 1.80$ (ASD)

$\phi = 0.85$ (LRFD)

* Elastic buckling loads may be determined by expressions in Appendix … *{an Appendix should be added to the Specification that provides closed-form expressions for local and distortional buckling similar to those expressions given in Appendix B of this report and used in Appendix D method C2 of this report}* In lieu of those expressions the elastic buckling load may be determined by rational analysis.