It's a bird… it's a plane…

it's… Super Table!

steelwise

ONE-STOP SHOP

BY ABBAS AMINMANSOUR, PHD

WHAT IF THERE WAS a table that could be directly used for designing tension members, compression members, flexural members, members subject to tension and bending and even members subject to compression and bending?

Good news: There is.

The 15th Edition of the AISC *Steel Construction Manual* (available this summer at **www.aisc.org/publications**) includes a new table, Table 6-2, that can serve as Swiss Army Knife of sorts for designing with all of these members. Additional information such as available shear strength, moment of inertia and radius of gyration is also included in the table to help designers with other strength and serviceability checks.

Table 6-2 lists all W-sections included in the latest AISC database of shapes and has been developed for steels with F_y = 50 ksi. This table will also be incorporated into V15.0 *Design Examples*, Part IV, for W-sections with F_y = 65 and 70 ksi, for HSS of ASTM A500 Grade C and ASTM A1085 material and for pipe of ASTM A53 Grade B material. Appropriate provisions of the 2016 AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360-16), available at **www.aisc.org/specifications**, have been addressed in the development of this new table.

Table Format

The main body of Table 6-2 follows a butterfly format with three W-sections per page. Figure 1 shows a sample page from the table with its general appearance. Available compressive strengths are listed on the left half of the page for both ASD and LRFD methods. This area of the table is boxed in red in Figure 1. The right half of the page lists the available flexural strengths of the same sections, also for both ASD and LRFD. This area of the table is boxed in blue in Figure 1.

The distance values listed in the middle of the page represent the effective length, L_c, with respect to the least radius of gyration, r_y, when looking up compressive strength of a section on the left half of the page. Similarly, the same distance values listed in the middle of the page serve as the unbraced length, L_b, when looking up the available flexural strength of a section on the right-hand half of the page.

The bottom portion of Table 6-2, labeled "Properties," lists helpful strengths and properties of the same shapes (boxed in black in Figure 1). Available strengths in tension based on the limit states of yielding and rupture as well as available strengths in shear and bending about the Y-Y axis are also included in the bottom of the table. The Properties portion of the table also includes other values such as L_p, L_r, I_x, I_y, r_y and r_x/r_y.

Table 6-2 (continued)
Available Strength for Members Subject to Axial, Shear, Flexural and Combined Forces
W-Shapes

F_y = 50 ksi
F_u = 65 ksi

W12

W12×						Shape	W12×					
72		65		58		lb/ft	72		65[f]		58	
P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	Design	M_{nx}/Ω_b	$\phi_b M_{nx}$	M_{nx}/Ω_b	$\phi_b M_{nx}$	M_{nx}/Ω_b	$\phi_b M_{nx}$
Available Compressive Strength, kips							Available Flexural Strength, kip-ft					
ASD	LRFD	ASD	LRFD	ASD	LRFD	Effective length, L_c, ft, with respect to least radius of gyration, r_y, or unbraced length, L_b, ft, for X-X axis bending	ASD	LRFD	ASD	LRFD	ASD	LRFD
632	949	572	859	509	765	0	269	405	237	356	216	324
606	911	549	825	479	720	6	269	405	237	356	216	324
597	898	540	812	469	705	7	269	405	237	356	216	324
587	883	531	798	457	687	8	269	405	237	356	216	324
576	866	521	783	445	668	9	269	405	237	356	215	323
564	847	510	766	431	647	10	269	405	237	356	211	318
550	827	497	747	416	625	11	268	404	237	356	207	312
536	806	484	728	400	601	12	265	398	237	356	204	306
521	783	470	707	384	577	13	261	392	233	350	200	301
505	759	456	685	367	551	14	257	387	230	345	196	295
489	735	441	663	349	525	15	254	381	226	340	192	289
472	709	426	640	332	499	16	250	376	222	334	189	283
455	683	410	616	314	472	17	246	370	219	329	185	278
437	656	393	591	296	445	18	242	364	215	323	181	272
419	629	377	567	278	418	19	239	359	212	318	177	266
401	602	360	542	261	392	20	235	353	208	313	173	261
364	547	327	492	227	341	22	228	342	201	302	166	249
328	493	294	442	194	292	24	220	331	194	291	158	238
292	440	262	394	165	249	26	213	320	186	280	151	227
259	389	231	348	143	214	28	205	309	179	269	143	215
226	340	202	304	124	187	30	198	297	172	259	135	203
199	299	178	267	109	164	32	190	286	165	248	125	188
176	265	157	236	96.7	145	34	183	275	158	237	116	174
157	236	140	211	86.3	130	36	176	264	149	224	108	163
141	212	126	189	77.4	116	38	167	251	139	209	102	153
127	191	114	171	69.9	105	40	157	236	130	196	95.7	144
115	173	103	155			42	148	223	123	185	90.5	136
105	158	93.9	141			44	140	211	116	175	85.8	129
96.2	145	85.9	129			46	133	200	110	166	81.6	123
88.3	133	78.9	119			48	127	191	105	158	77.8	117
81.4	122	72.7	109			50	121	182	100	150	74.3	112

