Design of Steel Components

(ANSI/AISC 360-16) LRFD, ASD E = 29,000 ksi

Beams

For doubly symmetric compact I-shaped members bent about their major axis, the *design flexural strength* $\phi_b M_n$ is determined with $\phi_b = 0.90$ and $\Omega = 1.67$ as follows:

Yielding

$$M_n = M_p = F_y Z_x$$

where

F_y = specified minimum yield stress
Z_x = plastic section modulus about the x-axis

Lateral-Torsional Buckling

Based on bracing where L_b is the length between points that are either braced against lateral displacement of the compression flange or braced against twist of the cross section with respect to the length limits L_p and L_r:

When $L_b \le L_p$, the limit state of lateral-torsional buckling does not apply.

When $L_p < L_b \le L_r$

$$M_n = C_b\left[M_p - \left(M_p - 0.7\,F_y S_x\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right] \le M_p$$

where

$$C_b = \frac{12.5 M_{\max}}{2.5 M_{\max} + 3M_A + 4M_B + 3M_C}$$

$M_{\max}$ = absolute value of maximum moment in the unbraced segment
M_A = absolute value of maximum moment at quarter point of the unbraced segment
M_B = absolute value of maximum moment at centerline of the unbraced segment
M_C = absolute value of maximum moment at three-quarter of the unbraced segment

Shear

The *design shear strength* $\phi_v V_n$ is determined with

ϕ_v = 1.00 for webs of rolled I-shaped members and is determined as follows:
Ω = 1.50
$V_n = 0.6\,F_y\,A_w\,C_{vl}$
C_{vl} = 1.0
A_w = area of web, the overall depth times the web thickness dt_w (in^2 *or* mm^2)

Columns

The *design compressive strength* $\phi_c P_n$ is determined with $\phi_c = 0.90$ and $\Omega = 1.67$ for flexural buckling of members without slender elements and is determined as follows:

$$P_n = F_{cr} A_g$$

where the critical stress F_{cr} is determined as follows:

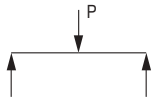
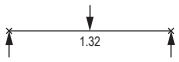
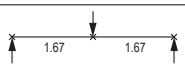
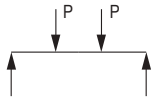
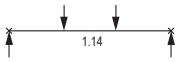
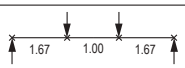
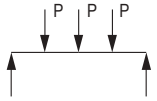
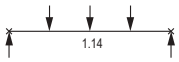
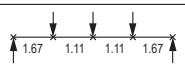
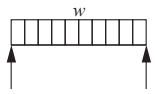
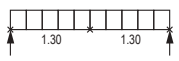
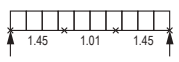
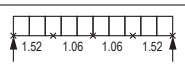
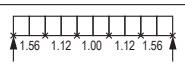
(a) When $\frac{Lc}{r} \le 4.71\sqrt{\frac{E}{Fy}}$, $F_{cr} = \left[0.658^{\frac{Fy}{Fe}}\right]F_y$

(b) When $\frac{Lc}{r} > 4.71\sqrt{\frac{E}{Fy}}$, $F_{cr} = 0.877\,F_e$

where

$Lc = KL$ = effective length of member (in.)

F_e = elastic buckling stress = $\pi^2 E/(KL/r)^2$

VALUES OF C_b FOR SIMPLY SUPPORTED BEAMS		
LOAD	LATERAL BRACING ALONG SPAN	C_b
	NONE LOAD AT MIDPOINT	
	AT LOAD POINT	
	NONE LOADS AT THIRD POINTS	
	AT LOAD POINTS LOADS SYMMETRICALLY PLACED	
	NONE LOADS AT QUARTER POINTS	
	AT LOAD POINTS LOADS AT QUARTER POINTS	
	NONE	
	AT MIDPOINT	
	AT THIRD POINTS	
	AT QUARTER POINTS	
	AT FIFTH POINTS	
NOTE: LATERAL BRACING MUST ALWAYS BE PROVIDED AT POINTS OF SUPPORT PER AISC *SPECIFICATIO*N CHAPTER F.		

Adapted from *Steel Construction Manual*, 14th ed., AISC, 2011.

