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Design Aids for Built-Up I-Shaped Beams with Slender Webs

PAUL P. NASADOS, JR.

With the advent of the 13th Edition AISC *Steel Construction Manual* (AISC, 2005a), hereafter referred to as the AISC *Steel Manual*, available strength design aids have been prepared for use in the design of built-up I-shaped beams with slender webs, with or without stiffeners, for allowable strength design (ASD) and load and resistance factor design (LRFD) methodologies.

While the application of slender web built-up sections is not as common as rolled shapes, their use is warranted under conditions of economy, specialization or unusual constraints. Section F4 of the *Specification for Structural Steel Buildings* (AISC, 2005b), hereafter referred to as the AISC *Specification*, governs the flexural design of beams with noncompact webs for doubly or singly symmetric I-shaped members; however, Section F5 provides a simplified and conservative approach to the flexural design of beams with compact, noncompact, or slender webs by ignoring the torsional properties of the cross section. This approach greatly simplifies the design equations; however, the engineer is still confronted with determining the controlling limit state by applying the numerous equations in Section F5. This is compounded by the provisions in Sections G2 and G3 for the limit states pertaining to shear and the proportioning limits imposed by Section F13.2. Hence, the available strength tables appearing in this paper were created to aid in the design of built-up I-shaped slender web beams.

Tables originally prepared by Nasados (1997) served as design aids for plate girder design in accordance with the *Load and Resistance Factor Design Specification for Structural Steel Buildings* (AISC, 1993). The plate girder design aids included homogeneous sections for 36- and 50-ksi yield strengths, and hybrid sections consisting of 50-ksi flanges and 36-ksi webs. Those original design aids have been revised and updated to reflect the current specifications and industry practice of using homogeneous material and minimum yield strength of 50 ksi.

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An example is presented to demonstrate the usage of the available strength tables. The example mimics the format of the design examples that appear on the companion CD that accompanies the AISC *Steel Manual* (AISC, 2005a).

GENERATION OF THE AVAILABLE STRENGTH TABLES

The provisions of Sections F5, G2, and G3 (AISC, 2005b) are largely based on the work of Basler and Thurlimann (1961) and Basler (1961a and 1961b) and essentially have remained unchanged since their adoption into the AISC specifications. Available strength tables were generated by employing the equations presented in the current *Specification* for each limit state with the following two simplifications: First, the effective radius of gyration of the compressed portion of the girder used for the calculation of the lateral torsional buckling limit state in Section F5.2 is approximated as the radius of gyration of the compression flange plus one-third of the web that is in compression; this approximation appears as a user note at the end of Section F4.2, specifically,

$$r_t \approx \frac{b_{fc}}{\sqrt{12\left(1+\dfrac{a_w}{6}\right)}} \tag{1}$$

where

$$a_w = \frac{h_c t_w}{b_{fc} t_{fc}} \le 10 \tag{2}$$

Second, the following equations were used for the slenderness parameters in Section F5.3 for the compression flange local buckling limit state:

$$\lambda_{fc} = \lambda = \frac{b_{fc}}{2t_{fc}} \tag{3}$$

(AISC *Specification* Table B4.1, Case 2)

$$\lambda_{pf} = \lambda_p = 0.38\sqrt{E/F_{yfc}} \tag{4}$$

(AISC *Specification* Table B4.1, Case 2, Footnote b)

$$\lambda_{rf} = \lambda_r = 0.95\sqrt{k_c E/F_L} \tag{5}$$

where
$F_L = 0.7F_y$
(AISC *Specification* Table B4.1, Case 2, footnote b)

Equation 5 yields:

$$\lambda_{rf} = 0.95\sqrt{\frac{k_c E}{0.7F_{yfc}}} \tag{6}$$

where

$$k_c = \frac{4}{\sqrt{h/t_w}} \quad 0.35 \le k_c \le 0.76 \tag{7}$$

(AISC *Specification* Table B4.1, footnote a)

Since there was a tremendous amount of data and innumerable subsequent calculations used to generate the available strength tables, a spreadsheet was programmed (Microsoft Excel utilizing Visual Basic for Applications) to determine the pertinent values shown in the tables. Equations for each limit state were programmed into the spreadsheet according to the specification and as noted earlier. Dimensions and section properties were calculated by applying basic geometric and mechanics equations.

FLEXURAL AND SHEAR DESIGN LIMIT STATES

The programmed spreadsheet determined the nominal flexural strength by calculating and selecting the controlling limit state for compression flange yielding per Section F5.1; lateral torsional buckling per Section F5.2, utilizing an effective radius of gyration given in Equation 1; compression flange local buckling per Section F5.3 utilizing Equations 3 to 7; and tension flange yielding per Section F5.4. Vertical flange buckling is checked by the program per the requirements of Section F13.2. It should be noted that the sections shown in the tables are all doubly symmetric; therefore, Equation F13-2 of Section F13.2 is not applicable, and no further treatment of this requirement is given within the tables.

The nominal shear strength is determined in the same fashion as the flexural strength but for the limit states of shear yielding and shear buckling per Section G2.1 and the limit state of tension field yielding per Section G3.2 subjected to the limits imposed by Section G3.1. Two shear strength tables were generated: one for utilizing the post buckling strength of the web including tension field action and one for excluding tension field action. This is clearly stated on each table. The requirements for including tension field action per Section G3.1 are inherent in the tables by programmed checks in the spreadsheet.

The allowable strength (ASD) or design strength (LRFD) for flexure and shear were determined by applying the appropriate safety or resistance factor. Consequently, the data shown in the available strength tables is the result of the generation process.

AVAILABLE STRENGTH TABLES

The available strength tables (Appendices B and C) provide the available flexural or shear strength in a tabular format based on either ASD or LRFD methodologies. The tables were generated for welded doubly symmetric I-shaped slender web beams. All tables display the available strength for ASD or LRFD in a side-by-side format similar to the aids presented in the AISC *Steel Manual* (AISC, 2005a). Each table displays the appropriate safety and resistance factors and material yield strength in the heading of the table. The flexural strength tables also indicate the beam bending coefficient, C_b, set to unity. Local effects due to concentrated loads are not accounted for in the tables.

DIMENSIONS

There are an infinite number of combinations that could be generated for design tables; however, that would preclude publishing in a journal. Thus, the tables have incorporated some practical minimum fabrication sizes and author-chosen increments of plate sizes that may compose a built-up slender web beam.

Web depths begin at 60 in. and increase to 120 in. at 12-in. intervals; very slender webs are not used. Plate thicknesses for the web increase at a constant 1⁄16-in. increment instead of the recommended ⅛-in. increment for thicknesses over ⅜ in. per AISC fabrication suggestions (AISC, 2005a).

Flange widths and thicknesses are given beginning with 12 in. wide by ¾ in. thick and ending at 30 in. wide by 3 in. thick with increments of 6 in. and ¼ in., respectively. The width-to-thickness ratio of the compression flange was kept at or below 24 for practical fabrication concerns.

Lateral brace points of the compression flange are given for a condition of full lateral support, intervals of 5 ft, from 10 to 30 ft, and at 50, 75, and 100 ft.

Basic section properties are given along with the raw dimensions. The tabulated weight per foot excludes any additional weight due to welds or other attachments.

AVAILABLE STRENGTH

Available flexural strength tables (Appendix B) present available flexural strength based on the laterally unbraced length for a predetermined cross section for ASD and LRFD. Sections not yielding adequate strength above that of supporting self-weight are shown dashed.

Available shear strength tables (Appendix C) correspond to the web depths and thicknesses in the available flexural strength tables. Available shear strength is presented as a function of transverse stiffener spacing for webs with and without tension field action for ASD and LRFD. Additionally, it should be noted that Tables 3-16 and 3-17 of the AISC *Steel Manual* (AISC, 2005a) give curves for determining available shear stress using the ratio of stiffener spacing to web depth versus web slenderness. If Table C1 is used, the limits of AISC *Specification* Section G3.1 must be satisfied.

Available shear strength is given up to a maximum stiffener spacing, a_{max}, as indicated in the tables by a vertical solid line. This point may readily be determined by the limiting equations for the shear buckling coefficient given in Section G2.1 of the AISC *Specification* for stiffened webs:

$$k_v = 5 \text{ if } \frac{a}{h} > 3.0 \text{ or } \left[\frac{260}{h/t_w}\right]^2 \tag{8}$$

Rearranging and solving for a yields:

$$a_{max} = \text{minimum of } 3.0h \text{ and } \frac{67{,}600t_w^2}{h} \tag{9}$$

The maximum stiffener spacing designation is rounded to the nearest stiffener increment given in the table rather than its precise location. This line also indicates that the stiffeners have no effect on increasing the shear strength of the web, and also serves as a practical limit when considering fabrication and erection issues.

An example demonstrating the usage of the tables is presented in Appendix A. A full complement of the generated tables is provided in Appendices B and C.

CONCLUSION

Available strength tables for slender web I-shaped beams have been presented. The tables allow rapid determination of available strength in flexure and shear for both ASD and LRFD design methodologies. The tables may be used during the course of design for preliminary member sizing, design checking, final design, or design comparison. Many tedious calculations regarding detailing, geometric dimensions, and numerous limit state checks for the design of slender-web I-shaped beams are eliminated by using the tables. The tables have been formatted similarly to the current AISC *Steel Manual* design aids in spirit and usage. An example has been presented to illustrate the usage of the tables.

NOMENCLATURE

The following symbols are used in this paper:

A_w = Area of web plate ($h \times t_w$)

a = Clear distance between transverse stiffeners

a_w = Ratio of twice the web area in compression to the compression flange area

b_{fc} = Width of the compression flange

C_b = Beam bending coefficient

E = Modulus of elasticity for steel (29,000 ksi)

F_L = Calculated stress used to determine the nominal flexural strength

F_y = Minimum yield stress

F_{yfc} = Minimum yield stress of the compression flange

F_u = Minimum tensile stress

h = Clear distance between flanges

h_c = Twice the distance from the centroid to the inside face of the compression flange

I = Moment of inertia

k_c = Buckling parameter of the compression flange

k_v = Shear buckling coefficient

L = Span length

L_b = Laterally unbraced length

M_a = Required flexural strength (ASD)

M_D = Moment due to dead load

M_L = Moment due to live load

M_n = Nominal flexural strength

M_n/Ω_b = Allowable flexural strength (ASD)

M_u = Required flexural strength (LRFD)

P = Point load

r_t = Radius of gyration of the compression flange plus one-third of the compressed portion of the web

t_{fc} = Thickness of the compression flange

t_w = Thickness of the web

V_a = Required shear strength (ASD)

V_D = Shear due to dead load

V_L = Shear due to live load

V_n = Nominal shear strength

V_n/Ω_v = Allowable shear strength (ASD)

V_u = Required shear strength (LRFD)

Δ_L = Deflection due to live load

λ = Slenderness parameter (generalized)

λ_{fc} = Slenderness parameter for compression flange

λ_p = Limiting slenderness parameter for compact element

λ_{pf} = Limiting slenderness parameter for compact flange

λ_r = Limiting slenderness parameter for noncompact element

λ_{rf} = Limiting slenderness parameter for noncompact flange

ϕ_b = Resistance factor for flexure = 0.9 (LRFD)

$\phi_b M_n$ = Design flexural strength (LRFD)

ϕ_v = Resistance factor for shear = 0.9 (LRFD)

$\phi_v V_n$ = Design shear strength (LRFD)

Ω_b = Safety factor for flexure = 1.67 (ASD)

Ω_v = Safety factor for shear = 1.67 (ASD)

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APPENDIX A
Example: Slender Web I-Shaped Flexural Member in Strong-Axis Bending

Given

A simply supported transfer girder with a span of 60 ft as shown in Figure A1. The nominal applied dead and live loads are 200 and 100 kips, respectively. The applied loads and lateral bracing are at the third points of the girder. The live load deflection is limited to $L/240$.

Determine

Using the available strength tables, select a suitable I-shaped flexural member section that satisfies the limit states of flexure and shear, and the limit state of deflection for serviceability. Use LRFD and ASD methodology.

Solution

The allowable maximum live load deflection is:

$$\Delta_{L(max)} = \frac{L}{240} = \frac{(60 \text{ ft} \times 12 \text{ in./ft})}{240} = 3.00 \text{ in.}$$

The maximum live load deflection will occur at the midspan, resulting in a required moment of inertia:

$$I_{req'd} = \frac{PL^3}{28E\Delta_L} = \frac{(100 \text{ kips})(60 \text{ ft} \times 12 \text{ in./ft})^3}{28(29{,}000 \text{ ksi})(3 \text{ in.})} = 15{,}300 \text{ in.}^4$$

(AISC *Steel Manual* Table 3-23, Diagram 9)

Assume an initial girder weight of 0.360 kip/ft.

The required moments and forces are determined as:

$$M_D = \frac{w_D L^2}{8} + P_D a = \frac{(0.360 \text{ kip/ft})(60 \text{ ft})^2}{8} + (200 \text{ kips})(20 \text{ ft}) = 4{,}160 \text{ kip-ft}$$

$$M_L = P_L a = (100 \text{ kips})(20 \text{ ft}) = 2{,}000 \text{ kip-ft}$$

$$V_D = \frac{w_D L}{2} + P_D = \frac{(0.360 \text{ kip/ft})(60 \text{ ft})}{2} + 200 \text{ kips} = 211 \text{ kips}$$

$$V_L = P_L = 100 \text{ kips}$$

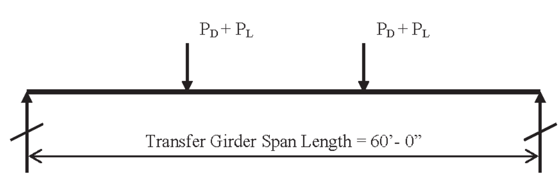

Fig. A1. Simply supported transfer girder.

For use of the available strength tables in Appendices B and C, the required strengths are determined per ASCE 7 (ASCE, 2002) Sections 2.3 and 2.4 (LRFD and ASD, respectively) for a typical load case:

LRFD	ASD
$M_u = 1.2(4{,}160 \text{ kip-ft}) + 1.6(2{,}000 \text{ kip-ft})$ $M_u = 8{,}190$ kip-ft) $V_u = 1.2(211 \text{ kips}) + 1.6(100 \text{ kips})$ $v_u = 413$ kips	$M_a = 4{,}160 \text{ kip-ft} + 2{,}000 \text{ kip-ft}$ $M_a = 6{,}160$ kip-ft $V_a = 211 \text{ kips} + 100 \text{ kips}$ $V_a = 311$ kips

Material Properties:

ASTM A572 Gr. 50, $F_y = 50$ ksi, $F_u = 65$ ksi (AISC *Steel Manual* Table 2-4)

For $L_b = 20$ ft, $C_b = 1.0$ for middle span (AISC *Steel Manual* Table 3-1), and $F_y = 50$ ksi

By inspection of the available flexural strength tables in Appendix B, narrow the options to a 60-in.-deep web.

LRFD	ASD
Web: 60 in. × 5⁄16 in., Flanges: 24 × 1½ in.	Web: 60 in. × 5⁄16 in., Flanges: 24 × 1¾ in.
From Appendix B, Table B1	From Appendix B, Table B1
$I = 73{,}700 \text{ in.}^4 > I_{req'd}$ **o.k.**	$I = 85{,}700 \text{ in.}^4 > I_{req'd}$ **o.k.**
$\phi_b M_n = 8{,}200 \text{ kip-ft} > 8{,}190 \text{ kip-ft}$ **o.k.**	$M_n/\Omega_b = 6{,}320 \text{ kip-ft} > 6{,}160 \text{ kip-ft}$ **o.k.**

By inspection of the available shear strength tables in Appendix C, it is clear that stiffeners must be used for a 5⁄16-in.-thick web. For end panels, tension field action is not permitted per AISC Section G3. Enter the available shear strength tables with tension field action EXCLUDED in Appendix C and find at an initial stiffener spacing:

LRFD	ASD
Stiffener spacing, $a = 20$ in.	Stiffener spacing, $a = 20$ in.
$\phi_v V_n = 494 \text{ kips} > 413 \text{ kips}$ **o.k.**	$V_n/\Omega_v = 329 \text{ kips} > 311 \text{ kips}$ **o.k.**

Tension field action may be used in the adjacent stiffened panels. As the shear reduces across the span, stiffeners may be detailed according to the distribution of shear and selected by using the available shear strength tables with tension field action INCLUDED in Appendix C.

The stiffener spacing may be optimized by using engineering judgment and interpolation of the available shear strength tables in Appendix C, or by using AISC *Steel Manual* Tables 3-17a and 3-17b for any given spacing and web size.

Finally, check the actual girder weight versus the assumed:

LRFD	ASD
Assumed: 0.360 kip/ft	Assumed: 0.360 kip/ft
Actual: 0.309 kip/ft **o.k.**	Actual: 0.350 kip/ft **o.k.**

Final Selection:

LRFD	ASD
Use: $F_y = 50$ ksi	Use: $F_y = 50$ ksi
Web: 60 in. × 5⁄16 in., with $a_{initial} = 20$ in.	Web: 60 in. × 5⁄16 in., with $a_{initial} = 20$ in.
Flanges: 24 in. × 1½ in.	Flanges: 24 in. × 1¾ in.

Other adequate sections that may be selected:

LRFD			
Web (in.)	Flanges (in.)	F_y (ksi)	$a_{initial}$ (in.)
72 × 3⁄8	18 × 1¾	50	30
84 × 3⁄8	18 × 1½	50	30
96 × 7⁄16	18 × 1¼	50	90
–	–	–	–
–	–	–	–
ASD			
Web (in.)	Flanges (in.)	F_y (ksi)	$a_{initial}$ (in.)
72 × 3⁄8	18 × 2	50	30
84 × 5⁄16	18 × 1¾	50	20
84 × 9⁄16	18 × 1½	50	90
96 × 3⁄8	18 × 1½	50	30
96 × 9⁄16	18 × 1¼	50	90

Choosing rolled sections for flexural strength from AISC *Steel Manual* Table 3-10 yields W40×593 or W36×529 for LRFD and W40×593 or W36×652 for ASD, which are also adequate for shear strength and serviceability. Special requirements may apply to these shapes per Section A3.1c of the AISC *Specification* and may be subject to availability through limited producers.

APPENDIX B
AVAILABLE FLEXURAL STRENGTH TABLES

Table B1. Available Flexural Strength of Members with 60-in. Web Height

$F_y = 50$ ksi, $C_b = 1.0$; ASD: $\Omega_b = 1.67$; LRFD: $\phi_b = 0.90$

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	I_x	S_x	r_t	L_b = 0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.																		
60x12	125	36.8	61.5	12	3/4	60	5/16	22200	723	2.98	1690	2540	1580	2380	1420	2140	1260	1900	958	1440	665	1000	240	360	106	160	–	–
	138	40.5	61.5	12	3/4	60	3/8	23400	760	2.91	1840	2770	1710	2570	1530	2310	1360	2040	991	1490	688	1030	248	372	110	166	–	–
	145	42.8	62.0	12	1	60	5/16	28000	902	3.09	2130	3210	2010	3020	1820	2730	1620	2440	1290	1940	898	1350	323	486	144	216	–	–
	158	46.5	62.0	12	1	60	3/8	29100	938	3.02	2280	3430	2140	3220	1930	2900	1720	2580	1330	2000	922	1390	332	499	148	222	–	–
	166	48.8	62.5	12	1¼	60	5/16	33800	1080	3.15	2580	3880	2440	3670	2210	3320	1980	2970	1630	2450	1130	1700	407	612	181	272	–	–
	179	52.5	62.5	12	1¼	60	3/8	34900	1120	3.10	2730	4100	2570	3860	2320	3490	2080	3120	1670	2500	1160	1740	416	626	185	278	–	–
	186	54.8	63.0	12	1½	60	5/16	39700	1260	3.20	3020	4540	2870	4310	2600	3910	2330	3510	1970	2960	1370	2050	492	739	219	328	–	–
	199	58.5	63.0	12	1½	60	3/8	40800	1300	3.15	3170	4770	3000	4510	2720	4080	2430	3660	2000	3010	1390	2090	501	753	223	335	–	–
	207	60.8	63.5	12	1¾	60	5/16	45700	1440	3.23	3470	5210	3300	4950	2990	4500	2690	4050	2310	3460	1600	2410	576	866	256	385	–	–
	219	64.5	63.5	12	1¾	60	3/8	46800	1470	3.19	3620	5440	3430	5160	3110	4680	2790	4200	2340	3520	1630	2450	586	881	260	391	–	–
	227	66.8	64.0	12	2	60	5/16	51800	1620	3.26	3920	5890	3730	5600	3390	5090	3050	4580	2640	3970	1840	2760	661	994	294	442	–	–
	240	70.5	64.0	12	2	60	3/8	52900	1650	3.22	4060	6110	3860	5800	3500	5270	3150	4730	2680	4030	1860	2800	671	1010	298	448	–	–
	248	72.8	64.5	12	2¼	60	5/16	58000	1800	3.28	4360	6560	4160	6250	3780	5680	3410	5120	2980	4490	2070	3120	746	1120	332	498	–	–
	260	76.5	64.5	12	2¼	60	3/8	59100	1830	3.25	4510	6780	4290	6450	3900	5860	3510	5270	3020	4540	2100	3160	756	1140	336	505	–	–
	268	78.8	65.0	12	2½	60	5/16	64300	1980	3.30	4810	7230	4590	6890	4180	6280	3770	5660	3330	5000	2310	3470	831	1250	369	555	–	–
	281	82.5	65.0	12	2½	60	3/8	65400	2010	3.27	4960	7450	4720	7090	4290	6450	3870	5810	3360	5060	2340	3510	841	1260	374	562	–	–
	288	84.8	65.5	12	2¾	60	5/16	70600	2160	3.31	5260	7900	5020	7540	4570	6870	4120	6200	3670	5510	2550	3830	917	1380	407	612	–	–
	301	88.5	65.5	12	2¾	60	3/8	71800	2190	3.28	5410	8130	5150	7740	4690	7050	4220	6350	3710	5570	2570	3870	926	1390	412	619	–	–
	309	90.8	66.0	12	3	60	5/16	77100	2340	3.32	5710	8580	5450	8190	4970	7470	4480	6740	4000	6010	2780	4180	1000	1510	445	669	–	–
	322	94.5	66.0	12	3	60	3/8	78200	2370	3.30	5860	8800	5580	8390	5080	7640	4580	6890	4050	6080	2810	4220	1010	1520	450	676	–	–
60x18	156	45.8	61.5	18	3/4	60	5/16	30500	993	4.68	2070	3120	2070	3120	2070	3120	2070	3120	1940	2920	1800	2710	823	1240	366	550	206	309
	168	49.5	61.5	18	3/4	60	3/8	31700	1030	4.60	2210	3320	2210	3320	2210	3320	2210	3320	2050	3090	1900	2860	844	1270	375	564	211	317
	186	54.8	62.0	18	1	60	5/16	39100	1260	4.80	3030	4550	3030	4550	2870	4320	2690	4050	2520	3780	2340	3520	1110	1670	493	740	277	416
	199	58.5	62.0	18	1	60	3/8	40200	1300	4.73	3180	4780	3180	4780	3010	4520	2820	4240	2630	3950	2440	3670	1130	1700	502	755	283	425
	217	63.8	62.5	18	1¼	60	5/16	47800	1530	4.87	3700	5560	3700	5560	3520	5290	3300	4970	3090	4640	2880	4320	1390	2100	620	931	349	524
	230	67.5	62.5	18	1¼	60	3/8	49000	1570	4.81	3850	5790	3850	5790	3650	5490	3430	5150	3200	4810	2980	4470	1420	2130	630	946	354	532
	248	72.8	63.0	18	1½	60	5/16	56700	1800	4.92	4370	6570	4370	6570	4160	6260	3910	5880	3660	5500	3410	5130	1680	2530	747	1120	420	632
	260	76.5	63.0	18	1½	60	3/8	57800	1840	4.87	4520	6790	4520	6790	4300	6460	4040	6070	3780	5670	3510	5280	1700	2560	757	1140	426	640
	278	81.8	63.5	18	1¾	60	5/16	65700	2070	4.96	5040	7580	5040	7580	4810	7230	4520	6800	4240	6370	3950	5940	1970	2960	875	1320	492	740
	291	85.5	63.5	18	1¾	60	3/8	66800	2100	4.91	5190	7800	5190	7800	4940	7430	4650	6980	4350	6540	4050	6090	1990	2990	885	1330	498	748
	309	90.8	64.0	18	2	60	5/16	74800	2340	4.98	5710	8590	5710	8590	5450	8200	5130	7710	4810	7230	4490	6740	2260	3390	1000	1510	564	848
	322	94.5	64.0	18	2	60	3/8	76000	2370	4.94	5860	8810	5860	8810	5590	8400	5260	7900	4920	7400	4590	6900	2280	3430	1010	1520	570	856
	339	99.8	64.5	18	2¼	60	5/16	84100	2610	5.01	6390	9600	6390	9600	6100	9170	5740	8630	5380	8090	5020	7550	2550	3830	1130	1700	636	956
	352	104	64.5	18	2¼	60	3/8	85300	2640	4.97	6530	9820	6530	9820	6240	9370	5870	8820	5500	8260	5130	7710	2570	3860	1140	1720	642	965
	370	109	65.0	18	2½	60	5/16	93600	2880	5.02	7060	10600	7060	10600	6750	10100	6350	9550	5960	8960	5560	8360	2830	4260	1260	1890	708	1060
	383	113	65.0	18	2½	60	3/8	94700	2910	4.99	7210	10800	7210	10800	6880	10300	6480	9740	6070	9130	5670	8510	2860	4290	1270	1910	714	1070
	401	118	65.5	18	2 ¾	60	5/16	103000	3150	5.04	7730	11600	7730	11600	7400	11100	6970	10500	6530	9820	6100	9170	3120	4690	1390	2090	781	1170
	413	122	65.5	18	2 ¾	60	3/8	104000	3180	5.01	7880	11800	7880	11800	7530	11300	7090	10700	6650	9990	6200	9320	3150	4730	1400	2100	786	1180
	431	127	66.0	18	3	60	5/16	113000	3420	5.05	8410	12600	8410	12600	8050	12100	7580	11400	7110	10700	6640	9980	3410	5130	1520	2280	853	1280
	444	131	66.0	18	3	60	3/8	114000	3450	5.02	8560	12900	8560	12900	8180	12300	7700	11600	7220	10900	6740	10100	3440	5160	1530	2290	859	1290

Available Flexural Strength, kip-ft: Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD); Lateral Unbraced Length—L_b, ft

Table B1. Available Flexural Strength of Members with 60-in. Web Height

60-in. Web Height Dimensions											Available Flexural Strength, kip-ft (F_y = 50 ksi, C_b = 1.0; ASD Ω_b = 1.67; LRFD ϕ_b = 0.90)																	
Nominal Shape	Wt/ft	Area	Depth	Flange		Web		Axis X-X			Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD)																	
											Lateral Unbraced Length—L_b, ft																	
			d	width b_f	thk. t_f	height h	thk. t_w	I_x	S_x	r_t	0		10		15		20		25		30		50		75		100	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
60x24	227	67	62.0	24	1	60	5⁄16	50300	1620	6.52	3450	5180	3450	5180	3450	5180	3450	5180	3450	5180	3400	5110	2650	3990	1180	1770	663	996
	240	71	62.0	24	1	60	3⁄8	51400	1660	6.44	3580	5380	3580	5380	3580	5380	3580	5380	3580	5380	3520	5280	2690	4050	1200	1800	673	1010
	268	79	62.5	24	1¼	60	5⁄16	61900	1980	6.59	4730	7110	4730	7110	4730	7110	4600	6910	4390	6600	4180	6290	3330	5010	1480	2230	833	1250
	281	83	62.5	24	1¼	60	3⁄8	63000	2020	6.53	4880	7330	4880	7330	4880	7330	4730	7110	4520	6790	4300	6470	3370	5070	1500	2250	843	1270
	309	91	63.0	24	1½	60	5⁄16	73700	2340	6.65	5720	8590	5720	8590	5700	8570	5460	8200	5220	7840	4970	7480	4010	6020	1780	2680	1000	1510
	322	95	63.0	24	1½	60	3⁄8	74800	2380	6.59	5870	8820	5870	8820	5850	8790	5590	8410	5340	8030	5090	7660	4060	6100	1800	2710	1010	1520
	350	103	63.5	24	1 ¾	60	5⁄16	85700	2700	6.68	6610	9940	6610	9940	6600	9920	6320	9500	6040	9080	5760	8660	4650	6990	2090	3140	1170	1770
	362	107	63.5	24	1 ¾	60	3⁄8	86800	2740	6.64	6760	10200	6760	10200	6740	10100	6460	9700	6170	9270	5880	8840	4740	7120	2110	3170	1180	1780
	390	115	64.0	24	2	60	5⁄16	97900	3060	6.71	7510	11300	7510	11300	7500	11300	7180	10800	6870	10300	6550	9850	5290	7960	2390	3600	1350	2020
	403	119	64.0	24	2	60	3⁄8	99000	3090	6.67	7660	11500	7660	11500	7640	11500	7320	11000	7000	10500	6670	10000	5380	8090	2410	3620	1360	2040
	431	127	64.5	24	2¼	60	5⁄16	110000	3420	6.74	8410	12600	8410	12600	8400	12600	8050	12100	7700	11600	7350	11000	5940	8930	2700	4050	1520	2280
	444	131	64.5	24	2¼	60	3⁄8	111000	3450	6.70	8560	12900	8560	12900	8540	12800	8180	12300	7820	11800	7460	11200	6030	9060	2710	4080	1530	2300
	472	139	65.0	24	2½	60	5⁄16	123000	3780	6.75	9310	14000	9310	14000	9300	14000	8910	13400	8530	12800	8140	12200	6590	9900	3000	4510	1690	2540
	485	143	65.0	24	2½	60	3⁄8	124000	3820	6.72	9460	14200	9460	14200	9440	14200	9050	13600	8650	13000	8260	12400	6670	10000	3020	4540	1700	2550
	513	151	65.5	24	2¾	60	5⁄16	136000	4140	6.77	10200	15300	10200	15300	10200	15300	9780	14700	9360	14100	8930	13400	7230	10900	3310	4970	1860	2800
	526	155	65.5	24	2¾	60	3⁄8	137000	4180	6.74	10400	15600	10400	15600	10300	15600	9910	14900	9480	14300	9050	13600	7320	11000	3320	5000	1870	2810
	554	163	66.0	24	3	60	5⁄16	149000	4500	6.78	11100	16700	11100	16700	11100	16700	10600	16000	10200	15300	9730	14600	7880	11800	3610	5430	2030	3050
	567	167	66.0	24	3	60	3⁄8	150000	4540	6.75	11300	16900	11300	16900	11300	16900	10800	16200	10300	15500	9840	14800	7970	12000	3630	5460	2040	3070
60x30	319	94	62.5	30	1¼	60	5⁄16	76000	2430	8.32	5220	7850	5220	7850	5220	7850	5220	7850	5220	7850	5220	7850	4670	7020	2910	4370	1640	2460
	332	98	62.5	30	1¼	60	3⁄8	77100	2470	8.26	5350	8050	5350	8050	5350	8050	5350	8050	5350	8050	5350	8050	4770	7180	2940	4410	1650	2480
	370	109	63.0	30	1½	60	5⁄16	90700	2880	8.37	6810	10200	6810	10200	6810	10200	6810	10200	6750	10200	6520	9800	5570	8370	3500	5260	1970	2960
	383	113	63.0	30	1½	60	3⁄8	91900	2920	8.32	6950	10500	6950	10500	6950	10500	6950	10500	6890	10400	6650	9990	5670	8520	3530	5310	1990	2980
	421	124	63.5	30	1¾	60	5⁄16	106000	3330	8.41	8190	12300	8190	12300	8190	12300	8110	12200	7830	11800	7560	11400	6460	9720	4090	6150	2300	3460
	434	128	63.5	30	1¾	60	3⁄8	107000	3370	8.37	8340	12500	8340	12500	8340	12500	8250	12400	7970	12000	7690	11600	6570	9870	4120	6200	2320	3490
	472	139	64.0	30	2	60	5⁄16	121000	3780	8.44	9310	14000	9310	14000	9310	14000	9220	13900	8910	13400	8600	12900	7360	11100	4690	7050	2640	3960
	485	143	64.0	30	2	60	3⁄8	122000	3820	8.40	9460	14200	9460	14200	9460	14200	9370	14100	9050	13600	8730	13100	7470	11200	4720	7090	2650	3990
	523	154	64.5	30	2¼	60	5⁄16	136000	4230	8.47	10400	15700	10400	15700	10400	15700	10300	15500	9990	15000	9650	14500	8260	12400	5280	7940	2970	4470
	536	158	64.5	30	2¼	60	3⁄8	138000	4270	8.43	10600	15900	10600	15900	10600	15900	10500	15800	10100	15200	9780	14700	8360	12600	5310	7990	2990	4490
	574	169	65.0	30	2½	60	5⁄16	152000	4680	8.49	11600	17400	11600	17400	11600	17400	11500	17200	11100	16600	10700	16100	9160	13800	5880	8840	3310	4970
	587	173	65.0	30	2½	60	3⁄8	153000	4720	8.45	11700	17600	11700	17600	11700	17600	11600	17400	11200	16900	10800	16300	9260	13900	5910	8880	3320	5000
	625	184	65.5	30	2¾	60	5⁄16	168000	5130	8.50	12700	19100	12700	19100	12700	19100	12600	18900	12200	18300	11700	17600	10100	15100	6480	9740	3640	5480
	638	188	65.5	30	2¾	60	3⁄8	169000	5170	8.47	12800	19300	12800	19300	12800	19300	12700	19100	12300	18500	11900	17800	10200	15300	6510	9780	3660	5500
	676	199	66.0	30	3	60	5⁄16	184000	5590	8.51	13800	20800	13800	20800	13800	20800	13700	20600	13200	19900	12800	19200	11000	16500	7080	10600	3980	5980
	689	203	66.0	30	3	60	3⁄8	185000	5620	8.49	14000	21000	14000	21000	14000	21000	13800	20800	13400	20100	12900	19400	11100	16600	7100	10700	4000	6010

