Elastic and Plastic Section Moduli of Steel Angles About Principal Axes

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Steel angles are frequently subjected to bending moment due to self-weight, wind load, eccentricity of connections, etc. Depending on the width-to-thickness ratios and unbraced length-to-width ratios, they can develop full plastic moment resistance under transverse loads (Madugula and Ding, 2002). AISC *Load and Resistance Factor Design Manual of Steel Construction* (*LRFD Manual*), 3rd Edition (AISC, 2001) gives the elastic and plastic section moduli about the geometric axes (X and Y axes) only and not about the principal axes. There is a need to calculate elastic and plastic section moduli of angle sections about the principal axes for use in determining their bending strength. Based on the simplified assumption that the cross-section consists of two rectangles (i.e., ignoring the effect of toe and heel radii), formulas to locate the major and minor plastic principal axes and to determine the corresponding section moduli are derived in this technical note. For the elastic case, the principal axes refer to the axes having maximum and minimum moments of inertia, while for the plastic case, the principal axes refer to the axes having maximum and minimum section moduli. The results of the computations for all the angle sections listed in the AISC *LRFD Manual* are given in Tables 1 and 2.

The locations of the elastic and plastic principal axes are different. Therefore, the shape factor is computed as the ratio of plastic section modulus about plastic principal axis to the minimum elastic section modulus about the elastic principal axis. For elastic analysis and design, elastic section moduli about elastic principal axes are to be used and the applied moments are to be resolved in the directions of the elastic principal axes. For strength limit state design, plastic section moduli about plastic principal axes are to be used. In this case, the applied moments are to be resolved in the directions of the plastic principal axes. It is not correct to compute the plastic section moduli about elastic principal axes, because equilibrium conditions will be violated.

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The problem becomes more complicated in the case of an elasto-plastic analysis of angle sections. The location of the neutral axis continually changes, depending on the magnitude of the applied moment. For each value of the applied moment, the location of the neutral axis has to be computed by trial and error to satisfy the equilibrium conditions and the tabulated values cannot be used.

It should be noted that the *Load and Resistance Factor Design Specification for Single-Angle Members* (the *Specification*) (AISC, 2000) does not allow the use of plastic section properties. When the section is compact or when tension is being checked at a particular location on the cross-section, the *Specification* uses 1.5 times the elastic section modulus in lieu of the plastic section modulus. Thus 1.5 times the minimum elastic section moduli about the elastic principal axes given in Table 1 can be used directly in the bending strength formulas given in the Specification.

DETERMINATION OF THE ELASTIC SECTION MODULI ABOUT MINOR AND MAJOR PRINCIPAL AXES

For the angle sections listed in the AISC *LRFD Manual* (AISC, 2001), moments of inertia about minor and major principal axes (I_z and I_w) are calculated using the tabulated values in the Manual and the results are given in Table 1. For use in bi-axial bending calculations, section moduli to the five corner points identified in Figure 1 (Points 1 to 5) are conservatively calculated neglecting the toe and fillet radii and results are also listed in Table 1.

DETERMINATION OF THE PLASTIC SECTION MODULI ABOUT MAJOR AND MINOR PRINCIPAL AXES

For the angle section $H \times B \times t$ ($H \geq B$) shown in Figure 2, the major principal axis $W_p - W_p$ intersects leg H at H_p, and the angle between $W_p - W_p$ and leg B is θ.

For equilibrium of axial forces, major principal axis $W_p - W_p$ should divide the total area into two equal parts. Referring to Figure 2,

$$H_p = \frac{H - B}{2} + \frac{t}{2}(1 - \tan\theta) \qquad (1)$$

The plastic section modulus Z_w about W_p-W_p can be computed as

$$Z_w = t[\frac{\cos\theta}{8}(H + B - t - t*\tan\theta)^2 + \frac{t\sin\theta}{2}(H - \frac{t}{3}\tan\theta) + \frac{\cos\theta}{8}(H - B + t - t*\tan\theta)^2 + \frac{B-t}{2}(H\cos\theta - B\cos\theta + B\sin\theta)] \quad (2)$$

For Z_w to be maximum, the condition

$$\frac{dZ_w}{d\theta} = 0 \quad (3)$$

must be satisfied. By trial and error, Equation 3 is solved for θ.

The minor plastic principal axis Z_p-Z_p is perpendicular to W_p-W_p, and also bisects the total area of the cross section. Therefore,

$$B_p = \frac{\tan\theta(H + B + t*\tan\theta)}{2(1+\tan\theta)} + \frac{t}{2} \quad (4)$$

Based on above equations and geometry, plastic section moduli Z_w and Z_z about plastic principal axes are calculated to three significant figures for all the angle sections listed in the AISC *LRFD Manual* (AISC, 2001), even though it is recognized that not all sections are compact according to the current AISC *Load and Resistance Factor Design Specification for Single-Angle Members* (AISC, 2000). The results of the computations are given in Table 2.

