WELDED BOX-BEAM FLEXURE DESIGN

Summary: A box-beam configuration may be used at openings in a floor or wall framing assembly. The AISI S100 contains design provisions for a built-up flexural members consisting of two C-sections back-to-back used as a flexural member. For built-up members to act as one unit (composite), the members must be connected together with sufficient fasteners and spacing. This Tech Note illustrates the extrapolation S100 Section D1.1 provisions to a box-beam configuration.

Disclaimer: Designs cited herein are not intended to preclude the use of other materials, assemblies, structures or designs when these other designs and materials demonstrate equivalent performance for the intended use; CFSEI documents are not intended to exclude the use and implementation of any other design or construction technique.

INTRODUCTION

AISI S100-12 provides design guidance for built-up beams formed by orienting two C-sections back-to-back to form an I-shaped section. These S100 provisions are based on stabilizing the shear flow in the flanges. The same shear flow would exist in a box-shaped cross section. Thus these same S100 provisions could be applicable to form a box-shaped section with the two C-sections oriented lip-to-lip.

The AISI S100-12 provisions are as follows:

“D1.1 Flexural Members Composed of Two Back-to-Back C-Sections

The maximum longitudinal spacing of connections (one or more welds or other connectors), $s_{max}$, joining two C-sections to form an I-section shall be:

$$s_{max} = \frac{2gT_s}{mq} \text{, whichever is smaller} \text{(Eq.D1.1-1)}$$

where

$L$ = Span of beam
$g$ = Vertical distance between two rows of connections nearest to top and bottom flanges
$T_s$ = Available strength [factored resistance] of connection in tension (Chapter E)
$m$ = Distance from shear center of one C-section to mid-plane of web
$q$ = Design load [factored load] on beam for determining longitudinal spacing of connections”.

The D1.1 provisions, Eq. D1.1-1, define the fastener spacing along the length of the member (Figure 1).

Figure 1 is Figure C-D1.1-2 (AISI S100-12C, p 110)

Because the current D1.1 provisions are intended to stabilize the C-section and achieve equilibrium of the cross section for the single C-section (Figure 2), the D1.1 provisions can be adapted to box-shaped sections by recognizing that “$g$” is the vertical distance between the two rows of welds that interconnect the two C-sections. To evaluate “$T_s$”, the available capacity for the welded connection, the provisions of AISI S100-12 Section E2.6, Equation E2.6-1, for flare groove welds applies. Using ASD, the safety factor is 2.55 and the nominal strength is as follows:

$$P_n = 0.833 t L F_u \text{ (Eq. E2.6-1)}$$

where $t$ is the thickness of the C-section, $L$ is the length of the weld and $F_u$ is the tensile strength of the C-section.

Figure 2 is Figure C-D1.1-1 (AISI S100-12C, p 109)
The various limit states applicable for the design of a flexural member are further defined by the following AISI S100 provisions:

Bending, Section C3.1
Shear, Section C3.2
Combined Bending and Shear, Section C3.3
Web Crippling, Section C3.4
Combined Bending and Web Crippling, Section C3.5.

The application of the limit states will be illustrated by the following example problem. For an example problem illustrating the application of Section D1.1 for a back-to-back configuration see page 303 of Yu and LaBoube (2010).

Example Problem
Given:
Two 800S300-54 having 1" lips interconnected lip-to-lip to form a box-shaped cross section (Figure 3). $F_y = 33$ ksi, $F_u = 45$ ksi Span length = 10 ft.
Applied load, $q = 0.50$ kip/ft

Check Bending Alone (Section C3.1.2.2):
The two interconnected C-sections will behave as a closed box member.

$$L_u = \frac{0.36 C_b \pi}{F_y S_f} \sqrt{\frac{E G I_y}{Y}}$$

$$= 1917 \text{ in.} = 159 \text{ ft.}$$

where $C_o = 1.0$, $S_t = 4.395$ in.$^3$, $E = 29500$ ksi, $G = 11500$ ksi, $j = 18.17$ in.$^4$, $I_y = 9.82$ in.$^4$

