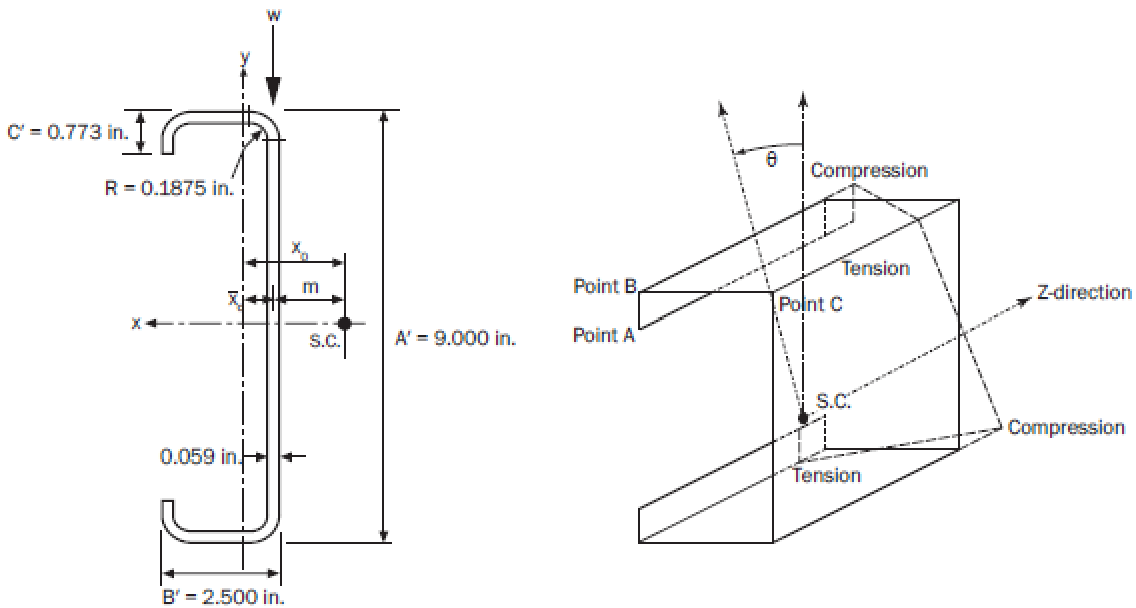
Example II-11: C-Section With Combined Bending and Torsional Loading (D100-17)



Case 1. Mid-Span Bracing

At mid-span, $\theta'' = 7.01\times10^{-6}$ rad/in², max w = 50.6 plf

Case 2. Third-Point Bracing

At ⅓ point, $\theta'' = 2.35\times10^{-6}$ rad/in², max w = 66.8 plf

At mid-span, $\theta'' = -0.529\times10^{-6}$ rad/in², max w = 66.4 plf CONTROLS

Case 3. No Bracing (not in Design Manual)

At mid-span, $\theta'' = -21.2\times10^{-6}$ rad/in²

$f_w = Ew_n\theta'' = 29500w_n(-21.2\times10^{-6}) = -0.625w_n$

$f_{wA} = -0.625(-8.82) = 5.51$ ksi $f_A = f_{bA} + f_{wA} = -3.39 + 5.51 = 2.12$ ksi

$f_{wB} = -0.625(-6.62) = 4.14$ ksi $f_B = f_{bB} + f_{wB} = -4.10 + 4.14 = 0.04$ ksi

$f_{wC} = -0.625(4.69) = -2.93$ ksi $f_C = f_{bC} + f_{wC} = -4.10 - 2.93 = -7.03$ ksi CONTROLS

$R = (1.15)(-4.10)/(-7.03) = 0.671$

Allowable moment strength: $M_a = RS_eF_y/\Omega_b = 0.671(1.89\text{ in}^3)(55\text{ ksi})/1.67 = 41.8$ k-in

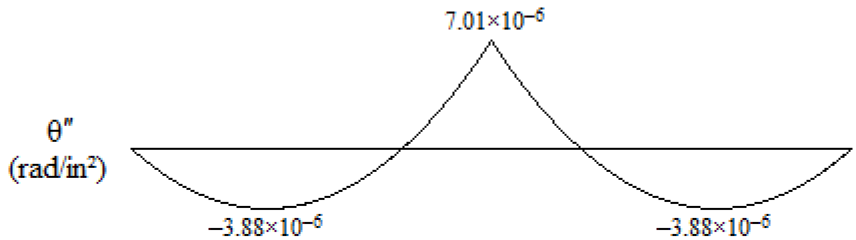
Max w = (10 plf)(41.8 k-in)/(9.38 k-in) = 44.6 plf