REFERENCES

AISC (2000), *Load and Resistance Factor Design Specification for Single-Angle Members*, American Institute of Steel Construction, Chicago, IL.

AISC (2001), *Load and Resistance Factor Design Manual of Steel Construction*, 3rd Edition, American Institute of Steel Construction, Chicago, IL.

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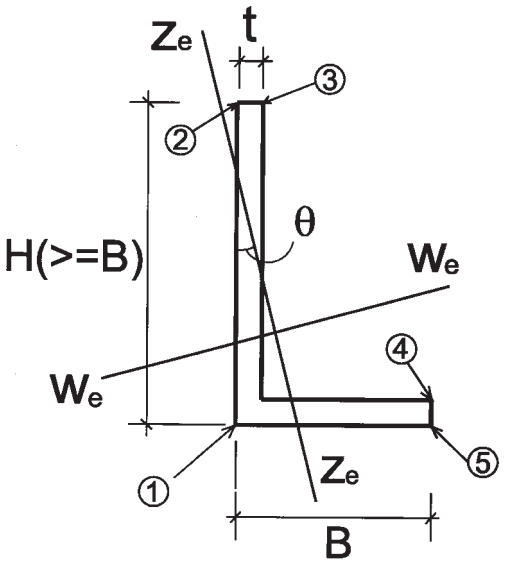

Fig. 1. Cross section of steel angle for calculation of elastic section moduli.

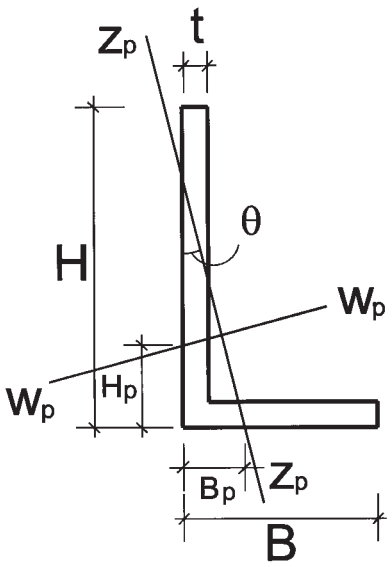

Fig. 2. Cross section of steel angle for calculation of plastic section moduli.

