Design Strength of Concentrically Loaded Single Angle Struts

A. ZUREICK

INTRODUCTION

In practice, the majority of single angle struts are eccentrically loaded, and an attempt to calculate exactly the strength of such members is a task of formidable complexity. Therefore, the designer often relies on approximate methods and guidelines, in which the key ingredient is the value of the design strength when the strut is loaded concentrically (AISC 1986, ASCE 1988, and Adluri and Madugula 1992).

In this brief note, a step-by-step solution and load tables are presented for the determination of the design strength of concentrically loaded single angle struts according to the AISC 1986 LRFD Specification. Equation A-E3-7, of Appendix E of the LRFD Specification requires the computation of the torsional-flexural buckling stress as the smallest of the three roots of a cubic equation.

GEOMETRY AND COORDINATE SYSTEMS

Consider the unsymmetrical single angle section, shown in Figure 1, with geomatric axes x and y and principal axes u and v, each passing through the centroid C. Let α be the angle of inclination between the horizonal axis x and the principal axis u; and b_1, b_2, and t be the dimensions of the vertical leg, horizontal leg, and thickness of the angle, respectively. The shear center of the section SC is located at the intersection of the center lines of the two legs and measures from the centroid x_o and y_o, in the (x, y) system, and u_o and v_o, in the (u, v) system, as shown in Figure 1. They are defined as follows:

$$\begin{aligned} x_o &= \bar{x} - \frac{t}{2} \\ y_o &= \bar{y} - \frac{t}{2} \\ u_o &= y_o \sin\alpha + x_o \cos\alpha \\ v_o &= y_o \cos\alpha - x_o \sin\alpha \end{aligned} \qquad (1)$$

$\bar{x}$, $\bar{y}$, and Tan α tabulated in the AISC Manual (AISC 1986).

FUNDAMENTAL FORMULAE

For an unequal-angle member under concentric loading the elastic flexural-torsional buckling stress is defined as the lowest root of the following cubic equation (Timoshenko and Gere 1961):

$$(F_e - F_{eu})(F_e - F_{ev})(F_e - F_{euz}) - F_e^{\,2}(F_e - F_{ev})\left(\frac{u_o}{r_o}\right)^2 - F_e^{\,2}(F_e - F_{eu})\left(\frac{v_o}{r_o}\right)^2 = 0 \qquad (2)$$

in which v

$$F_{eu} = \frac{\pi^2 E}{\left(\dfrac{K_u L}{r_u}\right)^2} \quad F_{ev} = \frac{\pi^2 E}{\left(\dfrac{K_v L}{r_v}\right)^2} \quad F_{ez} = \frac{1}{A r_o^2}\left[\frac{\pi^2 E C_w}{(K_z L)^2} + GJ\right] \qquad (3)$$

In the above equations, F_{eu} F_{ev}, and F_{ez} are the elastic flexural buckling stresses about the u and v axes and the elastic torsional buckling stress about the z-axis respectively. K_uL, K_vL are the effective lengths for bending about the principal axes u and v. K_zL is the effective length for twisting about the z-axis, which passes through the centroid of the section and

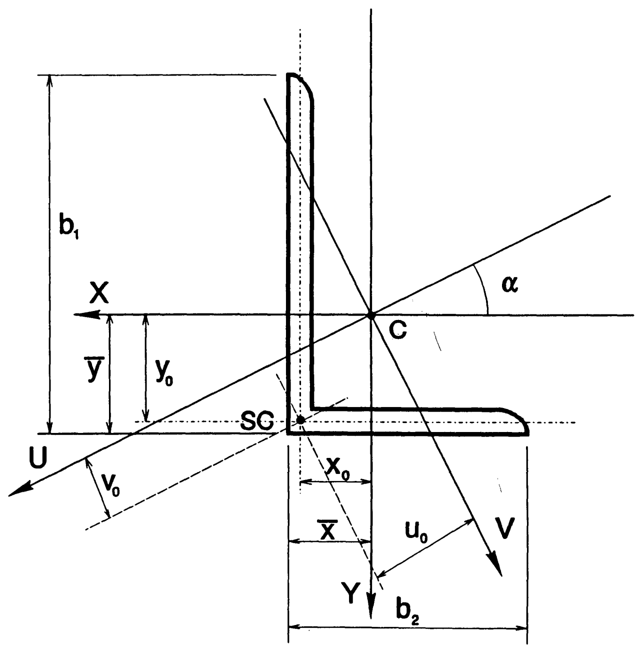

Figure 1

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coincides with the angle's longitudinal axis. The cross-sectional area of the angle is A; C_w and J are the warping constant and the St. Venant torsion constant, respectively. E and G are the modulus of elasticity and the shear modulus of the steel with values of 29,000 ksi and 11,200 ksi respectively. r_o, the polar radius of gyration of the cross section about the shear center, is defined as

$$r_o = \sqrt{u_o^2 + v_o^2 + \frac{I_u + I_v}{A}} \tag{4}$$

Equation 2 is identical to AISC LRFD Equation A-E3-7 and can be written conveniently in the form