Table B2. Available Flexural Strength of Members with 72-in. Web Height

72-in. Web Height Dimensions											Available Flexural Strength, kip-ft															F_y = 50 ksi C_b = 1.0 ASD Ω_b = 1.67		LRFD ϕ_b = 0.90
Nominal Shape	Wt/ft	Area	Depth	Flange		Web		Axis X-X			Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD)																	
											Lateral Unbraced Length—L_b, ft																	
			d	width b_f	thk. t_f	height h	thk. t_w	I_x	S_x	r_t	0		10		15		20		25		30		50		75		100	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
72x12	138	40.5	73.5	12	¾	72	5⁄16	33500	913	2.91	2010	3010	1870	2810	1670	2510	1480	2220	1080	1620	750	1130	270	406	120	180	–	–
	153	45.0	73.5	12	¾	72	⅜	35500	965	2.83	2220	3340	2050	3090	1830	2760	1610	2420	1130	1700	785	1180	282	425	126	189	–	–
	168	49.5	73.5	12	¾	72	7⁄16	37400	1020	2.75	2430	3660	2240	3360	1990	2990	1740	2620	1170	1760	814	1220	293	441	130	196	–	–
	158	46.5	74.0	12	1	72	5⁄16	41700	1130	3.02	2530	3810	2380	3570	2140	3220	1900	2860	1470	2210	1020	1540	368	554	164	246	–	–
	174	51.0	74.0	12	1	72	⅜	43600	1180	2.95	2750	4130	2570	3860	2310	3460	2040	3070	1530	2290	1060	1590	382	573	170	255	–	–
	189	55.5	74.0	12	1	72	7⁄16	45600	1230	2.89	2960	4450	2750	4140	2470	3710	2180	3270	1570	2360	1090	1640	393	591	175	263	–	–
	179	52.5	74.5	12	1¼	72	5⁄16	50000	1340	3.10	3060	4600	2890	4340	2610	3920	2330	3500	1870	2810	1300	1950	468	703	208	312	–	–
	194	57.0	74.5	12	1¼	72	⅜	51900	1390	3.04	3280	4930	3080	4630	2780	4170	2470	3720	1930	2890	1340	2010	481	724	214	322	–	–
	209	61.5	74.5	12	1¼	72	7⁄16	53900	1450	2.98	3490	5250	3270	4910	2940	4420	2610	3920	1980	2970	1370	2060	494	742	219	330	–	–
	199	58.5	75.0	12	1½	72	5⁄16	58300	1560	3.15	3600	5400	3400	5110	3080	4630	2760	4140	2270	3410	1580	2370	568	853	252	379	–	–
	214	63.0	75.0	12	1½	72	⅜	60300	1610	3.10	3810	5730	3590	5400	3250	4880	2900	4360	2330	3500	1620	2430	582	875	259	389	–	–
	230	67.5	75.0	12	1½	72	7⁄16	62200	1660	3.05	4030	6050	3780	5690	3410	5130	3040	4570	2380	3580	1650	2480	595	894	264	397	–	–
	219	64.5	75.5	12	1¾	72	5⁄16	66800	1770	3.19	4130	6200	3910	5880	3550	5330	3180	4790	2670	4020	1860	2790	668	1000	297	446	–	–
	235	69.0	75.5	12	1¾	72	⅜	68800	1820	3.14	4340	6530	4110	6170	3720	5590	3330	5000	2730	4100	1900	2850	683	1030	303	456	–	–
	250	73.5	75.5	12	1¾	72	7⁄16	70700	1870	3.10	4560	6850	4300	6460	3880	5840	3470	5210	2780	4180	1930	2910	696	1050	309	465	–	–
	240	70.5	76.0	12	2	72	5⁄16	75400	1990	3.22	4660	7010	4430	6650	4020	6040	3610	5430	3080	4630	2140	3210	769	1160	342	514	–	–
	255	75.0	76.0	12	2	72	⅜	77400	2040	3.18	4880	7330	4620	6940	4190	6300	3760	5650	3140	4710	2180	3270	784	1180	348	524	–	–
	271	79.5	76.0	12	2	72	7⁄16	79300	2090	3.14	5090	7650	4810	7230	4350	6540	3900	5860	3190	4790	2210	3330	797	1200	354	533	–	–
	260	76.5	76.5	12	2¼	72	5⁄16	84200	2200	3.25	5200	7810	4940	7430	4490	6750	4040	6070	3480	5230	2420	3630	871	1310	387	582	–	–
	276	81.0	76.5	12	2¼	72	⅜	86100	2250	3.21	5410	8130	5130	7720	4660	7000	4180	6290	3540	5320	2460	3700	885	1330	393	591	–	–
	291	85.5	76.5	12	2¼	72	7⁄16	88100	2300	3.17	5630	8460	5330	8000	4830	7250	4330	6500	3590	5400	2500	3750	899	1350	399	600	–	–
	281	82.5	77.0	12	2½	72	5⁄16	93000	2420	3.27	5730	8610	5460	8200	4960	7460	4470	6720	3890	5840	2700	4060	972	1460	432	649	–	–
	296	87.0	77.0	12	2½	72	⅜	94900	2470	3.23	5950	8940	5650	8490	5130	7710	4610	6930	3950	5930	2740	4120	987	1480	439	659	–	–
	311	91.5	77.0	12	2½	72	7⁄16	96900	2520	3.20	6160	9260	5840	8780	5300	7960	4760	7150	4000	6010	2780	4180	1000	1500	445	668	–	–
	301	88.5	77.5	12	2¾	72	5⁄16	102000	2630	3.28	6270	9420	5970	8980	5430	8170	4900	7360	4300	6460	2980	4480	1070	1610	477	717	–	–
	316	93.0	77.5	12	2¾	72	⅜	104000	2680	3.25	6480	9740	6170	9270	5600	8420	5040	7580	4350	6540	3020	4540	1090	1640	484	727	–	–
	332	97.5	77.5	12	2¾	72	7⁄16	106000	2730	3.22	6700	10100	6360	9550	5770	8670	5180	7790	4410	6630	3060	4600	1100	1660	490	736	–	–
	322	94.5	78.0	12	3	72	5⁄16	111000	2850	3.30	6800	10200	6490	9750	5910	8880	5330	8010	4700	7070	3270	4910	1180	1770	523	786	–	–
	337	99.0	78.0	12	3	72	⅜	113000	2900	3.27	7020	10500	6680	10000	6080	9130	5470	8220	4760	7160	3310	4970	1190	1790	529	795	–	–
	352	104	78.0	12	3	72	7⁄16	115000	2950	3.24	7230	10900	6870	10300	6240	9380	5610	8440	4820	7240	3350	5030	1200	1810	535	804	–	–

Table B2. Available Flexural Strength of Members with 72-in. Web Height

$F_y = 50$ ksi, $C_b = 1.0$; ASD: $\Omega_b = 1.67$; LRFD: $\phi_b = 0.90$

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
											Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD), kip-ft; Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
72x18	168	49.5	73.5	18	¾	72	5⁄16	45400	1240	4.60	2460	3700	2460	3700	2460	3700	2460	3700	2290	3450	2120	3190	942	1420	419	629	236	354
	184	54.0	73.5	18	¾	72	⅜	47400	1290	4.50	2650	3990	2650	3990	2650	3990	2640	3970	2450	3690	2260	3400	973	1460	432	650	243	366
	199	58.5	73.5	18	¾	72	7⁄16	49300	1340	4.41	2840	4270	2840	4270	2840	4270	2810	4230	2610	3920	2400	3610	1000	1500	445	668	250	376
	199	58.5	74.0	18	1	72	5⁄16	57700	1560	4.73	3600	5410	3600	5410	3410	5120	3190	4800	2980	4470	2760	4150	1280	1920	569	855	320	481
	214	63.0	74.0	18	1	72	⅜	59600	1610	4.65	3820	5740	3820	5740	3600	5410	3370	5070	3140	4720	2910	4370	1310	1970	583	877	328	493
	230	67.5	74.0	18	1	72	7⁄16	61600	1660	4.57	4040	6070	4040	6070	3790	5700	3540	5330	3300	4950	3050	4580	1340	2020	596	896	335	504
	230	67.5	74.5	18	1¼	72	5⁄16	70100	1880	4.81	4400	6620	4400	6620	4180	6280	3920	5890	3660	5500	3400	5120	1620	2440	720	1080	405	609
	245	72.0	74.5	18	1¼	72	⅜	72000	1930	4.74	4620	6950	4620	6950	4370	6570	4100	6160	3820	5750	3550	5340	1650	2490	735	1100	413	621
	260	76.5	74.5	18	1¼	72	7⁄16	74000	1990	4.68	4840	7270	4840	7270	4570	6860	4280	6430	3980	5990	3690	5550	1680	2530	749	1130	421	633
	260	76.5	75.0	18	1½	72	5⁄16	82700	2200	4.87	5210	7820	5210	7820	4950	7440	4650	6990	4350	6530	4050	6080	1960	2950	872	1310	491	737
	276	81.0	75.0	18	1½	72	⅜	84600	2260	4.81	5420	8150	5420	8150	5150	7730	4830	7260	4510	6780	4190	6300	2000	3000	887	1330	499	750
	291	85.5	75.0	18	1½	72	7⁄16	86500	2310	4.75	5640	8480	5640	8480	5340	8020	5010	7520	4670	7020	4340	6520	2030	3050	901	1350	507	762
	291	85.5	75.5	18	1¾	72	5⁄16	95400	2530	4.91	6010	9030	6010	9030	5720	8600	5380	8080	5030	7570	4690	7050	2310	3460	1020	1540	576	866
	306	90.0	75.5	18	1¾	72	⅜	97300	2580	4.86	6230	9360	6230	9360	5920	8900	5560	8350	5200	7810	4840	7270	2340	3520	1040	1560	585	879
	322	94.5	75.5	18	1¾	72	7⁄16	99300	2630	4.81	6440	9680	6440	9680	6110	9190	5740	8620	5360	8050	4980	7490	2370	3560	1050	1580	590	891
	322	94.5	76.0	18	2	72	5⁄16	108000	2850	4.94	6810	10200	6810	10200	6500	9760	6110	9180	5720	8600	5330	8020	2650	3980	1180	1770	660	995
	337	99.0	76.0	18	2	72	⅜	110000	2900	4.90	7030	10600	7030	10600	6690	10100	6290	9450	5880	8840	5480	8240	2680	4030	1190	1790	670	1010
	352	104	76.0	18	2	72	7⁄16	112000	2950	4.85	7250	10900	7250	10900	6890	10400	6470	9720	6050	9090	5630	8460	2720	4080	1210	1810	680	1020
	352	104	76.5	18	2¼	72	5⁄16	121000	3170	4.97	7620	11500	7620	11500	7270	10900	6840	10300	6410	9630	5980	8980	2990	4500	1330	2000	750	1120
	368	108	76.5	18	2¼	72	⅜	123000	3220	4.93	7840	11800	7840	11800	7470	11200	7020	10600	6570	9880	6120	9210	3030	4550	1350	2020	760	1140
	383	113	76.5	18	2¼	72	7⁄16	125000	3280	4.89	8050	12100	8050	12100	7660	11500	7200	10800	6730	10100	6270	9420	3060	4600	1360	2040	760	1150
	383	113	77.0	18	2½	72	5⁄16	135000	3500	4.99	8420	12700	8420	12700	8050	12100	7570	11400	7100	10700	6620	9950	3340	5020	1480	2230	830	1250
	398	117	77.0	18	2½	72	⅜	137000	3550	4.95	8640	13000	8640	13000	8240	12400	7750	11700	7260	10900	6770	10200	3370	5070	1500	2250	840	1270
	413	122	77.0	18	2½	72	7⁄16	139000	3600	4.92	8860	13300	8860	13300	8440	12700	7930	11900	7420	11200	6910	10400	3400	5120	1510	2270	850	1280
	413	122	77.5	18	2¾	72	5⁄16	148000	3820	5.01	9230	13900	9230	13900	8820	13300	8300	12500	7790	11700	7270	10900	3680	5540	1640	2460	920	1380
	429	126	77.5	18	2¾	72	⅜	150000	3870	4.97	9450	14200	9450	14200	9020	13600	8480	12800	7950	11900	7410	11100	3720	5590	1650	2480	930	1400
	444	131	77.5	18	2¾	72	7⁄16	152000	3920	4.94	9660	14500	9660	14500	9210	13800	8660	13000	8110	12200	7560	11400	3750	5640	1670	2510	940	1410
	444	131	78.0	18	3	72	5⁄16	162000	4150	5.02	10000	15100	10000	15100	9600	14400	9040	13600	8480	12700	7910	11900	4030	6060	1790	2690	1010	1510
	459	135	78.0	18	3	72	⅜	164000	4200	4.99	10300	15400	10300	15400	9800	14700	9220	13900	8640	13000	8060	12100	4060	6110	1810	2710	1020	1530
	475	140	78.0	18	3	72	7⁄16	166000	4250	4.96	10500	15700	10500	15700	9990	15000	9390	14100	8800	13200	8210	12300	4100	6160	1820	2740	1020	1540

Table B2. Available Flexural Strength of Members with 72-in. Web Height

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	L_b = 0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
											Available Flexural Strength, kip-ft; F_y = 50 ksi, C_b = 1.0; ASD Ω_b = 1.67, LRFD ϕ_b = 0.90; Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD); Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
72x24	240	70.5	74.0	24	1	72	5⁄16	73700	1990	6.44	4110	6170	4110	6170	4110	6170	4110	6170	4110	6170	4030	6060	3090	4640	1370	2060	770	1160
	255	75.0	74.0	24	1	72	3⁄8	75600	2040	6.36	4300	6460	4300	6460	4300	6460	4300	6460	4300	6460	4200	6320	3150	4730	1400	2100	790	1180
	271	79.5	74.0	24	1	72	7⁄16	77600	2100	6.28	4490	6750	4490	6750	4490	6750	4490	6750	4490	6750	4370	6570	3200	4810	1420	2140	800	1200
	281	82.5	74.5	24	1¼	72	5⁄16	90200	2420	6.53	5640	8470	5640	8470	5640	8470	5470	8220	5220	7850	4970	7480	3900	5860	1730	2600	970	1460
	296	87.0	74.5	24	1¼	72	3⁄8	92200	2470	6.46	5850	8790	5850	8790	5850	8790	5670	8520	5410	8130	5150	7740	3960	5950	1760	2640	990	1490
	311	91.5	74.5	24	1¼	72	7⁄16	94100	2530	6.39	6070	9120	6070	9120	6070	9120	5860	8810	5590	8400	5320	7990	4020	6040	1790	2680	1000	1510
	322	94.5	75.0	24	1½	72	5⁄16	107000	2850	6.59	6820	10200	6820	10200	6790	10200	6500	9770	6210	9330	5920	8900	4710	7080	2090	3150	1180	1770
	337	99.0	75.0	24	1½	72	3⁄8	109000	2900	6.53	7040	10600	7040	10600	7000	10500	6700	10100	6400	9610	6090	9160	4770	7180	2120	3190	1190	1790
	352	104	75.0	24	1½	72	7⁄16	111000	2960	6.47	7260	10900	7260	10900	7210	10800	6900	10400	6580	9890	6260	9410	4830	7260	2150	3230	1210	1820
	362	107	75.5	24	1¾	72	5⁄16	124000	3280	6.64	7890	11900	7890	11900	7870	11800	7530	11300	7200	10800	6870	10300	5530	8310	2460	3690	1380	2080
	378	111	75.5	24	1¾	72	3⁄8	126000	3340	6.58	8110	12200	8110	12200	8080	12100	7730	11600	7390	11100	7040	10600	5590	8400	2490	3740	1400	2100
	393	116	75.5	24	1¾	72	7⁄16	128000	3390	6.53	8330	12500	8330	12500	8290	12500	7930	11900	7570	11400	7210	10800	5650	8490	2510	3770	1410	2120
	403	119	76.0	24	2	72	5⁄16	141000	3720	6.67	8970	13500	8970	13500	8950	13400	8570	12900	8190	12300	7810	11700	6300	9470	2820	4240	1590	2390
	419	123	76.0	24	2	72	3⁄8	143000	3770	6.62	9190	13800	9190	13800	9160	13800	8770	13200	8380	12600	7990	12000	6410	9630	2850	4280	1600	2410
	434	128	76.0	24	2	72	7⁄16	145000	3820	6.58	9400	14100	9400	14100	9360	14100	8960	13500	8560	12900	8160	12300	6470	9720	2880	4320	1620	2430
	444	131	76.5	24	2¼	72	5⁄16	159000	4150	6.70	10000	15100	10000	15100	10000	15100	9600	14400	9180	13800	8760	13200	7070	10600	3190	4790	1790	2690
	459	135	76.5	24	2¼	72	3⁄8	161000	4200	6.66	10300	15400	10300	15400	10200	15400	9800	14700	9370	14100	8930	13400	7200	10800	3210	4830	1810	2720
	475	140	76.5	24	2¼	72	7⁄16	163000	4250	6.61	10500	15700	10500	15700	10400	15700	10000	15000	9550	14400	9100	13700	7290	11000	3240	4870	1820	2740
	485	143	77.0	24	2½	72	5⁄16	176000	4580	6.72	11100	16700	11100	16700	11100	16700	10600	16000	10200	15300	9710	14600	7850	11800	3550	5340	2000	3000
	500	147	77.0	24	2½	72	3⁄8	178000	4630	6.68	11300	17000	11300	17000	11300	17000	10800	16300	10400	15600	9880	14900	7970	12000	3580	5380	2010	3020
	516	152	77.0	24	2½	72	7⁄16	180000	4680	6.64	11600	17400	11600	17400	11500	17300	11000	16600	10500	15800	10100	15100	8090	12200	3600	5420	2030	3050
	526	155	77.5	24	2¾	72	5⁄16	194000	5010	6.74	12200	18300	12200	18300	12200	18300	11700	17600	11200	16800	10700	16000	8620	13000	3920	5890	2200	3310
	541	159	77.5	24	2¾	72	3⁄8	196000	5060	6.70	12400	18700	12400	18700	12400	18600	11900	17800	11400	17100	10800	16300	8740	13100	3940	5930	2220	3330
	556	164	77.5	24	2¾	72	7⁄16	198000	5110	6.67	12600	19000	12600	19000	12600	18900	12100	18100	11500	17300	11000	16500	8870	13300	3970	5970	2230	3360
	567	167	78.0	24	3	72	5⁄16	212000	5440	6.75	13300	20000	13300	20000	13300	19900	12700	19100	12200	18300	11600	17400	9390	14100	4280	6430	2410	3620
	582	171	78.0	24	3	72	3⁄8	214000	5490	6.72	13500	20300	13500	20300	13500	20300	12900	19400	12300	18600	11800	17700	9520	14300	4310	6480	2420	3640
	597	176	78.0	24	3	72	7⁄16	216000	5540	6.69	13700	20600	13700	20600	13700	20600	13100	19700	12500	18800	12000	18000	9640	14500	4330	6510	2440	3660
72x30	332	97.5	74.5	30	1¼	72	5⁄16	110000	2960	8.26	6230	9360	6230	9360	6230	9360	6230	9360	6230	9360	6230	9360	5550	8350	3420	5140	1920	2890
	347	102	74.5	30	1¼	72	3⁄8	112000	3010	8.18	6420	9650	6420	9650	6420	9650	6420	9650	6420	9650	6420	9650	5700	8570	3460	5200	1950	2930
	362	107	74.5	30	1¼	72	7⁄16	114000	3070	8.11	6610	9940	6610	9940	6610	9940	6610	9940	6610	9940	6610	9940	5850	8800	3500	5260	1970	2960
	383	113	75.0	30	1½	72	5⁄16	131000	3500	8.32	8130	12200	8130	12200	8130	12200	8130	12200	8060	12100	7770	11700	6630	9960	4130	6200	2320	3490
	398	117	75.0	30	1½	72	3⁄8	133000	3550	8.26	8340	12500	8340	12500	8340	12500	8340	12500	8250	12400	7960	12000	6780	10200	4170	6270	2350	3530
	413	122	75.0	30	1½	72	7⁄16	135000	3600	8.20	8550	12900	8550	12900	8550	12900	8550	12900	8450	12700	8150	12200	6930	10400	4210	6330	2370	3560
	434	128	75.5	30	1¾	72	5⁄16	153000	4040	8.37	9780	14700	9780	14700	9780	14700	9680	14500	9350	14100	9020	13600	7700	11600	4840	7270	2720	4090
	449	132	75.5	30	1¾	72	3⁄8	154000	4090	8.31	10000	15000	10000	15000	10000	15000	9890	14900	9550	14300	9210	13800	7850	11800	4880	7340	2750	4130
	465	137	75.5	30	1¾	72	7⁄16	156000	4140	8.26	10200	15400	10200	15400	10200	15400	10100	15200	9740	14600	9400	14100	8000	12000	4920	7400	2770	4160
	485	143	76.0	30	2	72	5⁄16	174000	4580	8.40	11100	16700	11100	16700	11100	16700	11000	16600	10600	16000	10300	15400	8780	13200	5550	8340	3120	4690
	500	147	76.0	30	2	72	3⁄8	176000	4630	8.35	11300	17000	11300	17000	11300	17000	11200	16900	10800	16300	10500	15700	8930	13400	5590	8400	3150	4730
	516	152	76.0	30	2	72	7⁄16	178000	4680	8.30	11600	17400	11600	17400	11600	17400	11400	17200	11000	16600	10600	16000	9080	13600	5630	8470	3170	4760
	536	158	76.5	30	2¼	72	5⁄16	196000	5120	8.43	12500	18700	12500	18700	12500	18700	12400	18600	11900	17900	11500	17300	9850	14800	6260	9410	3520	5290
	551	162	76.5	30	2¼	72	3⁄8	198000	5170	8.39	12700	19100	12700	19100	12700	19100	12600	18900	12100	18200	11700	17600	10000	15000	6300	9480	3550	5330
	567	167	76.5	30	2¼	72	7⁄16	200000	5220	8.34	12900	19400	12900	19400	12900	19400	12800	19200	12300	18500	11900	17900	10200	15300	6350	9540	3570	5370
	587	173	77.0	30	2½	72	5⁄16	218000	5660	8.45	13800	20800	13800	20800	13800	20800	13700	20600	13200	19900	12800	19200	10900	16400	6970	10500	3920	5900
	602	177	77.0	30	2½	72	3⁄8	220000	5710	8.41	14000	21100	14000	21100	14000	21100	13900	20900	13400	20200	13000	19500	11100	16700	7020	10500	3950	5930
	618	182	77.0	30	2½	72	7⁄16	222000	5760	8.37	14300	21400	14300	21400	14300	21400	14100	21200	13600	20500	13100	19800	11200	16900	7060	10600	3970	5970
	638	188	77.5	30	2¾	72	5⁄16	240000	6200	8.47	15200	22800	15200	22800	15200	22800	15000	22600	14500	21800	14000	21100	12000	18100	7690	11600	4330	6500
	653	192	77.5	30	2¾	72	3⁄8	242000	6250	8.43	15400	23100	15400	23100	15400	23100	15200	22900	14700	22100	14200	21400	12200	18300	7730	11600	4350	6540
	669	197	77.5	30	2¾	72	7⁄16	244000	6300	8.40	15600	23400	15600	23400	15600	23400	15400	23200	14900	22400	14400	21600	12300	18500	7770	11700	4370	6570
	689	203	78.0	30	3	72	5⁄16	263000	6740	8.49	16500	24800	16500	24800	16500	24800	16400	24600	15800	23800	15300	23000	13100	19700	8400	12600	4730	7110
	704	207	78.0	30	3	72	3⁄8	265000	6790	8.45	16700	25100	16700	25100	16700	25100	16600	24900	16000	24100	15500	23200	13200	19900	8450	12700	4750	7140
	720	212	78.0	30	3	72	7⁄16	267000	6840	8.42	16900	25500	16900	25500	16900	25500	16800	25200	16200	24400	15700	23500	13400	20100	8490	12800	4770	7180