Properties

Available Strength in Tensile Yielding, kips					
P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$
632	950	572	860	509	765
Available Strength in Tensile Rupture ($A_e = 0.75A_g$), kips					
P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$
514	770	465	697	416	624
Available Strength in Shear, kips					
V_n/Ω_v	$\phi_v V_n$	V_n/Ω_v	$\phi_v V_n$	V_n/Ω_v	$\phi_v V_n$
106	159	94.4	142	87.8	132
Available Strength in Flexure about Y-Y Axis, kip-ft					
M_{ny}/Ω_b	$\phi_b M_{ny}$	M_{ny}/Ω_b	$\phi_b M_{ny}$	M_{ny}/Ω_b	$\phi_b M_{ny}$
123	185	107	161	81.1	122

Limiting Unbraced Lengths, ft					
L_p	L_r	L_p	L_r	L_p	L_r
10.7	37.5	11.9	35.1	8.87	29.8
Area, in.^{2}					
21.1		19.1		17.0	
Moment of Inertia, in.^{4}					
I_x	I_y	I_x	I_y	I_x	I_y
597	195	533	174	475	107
r_y, in.					
3.04		3.02		2.51	
r_x/r_y					
1.75		1.75		2.10	

[f] Shape exceeds compact limit for flexure with F_y = 50 ksi.
Note: Heavy line indicates L_c/r equal to or greater than 200.

Figure 1: A sample page from Table 6-2.

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➤ Figure 2: Compression strength portion of a sample page from Table 6-2.

W12×						Shape	
72		65		58		lb/ft	
P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	Design	
Available Compressive Strength, kips							
ASD	LRFD	ASD	LRFD	ASD	LRFD		
632	949	572	859	509	765	Effective length, L_c, ft, with respect to least radius of gyration, r_y, or unbraced length, L_b, ft, for X-X axis bending	0
606	911	549	825	479	720		6
597	898	540	812	469	705		7
587	883	531	798	457	687		8
576	866	521	783	445	668		9
564	847	510	766	431	647		10
550	827	497	747	416	625		11
536	806	484	728	400	601		12
521	783	470	707	384	577		13
505	759	456	685	367	551		14
489	735	441	663	349	525		15
472	709	426	640	332	499		16
455	683	410	616	314	472		17
437	656	393	591	296	445		18
419	629	377	567	278	418		19
401	602	360	542	261	392		20
364	547	327	492	227	341		22
328	493	294	442	194	292		24
292	440	262	394	165	249		26
259	389	231	348	143	214		28
226	340	202	304	124	187		30
199	299	178	267	109	164		32
176	265	157	236	96.7	145		34
157	236	140	211	86.3	130		36
141	212	126	189	77.4	116		38
127	191	114	171	69.9	105		40
115	173	103	155				42
105	158	93.9	141				44
96.2	145	85.9	129				46
88.3	133	78.9	119				48
81.4	122	72.7	109				50

Design of Compression Members

The available strength in compression of all W-sections is included directly in the new table. To design a member of a known nominal depth, simply go to the table with $(L_c)_y$, the effective length with respect to the least radius of gyration, and select a shape that has the desired available strength in compression listed on the left half of the page.