$$F_e^3 + a_2 F_e^2 + a_1 F_e + a_0 = 0 \tag{5}$$

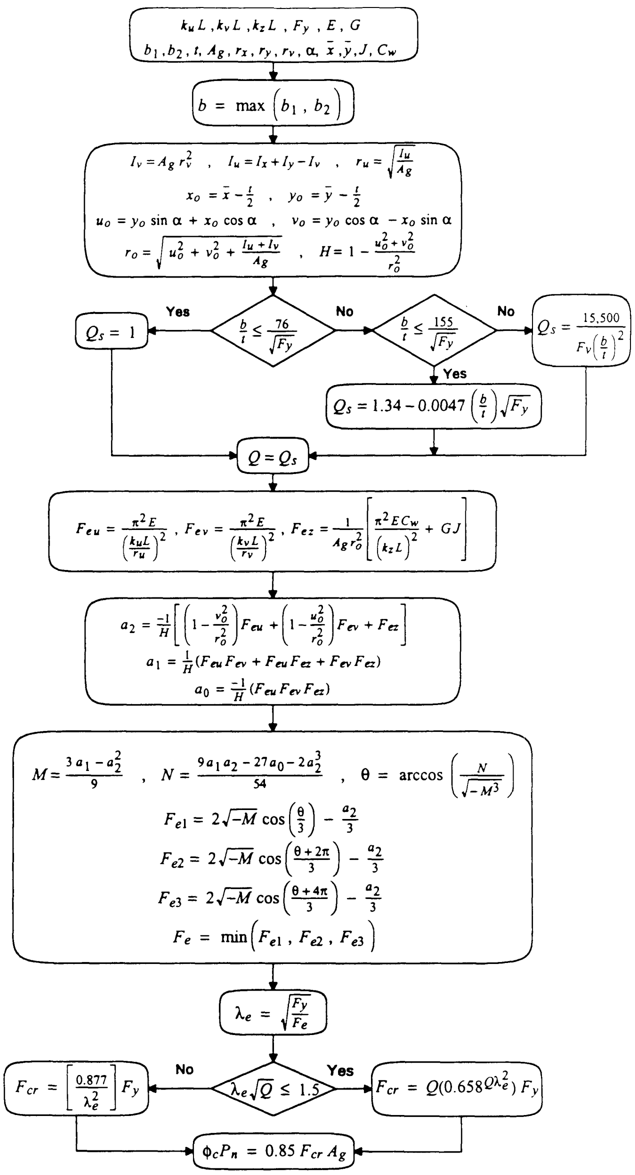

Figure 2

where

$$a_2 = \frac{-1}{H}\left[\left(1 - \frac{v_o^2}{r_o^2}\right)F_{eu} + \left(1 - \frac{u_o^2}{r_o^2}\right)F_{ev} + F_{ez}\right],$$

$$a_1 = \frac{1}{H}(F_{eu}F_{ev} + F_{eu}F_{ez} + F_{ev}F_{ez}),\quad a_0 = \frac{-1}{H}(F_{eu}F_{ev}F_{ez}) \tag{6}$$

in which H is defined as

$$H = 1 - \frac{u_o^2 + v_o^2}{r_o^2} \tag{7}$$

SOLUTION OF THE CUBIC EQUATION

In general, a cubic equation has either three real roots or one real and two complex conjugate roots. In the case of buckling of an unsymmetrical section, however, it can be shown that the three roots of the cubic equation are always real and positive (See, for example, the proof in texts by Timoshenko and Gere, 1961 or Galambos, 1968). In such a case the solution of the cubic equation can most conveniently be obtained as follows: Let

$$M = \frac{3a_1 - a_2^2}{9},\quad N = \frac{9a_2 a_1 - 2a_2^3 - 27a_0}{54},$$

$$\theta = \arccos\frac{N}{\sqrt{-M^3}} \tag{8}$$

then the three real roots are given by

$$F_{e1} = 2\sqrt{-M}\cos\frac{\theta}{3} - \frac{a_2}{3},\quad F_{e2} = 2\sqrt{-M}\cos\left(\frac{\theta}{3} + \frac{2\pi}{3}\right) - \frac{a_2}{3},$$

$$F_{e3} = 2\sqrt{-M}\cos\left(\frac{\theta}{3} + \frac{4\pi}{3}\right) - \frac{a_2}{3} \tag{9}$$

The above solution was first presented in 1615 by the French mathematician François Viète (Kline 1972) and is used in most mathematical handbooks nowadays (Tuma 1970, Beyer 1982). In the above equation the quantity M is always negative.

DESIGN STRENGTH OF CONCENTRICALLY LOADED STRUTS

Upon solving the cubic equation, the critical flexural-torsional buckling stress F_c for the angle strut is defined as the lowest of the three roots obtained previously. Thus,

$$F_e = \min\,[F_{e1}, F_{e2}, F_{e3}]$$

from which the slenderness parameter λ_c, the nominal critical stress $\phi_c F_{cr}$, and the design strength $\phi_c P_n$, can be calculated according to AISC LRFD Appendix E. A schematic showing all design steps for calculating the design strength of concentrically loaded angle struts is shown in Figure 2.

TAN α = C

Example

Calculate design strength for a 9 ft long concentrically loaded 5×3×¼ single angle made of A36 steel.

Solution

Given:

$K_u L = K_v L = K_z L = 9$ ft, $F_y = 36$ ksi, $E = 29{,}000$ ksi, $G = 11{,}200$ ksi

For L5×3×¼:

$A = 1.94$ in.^{2}, $r_x = 1.62$ in., $r_y = 0.861$ in., $r_v = 0.663$ in.,
Tan $\alpha = 0.371$ or ($\alpha = 0.355$ rad. $= 20.35°$)
$C_w \approx 0.0606$ in.^{6}, $J \approx 0.0438$ in.^{4},
$Ix = 5.11$ in.^{4}
$Iy = 1.44$ in.^{4}

Properties

$$I_v = Ar_v^2 = (1.94)(0.663)^2 = 0.852 \text{ in.}^4$$

$$I_u = I_x + I_y - I_v = 5.11 + 1.44 - 0.852 = 5.698 \text{ in.}^4$$

$$r_u = \sqrt{\frac{I_u}{A}} = \sqrt{\frac{5.698}{1.94}} = 1.713 \text{ in.}$$

$$x_o = \bar{x} - \frac{t}{2} = 0.657 - \frac{0.25}{2} = 0.532 \text{ in.}$$

$$y_o = \bar{y} - \frac{t}{2} = 1.66 - \frac{0.25}{2} = 1.535 \text{ in.}$$

$$u_o = y_o \sin\alpha + x_o \cos\alpha = 1.535 \sin(20.35°) + 0.532 \cos(20.35°) = 1.033 \text{ in.}$$

$$v_o = y_o \cos\alpha - x_o \sin\alpha = 1.535 \cos(20.35°) - 0.532 \sin(20.35°) = 1.254 \text{ in.}$$

$$r_o = \sqrt{u_o^2 + v_o^2 + \frac{I_u + I_v}{A}}$$

$$= \sqrt{(1.033)^2 + (1.254)^2 + \frac{5.698 + 0.852}{1.94}} = 2.453 \text{ in.}$$

$$H = 1 - \frac{u_o^2 + v_o^2}{r_o^2} = 1 - \frac{(1.033)^2 + (1.254)^2}{(2.452)^2} = 0.561$$