Table B3. Available Flexural Strength of Members with 84-in. Web Height

84-in. Web Height Dimensions											Available Flexural Strength, kip-ft																	
											F_y = 50 ksi C_b = 1.0; ASD Ω_b = 1.67; LRFD ϕ_b = 0.90																	
Nominal Shape	Wt/ft	Area	Depth	Flange		Web		Axis X-X			Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD)																	
											Lateral Unbraced Length—L_b, ft																	
			d	width b_f	thk. t_f	height h	thk. t_w	I_x	S_x	r_t	0		10		15		20		25		30		50		75		100	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
84x12	151	44.3	85.5	12	¾	84	5⁄16	47800	1120	2.91	2270	3410	2100	3160	1880	2820	1650	2490	1170	1750	810	1220	292	438	130	195	–	–
	168	49.5	85.5	12	¾	84	⅜	50800	1190	2.75	2570	3860	2360	3550	2100	3150	1840	2760	1240	1860	859	1290	309	465	137	207	–	–
	186	54.8	85.5	12	¾	84	7⁄16	53900	1260	2.67	2860	4290	2610	3920	2310	3470	2010	3020	1300	1950	901	1350	324	488	144	217	–	–
	204	60.0	85.5	12	¾	84	½	57000	1330	2.60	3140	4730	2850	4290	2510	3780	2110	3170	1350	2030	937	1410	337	507	150	225	–	–
	222	65.3	85.5	12	¾	84	9⁄16	60100	1410	2.53	3430	5150	3090	4650	2710	4070	2180	3280	1400	2100	969	1460	349	524	155	233	–	–
	171	50.3	86.0	12	1	84	5⁄16	58800	1370	2.97	2880	4330	2690	4050	2420	3640	2150	3230	1610	2420	1120	1680	403	606	179	269	–	–
	189	55.5	86.0	12	1	84	⅜	61900	1440	2.89	3180	4780	2950	4440	2640	3980	2340	3510	1690	2540	1170	1760	422	634	188	282	–	–
	207	60.8	86.0	12	1	84	7⁄16	65000	1510	2.82	3470	5220	3210	4820	2860	4300	2520	3780	1750	2640	1220	1830	439	659	195	293	–	–
	225	66.0	86.0	12	1	84	½	68000	1580	2.75	3760	5650	3460	5200	3070	4620	2690	4040	1810	2720	1260	1890	453	681	201	303	–	–
	242	71.3	86.0	12	1	84	9⁄16	71100	1650	2.69	4050	6080	3700	5560	3280	4930	2860	4290	1860	2800	1290	1950	466	700	207	311	–	–
	191	56.3	86.5	12	1¼	84	5⁄16	69900	1620	3.05	3500	5260	3290	4940	2960	4450	2640	3970	2070	3110	1430	2160	517	776	230	345	–	–
	209	61.5	86.5	12	1¼	84	⅜	73000	1690	2.98	3790	5700	3550	5330	3190	4800	2830	4260	2140	3220	1490	2240	536	806	238	358	–	–
	227	66.8	86.5	12	1¼	84	7⁄16	76100	1760	2.92	4090	6140	3810	5720	3410	5130	3020	4540	2210	3330	1540	2310	554	832	246	370	–	–
	245	72.0	86.5	12	1¼	84	½	79200	1830	2.86	4380	6580	4060	6100	3630	5450	3200	4810	2280	3420	1580	2380	569	856	253	380	–	–
	263	77.3	86.5	12	1¼	84	9⁄16	82300	1900	2.81	4660	7010	4310	6470	3840	5770	3370	5070	2330	3510	1620	2440	583	877	259	390	–	–
	212	62.3	87.0	12	1½	84	5⁄16	81200	1870	3.11	4110	6180	3880	5830	3510	5270	3130	4710	2530	3800	1750	2640	631	949	281	422	–	–
	230	67.5	87.0	12	1½	84	⅜	84300	1940	3.05	4410	6630	4140	6230	3740	5620	3330	5000	2610	3920	1810	2720	652	979	290	435	–	–
	248	72.8	87.0	12	1½	84	7⁄16	87400	2010	2.99	4700	7070	4400	6620	3960	5950	3520	5290	2680	4030	1860	2800	670	1010	298	447	–	–
	265	78.0	87.0	12	1½	84	½	90500	2080	2.94	4990	7510	4660	7000	4180	6280	3700	5560	2740	4130	1910	2860	686	1030	305	458	–	–
	283	83.3	87.0	12	1½	84	9⁄16	93600	2150	2.89	5280	7940	4910	7380	4390	6610	3880	5830	2800	4220	1950	2930	701	1050	312	468	–	–
	232	68.3	87.5	12	1¾	84	5⁄16	92700	2120	3.15	4730	7110	4480	6730	4050	6090	3630	5460	2990	4490	2080	3120	747	1120	332	499	–	–
	250	73.5	87.5	12	1¾	84	⅜	95700	2190	3.10	5030	7560	4740	7130	4280	6440	3830	5750	3070	4620	2130	3210	768	1150	341	513	–	–
	268	78.8	87.5	12	1¾	84	7⁄16	98800	2260	3.05	5320	8000	5000	7520	4510	6780	4020	6040	3150	4730	2180	3280	786	1180	349	525	–	–
	286	84.0	87.5	12	1¾	84	½	102000	2330	3.00	5610	8440	5260	7900	4730	7110	4200	6320	3210	4830	2230	3350	803	1210	357	537	–	–
	304	89.3	87.5	12	1¾	84	9⁄16	105000	2400	2.95	5900	8870	5510	8280	4950	7440	4390	6590	3280	4920	2270	3420	819	1230	364	547	–	–
	253	74.3	88.0	12	2	84	5⁄16	104000	2370	3.19	5350	8040	5070	7620	4600	6910	4130	6200	3460	5190	2400	3610	864	1300	384	577	–	–
	271	79.5	88.0	12	2	84	⅜	107000	2440	3.14	5650	8490	5340	8020	4830	7260	4320	6500	3540	5320	2460	3690	884	1330	393	591	–	–
	288	84.8	88.0	12	2	84	7⁄16	110000	2510	3.09	5940	8930	5600	8420	5060	7600	4520	6790	3610	5430	2510	3770	903	1360	402	603	–	–
	306	90.0	88.0	12	2	84	½	113000	2580	3.05	6230	9370	5860	8800	5280	7940	4710	7070	3680	5540	2560	3840	921	1380	409	615	–	–
	324	95.3	88.0	12	2	84	9⁄16	117000	2650	3.01	6520	9800	6110	9180	5500	8270	4890	7350	3750	5630	2600	3910	937	1410	416	626	–	–
	273	80.3	88.5	12	2¼	84	5⁄16	116000	2620	3.21	5970	8980	5670	8520	5150	7740	4620	6950	3920	5900	2720	4100	981	1470	436	655	–	–
	291	85.5	88.5	12	2¼	84	⅜	119000	2690	3.17	6270	9420	5940	8920	5380	8080	4820	7250	4010	6020	2780	4180	1000	1510	445	669	–	–
	309	90.8	88.5	12	2¼	84	7⁄16	122000	2760	3.13	6560	9860	6200	9320	5610	8430	5020	7540	4080	6140	2840	4260	1020	1530	454	682	–	–
	327	96.0	88.5	12	2¼	84	½	125000	2830	3.09	6850	10300	6460	9700	5830	8760	5210	7820	4150	6240	2880	4340	1040	1560	462	694	–	–
	345	101	88.5	12	2¼	84	9⁄16	128000	2900	3.05	7140	10700	6710	10100	6050	9090	5390	8100	4220	6340	2930	4400	1060	1590	469	705	–	–
	294	86.3	89.0	12	2½	84	5⁄16	128000	2870	3.24	6600	9910	6270	9420	5690	8560	5120	7700	4390	6600	3050	4590	1100	1650	488	734	–	–
	311	91.5	89.0	12	2½	84	⅜	131000	2940	3.20	6890	10400	6530	9820	5930	8910	5320	8000	4480	6730	3110	4670	1120	1680	497	748	–	–
	329	96.8	89.0	12	2½	84	7⁄16	134000	3010	3.16	7180	10800	6800	10200	6160	9250	5520	8290	4550	6840	3160	4750	1140	1710	506	761	–	–
	347	102	89.0	12	2½	84	½	137000	3080	3.12	7480	11200	7060	10600	6380	9590	5710	8580	4630	6950	3210	4830	1160	1740	514	773	–	–
	365	107	89.0	12	2½	84	9⁄16	140000	3150	3.08	7760	11700	7310	11000	6600	9920	5890	8860	4690	7050	3260	4900	1170	1760	521	784	–	–
	314	92.3	89.5	12	2¾	84	5⁄16	140000	3120	3.26	7220	10900	6870	10300	6240	9380	5620	8450	4870	7310	3380	5080	1220	1830	541	813	–	–
	332	97.5	89.5	12	2¾	84	⅜	143000	3190	3.22	7510	11300	7130	10700	6480	9730	5820	8750	4950	7440	3440	5160	1240	1860	550	826	–	–
	350	103	89.5	12	2¾	84	7⁄16	146000	3260	3.18	7810	11700	7400	11100	6710	10100	6010	9040	5030	7550	3490	5250	1260	1890	558	839	–	–
	368	108	89.5	12	2¾	84	½	149000	3330	3.15	8100	12200	7650	11500	6930	10400	6210	9330	5100	7660	3540	5320	1270	1920	567	851	–	–
	385	113	89.5	12	2¾	84	9⁄16	152000	3400	3.11	8380	12600	7910	11900	7150	10700	6390	9610	5170	7770	3590	5390	1290	1940	574	863	–	–
	334	98.3	90.0	12	3	84	5⁄16	152000	3370	3.27	7840	11800	7470	11200	6790	10200	6120	9200	5340	8020	3710	5570	1330	2010	593	891	–	–
	352	104	90.0	12	3	84	⅜	155000	3440	3.24	8140	12200	7730	11600	7030	10600	6320	9500	5420	8150	3760	5660	1360	2040	602	905	–	–
	370	109	90.0	12	3	84	7⁄16	158000	3510	3.20	8430	12700	8000	12000	7250	10900	6510	9790	5500	8260	3820	5740	1370	2070	611	918	–	–
	388	114	90.0	12	3	84	½	161000	3580	3.17	8720	13100	8250	12400	7480	11200	6710	10100	5570	8370	3870	5820	1390	2090	619	931	–	–
	406	119	90.0	12	3	84	9⁄16	164000	3650	3.14	9010	13500	8510	12800	7700	11600	6890	10400	5640	8480	3920	5890	1410	2120	627	942	–	–

Table B3. Available Flexural Strength of Members with 84-in. Web Height

Nominal Shape	Wt/ft	Area	Depth	Flange		Web		Axis X-X			Available Flexural Strength, kip-ft. Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD). F_y = 50 ksi, C_b = 1.0; ASD Ω_b = 1.67; LRFD ϕ_b = 0.90. Lateral Unbraced Length—L_b, ft																	
			d	width b_f	thk. t_f	height h	thk. t_w	I_x	S_x	r_t	0		10		15		20		25		30		50		75		100	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
84x18	181	53.3	85.5	18	¾	84	5/16	63900	1500	4.52	2810	4220	2810	4220	2810	4220	2800	4200	2600	3900	2400	3600	1040	1560	461	692	260	389
	199	58.5	85.5	18	¾	84	3/8	67000	1570	4.41	3070	4610	3070	4610	3070	4610	3040	4560	2810	4230	2590	3890	1080	1620	480	722	270	406
	217	63.8	85.5	18	¾	84	7/16	70100	1640	4.31	3330	5000	3330	5000	3330	5000	3270	4910	3020	4540	2770	4170	1120	1680	497	747	280	420
	235	69.0	85.5	18	¾	84	½	73200	1710	4.22	3580	5390	3580	5390	3580	5390	3500	5260	3220	4850	2950	4440	1150	1730	513	770	290	433
	253	74.3	85.5	18	¾	84	9/16	76300	1780	4.13	3840	5770	3840	5770	3840	5770	3720	5590	3420	5140	3120	4700	1180	1780	526	791	300	445
	212	62.3	86.0	18	1	84	5/16	80500	1870	4.66	4120	6200	4120	6200	3890	5840	3640	5470	3390	5090	3140	4720	1420	2140	633	951	360	535
	230	67.5	86.0	18	1	84	3/8	83600	1940	4.57	4420	6650	4420	6650	4150	6240	3880	5830	3610	5430	3340	5020	1470	2210	653	982	370	552
	248	72.8	86.0	18	1	84	7/16	86600	2010	4.49	4720	7090	4710	7080	4420	6640	4120	6190	3820	5750	3530	5300	1510	2270	672	1010	380	568
	265	78.0	86.0	18	1	84	½	89700	2090	4.41	5010	7530	4990	7500	4670	7020	4350	6540	4030	6060	3710	5580	1550	2330	688	1030	390	582
	283	83.3	86.0	18	1	84	9/16	92800	2160	4.33	5300	7970	5270	7920	4930	7400	4580	6890	4240	6370	3890	5850	1580	2380	703	1060	400	595
	242	71.3	86.5	18	1¼	84	5/16	97200	2250	4.75	5050	7590	5050	7590	4780	7190	4480	6740	4180	6290	3890	5840	1820	2730	807	1210	450	682
	260	76.5	86.5	18	1¼	84	3/8	100000	2320	4.68	5350	8040	5350	8040	5050	7590	4730	7110	4410	6620	4080	6140	1860	2800	828	1240	470	700
	278	81.8	86.5	18	1¼	84	7/16	103000	2390	4.61	5650	8490	5650	8490	5310	7990	4970	7470	4620	6950	4280	6430	1910	2860	847	1270	480	716
	296	87.0	86.5	18	1¼	84	½	106000	2460	4.54	5940	8930	5940	8930	5570	8380	5210	7820	4840	7270	4470	6720	1950	2920	865	1300	490	731
	314	92.3	86.5	18	1¼	84	9/16	110000	2530	4.47	6230	9370	6220	9350	5830	8760	5440	8170	5050	7580	4650	6990	1980	2980	881	1320	500	745
	273	80.3	87.0	18	1½	84	5/16	114000	2620	4.82	5990	9000	5990	9000	5680	8540	5330	8010	4980	7490	4630	6960	2210	3320	983	1480	550	831
	291	85.5	87.0	18	1½	84	3/8	117000	2690	4.75	6280	9450	6280	9450	5950	8940	5580	8380	5210	7820	4830	7260	2260	3400	1000	1510	560	849
	309	90.8	87.0	18	1½	84	7/16	120000	2770	4.69	6580	9890	6580	9890	6210	9340	5820	8750	5420	8150	5030	7560	2300	3460	1020	1540	580	865
	327	96.0	87.0	18	1½	84	½	123000	2840	4.63	6870	10300	6870	10300	6480	9730	6060	9100	5640	8480	5220	7850	2340	3520	1040	1570	590	881
	345	101	87.0	18	1½	84	9/16	126000	2910	4.57	7170	10800	7170	10800	6730	10100	6290	9460	5850	8790	5410	8130	2380	3580	1060	1590	600	895
	304	89.3	87.5	18	1¾	84	5/16	131000	3000	4.87	6920	10400	6920	10400	6580	9890	6180	9290	5780	8690	5380	8090	2610	3920	1160	1740	650	980
	322	94.5	87.5	18	1¾	84	3/8	134000	3070	4.81	7220	10800	7220	10800	6850	10300	6430	9660	6000	9020	5580	8390	2660	3990	1180	1770	660	998
	339	99.8	87.5	18	1¾	84	7/16	137000	3140	4.75	7510	11300	7510	11300	7110	10700	6670	10000	6220	9350	5780	8690	2700	4060	1200	1800	680	1010
	357	105	87.5	18	1¾	84	½	141000	3210	4.70	7810	11700	7810	11700	7380	11100	6910	10400	6440	9680	5970	8980	2740	4120	1220	1830	690	1030
	375	110	87.5	18	1¾	84	9/16	144000	3280	4.65	8100	12200	8100	12200	7630	11500	7140	10700	6650	10000	6160	9260	2780	4180	1240	1860	696	1050
	334	98.3	88.0	18	2	84	5/16	149000	3380	4.91	7860	11800	7860	11800	7480	11200	7030	10600	6580	9890	6130	9210	3010	4520	1340	2010	752	1130
	352	104	88.0	18	2	84	3/8	152000	3450	4.85	8150	12300	8150	12300	7750	11600	7280	10900	6800	10200	6330	9510	3060	4590	1360	2040	764	1150
	370	109	88.0	18	2	84	7/16	155000	3520	4.80	8450	12700	8450	12700	8010	12000	7520	11300	7020	10600	6530	9810	3100	4660	1380	2070	775	1160
	388	114	88.0	18	2	84	½	158000	3590	4.75	8740	13100	8740	13100	8280	12400	7760	11700	7240	10900	6720	10100	3140	4720	1400	2100	786	1180
	406	119	88.0	18	2	84	9/16	161000	3660	4.71	9040	13600	9040	13600	8540	12800	8000	12000	7460	11200	6920	10400	3180	4780	1410	2130	796	1200
	365	107	88.5	18	2¼	84	5/16	166000	3750	4.94	8790	13200	8790	13200	8380	12600	7880	11800	7380	11100	6880	10300	3410	5120	1510	2280	852	1280
	383	113	88.5	18	2¼	84	3/8	169000	3820	4.89	9090	13700	9090	13700	8650	13000	8130	12200	7600	11400	7080	10600	3460	5190	1540	2310	864	1300
	401	118	88.5	18	2¼	84	7/16	172000	3890	4.84	9390	14100	9390	14100	8920	13400	8370	12600	7820	11800	7280	10900	3500	5260	1560	2340	875	1320
	419	123	88.5	18	2¼	84	½	175000	3960	4.80	9680	14500	9680	14500	9180	13800	8610	12900	8040	12100	7480	11200	3540	5330	1570	2370	886	1330
	436	128	88.5	18	2¼	84	9/16	178000	4030	4.75	9970	15000	9970	15000	9440	14200	8850	13300	8260	12400	7670	11500	3580	5390	1590	2390	896	1350
	396	116	89.0	18	2½	84	5/16	184000	4130	4.96	9730	14600	9730	14600	9280	14000	8730	13100	8180	12300	7630	11500	3810	5720	1690	2540	952	1430
	413	122	89.0	18	2½	84	3/8	187000	4200	4.92	10000	15100	10000	15100	9550	14400	8980	13500	8400	12600	7830	11800	3860	5800	1710	2580	964	1450
	431	127	89.0	18	2½	84	7/16	190000	4270	4.87	10300	15500	10300	15500	9820	14800	9220	13900	8630	13000	8030	12100	3900	5860	1730	2610	975	1470
	449	132	89.0	18	2½	84	½	193000	4340	4.83	10600	16000	10600	16000	10100	15200	9460	14200	8840	13300	8230	12400	3940	5930	1750	2630	986	1480
	467	137	89.0	18	2½	84	9/16	196000	4410	4.79	10900	16400	10900	16400	10300	15500	9700	14600	9060	13600	8420	12700	3990	5990	1770	2660	996	1500
	426	125	89.5	18	2¾	84	5/16	202000	4510	4.98	10700	16000	10700	16000	10200	15300	9590	14400	8980	13500	8380	12600	4210	6330	1870	2810	1050	1580
	444	131	89.5	18	2¾	84	3/8	205000	4580	4.94	11000	16500	11000	16500	10500	15700	9830	14800	9210	13800	8580	12900	4260	6400	1890	2840	1060	1600
	462	136	89.5	18	2¾	84	7/16	208000	4650	4.90	11300	16900	11300	16900	10700	16100	10100	15100	9430	14200	8780	13200	4300	6470	1910	2870	1080	1620
	480	141	89.5	18	2¾	84	½	211000	4720	4.86	11600	17400	11600	17400	11000	16500	10300	15500	9650	14500	8980	13500	4350	6530	1930	2900	1090	1630
	498	146	89.5	18	2¾	84	9/16	214000	4780	4.83	11800	17800	11800	17800	11200	16900	10600	15900	9860	14800	9170	13800	4390	6590	1950	2930	1100	1650
	457	134	90.0	18	3	84	5/16	220000	4890	5.00	11600	17500	11600	17500	11100	16700	10400	15700	9780	14700	9130	13700	4610	6930	2050	3080	1150	1730
	475	140	90.0	18	3	84	3/8	223000	4950	4.96	11900	17900	11900	17900	11400	17100	10700	16100	10000	15000	9330	14000	4660	7000	2070	3110	1160	1750
	493	145	90.0	18	3	84	7/16	226000	5020	4.92	12200	18300	12200	18300	11600	17500	10900	16400	10200	15400	9530	14300	4700	7070	2090	3140	1180	1770
	510	150	90.0	18	3	84	½	229000	5090	4.89	12500	18800	12500	18800	11900	17900	11200	16800	10400	15700	9730	14600	4750	7140	2110	3170	1190	1780
	528	155	90.0	18	3	84	9/16	232000	5160	4.85	12800	19200	12800	19200	12100	18300	11400	17100	10700	16000	9920	14900	4790	7200	2130	3200	1200	1800

Table B3. Available Flexural Strength of Members with 84-in. Web Height

F_y = 50 ksi, C_b = 1.0; ASD: Ω_b = 1.67; LRFD: ϕ_b = 0.90

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	I_x	S_x	r_t	L_b = 0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
84-in. Web Height Dimensions								Axis X-X			Available Flexural Strength, kip-ft: Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD); Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.																		
84x24	253	74.3	86.0	24	1	84	5⁄16	102000	2380	6.37	4720	7090	4720	7090	4720	7090	4720	7090	4720	7090	4610	6930	3470	5210	1540	2320	866	1300
	271	79.5	86.0	24	1	84	3⁄8	105000	2450	6.28	4980	7480	4980	7480	4980	7480	4980	7480	4980	7480	4850	7290	3550	5340	1580	2370	888	1330
	288	84.8	86.0	24	1	84	7⁄16	108000	2520	6.18	5240	7880	5240	7880	5240	7880	5240	7880	5240	7880	5080	7630	3630	5450	1610	2420	907	1360
	306	90.0	86.0	24	1	84	1⁄2	111000	2590	6.10	5500	8270	5500	8270	5500	8270	5500	8270	5500	8270	5310	7970	3700	5560	1640	2470	925	1390
	324	95.3	86.0	24	1	84	9⁄16	114000	2660	6.01	5760	8650	5760	8650	5760	8650	5760	8650	5760	8650	5530	8310	3770	5660	1670	2520	942	1420
	294	86.3	86.5	24	1¼	84	5⁄16	124000	2880	6.47	6490	9750	6490	9750	6490	9750	6290	9450	6000	9020	5710	8580	4410	6620	1960	2940	1100	1660
	311	91.5	86.5	24	1¼	84	3⁄8	128000	2950	6.39	6780	10200	6780	10200	6780	10200	6560	9850	6250	9400	5950	8940	4490	6750	2000	3000	1120	1690
	329	96.8	86.5	24	1¼	84	7⁄16	131000	3020	6.31	7080	10600	7080	10600	7080	10600	6820	10300	6500	9770	6180	9290	4570	6870	2030	3050	1140	1720
	347	102	86.5	24	1¼	84	1⁄2	134000	3090	6.24	7370	11100	7370	11100	7370	11100	7090	10700	6750	10100	6410	9630	4650	6980	2070	3100	1160	1750
	365	107	86.5	24	1¼	84	9⁄16	137000	3160	6.17	7650	11500	7650	11500	7650	11500	7350	11000	6990	10500	6630	9970	4720	7090	2100	3150	1180	1770
	334	98	87.0	24	1½	84	5⁄16	147000	3380	6.54	7860	11800	7860	11800	7830	11800	7490	11300	7150	10700	6810	10200	5350	8040	2380	3570	1340	2010
	352	104	87.0	24	1½	84	3⁄8	150000	3450	6.47	8160	12300	8160	12300	8110	12200	7760	11700	7400	11100	7050	10600	5440	8170	2420	3630	1360	2040
	370	109	87.0	24	1½	84	7⁄16	153000	3520	6.40	8460	12700	8460	12700	8400	12600	8030	12100	7650	11500	7280	10900	5520	8300	2450	3690	1380	2070
	388	114	87.0	24	1½	84	1⁄2	156000	3590	6.34	8760	13200	8760	13200	8680	13000	8290	12500	7900	11900	7510	11300	5600	8410	2490	3740	1400	2100
	406	119	87.0	24	1½	84	9⁄16	159000	3660	6.28	9050	13600	9050	13600	8960	13500	8550	12900	8150	12200	7740	11600	5670	8520	2520	3790	1420	2130
	375	110	87.5	24	1¾	84	5⁄16	170000	3880	6.59	9110	13700	9110	13700	9080	13600	8690	13100	8300	12500	7910	11900	6300	9470	2800	4210	1570	2370
	393	116	87.5	24	1¾	84	3⁄8	173000	3950	6.53	9410	14100	9410	14100	9370	14100	8960	13500	8550	12900	8150	12200	6390	9600	2840	4270	1600	2400
	411	121	87.5	24	1¾	84	7⁄16	176000	4020	6.47	9710	14600	9710	14600	9650	14500	9230	13900	8810	13200	8380	12600	6470	9720	2870	4320	1620	2430
	429	126	87.5	24	1¾	84	1⁄2	179000	4090	6.41	10000	15000	10000	15000	9930	14900	9490	14300	9050	13600	8620	12900	6550	9840	2910	4370	1640	2460
	447	131	87.5	24	1¾	84	9⁄16	182000	4170	6.36	10300	15500	10300	15500	10200	15300	9760	14700	9300	14000	8840	13300	6620	9950	2940	4420	1660	2490
	416	122	88.0	24	2	84	5⁄16	193000	4390	6.63	10400	15600	10400	15600	10300	15500	9890	14900	9450	14200	9010	13500	7250	10900	3220	4840	1810	2720
	434	128	88.0	24	2	84	3⁄8	196000	4460	6.58	10700	16000	10700	16000	10600	16000	10200	15300	9710	14600	9250	13900	7340	11000	3260	4900	1830	2760
	452	133	88.0	24	2	84	7⁄16	199000	4530	6.52	11000	16500	11000	16500	10900	16400	10400	15700	9960	15000	9490	14300	7420	11200	3300	4960	1850	2790
	470	138	88.0	24	2	84	1⁄2	202000	4600	6.47	11300	16900	11300	16900	11200	16800	10700	16100	10200	15300	9720	14600	7500	11300	3330	5010	1870	2820
	487	143	88.0	24	2	84	9⁄16	205000	4670	6.42	11600	17400	11600	17400	11500	17200	11000	16500	10500	15700	9950	15000	7570	11400	3370	5060	1890	2850
	457	134	88.5	24	2¼	84	5⁄16	216000	4890	6.66	11600	17500	11600	17500	11600	17400	11100	16700	10600	15900	10100	15200	8150	12300	3650	5480	2050	3080
	475	140	88.5	24	2¼	84	3⁄8	219000	4960	6.61	11900	17900	11900	17900	11900	17900	11400	17100	10900	16300	10400	15600	8290	12500	3680	5540	2070	3110
	493	145	88.5	24	2¼	84	7⁄16	223000	5030	6.57	12200	18400	12200	18400	12200	18300	11600	17500	11100	16700	10600	15900	8370	12600	3720	5590	2090	3150
	510	150	88.5	24	2¼	84	1⁄2	226000	5100	6.52	12500	18800	12500	18800	12400	18700	11900	17900	11400	17100	10800	16300	8450	12700	3760	5650	2110	3180
	528	155	88.5	24	2¼	84	9⁄16	229000	5170	6.47	12800	19200	12800	19200	12700	19100	12200	18300	11600	17400	11100	16600	8530	12800	3790	5700	2130	3200
	498	146	89.0	24	2½	84	5⁄16	240000	5390	6.69	12900	19300	12900	19300	12800	19300	12300	18500	11800	17700	11200	16900	9050	13600	4070	6120	2290	3440
	516	152	89.0	24	2½	84	3⁄8	243000	5460	6.64	13200	19800	13200	19800	13100	19700	12600	18900	12000	18100	11500	17200	9230	13900	4110	6170	2310	3470
	533	157	89.0	24	2½	84	7⁄16	246000	5530	6.60	13500	20200	13500	20200	13400	20200	12800	19300	12300	18400	11700	17600	9330	14000	4140	6230	2330	3500
	551	162	89.0	24	2½	84	1⁄2	249000	5600	6.56	13800	20700	13800	20700	13700	20600	13100	19700	12500	18800	11900	17900	9410	14100	4180	6280	2350	3530
	569	167	89.0	24	2½	84	9⁄16	252000	5670	6.51	14100	21100	14100	21100	14000	21000	13400	20100	12800	19200	12200	18300	9480	14300	4210	6330	2370	3560
	539	158	89.5	24	2¾	84	5⁄16	264000	5900	6.71	14100	21200	14100	21200	14100	21200	13500	20300	12900	19400	12300	18500	9960	15000	4490	6760	2530	3800
	556	164	89.5	24	2¾	84	3⁄8	267000	5970	6.67	14400	21700	14400	21700	14400	21600	13800	20700	13200	19800	12600	18900	10100	15200	4530	6810	2550	3830
	574	169	89.5	24	2¾	84	7⁄16	270000	6030	6.63	14700	22100	14700	22100	14700	22100	14000	21100	13400	20200	12800	19200	10300	15500	4570	6870	2570	3860
	592	174	89.5	24	2¾	84	1⁄2	273000	6100	6.59	15000	22600	15000	22600	15000	22500	14300	21500	13700	20500	13000	19600	10400	15600	4600	6920	2590	3890
	610	179	89.5	24	2¾	84	9⁄16	276000	6170	6.55	15300	23000	15300	23000	15200	22900	14600	21900	13900	20900	13300	19900	10400	15700	4640	6970	2610	3920
	579	170	90.0	24	3	84	5⁄16	288000	6400	6.73	15400	23100	15400	23100	15400	23100	14700	22100	14100	21200	13400	20200	10900	16300	4920	7390	2770	4160
	597	176	90.0	24	3	84	3⁄8	291000	6470	6.69	15700	23600	15700	23600	15600	23500	15000	22500	14300	21500	13700	20500	11000	16600	4960	7450	2790	4190
	615	181	90.0	24	3	84	7⁄16	294000	6540	6.65	16000	24000	16000	24000	15900	23900	15300	22900	14600	21900	13900	20900	11200	16800	4990	7510	2810	4220
	633	186	90.0	24	3	84	1⁄2	297000	6610	6.61	16300	24500	16300	24500	16200	24400	15500	23300	14800	22300	14100	21200	11300	17000	5030	7560	2830	4250
	651	191	90.0	24	3	84	9⁄16	300000	6680	6.58	16600	24900	16600	24900	16500	24800	15800	23700	15100	22700	14400	21600	11400	17100	5060	7610	2850	4280

Table B3. Available Flexural Strength of Members with 84-in. Web Height

F_y = 50 ksi, C_b = 1.0; ASD: Ω_b = 1.67; LRFD: ϕ_b = 0.90

Available Flexural Strength, kip-ft: Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD)

