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Steel Column Design by ASD/LRFD Steel Construction Manual



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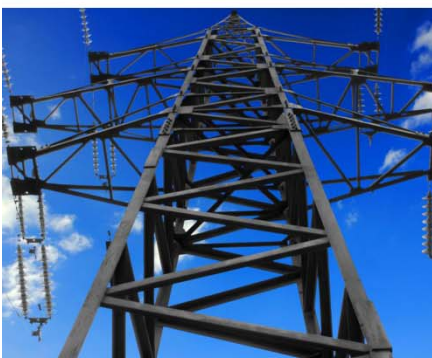
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**Steel Column Design by
ASD/LRFD Steel Construction Manual
13th Edition**

By Duane Nickols

Compression members are commonly used in structures. *Columns* are a type of compression member used to support beams, girders, floors, roofs and other areas. Compression members are also used in trusses. Compression members can be subjected to axial compression, eccentric compression or combined axial compression and flexure. This tends to buckle the compression member.












Camber, is the bending of a beam to help compensate for deflection. You do not camber a column. That would make it tend to buckle and buckle in a certain direction.

Compressive strength depends on the axis of bending and the type of end connections. A W section has an x-axis and a y-axis. The x-axis is parallel to the flanges and the y-axis is parallel to and goes through the web. The x-axis is the strong axis and the y-axis is the weak axis. Bucking will occur about the weak axis.

The type of end connection determines the *effective length factor*, K. There are three basic types of end connections used in most buildings.

- Fixed-fixed
- Pinned-pinned
- Fixed-pinned

Recommended design K values are given in the following table and the recommended K values should be used instead of the theoretical K values.

TABLE C-C2.2 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
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.10	2.0
End condition code	 <ul style="list-style-type: none">  Rotation fixed and translation fixed  Rotation free and translation fixed  Rotation fixed and translation free  Rotation free and translation free 					

- Case (a) has fixed, fixed connections
- Case (b) has pinned, fixed connections
- Case (d) has pinned, pinned connections

If the column is used in a frame, we would use a different method to determine the K value. The *effective length* is KL . KL/r is the *slenderness ratio*. Section E2 of the specification says that KL/r should be less than 200.

Section E1 of the specification explains how to calculate the *design compressive strength* and the *allowable compressive strength*.

The *design compressive strength*, $\phi_c P_n$, and the *allowable compressive strength*, P_n/Ω_c , are determined as follows:

The *nominal compressive strength*, P_n , shall be the lowest value obtained according to the *limit states* of *flexural buckling*, *torsional buckling* and *flexural-torsional buckling*.

- (a) For doubly symmetric and singly symmetric members the limit state of flexural buckling is applicable.
- (b) For singly symmetric and unsymmetric members, and certain doubly symmetric members, such as cruciform or built-up *columns*, the limit states of torsional or flexural-torsional buckling are also applicable.

$$\phi_c = 0.90 \text{ (LRFD)} \quad \Omega_c = 1.67 \text{ (ASD)}$$

A W section is *doubly symmetrical*.

Section B4 of the specification says that compression members are classified for local buckling as compact, non-compact or slender-elements. Most W sections are compact. Section E7 of the specification says there is a *reduction factor*, Q. It says that Q=1 for compact and non-compact but is less than 1 for slender-elements. Table B4.1, case 3 says a member is non-compact if

$$b/t = \lambda_r < 0.56 \sqrt{E/F_y} \text{ and case 10, if } h/t_w = \lambda_r < 1.49 \sqrt{E/F_y} .$$

Section E3 of the specification shows how to calculate the compressive strength of most compression members since most W sections are compact. The equations in section E3 are the basis of Table 4-22 in the Steel Manual. If you want to determine the available compressive strength of a section, use Table 4-22 and determine the available critical stress. Multiply the available critical stress by the gross area to calculate the available compressive stress.

The *nominal compressive strength*, P_n , shall be determined based on the *limit state of flexural buckling*.

$$P_n = F_{cr} A_g \quad (\text{E3-1})$$

The *flexural buckling stress*, F_{cr} , is determined as follows:

$$\text{(a) When } \frac{KL}{r} \leq 4.71 \sqrt{\frac{E}{F_y}} \quad (\text{or } F_e \geq 0.44F_y)$$

$$F_{cr} = \left[0.658 \frac{F_y}{F_e} \right] F_y \quad (\text{E3-2})$$

$$\text{(b) When } \frac{KL}{r} > 4.71 \sqrt{\frac{E}{F_y}} \quad (\text{or } F_e < 0.44F_y)$$

$$F_{cr} = 0.877 F_e \quad (\text{E3-3})$$

where

F_e = elastic critical buckling stress determined according to Equation E3-4, Section E4, or the provisions of Section C2, as applicable, ksi (MPa)

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r} \right)^2} \quad (\text{E3-4})$$

Design of columns by formulas involves trial-and-error. Table 4-1 helps with the design of W sections in axial compression. Table 4-22 also helps with the design of compression members with minimum yield strengths of 35 ksi, 36 ksi, 42 ksi, 46 ksi and 50 ksi. Most W sections would have a yield stress of 36 ksi or 50 ksi.

Example 1

Select an ASTM A992 ($F_y=50$ ksi) W section column to carry an axial dead load of 150 kips and live load of 400 kips. The column is 30" long and is pinned at the top and bottom. The limit is a 14" member.