Check local buckling

$$\frac{b}{t} = \frac{5}{1/4} = 20 > \frac{76}{\sqrt{36}} = 12.67 < \frac{155}{\sqrt{36}} = 25.83$$

Thus, use AISC LRFD Eq. A-B5-1

$$Q_s = 1.34 - 0.00447\left(\frac{b}{t}\right)\sqrt{F_y}$$

$$= 1.34 - 0.00447(20)\sqrt{36} = 0.804$$

$$Q = Q_s = 0.804$$

Check global buckling

The slenderness ratios about the principal axes are

$$\frac{K_u L}{r_u} = \frac{9(12)}{1.713} = 63.05, \quad \frac{K_v L}{r_v} = \frac{9(12)}{0.663} = 162.9$$

The elastic buckling stresses about the u, v, and z axes are

$$F_{eu} = \frac{\pi^2 E}{\left(\frac{K_u L}{r_u}\right)^2} = \frac{\pi^2(29{,}000)}{(63.05)^2} = 72 \text{ ksi,}$$

$$F_{ev} = \frac{\pi^2 E}{\left(\frac{K_v L}{r_v}\right)^2} = \frac{\pi^2(29{,}000)}{(162.9)^2} = 10.78 \text{ ksi}$$

$$F_{ez} = \left(\frac{\pi^2 E C_w}{(K_z L)^2} + GJ\right)\frac{1}{A\bar{r}_o^2}$$

$$= \left(\frac{\pi^2(29{,}000)(0.0606)}{(108)^2} + (11{,}200)(0.0438)\right)\frac{1}{(1.94)(2.453)^2}$$

$$= \frac{(1.48 + 490)}{11.67} = 42.1 \text{ ksi}$$

Now it is required to solve the cubic equation $F_e^3 + a_2 F_e^2 + a_1 F_e + a_0 = 0$, where

$$a_2 = \frac{-1}{H}\left[\left(1 - \frac{v_o^2}{r_o^2}\right)F_{eu} + \left(1 - \frac{u_o^2}{r_o^2}\right)F_{ev} + F_{ez}\right]$$

$$-\frac{1}{0.561}\left[\left(1 - \frac{(1.254)^2}{(2.453)^2}\right)(72) + \left(1 - \frac{(1.033)^2}{(2.453)^2}\right)(10.78) + (42.1)\right]$$

$$= -186$$

$$a_1 = \frac{1}{H}(F_{eu}F_{ev} + F_{eu}F_{ez} + F_{ev}F_{ez}) = \frac{1}{0.561}[(72)(10.78)$$

$$+ (72)(42.1) + (10.78)(42.1)] = 7{,}596$$

$$a_0 = -\frac{1}{H}(F_{eu}F_{ev}F_{ez}) = -\frac{1}{0.561}(72)(10.78)(42.1) = -58{,}247$$

$$M = \frac{3a_1 - a_2^2}{9} = \frac{3(7{,}596) - (-186)^2}{9} = -1{,}312$$

$$N = \frac{9a_1 a_2 - 27a_0 - 2a_2^3}{54}$$

$$= \frac{9(7{,}596)(-186) - 27(-58{,}247) - 2(-186)^3}{54} = 31{,}976$$

$$\theta = \arccos \frac{N}{\sqrt{-M^3}} = \arccos \frac{31{,}976}{\sqrt{-(-1{,}312)^3}}$$

$$= \arccos(0.6729) = 0.832 \text{ rad.}$$

$$F_{e1} = 2\sqrt{-M} \cos \frac{\theta}{3} - \frac{a_2}{3}$$

$$= 2\sqrt{-(-1{,}312)} \cos \frac{0.832}{3} - \frac{(-186)}{3} = 131.6 \text{ ksi}$$

$$F_{e2} = 2\sqrt{-M} \cos\left(\frac{\theta}{3} + \frac{2\pi}{3}\right) - \frac{a_2}{3}$$

$$= 2\sqrt{-(-1{,}312)} \cos\left(\frac{0.832}{3} + \frac{2\pi}{3}\right) - \frac{(-186)}{3} = 9.98 \text{ ksi}$$

$$F_{e3} = 2\sqrt{-M} \cos\left(\frac{\theta}{3} + \frac{4\pi}{3}\right) - \frac{a_2}{3}$$

$$= 2\sqrt{-(-1{,}312)} \cos\left(\frac{0.832}{3} + \frac{4\pi}{3}\right) - \frac{(-186)}{3} = 44.4 \text{ ksi}$$

Therefore

$$F_e = \min[131.6, 9.98, 44.4] = 9.98 \text{ ksi}$$

(please note how close the flexural-torsional buckling stress (F_e = 9.98 ksi) is to that calculated from the flexural buckling about the minor axis (F_{ev} = 10.78 ksi). The difference here is only eight percent.)

$$\lambda_e = \sqrt{\frac{F_y}{F_e}} = \sqrt{\frac{36}{9.98}} = 1.9$$

$$\lambda_e\sqrt{Q} = 1.9\sqrt{0.804} = 1.704 > 1.5$$

$$F_{cr} = \left[\frac{0.877}{\lambda_e^2}\right] F_y = \left[\frac{0.877}{(1.9)^2}\right](36) = 8.74 \text{ ksi}$$

$$\phi P_n = \phi F_{cr} A_g = 0.85(8.74)(1.94) = 14.4 \text{ kips}$$

Of some note, if the flexural buckling stress with respect to the minor axis (F_{ev} = 10.78 ksi) were used instead of the flexural-torsional buckling stress (F_e = 9.98 ksi), the design strength of the angle member would be 15.6 kips. Such an increase (8.3 percent) may not be regarded as significant. It should be emphasized, however, that for a strut with a small slenderness ratio the difference between the elastic flexural and the elastic flexural-torsional buckling stresses can be quite large. A procedure related to the design of axially loaded compressed angles by the method of minor axis buckling was presented by Galambos (1991).