Tension Members

Flat Bars or Angles, Bolted or Welded

Definitions

Bolt diameter: d_b

Nominal hole diameter: $d_h = d_b + \frac{1}{16}"$

Gross width of member: b_g

Member thickness: t

Connection eccentricity: $\overline{x}$

Gross area: $A_g = b_g\, t$ (use tabulated areas for angles)

Net area (parallel holes): $A_n = \left[b_g - \Sigma\left(d_b + \frac{1}{16}"\right)\right]t$

Net area (staggered holes):

$A_n = \left[b_g - \Sigma\left(d_b + \frac{1}{16}"\right) + \Sigma\frac{s^2}{4g}\right]t$

s = longitudinal spacing of consecutive holes

g = transverse spacing between lines of holes

Effective area (bolted members):

$A_e = UA_n$

- Flat bars: $U = 1.0$
- $U = 1 - \bar{x}/L$ All tension members where the tension load is transmitted to some but not all the elements by fasteners or welds

Effective area (welded members):

$A_e = UA_n$

- Flat bars or angles with transverse welds: $U = 1.0$
- Flat bars of width "w", longitudinal welds of length "L" only:
  - $U = 1.0$ ($L \geq 2w$)
  - $U = 0.87$ ($2w > L \geq 1.5w$)
  - $U = 0.75$ ($1.5w > L > w$)
- Angles with longitudinal welds only
  - $U = 1 - \overline{x}/L$

Limit States and Available Strengths

Yielding: $\phi_y = 0.90$, $P_n = F_y A_g$, $\Omega = 1.67$

Rupture: $\phi_f = 0.75$, $P_n = F_u A_e$, $\Omega = 2.00$

Block shear: $\phi = 0.75$, $\Omega = 2.00$

U_{bs} = 1.0 (flat bars and angles)

A_{gv} = gross area for shear

A_{nv} = net area for shear

A_{nt} = net area for tension

$$R_n = \text{Smaller} \begin{cases} F_u[0.6A_{nv} + U_{bs}A_{nt}] \\ [0.6F_y A_{gv} + U_{bs}F_u A_{nt}] \end{cases}$$