If X-direction flexural buckling controls, enter the table with the equivalent effective length using Equation 1 below just as you would when using Table 4-1 of the AISC *Manual*.

$$(L_c)_{eq} = \frac{(L_c)_x}{(r_x/r_y)} \qquad \text{(Equation 1)}$$

The available compressive strengths listed in Table 6-2 follow pertinent provisions of Chapter E of the *Specification* and account for the width-to-thickness ratio requirements of Section B4 of the *Specification*. Therefore, no further checks of the element width-to-thickness ratios or slenderness ratio are required. Remember that all W-sections are listed in Table 6-2, including shapes that may not be ordinarily used as columns but could be appropriate for certain situations nevertheless.

Figure 2 serves as a close-up of the red-boxed portion of Figure 1. Based on this figure, an A992 steel W12×72 with a critical effective length of 14 ft, with respect to the least radius of gyration, $(L_c)_y$, has an available strength in compression of 505 kips and 759 kips based on the ASD and LRFD methods, respectively. At the same time, the same shape with an effective length with respect to the X-axis, $(L_c)_x$, of 28 ft has an equivalent effective length as follows, using Equation 1 above.

$$(L_c)_{eq} = \frac{28\text{ ft}}{(1.75)} = 16\text{ ft}$$

To determine the strength of the column with $(L_c)_x$ = 28 ft, enter Table 6-2 with an effective length of $(L_c)_{eq}$ = 16 ft and read off the available strength. This column has an available strength in compression of 472 kips and 709 kips for $(L_c)_x$ = 28 ft based on the ASD and LRFD methods, respectively. Note that values of the r_x/r_y are conveniently listed at the bottom under the Properties portion of the same page (see Figures 1 and 5).

As another illustration, per Figure 3, an ASTM A992 W16×31 column with an effective length with respect to the least radius of gyration, $(L_c)_y$ = 10 ft has an available strength in compression of 127 kips and 190 kips based on the ASD and LRFD methods, respectively.

Note that a W16×31 is a slender-element column section in A992 steel. Therefore, in this case the provisions of Section E7 of the *Specification* ("Members with Slender Elements") have been used in determining the strength of the column. Keep in mind that the 2016 *Specification* has new provisions applying to columns with slender-element sections.

W16×						Shape	
40[c]		36[c]		31[c]		lb/ft	
P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	Design	
Available Compressive Strength, kips							
ASD	LRFD	ASD	LRFD	ASD	LRFD		
331	497	293	440	245	369	Effective length, L_c, ft, with respect to least radius of gyration, r_y, or unbraced length, L_b, ft, for X-X axis bending	0
289	435	254	382	194	291		6
276	414	241	363	178	268		7
261	392	228	342	161	243		8
245	368	213	320	144	217		9
228	342	198	297	127	190		10
211	317	182	274	108	162		11
191	287	165	247	90.6	136		12
172	258	147	221	77.2	116		13
153	230	130	195	66.6	100		14
135	203	114	171	58.0	87.1		15
119	178	99.9	150	51.0	76.6		16
105	158	88.5	133	45.1	67.8		17
93.7	141	78.9	119	40.3	60.5		18
84.1	126	70.8	106	36.1	54.3		19
75.9	114	63.9	96.1				20
62.7	94.3	52.8	79.4				22
52.7	79.2	44.4	66.7				24
44.9	67.5						26
							28
							30
							32
							34
							36
							38
							40
							42
							44

➤ Figure 3: Compression strength portion of a sample page from Table 6-2, with slender-element sections.