Table 1. Elastic Section Moduli of Angles

Size (in.)	I_z (in.^{4})	I_w (in.^{4})	S_{z1} (in.^{3})	S_{z2} (in.^{3})	S_{z3} (in.^{3})	S_{z4} (in.^{3})	S_{z5} (in.^{3})	S_{w1} (in.^{3})	S_{w2} (in.^{3})	S_{w3} (in.^{3})	S_{w4} (in.^{3})	S_{w5} (in.^{3})
L8X8X1-1/8	40.9	155	12.0	18.1	13.4	13.4	18.1	-	27.5	31.9	31.9	27.5
1	36.7	141	11.0	15.8	12.1	12.1	15.8	-	25.0	28.6	28.6	25.0
7/8	32.8	127	10.0	13.7	10.9	10.9	13.7	-	22.4	25.1	25.1	22.4
3/4	28.3	111	8.87	11.5	9.48	9.48	11.5	-	19.7	21.7	21.7	19.7
5/8	24.2	95.0	7.74	9.56	8.14	8.14	9.56	-	16.8	18.2	18.2	16.8
9/16	21.9	86.5	7.07	8.55	7.40	7.40	8.55	-	15.3	16.4	16.4	15.3
1/2	19.8	77.8	6.46	7.66	6.74	6.74	7.66	-	13.7	14.7	14.7	13.7
L8X6X1	21.5	98.2	7.91	19.5	10.9	7.06	8.38	63.6	17.9	19.6	27.9	22.3
7/8	18.8	88.5	7.11	15.9	9.66	6.21	7.20	58.4	16.1	17.4	24.4	20.1
3/4	16.6	77.7	6.40	13.2	8.67	5.50	6.25	52.4	14.1	15.0	20.9	17.8
5/8	14.0	66.6	5.53	10.4	7.40	4.64	5.15	45.8	12.0	12.7	17.5	15.3
9/16	12.9	60.6	5.13	9.32	6.87	4.27	4.70	42.0	10.9	11.5	15.7	13.9
1/2	11.5	54.6	4.65	8.09	6.19	3.81	4.15	38.0	9.84	10.3	13.9	12.5
7/16	10.3	48.3	4.21	7.04	5.58	3.42	3.68	34.1	8.68	9.03	12.2	11.1
L8X4X1	7.91	73.4	4.55	43.4	6.86	3.31	3.68	27.3	14.5	15.2	27.4	20.1
7/8	7.01	66.1	4.13	27.2	6.34	2.93	3.21	24.9	13.0	13.5	23.7	18.2
3/4	6.13	58.2	3.72	18.0	5.75	2.55	2.76	22.3	11.3	11.8	20.2	16.1
5/8	5.25	49.9	3.27	12.4	5.11	2.17	2.32	19.4	9.64	9.95	16.8	13.9
9/16	4.79	45.6	3.03	10.3	4.76	1.97	2.09	17.9	8.77	9.02	15.1	12.8
1/2	4.32	41.0	2.78	8.62	4.39	1.77	1.87	16.2	7.88	8.08	13.4	11.5
7/16	3.84	36.4	2.51	7.08	3.98	1.57	1.64	14.6	6.96	7.11	11.7	10.3
L7X4X3/4	5.63	41.2	3.27	12.9	4.90	2.43	2.70	19.9	8.97	9.45	15.9	12.5
5/8	4.81	35.6	2.87	9.39	4.35	2.07	2.26	17.5	7.70	8.03	13.2	10.8
1/2	3.94	29.1	2.43	6.64	3.69	1.69	1.82	14.7	6.26	6.48	10.5	8.95
7/16	3.50	25.9	2.19	5.50	3.33	1.50	1.60	13.1	5.56	5.73	9.13	7.97
3/8	3.05	22.5	1.94	4.50	2.95	1.30	1.37	11.5	4.81	4.94	7.82	6.96
L6X6X1	15.1	55.7	5.72	9.34	6.49	6.49	9.34	-	13.1	15.8	15.8	13.1
7/8	13.3	50.5	5.21	7.93	5.80	5.80	7.93	-	11.9	13.9	13.9	11.9
3/4	11.6	44.6	4.63	6.66	5.10	5.10	6.66	-	10.5	12.0	12.0	10.5
5/8	9.76	38.4	4.01	5.39	4.33	4.33	5.39	-	9.06	10.1	10.1	9.06
9/16	8.98	35.0	3.74	4.89	4.02	4.02	4.89	-	8.25	9.11	9.11	8.25
1/2	8.03	31.8	3.40	4.27	3.60	3.60	4.27	-	7.49	8.17	8.17	7.49
7/16	7.07	28.1	3.03	3.70	3.19	3.19	3.70	-	6.63	7.15	7.15	6.63
3/8	6.20	24.6	2.71	3.18	2.80	2.80	3.18	-	5.80	6.18	6.18	5.80
5/16	5.20	20.8	2.30	2.62	2.36	2.36	2.62	-	4.90	5.17	5.17	4.90
L6X4X7/8	5.81	31.5	3.13	12.2	4.53	2.68	3.18	20.7	7.85	8.58	13.9	10.2
3/4	5.07	28.0	2.80	9.16	4.08	2.35	2.72	18.8	6.94	7.49	11.8	9.13
5/8	4.31	24.2	2.46	6.75	3.56	1.99	2.25	16.7	5.96	6.35	9.77	7.93
9/16	3.92	22.1	2.26	5.80	3.29	1.81	2.03	15.4	5.45	5.77	8.76	7.28
1/2	3.53	20.0	2.07	4.93	3.01	1.64	1.81	14.0	4.91	5.17	7.75	6.58
7/16	3.13	17.8	1.86	4.14	2.71	1.45	1.58	12.6	4.37	4.57	6.77	5.87
3/8	2.72	15.5	1.65	3.40	2.38	1.26	1.36	11.2	3.80	3.94	5.80	5.14
5/16	2.28	13.1	1.41	2.72	2.03	1.06	1.13	9.55	3.20	3.31	4.81	4.35
L6X3-1/2X1/2	2.57	18.3	1.75	5.27	2.67	1.28	1.39	10.8	4.59	4.79	7.73	6.44
3/8	1.99	14.1	1.41	3.51	2.16	0.99	1.05	8.48	3.53	3.65	5.72	5.01
5/16	1.69	12.0	1.21	2.79	1.87	0.838	0.884	7.30	3.01	3.09	4.78	4.28
L5X5X7/8	7.56	28.0	3.43	5.69	3.88	3.88	5.69	-	7.93	9.61	9.61	7.93
3/4	6.59	24.8	3.07	4.76	3.44	3.44	4.76	-	7.02	8.25	8.25	7.02
5/8	5.61	21.6	2.70	3.85	2.95	2.95	3.85	-	6.11	6.98	6.98	6.11
1/2	4.60	18.0	2.29	3.01	2.45	2.45	3.01	-	5.09	5.66	5.66	5.09
7/16	4.08	15.9	2.06	2.62	2.19	2.19	2.62	-	4.50	4.94	4.94	4.50
3/8	3.55	14.0	1.83	2.22	1.90	1.90	2.22	-	3.95	4.27	4.27	3.95
5/16	3.01	11.9	1.58	1.85	1.63	1.63	1.85	-	3.36	3.58	3.58	3.36