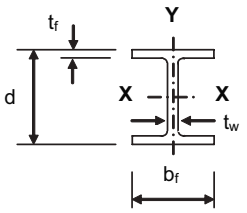


Table 1-1: W Shapes Dimensions and Properties

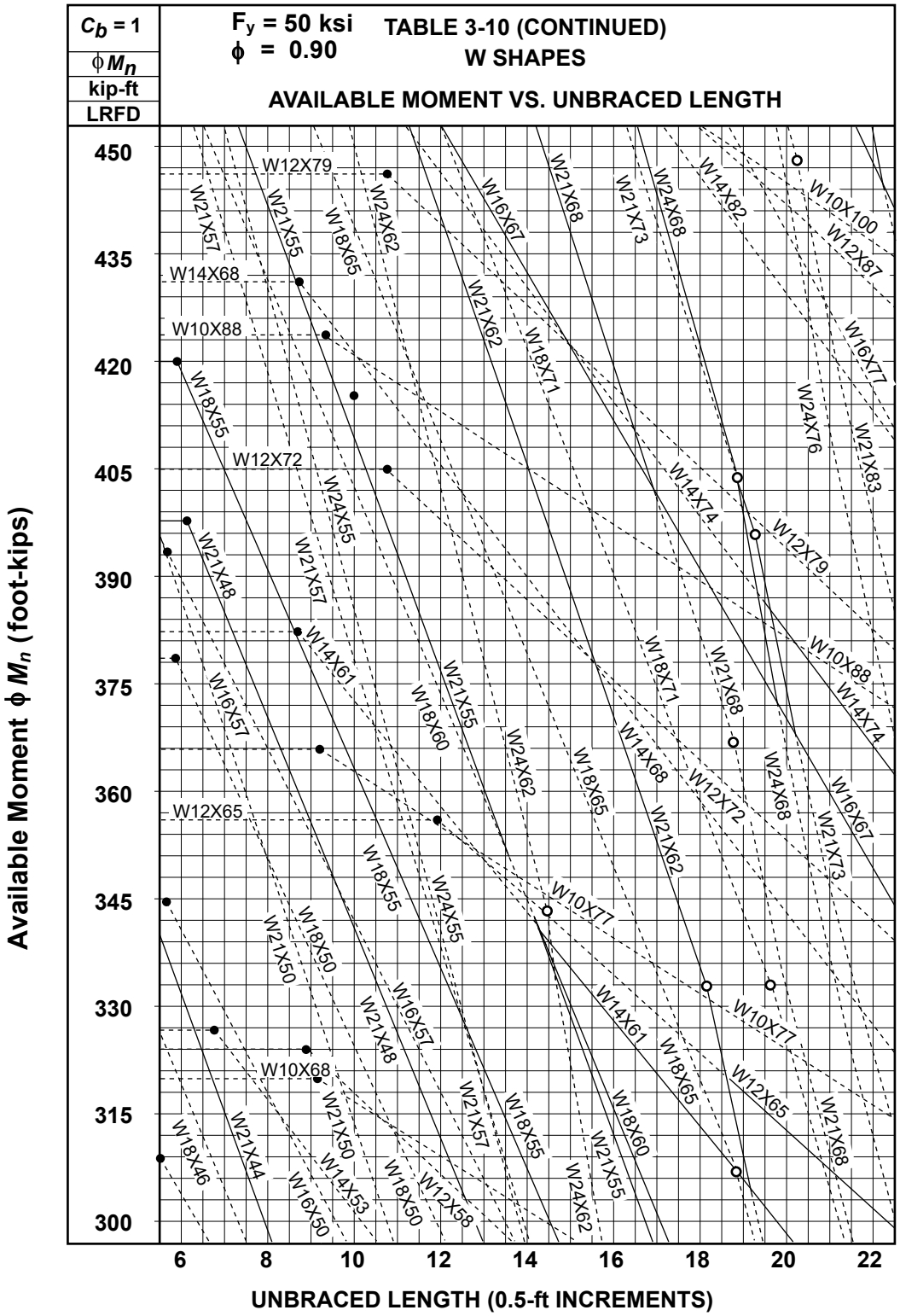
Shape	Area	Depth	Web	Flange		Axis X-X				Axis Y-Y	
	A	d	t_w	b_f	t_f	I	S	r	Z	I	r
	$In.^2$	In.	In.	In.	In.	$In.^4$	$In.^3$	In.	$In.^3$	$In.^4$	In.
W24X68	20.1	23.7	0.415	8.97	0.585	1830	154	9.55	177	70.4	1.87
W24X62	18.2	23.7	0.430	7.04	0.590	1550	131	9.23	153	34.5	1.38
W24X55	16.3	23.6	0.395	7.01	0.505	1350	114	9.11	134	29.1	1.34
W21X73	21.5	21.2	0.455	8.30	0.740	1600	151	8.64	172	70.6	1.81
W21X68	20.0	21.1	0.430	8.27	0.685	1480	140	8.60	160	64.7	1.80
W21X62	18.3	21.0	0.400	8.24	0.615	1330	127	8.54	144	57.5	1.77
W21X55	16.2	20.8	0.375	8.22	0.522	1140	110	8.40	126	48.4	1.73
W21X57	16.7	21.1	0.405	6.56	0.650	1170	111	8.36	129	30.6	1.35
W21X50	14.7	20.8	0.380	6.53	0.535	984	94.5	8.18	110	24.9	1.30
W21X48	14.1	20.6	0.350	8.14	0.430	959	93.0	8.24	107	38.7	1.66
W21X44	13.0	20.7	0.350	6.50	0.450	843	81.6	8.06	95.4	20.7	1.26
W18X71	20.8	18.5	0.495	7.64	0.810	1170	127	7.50	146	60.3	1.70
W18X65	19.1	18.4	0.450	7.59	0.750	1070	117	7.49	133	54.8	1.69
W18X60	17.6	18.2	0.415	7.56	0.695	984	108	7.47	123	50.1	1.68
W18X55	16.2	18.1	0.390	7.53	0.630	890	98.3	7.41	112	44.9	1.67
W18X50	14.7	18.0	0.355	7.50	0.570	800	88.9	7.38	101	40.1	1.65
W18X46	13.5	18.1	0.360	6.06	0.605	712	78.8	7.25	90.7	22.5	1.29
W18X40	11.8	17.9	0.315	6.02	0.525	612	68.4	7.21	78.4	19.1	1.27
W16X67	19.7	16.3	0.395	10.2	0.67	954	117	6.96	130	119	2.46