Shape		W21×					
lb/ft		50		48[f]		44	
Design		M_{nx}/Ω_b	$\phi_b M_{nx}$	M_{nx}/Ω_b	$\phi_b M_{nx}$	M_{nx}/Ω_b	$\phi_b M_{nx}$
		Available Flexural Strength, kip-ft					
		ASD	LRFD	ASD	LRFD	ASD	LRFD
Effective length, L_c, ft, with respect to least radius of gyration, r_y, or unbraced length, L_b, ft, for X-X axis bending	0	274	413	265	398	238	358
	6	257	387	265	398	221	332
	7	245	368	256	385	210	315
	8	233	350	246	370	198	298
	9	221	332	236	355	187	281
	10	209	314	226	340	176	264
	11	197	295	217	326	165	248
	12	184	277	207	311	154	231
	13	172	259	197	296	142	214
	14	157	236	187	282	125	188
	15	140	210	178	267	111	167
	16	126	189	168	252	99.9	150
	17	114	172	155	233	90.4	136
	18	105	157	140	210	82.4	124
	19	96.2	145	128	192	75.6	114
	20	89.0	134	117	176	69.8	105
	22	77.3	116	99.8	150	60.3	90.7
	24	68.2	103	86.7	130	53.0	79.7
	26	61.0	91.7	76.3	115	47.3	71.0
	28	55.2	82.9	68.1	102	42.6	64.0
	30	50.4	75.7	61.3	92.2	38.8	58.3
	32	46.3	69.6	55.8	83.8	35.6	53.4
	34	42.9	64.5	51.1	76.8	32.8	49.4
	36	39.9	60.0	47.1	70.8	30.5	45.9
	38	37.4	56.2	43.7	65.7	28.5	42.8
	40	35.1	52.8	40.7	61.2	26.7	40.2
	42	33.1	49.8	38.2	57.4	25.2	37.9
	44	31.4	47.2	35.9	53.9	23.8	35.8

Design of Flexural Members

Figure 4 illustrates a magnified portion of a sample page from Table 6-2 with available flexural strengths listed on the right-hand side of the page.

Again, all W-sections are listed in the table, including those that may not be ordinarily used as beams but may be appropriate for certain situations.

Values of the available flexural strength listed in Table 6-2 meet the appropriate provisions of Chapter F of the *Specification* and account for compact/noncompact/slender-element section provisions of Section B4. Therefore, there is no need for width-to-thickness ratio checks of the selected W-section. Further, appropriate AISC equations have been used in developing the tabulated values with respect to the unbraced length of the beam relative to limiting unbraced lengths L_p and L_r. Thus, no additional check of the unbraced length is needed when using this table.

The procedures for design of a flexural member using Table 6-2 is similar to design for compression members described above. The designer enters the table with the unbraced length L_b of the beam and selects a W-section from the desired nominal depth with available flexural strength equal to or greater than the required strength. Note that flexural strengths are listed on the right half of the butterfly formatted page. The left and right halves of the table are clearly labeled at the top to avoid confusion.

Figure 4: Flexural strength portion of a sample page from Table 6-2.

As an example, per Figure 4, an A992 W21×48 with an unbraced length of 10 ft has an available flexural strength of 226 kip-ft and 340 kip-ft based on the ASD and LRFD methods, respectively. Remember that a W21×48 of ASTM A992 is a noncompact beam section. However, Table 6-2 already accounts for this classification and there is no need to check the width-to-thickness ratio of the compression elements of this beam section. Also, there is no need to compare the unbraced length to L_p and L_r, though values of L_p and L_r are listed at the bottom of the page for convenience.