LRFD

$$P_u = 1.2D + 1.6L = (1.2 \times 150 \text{ kips}) + (1.6 \times 400 \text{ k}) = 820 \text{ k}$$

ASD

$$P_a = D + L = 150 \text{ k} + 400 \text{ k} = 550 \text{ k}$$

Assume $KL/r=50$

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} = 114 \text{ ksi}$$

$$F_{cr} = \left[0.658 \frac{F_y}{F_e} \right] F_y = 41.6 \text{ ksi}$$

LRFD

$$\phi_c F_{cr} = 0.9(41.6 \text{ ksi}) = 37.5 \text{ ksi}$$

$$A_{req} = \frac{P_u}{\phi_c F_{cr}} = \frac{820 \text{ k}}{37.5 \text{ ksi}} = 21.9 \text{ in}^2$$

ASD

$$\frac{F_{cr}}{\Omega_c} = \frac{41.6 \text{ ksi}}{1.67} = 24.9 \text{ ksi}$$

$$A_{req} = \frac{\Omega_c P_a}{F_{cr}} = \frac{550 \text{ k}}{24.9 \text{ ksi}} = 22.0 \text{ in}^2$$

Try W14 X 82

Shape	Weight w lbs/ft	Area A in ²	Depth d in	b _f in	t _w in	t _f in	k _{des} in	k _{det} in	k ₁ in	b _f /2t _f	h/t _f	I _x in ⁴	Z _x in ³	S _x in ³	r _x in	I _y in ⁴	Z _y in ³	S _y in ³	r _y in
W14X109	109	32.0	14.3	14.6	0.525	0.860	1.46	2.1875	1.5	8.49	21.7	1240	192	173	6.22	447	92.7	61.2	3
W14X99	99.0	29.1	14.2	14.6	0.485	0.780	1.38	2.0625	1.4375	9.34	23.5	1110	173	157	6.17	402	83.6	55.2	3
W14X90	90.0	26.5	14.0	14.5	0.440	0.710	1.31	2	1.4375	10.2	25.9	999	157	143	6.14	362	75.6	49.9	3
W14X82	82.0	24.0	14.3	10.1	0.510	0.855	1.45	1.6875	1.0625	5.92	22.4	881	139	123	6.05	148	44.8	29.3	2
W14X74	74.0	21.8	14.2	10.1	0.450	0.785	1.38	1.625	1.0625	6.41	25.4	795	126	112	6.04	134	40.5	26.6	2
W14X68	68.0	20.0	14.0	10.0	0.415	0.720	1.31	1.5625	1.0625	6.97	27.5	722	115	103	6.01	121	36.9	24.2	2
W14X61	61.0	17.9	13.9	10.0	0.375	0.645	1.24	1.5	1	7.75	30.4	640	102	92.1	5.98	107	32.8	21.5	2
W14X53	53.0	15.6	13.9	8.06	0.370	0.660	1.25	1.5	1	6.11	30.9	541	87.1	77.8	5.89	57.7	22.0	14.3	1
W14X48	48.0	14.1	13.8	8.03	0.340	0.595	1.19	1.4375	1	6.75	33.6	484	78.4	70.2	5.85	51.4	19.6	12.8	1
W14X43	43.0	12.6	13.7	8.00	0.305	0.530	1.12	1.375	1	7.54	37.4	428	69.6	62.6	5.82	45.2	17.3	11.3	1
W14X38	38.0	11.2	14.1	6.77	0.310	0.515	0.915	1.25	0.8125	6.57	39.6	385	61.5	54.6	5.87	26.7	12.1	7.88	1
W14X34	34.0	10.0	14.0	6.75	0.285	0.455	0.855	1.1875	0.75	7.41	43.1	340	54.6	48.6	5.83	23.3	10.6	6.91	1
W14X30	30.0	8.85	13.8	6.73	0.270	0.385	0.785	1.125	0.75	8.74	45.4	291	47.2	42.0	5.73	19.6	8.99	5.82	1

$A_g = 24 \text{ in}^2$, $r_x = 6.05 \text{ in}$, $r_y = 2.48 \text{ in}$

$$\frac{KL}{r_x} = \frac{1.0(30 \text{ ft})(12 \text{ in} / \text{ft})}{6.05 \text{ in}} = 59.5$$

$$\frac{KL}{r_y} = \frac{1.0(30 \text{ ft})(12 \text{ in} / \text{ft})}{2.48 \text{ in}} = 145.2 \text{ use larger}$$

$$F_e = \frac{\pi^2 E}{(145.2)^2} = 13.583 \text{ ksi}$$

$$F_{cr} = 0.877 F_e = 0.877(13.583 \text{ ksi}) = 11.912 \text{ ksi}$$

LRFD

$$\phi F_{cr} = 0.9 (11.912 \text{ ksi}) = 10.72 \text{ ksi}$$

$$\phi P_n = \phi F_{cr} A_g = (10.72 \text{ ksi})(24 \text{ in}^2) = 231 \text{ k}$$

$$231 \text{ k} < 820 \text{ k} \quad \text{NG}$$

ASD

$$\frac{F_{cr}}{\Omega} = \frac{11.912 \text{ ksi}}{1.67} = 7.133 \text{ ksi}$$

$$\frac{P_n}{\Omega} = \frac{F_{cr}}{\Omega} \times A_g = 7.133 \text{ ksi} (24 \text{ in}^2) = 171 \text{ k}$$