W16X57	16.8	16.4	0.430	7.12	0.715	758	92.2	6.72	105	43.1	1.60
W16X50	14.7	16.3	0.380	7.07	0.630	659	81.0	6.68	92.0	37.2	1.59
W16X45	13.3	16.1	0.345	7.04	0.565	586	72.7	6.65	82.3	32.8	1.57
W16X40	11.8	16.0	0.305	7.00	0.505	518	64.7	6.63	73.0	28.9	1.57
W16X36	10.6	15.9	0.295	6.99	0.430	448	56.5	6.51	64.0	24.5	1.52
W14X74	21.8	14.2	0.450	10.1	0.785	795	112	6.04	126	134	2.48
W14X68	20.0	14.0	0.415	10.0	0.720	722	103	6.01	115	121	2.46
W14X61	17.9	13.9	0.375	9.99	0.645	640	92.1	5.98	102	107	2.45
W14X53	15.6	13.9	0.370	8.06	0.660	541	77.8	5.89	87.1	57.7	1.92
W14X48	14.1	13.8	0.340	8.03	0.595	484	70.2	5.85	78.4	51.4	1.91
W12X79	23.2	12.4	0.470	12.1	0.735	662	107	5.34	119	216	3.05
W12X72	21.1	12.3	0.430	12.0	0.670	597	97.4	5.31	108	195	3.04
W12X65	19.1	12.1	0.390	12.0	0.605	533	87.9	5.28	96.8	174	3.02
W12X58	17.0	12.2	0.360	10.0	0.640	475	78.0	5.28	86.4	107	2.51
W12X53	15.6	12.1	0.345	9.99	0.575	425	70.6	5.23	77.9	95.8	2.48
W12X50	14.6	12.2	0.370	8.08	0.640	391	64.2	5.18	71.9	56.3	1.96
W12X45	13.1	12.1	0.335	8.05	0.575	348	57.7	5.15	64.2	50.0	1.95
W12X40	11.7	11.9	0.295	8.01	0.515	307	51.5	5.13	57.0	44.1	1.94
W10x60	17.6	10.2	0.420	10.1	0.680	341	66.7	4.39	74.6	116	2.57
W10x54	15.8	10.1	0.370	10.0	0.615	303	60.0	4.37	66.6	103	2.56
W10x49	14.4	10.0	0.340	10.0	0.560	272	54.6	4.35	60.4	93.4	2.54
W10x45	13.3	10.1	0.350	8.02	0.620	248	49.1	4.32	54.9	53.4	2.01
W10x39	11.5	9.92	0.315	7.99	0.530	209	42.1	4.27	46.8	45.0	1.98