Span length of 10 ft is much less than $L_u$, therefore no intermediate braces are required to achieve the yield moment as computed by Section C3.1.1,

$$M_{max} = S_{xe} F_y / \Omega = 0.0461 (33) / 1.67 = 79.95 \text{ in-kips}$$

Applied Moment = $wL^2/8 = 0.50 (10)^2 (12)/8 = 75.0$ in-kips OK

Check Shear Alone (Section C3.2):
The available shear capacity per web is computed as follows:

$$h = 8.0 - 2 (r + t) = 8 - 2 (0.0849 + 0.0566) = 7.717 \text{ in.}$$

$$A_w = 7.717 (0.0566) = 0.437 \text{ in}^2$$

$$h/t = 7.717 / 0.0566 = 136.3$$

$$\sqrt{\frac{E k_v}{F_y}} = 1.51$$

where $E = 29500$ ksi, $k_v = 5.34$, $F_y = 33$ ksi

$h/t > 104$, therefore elastic shear buckling governs the web design and the available shear capacity is computed as

$$F_v = \frac{\pi^2 E k_v}{12(1 - \mu^2)(h/t)^2} = 7.66 \text{ ksi}$$

where $\mu$ is 0.3 and the other parameters were previously defined.

$$V_n / \Omega = 7.66 (0.437) / 1.6 = 2.09 \text{ kips/web}$$

Available shear capacity per cross section = 2 webs x 2.09 = 4.18 kips

Applied shear = $wL/2 = 0.50 (10)/2 = 2.50$ kips < 4.18 kips OK

Web Crippling Alone (Section C3.4):
The box-beam is uniformly loaded therefore web crippling need only to be considered at the end support if the box-beam is being supported on its’ bottom flange and no web stiffener or clip is provided at the support location.

When checking web crippling AISI Eq. C3.4.1-1 is applicable. The appropriate coefficients and safety factor are provided in Table C3.4.1-2. The coefficients and safety factor tabulated in Table C3.4.1-1 are not appropriate because these coefficients, although indicated to be valid for “built-up sections” were experimentally developed for only I-shaped sections.

Check the Interconnection of the Two C-sections (Section D1.1 modified):
Using flare groove welds, the two C-sections are interconnected as illustrated by Figure 3.

The ASD available capacity for a 1 inch long groove weld, $L = 1''$, is

$$T_s = 0.833 t L F_u / \Omega = 0.832 \text{ kips}$$

where all terms have been previously defined.
The maximum longitudinal spacing, \( s_{\text{max}} \), of the welds is the lesser of

\[
\frac{2gT_s}{mq} \quad \text{or} \\
\frac{2gT_s}{m(q)} = \frac{211}{6} = 20 \text{ inches}
\]

where \( g = 8" - 0.0566" = 7.943" \), \( m = x_0 - x_{cg} + t/2 = 2.320 - 0.9332 + 0.0566/2 = 1.504" \) \( (x_0 \) is the distance between the shear center and the center of gravity, \( x_{cg} \) is the distance from the center of gravity to the outside of the web – both parameters were determined using software). An approximate equation for “m” is given on page 110 of the Commentary to AISI S100-12 or page 301 of Yu and LaBoube (2010).

Although not required by Section D1.1, it is suggested that the maximum unbraced length, \( L_u \), to achieve the yield moment, \( M_{\text{yax}} \), for the single C-section be considered. It is suggested that \( L_u \) be considered to ensure that the weld spacing is less than the unbraced length to preclude overall buckling of the single C-section between the welds. The AISI S100-12 Commentary provides the following equation for \( L_u \) (Eq. C-C3.1.2.1-11).

When evaluated \( L_u \) equals 83.69 in. which is greater than \( s_{\text{max}} \) of 20 in.: 

\[
L_u = \left[ \frac{GJ}{2C_1} + \frac{C_2}{C_1} \left( \frac{GJ}{2C_1} \right)^{1/2} \right]^{1/2}
\]

\[
C_1 = \frac{7.72}{AE} \left( \frac{K_y S_f}{C_0 \pi r_y} \right)^2 \quad C_2 = \frac{\pi^2 E C_w}{(K_i)^2}
\]

where \( A = 0.8819 \text{ in}^2 \), \( S_f = 2.1977 \text{ in}^3 \), \( r_y = 1.1396 \text{ in} \), \( C_w = 15.681 \text{ in}^3 \), \( K_y = K_i = 1 \). The other parameters have been previously defined.

**Conclusion:**
Use a 1” long groove weld spaced 20” on-center longitudinally along the length of the beam to interconnect the two C-sections at both the top and bottom of the section.
References:

AISI S100-12, North American Specification for the Design of Cold-Formed Steel Structural Members, American Iron and Steel Institute, Washington, D.C.

AISI S100-12C, Commentary on North American Specification for the Design of Cold-Formed Steel Structural Members, American Iron and Steel Institute, Washington, D.C.


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