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	L_b = 0 ft ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.																		
84x30	345	101	86.5	30	1¼	84	5/16	152000	3510	8.20	7190	10800	7190	10800	7190	10800	7190	10800	7190	10800	7190	10800	6390	9600	3880	5840	2180	3280
	362	107	86.5	30	1¼	84	3/8	155000	3580	8.11	7450	11200	7450	11200	7450	11200	7450	11200	7450	11200	7450	11200	6590	9910	3940	5930	2220	3330
	380	112	86.5	30	1¼	84	7/16	158000	3650	8.03	7710	11600	7710	11600	7710	11600	7710	11600	7710	11600	7710	11600	6790	10200	4000	6010	2250	3380
	398	117	86.5	30	1¼	84	½	161000	3720	7.95	7970	12000	7970	12000	7970	12000	7970	12000	7970	12000	7970	12000	6990	10500	4050	6090	2280	3430
	416	122	86.5	30	1¼	84	9/16	164000	3790	7.87	8230	12400	8230	12400	8230	12400	8230	12400	8230	12400	8230	12400	7190	10800	4110	6170	2310	3470
	396	116	87.0	30	1½	84	5/16	180000	4140	8.27	9390	14100	9390	14100	9390	14100	9390	14100	9300	14000	8960	13500	7640	11500	4710	7070	2650	3980
	413	122	87.0	30	1½	84	3/8	183000	4210	8.20	9680	14600	9680	14600	9680	14600	9680	14600	9570	14400	9220	13900	7840	11800	4770	7170	2680	4030
	431	127	87.0	30	1½	84	7/16	186000	4280	8.12	9970	15000	9970	15000	9970	15000	9970	15000	9840	14800	9480	14200	8050	12100	4830	7250	2710	4080
	449	132	87.0	30	1½	84	½	189000	4350	8.06	10300	15400	10300	15400	10300	15400	10300	15400	10100	15200	9730	14600	8250	12400	4880	7340	2750	4130
	467	137	87.0	30	1½	84	9/16	192000	4420	7.99	10500	15800	10500	15800	10500	15800	10500	15800	10400	15600	9980	15000	8440	12700	4930	7410	2770	4170
	447	131	87.5	30	1¾	84	5/16	208000	4770	8.32	11300	17000	11300	17000	11300	17000	11200	16800	10800	16200	10400	15700	8890	13400	5530	8320	3110	4680
	465	137	87.5	30	1¾	84	3/8	212000	4840	8.26	11600	17500	11600	17500	11600	17500	11500	17200	11100	16600	10700	16000	9100	13700	5590	8410	3150	4730
	482	142	87.5	30	1¾	84	7/16	215000	4910	8.20	11900	17900	11900	17900	11900	17900	11800	17700	11300	17000	10900	16400	9300	14000	5650	8500	3180	4780
	500	147	87.5	30	1¾	84	½	218000	4980	8.13	12200	18300	12200	18300	12200	18300	12000	18100	11600	17500	11200	16800	9500	14300	5710	8580	3210	4830
	518	152	87.5	30	1¾	84	9/16	221000	5050	8.08	12500	18800	12500	18800	12500	18800	12300	18500	11900	17800	11400	17200	9700	14600	5760	8660	3240	4870
	498	146	88.0	30	2	84	5/16	237000	5390	8.36	12900	19400	12900	19400	12900	19400	12700	19200	12300	18500	11900	17900	10100	15200	6360	9560	3580	5380
	516	152	88.0	30	2	84	3/8	240000	5460	8.30	13200	19800	13200	19800	13200	19800	13000	19600	12600	18900	12100	18200	10300	15600	6420	9650	3610	5430
	533	157	88.0	30	2	84	7/16	244000	5530	8.25	13500	20300	13500	20300	13500	20300	13300	20000	12900	19300	12400	18600	10600	15900	6480	9740	3650	5480
	551	162	88.0	30	2	84	½	247000	5600	8.20	13800	20700	13800	20700	13800	20700	13600	20400	13100	19700	12600	19000	10800	16200	6540	9820	3680	5530
	569	167	88.0	30	2	84	9/16	250000	5680	8.14	14100	21100	14100	21100	14100	21100	13900	20800	13400	20100	12900	19400	11000	16500	6590	9910	3710	5570
	549	161	88.5	30	2¼	84	5/16	267000	6020	8.39	14400	21700	14400	21700	14400	21700	14300	21500	13800	20800	13300	20000	11400	17100	7190	10800	4040	6080
	567	167	88.5	30	2¼	84	3/8	270000	6090	8.34	14700	22200	14700	22200	14700	22200	14600	21900	14100	21200	13600	20400	11600	17400	7250	10900	4080	6130
	584	172	88.5	30	2¼	84	7/16	273000	6160	8.29	15000	22600	15000	22600	15000	22600	14900	22300	14400	21600	13800	20800	11800	17700	7310	11000	4110	6180
	602	177	88.5	30	2¼	84	½	276000	6230	8.24	15300	23100	15300	23100	15300	23100	15100	22800	14600	22000	14100	21200	12000	18000	7370	11100	4140	6230
	620	182	88.5	30	2¼	84	9/16	279000	6300	8.20	15600	23500	15600	23500	15600	23500	15400	23200	14900	22400	14400	21600	12200	18300	7420	11200	4170	6270
	600	176	89.0	30	2½	84	5/16	296000	6650	8.42	16000	24100	16000	24100	16000	24100	15900	23800	15300	23000	14800	22200	12700	19000	8020	12100	4510	6780
	618	182	89.0	30	2½	84	3/8	299000	6720	8.37	16300	24500	16300	24500	16300	24500	16100	24300	15600	23400	15100	22600	12900	19300	8080	12100	4550	6830
	636	187	89.0	30	2½	84	7/16	302000	6790	8.33	16600	25000	16600	25000	16600	25000	16400	24700	15900	23800	15300	23000	13100	19600	8140	12200	4580	6880
	653	192	89.0	30	2½	84	½	305000	6860	8.28	16900	25400	16900	25400	16900	25400	16700	25100	16100	24200	15600	23400	13300	19900	8200	12300	4610	6930
	671	197	89.0	30	2½	84	9/16	308000	6930	8.24	17200	25900	17200	25900	17200	25900	17000	25500	16400	24600	15800	23800	13500	20200	8250	12400	4640	6970
	651	191	89.5	30	2¾	84	5/16	326000	7280	8.44	17600	26400	17600	26400	17600	26400	17400	26200	16800	25300	16300	24400	13900	20900	8850	13300	4980	7480
	669	197	89.5	30	2¾	84	3/8	329000	7350	8.40	17900	26900	17900	26900	17900	26900	17700	26600	17100	25700	16500	24800	14100	21200	8910	13400	5010	7530
	687	202	89.5	30	2¾	84	7/16	332000	7420	8.36	18200	27300	18200	27300	18200	27300	18000	27000	17400	26100	16800	25200	14300	21500	8970	13500	5050	7580
	704	207	89.5	30	2¾	84	½	335000	7490	8.31	18500	27800	18500	27800	18500	27800	18300	27500	17600	26500	17000	25600	14500	21800	9030	13600	5080	7630
	722	212	89.5	30	2¾	84	9/16	338000	7560	8.27	18800	28200	18800	28200	18800	28200	18500	27900	17900	26900	17300	26000	14700	22100	9080	13600	5110	7680
	702	206	90.0	30	3	84	5/16	356000	7920	8.46	19200	28800	19200	28800	19200	28800	19000	28500	18400	27600	17700	26600	15200	22800	9680	14600	5450	8190
	720	212	90.0	30	3	84	3/8	359000	7980	8.42	19500	29200	19500	29200	19500	29200	19300	29000	18600	28000	18000	27000	15400	23100	9740	14600	5480	8240
	738	217	90.0	30	3	84	7/16	362000	8050	8.38	19800	29700	19800	29700	19800	29700	19600	29400	18900	28400	18200	27400	15600	23400	9800	14700	5510	8290
	755	222	90.0	30	3	84	½	365000	8120	8.34	20000	30100	20000	30100	20000	30100	19800	29800	19200	28800	18500	27800	15800	23700	9860	14800	5540	8330
	773	227	90.0	30	3	84	9/16	369000	8190	8.30	20300	30600	20300	30600	20300	30600	20100	30200	19400	29200	18700	28100	16000	24000	9910	14900	5580	8380

Table B4. Available Flexural Strength of Members with 96-in. Web Height

F_y = 50 ksi, C_b = 1.0; ASD: $\Omega_b = 1.67$; LRFD: $\phi_b = 0.90$

Available Flexural Strength, kip-ft

Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD)

96-in. Web Height Dimensions											Lateral Unbraced Length—L_b, ft																	
Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	r_t	0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.																		
96x12	163	48.0	97.5	12	¾	96	5/16	65200	1340	2.78	2480	3720	2280	3430	2030	3050	1780	2680	1220	1830	844	1270	304	457	135	203	–	–
	184	54.0	97.5	12	¾	96	3/8	69800	1430	2.68	2860	4310	2620	3940	2320	3490	2020	3030	1310	1970	911	1370	328	493	146	219	–	–
	204	60.0	97.5	12	¾	96	7/16	74400	1530	2.60	3250	4880	2950	4430	2590	3900	2180	3270	1390	2090	968	1450	348	524	155	233	–	–
	225	66.0	97.5	12	¾	96	½	79000	1620	2.52	3620	5440	3260	4900	2860	4300	2290	3440	1460	2200	1020	1530	366	550	163	244	–	–
	245	72.0	97.5	12	¾	96	9/16	83600	1710	2.45	3990	6000	3570	5370	3110	4680	2380	3580	1520	2290	1060	1590	381	573	169	254	–	–
	184	54.0	98.0	12	1	96	5/16	79500	1620	2.91	3170	4760	2950	4430	2640	3970	2330	3510	1710	2560	1180	1780	426	641	190	285	–	–
	204	60.0	98.0	12	1	96	3/8	84100	1720	2.83	3560	5340	3290	4950	2940	4410	2580	3880	1810	2720	1260	1890	452	680	201	302	–	–
	225	66.0	98.0	12	1	96	7/16	88700	1810	2.75	3940	5920	3620	5450	3220	4840	2820	4240	1900	2850	1320	1980	475	714	211	317	–	–
	245	72.0	98.0	12	1	96	½	93300	1900	2.68	4320	6490	3950	5940	3500	5250	3040	4570	1980	2970	1370	2060	494	743	220	330	–	–
	265	78.0	98.0	12	1	96	9/16	97900	2000	2.62	4690	7050	4270	6410	3760	5650	3200	4810	2050	3080	1420	2140	512	769	227	342	–	–
	204	60.0	98.5	12	1¼	96	5/16	94000	1910	3.00	3860	5800	3620	5440	3250	4890	2890	4350	2210	3320	1540	2310	553	831	246	369	–	–
	225	66.0	98.5	12	1¼	96	3/8	98600	2000	2.93	4250	6390	3960	5960	3550	5340	3150	4730	2320	3480	1610	2420	580	871	258	387	–	–
	245	72.0	98.5	12	1¼	96	7/16	103000	2100	2.86	4640	6970	4300	6470	3850	5780	3390	5090	2410	3630	1680	2520	603	907	268	403	–	–
	265	78.0	98.5	12	1¼	96	½	108000	2190	2.80	5020	7540	4630	6960	4130	6200	3620	5440	2500	3750	1730	2610	625	939	278	417	–	–
	286	84.0	98.5	12	1¼	96	9/16	112000	2280	2.74	5390	8110	4960	7450	4400	6620	3850	5780	2570	3870	1790	2690	643	967	286	430	–	–
	225	66.0	99.0	12	1½	96	5/16	109000	2190	3.06	4560	6860	4290	6450	3870	5820	3450	5190	2730	4100	1890	2840	681	1020	303	455	–	–
	245	72.0	99.0	12	1½	96	3/8	113000	2290	3.00	4950	7450	4640	6970	4170	6270	3710	5580	2840	4260	1970	2960	709	1070	315	474	–	–
	265	78.0	99.0	12	1½	96	7/16	118000	2380	2.94	5340	8030	4980	7490	4470	6720	3960	5950	2930	4410	2040	3060	734	1100	326	490	–	–
	286	84.0	99.0	12	1½	96	½	122000	2470	2.88	5720	8600	5310	7990	4760	7150	4200	6310	3020	4540	2100	3160	756	1140	336	505	–	–
	306	90.0	99.0	12	1½	96	9/16	127000	2570	2.83	6100	9160	5640	8480	5030	7570	4430	6660	3100	4660	2150	3240	776	1170	345	518	–	–
	245	72.0	99.5	12	1¾	96	5/16	123000	2480	3.11	5270	7910	4970	7470	4490	6750	4020	6030	3250	4880	2250	3390	811	1220	361	542	–	–
	265	78.0	99.5	12	1¾	96	3/8	128000	2570	3.06	5660	8500	5320	7990	4800	7210	4270	6420	3360	5050	2330	3500	839	1260	373	561	–	–
	286	84.0	99.5	12	1¾	96	7/16	133000	2670	3.00	6040	9080	5660	8510	5090	7650	4530	6800	3460	5200	2400	3610	865	1300	384	578	–	–
	306	90.0	99.5	12	1¾	96	½	137000	2760	2.95	6420	9660	6000	9010	5380	8090	4770	7170	3550	5340	2470	3710	888	1330	395	593	–	–
	327	96.0	99.5	12	1¾	96	9/16	142000	2850	2.90	6800	10200	6330	9510	5670	8520	5000	7520	3630	5460	2520	3790	909	1370	404	607	–	–
	265	78.0	100	12	2	96	5/16	138000	2770	3.15	5970	8970	5650	8490	5110	7680	4580	6880	3770	5670	2620	3940	943	1420	419	630	–	–
	286	84.0	100	12	2	96	3/8	143000	2860	3.10	6360	9560	6000	9010	5420	8140	4840	7270	3880	5840	2700	4050	971	1460	432	649	–	–
	306	90.0	100	12	2	96	7/16	148000	2950	3.05	6750	10100	6340	9530	5720	8590	5090	7660	3990	5990	2770	4160	997	1500	443	666	–	–
	327	96.0	100	12	2	96	½	152000	3040	3.00	7130	10700	6680	10000	6010	9030	5340	8030	4080	6130	2830	4260	1020	1530	453	682	–	–
	347	102	100	12	2	96	9/16	157000	3130	2.95	7510	11300	7010	10500	6290	9460	5580	8390	4170	6260	2890	4350	1040	1570	463	696	–	–
	286	84.0	101	12	2¼	96	5/16	153000	3050	3.18	6680	10000	6330	9510	5740	8620	5140	7730	4300	6460	2990	4490	1080	1620	478	718	–	–
	306	90.0	101	12	2¼	96	3/8	158000	3140	3.13	7070	10600	6680	10000	6040	9080	5410	8130	4410	6630	3070	4610	1100	1660	490	737	–	–
	327	96.0	101	12	2¼	96	7/16	163000	3240	3.09	7450	11200	7020	10600	6340	9530	5660	8510	4520	6790	3140	4720	1130	1700	502	755	–	–
	347	102	101	12	2¼	96	½	167000	3330	3.04	7840	11800	7360	11100	6630	9970	5910	8880	4610	6930	3200	4820	1150	1730	513	770	–	–
	368	108	101	12	2¼	96	9/16	172000	3420	3.00	8210	12300	7690	11600	6920	10400	6150	9250	4700	7070	3270	4910	1180	1770	522	785	–	–
	306	90.0	101	12	2½	96	5/16	169000	3340	3.21	7390	11100	7010	10500	6360	9560	5710	8580	4830	7260	3360	5040	1210	1820	537	807	–	–
	327	96.0	101	12	2½	96	3/8	173000	3430	3.16	7780	11700	7360	11100	6670	10000	5970	8980	4950	7430	3430	5160	1240	1860	550	826	–	–
	347	102	101	12	2½	96	7/16	178000	3520	3.12	8160	12300	7700	11600	6970	10500	6230	9360	5050	7590	3510	5270	1260	1900	561	843	–	–
	368	108	101	12	2½	96	½	182000	3610	3.08	8540	12800	8040	12100	7260	10900	6480	9740	5150	7740	3570	5370	1290	1930	572	860	–	–
	388	114	101	12	2½	96	9/16	187000	3700	3.04	8920	13400	8380	12600	7550	11300	6720	10100	5240	7870	3640	5470	1310	1970	582	875	–	–
	327	96.0	102	12	2¾	96	5/16	184000	3630	3.23	8100	12200	7690	11600	6980	10500	6280	9440	5370	8070	3730	5600	1340	2020	596	896	–	–
	347	102	102	12	2¾	96	3/8	189000	3720	3.19	8490	12800	8040	12100	7290	11000	6540	9830	5480	8240	3810	5720	1370	2060	609	915	–	–
	368	108	102	12	2¾	96	7/16	193000	3810	3.15	8870	13300	8390	12600	7590	11400	6800	10200	5590	8390	3880	5830	1400	2100	621	933	–	–
	388	114	102	12	2¾	96	½	198000	3900	3.11	9250	13900	8730	13100	7890	11900	7050	10600	5680	8540	3950	5930	1420	2140	631	949	–	–
	408	120	102	12	2¾	96	9/16	202000	3990	3.07	9630	14500	9060	13600	8180	12300	7300	11000	5770	8680	4010	6030	1440	2170	642	964	–	–
	347	102	102	12	3	96	5/16	200000	3910	3.25	8810	13200	8370	12600	7610	11400	6850	10300	5900	8870	4100	6160	1480	2220	656	986	–	–
	368	108	102	12	3	96	3/8	204000	4000	3.21	9200	13800	8720	13100	7920	11900	7110	10700	6020	9040	4180	6280	1500	2260	668	1000	–	–
	388	114	102	12	3	96	7/16	209000	4090	3.17	9580	14400	9070	13600	8220	12400	7370	11100	6120	9200	4250	6390	1530	2300	680	1020	–	–
	408	120	102	12	3	96	½	213000	4180	3.13	9960	15000	9410	14100	8510	12800	7620	11500	6220	9350	4320	6490	1560	2340	691	1040	–	–
	429	126	102	12	3	96	9/16	218000	4270	3.10	10300	15500	9740	14600	8810	13200	7870	11800	6310	9490	4380	6590	1580	2370	701	1050	–	–

Table B4. Available Flexural Strength of Members with 96-in. Web Height

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	L_b = 0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
											Available Flexural Strength, kip-ft; F_y = 50 ksi, C_b = 1.0; ASD Ω_b = 1.67, LRFD ϕ_b = 0.90																	
											Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD)																	
											Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
96x18	194	57.0	97.5	18	3/4	96	5/16	86200	1770	4.44	3090	4650	3090	4650	3090	4650	3060	4610	2840	4270	2620	3940	1100	1660	490	737	280	414
	214	63.0	97.5	18	3/4	96	3/8	90800	1860	4.32	3440	5170	3440	5170	3440	5170	3380	5080	3130	4700	2870	4310	1160	1750	517	777	290	437
	235	69.0	97.5	18	3/4	96	7/16	95400	1960	4.22	3780	5680	3780	5680	3780	5680	3690	5540	3400	5110	3110	4680	1220	1830	540	812	300	457
	255	75.0	97.5	18	3/4	96	1/2	100000	2050	4.12	4110	6180	4110	6180	4110	6180	3980	5990	3660	5500	3340	5020	1260	1900	561	843	320	474
	276	81.0	97.5	18	3/4	96	9/16	105000	2150	4.02	4440	6680	4440	6680	4440	6680	4270	6420	3920	5890	3560	5360	1300	1960	579	870	330	490
	225	66.0	98.0	18	1	96	5/16	108000	2200	4.60	4570	6870	4570	6870	4300	6460	4020	6040	3740	5620	3460	5200	1540	2310	683	1030	380	577
	245	72.0	98.0	18	1	96	3/8	112000	2290	4.50	4970	7460	4960	7460	4650	6990	4340	6520	4030	6060	3720	5590	1600	2400	711	1070	400	601
	265	78.0	98.0	18	1	96	7/16	117000	2390	4.41	5350	8050	5340	8020	4990	7510	4650	6990	4310	6480	3970	5960	1650	2490	736	1110	410	622
	286	84.0	98.0	18	1	96	1/2	122000	2480	4.32	5740	8620	5700	8570	5330	8010	4960	7450	4580	6890	4210	6330	1710	2560	758	1140	430	641
	306	90.0	98.0	18	1	96	9/16	126000	2570	4.24	6120	9190	6070	9120	5660	8510	5250	7900	4850	7290	4440	6680	1750	2630	778	1170	440	658
	255	75.0	98.5	18	1 1/4	96	5/16	129000	2630	4.70	5630	8460	5630	8460	5320	7990	4980	7490	4640	6980	4310	6470	1980	2970	879	1320	490	743
	276	81.0	98.5	18	1 1/4	96	3/8	134000	2720	4.62	6020	9050	6020	9050	5670	8520	5300	7970	4940	7420	4570	6870	2040	3070	907	1360	510	767
	296	87.0	98.5	18	1 1/4	96	7/16	139000	2820	4.54	6410	9640	6410	9640	6020	9040	5620	8440	5220	7850	4820	7250	2100	3160	933	1400	520	789
	316	93.0	98.5	18	1 1/4	96	1/2	143000	2910	4.46	6800	10200	6780	10200	6360	9550	5930	8910	5500	8260	5070	7620	2150	3240	957	1440	540	809
	337	99.0	98.5	18	1 1/4	96	9/16	148000	3000	4.39	7180	10800	7150	10700	6690	10100	6230	9360	5770	8670	5310	7980	2200	3310	978	1470	550	827
	286	84.0	99.0	18	1 1/2	96	5/16	151000	3060	4.77	6690	10100	6690	10100	6340	9530	5940	8930	5550	8340	5150	7750	2420	3640	1080	1620	610	911
	306	90.0	99.0	18	1 1/2	96	3/8	156000	3150	4.70	7080	10600	7080	10600	6690	10100	6270	9420	5840	8780	5420	8150	2490	3740	1110	1660	620	935
	327	96.0	99.0	18	1 1/2	96	7/16	161000	3240	4.63	7470	11200	7470	11200	7040	10600	6590	9900	6130	9220	5680	8530	2550	3830	1130	1700	640	958
	347	102	99.0	18	1 1/2	96	1/2	165000	3340	4.56	7860	11800	7860	11800	7380	11100	6900	10400	6410	9640	5930	8910	2600	3910	1160	1740	650	978
	368	108	99.0	18	1 1/2	96	9/16	170000	3430	4.50	8240	12400	8240	12400	7720	11600	7200	10800	6690	10100	6170	9280	2650	3990	1180	1770	660	997
	316	93.0	99.5	18	1 3/4	96	5/16	174000	3490	4.83	7760	11700	7760	11700	7360	11100	6910	10400	6460	9710	6010	9030	2870	4320	1280	1920	720	1080
	337	99.0	99.5	18	1 3/4	96	3/8	178000	3580	4.76	8150	12200	8150	12200	7720	11600	7230	10900	6750	10200	6270	9430	2940	4420	1310	1960	730	1100
	357	105	99.5	18	1 3/4	96	7/16	183000	3670	4.70	8540	12800	8540	12800	8070	12100	7550	11400	7040	10600	6530	9820	3000	4510	1330	2000	750	1130
	378	111	99.5	18	1 3/4	96	1/2	187000	3770	4.64	8920	13400	8920	13400	8410	12600	7870	11800	7330	11000	6780	10200	3060	4590	1360	2040	760	1150
	398	117	99.5	18	1 3/4	96	9/16	192000	3860	4.58	9310	14000	9310	14000	8750	13100	8180	12300	7600	11400	7030	10600	3110	4670	1380	2080	777	1170
	347	102	100	18	2	96	5/16	196000	3920	4.87	8820	13300	8820	13300	8390	12600	7880	11800	7370	11100	6860	10300	3330	5000	1480	2220	831	1250
	368	108	100	18	2	96	3/8	201000	4010	4.81	9220	13900	9220	13900	8740	13100	8200	12300	7660	11500	7120	10700	3390	5100	1510	2270	848	1270
	388	114	100	18	2	96	7/16	205000	4100	4.75	9600	14400	9600	14400	9090	13700	8520	12800	7950	12000	7390	11100	3450	5190	1530	2310	863	1300
	408	120	100	18	2	96	1/2	210000	4200	4.70	9990	15000	9990	15000	9440	14200	8840	13300	8240	12400	7640	11500	3510	5270	1560	2340	877	1320
	429	126	100	18	2	96	9/16	214000	4290	4.65	10400	15600	10400	15600	9780	14700	9150	13800	8520	12800	7890	11900	3560	5350	1580	2380	891	1340
	378	111	101	18	2 1/4	96	5/16	219000	4350	4.90	9890	14900	9890	14900	9420	14200	8850	13300	8280	12400	7710	11600	3780	5680	1680	2520	945	1420
	398	117	101	18	2 1/4	96	3/8	223000	4440	4.85	10300	15500	10300	15500	9770	14700	9170	13800	8580	12900	7980	12000	3850	5780	1710	2570	961	1440
	419	123	101	18	2 1/4	96	7/16	228000	4530	4.80	10700	16000	10700	16000	10100	15200	9490	14300	8870	13300	8240	12400	3910	5870	1740	2610	977	1470
	439	129	101	18	2 1/4	96	1/2	232000	4620	4.75	11100	16600	11100	16600	10500	15700	9810	14700	9150	13800	8500	12800	3960	5960	1760	2650	991	1490
	459	135	101	18	2 1/4	96	9/16	237000	4720	4.70	11400	17200	11400	17200	10800	16200	10100	15200	9440	14200	8750	13200	4020	6040	1790	2680	1000	1510
	408	120	101	18	2 1/2	96	5/16	241000	4780	4.93	11000	16500	11000	16500	10400	15700	9820	14800	9190	13800	8570	12900	4240	6370	1880	2830	1060	1590
	429	126	101	18	2 1/2	96	3/8	246000	4870	4.88	11400	17100	11400	17100	10800	16200	10100	15200	9490	14300	8830	13300	4300	6460	1910	2870	1080	1620
	449	132	101	18	2 1/2	96	7/16	251000	4960	4.83	11700	17600	11700	17600	11100	16800	10500	15700	9780	14700	9100	13700	4360	6560	1940	2910	1090	1640
	470	138	101	18	2 1/2	96	1/2	255000	5050	4.79	12100	18200	12100	18200	11500	17300	10800	16200	10100	15100	9350	14100	4420	6640	1960	2950	1100	1660
	490	144	101	18	2 1/2	96	9/16	260000	5140	4.74	12500	18800	12500	18800	11800	17800	11100	16700	10400	15600	9610	14400	4470	6730	1990	2990	1120	1680
	439	129	102	18	2 3/4	96	5/16	264000	5210	4.95	12000	18100	12000	18100	11500	17200	10800	16200	10100	15200	9420	14200	4690	7050	2090	3130	1170	1760
	459	135	102	18	2 3/4	96	3/8	269000	5300	4.91	12400	18700	12400	18700	11800	17800	11100	16700	10400	15600	9690	14600	4760	7150	2110	3180	1190	1790
	480	141	102	18	2 3/4	96	7/16	274000	5390	4.86	12800	19300	12800	19300	12200	18300	11400	17200	10700	16100	9950	15000	4820	7240	2140	3220	1200	1810
	500	147	102	18	2 3/4	96	1/2	278000	5480	4.82	13200	19800	13200	19800	12500	18800	11800	17700	11000	16500	10200	15300	4880	7330	2170	3260	1220	1830
	521	153	102	18	2 3/4	96	9/16	283000	5570	4.78	13600	20400	13600	20400	12900	19300	12100	18100	11300	16900	10500	15700	4930	7410	2190	3290	1230	1850
	470	138	102	18	3	96	5/16	288000	5640	4.97	13100	19700	13100	19700	12500	18800	11800	17700	11000	16600	10300	15500	5150	7740	2290	3440	1290	1930
	490	144	102	18	3	96	3/8	292000	5730	4.93	13500	20300	13500	20300	12900	19300	12100	18200	11300	17000	10500	15900	5210	7840	2320	3480	1300	1960
	510	150	102	18	3	96	7/16	297000	5820	4.89	13900	20900	13900	20900	13200	19900	12400	18700	11600	17400	10800	16200	5280	7930	2340	3520	1320	1980
	531	156	102	18	3	96	1/2	302000	5910	4.85	14300	21400	14300	21400	13600	20400	12700	19100	11900	17900	11100	16600	5330	8020	2370	3560	1330	2000
	551	162	102	18	3	96	9/16	306000	6000	4.81	14600	22000	14600	22000	13900	20900	13000	19600	12200	18300	11300	17000	5390	8100	2400	3600	1350	2030

