steel quiz

This month's Steel Quiz is based on guidance and equations provided on eccentrically loaded weld groups in Part 8 of the 15th Edition AISC *Steel Construction Manual*.

The question and answers for this month's Steel Quiz were contributed by Hamza Sekkak, a PhD student at the Illinois Institute of Technology. Thank you, Hamza!

Refer to Figure 1. Given that weld size, *a*, is 5/16 in. and F_{EXX} is 70 ksi, solve for weld available strength, ϕR_n, using:

1 Table 8-4

2 Instantaneous center of rotation method

3 Elastic method

4 Plastic method

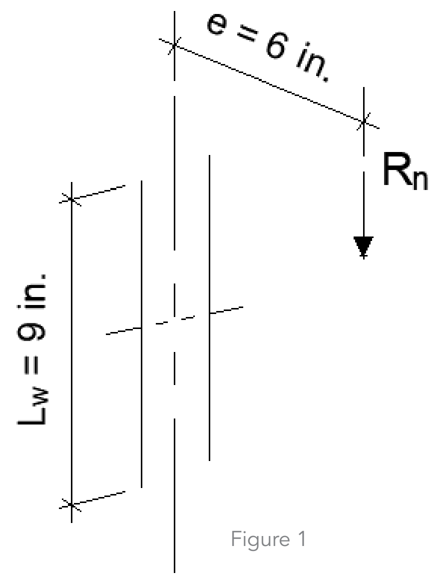

Figure 1

TURN PAGE FOR THE ANSWERS

1 **Using Table 8-4.** $k = 0$, because the force applied is out-of-plane with regard to the cross-sectional plane of the plate. From Table 8-4:

$$C = 1.84$$

$$\phi R_n = \phi C C_1 D l = (0.75)(1.84)(1.0)(5)(9) = 62.1 \text{ kips}$$

2 **Using the instantaneous center of rotation method.** Break half of the weld length into equal segments (see Figure 2).

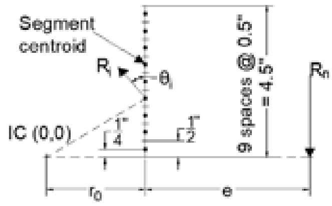

Figure 2

Select a trial location for the instantaneous center of rotation, r_0. Compute coordinates of the centroids of the segments and their angles. Compute the deformations Δ_{mi} and Δ_{ui} using the following equations:

$$\Delta_{mi} = 0.209(\theta_i + 2)^{-0.32} w$$

$$\Delta_{ui} = 1.087(\theta_i + 6)^{-0.65} w \le 0.17w$$

where θ_i is the segment angle in degrees and w is the weld size in in.

Compute Δ_i as follows:

$$\Delta_i = r_i \frac{\Delta_{ucr}}{r_{cri}} = r_i(0.0046)$$

Compute R_n, the resistance of each segment:

$$R_i = 0.60 F_{EXX} t_e l_w \left(1.0 + 0.50 \sin^{1.5}\theta_i\right)\left[\frac{\Delta_i}{\Delta_{mi}}\left(1.9 - 0.9\frac{\Delta_i}{\Delta_{mi}}\right)\right]^{0.3}$$

Vertical Segments	Length l_w (in.)	X (in.)	Y (in.)	r_i (in.)	R_i (kip)	$(R_i)_x$ (kip)	$(R_i)_y$ (kip)	$R_i r_i$ (kip-in.)
1	0.5	0.82	4.25	4.329	6.87	6.75	1.31	29.75
2	0.5	0.82	3.75	3.839	6.89	6.72	1.48	26.44
3	0.5	0.82	3.25	3.353	6.82	6.61	1.68	22.86
4	0.5	0.82	2.75	2.871	6.66	6.38	1.91	19.13
5	0.5	0.82	2.25	2.396	6.41	6.02	2.20	15.35
6	0.5	0.82	1.75	1.934	6.02	5.44	2.56	11.64
7	0.5	0.82	1.25	1.497	5.44	4.54	2.99	8.14
8	0.5	0.82	0.75	1.114	4.56	3.07	3.38	5.09
9	0.5	0.82	0.25	0.861	3.34	0.97	3.20	2.88
					Σ =	46.51	20.71	141.27

Check rotational and force equilibrium until both values become the same ($r_0 = 0.824$ in.).

Rotational equilibrium:

$$R_n = \frac{2\left(\sum R_i r_i\right)}{e + r_0} = \frac{2\,(141.3)}{6.824} = 41.4 \text{ kips}$$

Force equilibrium:

$$R_n = 2\sum (R_i)_y = 41.4 \text{ kips}$$

Finally:

$$\phi R_n = (0.75)(2 \text{ weld lines}) \times 41.4 \text{ kips} = 62.1 \text{ kips}$$

3 **Using the elastic method.**

The moment of inertia of the weld is:

$$I_x = 2\left(\frac{9^3}{12}\right) = 121.50 \text{ in.}^3$$

Solve for the welding strength from the following:

$$\sqrt{\left(\frac{R_n}{2l}\right)^2 + \left(\frac{R_n ec}{I_p}\right)^2} = \left(0.707 \times \frac{5}{16}\text{in.}\right)0.6(70 \text{ ksi})$$

$$R_n = 40.5 \text{ kips} \rightarrow \phi R_n = 30.4 \text{ kips}$$

4 **Using the plastic method.**

For one weld:

$$f_w = \sqrt{f_v^2 + (f_a + f_b)^2}$$

$$f_v = \frac{R_n}{l},\ f_a = 0,\ f_b = \frac{4M}{l^2} = \frac{4R_n e}{l^2}$$

$$f_w = \left(\frac{5}{16}\text{ in.}\right)(0.707)(0.6)(70 \text{ ksi})$$

For two welds:

$$R_n = 58.7 \text{ kips} \rightarrow \phi R_n = 44.0 \text{ kips}$$

Notes: The Steel Quiz submitted by Hamza Sekkak did not account for the directional strength increase when applying the plastic method. Section J2.4.(b) of the AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360) states: "For fillet welds, the available strength is permitted to be determined accounting for a directional strength increase of ($1.0 + 0.50\sin^{1.5}\theta$) if strain compatibility of the various weld elements is considered." Though not explicitly addressed in the use of the plastic method, strain compatibility will likely not be a problem for the condition shown. This is a matter of engineering judgment. If the directional strength increase is to be included, it can be done as follows:

$$\theta = \text{atan}\left(\frac{f_b}{f_v}\right) = \text{atan}\left(\frac{4e}{l}\right) = \text{atan}\left(\frac{4(6)}{9}\right) = 69.4°$$

$$\left[1.0 + 0.50\sin^{1.5}(69.4°)\right] = 1.4$$

Accounting for the directional strength increase $\phi R_n = 63.9$ kips, this is within 3% of the strength predicted by the instantaneous center of rotation method, which explicitly considers strain compatibility of the various weld elements.

—Larry Muir, PE, AISC Director of Technical Assistance