DESIGN TABLES

The procedure outlined in this note was implemented to generate angle load tables for 139 equal and unequal leg angle sections made of either A36 or Grade 50 steel. Tabulated loads are for, $K_uL = K_vL = L$, and are terminated when the slenderness ratio with respect to the minor axis of the angle exceeds 200. Numerical values are rounded to the nearest whole number. It should be noted that it is, of course, not necessary to use the solution of the cubic equation to calculate the design strength of a concentrically loaded equal leg angle strut. Equal leg angle struts can be regarded as singly symmetric sections (symmetry about the u-axis) for which either flexural-torsional buckling about the axis of symmetry (u-axis) or flexural buckling about an axis perpendicular to the axis of symmetry (v-axis) may occur. In such a case the cubic equation is reduced to a quadratic equation, the solution of which is given as Equation A-E3-6 in the AISC LRFD Specification. Solutions from either AISC LRFD Equation A-E3-6 or A-E3-7 yield the same results when applied to equal leg angles.

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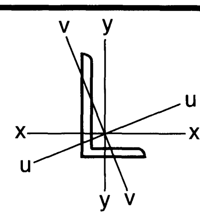
F_y = 36 ksi
F_y = 50 ksi

CONCENTRICALLY LOADED COLUMNS
Single Angles
Design axial strength in kips (ϕ = 0.85)



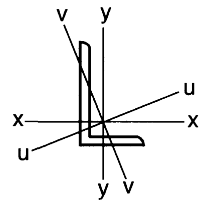
Size		9 × 4					
Thickness		5/8		9/16		1/2	
Wt. / ft		26.3		23.8		21.3	
F_y		36	50	36	50	36	50
Effective length in feet, KL	0	226	291	195	248	164	205
	1	203	254	173	213	142	171
	2	191	234	161	194	131	155
	3	182	220	154	183	125	146
	4	171	204	145	171	119	137
	5	158	184	135	156	112	127
	6	143	161	123	138	102	114
	7	126	137	109	119	92	100
	8	108	113	95	100	81	85
	9	92	92	81	82	70	71
	10	76	76	68	68	59	59
	11	64	64	57	57	50	50
	12	54	54	49	49	43	43
	13	46	46	42	42	37	37
	14	40	40	36	36	32	32

Size		8 × 6													
Thickness		1		7/8		3/4		5/8		9/16		1/2		7/16	
Wt. / ft		44.2		39.1		33.8		28.5		25.7		23.0		20.2	
F_y		36	50	36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, KL	0	398	553	352	489	304	422	255	332	222	286	188	239	154	192
	1	383	524	335	457	285	385	232	293	198	247	164	201	131	156
	2	376	511	327	442	276	369	222	277	188	231	154	186	121	142
	3	371	502	323	434	272	362	218	271	184	225	151	181	118	138
	4	363	487	317	423	268	354	215	266	182	222	149	178	117	135
	5	350	462	307	405	262	343	211	260	179	217	147	175	115	133
	6	333	432	293	379	251	324	205	250	175	211	144	171	113	131
	7	314	398	277	350	238	301	196	236	169	201	140	165	111	128
	8	293	362	258	318	223	274	184	218	161	189	135	157	108	123
	9	271	324	239	286	207	247	171	198	150	173	128	146	104	117
	10	248	287	219	253	190	219	158	178	139	157	119	134	98	110
	11	225	251	199	221	173	192	144	157	128	140	110	121	92	101
	12	203	217	179	191	155	166	130	137	116	124	100	108	85	91
	13	181	185	159	163	139	142	116	119	104	108	91	95	78	82
	14	159	160	141	141	123	123	102	103	93	94	82	83	70	72
	15	139	139	123	123	107	107	90	90	82	82	73	73	63	64
	16	122	122	108	108	95	95	79	79	72	72	64	64	56	56
	17	109	109	96	96	84	84	70	70	64	64	57	57	50	50
	18	97	97	86	86	75	75	63	63	57	57	51	51	45	45
	19	87	87	77	77	67	67	56	56	52	52	46	46	41	41
	20	79	79	69	69	61	61	51	51	47	47	42	42	37	37
	21	71	71	63	63	55	55	46	46	42	42	38	38	33	33

F_y = 36 ksi

F_y = 50 ksi

CONCENTRICALLY LOADED COLUMNS
Single Angles
Design axial strength in kips (ϕ = 0.85)

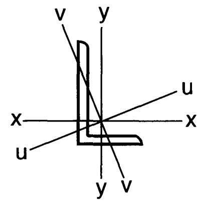


Size		8 × 4							
Thickness		1		¾		9/16		½	
Wt. / ft		37.4		28.7		21.9		19.6	
F_y		36	50	36	50	36	50	36	50
Effective length in feet, kL	0	337	468	258	359	189	243	160	204
	1	323	442	241	327	169	211	140	172
	2	312	421	231	308	159	196	131	158
	3	297	394	221	290	153	186	126	151
	4	277	356	207	264	145	173	120	142
	5	252	313	190	234	134	157	113	130
	6	224	266	170	200	122	138	103	116
	7	196	220	148	166	108	118	92	101
	8	167	176	127	133	93	98	81	85
	9	140	140	106	107	79	80	69	70
	10	114	114	87	87	66	66	58	58
	11	95	95	73	73	55	55	49	49
	12	80	80	61	61	47	47	42	42
	13	68	68	53	53	40	40	36	36
	14	59	59	45	45	35	35	31	31

Size		7 × 4							
Thickness		¾		5/8		½		3/8	
Wt. / ft		26.2		22.1		17.9		13.6	
F_y		36	50	36	50	36	50	36	50
Effective length in feet, kL	0	235	327	198	272	155	200	102	127
	1	222	302	183	244	138	172	85	101
	2	215	289	176	231	131	162	80	94
	3	207	273	170	220	127	155	77	90
	4	193	249	160	203	121	145	75	86
	5	177	220	147	180	113	132	71	81
	6	158	189	132	156	102	117	66	74
	7	139	157	116	130	91	100	61	66
	8	119	127	100	106	79	84	54	58
	9	100	101	84	85	67	68	47	49
	10	82	82	69	69	56	56	41	41
	11	68	68	58	58	47	47	35	35
	12	58	58	49	49	40	40	29	29
	13	49	49	42	42	43	34	25	25
	14	42	42	36	36	29	29	22	22