Table 1. Elastic Section Moduli of Angles (Continued)

Size (in.)	I_z (in.^{4})	I_w (in.^{4})	S_{z1} (in.^{3})	S_{z2} (in.^{3})	S_{z3} (in.^{3})	S_{z4} (in.^{3})	S_{z5} (in.^{3})	S_{w1} (in.^{3})	S_{w2} (in.^{3})	S_{w3} (in.^{3})	S_{w4} (in.^{3})	S_{w5} (in.^{3})
L5X3-1/2X3/4	3.22	16.2	1.97	6.83	2.80	1.73	2.09	14.0	4.80	5.29	8.29	6.15
5/8	2.74	14.1	1.74	4.93	2.45	1.48	1.73	12.5	4.14	4.49	6.85	5.37
1/2	2.25	11.7	1.48	3.55	2.07	1.22	1.38	10.7	3.44	3.67	5.43	4.49
3/8	1.74	9.16	1.18	2.42	1.65	0.943	1.03	8.60	2.67	2.80	4.06	3.53
5/16	1.47	7.80	1.03	1.93	1.41	0.796	0.860	7.45	2.26	2.36	3.39	3.02
1/4	1.20	6.36	0.853	1.50	1.17	0.649	0.690	6.13	1.84	1.90	2.70	2.47
L5X3X1/2	1.55	10.4	1.20	3.93	1.79	0.906	1.01	7.52	3.14	3.31	5.42	4.35
7/16	1.37	9.33	1.09	3.16	1.62	0.804	0.881	6.80	2.80	2.93	4.71	3.90
3/8	1.19	8.17	0.967	2.51	1.44	0.697	0.753	6.05	2.44	2.54	4.04	3.44
5/16	1.02	6.94	0.840	1.96	1.25	0.592	0.632	5.20	2.07	2.14	3.34	2.93
1/4	0.825	5.68	0.700	1.47	1.04	0.479	0.505	4.33	1.68	1.73	2.68	2.41
L4X4X3/4	3.25	12.0	1.81	3.15	2.08	2.08	3.15	-	4.24	5.22	5.22	4.24
5/8	2.76	10.5	1.60	2.50	1.79	1.79	2.50	-	3.70	4.39	4.39	3.70
1/2	2.26	8.78	1.35	1.95	1.49	1.49	1.95	-	3.10	3.55	3.55	3.10
7/16	1.99	7.87	1.23	1.66	1.32	1.32	1.66	-	2.78	3.12	3.12	2.78
3/8	1.74	6.90	1.09	1.41	1.16	1.16	1.41	-	2.44	2.69	2.69	2.44
5/16	1.46	5.88	0.933	1.16	0.99	0.99	1.16	-	2.08	2.25	2.25	2.08
1/4	1.18	4.82	0.775	0.909	0.801	0.801	0.909	-	1.70	1.82	1.82	1.70
L4X3-1/2X1/2	1.79	7.27	1.17	2.08	1.42	1.15	1.42	18.4	2.59	2.90	3.47	2.91
3/8	1.39	5.72	0.937	1.49	1.13	0.899	1.05	14.8	2.04	2.22	2.61	2.29
5/16	1.17	4.88	0.811	1.20	0.958	0.761	0.867	13.0	1.73	1.86	2.18	1.96
1/4	0.951	4.01	0.678	0.938	0.784	0.620	0.687	11.0	1.42	1.50	1.76	1.62
L4X3X5/8	1.59	7.27	1.13	3.35	1.55	1.04	1.29	9.09	2.67	2.99	4.38	3.29
1/2	1.30	6.12	0.963	2.34	1.31	0.855	1.01	7.97	2.23	2.44	3.48	2.78
3/8	1.01	4.82	0.780	1.58	1.04	0.664	0.754	6.53	1.74	1.87	2.60	2.21
5/16	0.851	4.13	0.674	1.26	0.896	0.562	0.624	5.66	1.49	1.58	2.16	1.89
1/4	0.690	3.39	0.562	0.96	0.734	0.456	0.496	4.76	1.22	1.27	1.73	1.56
L3-1/2X3-1/2X1/2	1.51	5.75	1.02	1.52	1.12	1.12	1.52	-	2.32	2.71	2.71	2.32
7/16	1.34	5.16	0.920	1.32	1.01	1.01	1.32	-	2.08	2.38	2.38	2.08
3/8	1.17	4.55	0.825	1.10	0.880	0.880	1.10	-	1.84	2.06	2.06	1.84
5/16	0.985	3.89	0.712	0.904	0.751	0.751	0.904	-	1.57	1.73	1.73	1.57
1/4	0.805	3.20	0.596	0.715	0.618	0.618	0.715	-	1.29	1.39	1.39	1.29
L3-1/2X3X1/2	1.15	4.62	0.849	1.71	1.07	0.839	1.06	11.3	1.89	2.15	2.65	2.15
7/16	1.03	4.16	0.776	1.43	0.957	0.749	0.920	10.6	1.70	1.90	2.33	1.94
3/8	0.898	3.67	0.694	1.19	0.850	0.660	0.786	9.48	1.50	1.64	2.00	1.72
5/16	0.759	3.15	0.602	0.965	0.730	0.561	0.649	8.20	1.28	1.39	1.67	1.47
1/4	0.623	2.60	0.509	0.751	0.604	0.461	0.517	6.98	1.05	1.12	1.35	1.22
L3-1/2X2-1/2X1/2	0.781	3.82	0.677	2.09	0.949	0.595	0.713	4.94	1.61	1.77	2.70	2.05
3/8	0.607	3.04	0.553	1.33	0.767	0.463	0.531	4.11	1.27	1.36	2.01	1.65
5/16	0.518	2.62	0.484	1.05	0.669	0.397	0.445	3.60	1.09	1.16	1.67	1.42
1/4	0.424	2.16	0.409	0.789	0.557	0.324	0.355	3.05	0.894	0.938	1.34	1.18
L3X3X1/2	0.925	3.47	0.704	1.15	0.797	0.797	1.15	-	1.64	1.97	1.97	1.64
7/16	0.817	3.14	0.637	0.97	0.712	0.712	0.97	-	1.48	1.73	1.73	1.48
3/8	0.712	2.79	0.570	0.818	0.627	0.627	0.818	-	1.31	1.50	1.50	1.31
5/16	0.605	2.39	0.497	0.668	0.537	0.537	0.668	-	1.13	1.26	1.26	1.13
1/4	0.493	1.97	0.417	0.525	0.442	0.442	0.525	-	0.927	1.01	1.01	0.927
3/16	0.374	1.52	0.326	0.385	0.339	0.339	0.385	-	0.717	0.765	0.765	0.717