Available flexural strength of W-shapes bent about their minor axis is also included in the Properties portion of the super table in the bottom, as shown in Figure 5. Given that lateral torsional buckling does not apply to bending of W-sections about their minor axis, these values are independent of any length and are a single value for each shape. Again, the width-to-thickness ratio provisions of the *Specification* have been followed in developing the available flexural strength of W-sections bent about their minor axis. Therefore, no further check of the compression element width-to-thickness ratios is required.

Tension Members and Shear Strength

The bottom portion of Table 6-2 includes available strengths in tension of all W-sections. Both yielding and rupture limit states are addressed in generating the listed values (Figure 5). However, it should be noted that the values listed based on the rupture limit state assume an effective area of $A_e = 0.75A_g$ just as is the case when using Table 5-1 of the *Manual*. Therefore, the designer should check the available tensile strength of the member based on the calculated A_e for the rupture limit state. The table does not address other limit states that may control design of tension members, such as block shear strength.

As illustrated in Figure 5, the bottom portion of Table 6-2 also includes the available shear strength of all W-sections for Grade-50 steel based on the ASD and LRFD methods. Provisions of Chapter G of the *Specification* have been used for calculation of the tabulated values.

Design of Members Subject to Combined Forces

The new table provides direct strengths for members subject to combined forces, namely tension and bending or compression and bending. Recall Table 6-1 of previous versions of the *Manual*, which provided coefficients for design of members subject to combined forces. That table is available in V15.0 *Design Examples*, Part IV, available at **www.aisc.org**.

To check compliance of a member subject to combined forces with the appropriate equation of Chapter H of the *Specification*, refer to Table 6-2 as described previously to look up the appropriate available axial and flexural strengths for use in Equation H1-1a or H1-1b.

Using the table for designing members subject to combined forces not only readily provides available flexural and axial (tension or compression) strength of any W-section, but also saves you from having to check width-to-thickness ratios and unbraced length ranges when considering beam or column action of the member.

As an example of using Table 6-2 for checking a member subject to combined forces, consider an ASTM A992 W12×72 beam-column as follows.

➤ Figure 5: Bottom portion of a sample page from Table 6-2.

Table 6-2 (continued)
Available Strength for Members Subject to Axial, Shear, Flexural and Combined Forces
W-Shapes

F_y = 50 ksi
F_u = 65 ksi

W10

W10×						Shape	W10×					
33		30		26		lb/ft	33		30		26	
P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	Design	M_{nx}/Ω_b	$\phi_b M_{nx}$	M_{nx}/Ω_b	$\phi_b M_{nx}$	M_{nx}/Ω_b	$\phi_b M_{nx}$
Available Compressive Strength, kips							Available Flexural Strength, kip-ft					
ASD	LRFD	ASD	LRFD	ASD	LRFD		ASD	LRFD	ASD	LRFD	ASD	LRFD
						Properties						
Available Strength in Tensile Yielding, kips							Limiting Unbraced Lengths, ft					
P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$		L_p	L_r	L_p	L_r	L_p	L_r
291	437	265	398	228	342		6.85	21.8	4.84	16.1	4.80	14.9
Available Strength in Tensile Rupture ($A_e = 0.75A_g$), kips							Area, in.^{2}					
P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$	P_n/Ω_t	$\phi_t P_n$		9.71		8.84		7.61	
237	355	215	323	186	278		Moment of Inertia, in.^{4}					
Available Strength in Shear, kips							I_x	I_y	I_x	I_y	I_x	I_y
V_n/Ω_v	$\phi_v V_n$	V_n/Ω_v	$\phi_v V_n$	V_n/Ω_v	$\phi_v V_n$		171	36.6	170	16.7	144	14.1
56.4	84.7	63.0	94.5	53.6	80.3		r_y, in.					
Available Strength in Flexure about Y-Y Axis, kip-ft							1.94		1.37		1.36	
M_{ny}/Ω_b	$\phi_b M_{ny}$	M_{ny}/Ω_b	$\phi_b M_{ny}$	M_{ny}/Ω_b	$\phi_b M_{ny}$		r_x/r_y					
34.9	52.5	22.1	33.2	18.7	28.1		2.16		3.20		3.20	