$$171 \text{ k} < 550 \text{ k} \quad \text{NG}$$

Try a larger section, W14 X 132

1	AISC_MANUAL_LABEL	Weight w	Area A	Depth d	b _f	t _w	t _f	t _{des}	k _{des}	k _{det}	k ₁	b _f /2t _f	h/t _f	I _x	Z _x	S _x	r _x	I _y	Z _y
2		lbs/ft	in ²	in	in	in	in	in	in	in	in			in ⁴	in ³	in ³	in	in ⁴	in ³
190	W14X145	145	42.7	14.8	15.5	0.680	1.09	0.00	1.69	2.375	1.5625	7.11	16.8	1710	260	232	6.33	677	133
191	W14X132	132	38.8	14.7	14.7	0.645	1.03	0.00	1.63	2.3125	1.5625	7.15	17.7	1530	234	209	6.28	548	113
192	W14X120	120	35.3	14.5	14.7	0.590	0.940	0.00	1.54	2.25	1.5	7.80	19.3	1380	212	190	6.24	495	102
193	W14X109	109	32.0	14.3	14.6	0.525	0.860	0.00	1.46	2.1875	1.5	8.49	21.7	1240	192	173	6.22	447	92.7
194	W14X99	99.0	29.1	14.2	14.6	0.485	0.780	0.00	1.38	2.0625	1.4375	9.34	23.5	1110	173	157	6.17	402	83.6

$$A_g = 38.8 \text{ in}^2, r_x = 6.28 \text{ in}, r_y = 3.76 \text{ in}$$

$$\frac{KL}{r_x} = \frac{1.0(30 \text{ ft})(12 \text{ in} / \text{ft})}{6.28 \text{ in}} = 57.32$$

$$\frac{KL}{r_y} = \frac{1.0(30 \text{ ft})(12 \text{ in} / \text{ft})}{3.76 \text{ in}} = 95.74 \text{ use larger}$$

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} = \frac{\pi^2 (29,000 \text{ ksi})}{(95.74)^2} = 31.22 \text{ ksi}$$

$$F_{cr} = (0.658^{F_y}) F_y = (0.658^{31.22}) 50 \text{ ksi} = 25.579 \text{ ksi}$$

LRFD

$$\phi F_{cr} = 0.9 (25.579 \text{ ksi}) = 23.02 \text{ ksi}$$

$$\phi P_n = \phi F_{cr} A_g = (23.02 \text{ ksi})(38.8 \text{ in}^2) = 893 \text{ k}$$

$$893 \text{ k} > 820 \text{ k} \quad \text{OK}$$

ASD

$$\frac{F_{cr}}{\Omega} = \frac{25.579 \text{ ksi}}{1.67} = 15.31 \text{ ksi}$$

$$\frac{P_n}{\Omega} = \frac{F_{cr}}{\Omega} (A_g) = (15.31 \text{ ksi})(38.8 \text{ in}^2) = 594 \text{ k}$$

$$594 \text{ k} > 550 \text{ k} \quad \text{OK}$$

Table 4-1 of the Steel Manual has $\phi P_n=892$ k and $P_n/\Omega=594$ k. Using Table 4-1 would have been much easier to select a column than designing by trial-and-error. Table 4-22 shows $\phi F_{cr}=22.9$ ksi and $F_{cr}/\Omega=15.3$ ksi. So, what we did checks.

Be sure to go to the AISC web site and print the errata for the 1st printing and the 2nd printing because Table 4-22 has changed.

Part of table 4-22: [See my version for part of Table 4-22](#)

KL/r	$F_y=50$ ksi		
	F_{cr} (ksi)	F_{cr}/Ω_c (ksi) ASD	$\phi_c F_{cr}$ (ksi) LRFD
90	27.7	16.6	24.9
91	27.3	16.3	24.6
92	26.9	16.1	24.2
93	26.6	15.9	23.9
94	26.2	15.7	23.6
95	25.8	15.5	23.3
96	25.5	15.3	22.9
97	25.1	15.0	22.6
98	24.8	14.8	22.3
99	24.4	14.6	22.0
100	24.1	14.4	21.7
101	23.7	14.2	21.3
102	23.4	14.0	21.0
103	23.0	13.8	20.7
104	22.7	13.6	20.4
105	22.3	13.4	20.1
106	22.0	13.2	19.8
107	21.6	13.0	19.5
108	21.3	12.8	19.2
109	21.0	12.6	18.9
110	20.6	12.4	18.6
111	20.3	12.2	18.3
112	20.0	12.0	18.0
113	19.7	11.8	17.7

Using Table 4-1, you just find $P_n/\Omega_c > P_a$ for $KL = 30$ ft. That is $594 \text{ k} > 550 \text{ k}$ and $\phi_c P_n > P_u$ for $KL = 30$ ft. That is $893 \text{ k} > 820 \text{ k}$. A W14X 132 will work.

Part of Table 4-1 [See my version for part of Table 4-1](#)

4-13

KL	W14X											
	145		132		120		109		99		90	
	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
0	1278	1922	1162	1746	1057	1589	958	1440	871	1310	793	1193
6	1248	1876	1131	1700	1029	1546	932	1401	848	1274	772	1160
7	1237	1860	1120	1683	1019	1531	923	1388	839	1261	764	1148
8	1225	1841	1108	1665	1007	1514	913	1372	830	1247	755	1135
9	1211	1821	1094	1644	994	1495	901	1354	819	1231	745	1120
10	1196	1798	1078	1621	980	1473	888	1335	807	1213	735	1104
11	1180	1773	1062	1596	965	1450	874	1314	794	1194	723	1087
12	1162	1746	1044	1568	948	1425	859	1291	780	1173	710	1067
13	1143	1717	1024	1540	931	1399	843	1267	766	1151	697	1047
14	1122	1687	1004	1509	912	1371	826	1241	750	1127	682	1026
15	1101	1655	982	1477	892	1341	808	1215	733	1102	667	1003
16	1078	1621	960	1443	872	1310	789	1186	716	1077	652	979
17	1055	1586	937	1408	850	1278	770	1157	698	1050	635	955
18	1031	1549	913	1372	828	1245	750	1127	680	1022	618	929
19	1006	1512	888	1334	805	1211	729	1096	661	994	601	903
20	980	1473	862	1296	782	1176	708	1064	642	964	583	877
22	927	1393	810	1218	734	1103	664	998	602	904	547	822
24	872	1310	756	1137	685	1030	620	931	561	843	509	766
26	816	1226	702	1055	635	955	574	863	519	781	472	709
28	759	1141	648	974	586	880	529	796	478	719	434	653
30	703	1056	594	893	537	807	485	729	438	658	397	597
32	647	973	542	814	489	735	441	663	398	598	361	543
34	593	891			443	665	399	600	360	541	326	490
36	540					599	359	540	323	486	293	440
38	489	735				536	322	484	290	435	262	394
40	441	663				484	290	437	261	393	237	356