Adapted from *Steel Construction Manual*, 14th ed., AISC, 2011.

Z_x	AISC Table 3-2 W Shapes – Selection by Z_x							F_y = 50 ksi ϕ_b = 0.90 ϕ_v = 1.00
Shape	**Z_x in.^{3}**	**$\phi_b M_{px}$ kip-ft**	**$\phi_b M_{rx}$ kip-ft**	**ϕ_bBF kips**	**L_p ft.**	**L_r ft.**	**I_x in.^{4}**	**$\phi_v V_{nx}$ kips**
W24 x 55	**134**	**503**	**299**	**22.2**	**4.73**	**13.9**	**1350**	**251**
W18 x 65	133	499	307	14.9	5.97	18.8	1070	248
W12 x 87	132	495	310	5.76	10.8	43.0	740	194
W16 x 67	130	488	307	10.4	8.69	26.1	954	194
W10 x 100	130	488	294	4.01	9.36	57.7	623	226
W21 x 57	129	484	291	20.1	4.77	14.3	1170	256
W21 x 55	**126**	**473**	**289**	**16.3**	**6.11**	**17.4**	**1140**	**234**
W14 x 74	126	473	294	8.03	8.76	31.0	795	191
W18 x 60	123	461	284	14.5	5.93	18.2	984	227
W12 x 79	119	446	281	5.67	10.8	39.9	662	175
W14 x 68	115	431	270	7.81	8.69	29.3	722	175
W10 x 88	113	424	259	3.95	9.29	51.1	534	197
W18 x 55	**112**	**420**	**258**	**13.9**	**5.90**	**17.5**	**890**	**212**
W21 x 50	**110**	**413**	**248**	**18.3**	**4.59**	**13.6**	**984**	**237**
W12 x 72	108	405	256	5.59	10.7	37.4	597	158
W21 x 48	**107**	**398**	**244**	**14.7**	**6.09**	**16.6**	**959**	**217**
W16 x 57	105	394	242	12.0	5.56	18.3	758	212
W14 x 61	102	383	242	7.46	8.65	27.5	640	156
W18 x 50	101	379	233	13.1	5.83	17.0	800	192
W10 x 77	97.6	366	225	3.90	9.18	45.2	455	169
W12 x 65	96.8	356	231	5.41	11.9	35.1	533	142
W21 x 44	**95.4**	**358**	**214**	**16.8**	**4.45**	**13.0**	**843**	**217**
W16 x 50	92.0	345	213	11.4	5.62	17.2	659	185
W18 x 46	90.7	340	207	14.6	4.56	13.7	712	195
W14 x 53	87.1	327	204	7.93	6.78	22.2	541	155
W12 x 58	86.4	324	205	5.66	8.87	29.9	475	132
W10 x 68	85.3	320	199	3.86	9.15	40.6	394	147
W16 x 45	82.3	309	191	10.8	5.55	16.5	586	167
W18 x 40	**78.4**	**294**	**180**	**13.3**	**4.49**	**13.1**	**612**	**169**
W14 x 48	78.4	294	184	7.66	6.75	21.1	484	141
W12 x 53	77.9	292	185	5.48	8.76	28.2	425	125
W10 x 60	74.6	280	175	3.80	9.08	36.6	341	129
W16 x 40	**73.0**	**274**	**170**	**10.1**	**5.55**	**15.9**	**518**	**146**
W12 x 50	71.9	270	169	5.97	6.92	23.9	391	135
W8 x 67	70.1	263	159	2.60	7.49	47.7	272	154
W14 x 43	69.6	261	164	7.24	6.68	20.0	428	125
W10 x 54	66.6	250	158	3.74	9.04	33.7	303	112
W18 x 35	**66.5**	**249**	**151**	**12.3**	**4.31**	**12.4**	**510**	**159**
W12 x 45	64.2	241	151	5.75	6.89	22.4	348	121
W16 x 36	64.0	240	148	9.31	5.37	15.2	448	140
W14 x 38	61.5	231	143	8.10	5.47	16.2	385	131
W10 x 49	60.4	227	143	3.67	8.97	31.6	272	102
W8 x 58	59.8	224	137	2.56	7.42	41.7	228	134
W12 x 40	57.0	214	135	5.50	6.85	21.1	307	106
W10 x 45	54.9	206	129	3.89	7.10	26.9	248	106

$$M_{rx} = (0.7F_y)S_x \qquad BF = \frac{M_{px} - M_{rx}}{L_r - L_p}$$

Adapted from *Steel Construction Manual*, 14th ed., AISC, 2011.



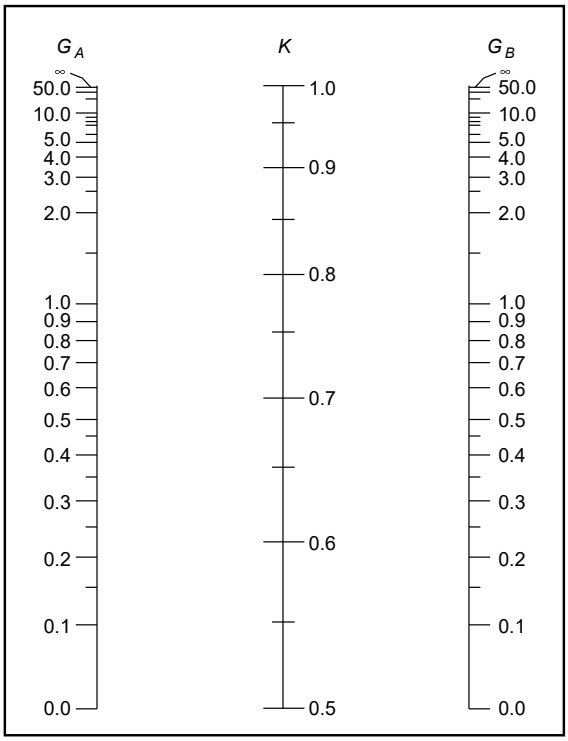
Steel Construction Manual, 14th ed., AISC, 2011.