Table B4. Available Flexural Strength of Members with 96-in. Web Height

F_y = 50 ksi, C_b = 1.0; ASD: Ω_b = 1.67; LRFD: ϕ_b = 0.90

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
											Available Flexural Strength, kip-ft — Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD) — Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.²	in.	in.	in.	in.	in.	in.⁴	in.³	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
96x24	265	78.0	98.0	24	1	96	5⁄16	136000	2770	6.30	5260	7910	5260	7910	5260	7910	5260	7910	5260	7910	5130	7710	3780	5690	1680	2530	946	1420
	286	84.0	98.0	24	1	96	3⁄8	141000	2870	6.20	5610	8430	5610	8430	5610	8430	5610	8430	5610	8430	5440	8170	3900	5860	1730	2600	975	1460
	306	90.0	98.0	24	1	96	7⁄16	145000	2960	6.10	5950	8950	5950	8950	5950	8950	5950	8950	5950	8950	5740	8630	4000	6020	1780	2670	1000	1500
	327	96.0	98.0	24	1	96	1⁄2	150000	3060	6.00	6290	9460	6290	9460	6290	9460	6290	9460	6290	9460	6040	9070	4100	6160	1820	2740	1030	1540
	347	102	98.0	24	1	96	9⁄16	154000	3150	5.91	6630	9960	6630	9960	6630	9960	6630	9960	6630	9960	6330	9510	4190	6300	1860	2800	1050	1570
	306	90.0	98.5	24	1¼	96	5⁄16	165000	3350	6.41	7270	10900	7270	10900	7270	10900	7030	10600	6700	10100	6380	9590	4850	7280	2150	3240	1210	1820
	327	96.0	98.5	24	1¼	96	3⁄8	170000	3440	6.32	7650	11500	7650	11500	7650	11500	7380	11100	7040	10600	6690	10100	4960	7460	2210	3320	1240	1860
	347	102	98.5	24	1¼	96	7⁄16	174000	3540	6.24	8040	12100	8040	12100	8040	12100	7730	11600	7360	11100	6990	10500	5070	7620	2250	3390	1270	1910
	368	108	98.5	24	1¼	96	1⁄2	179000	3630	6.16	8420	12700	8420	12700	8420	12700	8080	12100	7690	11600	7290	11000	5170	7770	2300	3450	1290	1940
	388	114	98.5	24	1¼	96	9⁄16	183000	3720	6.08	8800	13200	8800	13200	8800	13200	8420	12700	8000	12000	7590	11400	5260	7910	2340	3520	1320	1980
	347	102	99.0	24	1½	96	5⁄16	194000	3920	6.49	8830	13300	8830	13300	8780	13200	8400	12600	8010	12000	7630	11500	5920	8900	2630	3950	1480	2220
	368	108	99.0	24	1½	96	3⁄8	199000	4020	6.41	9230	13900	9230	13900	9160	13800	8750	13200	8350	12500	7940	11900	6040	9070	2680	4030	1510	2270
	388	114	99.0	24	1½	96	7⁄16	203000	4110	6.34	9620	14500	9620	14500	9530	14300	9100	13700	8680	13000	8250	12400	6150	9240	2730	4110	1540	2310
	408	120	99.0	24	1½	96	1⁄2	208000	4200	6.27	10000	15000	10000	15000	9900	14900	9450	14200	9000	13500	8550	12900	6250	9390	2780	4170	1560	2350
	429	126	99.0	24	1½	96	9⁄16	213000	4290	6.20	10400	15600	10400	15600	10300	15400	9790	14700	9320	14000	8850	13300	6340	9540	2820	4240	1590	2380
	388	114	99.5	24	1¾	96	5⁄16	224000	4500	6.55	10300	15400	10300	15400	10200	15300	9770	14700	9330	14000	8890	13400	7000	10500	3110	4670	1750	2630
	408	120	99.5	24	1¾	96	3⁄8	228000	4590	6.48	10700	16000	10700	16000	10600	15900	10100	15200	9660	14500	9200	13800	7110	10700	3160	4750	1780	2670
	429	126	99.5	24	1¾	96	7⁄16	233000	4680	6.41	11000	16600	11000	16600	11000	16500	10500	15700	9990	15000	9510	14300	7220	10900	3210	4830	1810	2710
	449	132	99.5	24	1¾	96	1⁄2	238000	4770	6.35	11400	17200	11400	17200	11300	17000	10800	16300	10300	15500	9810	14700	7330	11000	3260	4900	1830	2750
	470	138	99.5	24	1¾	96	9⁄16	242000	4870	6.29	11800	17800	11800	17800	11700	17600	11200	16800	10600	16000	10100	15200	7430	11200	3300	4960	1860	2790
	429	126	100	24	2	96	5⁄16	254000	5070	6.59	11700	17600	11700	17600	11600	17500	11100	16700	10600	16000	10100	15200	8080	12100	3590	5400	2020	3030
	449	132	100	24	2	96	3⁄8	258000	5160	6.53	12100	18200	12100	18200	12000	18100	11500	17300	11000	16500	10500	15700	8190	12300	3640	5470	2050	3080
	470	138	100	24	2	96	7⁄16	263000	5260	6.47	12500	18700	12500	18700	12400	18600	11800	17800	11300	17000	10800	16200	8310	12500	3690	5550	2080	3120
	490	144	100	24	2	96	1⁄2	267000	5350	6.41	12900	19300	12900	19300	12800	19200	12200	18300	11600	17500	11100	16600	8410	12600	3740	5620	2100	3160
	510	150	100	24	2	96	9⁄16	272000	5440	6.36	13200	19900	13200	19900	13100	19700	12500	18900	12000	18000	11400	17100	8510	12800	3780	5690	2130	3200
	470	138	101	24	2¼	96	5⁄16	284000	5650	6.63	13100	19700	13100	19700	13100	19600	12500	18800	12000	18000	11400	17100	9160	13800	4070	6120	2290	3440
	490	144	101	24	2¼	96	3⁄8	288000	5740	6.57	13500	20300	13500	20300	13400	20200	12900	19300	12300	18500	11700	17600	9280	13900	4120	6200	2320	3490
	510	150	101	24	2¼	96	7⁄16	293000	5830	6.52	13900	20900	13900	20900	13800	20800	13200	19900	12600	19000	12000	18100	9390	14100	4170	6270	2350	3530
	531	156	101	24	2¼	96	1⁄2	298000	5920	6.47	14300	21500	14300	21500	14200	21300	13600	20400	12900	19500	12300	18500	9500	14300	4220	6340	2370	3570
	551	162	101	24	2¼	96	9⁄16	302000	6010	6.41	14700	22000	14700	22000	14600	21900	13900	20900	13300	19900	12600	19000	9600	14400	4260	6410	2400	3610
	510	150	101	24	2½	96	5⁄16	314000	6220	6.66	14500	21900	14500	21900	14500	21800	13900	20900	13300	20000	12700	19000	10200	15300	4550	6850	2560	3850
	531	156	101	24	2½	96	3⁄8	319000	6310	6.61	14900	22400	14900	22400	14900	22400	14200	21400	13600	20500	13000	19500	10400	15600	4610	6920	2590	3890
	551	162	101	24	2½	96	7⁄16	323000	6400	6.56	15300	23000	15300	23000	15300	22900	14600	21900	13900	21000	13300	20000	10500	15700	4660	7000	2620	3940
	572	168	101	24	2½	96	1⁄2	328000	6490	6.51	15700	23600	15700	23600	15600	23500	14900	22500	14300	21400	13600	20400	10600	15900	4700	7070	2650	3980
	592	174	101	24	2½	96	9⁄16	333000	6590	6.46	16100	24200	16100	24200	16000	24000	15300	23000	14600	21900	13900	20900	10700	16100	4750	7140	2670	4010
	551	162	102	24	2¾	96	5⁄16	345000	6800	6.68	16000	24000	16000	24000	15900	24000	15300	23000	14600	21900	13900	20900	11200	16900	5040	7570	2830	4260
	572	168	102	24	2¾	96	3⁄8	350000	6890	6.63	16400	24600	16400	24600	16300	24500	15600	23500	14900	22400	14200	21400	11500	17200	5090	7650	2860	4300
	592	174	102	24	2¾	96	7⁄16	354000	6980	6.59	16800	25200	16800	25200	16700	25100	16000	24000	15300	22900	14500	21900	11600	17400	5140	7720	2890	4340
	613	180	102	24	2¾	96	1⁄2	359000	7070	6.54	17100	25800	17100	25800	17100	25600	16300	24500	15600	23400	14800	22300	11700	17500	5190	7800	2920	4380
	633	186	102	24	2¾	96	9⁄16	363000	7160	6.50	17500	26300	17500	26300	17400	26200	16700	25100	15900	23900	15100	22800	11800	17700	5230	7860	2940	4420
	592	174	102	24	3	96	5⁄16	376000	7370	6.70	17400	26200	17400	26200	17400	26100	16600	25000	15900	23900	15200	22800	12300	18400	5520	8300	3110	4670
	613	180	102	24	3	96	3⁄8	381000	7460	6.66	17800	26800	17800	26800	17800	26700	17000	25600	16200	24400	15500	23300	12500	18800	5570	8380	3140	4710
	633	186	102	24	3	96	7⁄16	385000	7550	6.61	18200	27300	18200	27300	18100	27200	17400	26100	16600	24900	15800	23800	12700	19000	5620	8450	3160	4750
	653	192	102	24	3	96	1⁄2	390000	7640	6.57	18600	27900	18600	27900	18500	27800	17700	26600	16900	25400	16100	24200	12800	19200	5670	8520	3190	4790
	674	198	102	24	3	96	9⁄16	394000	7730	6.53	19000	28500	19000	28500	18900	28300	18000	27100	17200	25900	16400	24700	12900	19300	5720	8590	3220	4830

Table B4. Available Flexural Strength of Members with 96-in. Web Height

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
			96-in. Web Height Dimensions								Available Flexural Strength, kip-ft; F_y = 50 ksi, C_b = 1.0; ASD $\Omega_b = 1.67$, LRFD $\phi_b = 0.90$																	
											Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD)																	
											Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.																		
96x30	357	105	98.5	30	1¼	96	5/16	200000	4070	8.13	8070	12100	8070	12100	8070	12100	8070	12100	8070	12100	8070	12100	7150	10800	4300	6460	2420	3630
	378	111	98.5	30	1¼	96	3/8	205000	4160	8.04	8420	12700	8420	12700	8420	12700	8420	12700	8420	12700	8420	12700	7420	11200	4380	6590	2460	3700
	398	117	98.5	30	1¼	96	7/16	210000	4260	7.95	8770	13200	8770	13200	8770	13200	8770	13200	8770	13200	8770	13200	7690	11600	4460	6700	2510	3770
	419	123	98.5	30	1¼	96	1/2	214000	4350	7.86	9110	13700	9110	13700	9110	13700	9110	13700	9110	13700	9110	13700	7950	11900	4530	6810	2550	3830
	439	129	98.5	30	1¼	96	9/16	219000	4440	7.78	9450	14200	9450	14200	9450	14200	9450	14200	9450	14200	9450	14200	8200	12300	4600	6910	2590	3890
	408	120	99.0	30	1½	96	5/16	237000	4790	8.22	10600	15900	10600	15900	10600	15900	10600	15900	10500	15700	10100	15200	8580	12900	5240	7870	2950	4430
	429	126	99.0	30	1½	96	3/8	242000	4880	8.13	11000	16500	11000	16500	11000	16500	11000	16500	10800	16300	10400	15700	8850	13300	5320	7990	2990	4500
	449	132	99.0	30	1½	96	7/16	246000	4970	8.06	11300	17000	11300	17000	11300	17000	11300	17000	11200	16800	10800	16200	9120	13700	5400	8110	3040	4560
	470	138	99.0	30	1½	96	1/2	251000	5070	7.98	11700	17600	11700	17600	11700	17600	11700	17600	11500	17300	11100	16700	9380	14100	5470	8220	3080	4620
	490	144	99.0	30	1½	96	9/16	255000	5160	7.91	12100	18200	12100	18200	12100	18200	12100	18200	11900	17800	11400	17200	9630	14500	5540	8330	3120	4680
	459	135	99.5	30	1¾	96	5/16	274000	5510	8.28	12800	19200	12800	19200	12800	19200	12600	19000	12200	18300	11700	17700	10000	15000	6180	9280	3470	5220
	480	141	99.5	30	1¾	96	3/8	278000	5600	8.20	13200	19800	13200	19800	13200	19800	13000	19500	12500	18800	12100	18200	10300	15400	6260	9410	3520	5290
	500	147	99.5	30	1¾	96	7/16	283000	5690	8.13	13500	20400	13500	20400	13500	20400	13400	20100	12900	19400	12400	18700	10500	15800	6340	9520	3560	5360
	521	153	99.5	30	1¾	96	1/2	288000	5780	8.07	13900	21000	13900	21000	13900	21000	13700	20600	13200	19900	12800	19200	10800	16200	6410	9640	3610	5420
	541	159	99.5	30	1¾	96	9/16	292000	5880	8.00	14300	21500	14300	21500	14300	21500	14100	21200	13600	20400	13100	19700	11100	16600	6480	9740	3650	5480
	510	150	100	30	2	96	5/16	311000	6220	8.32	14600	21900	14600	21900	14600	21900	14400	21600	13900	20900	13400	20100	11400	17200	7120	10700	4000	6020
	531	156	100	30	2	96	3/8	316000	6320	8.26	14900	22500	14900	22500	14900	22500	14800	22200	14300	21400	13700	20700	11700	17600	7200	10800	4050	6090
	551	162	100	30	2	96	7/16	320000	6410	8.20	15300	23100	15300	23100	15300	23100	15100	22700	14600	22000	14100	21200	12000	18000	7280	10900	4090	6150
	572	168	100	30	2	96	1/2	325000	6500	8.13	15700	23600	15700	23600	15700	23600	15500	23300	15000	22500	14400	21700	12200	18400	7350	11100	4140	6220
	592	174	100	30	2	96	9/16	330000	6590	8.08	16100	24200	16100	24200	16100	24200	15900	23900	15300	23000	14700	22200	12500	18800	7430	11200	4180	6280
	561	165	101	30	2¼	96	5/16	349000	6940	8.36	16300	24600	16300	24600	16300	24600	16200	24300	15600	23500	15100	22600	12900	19300	8060	12100	4540	6820
	582	171	101	30	2¼	96	3/8	353000	7030	8.30	16700	25200	16700	25200	16700	25200	16500	24900	16000	24000	15400	23200	13100	19700	8150	12200	4580	6890
	602	177	101	30	2¼	96	7/16	358000	7130	8.24	17100	25700	17100	25700	17100	25700	16900	25400	16300	24500	15700	23700	13400	20100	8220	12400	4630	6950
	623	183	101	30	2¼	96	1/2	363000	7220	8.19	17500	26300	17500	26300	17500	26300	17300	26000	16700	25100	16100	24200	13700	20500	8300	12500	4670	7020
	643	189	101	30	2¼	96	9/16	367000	7310	8.13	17900	26900	17900	26900	17900	26900	17600	26500	17000	25600	16400	24700	13900	20900	8370	12600	4710	7080
	613	180	101	30	2½	96	5/16	387000	7660	8.39	18100	27300	18100	27300	18100	27300	18000	27000	17300	26100	16700	25200	14300	21500	9010	13500	5070	7620
	633	186	101	30	2½	96	3/8	392000	7750	8.33	18500	27800	18500	27800	18500	27800	18300	27500	17700	26600	17100	25700	14600	21900	9090	13700	5110	7690
	653	192	101	30	2½	96	7/16	396000	7840	8.28	18900	28400	18900	28400	18900	28400	18700	28100	18100	27100	17400	26200	14800	22300	9170	13800	5160	7750
	674	198	101	30	2½	96	1/2	401000	7940	8.23	19300	29000	19300	29000	19300	29000	19100	28600	18400	27700	17700	26700	15100	22700	9240	13900	5200	7820
	694	204	101	30	2½	96	9/16	405000	8030	8.18	19700	29600	19700	29600	19700	29600	19400	29200	18700	28200	18100	27200	15400	23100	9320	14000	5240	7880
	664	195	102	30	2¾	96	5/16	425000	8380	8.41	19900	29900	19900	29900	19900	29900	19700	29700	19100	28700	18400	27700	15700	23600	9960	15000	5600	8420
	684	201	102	30	2¾	96	3/8	430000	8470	8.36	20300	30500	20300	30500	20300	30500	20100	30200	19400	29200	18700	28200	16000	24100	10000	15100	5650	8490
	704	207	102	30	2¾	96	7/16	435000	8560	8.31	20700	31100	20700	31100	20700	31100	20500	30800	19800	29700	19100	28700	16300	24500	10100	15200	5690	8550
	725	213	102	30	2¾	96	1/2	439000	8650	8.27	21100	31700	21100	31700	21100	31700	20800	31300	20100	30200	19400	29200	16500	24800	10200	15300	5730	8620
	745	219	102	30	2¾	96	9/16	444000	8750	8.22	21500	32300	21500	32300	21500	32300	21200	31900	20500	30800	19700	29700	16800	25200	10300	15400	5770	8680
	715	210	102	30	3	96	5/16	464000	9100	8.43	21700	32600	21700	32600	21700	32600	21500	32300	20800	31300	20100	30200	17200	25800	10900	16400	6140	9220
	735	216	102	30	3	96	3/8	469000	9190	8.39	22100	33200	22100	33200	22100	33200	21900	32900	21100	31800	20400	30700	17400	26200	11000	16500	6180	9290
	755	222	102	30	3	96	7/16	473000	9280	8.34	22500	33800	22500	33800	22500	33800	22300	33500	21500	32300	20700	31200	17700	26600	11100	16600	6220	9350
	776	228	102	30	3	96	1/2	478000	9370	8.30	22900	34400	22900	34400	22900	34400	22600	34000	21800	32800	21100	31700	18000	27000	11100	16700	6270	9420
	796	234	102	30	3	96	9/16	483000	9460	8.26	23300	35000	23300	35000	23300	35000	23000	34600	22200	33400	21400	32200	18200	27400	11200	16900	6310	9480

Table B5. Available Flexural Strength of Members with 108-in. Web Height

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
108-in. Web Height Dimensions											Available Flexural Strength, kip-ft; $F_y = 50$ ksi, $C_b = 1.0$; ASD $\Omega_b = 1.67$, LRFD $\phi_b = 0.90$; Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD); Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
108x12	199	58.5	110	12	¾	108	⅜	92600	1690	2.62	3100	4650	2820	4230	2480	3730	2110	3170	1350	2030	938	1410	338	508	150	226	–	–
	222	65.3	110	12	¾	108	7/16	99100	1810	2.53	3580	5380	3230	4850	2830	4260	2280	3420	1460	2190	1010	1520	364	548	162	243	–	–
	245	72.0	110	12	¾	108	½	106000	1930	2.45	4060	6100	3630	5460	3160	4760	2420	3640	1550	2330	1080	1620	387	582	172	259	–	–
	268	78.8	110	12	¾	108	9/16	112000	2050	2.38	4530	6810	4020	6040	3480	5240	2540	3820	1630	2450	1130	1700	407	611	181	272	–	–
	219	64.5	110	12	1	108	⅜	111000	2010	2.77	3870	5810	3560	5350	3170	4760	2780	4170	1890	2840	1310	1970	472	710	210	315	–	–
	242	71.3	110	12	1	108	7/16	117000	2130	2.69	4350	6540	3980	5990	3530	5300	3070	4620	2010	3020	1390	2090	502	754	223	335	–	–
	265	78.0	110	12	1	108	½	124000	2250	2.62	4830	7270	4400	6610	3880	5830	3290	4950	2110	3170	1460	2200	527	792	234	352	–	–
	288	84.8	110	12	1	108	9/16	130000	2370	2.55	5310	7980	4800	7210	4210	6330	3430	5160	2200	3300	1530	2290	550	826	244	367	–	–
	240	70.5	111	12	1¼	108	⅜	129000	2330	2.88	4640	6980	4310	6480	3860	5800	3400	5110	2440	3670	1700	2550	611	918	271	408	–	–
	263	77.3	111	12	1¼	108	7/16	135000	2450	2.81	5130	7710	4740	7120	4230	6350	3710	5580	2570	3860	1780	2680	642	965	285	429	–	–
	286	84.0	111	12	1¼	108	½	142000	2570	2.74	5620	8440	5160	7750	4580	6890	4000	6020	2680	4030	1860	2800	670	1010	298	447	–	–
	309	90.8	111	12	1¼	108	9/16	149000	2690	2.68	6090	9160	5570	8370	4930	7410	4290	6440	2780	4170	1930	2900	694	1040	309	464	–	–
	260	76.5	111	12	1½	108	⅜	147000	2650	2.95	5420	8150	5060	7610	4550	6830	4030	6060	3010	4520	2090	3140	753	1130	335	503	–	–
	283	83.3	111	12	1½	108	7/16	154000	2770	2.89	5920	8890	5500	8260	4920	7400	4350	6530	3140	4720	2180	3280	785	1180	349	524	–	–
	306	90.0	111	12	1½	108	½	160000	2890	2.83	6400	9620	5920	8900	5280	7940	4650	6990	3260	4890	2260	3400	814	1220	362	544	–	–
	329	96.8	111	12	1½	108	9/16	167000	3010	2.77	6880	10300	6340	9520	5640	8470	4940	7420	3360	5050	2330	3510	840	1260	373	561	–	–
	281	82.5	112	12	1¾	108	⅜	166000	2970	3.01	6210	9330	5820	8750	5240	7880	4660	7010	3590	5390	2490	3740	897	1350	398	599	–	–
	304	89.3	112	12	1¾	108	7/16	172000	3090	2.95	6700	10100	6260	9400	5620	8440	4980	7480	3720	5590	2580	3880	930	1400	413	621	–	–
	327	96.0	112	12	1¾	108	½	179000	3210	2.90	7190	10800	6680	10000	5990	9000	5290	7950	3840	5770	2670	4010	960	1440	427	641	–	–
	350	103	112	12	1¾	108	9/16	186000	3330	2.85	7670	11500	7100	10700	6340	9540	5590	8400	3950	5930	2740	4120	987	1480	439	659	–	–
	301	88.5	112	12	2	108	⅜	185000	3300	3.06	7000	10500	6580	9890	5940	8920	5290	7960	4170	6270	2890	4350	1040	1570	463	696	–	–
	324	95.3	112	12	2	108	7/16	191000	3410	3.01	7490	11300	7020	10500	6320	9490	5620	8440	4300	6470	2990	4490	1080	1620	478	719	–	–
	347	102	112	12	2	108	½	198000	3530	2.95	7980	12000	7450	11200	6690	10100	5930	8910	4430	6650	3070	4620	1110	1660	492	739	–	–
	370	109	112	12	2	108	9/16	204000	3650	2.91	8460	12700	7870	11800	7050	10600	6230	9360	4540	6820	3150	4740	1130	1710	504	758	–	–
	322	94.5	113	12	2¼	108	⅜	203000	3620	3.10	7790	11700	7340	11000	6630	9970	5930	8910	4760	7150	3300	4960	1190	1790	528	794	–	–
	345	101	113	12	2¼	108	7/16	210000	3730	3.05	8280	12400	7780	11700	7020	10500	6250	9390	4890	7350	3400	5110	1220	1840	544	817	–	–
	368	108	113	12	2¼	108	½	217000	3850	3.00	8770	13200	8210	12300	7390	11100	6570	9870	5020	7540	3490	5240	1250	1890	558	838	–	–
	390	115	113	12	2¼	108	9/16	223000	3970	2.95	9250	13900	8640	13000	7750	11700	6870	10300	5130	7720	3570	5360	1280	1930	570	857	–	–
	342	101	113	12	2½	108	⅜	223000	3940	3.13	8580	12900	8100	12200	7330	11000	6560	9860	5350	8040	3710	5580	1340	2010	594	893	–	–
	365	107	113	12	2½	108	7/16	229000	4060	3.08	9070	13600	8540	12800	7720	11600	6890	10400	5490	8240	3810	5730	1370	2060	609	916	–	–
	388	114	113	12	2½	108	½	236000	4170	3.04	9560	14400	8980	13500	8090	12200	7200	10800	5610	8440	3900	5860	1400	2110	624	937	–	–
	411	121	113	12	2½	108	9/16	242000	4290	3.00	10000	15100	9400	14100	8460	12700	7510	11300	5730	8610	3980	5980	1430	2150	637	957	–	–
	362	107	114	12	2¾	108	⅜	242000	4260	3.16	9380	14100	8870	13300	8030	12100	7200	10800	5940	8930	4130	6200	1490	2230	660	992	–	–
	385	113	114	12	2¾	108	7/16	248000	4380	3.11	9870	14800	9310	14000	8420	12600	7520	11300	6080	9140	4220	6350	1520	2280	676	1020	–	–
	408	120	114	12	2¾	108	½	255000	4490	3.07	10400	15600	9740	14600	8790	13200	7840	11800	6210	9330	4310	6480	1550	2330	690	1040	–	–
	431	127	114	12	2¾	108	9/16	261000	4610	3.03	10800	16300	10200	15300	9160	13800	8160	12300	6330	9510	4390	6600	1580	2380	703	1060	–	–
	383	113	114	12	3	108	⅜	261000	4580	3.18	10200	15300	9630	14500	8730	13100	7830	11800	6540	9830	4540	6820	1630	2460	726	1090	–	–
	406	119	114	12	3	108	7/16	268000	4700	3.14	10700	16000	10100	15100	9120	13700	8160	12300	6680	10000	4640	6970	1670	2510	742	1120	–	–
	429	126	114	12	3	108	½	274000	4810	3.10	11100	16800	10500	15800	9500	14300	8480	12700	6810	10200	4730	7100	1700	2560	756	1140	–	–
	452	133	114	12	3	108	9/16	281000	4930	3.06	11600	17500	10900	16400	9870	14800	8800	13200	6930	10400	4810	7230	1730	2600	770	1160	–	–

Table B5. Available Flexural Strength of Members with 108-in. Web Height

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	L_b = 0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
											Available Flexural Strength, kip-ft. F_y = 50 ksi, C_b = 1.0. ASD: Ω_b = 1.67; LRFD: ϕ_b = 0.90. Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD). Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
108x18	230	67.5	110	18	¾	108	⅜	119000	2180	4.24	3740	5630	3740	5630	3740	5630	3660	5500	3380	5080	3100	4650	1220	1830	542	815	305	458
	253	74.3	110	18	¾	108	7/16	126000	2300	4.13	4180	6280	4180	6280	4180	6280	4050	6080	3720	5600	3400	5110	1290	1940	573	861	322	484
	276	81.0	110	18	¾	108	½	132000	2420	4.02	4600	6920	4600	6920	4600	6920	4420	6650	4060	6100	3690	5550	1350	2030	600	901	337	507
	299	87.8	110	18	¾	108	9/16	139000	2540	3.93	5020	7550	5020	7550	5020	7550	4790	7200	4380	6580	3900	5860	1400	2110	623	937	351	527
	260	76.5	110	18	1	108	⅜	146000	2660	4.43	5440	8170	5420	8150	5080	7630	4730	7110	4390	6590	4040	6070	1700	2550	754	1130	420	638
	283	83.3	110	18	1	108	7/16	153000	2780	4.33	5930	8910	5900	8860	5510	8280	5130	7710	4740	7130	4360	6550	1770	2660	787	1180	440	666
	306	90.0	110	18	1	108	½	159000	2900	4.24	6420	9650	6360	9570	5940	8930	5510	8290	5090	7650	4660	7010	1840	2760	816	1230	460	690
	329	96.8	110	18	1	108	9/16	166000	3020	4.16	6900	10400	6820	10300	6360	9550	5890	8850	5420	8150	4950	7450	1900	2850	843	1270	470	712
	291	85.5	111	18	1¼	108	⅜	174000	3140	4.56	6620	9950	6620	9950	6220	9340	5810	8730	5400	8110	4990	7500	2190	3290	972	1460	550	821
	314	92.3	111	18	1¼	108	7/16	180000	3260	4.47	7110	10700	7100	10700	6660	10000	6210	9330	5760	8660	5310	7980	2260	3400	1010	1510	570	850
	337	99.0	111	18	1¼	108	½	187000	3380	4.39	7600	11400	7570	11400	7090	10700	6600	9920	6110	9190	5620	8450	2330	3500	1040	1560	580	876
	360	106	111	18	1¼	108	9/16	193000	3500	4.32	8090	12200	8040	12100	7510	11300	6980	10500	6460	9700	5930	8910	2390	3600	1060	1600	600	900
	322	94.5	111	18	1½	108	⅜	201000	3630	4.65	7810	11700	7810	11700	7360	11100	6890	10300	6410	9640	5940	8930	2680	4030	1190	1790	670	1010
	345	101	111	18	1½	108	7/16	208000	3740	4.57	8300	12500	8300	12500	7800	11700	7290	11000	6780	10200	6270	9420	2760	4150	1230	1840	690	1040
	368	108	111	18	1½	108	½	214000	3860	4.50	8790	13200	8790	13200	8240	12400	7690	11600	7140	10700	6590	9900	2830	4260	1260	1890	710	1060
	390	115	111	18	1½	108	9/16	221000	3980	4.43	9280	13900	9250	13900	8660	13000	8070	12100	7490	11300	6900	10400	2900	4350	1290	1940	720	1090
	352	104	112	18	1¾	108	⅜	229000	4110	4.72	9000	13500	9000	13500	8510	12800	7970	12000	7430	11200	6890	10400	3180	4780	1410	2130	800	1200
	375	110	112	18	1¾	108	7/16	236000	4230	4.65	9500	14300	9500	14300	8950	13500	8380	12600	7800	11700	7220	10900	3260	4900	1450	2180	820	1230
	398	117	112	18	1¾	108	½	242000	4340	4.58	9990	15000	9990	15000	9390	14100	8770	13200	8160	12300	7550	11300	3330	5010	1480	2230	830	1250
	421	124	112	18	1¾	108	9/16	249000	4460	4.52	10500	15700	10500	15700	9820	14800	9170	13800	8510	12800	7860	11800	3400	5110	1510	2270	850	1280
	383	113	112	18	2	108	⅜	257000	4590	4.77	10200	15300	10200	15300	9660	14500	9050	13600	8450	12700	7850	11800	3690	5540	1640	2460	920	1380
	406	119	112	18	2	108	7/16	264000	4710	4.71	10700	16100	10700	16100	10100	15200	9460	14200	8820	13300	8180	12300	3770	5660	1670	2520	940	1420
	429	126	112	18	2	108	½	270000	4830	4.65	11200	16800	11200	16800	10500	15800	9860	14800	9180	13800	8510	12800	3840	5770	1710	2570	960	1440
	452	133	112	18	2	108	9/16	277000	4940	4.59	11700	17500	11700	17500	11000	16500	10300	15400	9540	14300	8830	13300	3910	5880	1740	2610	980	1470
	413	122	113	18	2¼	108	⅜	286000	5080	4.81	11400	17100	11400	17100	10800	16200	10100	15200	9480	14200	8810	13200	4190	6300	1860	2800	1050	1580
	436	128	113	18	2¼	108	7/16	292000	5190	4.75	11900	17900	11900	17900	11300	16900	10500	15900	9850	14800	9140	13700	4270	6420	1900	2850	1070	1610
	459	135	113	18	2¼	108	½	299000	5310	4.70	12400	18600	12400	18600	11700	17600	11000	16500	10200	15300	9470	14200	4350	6540	1930	2900	1090	1630
	482	142	113	18	2¼	108	9/16	305000	5430	4.65	12900	19300	12900	19300	12100	18200	11300	17100	10600	15900	9790	14700	4420	6640	1960	2950	1100	1660
	444	131	113	18	2½	108	⅜	314000	5560	4.85	12600	18900	12600	18900	12000	18000	11200	16900	10500	15800	9770	14700	4700	7070	2090	3140	1180	1770
	467	137	113	18	2½	108	7/16	321000	5680	4.79	13100	19700	13100	19700	12400	18600	11600	17500	10900	16300	10100	15200	4780	7190	2130	3190	1200	1800
	490	144	113	18	2½	108	½	327000	5790	4.74	13600	20400	13600	20400	12800	19300	12000	18100	11200	16900	10400	15700	4860	7300	2160	3240	1210	1830
	513	151	113	18	2½	108	9/16	334000	5910	4.69	14100	21100	14100	21100	13300	20000	12400	18700	11600	17400	10800	16200	4930	7410	2190	3290	1230	1850
	475	140	114	18	2¾	108	⅜	343000	6040	4.87	13800	20700	13800	20700	13100	19700	12300	18500	11500	17300	10700	16100	5210	7830	2320	3480	1300	1960
	498	146	114	18	2¾	108	7/16	350000	6160	4.83	14300	21500	14300	21500	13600	20400	12700	19100	11900	17900	11100	16600	5290	7950	2350	3530	1320	1990
	521	153	114	18	2¾	108	½	356000	6280	4.78	14800	22200	14800	22200	14000	21000	13100	19700	12300	18400	11400	17100	5370	8070	2390	3590	1340	2020
	544	160	114	18	2¾	108	9/16	363000	6390	4.73	15300	22900	15300	22900	14400	21700	13500	20300	12600	19000	11700	17600	5440	8180	2420	3630	1360	2040
	505	149	114	18	3	108	⅜	372000	6530	4.90	15000	22500	15000	22500	14300	21500	13400	20200	12600	18900	11700	17600	5720	8600	2540	3820	1430	2150
	528	155	114	18	3	108	7/16	379000	6640	4.85	15500	23300	15500	23300	14700	22100	13800	20800	12900	19400	12000	18100	5800	8720	2580	3880	1450	2180
	551	162	114	18	3	108	½	385000	6760	4.81	16000	24000	16000	24000	15200	22800	14200	21400	13300	20000	12400	18600	5880	8840	2610	3930	1470	2210
	574	169	114	18	3	108	9/16	392000	6870	4.77	16500	24700	16500	24700	15600	23400	14600	22000	13600	20500	12700	19100	5950	8950	2650	3980	1490	2240