$F_y = 36$ ksi
$F_y = 50$ ksi

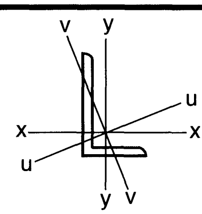
CONCENTRICALLY LOADED COLUMNS
Single Angles
Design axial strength in kips ($\phi = 0.85$)



Size		6 × 4															
Thickness		7/8		3/4		5/8		9/16		1/2		7/16		3/8		5/16	
Wt. / ft		27.2		23.6		20.0		18.1		16.2		14.3		12.3		10.3	
F_y		36	50	36	50	36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	244	339	212	295	179	249	162	226	145	194	124	161	101	128	76	94
	1	236	324	203	277	168	228	150	202	132	170	110	137	86	105	62	73
	2	230	313	198	268	164	220	146	194	127	163	106	130	82	99	59	68
	3	220	293	190	253	158	209	141	186	124	156	103	126	80	96	58	66
	4	205	266	177	230	149	192	133	172	118	146	99	119	78	92	56	64
	5	187	234	162	203	136	170	123	153	109	132	92	109	73	86	54	61
	6	167	200	145	173	122	146	110	131	98	114	84	96	68	77	51	57
	7	146	166	127	144	107	122	97	110	86	96	74	82	61	68	47	51
	8	125	134	109	117	92	98	83	89	74	79	64	69	54	57	42	45
	9	105	106	91	93	77	78	70	71	63	63	55	56	46	47	37	38
	10	86	86	75	75	64	64	58	58	52	52	45	45	39	39	32	32
	11	71	71	62	62	53	53	48	48	43	43	38	38	33	33	27	27
	12	60	60	52	52	44	44	40	40	36	36	32	32	28	28	23	23
	13	51	51	45	45	38	38	34	34	31	31	27	27	24	24	20	20
	14	44	44	39	39	33	33	30	30	27	27	24	24	20	20	17	17

Size		6 × 3½					
Thickness		1/2		3/8		5/16	
Wt. / ft		15.3		11.7		9.8	
F_y		36	50	36	50	36	50
Effective length in feet, kL	0	138	184	95	121	72	89
	1	125	161	82	99	59	70
	2	120	153	78	93	56	65
	3	114	143	75	89	54	62
	4	106	129	71	83	52	59
	5	95	111	65	74	48	54
	6	82	92	58	64	44	48
	7	69	74	50	53	39	42
	8	57	57	42	43	34	35
	9	46	46	34	34	28	28
	10	37	37	28	28	23	23
	11	31	31	24	24	20	20
	12	26	26	20	20	17	17

F_y = 36 ksi
F_y = 50 ksi



CONCENTRICALLY LOADED COLUMNS
Single Angles
Design axial strength in kips (ϕ = 0.85)

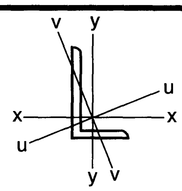
Size		5 × 3½													
Thickness		¾		⅝		½		7/16		⅜		5/16		¼	
Wt. / ft		19.8		16.8		13.6		12.0		10.4		8.7		7.0	
F_y		36	50	36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	178	247	151	209	122	170	108	147	92	119	71	91	51	62
	1	172	235	143	195	113	153	98	128	80	101	60	73	40	47
	2	166	225	139	188	110	147	95	123	78	96	58	69	38	44
	3	156	206	131	173	105	138	91	117	75	92	56	67	37	43
	4	142	181	120	152	97	123	85	105	71	85	54	63	36	41
	5	126	153	106	129	86	104	76	90	64	74	50	57	34	39
	6	108	124	92	105	74	85	66	74	56	62	44	49	32	35
	7	91	97	77	83	63	67	55	59	47	50	38	41	28	30
	8	74	75	63	63	51	52	45	46	39	40	32	33	25	26
	9	59	59	50	50	41	41	36	36	32	32	26	26	21	21
	10	48	48	41	41	33	33	30	30	26	26	22	22	17	17
	11	40	40	34	34	28	28	25	25	21	21	18	18	14	14
	12	33	33	28	28	23	23	21	21	18	18	15	15	12	12

Size		5 × 3											
Thickness		⅝		½		7/16		⅜		5/16		¼	
Wt. / ft		15.7		12.8		11.3		9.8		8.2		6.6	
F_y		36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	141	196	115	159	101	138	86	112	67	85	48	58
	1	134	182	106	143	92	120	75	94	56	68	38	44
	2	128	171	102	135	88	113	72	89	54	64	36	41
	3	117	152	94	121	82	103	68	82	51	60	34	39
	4	103	127	83	102	73	88	61	72	47	54	32	36
	5	88	101	71	82	62	71	53	59	41	46	29	32
	6	72	77	58	62	51	55	44	46	35	37	26	28
	7	57	57	46	46	41	41	35	35	29	29	22	22
	8	44	44	36	36	32	32	27	27	23	23	18	18
	9	35	35	28	28	25	25	22	22	18	18	14	14
	10	28	28	23	23	20	20	18	18	15	15	12	12

F_y = 36 ksi

F_y = 50 ksi

CONCENTRICALLY LOADED COLUMNS
Single Angles
Design axial strength in kips (ϕ = 0.85)