TABLE C-A-7.1
AISC APPROXIMATE VALUES OF EFFECTIVE LENGTH FACTOR, *K*

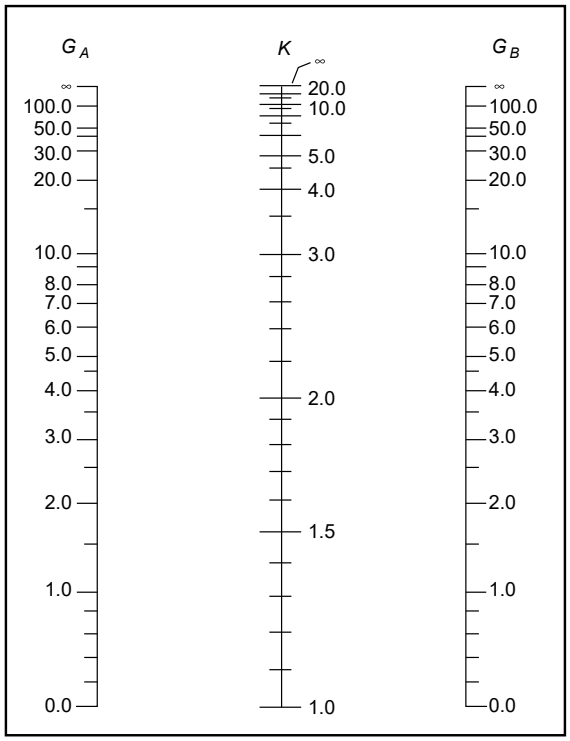
BUCKLED SHAPE OF COLUMN IS SHOWN BY DASHED LINE.	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)
THEORETICAL *K* VALUE	0.5	0.7	1.0	1.0	2.0	2.0
AISC-RECOMMENDED DESIGN VALUE WHEN IDEAL CONDITIONS ARE APPROXIMATED	0.65	0.80	1.2	1.0	2.10	2.0
END CONDITION CODE	*ROTATION FIXED AND TRANSLATION FIXED* *ROTATION FREE AND TRANSLATION FIXED* *ROTATION FIXED AND TRANSLATION FREE* *ROTATION FREE AND TRANSLATION FREE*					

FOR COLUMN ENDS SUPPORTED BY, BUT NOT RIGIDLY CONNECTED TO, A FOOTING OR FOUNDATION, G IS THEORETICALLY INFINITY BUT UNLESS DESIGNED AS A TRUE FRICTION-FREE PIN, MAY BE TAKEN AS 10 FOR PRACTICAL DESIGNS. IF THE COLUMN END IS RIGIDLY ATTACHED TO A PROPERLY DESIGNED FOOTING, G MAY BE TAKEN AS 1.0. SMALLER VALUES MAY BE USED IF JUSTIFIED BY ANALYSIS.

AISC Figure C-A-7.1
Alignment chart, sidesway inhibited (braced frame)



AISC Figure C-A-7.2
Alignment chart, sidesway uninhibited (moment frame)



Steel Construction Manual, 15th ed., AISC 2017.

AISC Table 4-14
Available Critical Stress $\phi_c F_{cr}$ for Compression Members
F_y = 50 ksi ϕ_c = 0.90