Table B5. Available Flexural Strength of Members with 108-in. Web Height

F_y = 50 ksi, C_b = 1.0
ASD: Ω_b = 1.67; LRFD: ϕ_b = 0.90

108-in. Web Height Dimensions											Available Flexural Strength, kip-ft																	
Nominal Shape	Wt/ft	Area	Depth	Flange		Web		Axis X-X			Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD)																	
			d	width b_f	thk. t_f	height h	thk. t_w	I_x	S_x	r_t	Lateral Unbraced Length—L_b, ft																	
											0		10		15		20		25		30		50		75		100	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
108x24	301	88.5	110	24	1	108	3/8	182000	3310	6.12	6170	9270	6170	9270	6170	9270	6170	9270	6170	9270	5960	8950	4180	6290	1860	2790	1050	1570
	324	95.3	110	24	1	108	7/16	189000	3430	6.01	6610	9930	6610	9930	6610	9930	6610	9930	6610	9930	6340	9530	4320	6500	1920	2890	1080	1620
	347	102	110	24	1	108	1/2	195000	3550	5.91	7040	10600	7040	10600	7040	10600	7040	10600	7040	10600	6720	10100	4450	6690	1980	2970	1110	1670
	370	109	110	24	1	108	9/16	202000	3670	5.81	7470	11200	7470	11200	7470	11200	7470	11200	7470	11200	7090	10600	4560	6860	2030	3050	1140	1710
	342	101	111	24	1¼	108	3/8	218000	3950	6.26	8450	12700	8450	12700	8450	12700	8130	12200	7750	11600	7360	11100	5370	8070	2380	3580	1340	2020
	365	107	111	24	1¼	108	7/16	225000	4070	6.17	8940	13400	8940	13400	8940	13400	8580	12900	8160	12300	7750	11600	5510	8280	2450	3680	1380	2070
	388	114	111	24	1¼	108	1/2	232000	4190	6.08	9420	14200	9420	14200	9420	14200	9020	13600	8570	12900	8130	12200	5640	8470	2510	3770	1410	2120
	411	121	111	24	1¼	108	9/16	238000	4310	5.99	9900	14900	9900	14900	9900	14900	9450	14200	8980	13500	8500	12800	5760	8660	2560	3850	1440	2160
	383	113	111	24	1½	108	3/8	255000	4600	6.36	10200	15300	10200	15300	10100	15200	9670	14500	9220	13900	8760	13200	6560	9860	2920	4380	1640	2470
	406	119	111	24	1½	108	7/16	262000	4720	6.28	10700	16100	10700	16100	10600	15900	10100	15200	9640	14500	9150	13800	6700	10100	2980	4480	1680	2520
	429	126	111	24	1½	108	1/2	268000	4830	6.20	11200	16800	11200	16800	11100	16600	10600	15900	10000	15100	9540	14300	6840	10300	3040	4570	1710	2570
	452	133	111	24	1½	108	9/16	275000	4950	6.12	11700	17600	11700	17600	11500	17300	11000	16500	10500	15700	9920	14900	6960	10500	3090	4650	1740	2620
	424	125	112	24	1¾	108	3/8	292000	5240	6.43	11800	17700	11800	17700	11700	17600	11200	16800	10700	16100	10200	15300	7760	11700	3450	5190	1940	2920
	447	131	112	24	1¾	108	7/16	299000	5360	6.36	12300	18500	12300	18500	12200	18300	11700	17500	11100	16700	10600	15900	7910	11900	3510	5280	1980	2970
	470	138	112	24	1¾	108	1/2	305000	5480	6.29	12800	19200	12800	19200	12700	19000	12100	18200	11500	17300	11000	16500	8040	12100	3580	5370	2010	3020
	493	145	112	24	1¾	108	9/16	312000	5600	6.22	13300	20000	13300	20000	13100	19700	12500	18800	11900	17900	11300	17000	8170	12300	3630	5460	2040	3070
	465	137	112	24	2	108	3/8	330000	5890	6.49	13400	20200	13400	20200	13300	20000	12700	19200	12200	18300	11600	17400	8970	13500	3990	5990	2240	3370
	487	143	112	24	2	108	7/16	336000	6010	6.42	13900	20900	13900	20900	13800	20700	13200	19800	12600	18900	12000	18000	9120	13700	4050	6090	2280	3430
	510	150	112	24	2	108	1/2	343000	6120	6.36	14400	21600	14400	21600	14300	21500	13600	20500	13000	19500	12400	18600	9250	13900	4110	6180	2310	3480
	533	157	112	24	2	108	9/16	349000	6240	6.30	14900	22400	14900	22400	14700	22200	14100	21200	13400	20200	12700	19200	9380	14100	4170	6270	2350	3530
	505	149	113	24	2¼	108	3/8	368000	6540	6.53	15000	22600	15000	22600	14900	22400	14300	21500	13600	20500	13000	19500	10200	15300	4530	6800	2550	3830
	528	155	113	24	2¼	108	7/16	374000	6650	6.47	15500	23300	15500	23300	15400	23200	14700	22200	14100	21100	13400	20100	10300	15500	4590	6900	2580	3880
	551	162	113	24	2¼	108	1/2	381000	6770	6.41	16000	24000	16000	24000	15900	23900	15200	22800	14500	21800	13800	20700	10500	15700	4650	6990	2620	3930
	574	169	113	24	2¼	108	9/16	387000	6890	6.36	16500	24800	16500	24800	16300	24600	15600	23500	14900	22400	14200	21300	10600	15900	4710	7080	2650	3980
	546	161	113	24	2½	108	3/8	406000	7180	6.57	16600	25000	16600	25000	16500	24900	15800	23800	15100	22700	14400	21700	11400	17100	5070	7620	2850	4280
	569	167	113	24	2½	108	7/16	412000	7300	6.51	17100	25700	17100	25700	17000	25600	16300	24500	15500	23400	14800	22200	11500	17400	5130	7710	2890	4340
	592	174	113	24	2½	108	1/2	419000	7410	6.46	17600	26500	17600	26500	17500	26300	16700	25100	16000	24000	15200	22800	11700	17600	5190	7810	2920	4390
	615	181	113	24	2½	108	9/16	425000	7530	6.41	18100	27200	18100	27200	18000	27000	17200	25800	16400	24600	15600	23400	11800	17800	5250	7890	2950	4440
	587	173	114	24	2¾	108	3/8	444000	7830	6.60	18200	27400	18200	27400	18200	27300	17400	26100	16600	25000	15800	23800	12600	19000	5610	8430	3150	4740
	610	179	114	24	2¾	108	7/16	451000	7940	6.55	18700	28100	18700	28100	18600	28000	17800	26800	17000	25600	16200	24400	12800	19200	5670	8530	3190	4800
	633	186	114	24	2¾	108	1/2	457000	8060	6.50	19200	28900	19200	28900	19100	28700	18300	27500	17400	26200	16600	25000	12900	19400	5730	8620	3230	4850
	656	193	114	24	2¾	108	9/16	464000	8170	6.45	19700	29600	19700	29600	19600	29400	18700	28100	17800	26800	17000	25500	13000	19600	5790	8710	3260	4900
	628	185	114	24	3	108	3/8	483000	8470	6.62	19800	29800	19800	29800	19800	29700	18900	28400	18100	27200	17200	25900	13800	20800	6150	9250	3460	5200
	651	191	114	24	3	108	7/16	490000	8590	6.58	20300	30600	20300	30600	20200	30400	19400	29100	18500	27800	17600	26500	14000	21000	6220	9340	3500	5250
	674	198	114	24	3	108	1/2	496000	8700	6.53	20800	31300	20800	31300	20700	31100	19800	29800	18900	28400	18000	27100	14100	21200	6280	9430	3530	5310
	697	205	114	24	3	108	9/16	503000	8820	6.49	21300	32000	21300	32000	21200	31800	20300	30400	19300	29100	18400	27700	14300	21400	6340	9520	3560	5360

Table B5. Available Flexural Strength of Members with 108-in. Web Height

F_y = 50 ksi, C_b = 1.0; ASD: $\Omega_b = 1.67$; LRFD: $\phi_b = 0.90$

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	L_b = 0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
											Available Flexural Strength, kip-ft: Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD); Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.[2]	in.	in.	in.	in.	in.	in.[4]	in.[3]	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
108x30	393	116	111	30	1¼	108	⅜	263000	4760	7.97	9320	14000	9320	14000	9320	14000	9320	14000	9320	14000	9320	14000	8190	12300	4770	7170	2680	4030
	416	122	111	30	1¼	108	7⁄16	270000	4880	7.87	9760	14700	9760	14700	9760	14700	9760	14700	9760	14700	9760	14700	8520	12800	4870	7320	2740	4120
	439	129	111	30	1¼	108	½	276000	5000	7.78	10200	15300	10200	15300	10200	15300	10200	15300	10200	15300	10200	15300	8850	13300	4960	7460	2790	4200
	462	136	111	30	1¼	108	9⁄16	283000	5120	7.68	10600	16000	10600	16000	10600	16000	10600	16000	10600	16000	10600	16000	9170	13800	5050	7590	2840	4270
	444	131	111	30	1½	108	⅜	309000	5570	8.08	12200	18300	12200	18300	12200	18300	12200	18300	12000	18000	11500	17400	9790	14700	5810	8740	3270	4920
	467	137	111	30	1½	108	7⁄16	316000	5690	7.99	12600	19000	12600	19000	12600	19000	12600	19000	12400	18700	12000	18000	10100	15200	5920	8890	3330	5000
	490	144	111	30	1½	108	½	322000	5810	7.91	13100	19700	13100	19700	13100	19700	13100	19700	12900	19400	12400	18600	10500	15700	6010	9040	3380	5080
	513	151	111	30	1½	108	9⁄16	329000	5930	7.82	13600	20400	13600	20400	13600	20400	13600	20400	13300	20000	12800	19300	10800	16200	6100	9170	3430	5160
	495	146	112	30	1¾	108	⅜	356000	6380	8.15	14600	22000	14600	22000	14600	22000	14400	21700	13900	20900	13400	20200	11400	17100	6870	10300	3860	5810
	518	152	112	30	1¾	108	7⁄16	362000	6500	8.08	15100	22700	15100	22700	15100	22700	14900	22400	14400	21600	13800	20800	11700	17600	6970	10500	3920	5890
	541	159	112	30	1¾	108	½	369000	6610	8.00	15600	23500	15600	23500	15600	23500	15400	23100	14800	22300	14300	21400	12100	18100	7070	10600	3970	5970
	564	166	112	30	1¾	108	9⁄16	375000	6730	7.93	16100	24200	16100	24200	16100	24200	15800	23800	15200	22900	14700	22100	12400	18600	7160	10800	4030	6050
	546	161	112	30	2	108	⅜	402000	7190	8.21	16600	25000	16600	25000	16600	25000	16400	24700	15800	23800	15300	23000	13000	19500	7920	11900	4460	6700
	569	167	112	30	2	108	7⁄16	409000	7300	8.14	17100	25700	17100	25700	17100	25700	16900	25400	16300	24500	15700	23600	13300	20000	8020	12100	4510	6780
	592	174	112	30	2	108	½	416000	7420	8.08	17600	26500	17600	26500	17600	26500	17400	26100	16700	25200	16100	24200	13700	20500	8120	12200	4570	6870
	615	181	112	30	2	108	9⁄16	422000	7540	8.01	18100	27200	18100	27200	18100	27200	17800	26800	17200	25800	16500	24900	14000	21000	8210	12300	4620	6940
	597	176	113	30	2¼	108	⅜	450000	7990	8.26	18600	28000	18600	28000	18600	28000	18400	27700	17800	26700	17100	25800	14600	21900	8980	13500	5050	7590
	620	182	113	30	2¼	108	7⁄16	456000	8110	8.20	19100	28800	19100	28800	19100	28800	18900	28400	18200	27400	17600	26400	14900	22500	9080	13700	5110	7680
	643	189	113	30	2¼	108	½	463000	8230	8.13	19600	29500	19600	29500	19600	29500	19400	29100	18700	28100	18000	27000	15300	23000	9180	13800	5160	7760
	666	196	113	30	2¼	108	9⁄16	469000	8340	8.08	20100	30200	20100	30200	20100	30200	19800	29800	19100	28700	18400	27700	15600	23500	9270	13900	5220	7840
	648	191	113	30	2½	108	⅜	497000	8800	8.30	20600	31000	20600	31000	20600	31000	20400	30700	19700	29600	19000	28600	16200	24400	10000	15100	5650	8490
	671	197	113	30	2½	108	7⁄16	504000	8920	8.24	21100	31800	21100	31800	21100	31800	20900	31400	20200	30300	19400	29200	16500	24900	10100	15200	5710	8580
	694	204	113	30	2½	108	½	510000	9030	8.18	21600	32500	21600	32500	21600	32500	21400	32100	20600	31000	19900	29900	16900	25400	10200	15400	5760	8660
	717	211	113	30	2½	108	9⁄16	517000	9150	8.13	22100	33300	22100	33300	22100	33300	21800	32800	21000	31600	20300	30500	17200	25900	10300	15500	5810	8740
	699	206	114	30	2¾	108	⅜	545000	9610	8.33	22700	34100	22700	34100	22700	34100	22400	33700	21600	32500	20900	31400	17800	26800	11100	16700	6250	9390
	722	212	114	30	2¾	108	7⁄16	552000	9730	8.27	23200	34800	23200	34800	23200	34800	22900	34400	22100	33200	21300	32000	18200	27300	11200	16800	6300	9470
	745	219	114	30	2¾	108	½	559000	9840	8.22	23700	35500	23700	35500	23700	35500	23400	35100	22500	33900	21700	32700	18500	27800	11300	17000	6360	9560
	768	226	114	30	2¾	108	9⁄16	565000	9960	8.17	24100	36300	24100	36300	24100	36300	23800	35800	23000	34500	22200	33300	18800	28300	11400	17100	6410	9640
	750	221	114	30	3	108	⅜	594000	10400	8.35	24700	37100	24700	37100	24700	37100	24400	36700	23600	35400	22800	34200	19400	29200	12200	18300	6840	10300
	773	227	114	30	3	108	7⁄16	601000	10500	8.30	25200	37800	25200	37800	25200	37800	24900	37400	24000	36100	23200	34800	19800	29700	12300	18400	6900	10400
	796	234	114	30	3	108	½	607000	10700	8.26	25700	38600	25700	38600	25700	38600	25400	38100	24500	36800	23600	35500	20100	30200	12400	18600	6960	10500
	819	241	114	30	3	108	9⁄16	614000	10800	8.21	26200	39300	26200	39300	26200	39300	25800	38800	24900	37500	24000	36100	20400	30700	12500	18700	7010	10500

Table B6. Available Flexural Strength of Members with 120-in. Web Height

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	r_t	L_b = 0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
											Available Flexural Strength, kip-ft; F_y = 50 ksi, C_b = 1.0; ASD $\Omega_b = 1.67$, LRFD $\phi_b = 0.90$																	
											Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD); Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
120x12	214	63.0	122	12	¾	120	⅜	120000	1970	2.56	3250	4890	2940	4420	2580	3880	2110	3180	1350	2030	940	1410	338	508	150	226	–	–
	240	70.5	122	12	¾	120	7/16	129000	2120	2.47	3850	5790	3450	5190	3010	4530	2330	3500	1490	2240	1030	1560	373	560	166	249	–	–
	265	78.0	122	12	¾	120	½	138000	2270	2.38	4440	6680	3950	5930	3420	5140	2510	3770	1610	2410	1120	1680	402	603	178	268	–	–
	291	85.5	122	12	¾	120	9/16	147000	2410	2.31	5030	7550	4430	6650	3810	5730	2660	4000	1700	2560	1180	1780	426	641	189	285	–	–
	235	69.0	122	12	1	120	⅜	142000	2330	2.72	4090	6150	3750	5640	3330	5000	2900	4370	1920	2890	1330	2010	480	722	214	321	–	–
	260	76.5	122	12	1	120	7/16	151000	2470	2.63	4700	7060	4280	6430	3780	5670	3240	4870	2070	3120	1440	2160	518	779	230	346	–	–
	286	84.0	122	12	1	120	½	160000	2620	2.56	5290	7960	4790	7200	4200	6320	3440	5180	2200	3310	1530	2300	551	828	245	368	–	–
	311	91.5	122	12	1	120	9/16	169000	2770	2.49	5880	8840	5280	7940	4620	6940	3620	5440	2320	3480	1610	2420	579	871	257	387	–	–
	255	75.0	123	12	1¼	120	⅜	164000	2680	2.83	4940	7430	4570	6880	4080	6140	3590	5400	2520	3780	1750	2630	629	945	280	420	–	–
	281	82.5	123	12	1¼	120	7/16	173000	2830	2.75	5550	8350	5110	7680	4540	6820	3970	5970	2680	4020	1860	2790	669	1010	297	447	–	–
	306	90.0	123	12	1¼	120	½	182000	2980	2.68	6150	9250	5630	8460	4980	7490	4340	6520	2820	4240	1960	2940	704	1060	313	471	–	–
	332	97.5	123	12	1¼	120	9/16	191000	3120	2.62	6750	10100	6130	9220	5410	8130	4600	6910	2940	4420	2040	3070	735	1110	327	491	–	–
	276	81.0	123	12	1½	120	⅜	187000	3040	2.91	5810	8730	5400	8120	4840	7280	4280	6430	3130	4700	2170	3260	782	1180	348	522	–	–
	301	88.5	123	12	1½	120	7/16	196000	3180	2.84	6420	9640	5940	8930	5310	7980	4670	7020	3300	4950	2290	3440	824	1240	366	550	–	–
	327	96.0	123	12	1½	120	½	205000	3330	2.78	7020	10500	6470	9720	5760	8650	5040	7580	3440	5180	2390	3590	861	1290	383	575	–	–
	352	104	123	12	1½	120	9/16	214000	3480	2.72	7610	11400	6980	10500	6190	9310	5400	8120	3580	5370	2480	3730	894	1340	397	597	–	–
	296	87.0	124	12	1¾	120	⅜	210000	3400	2.97	6670	10000	6240	9370	5610	8430	4970	7480	3750	5640	2610	3920	938	1410	417	627	–	–
	322	94.5	124	12	1¾	120	7/16	219000	3540	2.91	7280	10900	6780	10200	6070	9130	5370	8070	3920	5900	2720	4100	981	1470	436	655	–	–
	347	102	124	12	1¾	120	½	228000	3690	2.85	7890	11900	7310	11000	6530	9810	5750	8640	4080	6130	2830	4260	1020	1530	453	681	–	–
	373	110	124	12	1¾	120	9/16	237000	3830	2.80	8480	12700	7830	11800	6970	10500	6120	9200	4220	6340	2930	4400	1050	1580	468	704	–	–
	316	93.0	124	12	2	120	⅜	233000	3750	3.02	7540	11300	7070	10600	6370	9580	5670	8520	4390	6590	3050	4580	1100	1650	487	732	–	–
	342	101	124	12	2	120	7/16	242000	3900	2.97	8150	12300	7620	11500	6840	10300	6070	9120	4560	6850	3170	4760	1140	1710	507	762	–	–
	368	108	124	12	2	120	½	251000	4040	2.91	8760	13200	8150	12300	7300	11000	6460	9710	4720	7090	3280	4920	1180	1770	524	788	–	–
	393	115.5	124	12	2	120	9/16	260000	4190	2.86	9350	14100	8670	13000	7750	11700	6830	10300	4860	7310	3380	5070	1220	1830	540	812	–	–
	337	99.0	125	12	2¼	120	⅜	256000	4110	3.06	8420	12600	7920	11900	7140	10700	6370	9570	5030	7560	3490	5250	1260	1890	559	839	–	–
	362	107	125	12	2¼	120	7/16	265000	4250	3.01	9030	13600	8460	12700	7620	11400	6770	10200	5200	7820	3610	5430	1300	1960	578	869	–	–
	388	114	125	12	2¼	120	½	274000	4400	2.96	9630	14500	9000	13500	8080	12100	7160	10800	5360	8060	3730	5600	1340	2020	596	896	–	–
	413	122	125	12	2¼	120	9/16	283000	4540	2.91	10200	15400	9520	14300	8530	12800	7540	11300	5510	8280	3830	5750	1380	2070	612	920	–	–
	357	105	125	12	2½	120	⅜	279000	4470	3.10	9290	14000	8760	13200	7910	11900	7070	10600	5670	8530	3940	5920	1420	2130	630	947	–	–
	383	113	125	12	2½	120	7/16	288000	4610	3.05	9900	14900	9300	14000	8390	12600	7480	11200	5850	8800	4060	6110	1460	2200	650	977	–	–
	408	120	125	12	2½	120	½	297000	4750	3.00	10500	15800	9840	14800	8860	13300	7870	11800	6010	9040	4180	6280	1500	2260	668	1000	–	–
	434	128	125	12	2½	120	9/16	306000	4900	2.95	11100	16700	10400	15600	9310	14000	8250	12400	6160	9270	4280	6430	1540	2320	685	1030	–	–
	378	111	126	12	2¾	120	⅜	303000	4820	3.13	10200	15300	9600	14400	8690	13100	7770	11700	6330	9510	4390	6600	1580	2380	703	1060	–	–
	403	119	126	12	2¾	120	7/16	312000	4970	3.08	10800	16200	10200	15300	9160	13800	8180	12300	6500	9780	4520	6790	1630	2440	723	1090	–	–
	429	126	126	12	2¾	120	½	321000	5110	3.03	11400	17100	10700	16100	9630	14500	8580	12900	6670	10000	4630	6960	1670	2510	741	1110	–	–
	454	134	126	12	2¾	120	9/16	330000	5250	2.99	12000	18000	11200	16900	10100	15200	8960	13500	6820	10300	4740	7120	1710	2560	758	1140	–	–
	398	117	126	12	3	120	⅜	326000	5180	3.15	11100	16600	10500	15700	9460	14200	8480	12700	6980	10500	4850	7290	1750	2620	776	1170	–	–
	424	125	126	12	3	120	7/16	335000	5320	3.11	11700	17500	11000	16500	9940	14900	8880	13400	7160	10800	4970	7470	1790	2690	796	1200	–	–
	449	132	126	12	3	120	½	344000	5470	3.06	12300	18400	11500	17300	10400	15600	9280	14000	7330	11000	5090	7650	1830	2750	814	1220	–	–
	475	140	126	12	3	120	9/16	353000	5610	3.02	12900	19300	12100	18100	10900	16300	9670	14500	7480	11200	5190	7810	1870	2810	831	1250	–	–

Table B6. Available Flexural Strength of Members with 120-in. Web Height

F_y = 50 ksi, C_b = 1.0

ASD: Ω_b = 1.67 | LRFD: ϕ_b = 0.90

Available Flexural Strength, kip-ft

Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD)

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	L_b = 0 ASD	L_b = 0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.																		
120x18	245	72.0	122	18	¾	120	⅜	152000	2510	4.17	3980	5980	3980	5980	3980	5980	3870	5810	3560	5350	3250	4890	1250	1880	555	835	312	469
	271	79.5	122	18	¾	120	7/16	161000	2660	4.05	4510	6780	4510	6780	4510	6780	4350	6530	3990	6000	3630	5460	1340	2010	595	894	335	503
	296	87.0	122	18	¾	120	½	170000	2810	3.94	5040	7580	5040	7580	5040	7580	4810	7230	4400	6610	3930	5910	1420	2130	629	945	354	532
	322	94.5	122	18	¾	120	9/16	179000	2950	3.84	5560	8360	5560	8360	5560	8360	5260	7910	4800	7210	4120	6190	1480	2230	659	990	371	557
	276	81.0	122	18	1	120	⅜	186000	3050	4.37	5820	8750	5790	8700	5420	8140	5040	7580	4670	7010	4290	6450	1760	2650	784	1180	440	663
	301	88.5	122	18	1	120	7/16	195000	3190	4.26	6430	9670	6380	9590	5960	8950	5530	8320	5110	7680	4680	7040	1860	2790	826	1240	460	698
	327	96.0	122	18	1	120	½	204000	3340	4.17	7040	10600	6960	10500	6490	9750	6010	9030	5530	8320	5060	7600	1940	2920	863	1300	490	730
	352	104	122	18	1	120	9/16	213000	3490	4.08	7640	11500	7530	11300	7000	10500	6470	9730	5950	8940	5420	8150	2020	3030	897	1350	500	758
	306	90.0	123	18	1¼	120	⅜	219000	3580	4.50	7120	10700	7120	10700	6670	10000	6230	9360	5780	8690	5330	8020	2290	3450	1020	1530	570	862
	332	97.5	123	18	1¼	120	7/16	228000	3730	4.41	7740	11600	7710	11600	7220	10800	6720	10100	6230	9360	5740	8620	2390	3600	1060	1600	600	899
	357	105	123	18	1¼	120	½	237000	3880	4.32	8350	12500	8300	12500	7750	11700	7210	10800	6670	10000	6120	9200	2480	3730	1100	1660	620	932
	383	113	123	18	1¼	120	9/16	246000	4020	4.24	8950	13400	8870	13300	8280	12400	7680	11500	7090	10700	6500	9760	2560	3850	1140	1710	640	962
	337	99.0	123	18	1½	120	⅜	253000	4120	4.60	8440	12700	8440	12700	7930	11900	7420	11100	6900	10400	6380	9600	2830	4260	1260	1890	710	1060
	362	107	123	18	1½	120	7/16	262000	4270	4.52	9050	13600	9050	13600	8480	12800	7920	11900	7360	11100	6790	10200	2930	4410	1300	1960	730	1100
	388	114	123	18	1½	120	½	271000	4410	4.44	9660	14500	9640	14500	9020	13600	8410	12600	7800	11700	7190	10800	3030	4550	1350	2020	760	1140
	413	122	123	18	1½	120	9/16	280000	4560	4.37	10300	15400	10200	15400	9550	14400	8890	13400	8230	12400	7570	11400	3110	4670	1380	2080	780	1170
	368	108	124	18	1¾	120	⅜	287000	4660	4.67	9750	14700	9750	14700	9200	13800	8610	12900	8030	12100	7440	11200	3380	5080	1500	2260	850	1270
	393	116	124	18	1¾	120	7/16	296000	4800	4.60	10400	15600	10400	15600	9750	14700	9120	13700	8480	12800	7850	11800	3480	5240	1550	2330	870	1310
	419	123	124	18	1¾	120	½	305000	4950	4.53	11000	16500	11000	16500	10300	15500	9610	14400	8930	13400	8250	12400	3580	5380	1590	2390	890	1340
	444	131	124	18	1¾	120	9/16	314000	5090	4.46	11600	17400	11600	17400	10800	16300	10100	15200	9370	14100	8640	13000	3660	5510	1630	2450	920	1380
	398	117	124	18	2	120	⅜	322000	5190	4.73	11100	16600	11100	16600	10500	15700	9810	14800	9160	13800	8500	12800	3940	5920	1750	2630	980	1480
	424	125	124	18	2	120	7/16	331000	5340	4.66	11700	17600	11700	17600	11000	16600	10300	15500	9610	14500	8910	13400	4040	6070	1790	2700	1010	1520
	449	132	124	18	2	120	½	340000	5480	4.60	12300	18500	12300	18500	11600	17400	10800	16300	10100	15100	9310	14000	4130	6210	1840	2760	1030	1550
	475	140	124	18	2	120	9/16	349000	5630	4.54	12900	19400	12900	19400	12100	18200	11300	17000	10500	15800	9700	14600	4220	6340	1880	2820	1060	1590
	429	126	125	18	2¼	120	⅜	357000	5730	4.77	12400	18600	12400	18600	11700	17700	11000	16600	10300	15500	9560	14400	4490	6750	2000	3000	1120	1690
	454	134	125	18	2¼	120	7/16	366000	5870	4.71	13000	19600	13000	19600	12300	18500	11500	17300	10700	16200	9970	15000	4600	6910	2040	3070	1150	1730
	480	141	125	18	2¼	120	½	375000	6020	4.65	13600	20500	13600	20500	12800	19300	12000	18100	11200	16800	10400	15600	4690	7050	2090	3130	1170	1760
	505	149	125	18	2¼	120	9/16	384000	6160	4.60	14200	21400	14200	21400	13400	20100	12500	18800	11600	17500	10800	16200	4780	7190	2130	3190	1200	1800
	459	135	125	18	2½	120	⅜	392000	6270	4.81	13700	20600	13700	20600	13000	19600	12200	18400	11400	17200	10600	16000	5050	7590	2250	3380	1260	1900
	485	143	125	18	2½	120	7/16	401000	6410	4.75	14300	21600	14300	21600	13600	20400	12700	19100	11900	17900	11000	16600	5160	7750	2290	3440	1290	1940
	510	150	125	18	2½	120	½	410000	6560	4.70	15000	22500	15000	22500	14100	21200	13200	19900	12300	18500	11400	17200	5250	7900	2330	3510	1310	1970
	536	158	125	18	2½	120	9/16	419000	6700	4.65	15600	23400	15600	23400	14700	22000	13700	20600	12800	19200	11800	17800	5340	8030	2370	3570	1340	2010
	490	144	126	18	2¾	120	⅜	427000	6800	4.84	15100	22600	15100	22600	14300	21500	13400	20200	12600	18900	11700	17600	5620	8440	2500	3750	1400	2110
	516	152	126	18	2¾	120	7/16	436000	6950	4.79	15700	23600	15700	23600	14900	22300	13900	21000	13000	19600	12100	18200	5720	8600	2540	3820	1430	2150
	541	159	126	18	2¾	120	½	445000	7090	4.74	16300	24500	16300	24500	15400	23200	14400	21700	13500	20200	12500	18800	5820	8740	2580	3890	1450	2190
	567	167	126	18	2¾	120	9/16	454000	7230	4.69	16900	25400	16900	25400	15900	24000	14900	22400	13900	20900	12900	19400	5910	8880	2630	3950	1480	2220
	521	153	126	18	3	120	⅜	463000	7340	4.87	16400	24600	16400	24600	15600	23400	14600	22000	13700	20600	12700	19200	6180	9290	2750	4130	1550	2320
	546	161	126	18	3	120	7/16	472000	7490	4.82	17000	25600	17000	25600	16100	24300	15100	22800	14200	21300	13200	19800	6280	9440	2790	4200	1570	2360
	572	168	126	18	3	120	½	481000	7630	4.77	17600	26500	17600	26500	16700	25100	15600	23500	14600	22000	13600	20400	6380	9590	2840	4260	1600	2400
	597	176	126	18	3	120	9/16	490000	7770	4.73	18200	27400	18200	27400	17200	25900	16100	24300	15100	22600	14000	21000	6470	9730	2880	4320	1620	2430