Table 1. Elastic Section Moduli of Angles (Continued)

Size (in.)	I_z (in.^{4})	I_w (in.^{4})	S_{z1} (in.^{3})	S_{z2} (in.^{3})	S_{z3} (in.^{3})	S_{z4} (in.^{3})	S_{z5} (in.^{3})	S_{w1} (in.^{3})	S_{w2} (in.^{3})	S_{w3} (in.^{3})	S_{w4} (in.^{3})	S_{w5} (in.^{3})
L3X2-1/2X1/2	0.668	2.69	0.570	1.36	0.737	0.564	0.736	6.49	1.29	1.49	1.94	1.50
7/16	0.591	2.45	0.517	1.12	0.663	0.502	0.633	6.07	1.17	1.33	1.71	1.36
3/8	0.516	2.16	0.464	0.911	0.588	0.441	0.537	5.49	1.03	1.15	1.46	1.21
5/16	0.437	1.86	0.405	0.721	0.505	0.376	0.443	4.84	0.887	0.969	1.21	1.04
1/4	0.357	1.54	0.341	0.553	0.419	0.308	0.351	4.10	0.731	0.784	0.974	0.861
3/16	0.271	1.20	0.268	0.395	0.323	0.235	0.259	3.27	0.567	0.597	0.735	0.671
L3X2X1/2	0.408	2.18	0.430	2.07	0.619	0.374	0.453	2.80	1.09	1.21	2.02	1.41
3/8	0.318	1.76	0.354	1.13	0.508	0.291	0.336	2.39	0.871	0.939	1.50	1.16
5/16	0.271	1.52	0.312	0.847	0.447	0.249	0.281	2.09	0.747	0.796	1.23	0.999
1/4	0.223	1.26	0.266	0.615	0.377	0.204	0.224	1.79	0.614	0.646	0.986	0.836
3/16	0.174	0.978	0.215	0.428	0.301	0.158	0.170	1.43	0.475	0.493	0.741	0.656
L2-1/2X2-1/2X1/2	0.521	1.92	0.458	0.823	0.528	0.528	0.823	-	1.09	1.36	1.36	1.09
3/8	0.400	1.54	0.373	0.575	0.417	0.417	0.575	-	0.873	1.03	1.03	0.873
5/16	0.338	1.34	0.325	0.464	0.356	0.356	0.464	-	0.756	0.864	0.864	0.756
1/4	0.276	1.11	0.275	0.363	0.294	0.294	0.363	-	0.627	0.696	0.696	0.627
3/16	0.209	0.861	0.215	0.263	0.225	0.225	0.263	-	0.487	0.526	0.526	0.487
L2-1/2X2X3/8	0.274	1.15	0.296	0.717	0.390	0.280	0.351	2.87	0.667	0.752	1.02	0.797
5/16	0.233	1.00	0.260	0.554	0.340	0.240	0.289	2.56	0.578	0.639	0.852	0.695
1/4	0.191	0.837	0.222	0.416	0.285	0.198	0.230	2.21	0.480	0.520	0.682	0.582
3/16	0.148	0.655	0.179	0.298	0.226	0.154	0.172	1.78	0.374	0.397	0.514	0.457
L2X2X3/8	0.204	0.748	0.228	0.392	0.260	0.260	0.392	-	0.529	0.651	0.651	0.529
5/16	0.173	0.655	0.201	0.313	0.223	0.223	0.313	-	0.463	0.549	0.549	0.463
1/4	0.141	0.551	0.171	0.241	0.185	0.185	0.241	-	0.389	0.445	0.445	0.389
3/16	0.109	0.433	0.138	0.176	0.145	0.145	0.176	-	0.306	0.338	0.338	0.306
1/8	0.0751	0.303	0.099	0.114	0.100	0.100	0.114	-	0.214	0.228	0.228	0.214