$\frac{KL}{r}$	ϕF_{cr} ksi	$\frac{KL}{r}$	ϕF_{cr} ksi	$\frac{KL}{r}$	ϕF_{cr} ksi	$\frac{KL}{r}$	ϕF_{cr} ksi	$\frac{KL}{r}$	ϕF_{cr} ksi
1	45.0	41	39.8	81	27.9	121	15.4	161	8.72
2	45.0	42	39.5	82	27.5	122	15.2	162	8.61
3	45.0	43	39.3	83	27.2	123	14.9	163	8.50
4	44.9	44	39.1	84	26.9	124	14.7	164	8.40
5	44.9	45	38.8	85	26.5	125	14.5	165	8.30
6	44.9	46	38.5	86	26.2	126	14.2	166	8.20
7	44.8	47	38.3	87	25.9	127	14.0	167	8.10
8	44.8	48	38.0	88	25.5	128	13.8	168	8.00
9	44.7	49	37.7	89	25.2	129	13.6	169	7.89
10	44.7	50	37.5	90	24.9	130	13.4	170	7.82
11	44.6	51	37.2	91	24.6	131	13.2	171	7.73
12	44.5	52	36.9	92	24.2	132	13.0	172	7.64
13	44.4	53	36.7	93	23.9	133	12.8	173	7.55
14	44.4	54	36.4	94	23.6	134	12.6	174	7.46
15	44.3	55	36.1	95	23.3	135	12.4	175	7.38
16	44.2	56	35.8	96	22.9	136	12.2	176	7.29
17	44.1	57	35.5	97	22.6	137	12.0	177	7.21
18	43.9	58	35.2	98	22.3	138	11.9	178	7.13
19	43.8	59	34.9	99	22.0	139	11.7	179	7.05
20	43.7	60	34.6	100	21.7	140	11.5	180	6.97
21	43.6	61	34.3	101	21.3	141	11.4	181	6.90
22	43.4	62	34.0	102	21.0	142	11.2	182	6.82
23	43.3	63	33.7	103	20.7	143	11.0	183	6.75
24	43.1	64	33.4	104	20.4	144	10.9	184	6.67
25	43.0	65	33.0	105	20.1	145	10.7	185	6.60
26	42.8	66	32.7	106	19.8	146	10.6	186	6.53
27	42.7	67	32.4	107	19.5	147	10.5	187	6.46
28	42.5	68	32.1	108	19.2	148	10.3	188	6.39
29	42.3	69	31.8	109	18.9	149	10.2	189	6.32
30	42.1	70	31.4	110	18.6	150	10.0	190	6.26
31	41.9	71	31.1	111	18.3	151	9.91	191	6.19
32	41.8	72	30.8	112	18.0	152	9.78	192	6.13
33	41.6	73	30.5	113	17.7	153	9.65	193	6.06
34	41.4	74	30.2	114	17.4	154	9.53	194	6.00
35	41.2	75	29.8	115	17.1	155	9.40	195	5.94
36	40.9	76	29.5	116	16.8	156	9.28	196	5.88
37	40.7	77	29.2	117	16.5	157	9.17	197	5.82
38	40.5	78	28.8	118	16.2	158	9.05	198	5.76
39	40.3	79	28.5	119	16.0	159	8.94	199	5.70
40	40.0	80	28.2	120	15.7	160	8.82	200	5.65

Adapted from *Steel Construction Manual*, 15th ed., AISC 2017.

Selected W14, W12, W10

AISC Table 4–1
Available Strength in Axial Compression, kips—W shapes
LRFD: ϕP_n

F_y = 50 ksi
ϕ_c = 0.90

Effective length KL (ft) with respect to least radius of gyration r_y	Shape wt/ft	W14					W12					W10				
		74	68	61	53	48	58	53	50	45	40	60	54	49	45	39
	0	980	899	806	702	636	767	701	657	590	526	794	712	649	597	516
	6	922	844	757	633	573	722	659	595	534	475	750	672	612	543	469
	7	901	826	740	610	552	707	644	574	516	458	734	658	599	525	452
	8	878	804	721	585	529	689	628	551	495	439	717	643	585	505	435
	9	853	781	700	557	504	670	610	526	472	419	698	625	569	483	415
	10	826	755	677	528	477	649	590	499	448	397	677	607	551	460	395
	11	797	728	652	497	449	627	569	471	422	375	655	586	533	435	373
	12	766	700	626	465	420	603	547	443	396	351	631	565	513	410	351
	13	734	670	599	433	391	578	525	413	370	328	606	543	493	384	328
	14	701	639	572	401	361	553	501	384	343	304	581	520	471	358	305
	15	667	608	543	369	332	527	477	354	317	280	555	496	450	332	282
	16	632	576	515	338	304	500	452	326	291	257	528	472	428	306	260
	17	598	544	486	308	276	473	427	297	265	234	501	448	405	281	238
	18	563	512	457	278	250	446	402	270	241	212	474	423	383	256	216
	19	528	480	428	250	224	420	378	244	217	191	447	399	360	233	195
	20	494	448	400	226	202	393	353	220	196	172	420	375	338	210	176
	22	428	387	345	186	167	342	306	182	162	142	367	327	295	174	146
	24	365	329	293	157	140	293	261	153	136	120	317	282	254	146	122
	26	311	281	250	133	120	249	222	130	116	102	270	241	216	124	104
	28	268	242	215	115	103	215	192	112	99.8	88.0	233	208	186	107	90.0
	30	234	211	187	100	89.9	187	167	97.7	87.0	76.6	203	181	162	93.4	78.4
	32	205	185	165	88.1		165	147	82.9	76.4	67.3	179	159	143	82.1	68.9
	34	182	164	146			146	130				158	141	126		
	36	162	146	130			130	116				141	126	113		
	38	146	131	117			117	104				127	113	101		
	40	131	119	105			105	93.9				114	102	91.3		