Table B6. Available Flexural Strength of Members with 120-in. Web Height

Nominal Shape	Wt/ft	Area	Depth *d*	Flange width b_f	Flange thk. t_f	Web height *h*	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	L_b = 0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
120-in. Web Height Dimensions											Available Flexural Strength, kip-ft — F_y = 50 ksi, C_b = 1.0; ASD Ω_b = 1.67; LRFD ϕ_b = 0.90																	
											Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD)																	
											Lateral Unbraced Length—L_b, ft																	
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
120x24	316	93.0	122	24	1	120	3/8	230000	3770	6.05	6650	9990	6650	9990	6650	9990	6650	9990	6650	9990	6400	9610	4400	6620	1960	2940	1100	1650
	342	101	122	24	1	120	7/16	239000	3910	5.93	7190	10800	7190	10800	7190	10800	7190	10800	7190	10800	6870	10300	4580	6880	2040	3060	1140	1720
	368	108	122	24	1	120	1/2	248000	4060	5.82	7730	11600	7730	11600	7730	11600	7730	11600	7730	11600	7340	11000	4740	7120	2110	3170	1180	1780
	393	116	122	24	1	120	9/16	257000	4210	5.72	8260	12400	8260	12400	8260	12400	8260	12400	8250	12400	7790	11700	4880	7340	2170	3260	1220	1840
	357	105	123	24	1¼	120	3/8	275000	4480	6.20	9150	13700	9150	13700	9150	13700	8790	13200	8370	12600	7940	11900	5690	8560	2530	3800	1420	2140
	383	113	123	24	1¼	120	7/16	284000	4630	6.10	9750	14700	9750	14700	9750	14700	9340	14000	8880	13400	8420	12700	5880	8830	2610	3930	1470	2210
	408	120	123	24	1¼	120	1/2	293000	4780	6.00	10400	15600	10400	15600	10400	15600	9890	14900	9390	14100	8900	13400	6040	9080	2690	4040	1510	2270
	434	128	123	24	1¼	120	9/16	302000	4920	5.91	10900	16500	10900	16500	10900	16500	10400	15700	9890	14900	9360	14100	6200	9310	2750	4140	1550	2330
	398	117	123	24	1½	120	3/8	320000	5200	6.30	11100	16700	11100	16700	11000	16500	10500	15800	9990	15000	9500	14300	7010	10500	3110	4680	1750	2630
	424	125	123	24	1½	120	7/16	329000	5350	6.21	11700	17600	11700	17600	11600	17400	11000	16600	10500	15800	9980	15000	7190	10800	3200	4800	1800	2700
	449	132	123	24	1½	120	1/2	338000	5490	6.13	12300	18500	12300	18500	12200	18300	11600	17400	11000	16600	10500	15700	7360	11100	3270	4920	1840	2770
	475	140	123	24	1½	120	9/16	347000	5640	6.05	12900	19400	12900	19400	12700	19100	12100	18200	11500	17300	10900	16400	7520	11300	3340	5020	1880	2820
	439	129	124	24	1¾	120	3/8	365000	5920	6.38	12900	19300	12900	19300	12800	19200	12200	18300	11600	17500	11100	16600	8330	12500	3700	5560	2080	3130
	465	137	124	24	1¾	120	7/16	374000	6060	6.30	13500	20300	13500	20300	13300	20100	12700	19200	12100	18300	11500	17300	8510	12800	3780	5690	2130	3200
	490	144	124	24	1¾	120	1/2	383000	6210	6.23	14100	21200	14100	21200	13900	20900	13300	20000	12700	19000	12000	18100	8690	13100	3860	5800	2170	3260
	516	152	124	24	1¾	120	9/16	392000	6350	6.15	14700	22100	14700	22100	14500	21800	13800	20800	13200	19800	12500	18800	8850	13300	3930	5910	2210	3320
	480	141	124	24	2	120	3/8	411000	6630	6.44	14600	22000	14600	22000	14500	21800	13900	20900	13300	19900	12600	19000	9660	14500	4290	6450	2420	3630
	505	149	124	24	2	120	7/16	420000	6780	6.37	15300	22900	15300	22900	15100	22700	14500	21700	13800	20700	13100	19700	9850	14800	4380	6580	2460	3700
	531	156	124	24	2	120	1/2	429000	6920	6.30	15900	23800	15900	23800	15700	23600	15000	22500	14300	21500	13600	20400	10000	15100	4450	6690	2510	3770
	556	164	124	24	2	120	9/16	438000	7070	6.24	16500	24800	16500	24800	16300	24500	15500	23400	14800	22200	14100	21100	10200	15300	4530	6800	2550	3830
	521	153	125	24	2¼	120	3/8	458000	7350	6.49	16400	24700	16400	24700	16300	24500	15600	23500	14900	22400	14200	21300	11000	16500	4890	7350	2750	4130
	546	161	125	24	2¼	120	7/16	467000	7490	6.43	17000	25600	17000	25600	16900	25400	16200	24300	15400	23200	14700	22100	11200	16800	4970	7470	2800	4200
	572	168	125	24	2¼	120	1/2	476000	7640	6.36	17600	26500	17600	26500	17500	26300	16700	25100	15900	23900	15200	22800	11400	17100	5050	7590	2840	4270
	597	176	125	24	2¼	120	9/16	485000	7780	6.30	18200	27400	18200	27400	18100	27200	17300	25900	16400	24700	15600	23500	11500	17300	5120	7700	2880	4330
	561	165	125	24	2½	120	3/8	504000	8070	6.53	18200	27300	18200	27300	18100	27200	17300	26000	16500	24900	15800	23700	12300	18600	5490	8250	3090	4640
	587	173	125	24	2½	120	7/16	513000	8210	6.47	18800	28300	18800	28300	18700	28100	17900	26900	17100	25600	16200	24400	12500	18800	5570	8370	3130	4710
	613	180	125	24	2½	120	1/2	522000	8360	6.41	19400	29200	19400	29200	19300	29000	18400	27700	17600	26400	16700	25100	12700	19100	5650	8490	3180	4770
	638	188	125	24	2½	120	9/16	531000	8500	6.36	20000	30100	20000	30100	19900	29800	19000	28500	18100	27200	17200	25800	12900	19300	5720	8600	3220	4840
	602	177	126	24	2¾	120	3/8	551000	8790	6.57	20000	30000	20000	30000	19900	29900	19000	28600	18200	27300	17300	26000	13700	20600	6080	9150	3420	5140
	628	185	126	24	2¾	120	7/16	560000	8930	6.51	20600	30900	20600	30900	20500	30800	19600	29400	18700	28100	17800	26800	13900	20900	6170	9270	3470	5210
	653	192	126	24	2¾	120	1/2	569000	9070	6.46	21200	31900	21200	31900	21100	31700	20100	30300	19200	28900	18300	27500	14100	21100	6250	9390	3510	5280
	679	200	126	24	2¾	120	9/16	578000	9220	6.40	21800	32800	21800	32800	21600	32500	20700	31100	19700	29600	18800	28200	14200	21400	6320	9500	3560	5340
	643	189	126	24	3	120	3/8	599000	9500	6.59	21800	32700	21800	32700	21700	32600	20700	31200	19800	29800	18900	28400	15000	22600	6690	10000	3760	5650
	669	197	126	24	3	120	7/16	608000	9650	6.54	22400	33600	22400	33600	22300	33500	21300	32000	20300	30600	19400	29100	15200	22900	6770	10200	3810	5720
	694	204	126	24	3	120	1/2	617000	9790	6.49	23000	34500	23000	34500	22900	34300	21900	32800	20900	31300	19900	29900	15400	23200	6850	10300	3850	5790
	720	212	126	24	3	120	9/16	626000	9930	6.44	23600	35500	23600	35500	23400	35200	22400	33700	21400	32100	20300	30600	15600	23400	6920	10400	3890	5850

Table B6. Available Flexural Strength of Members with 120-in. Web Height

Nominal Shape	Wt/ft	Area	Depth d	Flange width b_f	Flange thk. t_f	Web height h	Web thk. t_w	Axis X-X I_x	Axis X-X S_x	Axis X-X r_t	L_b=0 ASD	0 LRFD	10 ASD	10 LRFD	15 ASD	15 LRFD	20 ASD	20 LRFD	25 ASD	25 LRFD	30 ASD	30 LRFD	50 ASD	50 LRFD	75 ASD	75 LRFD	100 ASD	100 LRFD
in.	lb/ft	in.^{2}	in.	in.	in.	in.	in.	in.^{4}	in.^{3}	in.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
120x30	408	120	123	30	1¼	120	⅜	330000	5380	7.91	10100	15200	10100	15200	10100	15200	10100	15200	10100	15200	10100	15200	8870	13300	5100	7660	2870	4310
	434	128	123	30	1¼	120	7/16	339000	5530	7.80	10700	16100	10700	16100	10700	16100	10700	16100	10700	16100	10700	16100	9280	14000	5230	7860	2940	4420
	459	135	123	30	1¼	120	½	348000	5680	7.69	11200	16900	11200	16900	11200	16900	11200	16900	11200	16900	11200	16900	9690	14600	5350	8040	3010	4520
	485	143	123	30	1¼	120	9/16	357000	5820	7.60	11800	17700	11800	17700	11800	17700	11800	17700	11800	17700	11800	17700	10100	15200	5460	8200	3070	4610
	459	135	123	30	1½	120	⅜	386000	6280	8.02	13300	19900	13300	19900	13300	19900	13300	19900	13100	19600	12600	18900	10600	16000	6250	9390	3520	5280
	485	143	123	30	1½	120	7/16	395000	6430	7.92	13900	20800	13900	20800	13900	20800	13900	20800	13600	20500	13100	19700	11100	16600	6380	9590	3590	5390
	510	150	123	30	1½	120	½	404000	6570	7.83	14500	21700	14500	21700	14500	21700	14500	21700	14200	21300	13600	20500	11500	17200	6500	9770	3660	5500
	536	158	123	30	1½	120	9/16	413000	6720	7.75	15000	22600	15000	22600	15000	22600	15000	22600	14700	22100	14100	21300	11900	17800	6620	9940	3720	5590
	510	150	124	30	1¾	120	⅜	443000	7180	8.10	16000	24000	16000	24000	16000	24000	15700	23700	15200	22800	14600	22000	12400	18700	7410	11100	4170	6270
	536	158	124	30	1¾	120	7/16	452000	7320	8.02	16600	24900	16600	24900	16600	24900	16300	24500	15700	23700	15200	22800	12800	19300	7540	11300	4240	6380
	561	165	124	30	1¾	120	½	461000	7470	7.94	17200	25900	17200	25900	17200	25900	16900	25400	16300	24500	15700	23600	13200	19900	7660	11500	4310	6480
	587	173	124	30	1¾	120	9/16	470000	7610	7.86	17800	26800	17800	26800	17800	26800	17500	26300	16800	25300	16200	24400	13700	20500	7780	11700	4380	6580
	561	165	124	30	2	120	⅜	501000	8070	8.16	18200	27400	18200	27400	18200	27400	18000	27000	17300	26000	16700	25100	14200	21300	8580	12900	4820	7250
	587	173	124	30	2	120	7/16	510000	8220	8.09	18800	28300	18800	28300	18800	28300	18500	27900	17900	26900	17200	25900	14600	22000	8710	13100	4900	7360
	613	180	124	30	2	120	½	519000	8360	8.02	19400	29200	19400	29200	19400	29200	19100	28700	18400	27700	17800	26700	15000	22600	8830	13300	4970	7470
	638	188	124	30	2	120	9/16	528000	8510	7.95	20000	30100	20000	30100	20000	30100	19700	29600	19000	28500	18300	27500	15400	23200	8950	13400	5030	7570
	613	180	125	30	2¼	120	⅜	558000	8970	8.22	20400	30700	20400	30700	20400	30700	20200	30300	19500	29300	18800	28200	16000	24000	9750	14700	5480	8240
	638	188	125	30	2¼	120	7/16	567000	9120	8.15	21100	31600	21100	31600	21100	31600	20800	31200	20000	30100	19300	29000	16400	24600	9880	14800	5560	8350
	664	195	125	30	2¼	120	½	576000	9260	8.08	21700	32600	21700	32600	21700	32600	21300	32100	20600	30900	19800	29800	16800	25300	10000	15000	5630	8460
	689	203	125	30	2¼	120	9/16	585000	9400	8.02	22300	33500	22300	33500	22300	33500	21900	32900	21100	31800	20400	30600	17200	25900	10100	15200	5690	8560
	664	195	125	30	2½	120	⅜	617000	9870	8.26	22700	34100	22700	34100	22700	34100	22400	33700	21600	32500	20800	31300	17800	26700	10900	16400	6140	9230
	689	203	125	30	2½	120	7/16	626000	10000	8.20	23300	35000	23300	35000	23300	35000	23000	34500	22200	33300	21400	32100	18200	27300	11100	16600	6220	9340
	715	210	125	30	2½	120	½	635000	10200	8.13	23900	35900	23900	35900	23900	35900	23600	35400	22700	34200	21900	32900	18600	28000	11200	16800	6290	9450
	740	218	125	30	2½	120	9/16	644000	10300	8.08	24500	36800	24500	36800	24500	36800	24100	36300	23300	35000	22400	33700	19000	28600	11300	17000	6350	9550
	715	210	126	30	2¾	120	⅜	676000	10800	8.29	24900	37400	24900	37400	24900	37400	24600	37000	23800	35700	22900	34500	19500	29400	12100	18200	6810	10200
	740	218	126	30	2¾	120	7/16	685000	10900	8.23	25500	38400	25500	38400	25500	38400	25200	37900	24300	36600	23500	35300	20000	30000	12200	18400	6880	10300
	766	225	126	30	2¾	120	½	694000	11100	8.18	26100	39300	26100	39300	26100	39300	25800	38700	24900	37400	24000	36000	20400	30600	12400	18600	6950	10400
	791	233	126	30	2¾	120	9/16	703000	11200	8.12	26700	40200	26700	40200	26700	40200	26400	39600	25400	38200	24500	36800	20800	31300	12500	18700	7010	10500
	766	225	126	30	3	120	⅜	735000	11700	8.32	27100	40800	27100	40800	27100	40800	26800	40300	25900	39000	25000	37600	21300	32100	13300	20000	7470	11200
	791	233	126	30	3	120	7/16	744000	11800	8.27	27700	41700	27700	41700	27700	41700	27400	41200	26500	39800	25500	38400	21800	32700	13400	20100	7540	11300
	817	240	126	30	3	120	½	753000	12000	8.22	28400	42600	28400	42600	28400	42600	28000	42100	27000	40600	26100	39200	22200	33300	13500	20300	7610	11400
	842	248	126	30	3	120	9/16	762000	12100	8.16	29000	43500	29000	43500	29000	43500	28600	42900	27600	41400	26600	39900	22600	33900	13600	20500	7680	11500

Available Flexural Strength, kip-ft: Allowable Flexural Strength = M_n/Ω_b (ASD) or Design Flexural Strength = $\phi_b M_n$ (LRFD); Lateral Unbraced Length—L_b, ft

F_y = 50 ksi, C_b = 1.0; ASD: Ω_b = 1.67; LRFD: ϕ_b = 0.90

APPENDIX C
AVAILABLE SHEAR STRENGTH TABLES

Table C1. Available Shear Strength with Tension Field Action INCLUDED

Available Shear Strength, kips

F_y = 50 ksi	
ASD	LRFD
$\Omega_v = 1.67$	$\phi_v = 0.90$

Web height h (in.)	Web thk. t_w (in.)	Web area A_w (in.²)		Allowable Shear Strength = V_n/Ω_v (ASD) or Design Shear Strength = $\phi_v V_n$ (LRFD) — Transverse Stiffener Spacing (α, in.) 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230
60	5/16	18.8	ASD	337	335	306	280	257	238	221	206	192	181	171												
			LRFD	506	504	461	420	387	358	332	309	289	272	256												
60	3/8	22.5	ASD	404	404	389	355	326	302	281	263	247	233	221	210	201	192	185								
			LRFD	608	608	584	533	490	454	422	395	371	350	332	316	301	289	278								
72	5/16	22.5	ASD	404	402	369	341	318	297	278	260	245														
			LRFD	608	604	554	513	478	446	418	391	368														
72	3/8	27.0	ASD	485	485	466	427	397	371	347	326	307	289	274	260	248										
			LRFD	729	729	701	642	597	557	522	490	461	435	412	391	373										
72	7/16	31.5	ASD	566	566	559	523	485	452	424	398	376	356	338	322	308	295	283	273	263						
			LRFD	851	851	840	786	728	680	637	599	565	535	508	484	462	443	426	410	396						
84	5/16	26.3	ASD	472	468	432	403	380	358	338																
			LRFD	709	703	649	606	571	539	508																
84	3/8	31.5	ASD	566	566	542	502	471	443	418	395	373	354	336												
			LRFD	851	851	815	754	707	666	628	593	561	531	504												
84	7/16	36.8	ASD	660	660	650	609	569	535	505	477	451	428	407	388	370	354	340								
			LRFD	992	992	977	916	855	804	758	717	678	644	612	583	556	533	511								
84	1/2	42.0	ASD	754	754	754	725	677	635	599	566	537	510	486	464	444	426	409	394	380	368	356	345			
			LRFD	1130	1130	1130	1090	1020	955	900	851	807	766	730	697	667	640	615	592	571	552	535	519			
84	9/16	47.3	ASD	849	849	849	835	795	745	702	664	630	600	573	548	525	505	487	470	454	440	428	416	405	395	386
			LRFD	1280	1280	1280	1250	1200	1120	1060	998	948	902	861	823	790	759	731	706	683	662	643	625	609	594	580
96	5/16	30.0	ASD	539	535	495	466	442	421																	
			LRFD	810	803	744	700	665	632																	
96	3/8	36.0	ASD	647	647	619	577	545	517	491	467	444														
			LRFD	972	972	931	867	819	777	739	702	667														
96	7/16	42.0	ASD	754	754	742	697	655	621	589	560	532	507	483	461	441										
			LRFD	1130	1130	1120	1050	985	933	885	841	800	762	726	693	663										
96	1/2	48.0	ASD	862	862	862	829	775	732	694	659	627	598	570	545	522	501	481	463	446						
			LRFD	1300	1300	1300	1250	1160	1100	1040	990	942	898	857	819	784	752	723	696	670						
96	9/16	54.0	ASD	970	970	970	951	904	852	807	766	729	696	665	636	610	586	564	544	525	508	492	477	463	451	
			LRFD	1460	1460	1460	1430	1360	1280	1210	1150	1100	1050	999	956	917	881	848	817	789	763	739	717	696	677	
108	3/8	40.5	ASD	728	728	697	652	620	592	566	541															
			LRFD	1090	1090	1050	980	932	890	851	813															
108	7/16	47.3	ASD	849	849	835	785	743	707	675	645	616	589	564												
			LRFD	1280	1280	1250	1180	1120	1060	1010	969	926	886	848												
108	1/2	54.0	ASD	970	970	970	930	874	830	791	755	722	690	661	633	607	583	561								
			LRFD	1460	1460	1460	1400	1310	1250	1190	1140	1080	1040	993	952	913	877	843								
108	9/16	60.8	ASD	1090	1090	1090	1070	1020	961	915	873	834	798	764	733	704	677	651	628	606	586	567				
			LRFD	1640	1640	1640	1610	1530	1440	1370	1310	1250	1200	1150	1100	1060	1020	979	944	911	880	852				
120	3/8	45.0	ASD	808	808	774	727	695	667	641																
			LRFD	1220	1220	1160	1090	1040	1000	964																
120	7/16	52.5	ASD	943	943	927	874	830	795	762	732	702	674													
			LRFD	1420	1420	1390	1310	1250	1190	1150	1100	1060	1010													
120	1/2	60.0	ASD	1080	1080	1080	1030	974	929	890	853	819	786	755	726	698	672									
			LRFD	1620	1620	1620	1550	1460	1400	1340	1280	1230	1180	1140	1090	1050	1010									
120	9/16	67.5	ASD	1210	1210	1210	1190	1130	1070	1030	982	942	905	869	835	804	774	746	720	695						
			LRFD	1820	1820	1820	1780	1700	1610	1540	1480	1420	1360	1310	1260	1210	1160	1120	1080	1040						

Notes: 1) Solid vertical line indicates maximum stiffener spacing; 2) A_w is conservatively taken as ht_w; 3) Limits of Specification Section G3.1 must be satisfied.

Table C2. Available Shear Strength with Tension Field Action EXCLUDED

Available Shear Strength, kips

F_y = 50 ksi	
ASD	LRFD
$\Omega_v = 1.67$	$\phi_v = 0.90$

Allowable Shear Strength = V_n/Ω_v (ASD) or Design Shear Strength = $\phi_v V_n$ (LRFD)

Web height h (in.)	Web thk. t_w (in.)	Web area A_w (in.²)		Transverse Stiffener Spacing (a, in.) 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230
60	5/16	18.8	ASD	337	329	200	130	98	80	69	63	58	54	52												
			LRFD	506	494	301	195	147	120	104	94	87	82	78												
60	3/8	22.5	ASD	404	404	335	225	169	138	120	108	100	94	90	86	84	82	80								
			LRFD	608	608	503	338	254	208	180	162	150	141	135	130	126	123	121								
72	5/16	22.5	ASD	404	388	225	141	102	81	69	60	55														
			LRFD	608	584	339	212	154	122	103	91	82														
72	3/8	27.0	ASD	485	485	389	244	177	141	119	104	94	87	82	78	75										
			LRFD	729	729	585	367	266	211	178	157	142	131	124	118	113										
72	7/16	31.5	ASD	566	566	530	388	281	223	188	166	150	139	131	124	120	116	113	110	108						
			LRFD	851	851	796	583	423	336	283	249	226	209	196	187	180	174	169	165	162						
84	5/16	26.3	ASD	472	449	253	155	109	85	70																
			LRFD	709	674	380	232	164	127	105																
84	3/8	31.5	ASD	566	566	437	267	189	146	120	104	92	84	78												
			LRFD	851	851	656	402	284	220	181	156	139	127	118												
84	7/16	36.8	ASD	660	660	606	424	300	232	191	165	147	134	124	117	111	107	103								
			LRFD	992	992	910	638	451	349	288	248	221	201	187	176	167	160	155								
84	1/2	42.0	ASD	754	754	754	619	447	346	286	246	219	200	185	174	166	159	154	149	146	143	140	138			
			LRFD	1130	1130	1130	930	673	521	429	370	329	300	279	262	249	239	231	224	219	214	210	207			
84	9/16	47.3	ASD	849	849	849	783	637	493	407	350	312	284	264	248	236	227	219	213	207	203	199	196	193	191	189
			LRFD	1280	1280	1280	1180	958	742	611	527	469	427	397	373	355	341	329	320	312	305	299	295	291	287	284
96	5/16	30.0	ASD	539	510	281	169	117	89																	
			LRFD	810	766	422	254	176	134																	
96	3/8	36.0	ASD	647	647	486	292	203	154	124	105	92														
			LRFD	972	972	730	439	304	231	187	158	139														
96	7/16	42.0	ASD	754	754	683	464	322	244	198	167	147	132	121	113	106										
			LRFD	1130	1130	1030	697	483	367	297	252	220	198	182	169	159										
96	1/2	48.0	ASD	862	862	862	692	480	365	295	250	219	197	180	168	158	151	144	139	135						
			LRFD	1300	1300	1300	1040	721	548	443	376	329	296	271	252	238	226	217	209	203						
96	9/16	54.0	ASD	970	970	970	875	683	519	420	356	312	280	257	239	225	214	206	198	192	187	183	179	176	174	
			LRFD	1460	1460	1460	1320	1030	780	631	535	469	421	386	359	339	322	309	298	289	282	275	270	265	261	
108	3/8	40.5	ASD	728	728	536	318	218	163	130	108															
			LRFD	1090	1090	806	479	327	245	195	163															
108	7/16	47.3	ASD	849	849	761	506	346	259	206	172	149	132	120												
			LRFD	1280	1280	1140	760	519	389	310	259	224	199	180												
108	1/2	54.0	ASD	970	970	970	755	516	386	308	257	222	197	179	165	154	145	138								
			LRFD	1460	1460	1460	1130	775	580	463	386	334	296	269	248	231	218	208								
108	9/16	60.8	ASD	1090	1090	1090	969	734	550	438	366	316	281	255	235	219	207	197	189	182	176	172				
			LRFD	1640	1640	1640	1460	1100	826	659	550	475	422	383	353	329	311	296	284	273	265	258				
120	3/8	45.0	ASD	808	808	588	346	234	173	136																
			LRFD	1220	1220	883	520	351	260	205																
120	7/16	52.5	ASD	943	943	840	549	371	274	216	178	152	134													
			LRFD	1420	1420	1260	825	558	413	325	268	229	201													
120	1/2	60.0	ASD	1080	1080	1080	819	554	410	323	266	228	200	179	164	152	142									
			LRFD	1620	1620	1620	1230	833	616	485	400	342	301	270	246	228	214									
120	9/16	67.5	ASD	1210	1210	1210	1060	789	583	460	379	324	285	256	233	216	202	191	182	175						
			LRFD	1820	1820	1820	1600	1190	877	691	570	487	428	384	351	325	304	288	274	263						

Notes: 1) Solid vertical line indicates maximum stiffener spacing; 2) A_w is conservatively taken as ht_w.

A Model Specification for Stability Design by Direct Analysis

R. SHANKAR NAIR

The 2005 AISC *Specification for Structural Steel Buildings* (AISC, 2005a), hereafter referred to as the AISC *Specification*, offers three alternatives for the design of structures for stability. The main body of the AISC *Specification*, in Chapter C, prescribes two methods: the Effective Length Method in Section C2.2a and the First-Order Analysis Method in Section C2.2b. (Neither method is identified by these names in the AISC *Specification*.) Appendix 7 presents the Direct Analysis Method. The Effective Length and First-Order Analysis Methods have limited applicability; the Direct Analysis Method is applicable to all structures.

Of the three approaches, the Effective Length Method will be most familiar to users of previous editions of the AISC *Specification* and that is why it was placed in the main body of the current edition. The Direct Analysis Method (now in an appendix) is, however, the most powerful and versatile of the available methods and, as noted, it is applicable to all structures, unlike the other approaches. It is likely that in time the Direct Analysis Method will become the "standard" method of design for stability.

This paper presents a model specification for stability design by direct analysis. It is based on the stability provisions of the 2005 AISC *Specification*, rewritten around the Direct Analysis Method alone. The material is presented in the language and format of the AISC *Specification*, including "User Notes" and the italicizing of terms listed in the glossary where they first appear in a section. The focus on a single method has offered the opportunity to expand some of the provisions beyond what is in the current AISC *Specification*, both to improve clarity and to address issues that have arisen from use of the document. Where this involved substantive changes, they are explained in an appendix to this paper (Appendix A).

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A second appendix (Appendix B) outlines the purpose or physical significance of each of the important steps in the Direct Analysis Method by showing the correlation of these steps to the basic requirements for design of structures for stability. The "traditional" Effective Length Method is included in the correlation to show how that method differs from the Direct Analysis Method.

A third appendix (Appendix C) provides guidance to the user on the modeling of structures for the application of the Direct Analysis Method.

This model specification is not an approved AISC specification or American National Standards Institute (ANSI) standard. In the author's judgment, however, a design that conformed to this model specification would also conform to the stability provisions of the 2005 AISC *Specification* (AISC, 2005a). Indeed, it is anticipated that Chapter C of the 2010 edition of the AISC *Specification* (which is in the ballot process as this paper goes to press) will be substantially similar to this model specification; the Effective Length Method and the First-Order Analysis Method (now in Chapter C) will be moved to Appendix 7.

MODEL SPECIFICATION: DESIGN FOR STABILITY

This specification addresses requirements for the design of structures for stability by the Direct Analysis Method. It is organized as follows:

1. General Stability Requirements
2. Calculation of Required Strengths
3. Calculation of Available Strengths

1. GENERAL STABILITY REQUIREMENTS

Stability shall be provided for the structure as a whole and for each of its elements. The effects of all of the following on the stability of the structure and its elements shall be considered: (1) *second-order effects* (both *P*-Δ and *P*-δ *effects*); (2) flexural, shear, and axial deformations, and all other deformations that contribute to displacements of the structure; (3) geometric imperfections; (4) stiffness reductions due to inelasticity; and (5) uncertainty in stiffness and strength. All load-dependent effects shall be calculated at a level of loading corresponding to *LRFD load combinations* or 1.6 times *ASD load combinations*.

Any rational method of design for stability that considers all of the listed effects is permitted.

User Note: The term "design" as used in these provisions is the combination of analysis of the structure to determine the *required strengths* of components and the proportioning of the components to have adequate *available strength*.

The *Direct Analysis Method*, which consists of the calculation of required strengths in accordance with Section 2 and the calculation of available strengths of members and connections in accordance with Section 3, is permitted for all structures.

User Note: See Appendix B for an explanation of how requirements (1) through (5) of Section 1 are satisfied in the Direct Analysis Method.

2. CALCULATION OF REQUIRED STRENGTHS

The *required strengths* of components of the structure shall be determined from an analysis conforming to Section 2.1. The analysis shall include consideration of initial imperfections in accordance with Section 2.2 and adjustments to stiffness in accordance with Section 2.3.

2.1. General Analysis Requirements

The analysis of the structure shall conform to the following requirements:

(1) The analysis shall be an elastic *second-order analysis* that considers both P-Δ and P-δ *effects*.

User Note: The second-order analysis may consist of either a rigorous second-order analysis or a *first-order analysis* amplified to account for second-order effects. The impact of P-δ effects on structure response may be neglected where it can be shown to be negligible; however, it will still be necessary, in all cases, to consider the effects of P-δ on individual members.

(2) The analysis shall consider flexural, shear and axial member deformations, and all other deformations that contribute to displacements of the structure. The analysis shall incorporate reductions in all stiffnesses that are considered to contribute to the stability of the structure, as specified in Section 2.3.

(3) The analysis shall consider all gravity and other applied *loads* that may influence the stability of the structure.

User Note: It is important to include in the analysis all gravity loads, including loads on *leaning columns* and other elements that are not part of the *lateral load-resisting system*.

(4) For design by LRFD, the second-order analysis shall be carried out under *LRFD load combinations*. For design by ASD, the second-order analysis shall be carried out under 1.6 times the *ASD load combinations*, and the results shall be divided by 1.6 to obtain the required strengths of components.

2.2. Consideration of Initial Imperfections

The effect of initial imperfections on the stability of the structure shall be taken into account either by direct modeling of imperfections in the analysis as specified in Section 2.2a or by the application of *notional loads* as specified in Section 2.2b.