Using proposed provisions:

Case 1. Mid-Span Bracing

Nominal bimoment strength: $B_n = F_yC_w/w_n = (55\text{ ksi})(11.9\text{ in}^6)/(8.82\text{ in}^2) = 74.2$ k-in²

Allowable bimoment strength: $B_a = B_n/\Omega_b = (74.2\text{ k-in}^2)/1.67 = 44.4$ k-in²



At mid-span, $\overline{B} = EC_w\theta'' = (29500\text{ ksi})(11.9\text{ in}^6)(7.01\times10^{-6}\text{ rad/in}^2) = 2.46\text{ k-in}^2$

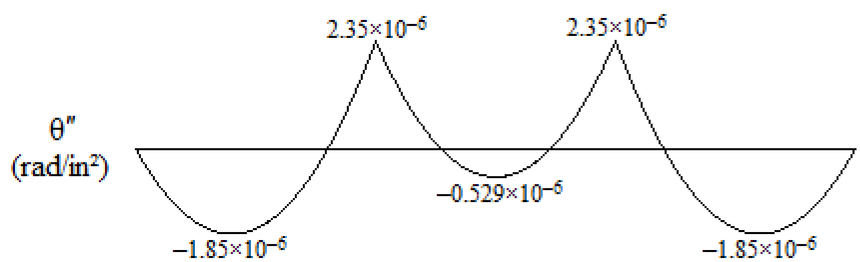
Allowable moment strength: $M_{axlo} = S_eF_y/\Omega_b = (1.89\text{ in}^3)(55\text{ ksi})/1.67 = 62.25\text{ ksi}$

$$\frac{9.38}{62.25} + \frac{0}{M_{aylo}} + \frac{2.46}{44.4} = 0.206 < 1.15 \qquad (\textit{Eq. } \text{H4.2-1})$$

Max w = (10 plf)(1.15/0.206) = <u>55.8 plf (vs. 50.6 plf)</u>

For bending alone, max w = (10 plf)(62.25 k-in)/(9.38 k-in) = 66.4 plf

Case 2. Third-Point Bracing



At ⅓ point, $\overline{B} = EC_w\theta'' = (29500\text{ ksi})(11.9\text{ in}^6)(2.35\times10^{-6}\text{ rad/in}^2) = 0.825\text{ k-in}^2$

$$\frac{8.33}{62.25} + \frac{0}{M_{aylo}} + \frac{0.825}{44.4} = 0.152 < 1.15 \qquad (\textit{Eq. } \text{H4.2-1})$$

Max w = (10 plf)(1.15/0.152) = 75.7 plf

For bending alone, max w = (10 plf)(62.25 k-in)/(8.33 k-in) = <u>74.7 plf (vs. 66.8 plf)</u>

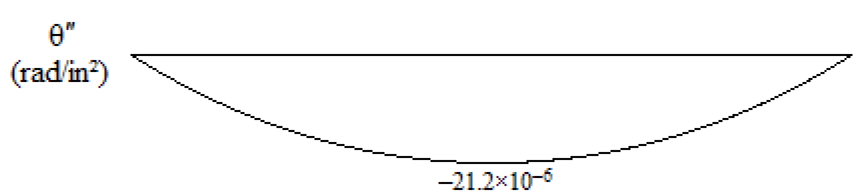
At mid-span, $\overline{B} = EC_w\theta'' = (29500\text{ ksi})(11.9\text{ in}^6)(-0.529\times10^{-6}\text{ rad/in}^2) = -0.186\text{ k-in}^2$

$$\frac{9.38}{62.25} + \frac{0}{M_{aylo}} + \frac{0.186}{44.4} = 0.155 < 1.15 \qquad (\textit{Eq. } \text{H4.2-1})$$

Max w = (10 plf)(1.15/0.155) = 74.2 plf

For bending alone, max w = (10 plf)(62.25 k-in)/(9.38 k-in) = <u>66.4 plf (vs. 66.4 plf)</u>   CONTROLS