ASD Method:

P_a = 100 kips (compression), $(L_c)_y = L_b$ = 15 ft,
$(M_a)_x$ = 150 kip-ft, $(M_a)_y$ = 30 kip-ft

Obtain the following from Table 6-2:

For $(L_c)_y$ = 15 ft, P_n/Ω_c = 489 kips
For L_b = 15 ft, M_{nx}/Ω_c = 254 kip-ft
M_{ny}/Ω_c = 123 kip-ft

Because $\dfrac{P_r}{P_c} = \dfrac{100 \text{ kips}}{489 \text{ kips}} = 0.204 > 0.20$,

use AISC Equation H1-1a as follows:

$$\frac{P_a}{P_n/\Omega_c} + \frac{8}{9}\left(\frac{M_{ax}}{M_{nx}/\Omega_c} + \frac{M_{ay}}{M_{ny}/\Omega_c}\right)$$
$$= \frac{100 \text{ kips}}{489 \text{ kips}} + \left(\frac{8}{9}\right)\left(\frac{150 \text{ kip-ft}}{254 \text{ kip-ft}} + \frac{30 \text{ kip-ft}}{123 \text{ kip-ft}}\right)$$
$$= 0.204 + 0.525 + 0.217 = 0.946 < 1.0$$

A992 W12×72 satisfies the provisions of Chapter H of the *Specification*.

LRFD Method:

P_u = 170 kips (compression), $(L_c)_y = L_b$ = 15 ft,
$(M_u)_x$ = 210 kip-ft, $(M_u)_y$ = 40 kip-ft

Obtain the following from Table 6-2 as described above:

For $(L_c)_y$ = 15 ft, $\phi_c P_n$ = 735 kips
For L_b = 15 ft, $\phi_b M_{nx}$ = 381 kip-ft
$\phi_b M_{ny}$ = 185 kip-ft

Because $\dfrac{P_u}{\phi_c P_n} = \dfrac{170 \text{ kips}}{735 \text{ kips}} = 0.231 > 0.20$,

use AISC Equation H1-1a as follows:

$$\frac{P_u}{\phi_c P_n} + \frac{8}{9}\left(\frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}}\right)$$
$$= \frac{170 \text{ kips}}{735 \text{ kips}} + \left(\frac{8}{9}\right)\left(\frac{210 \text{ kip-ft}}{381 \text{ kip-ft}} + \frac{40 \text{ kip-ft}}{185 \text{ kip-ft}}\right)$$
$$= 0.231 + 0.490 + 0.192 = 0.913 < 1.0$$

A992 W12×72 satisfies the provisions of Chapter H of the *Specification*.

Additional Information

The Properties portion of Table 6-2 in the bottom of the table (Figure 5) includes such values as L_p and L_r. As noted earlier, the available flexural strength of W-sections listed have been calculated based on the unbraced lengths provided in the middle of the table, and there is no need for further checks. The values of L_p and L_r are listed for informational purposes only.

In addition, the moments of inertia of sections about both axes are listed in the bottom portion of Table 6-2 to facilitate checking serviceability requirements. Further, values of r_x/r_y are included in the table for use when needed, such as the case of using Equation 1 discussed earlier.

There are a number of design tables in the *Manual* that provide various strengths for members subject to different forces, such as Table 3-2: W-Shapes Selection by Z_x, Table 4-1: Available Strength in Axial Compression, Table 5-1: Available Strength in Axial Tension and Table 6-1: Combined Flexure and Axial Forces, all of which existed in previous editions of the *Manual*. All those tables are still included in the 15th Edition, with the exception of Table 6-1, which has moved to the AISC *Design Examples*, Part IV. And Table 6-2 brings together all of this information into one location for more convenience. ■