Ag	42.7	35.3	32	29.1	26.5
ry	3.98	3.74	3.73	3.71	3.7

A W12X 170 will also work $P_n/\Omega_c > P_a$ is $600 \text{ k} > 550 \text{ k}$ and $\phi_c P_n > P_u$ is $902 \text{ k} > 820 \text{ k}$ for $KL = 30$ ft.

KL	W12X									
	190		170		152		136			
	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
0	1671	2511	1497	2250	1338	2012	1195	1796	1057	
6	1612	2422	1443	2169	1289	1938	1150	1729	1017	
7	1591	2391	1424	2141	1272	1912	1134	1705	1003	
8	1567	2356	1403	2108	1253	1883	1117	1678	987	
9	1541	2316	1379	2072	1231	1850	1097	1649	969	
10	1512	2273	1352	2033	1207	1814	1075	1616	949	
11	1481	2226	1324	1990	1181	1775	1052	1580	928	
12	1447	2175	1293	1944	1153	1733	1026	1543	905	
13	1412	2122	1261	1895	1124	1689	1000	1502	881	
14	1374	2065	1227	1844	1093	1642	972	1460	856	
15	1335	2007	1191	1790	1060	1594	942	1416	830	
16	1294	1945	1154	1735	1027	1543	912	1371	803	
17	1252	1883	1116	1678	992	1492	881	1324	775	
18	1210	1818	1077	1619	957	1439	849	1276	746	
19	1166	1752	1038	1559	921	1385	816	1227	717	
20	1121	1685	997	1499	885	1330	784	1178	688	
22	1031	1550			811	1219	717	1078	628	
24	941	1414			737	1108	651	978	569	
26	852	1280			665	999	586	880	511	
28	765	1149	675	1015	595	894	523	786	455	
30	681	1024	600	902	527	793	462	695	402	
32	601	903	528	794	464	697	406	610	353	

These are the lightest two sections that will support the required load. The W14 section is 132 pounds / foot and the W12 section is 170 pounds / foot so we would probably choose the W 14 section since it is so much lighter.

Example 1a

Now let's change the first problem and brace the column at the mid point in the Y-direction. That means $KL_y = 15$ ft but $L_x = 30$ ft. Our $P_u = 820$ k and $P_a = 550$ k. Now the r_x/r_y ratio is 1.66 so $KL_x = 30.0$ ft / 1.66 = 18 ft. We use Table 4-1 for the largest KL of 15 ft or 18 ft, so that would be 18 ft. Start on page 4-21 for KL = 18 ft and look for the first $P_n/\Omega_c > P_a = 550$ k and $\phi_c P_n > P_u = 820$ k.

That would be a W10X 112 with $P_n/\Omega_c = 613$ k and $\phi_c P_n > P_u = 921$ k.

4-19

KL	W10X											
	112		100		88		77		68		60	
	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$
0	985	1481	880	1323	775	1166	677	1017	599	900	527	792
6	934	1404	834	1253	734	1103	640	962	566	851	498	748
7	917	1378	818	1229	720	1082	627	942	554	833	487	732
8	897	1348	800	1202	703	1057	612	921	542	814	476	715
9	875	1315	780	1172	685	1030	596	896	527	793	463	696
10	851	1279	758	1139	666	1001	579	870	512	769	449	675
11	825	1240	734	1103	645	969	560	842	495	744	435	653
12	798	1199	709	1066	623	936	541	813	478	718	419	630
13	769	1156	683	1027	600	901	520	782	459	690	402	605
14	739	1111	656	986	575	865	499	749	440	662	386	579
15	708	1065	628	944	551	828	477	716	421	632	368	553
16	677	1017	601	901	525	789	454	683	401	602	350	527
17	645	969	574	858	499	751	431	648	380	572	332	500
18	613	921	548	815	474	712	409	614	360	541	314	473
19	580	872	521	772	448	673	386	580	340	511	296	445
20	548	824	495	726	422	634	363	545	320	480	279	419
22	485	728	426	640	371	558	318	479	280	421	244	366
24	423	636	371	558	323	485	276	415	242	364	210	316
26	366	548	319	479	277	416	236	355	207	311	179	270
28	315	473	275	413	239	358	203	306	179	268	155	233
30	274	412	239	360	208	312	177	266	156	234	135	203
32	241	362	210	316	183	274	156	234	137	206	118	178
34	213	321	186	280	162	243	138	207	121	182	105	158
36	190	286	166	250	144	217	123	185	108	162	93.6	141
38	171	257	149	224	129	195	110	166	97.0	146	84.0	126
40	154	232	135	202	117	176	100	150	87.5	132	75.8	114

Ag	32.9	29.4	25.9	22.6	20	17.6
r _y	2.68	2.65	2.63	2.6	2.59	2.57

Following the table, we find a W12X 96 with $P_n/\Omega_c = 591$ k and $\phi_c P_n > P_u = 888$ k.