Table 2. Plastic Section Moduli of Angles

Size (in.)	θ (degrees)	tan θ	B_p (in.)	H_p (in.)	Z_z (in.^{3})	Z_w (in.^{3})	Shape factor (Z axis)	Shape factor (W axis)
L8x8x1-1/8	45.0	1.00	4.84	0	22.4	44.1	1.86	1.61
1	45.0	1.00	4.75	0	20.2	39.8	1.83	1.59
7/8	45.0	1.00	4.66	0	17.9	35.4	1.78	1.58
3/4	45.0	1.00	4.56	0	15.5	30.9	1.75	1.57
5/8	45.0	1.00	4.47	0	13.1	26.1	1.70	1.56
9/16	45.0	1.00	4.42	0	11.9	23.7	1.68	1.55
1/2	45.0	1.00	4.37	0	10.7	21.2	1.65	1.54
L8x6x1	30.4	0.586	3.19	1.21	14.1	30.8	2.00	1.72
7/8	30.5	0.588	3.12	1.18	12.5	27.4	2.02	1.71
3/4	30.5	0.590	3.05	1.15	10.9	23.9	1.98	1.70
5/8	30.6	0.592	2.98	1.13	9.24	20.3	1.99	1.69
9/16	30.7	0.593	2.95	1.11	8.38	18.5	1.96	1.69
1/2	30.7	0.594	2.91	1.10	7.51	16.6	1.97	1.68
7/16	30.7	0.594	2.88	1.09	6.63	14.6	1.94	1.68
L8x4x1	17.9	0.322	2.00	2.34	7.85	22.9	2.37	1.58
7/8	18.0	0.324	1.94	2.30	6.97	20.5	2.38	1.58
3/4	18.0	0.326	1.88	2.25	6.07	18.0	2.38	1.59
5/8	18.1	0.327	1.82	2.21	5.14	15.4	2.38	1.60
9/16	18.1	0.328	1.78	2.19	4.67	14.0	2.37	1.60
1/2	18.2	0.328	1.75	2.17	4.19	12.6	2.37	1.60
7/16	18.2	0.329	1.72	2.15	3.71	11.2	2.36	1.60
L7x4x3/4	21.3	0.390	1.96	1.73	5.58	14.8	2.29	1.65
5/8	21.4	0.392	1.89	1.69	4.74	12.7	2.29	1.65
1/2	21.5	0.393	1.83	1.65	3.87	10.4	2.28	1.66
7/16	21.5	0.394	1.80	1.63	3.42	9.22	2.28	1.66
3/8	21.6	0.395	1.77	1.61	2.96	8.00	2.27	1.66
L6x6x1	45.0	1.00	3.75	0	11.0	21.4	1.92	1.63
7/8	45.0	1.00	3.66	0	9.77	19.2	1.87	1.61
3/4	45.0	1.00	3.56	0	8.51	16.8	1.84	1.60
5/8	45.0	1.00	3.47	0	7.22	14.3	1.80	1.58
9/16	45.0	1.00	3.42	0	6.56	13.0	1.76	1.58
1/2	45.0	1.00	3.37	0	5.88	11.7	1.73	1.56
7/16	45.0	1.00	3.33	0	5.19	10.3	1.71	1.56
3/8	45.0	1.00	3.28	0	4.49	8.96	1.66	1.55
5/16	45.0	1.00	3.23	0	3.78	7.55	1.65	1.54
L6x4x7/8	25.8	0.484	2.14	1.23	5.77	13.5	2.16	1.72
3/4	25.9	0.486	2.07	1.19	5.04	11.9	2.15	1.71
5/8	26.1	0.489	2.00	1.16	4.29	10.2	2.15	1.71
9/16	26.1	0.490	1.97	1.14	3.90	9.29	2.15	1.70
1/2	26.2	0.491	1.94	1.13	3.51	8.37	2.14	1.70
7/16	26.2	0.493	1.90	1.11	3.10	7.42	2.14	1.70
3/8	26.3	0.494	1.87	1.09	2.69	6.44	2.14	1.70
5/16	26.3	0.495	1.84	1.08	2.27	5.44	2.14	1.70