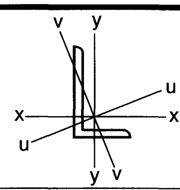


Size		4 × 3½											
Thickness		⅝		½		7/16		⅜		5/16		¼	
Wt. / ft		14.7		11.9		10.6		9.1		7.7		6.2	
F_y		36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	132	183	107	149	95	131	82	113	69	89	50	64
	1	127	174	101	137	88	118	74	99	59	74	41	49
	2	124	168	99	134	86	116	72	96	58	72	40	47
	3	115	152	94	123	82	109	70	92	57	70	39	47
	4	104	132	85	107	75	95	64	82	54	65	38	45
	5	91	110	74	89	66	79	57	68	48	56	36	41
	6	78	88	63	72	56	63	49	55	41	46	31	35
	7	64	67	52	55	46	49	40	42	34	36	27	28
	8	51	51	42	42	37	37	32	33	28	28	22	22
	9	41	41	33	33	30	30	26	26	22	22	18	18
	10	33	33	27	27	24	24	21	21	18	18	14	14
	11	27	27	22	22	20	20	17	17	15	15	12	12
	12			19	19	17	17	14	14	12	12	10	10

Size		4 × 3											
Thickness		⅝		½		7/16		⅜		5/16		¼	
Wt. / ft		13.6		11.1		9.8		8.5		7.2		5.8	
F_y		36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	122	169	99	138	88	122	76	105	64	83	47	60
	1	117	161	94	128	82	111	69	92	56	70	39	47
	2	112	151	91	122	79	106	67	89	54	67	38	45
	3	102	133	83	108	73	95	63	81	52	63	37	43
	4	90	111	73	90	65	80	56	68	46	55	34	40
	5	76	88	62	72	55	63	47	55	40	45	30	34
	6	62	66	51	54	45	48	39	41	33	35	25	27
	7	49	49	40	40	35	35	31	31	26	26	21	21
	8	37	37	31	31	27	27	24	24	20	20	16	16
	9	29	29	24	24	21	21	19	19	16	16	13	13
	10	24	24	20	20	17	17	15	15	13	13	10	10

Size		3½ × 3									
Thickness		½		7/16		⅜		5/16		¼	
Wt. / ft		10.2		9.1		7.9		6.6		5.4	
F_y		36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	92	128	81	113	70	98	59	81	46	60
	1	88	120	76	104	65	88	53	69	39	48
	2	84	114	74	100	64	85	52	67	38	46
	3	77	99	68	88	59	76	49	62	37	45
	4	67	82	59	73	51	63	43	52	34	40
	5	56	64	50	57	43	50	36	41	29	32
	6	45	47	40	42	35	37	29	31	24	25
	7	35	35	31	31	27	27	23	23	19	19
	8	27	27	24	24	21	21	17	17	14	14
	9	21	21	19	19	16	16	14	14	11	11
	10	17	17	15	15	13	13	11	11	9	9

F_y = 36 ksi
F_y = 50 ksi



CONCENTRICALLY LOADED COLUMNS
Single Angles
Design axial strength in kips (ϕ = 0.85)

Size		3½ × 2½									
Thickness		½		7/16		3/8		5/16		¼	
Wt. / ft		9.4		8.3		7.2		6.1		4.9	
F_y		36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	84	117	74	103	65	90	54	75	43	55
	1	80	109	70	95	60	80	49	64	36	44
	2	75	99	66	87	57	75	47	60	35	42
	3	66	83	58	73	50	63	42	52	32	38
	4	55	64	48	57	42	49	35	41	28	31
	5	43	46	38	41	33	35	28	30	22	24
	6	32	32	28	28	25	25	21	21	17	17
	7	24	24	21	21	18	18	15	15	13	13
	8	18	18	16	16	14	14	12	12	10	10
	9							9	9	8	8

Size		3 × 2½											
Thickness		½		7/16		3/8		5/16		¼		3/16	
Wt. / ft		8.5		7.6		6.6		5.6		4.5		3.39	
F_y		36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	77	106	68	94	59	82	50	69	40	53	28	35
	1	74	101	65	88	55	75	45	61	35	45	23	27
	2	68	91	60	80	52	69	44	58	34	43	22	26
	3	59	75	52	66	46	57	38	48	31	38	21	25
	4	49	57	43	50	38	44	32	37	26	30	18	21
	5	38	40	34	35	29	31	25	26	20	21	15	16
	6	28	28	25	25	21	21	18	18	15	15	11	11
	7	20	20	18	18	16	16	13	13	11	11	8	8
	8	16	16	14	14	12	12	10	10	8	8	6	6

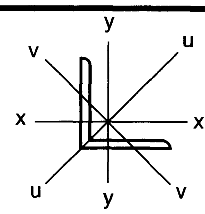
Size		3 × 2											
Thickness		½		7/16		3/8		5/16		¼		3/16	
Wt. / ft		7.7		6.8		5.9		5.0		4.1		3.07	
F_y		36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	69	96	61	85	53	74	45	62	36	49	25	32
	1	65	89	58	78	49	67	41	55	32	41	21	25
	2	58	75	51	67	44	57	37	48	30	37	20	23
	3	47	56	42	50	36	43	30	36	25	29	17	19
	4	35	38	31	34	27	29	23	25	19	20	13	14
	5	24	24	22	22	19	19	16	16	13	13	10	10
	6	17	17	15	15	13	13	11	11	9	9	7	7
	7	12	12	11	11	10	10	8	8	7	7	5	5

Size		2½ × 2							
Thickness		3/8		5/16		¼		3/16	
Wt. / ft		5.3		4.5		3.62		2.75	
F_y		36	50	36	50	36	50	36	50
Effective length in feet, kL	0	47	66	40	56	32	45	24	32
	1	45	61	37	51	29	39	21	25
	2	40	52	34	44	27	35	20	24
	3	32	38	27	32	22	26	16	19
	4	24	25	20	21	16	17	12	13
	5	16	16	14	14	11	11	9	9
	6	11	11	10	10	8	8	6	6
	7	8	8	7	7	6	6	4	4

F_y = 36 ksi

F_y = 50 ksi

CONCENTRICALLY LOADED COLUMNS
Single Angles
Design axial strength in kips (ϕ = 0.85)