KL	W12X									
	96		87		79		72		65	
	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
0	844	1269	766	1152	695	1044	632	950	572	860
6	811	1220	736	1107	667	1002	606	911	549	825
7	800	1202	726	1091	657	988	597	898	540	812
8	787	1183	714	1073	646	971	587	883	531	798
9	772	1161	700	1052	634	953	576	866	521	783
10	756	1137	685	1030	620	932	564	847	510	766
11	739	1110	670	1006	606	910	550	827	497	747
12	720	1083	653	981	590	887	536	806	484	728
13	701	1053	635	954	574	862	521	783	470	707
14	680	1022	616	925	556	836	505	759	456	685
15	659	990	596	896	538	809	489	735	441	663
16	637	957	576	865	520	781	472	709	426	640
17	614	923	556	834	501	753	455	683	410	616
18	591	888	536	803	481	723	437	656	393	591
19	567	852	516	772	462	694	419	629	377	567
20	543	816	496	737	442	664	401	602	360	542
22	495	744	446	671	402	604	364	547	327	492
24	447	672	403	605	362	544	328	493	294	442
26	401	602	360	541	323	486	292	440	262	394
28	356	535	319	480	286	430	259	389	231	348
30	312	469	280	421	250	376	226	340	202	304
32	274	413	246	370	220	331	199	299	178	267
34	243	365	218	327	195	293	176	265	157	236
36	217	326	194	292	174	261	157	236	140	211
38	195	293	174	262	156	234	141	212	126	189
40	176	264	157	237	141	212	127	191	114	171

Ag	28.2	25.6	23.2	21.1	19.1
r_y	3.09	3.07	3.05	3.04	3.02

Following the table, a W 14X 90 of $P_n/\Omega_c = 618$ k and $\phi_c P_n = 929$ k will work.

KL	W14X											
	145		132		120		109		99		90	
	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
0	1278	1922	1162	1746	1057	1589	958	1440	871	1310	793	1193
6	1248	1876	1131	1700	1029	1546	932	1401	848	1274	772	1160
7	1237	1860	1120	1683	1019	1531	923	1388	839	1261	764	1148
8	1225	1841	1108	1665	1007	1514	913	1372	830	1247	755	1135
9	1211	1821	1094	1644	994	1495	901	1354	819	1231	745	1120
10	1196	1798	1078	1621	980	1473	888	1335	807	1213	735	1104
11	1180	1773	1062	1596	965	1450	874	1314	794	1194	723	1087
12	1162	1746	1044	1568	948	1425	859	1291	780	1173	710	1067
13	1143	1717	1024	1540	931	1399	843	1267	766	1151	697	1047
14	1122	1687	1004	1509	912	1371	826	1241	750	1127	682	1026
15	1101	1655	982	1477	892	1341	808	1215	733	1102	667	1003
16	1078	1621	960	1443	872	1310	789	1186	716	1077	652	979
17	1055	1586	937	1408	850	1278	770	1157	699	1051	635	955
18	1031	1549	913	1372	828	1245	750	1127	682	1025	618	929
19	1006	1512	888	1334	805	1211	729	1094	665	1000	601	903
20	980	1473	862	1296	782	1176	708	1064	642	974	583	877
22	927	1393	810	1218	734	1103	664	998	602	904	547	822
24	872	1310	756	1137	685	1030	620	931	561	843	509	766
26	816	1226	702	1055	635	955	574	863	519	781	472	709
28	759	1141	648	974	586	880	529	796	478	719	434	653
30	703	1056	594	893	537	807	485	729	438	658	397	597
32	647	973	542	814	489	735	441	663	398	598	361	543
34	593	891	491	738	443	665	399	600	360	541	326	490
36	540	812	442	665	398	599	359	540	323	486	293	440
38	489	735	397	596	357	536	322	484	290	435	262	394
40	441	663	358	538	322	484	290	437	261	393	237	356

Ag	42.7	38.8	35.3	32	29.1	26.5
ry	3.98	3.76	3.74	3.73	3.71	3.7

We would probably use the W14X 90 section since it is the lightest. The other tables in the Steel Manual are for different sections.

- Table 4-2 HP
- Table 4-3 Rectangular HSS
- Table 4-4 Square HSS
- Table 4-5 Round HSS
- Table 4-6 Pipe
- Table 4-7 WT
- Table 4-8 to 4-10 Double Angles
- Table 4-11 to 4-12 Single Angles

So Table 4-1 is very useful in designing W section columns. Table 4-22 is more for analysis of a column to determine its available compressive strength.

Example 2

Calculate the available compressive strength of a W14X 12 column with an unbraced length of 28 feet in both directions. The material is ASTM A992, $F_y = 50$ ksi and $F_u = 65$ ksi. Assume the column is pinned-pinned so $K=1.0$.