Table 2. Plastic Section Moduli of Angles (Continued)

Size (in.)	θ (degrees)	tan θ	B_p (in.)	H_p (in.)	Z_z (in.^{3})	Z_w (in.^{3})	Shape factor (Z axis)	Shape factor (W axis)
L6x3-1/2x1/2	22.0	0.404	1.65	1.40	2.89	7.65	2.26	1.67
3/8	22.1	0.406	1.58	1.36	2.22	5.90	2.24	1.67
5/16	22.1	0.407	1.55	1.34	1.87	4.99	2.24	1.66
L5x5x7/8	45.0	1.00	3.16	0	6.64	12.92	1.94	1.63
3/4	45.0	1.00	3.06	0	5.80	11.37	1.89	1.62
5/8	45.0	1.00	2.97	0	4.93	9.73	1.83	1.59
1/2	45.0	1.00	2.87	0	4.03	7.98	1.76	1.57
7/16	45.0	1.00	2.83	0	3.56	7.08	1.73	1.57
3/8	45.0	1.00	2.78	0	3.09	6.14	1.69	1.55
5/16	45.0	1.00	2.73	0	2.60	5.19	1.65	1.54
L5x3-1/2x3/4	27.5	0.521	1.90	0.930	3.67	8.33	2.12	1.74
5/8	27.7	0.525	1.83	0.899	3.13	7.16	2.11	1.73
1/2	27.8	0.528	1.76	0.868	2.57	5.91	2.11	1.72
3/8	28.0	0.531	1.70	0.838	1.97	4.57	2.10	1.71
5/16	28.0	0.532	1.66	0.823	1.67	3.87	2.10	1.71
1/4	28.1	0.533	1.63	0.808	1.35	3.14	2.09	1.70
L5x3x1/2	22.7	0.419	1.46	1.15	2.05	5.31	2.27	1.69
7/16	22.8	0.420	1.43	1.13	1.82	4.73	2.26	1.69
3/8	22.9	0.421	1.40	1.11	1.58	4.12	2.27	1.69
5/16	22.9	0.423	1.36	1.09	1.34	3.49	2.26	1.69
1/4	23.0	0.424	1.33	1.07	1.09	2.84	2.27	1.69
L4x4x3/4	45.0	1.00	2.56	0	3.61	6.99	1.99	1.65
5/8	45.0	1.00	2.47	0	3.08	6.02	1.92	1.63
1/2	45.0	1.00	2.37	0	2.52	4.98	1.86	1.60
7/16	45.0	1.00	2.33	0	2.24	4.43	1.83	1.59
3/8	45.0	1.00	2.28	0	1.94	3.86	1.79	1.58
5/16	45.0	1.00	2.23	0	1.64	3.27	1.76	1.57
1/4	45.0	1.00	2.19	0	1.33	2.66	1.72	1.56
L4x3-1/2x1/2	37.5	0.766	1.96	0.308	2.16	4.39	1.88	1.69
3/8	37.6	0.770	1.88	0.293	1.67	3.41	1.85	1.67
5/16	37.6	0.771	1.84	0.286	1.41	2.89	1.85	1.67
1/4	37.7	0.773	1.80	0.278	1.15	2.35	1.85	1.65
L4x3x5/8	30.2	0.582	1.67	0.631	2.15	4.67	2.07	1.75
1/2	30.4	0.586	1.60	0.604	1.76	3.88	2.06	1.74
3/8	30.5	0.590	1.53	0.577	1.36	3.02	2.05	1.73
5/16	30.6	0.592	1.49	0.564	1.15	2.56	2.06	1.72
1/4	30.7	0.594	1.46	0.551	0.939	2.09	2.06	1.71
L3-1/2x3-1/2x1/2	45.0	1.00	2.12	0	1.90	3.74	1.88	1.61
7/16	45.0	1.00	2.08	0	1.69	3.34	1.84	1.60
3/8	45.0	1.00	2.03	0	1.47	2.91	1.78	1.58
5/16	45.0	1.00	1.98	0	1.24	2.47	1.75	1.57
1/4	45.0	1.00	1.94	0	1.01	2.01	1.70	1.56