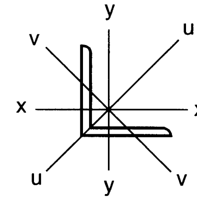


Size		8 × 8													
Thickness		1⅛		1		⅞		¾		⅝		9/16		½	
Wt. / ft		56.9		51.0		45.0		38.9		32.7		29.6		26.4	
F_y		36	50	36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, KL	0	511	710	459	638	404	561	349	485	293	382	255	328	216	275
	5	473	637	423	569	364	486	304	400	241	296	202	244	164	193
	6	457	607	410	546	362	481	302	397	239	294	201	242	163	192
	7	439	574	394	516	347	455	300	393	238	291	200	240	162	190
	8	419	538	376	483	332	427	287	370	237	289	198	238	161	189
	9	397	500	357	449	315	397	273	344	229	278	197	236	160	188
	10	374	460	336	414	297	366	257	318	217	258	191	227	159	186
	11	351	420	315	378	278	335	242	291	203	237	180	210	155	180
	12	326	381	293	342	259	303	225	264	190	216	168	193	146	167
	13	302	342	271	307	240	273	209	238	176	196	157	176	136	153
	14	278	304	249	273	221	243	192	212	162	176	145	159	126	139
	15	254	268	228	240	202	214	176	187	148	157	133	143	117	126
	16	230	235	207	211	184	188	160	165	135	139	122	127	107	113
	17	208	208	187	187	166	167	145	146	122	123	111	113	98	100
	18	186	186	167	167	149	149	130	130	110	110	100	100	89	90
	19	167	167	150	150	134	134	117	117	98	98	90	90	80	80
	20	151	151	135	135	121	121	105	105	89	89	81	81	73	73
	21	137	137	123	123	109	109	96	96	81	81	74	74	66	66
	22	124	124	112	112	100	100	87	87	73	73	67	67	60	60
	23	114	114	102	102	91	91	80	80	67	67	61	61	55	55
	24	105	105	94	94	84	84	73	73	62	62	56	56	50	50
	25	96	96	87	87	77	77	67	67	57	57	52	52	46	46
	26	89	89	80	80	71	71	62	62	53	53	48	48	43	43

F_y = 36 ksi

F_y = 50 ksi

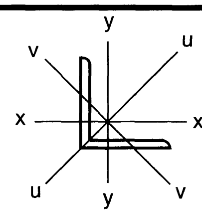
CONCENTRICALLY LOADED COLUMNS
Single Angles
Design axial strength in kips (ϕ = 0.85)



Size	6 × 6																	
Thickness	1		7/8		3/4		5/8		9/16		1/2		7/16		3/8		5/16	
Wt. / ft	37.4		33.1		28.7		24.2		21.9		19.6		17.2		14.9		12.4	
F_y	36	50	36	50	36	50	36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL: 0	337	468	298	414	258	359	218	302	197	273	176	235	151	195	122	155	92	114
1	327	449	287	392	245	334	202	272	179	240	157	201	130	161	101	122	72	84
2	324	443	283	385	241	326	197	263	174	230	151	191	124	151	95	113	67	76
3	320	436	281	382	239	322	195	260	172	227	149	188	122	148	93	110	65	74
4	308	413	272	366	236	317	194	258	171	225	148	186	121	147	92	109	65	73
5	293	368	259	341	225	296	190	250	170	223	147	184	120	145	92	108	64	73
6	276	354	244	314	212	272	179	230	162	208	145	181	119	144	91	107	64	72
7	257	321	227	284	197	246	167	209	151	189	135	164	117	140	90	106	63	71
8	236	286	209	253	181	219	154	186	139	168	124	147	108	127	89	104	63	71
9	215	251	190	222	165	192	140	164	127	148	113	130	99	113	82	94	62	70
10	193	217	171	192	148	166	126	142	114	128	102	114	89	99	75	83	60	67
11	172	184	152	163	132	141	113	121	102	109	91	97	80	86	67	73	54	59
12	152	155	134	137	116	119	99	102	90	92	80	82	71	74	60	63	49	53
13	132	132	117	117	101	101	87	87	78	78	70	70	62	63	53	54	44	46
14	114	114	101	101	87	87	75	75	68	68	61	61	54	54	47	47	39	40
15	99	99	88	88	76	76	65	65	59	59	53	53	47	47	41	41	35	35
16	87	87	77	77	67	67	57	57	52	52	46	46	41	41	36	36	30	30
17	77	77	68	68	59	59	51	51	46	46	41	41	37	37	32	32	27	27
18	69	69	61	61	53	53	45	45	41	41	37	37	33	33	28	28	24	24
19	62	62	55	55	47	47	41	41	37	37	33	33	29	29	25	25	22	22

Size	5 × 5													
Thickness	7/8		3/4		5/8		1/2		7/16		3/8		5/16	
Wt. / ft	27.2		23.6		20.0		16.2		14.3		12.3		10.3	
F_y	36	50	36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL: 0	244	339	212	295	179	249	145	202	128	174	109	141	84	107
1	237	326	204	279	169	230	133	178	114	149	93	115	69	83
2	235	322	202	275	167	226	130	173	111	143	90	110	66	78
3	227	307	198	267	166	223	129	171	110	141	89	108	65	77
4	215	284	187	247	158	209	128	169	109	140	88	107	64	76
5	200	257	174	224	147	189	119	154	105	133	87	106	64	75
6	183	227	159	198	135	168	110	136	97	119	83	99	63	74
7	165	197	144	171	122	145	99	118	87	103	75	87	60	69
8	146	166	127	145	108	123	88	101	78	88	67	75	54	61
9	128	138	111	120	94	102	77	84	68	74	59	63	48	52
10	110	112	96	98	81	83	66	68	59	60	51	52	42	44
11	93	93	81	81	69	59	56	56	50	50	43	43	36	37
12	78	78	68	68	58	58	47	47	42	42	36	36	31	31
13	66	66	58	58	49	49	40	40	36	36	31	31	26	26
14	57	57	50	50	42	42	35	35	31	31	27	27	23	23
15	50	50	43	43	37	37	30	30	27	27	23	23	20	20
16	44	44	38	38	32	32	27	27	24	24	20	20	17	17

F_y = 36 ksi
F_y = 50 ksi



CONCENTRICALLY LOADED COLUMNS
Single Angles
Design axial strength in kips ($\phi = 0.85$)