	C	E	F	G	J	M	N	R	Z	AB	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1	Shape	Weight	Area	Depth	b_f	t_w	t_f	k_{des}	$b_f/2t_f$	h/t_f	I_x	Z_x	S_x	r_x	I_y	Z_y	S_y	r_y	r_z	J
2		w	A	d							in^4	in^3	in^3	in	in^4	in^3	in^3	in	in	in
3		lbs/ft	in^2	in	in	in	in	in			in^4	in^3	in^3	in	in^4	in^3	in^3	in	in	in
190	W14X145	145	42.7	14.8	15.5	0.680	1.09	1.69	7.11	16.8	1710	260	232	6.33	677	133	87.3	3.98	0.00	15
191	W14X132	132	38.8	14.7	14.7	0.645	1.03	1.63	7.15	17.7	1530	234	209	6.28	548	113	74.5	3.76	0.00	12
192	W14X120	120	35.3	14.5	14.7	0.590	0.940	1.54	7.80	19.3	1380	212	190	6.24	495	102	67.5	3.74	0.00	9.3
193	W14X109	109	32.0	14.3	14.6	0.525	0.860	1.46	8.49	21.7	1240	192	173	6.22	447	92.7	61.2	3.73	0.00	7.1
194	W14X99	99.0	29.1	14.2	14.6	0.485	0.780	1.38	9.34	23.5	1110	173	157	6.17	402	83.6	55.2	3.71	0.00	5.3
195	W14X90	90.0	26.5	14.0	14.5	0.440	0.710	1.31	10.2	25.9	999	157	143	6.14	362	75.6	49.9	3.70	0.00	4.0
196	W14X82	82.0	24.0	14.3	10.1	0.510	0.855	1.45	5.92	22.4	881	139	123	6.05	148	44.8	29.3	2.48	0.00	5.0
197	W14X74	74.0	21.8	14.2	10.1	0.450	0.785	1.38	6.41	25.4	795	126	112	6.04	134	40.5	26.6	2.48	0.00	3.8

$A_g = 35.3 \text{ in}^2$, $r_x = 6.25 \text{ in}$ and $r_y = 3.74 \text{ in}$

$$\frac{KL}{r_x} = \frac{1.0(28 \text{ ft})(12 \text{ in} / \text{ft})}{6.24 \text{ in}} = 53.76$$

$$\frac{KL}{r_y} = \frac{1.0(28 \text{ ft})(12 \text{ in} / \text{ft})}{3.74 \text{ in}} = 89.84 \quad \text{use larger}$$

$$F_e = \frac{\pi^2 E}{(KL/r)^2} = \frac{\pi^2 (29,000 \text{ ksi})}{89.84^2} = 35.462 \text{ ksi}$$

$$F_{cr} = \left[0.658^{F_y/F_e} \right] F_y = \left[0.658^{50/35.462} \right] 50 \text{ ksi} = 27.712 \text{ ksi}$$

LRFD

$$\phi P_n = \phi F_{cr} A_g = 0.9(27.712 \text{ ksi})(35.3 \text{ in}^2) = 880 \text{ k}$$

ASD

$$\frac{P_n}{\Omega} = \frac{F_{cr}}{\Omega} A_g = \frac{27.712 \text{ ksi}}{1.67} (35.3 \text{ in}^2) = 586 \text{ k}$$

Let's use Table 4-22 to verify these values. $KL/r = 89.84$. Enter the table for 50 ksi steel and determine the values for F_{cr}/Ω and ϕF_{cr} that correspond to KL/r of 89 and 90. Then we interpolate to get the F_{cr}/Ω and ϕF_{cr} values for KL/r of 89.84. We multiply these values by A_g (gross area) to get P_n/Ω and ϕP_n .

F_y = 50 ksi			
KL/r	F _{cr} (ksi)	F _{cr} /Ω _c (ksi)	φ _c F _{cr} (ksi)
		ASD	LRFD
81	30.9	18.5	27.9
82	30.6	18.3	27.5
83	30.2	18.1	27.2
84	29.8	17.9	26.9
85	29.5	17.7	26.5
86	29.1	17.4	26.2
87	28.7	17.2	25.9
88	28.4	17.0	25.5
89	28.0	16.8	25.2
90	27.7	16.6	24.9
91	27.3	16.3	24.6
92	26.9	16.1	24.2
93	26.6	15.9	23.9

KL/r	F _{cr} /Ω	φF _{cr}
89	16.8	25.2
89.84	?	?
90	16.6	24.9

$$\Delta = \frac{(89.84 - 89)}{(90 - 89)}(16.8 - 16.6) = 0.168 \text{ ksi}$$

$$\frac{F_{cr}}{\Omega} = (16.8 - 0.168) = 16.632 \text{ ksi}$$

$$\frac{P_n}{\Omega} = \frac{F_{cr}}{\Omega} Ag = (16.632 \text{ ksi})(35.3 \text{ in}^2) = 587 \text{ k} \quad \text{close to } 586 \text{ k} \quad \text{OK}$$

$$\delta = \frac{(89.84 - 89)}{(90 - 89)}(25.2 - 24.9) = 0.252 \text{ ksi}$$

$$\phi F_{cr} = (25.2 - 0.252) = 24.948 \text{ ksi}$$

$$\phi P_n = \phi F_{cr} Ag = (24.948 \text{ ksi})(35.3 \text{ in}^2) = 881 \text{ k} \quad \text{close to } 880 \text{ k}$$

Table 4-1 also verifies these values. Enter the table for KL = 28 ft and determine the values P_n/Ω and ϕP_n for W14X 120. $P_n/\Omega=586$ k and $\phi P_n=880$ k