Case 3. No Bracing



At mid-span, $\overline{B} = EC_w\theta'' = (29500 \text{ ksi})(11.9 \text{ in}^6)(-21.2\times10^{-6} \text{ rad/in}^2) = -7.44 \text{ k-in}^2$

$$\frac{9.38}{62.25} + \frac{0}{M_{aylo}} + \frac{7.44}{44.4} = 0.318 < 1.15 \qquad (\textit{Eq. } \text{H4.2-1})$$

Max w = (10 plf)(1.15/0.318) = 36.2 plf (vs. 44.6 plf)

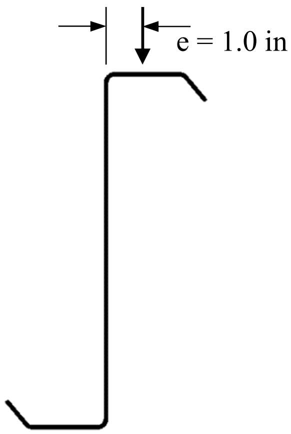
For bending alone, max w = (10 plf)(62.25 k-in)/(9.38 k-in) = 66.4 plf

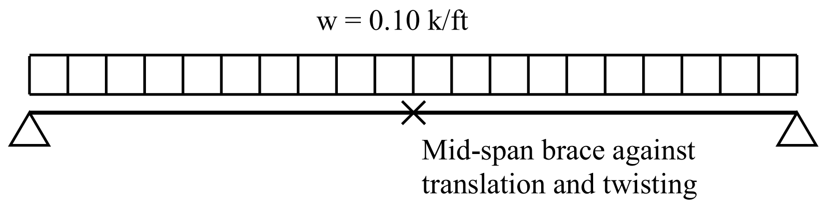
Observations:

1. For some cases, the proposed provisions give the same result as the current provisions. This occurs where R is calculated greater than 1.0, so the strength is limited by bending alone. This can also occur where R is permitted a 15% increase, and the locations of maximum warping stress and maximum bending stress are the same, and in the same direction.
2. For some cases, the proposed provisions permit a higher load than the current provisions. This occurs where R is not permitted a 15% increase, but the proposed interaction limit is 1.15.
3. For some cases, the current provisions permit a higher load than the proposed provisions. This occurs where R is permitted a 15% increase, R < 1.0 (high warping stress), and the locations of maximum warping stress and maximum bending stress are different, or in different directions.

Z Section Example

Check combined bending and torsion at mid-span using ASD method





10ZS2.25x105, F_y=50 ksi, t=0.105 in, R=0.1875 in.

S_x=4.659 in^3, C_w=36.76 in^6, w_n= –12.38 in^2 (at end of lip), J=0.00615 in^4

Internal forces

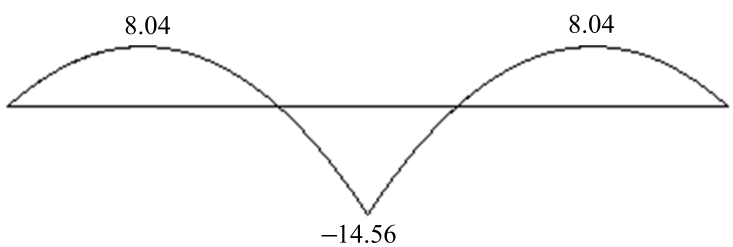
$M_x = wL^2/8 = (0.10/12)(240)^2/8 = 60.0$ k-in

$m_t = w \cdot e = (0.10/12)(1.0) = 0.00833$ k-in/in

Conservative estimate of bimoment using 2-span beam formula:

$B = -m_t(L/2)^2/8 = -(0.00833)(120)^2/8 = -15.0$ k-in^2

Actual Bimoment ($k\text{-}in^2$)



Strength

$M_{crl} > 1.66M_y$ for constrained bending, therefore not subject to local buckling

$M_{axlo} = S_xF_y/\Omega_b = (4.659)(50)/1.67 = 139.5$ k-in

$B_n = F_yC_w/w_n = (50)(36.76)/(12.38) = 148.5$ k-in^2

$B_a = B_n/\Omega_b = 148.5/1.67 = 88.92$ k-in^2

Interaction Equation

$$\frac{60.0}{139.5} + \frac{0}{M_{aylo}} + \frac{14.56}{88.92} = 0.594 < 1.15 \qquad (Eq.\ \text{H4.2-1})$$