Size		4 × 4													
Thickness		3/4		5/8		1/2		7/16		3/8		5/16		1/4	
Wt. / ft		18.5		15.7		12.8		11.3		9.8		8.2		6.6	
F_y		36	50	36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	166	231	141	196	115	159	101	141	88	122	73	95	54	69
	1	162	222	136	185	108	146	93	126	78	104	62	78	43	52
	2	158	216	134	183	106	144	92	123	77	101	61	75	42	49
	3	149	198	126	168	103	136	91	121	76	100	60	74	41	49
	4	136	175	116	148	94	121	83	107	72	93	59	72	41	48
	5	122	150	103	127	84	104	74	92	64	80	54	64	40	47
	6	106	124	90	105	73	86	65	76	56	66	47	54	36	42
	7	90	99	76	84	63	69	55	61	48	53	41	44	32	35
	8	75	76	63	65	52	53	46	47	40	41	34	35	27	28
	9	60	60	51	51	42	42	37	37	32	32	27	27	22	22
	10	49	49	41	41	34	34	30	30	26	26	22	22	18	18
	11	40	40	34	34	28	28	25	25	22	22	18	18	15	15
	12	34	34	29	29	24	24	21	21	18	18	15	15	13	13
	13					20	20	18	18	16	16	13	13	11	11

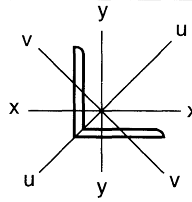
Size		3½ × 3½									
Thickness		1/2		7/16		3/8		5/16		1/4	
Wt. / ft		11.1		9.8		8.5		7.2		5.8	
F_y		36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	99	138	88	122	76	105	64	88	50	64
	1	95	129	82	111	70	93	56	74	41	50
	2	93	126	81	110	68	91	55	72	40	49
	3	86	113	76	100	66	86	55	71	40	48
	4	77	96	68	85	59	74	50	62	39	47
	5	66	79	59	69	51	60	43	51	34	39
	6	55	61	49	54	43	47	36	40	29	32
	7	45	46	40	41	35	35	29	30	24	25
	8	35	35	31	31	27	27	23	23	19	19
	9	28	28	25	25	21	21	18	18	15	15
	10	22	22	20	20	17	17	15	15	12	12
	11	19	19	16	16	14	14	12	12	10	10

Size		756 3 × 3											
Thickness		1/2		7/16		3/8		5/16		1/4		3/16	
Wt. / ft		9.4		8.3		7.2		6.1		4.9		3.71	
F_y		36	50	36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	84	117	74	103	65	90	54	76	44	59	30	39
	1	81	111	71	96	60	82	49	66	38	48	24	28
	2	77	103	68	91	59	79	49	65	37	47	23	27
	3	69	89	61	78	53	68	45	58	36	45	23	27
	4	59	71	52	63	45	55	38	47	31	37	22	26
	5	48	54	43	48	37	42	32	35	26	29	19	21
	6	38	39	33	34	29	30	25	25	20	21	15	16
	7	28	28	25	25	22	22	19	19	15	15	12	12
	8	22	22	19	19	17	17	14	14	12	12	9	9
	9	17	17	15	15	13	13	11	11	9	9	7	7

F_y = 36 ksi

F_y = 50 ksi

CONCENTRICALLY LOADED COLUMNS
Single Angles
Design axial strength in kips (ϕ = 0.85)



Size		$2\frac{1}{2} \times 2\frac{1}{2}$									
Thickness		$\frac{1}{2}$		$\frac{3}{8}$		$\frac{5}{16}$		$\frac{1}{4}$		$\frac{3}{16}$	
Wt. / ft		7.7		5.9		5.0		4.1		3.07	
F_y		36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	69	96	53	74	45	62	36	51	27	35
	1	67	91	50	69	42	56	32	43	23	28
	2	51	80	47	62	39	52	32	42	22	27
	3	52	64	40	49	34	42	27	34	21	25
	4	41	47	32	36	27	31	22	25	17	19
	5	31	32	24	24	20	21	17	17	13	13
	6	22	22	17	17	14	14	12	12	9	9
	7	16	16	12	12	11	11	9	9	7	7
	8	12	12	9	9	8	8	7	7	5	5

Size		2×2									
Thickness		$\frac{3}{8}$		$\frac{5}{16}$		$\frac{1}{4}$		$\frac{3}{16}$		$\frac{1}{8}$	
Wt. / ft		4.7		3.92		3.19		2.44		1.65	
F_y		36	50	36	50	36	50	36	50	36	50
Effective length in feet, kL	0	42	58	35	49	29	40	22	30	13	17
	1	40	54	33	46	27	36	19	25	10	12
	2	34	44	29	37	24	30	18	23	10	12
	3	27	31	22	26	18	21	14	17	9	10
	4	19	19	16	16	13	13	10	10	7	7
	5	12	12	10	10	8	8	7	7	5	5
	6	8	8	7	7	6	6	5	5	3	3

Size		$1\frac{3}{4} \times 1\frac{3}{4}$				$1\frac{1}{2} \times 1\frac{1}{2}$			
Thickness		$\frac{1}{4}$		$\frac{3}{16}$		$\frac{1}{4}$		$\frac{3}{16}$	
Wt. / ft		2.77		2.12		2.34		1.8	
F_y		36	50	36	50	36	50	36	50
Effective length in feet, kL	0	25	35	19	26	21	29	16	22
	1	23	32	17	23	19	26	15	20
	2	19	24	15	19	15	18	11	14
	3	14	15	11	12	10	10	7	7
	4	9	9	7	7	5	5	4	4
	5	6	6	4	4				

Size		$1\frac{1}{4} \times 1\frac{1}{4}$				$1\frac{1}{8} \times 1\frac{1}{8}$		1×1	
Thickness		$\frac{1}{4}$		$\frac{3}{16}$		$\frac{1}{8}$		$\frac{1}{8}$	
Wt. / ft		1.92		1.48		0.9		0.8	
F_y		36	50	36	50	36	50	36	50
Effective length in feet, kL	0	17	24	13	19	8	11	7	10
	1	15	20	12	16	7	9	6	8
	2	10	12	8	9	4	5	3	3
	3	6	6	4	4	2	2	1	1
	4	3	3	2	2				