KL	W14X							
	145		132		120		109	
	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$
0	1278	1922	1162	1746	1057	1589	958	1440
6	1248	1876	1131	1700	1029	1546	932	1401
7	1237	1860	1120	1683	1019	1531	923	1388
8	1225	1841	1108	1665	1007	1514	913	1372
9	1211	1821	1094	1644	994	1495	901	1354
10	1196	1798	1078	1621	980	1473	888	1335
11	1180	1773	1062	1596	965	1450	874	1314
12	1162	1746	1044	1568	948	1425	859	1291
13	1143	1717	1024	1540	931	1399	843	1267
14	1122	1687	1004	1509	912	1371	826	1241
15	1101	1655	982	1477	892	1341	808	1215
16	1078	1621	960	1443	872	1310	789	1186
17	1055	1586	937	1408	850	1278	770	1157
18	1031	1549	913	1372	828	1245	750	1127
19	1006	1512	888	1334	805	1211	729	1096
20	980	1473	862	1296	782	1176	708	1064
22	927	1393	810	1218	734	1103	664	998
24	872	1310	756	1137	685	1030	620	931
26	816	1226	702	1055	635	955	574	863
28	759	1141	648	974	586	880	529	796
30	703	1056	594	893	537	807	485	729
32	647	973	542	814	489	735	441	663
34	593	891	491	738	443	665	399	600
36	540	812	442	665	398	599	359	540

Example 3

Calculate the available strength of a W14X 99 with $L_x= 30$ ft and $L_y= 15$ ft. The material is ASTM A992 so $F_y= 50$ ksi. Assume the connections are pinned-pinned so $K=1.0$.

1	Shape	Weight	Area	Depth	b_f	t_w	t_f	k_{des}	$b_f/2t_f$	h/t_f	I_x	Z_x	S_x	r_x	I_y	Z_y	S_y	r_y	r_z	J
2		w	A	d	in	in	in	in			in ⁴	in ³	in ³	in	in ⁴	in ³	in ³	in	in	in ⁴
3		lbs/ft	in ²	in	in	in	in	in			in ⁴	in ³	in ³	in	in ⁴	in ³	in ³	in	in	in ⁴
190	W14X145	145	42.7	14.8	15.5	0.680	1.09	1.69	7.11	16.8	1710	260	232	6.33	677	133	87.3	3.98	0.00	15
191	W14X132	132	38.8	14.7	14.7	0.645	1.03	1.63	7.15	17.7	1530	234	209	6.28	548	113	74.5	3.76	0.00	12
192	W14X120	120	35.3	14.5	14.7	0.590	0.940	1.54	7.80	19.3	1380	212	190	6.24	495	102	67.5	3.74	0.00	9.3
193	W14X109	109	32.0	14.3	14.6	0.525	0.860	1.46	8.49	21.7	1240	192	173	6.22	447	92.7	61.2	3.73	0.00	7.1
194	W14X99	99.0	29.1	14.2	14.6	0.485	0.780	1.38	9.34	23.5	1110	173	157	6.17	402	83.6	55.2	3.71	0.00	5.3
195	W14X90	90.0	26.5	14.0	14.5	0.440	0.710	1.31	10.2	25.9	999	157	143	6.14	362	75.6	49.9	3.70	0.00	4.0
196	W14X82	82.0	24.0	14.3	10.1	0.510	0.855	1.45	5.92	22.4	881	139	123	6.05	148	44.8	29.3	2.48	0.00	5.0
197	W14X74	74.0	21.8	14.2	10.1	0.450	0.785	1.38	6.41	25.4	795	126	112	6.04	134	40.5	26.6	2.48	0.00	3.8
198	W14X68	68.0	20.0	14.0	10.0	0.415	0.720	1.31	6.97	27.5	722	115	103	6.01	121	36.9	24.2	2.46	0.00	3.0
199	W14X61	61.0	17.9	13.9	10.0	0.375	0.645	1.24	7.75	30.4	640	102	92.1	5.98	107	32.8	21.5	2.45	0.00	2.1
200	W14X53	53.0	15.6	13.9	8.06	0.370	0.660	1.25	6.11	30.9	541	87.1	77.8	5.89	57.7	22.0	14.3	1.92	0.00	1.9
201	W14X48	48.0	14.1	13.8	8.03	0.340	0.595	1.19	6.75	33.6	484	78.4	70.2	5.85	51.4	19.6	12.8	1.91	0.00	1.4

$A_g= 29.1$ in², $r_x= 6.17$ in and $r_y=3.71$ in.

Now we calculate KL/r and determine which to use to enter table 4-22.

$$\frac{KL_x}{r_x} = \frac{1.0(30 \text{ ft})(12 \text{ in} / \text{ ft})}{6.17 \text{ in}} = 58.347 \quad \text{use larger}$$

$$\frac{KL_y}{r_y} = \frac{1.0(15 \text{ ft})(12 \text{ in} / \text{ ft})}{3.71 \text{ in}} = 48.518$$

Interpolate values F_{cr}/Ω and ϕF_{cr} from Table 4-22 for $KL/r = 58.347$

KL/r	$F_y = 50 \text{ ksi}$		
	F_{cr} (ksi)	F_{cr}/Ω_c (ksi) ASD	$\phi_c F_{cr}$ (ksi) LRFD
48	42.2	25.3	38.0
49	41.9	25.1	37.8
50	41.6	24.9	37.5
51	41.3	24.8	37.2
52	41.0	24.6	36.9
53	40.7	24.4	36.6
54	40.4	24.2	36.4
55	40.1	24.0	36.1
56	39.8	23.8	35.8
57	39.4	23.6	35.5
58	39.1	23.4	35.2
59	38.8	23.2	34.9
60	38.4	23.0	34.6
61	38.1	22.8	34.3
62	37.7	22.6	34.0
63	37.4	22.4	33.7

ASD

$$\frac{F_{cr}}{\Omega} = 23.3306 \text{ ksi}$$

$$\frac{P_n}{\Omega} = \frac{F_{cr}}{\Omega} Ag = (23.3306 \text{ ksi})(29.1 \text{ in}^2) = 679 \text{ k}$$

LRFD

$$\phi F_{cr} = 35.0959 \text{ ksi}$$

$$\phi P_n = \phi F_{cr} Ag = (35.0959 \text{ ksi})(29.1 \text{ in}^2) = 1021 \text{ k}$$

Now to use Table 4-1, $r_x/r_y=1.66$ so $KL = (30 \text{ ft})/1.66 = 18 \text{ ft}$. Enter Table 4-1 for $KL= 18 \text{ ft}$ and $W14X 99$.