Table 2. Plastic Section Moduli of Angles (Continued)

Size (in.)	θ (degrees)	tan θ	B_p (in.)	H_p (in.)	Z_z (in.^{3})	Z_w (in.^{3})	Shape factor (Z axis)	Shape factor (W axis)
L3-1/2x3x1/2	36.3	0.736	1.71	0.316	1.59	3.24	1.89	1.72
7/16	36.4	0.738	1.67	0.307	1.41	2.89	1.88	1.70
3/8	36.5	0.740	1.63	0.299	1.23	2.53	1.86	1.69
5/16	36.6	0.742	1.59	0.290	1.04	2.15	1.86	1.67
1/4	36.6	0.744	1.55	0.282	0.848	1.75	1.84	1.66
L3-1/2x2-1/2x1/2	28.3	0.539	1.35	0.615	1.24	2.81	2.09	1.75
3/8	28.5	0.544	1.28	0.586	0.963	2.20	2.08	1.73
5/16	28.6	0.546	1.25	0.571	0.817	1.87	2.06	1.72
1/4	28.7	0.548	1.21	0.556	0.666	1.53	2.05	1.71
L3x3x1/2	45.0	1.00	1.87	0	1.37	2.68	1.95	1.64
7/16	45.0	1.00	1.83	0	1.22	2.40	1.92	1.62
3/8	45.0	1.00	1.78	0	1.06	2.10	1.87	1.60
5/16	45.0	1.00	1.73	0	0.902	1.79	1.81	1.58
1/4	45.0	1.00	1.69	0	0.735	1.46	1.76	1.58
3/16	45.0	1.00	1.64	0	0.562	1.12	1.72	1.56
L3x2-1/2x1/2	34.8	0.696	1.45	0.326	1.10	2.27	1.96	1.76
7/16	34.9	0.699	1.41	0.316	0.983	2.03	1.96	1.73
3/8	35.0	0.701	1.38	0.306	0.858	1.78	1.94	1.72
5/16	35.1	0.704	1.34	0.296	0.728	1.52	1.94	1.71
1/4	35.2	0.706	1.30	0.287	0.594	1.25	1.93	1.70
3/16	35.3	0.708	1.26	0.277	0.455	0.955	1.94	1.68
L3x2x1/2	25.7	0.481	1.10	0.630	0.811	1.91	2.17	1.75
3/8	25.9	0.486	1.04	0.596	0.630	1.51	2.17	1.74
5/16	26.1	0.489	1.00	0.580	0.536	1.29	2.16	1.73
1/4	26.2	0.491	0.969	0.564	0.438	1.06	2.15	1.73
3/16	26.3	0.494	0.935	0.547	0.336	0.817	2.13	1.72
L2-1/2x2-1/2x1/2	45.0	1.00	1.62	0	0.932	1.80	2.03	1.66
3/8	45.0	1.00	1.53	0	0.725	1.42	1.94	1.63
5/16	45.0	1.00	1.48	0	0.616	1.22	1.90	1.61
1/4	45.0	1.00	1.44	0	0.503	1.00	1.83	1.59
3/16	45.0	1.00	1.39	0	0.386	0.768	1.79	1.58
L2-1/2x2x3/8	33.0	0.650	1.12	0.316	0.552	1.17	1.97	1.75
5/16	33.1	0.653	1.09	0.304	0.470	1.00	1.96	1.73
1/4	33.3	0.656	1.05	0.293	0.385	0.825	1.94	1.72
3/16	33.4	0.659	1.01	0.282	0.296	0.636	1.92	1.70
L2x2x3/8	45.0	1.00	1.28	0	0.451	0.874	1.98	1.65
5/16	45.0	1.00	1.23	0	0.385	0.753	1.92	1.63
1/4	45.0	1.00	1.19	0	0.315	0.622	1.85	1.60
3/16	45.0	1.00	1.14	0	0.243	0.482	1.76	1.58
1/8	45.0	1.00	1.09	0	0.166	0.332	1.67	1.55