W14X										
KL	145		132		120		109		99	
	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$	ASD P_n/Ω_c	LRFD $\phi_c P_n$
0	1278	1922	1162	1746	1057	1589	958	1440	871	1310
6	1248	1876	1131	1700	1029	1546	932	1401	848	1274
7	1237	1860	1120	1683	1019	1531	923	1388	839	1261
8	1225	1841	1108	1665	1007	1514	913	1372	830	1247
9	1211	1821	1094	1644	994	1495	901	1354	819	1231
10	1196	1798	1078	1621	980	1473	888	1335	807	1213
11	1180	1773	1062	1596	965	1450	874	1314	794	1194
12	1162	1746	1044	1568	948	1425	859	1291	780	1173
13	1143	1717	1024	1540	931	1399	843	1267	766	1151
14	1122	1687	1004	1509	912	1371	826	1241	750	1127
15	1101	1655	982	1477	892	1341	808	1215	733	1102
16	1078	1621	960	1443	872	1310	789	1186	716	1077
17	1055	1586	937	1408	850	1278	770	1157	698	1050
18	1031	1549	913	1372	828	1245	750	1127	680	1022
19	1006	1512	888	1334	805	1211	729	1096	661	994
20	980	1473	862	1296	782	1176	708	1064	642	964
22	927	1393	810	1218	734	1103	664	998	602	904
24	872	1310	756	1137	685	1030	620	931	561	843
26	816	1226	702	1055	635	955	574	863	519	781
28	759	1141	648	974	586	880	529	796	478	719
30	703	1056	594	893	537	807	485	729	438	658
33	647	972	542	814	490	735	441	662	398	598

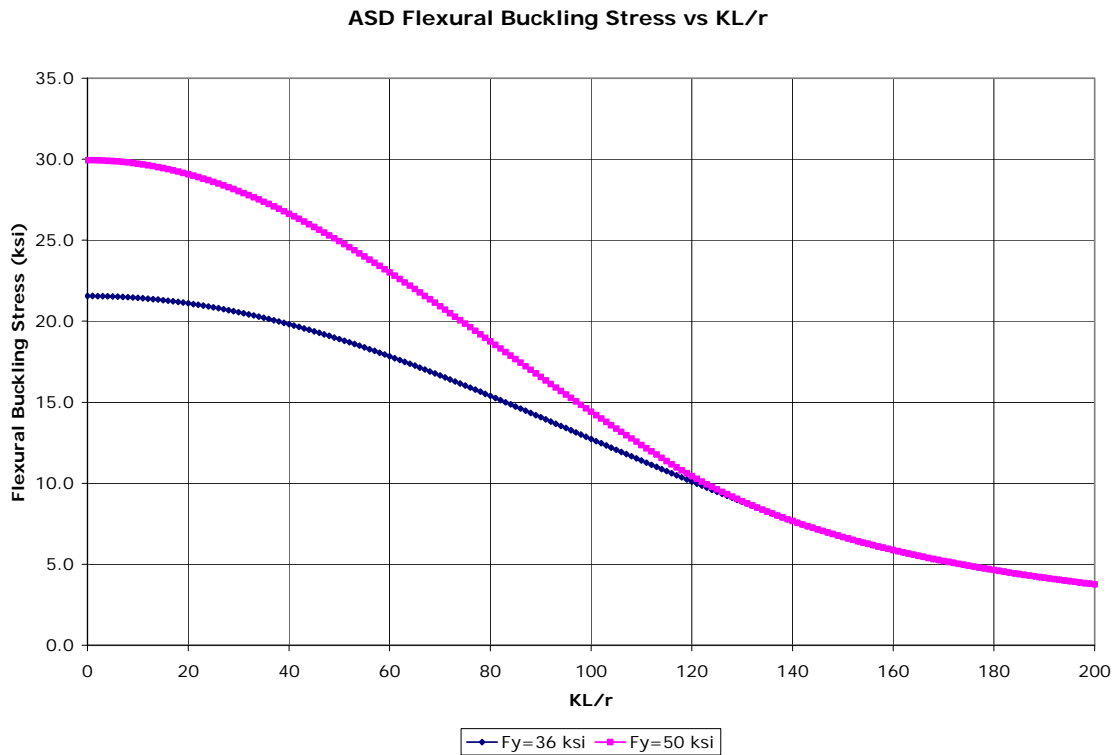
$P_n/\Omega=680 \text{ k}$ and $\phi P_n=1022 \text{ k}$ which are very close to 679 k and 1021 k from table 4-22.

Conclusion

You can use the equations in section E3 of the specification to design columns by trial-and-error or to analyze the nominal compressive strength of columns. These equations are for axial compressive loads on W sections. Table 4-1 is used to assist with the design of W sections under axial compression loads for $F_y= 50 \text{ ksi}$. Table 4-22 is used to calculate the critical stress for $F_y= 35 \text{ ksi}$, 36 ksi , 42 ksi , 48 ksi and 50 ksi . The critical stress times the gross area give the compressive strength of the column.

Steel is recyclable material.

This is a plot of a part of Table 4-22 for ASD values.



It appears that we use equation E3-2 for calculating F_{cr} to about $KL/r = 120$ and then we use equation E3-3 to calculate F_{cr} to $KL/r = 200$. LRFD values would plot about the same.