User Note: The imperfections considered in this section are imperfections in the locations of points of intersection of members. In typical building structures, the important imperfection of this type is the out-of-plumbness of columns. Initial out-of-straightness of individual members is not addressed in this section; it is accounted for in the compression member design provisions of Chapter E of the AISC *Specification* (AISC, 2005a) and need not be considered explicitly as long as it is within the limits specified in the AISC *Code of Standard Practice* (AISC, 2005b).

2.2a. Direct Modeling of Imperfections

In all cases and all types of structures, it is permissible to account for the effect of initial imperfections by including the imperfections in the analysis. The structure shall be analyzed with points of intersection of members displaced from their nominal locations.* The magnitude of the initial displacements shall be the maximum amount considered in the design; the pattern of the displacements shall be such that it provides the greatest destabilizing effect.

* As a logical extension of the Direct Analysis Method (beyond the explicit provisions of the 2005 *Specification*), imperfections may be modeled at additional locations in the analysis. When this is done, the effective unbraced lengths of members, for calculation of compressive strength for flexural buckling in the direction in which imperfections were included in the analysis, may be taken as the length between the points at which the imperfections were modeled.

User Note: Initial displacements similar in configuration to both displacements due to loading and anticipated buckling modes should be considered in the modeling of imperfections. The magnitude of the initial displacements should be based on permissible construction tolerances, as specified in the AISC *Code of Standard Practice* (AISC, 2005b) or other governing requirements, or on actual imperfections if known.

In the analysis of structures that support gravity loads primarily through nominally vertical columns, walls or frames, where the ratio of maximum second-order drift to maximum first-order drift (both determined for LRFD load combinations or 1.6 times ASD load combinations, with stiffnesses adjusted as specified in Section 2.3) in all stories is equal to or less than 1.7, it is permissible to neglect initial imperfections in the analysis for load combinations that include applied lateral loads.

2.2b. Use of Notional Loads to Represent Imperfections

For structures that support gravity loads primarily through nominally vertical columns, walls or frames, it is permissible to use notional loads to represent the effect of initial imperfections in accordance with the requirements of this section. The notional loads shall be applied to a model of the structure based on its nominal geometry.

User Note: The notional load concept is applicable to all types of structures, but the specific requirements in 2.2b(1) through 2.2b(4) are applicable only for the particular class of structure identified above.

(1) Notional loads shall be applied as *lateral loads* at all levels. The notional loads shall be additive to other lateral loads and shall be applied in all load combinations, except as indicated in Section 2.2b(4). The magnitude of the notional loads shall be:

$$N_i = 0.002Y_i \qquad (2\text{-}1)$$

where

N_i = notional load applied at level i, kips (N)

Y_i = *gravity load* applied at level i from the LRFD load combination or 1.6 times the ASD load combination, as applicable, kips (N)

User Note: The notional loads can lead to additional (generally small) fictitious base shears in the structure. The correct horizontal reactions at the foundation may be obtained by applying an additional horizontal force at the base of the structure, equal and opposite in direction to the sum of all notional loads, distributed among vertical load-carrying elements in the same proportion as the gravity load supported by those elements.

(2) The notional load at any level, N_i, shall be distributed over the level in the same manner as the gravity load at that level. The notional loads shall be applied in the direction that provides the greatest destabilizing effect.

User Note: For most building structures, the requirement regarding notional load direction may be satisfied as follows: For load combinations that do not include lateral loading, consider four alternative directions of notional load application, 90° apart, in the same direction at all levels; in load combinations that include lateral loading, apply all notional loads in the direction of the resultant of all lateral loads in the combination.

(3) The notional load coefficient of 0.002 in Equation 2-1 is based on a nominal initial story out-of-plumbness ratio of 1/500. Where the use of a different maximum out-of-plumbness is justified, it is permissible to adjust the notional load coefficient proportionally.

User Note: An initial out-of-plumbness of 1/500 represents the tolerance on column plumbness specified in the AISC *Code of Standard Practice* (AISC, 2005b).

(4) For frames in which the ratio of maximum second-order drift to maximum first-order drift (both determined for LRFD load combinations or 1.6 times ASD load combinations, with stiffnesses adjusted as specified in Section 2.3) is equal to or less than 1.7 in all stories, it is permissible to apply the notional load, N_i, only in gravity-only load combinations and not in combinations that include other lateral loads.

User Note: The specified drift ratio threshold of 1.7 is based on analyses using reduced stiffnesses. If the drift ratio is determined from analyses using nominal, unreduced stiffnesses, the equivalent drift ratio is 1.5.

2.3. Adjustments to Stiffness

The analysis of the structure to determine the *required strengths* of components shall use reduced stiffnesses, as follows:

(1) A factor of 0.8 shall be applied to all stiffnesses that are considered to contribute to the stability of the structure. It is permissible to apply this reduction factor to all stiffnesses in the structure.

User Note: Applying the stiffness reduction to some members and not others can, in some cases, result in artificial distortion of the structure under load and possible unintended redistribution of forces. This can be avoided by applying the reduction to all members, including those that do not contribute to the stability of the structure.

(2) An additional factor, τ_b, shall be applied to the flexural stiffnesses of all members whose flexural stiffnesses are considered to contribute to the stability of the structure,

where

$$\tau_b = 1.0 \text{ for } \alpha P_r/P_y \le 0.5$$
$$= 4(\alpha P_r/P_y)[1-(\alpha P_r/P_y)] \text{ for } \alpha P_r/P_y > 0.5$$

$$\alpha = 1.0 \text{ (LRFD)} \qquad \alpha = 1.6 \text{ (ASD)}$$

and

P_r = required axial compressive strength under LRFD or ASD load combinations, kips (N)

P_y = axial *yield strength*, kips (N)

User Note: Taken together, sections (1) and (2) require the use of $0.8EA$ and $0.8\tau_b\ EI$ for structural steel members in the analysis instead of EA and EI.

(3) In structures to which Section 2.2b is applicable, in lieu of using $\tau_b < 1.0$ where $\alpha P_r/P_y > 0.5$, it is permissible to use $\tau_b = 1.0$ for all members if a notional load of $0.001Y_i$ [where Y_i is as defined in Section 2.2b(1)] is applied at all levels, in the direction specified in Section 2.2b(2), in all load combinations. These notional loads shall be added to those, if any, used to account for imperfections and shall not be subject to Section 2.2b(4).

(4) Where components comprised of materials other than structural steel are considered to contribute to the stability of the structure and the governing codes and specifications for the other materials require greater reductions in stiffness, such greater stiffness reductions shall be applied to those components.

3. CALCULATION OF AVAILABLE STRENGTHS

When *required strengths* have been determined in accordance with Section 2, the *available strengths* of members and connections shall be calculated in accordance with the provisions of Chapters D, E, F, G, H, I and J, as applicable, of the 2005 AISC *Specification for Structural Steel Buildings* (AISC, 2005a), with no further consideration of overall structure stability. The *effective length factor*, K, of all members shall be taken as unity unless a smaller value can be justified by rational analysis.

Bracing intended to define the unbraced lengths of members shall have sufficient stiffness and strength to control member movement at the braced points. Methods of satisfying this requirement are provided in Appendix 6 of the 2005 AISC *Specification* (AISC, 2005a).

User Note: The requirements of Appendix 6 of the 2005 AISC *Specification* are not applicable to bracing that is included in the analysis of the overall structure as part of the overall load-resisting system.

REFERENCES

AISC (2005a), *Specification for Structural Steel Buildings*, ANSI/AISC 360, American Institute of Steel Construction, Chicago, IL.

AISC (2005b), *Code of Standard Practice for Steel Buildings and Bridges*, American Institute of Steel Construction, Chicago, IL.

APPENDIX A

EXPLANATION OF CHANGES

The model specification for stability design presented in this paper is based on Chapter C and Appendix 7 of the 2005 AISC *Specification for Structural Steel Buildings* (AISC, 2005a). Where substantive technical changes have been made in AISC *Specification* provisions, they are explained in this appendix. The changes are conservative in that a design that conforms to the proposed model specification would also conform to the 2005 AISC *Specification*.

Type of Structure

Some of the provisions of the 2005 AISC *Specification*, specifically those related to the use of notional loads, are applicable only to conventional building structures that support gravity loads primarily through nominally vertical columns, walls or frames. They are not applicable, for instance, to arches or laterally unsupported compression chords of long-span trusses. This limitation is not noted explicitly in the AISC *Specification*.

The model specification is based on the very versatile Direct Analysis Method and is intended to be applicable to a broader range of structures than just conventional building frames. Therefore, those provisions that can only be used for typical building structures [Sections 2.2b and 2.3(3)] are clearly identified and alternatives usable with all structures are provided. [The notional load concept is broadly applicable, but the specific provisions in Sections 2.2b and 2.3(3) are intended only for the limited class of building structures.]

General Stability Requirements

Uncertainty in stiffness and strength has been added to the list of effects to be considered. All three of the stability design methods in the 2005 AISC *Specification* (as well as the method in the present work) include consideration of uncertainty in stiffness and strength, but this item was not included explicitly in the list of general requirements.

The requirement that second-order effects be considered at a level of load corresponding to LRFD load combinations or 1.6 times ASD load combinations is set forth now as a general requirement. The 2005 AISC *Specification* has this requirement only in the sections on specific methods, which could be taken to imply, incorrectly, that it applied only to those methods and was not a general requirement for all designs.

Exclusion of P-δ Effects

The 2005 AISC *Specification* permitted second-order analyses that neglected P-δ effects under certain conditions. This exclusion has been eliminated. Given that most structures would not have qualified for the exclusion and would have required consideration of both P-Δ and P-δ effects, and therefore design offices would need the capability to handle both effects, there was little to be gained from the extra step of checking for applicability of the exclusion.

Inclusion of All Loads in the Analysis

Section 2.1(3) makes it clear that all loads on the structure, including loads on "leaner" columns and other components that are not part of the lateral load-resisting frame, must be included in the second-order analysis. This might appear obvious to engineers familiar with the fundamental principles of stability analysis, but there has been confusion on this point among some users of the 2005 AISC *Specification*.

Direct Modeling of Imperfections

The requirements for direct modeling of imperfections, covered in one sentence in the 2005 AISC *Specification*, are presented in greater detail.

Direct Modeling of Imperfections, Exclusion

When notional loads are used to simulate the effects of initial imperfections, the imperfections can, in effect, be neglected under certain conditions (when the ratio of second-order to first-order drift is below a certain threshold and the load combination includes applied lateral loads). The 2005 AISC *Specification* offers no analogous exclusion to consideration of imperfections when direct modeling of imperfections is used. The model specification offers the same exclusion for the direct-modeling approach as for the notional-load approach (see last paragraph of Section 2.2a).

Application of Notional Loads

Requirements regarding the distribution and direction of notional loads are specified in much greater detail in the present work [Section 2.2b(2)]. These requirements may have been implicit in the 2005 AISC *Specification*; they are now spelled out.

Drift Ratio Threshold for Excluding Notional Loads in Combination with Applied Lateral Loads

In the 2005 AISC *Specification*, the drift ratio (ratio of second-order drift to first-order drift) below which notional loads need not be combined with applied lateral loads is 1.5, based on analyses with nominal, unadjusted stiffnesses. Given that stiffnesses will always be reduced (by Section 2.3) in the Direct Analysis Method, this model specification defines the threshold value on the basis of analyses with reduced stiffnesses, which increases the value to 1.7.

<table>
<tr><th colspan="4">Table 1. Comparison of Basic Stability Requirements with Specific Provisions</th></tr>
<tr><th colspan="2">Basic Requirement in Section 1 of This Model Specification</th><th>Provision in
Direct Analysis Method
(DAM)</th><th>Provision in
Effective Length Method
(ELM)</th></tr>
<tr><td colspan="2">(1) Consider second-order effects (both P-Δ and P-δ)</td><td>2.1(1). Consider second-order effects (P-Δ and P-δ)**</td><td>Consider second-order effects (P-Δ and P-δ)**</td></tr>
<tr><td colspan="2">(2) Consider all deformations</td><td>2.1(2). Consider all deformations</td><td>Consider all deformations</td></tr>
<tr><td rowspan="3">(3) Consider geometric imperfections
This includes joint-position imperfections* (which affect structure response) and member imperfections (which affect structure response and member strength)</td><td>Effect of joint-position imperfections* on structure response</td><td>2.2a. Direct modeling
or
2.2b. Notional loads</td><td>Apply notional loads</td></tr>
<tr><td>Effect of member imperfections on structure response</td><td>Included in the stiffness reduction specified in 2.3</td><td rowspan="6">All these effects are considered by using KL from a sidesway buckling analysis in the member strength check. Note that the only difference between DAM and ELM is that:
• DAM uses reduced stiffness in the analysis; $KL = L$ in the member strength check
• ELM uses full stiffness in the analysis; KL from sidesway buckling analysis in the member strength check for frame members</td></tr>
<tr><td>Effect of member imperfections on member strength</td><td>Included in member strength formulas, with $KL = L$</td></tr>
<tr><td rowspan="2">(4) Consider stiffness reduction due to inelasticity
This affects structure response and member strength</td><td>Effect of stiffness reduction on structure response</td><td>Included in the stiffness reduction specified in 2.3</td></tr>
<tr><td>Effect of stiffness reduction on member strength</td><td>Included in member strength formulas, with $KL = L$</td></tr>
<tr><td rowspan="2">(5) Consider uncertainty in strength and stiffness
This affects structure response and member strength</td><td>Effect of stiffness/strength uncertainty on structure response</td><td>Included in the stiffness reduction specified in 2.3</td></tr>
<tr><td>Effect of stiffness/strength uncertainty on member strength</td><td>Included in member strength formulas, with $KL = L$</td></tr>
<tr><td colspan="4">* In typical building structures, the “joint-position imperfections” are the column out-of-plumbnesses.
** Second-order effects may be considered either by rigorous second-order analysis or by amplification of the results of first-order analysis (using the B1 and B2 amplifiers in the AISC Specification).</td></tr>
</table>

Adjustments to Stiffness

The 2005 AISC *Specification* requires analysis with reduced axial and flexural stiffnesses of members whose stiffnesses are considered to contribute to the lateral stability of the structure. It offers no explicit guidance, however, about member shear stiffnesses, diaphragm stiffnesses, column base rotational stiffnesses, etc. The present work takes the more conservative approach of applying the basic 0.8 reduction to all stiffnesses that contribute to the stability of the structure [see Section 2.3(1)].

Adjustments to Stiffness of Other Materials

The Direct Analysis Method is applicable to all structures including, for instance, combinations of concrete shear walls and steel frames. The model specification states that if the governing codes or specifications for other materials used in combination with structural steel require greater stiffness reductions than specified here for the steel, those greater reductions should be applied to the non-steel components in the analysis of the combined structure [see Section 2.3(4)]. This is not stated explicitly in the 2005 AISC *Specification*.

APPENDIX B

RELATIONSHIP OF SPECIFICATION PROVISIONS TO GENERAL STABILITY REQUIREMENTS

The general requirements for design of structures for stability are listed as Items 1 through 5 in Section 1 of this model specification. Table 1 shows how these five requirements are addressed in the Direct Analysis Method (defined in Sections 2 and 3 of this specification). For comparison, the last column shows how the five requirements are addressed in the “traditional” Effective Length Method (Section C2.2a of the 2005 AISC *Specification*).

The First-Order Analysis Method (Section C2.2b of the 2005 AISC *Specification*) is not included in Table 1 because of its very indirect relationship to the five basic requirements. It uses mathematical manipulation to achieve roughly the same results as the Direct Analysis Method, as follows: The “additional lateral load” in Section C2.2b(2) of the 2005 AISC *Specification* is calibrated to achieve roughly the same result as a notional load for initial out-of-plumbness plus a B_2 multiplier for P-Δ plus a stiffness reduction; add a B_1 multiplier for P-δ as specified in Section C2.2b(3) of the 2005 AISC *Specification*, check member capacity using $KL = L$, and everything in the Direct Analysis Method is covered.

APPENDIX C

MODELING OF STRUCTURES FOR DESIGN BY THE DIRECT ANALYSIS METHOD

This appendix provides guidance and suggestions for the modeling of structures for the application of the Direct Analysis Method of design for stability. Though focused on the specification for stability design by direct analysis proposed in this paper, the modeling suggestions in this appendix are also applicable to stability design by direct analysis using Appendix 7 of the 2005 AISC *Specification*.

The Direct Analysis Method of design for stability is applicable to all types of structures; however, the following discussion on modeling is intended primarily for "typical" building structures made up of nominally vertical columns, walls or frames and horizontal floors and roofs. (The final section of this appendix discusses structures other than typical buildings.)

Components and Effects to Be Included

The specification contains the following requirements:

- The analysis shall consider flexural, shear and axial member deformations, and all other deformations that contribute to displacements of the structure.
- The analysis shall consider all gravity and other applied loads that may influence the stability of the structure.

It is important to note that "consider" is not synonymous with "include" in these provisions. Some of the listed effects could be considered and then, if judged to be insignificant (on the basis of a rational evaluation of their importance), be excluded from the analysis. Suggestions regarding the inclusion in the model of certain typical building components and their properties follow.

Lateral Load-Resisting Systems

Clearly, all lateral load-resisting systems and components must be included in the model. These might include braced frames, moment-resisting frames, shear walls, and other systems intended to provide lateral stability and resistance to lateral loads.

In general, it will be necessary to model these components at their correct locations in three-dimensional space. In symmetric structures with lateral load-resisting systems completely uncoupled in the two orthogonal directions, it may be possible in some cases to employ two-dimensional models. This should be attempted only when overall torsional instability is clearly not an issue (such as when the lateral load resisting components are well distributed through the building footprint or are located at or near the building perimeter).

Braced frames may be represented in the model as either pin-connected or rigidly connected assemblies. What is important is that the analysis be consistent with the design: If rigid connections are assumed in the model, the design must account for the resulting moments; if pin connections are modeled, end moments may be neglected in the design of members.

Components Not Part of Lateral Load-Resisting Systems

The analysis must account for the destabilizing effect of all loads on the structure, including loads applied on components that are not part of the lateral load-resisting systems. This means that all vertical load-carrying components, including "leaning columns" (columns stabilized laterally through their connection to the rest of the building), and all the loads on these components, must be included in the model and the analysis.

It is not always necessary to model all leaning columns individually. A group of leaning columns that have equal lateral displacements may be modeled as a single column, with the load on the entire group applied to that single column. The single column should be located at the approximate centroid of the load on the group of columns it represents. (Where overall torsional instability of the building is of concern, leaning columns should not be grouped, since torsional displacements of floors and roof correspond to unequal lateral displacements in all columns.)

Beams and girders whose only function in the structure is to deliver floor loads to columns (with simple connections at the columns) need not, in general, be included in the model. The floor loads may be applied directly to the columns as concentrated loads.

Floor and Roof Diaphragms

Most of the computer programs in common use for the analysis of building structures allow floor and roof diaphragms to be modeled as being rigid in their own plane, which can greatly simplify the analysis. Even with general frame analysis software, modeling the floor and roof diaphragms as rigid (through the use of appropriate plate or beam elements) can simplify the analysis.

While the floor and roof diaphragms in real buildings are never perfectly rigid, the rigid-diaphragm assumption can often be justified. What is important is the in-plane deformation of the diaphragm relative to the interstory drift of the building. If the maximum diaphragm deformation is no more than a small fraction of the maximum interstory drift, the rigid-diaphragm idealization will cause little error in the results of the analysis.

Most concrete slabs (formed or on steel deck) are stiff enough to be modeled as rigid in their own plane. Steel roof deck is much less rigid. Nevertheless, the flexibility of steel-deck roof diaphragms on multi-story residential and office buildings can often be neglected. These buildings do not typically have large distances between lateral load-resisting components (distances that the diaphragm must span horizontally); moreover, the stability demand at the top floor of a multi-story building is likely to be small.

Cold-formed steel roof diaphragms on industrial buildings with widely spaced lateral load-resisting components cannot usually be idealized as rigid. Nonrigid diaphragms may be modeled as horizontal beams of appropriate stiffness spanning between lateral load-resisting elements, supporting the tops of leaning columns. Or they could be modeled rigorously as plate elements.

Stiffness Adjustments

The specification (Section 2.3) requires adjustments to stiffness in the analysis model. This stiffness reduction is mandatory in analyses to be used for design for strength but is not necessary in analyses for serviceability. Instead of developing two separate models with different stiffnesses, it would be generally conservative to use the same model (with reduced stiffness) for serviceability as for strength, with the prescribed serviceability deformation limits increased appropriately.

Application of Notional Loads

The specification requires that the notional load at any level be distributed over the level in the same manner as the gravity load at that level. The most straightforward way to do this is to model the notional load as a fraction (typically 1/500) of the gravity load, applied horizontally rather than vertically, at the same locations as the gravity load. Thus, if the gravity loading is applied as concentrated loads at columns, the notional loads would also be applied that way. And if gravity load is applied as a distributed load on the floor, so too would the notional loads be applied. (If the program or modeling details do not permit distributed horizontal load on the floor diaphragms or framing, it will be necessary to convert these loads into concentrated loads at the columns.)

For gravity-only load combinations, four directions of notional load application, 90° apart, same direction at all floors, must be considered. For combinations that include wind or other lateral loading, the notional loads at all floors are applied in the direction of the resultant of all lateral loads in the combination.

Load Combinations

The codes that specify design loadings require consideration of numerous combinations of gravity and environmental loads. When different directions of the environmental loads are taken into account, the result can be a very large number of combinations. The number of loadings will be increased even further by the need to consider four different directions of notional load application for each gravity-only load combination.

For the second-order analysis that is required for stability design, the principle of superposition of loads does not apply; each load combination requires an independent analysis (and not just an adding together, with appropriate factors, of the results for each load component, as would be possible for a linear analysis).

The practice in many design offices is to apply all load combinations in every analysis. This approach has the benefit of simplicity (requiring no judgment in the selection of loads to be considered), and for linear analysis the penalty in computation time is small. But when the analysis is a second-order analysis, the time penalty can be significant.

To reduce computation time, designers using the Direct Analysis Method (or any method of design that requires second-order analysis) could attempt to identify the load combinations most likely to govern the design, and apply only those few combinations in all but the final cycles of the analysis, code-checking, resizing and re-analysis process.

Second-Order Analysis

Almost all computer programs that claim to do second-order analysis handle P-Δ effects adequately, but some do not consider P-δ effects. For many (if not most) real-world buildings, it is acceptable to use a program that neglects the effect of P-δ on the overall response of the structure: If the ratio of second-order drift to first-order drift is less than 1.5, and no more than one-third of the total gravity load on the building is on columns that are moment-connected in the direction of translation being considered, the error in a P-Δ-only analysis will be less than about 3% and may be considered negligible. (It is necessary in all cases to consider the effect of P-δ on individual compression members.)

The Direct Analysis Method of design for stability is compatible with approximate analysis procedures. While a second-order analysis is required, it does not have to be a rigorous large-deformation analysis using a sophisticated computer program. Linear, first-order analysis with results amplified to account for second-order effects, the "B_1-B_2 procedure" specified as an option in the AISC *Specification* is an acceptable means of second-order analysis.

In the B_1-B_2 procedure, the B_1 multiplier, calculated for each member subject to combined compression and flexure and each direction of bending of the member, accounts for the increase in moment caused by P-δ effects on that individual member. The B_2 multiplier, calculated for each story of the structure and each direction of lateral translation of the story, accounts for the increase in member forces and moments caused by P-Δ effects.

Structures Other Than Typical Buildings

The Direct Analysis Method with direct modeling of imperfections can be a particularly powerful tool in the design of structures other than typical building frames. In the method as presented in this model specification (and, less explicitly, in the 2005 *Specification*), initial imperfections may be modeled directly in the analysis at points of intersection of members; individual members can then be designed assuming an effective length equal to the actual length between these points.

In a logical extension of the method, initial imperfections can be modeled directly in the analysis at additional points beyond the points of intersection of members; members can then be designed assuming an effective length equal to the length between these more closely-spaced points. (See footnote to Section 2.2a of the model specification.)

For example, for a long-span truss with a laterally unbraced compression chord, initial lateral displacements could be included in the analysis model at each panel point. For an arch rib, initial lateral and vertical displacements could be modeled at a number of points along the rib.

In each case, the magnitude of the modeled initial displacements should be based on permissible construction tolerances and the pattern should reflect the anticipated buckling modes (typically single curve for lateral displacement of the truss chord or arch rib, double curve for in-plane displacement of the arch, and so on). Initial displacement patterns similar in shape to anticipated displacements due to loading should also be considered, if different from the buckling modes.

In the calculation of the available compressive strengths of individual members for comparison with required strengths determined from the analysis, the effective lengths of the members, for flexural buckling in the direction in which initial displacements were defined, should be taken as the lengths between the points at which the displacements were defined.

Thus, in the truss example, KL for lateral buckling of the chord would be the distance between panel points (even though the chord is not fully braced at these points). In the arch example, if initial displacements, in-plane and lateral, were applied to the rib at intervals of 20 ft in the analysis, KL for checking the available compressive strength of the rib may be taken as 20 ft, regardless of the actual spacing of "bracing" points on the rib.

The Effect of Selected RFI Variables on Steel Fabrication Performance

THOMAS M. BURNS

The fabrication of structural steel is a critical process in the supply chain of many construction projects. An effective transfer of design information is necessary for a steel fabricator to estimate quantities, place mill orders, prepare shop drawings, and receive necessary approvals. Design documentation (i.e., plans and specifications) must be interpreted, transformed into shop drawings, and approved before the physical task of fabrication can commence. Questions seeking clarification on any aspect of the design will generate a request for information (RFI) by the steel fabricator. Although the steel fabricator may focus on other tasks while awaiting an answer, the time spent waiting for an answer represents a discontinuity in the flow of information at this point in the design-construction interface. These discontinuities may cause delays in the shop drawing production process and affect performance in subsequent fabrication activities. Since structural steel is a long lead item, fabrication performance is important to the steel supply chain as well as subsequent project activities.

Characteristics of RFI variables within a project may provide an indication of both documentation and communication quality. In order to keep the fabrication of steel on schedule, the design documentation must be sufficiently complete and, where necessary, clarified in a responsive manner. Design documentation containing a minimal number of errors, omissions and inconsistencies will typically generate a smaller number of requests by the steel fabricator. A reduced need for clarification minimizes the potential for delays in the production and approval of shop drawings. The characteristics of communication within a given project are important when clarifications are requested. Once a need for the RFI has been determined, communication between the engineer and fabricator will affect the potential for delays in the shop drawing production phase. The volume of RFIs is a function of the extent of deficiencies within the design documentation while the effectiveness of the RFI process is a function of the severity of the deficiencies and communication characteristics. Figure 1 illustrates the factors and variables involved.

Poor fabrication outcomes can affect construction productivity as well. Fabricated elements that arrive late, contain deficiencies, or are out-of-sequence have been linked to significant schedule slippage (Thomas and Sanvido, 2000) while poor shop drawings can decrease erection productivity (Thomas, Riley and Sanvido, 1999). It is crucial that structural steel be on-schedule and correctly fabricated to maintain performance objectives. High-quality shop drawings are essential in achieving this result and are dependent on the need for and processing of RFIs.

RFIS AND PERFORMANCE

It is crucial that structural steel be correctly fabricated and on-schedule to maintain performance objectives. Thomas and Sanvido (2000) analyzed three construction projects and found that problems with fabricated components caused slippage of the construction schedule by as much as 129%. The delivery of the steel to the project is affected by its predecessors, including shop drawing production and approval. The successful completion of these tasks relies on an efficient use of RFIs. Poor project performance has been linked

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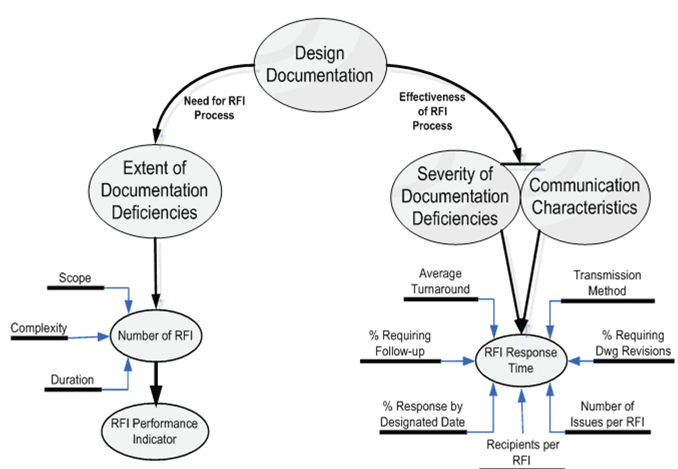

Fig. 1. Factors and variables in the RFI process.

to higher numbers of RFIs (Pugh, 1994) while the time it takes to respond to RFIs has also been associated with project performance (Tilley, Wyatt and Mohamed, 1997; Pugh, 1994). Pugh (1994) concluded that the RFI process is a leading indicator of performance at the design-construction interface and a strong indicator for potential schedule delays. Therefore, it seems apparent that characteristics of RFI variables will influence shop drawing production, approval and fabrication of structural steel.

The time and cost consequences of RFIs and their management have been studied and found to have a significant impact on organizational resources. A 2004 study sponsored by the National Institute of Standards and Technology used interviews, surveys and focus groups to estimate the impact of inadequate interoperability in the United States capital facilities sector. Information gathered from this study revealed that specialty fabricators average 15.5 hours processing a single RFI while design firms average approximately 200 hours per month managing RFIs (Gallaher, O'Connor, Dettbarn and Gilday, 2004). This finding is similar to another study which concluded that project participants spent an average of 17 hours processing a single RFI (Mohamed, Tilley and Tucker, 1999).

Although the steel construction industry would benefit from information regarding the relationship between various RFI variables and the shop drawing production process, no such quantitative study has been performed. Similarly, there has been no quantitative study performed on the relationship between any RFI variables and subsequent steel fabrication activities. This study fills this void by investigating the relationship between selected RFI variables and performance in both the shop drawing production and fabrication phases.

DATA COLLECTION AND SAMPLE

The data used in this study was collected from 10 AISC-member steel fabricators located throughout the continental United States. Project data regarding actual and estimated milestone dates in the fabrication process were collected from the steel fabricators via a questionnaire. The fabricators were asked to submit information on projects where (1) only traditional fabrication services were provided and (2) services were procured using lump sum contracts. Traditional fabrication services were defined as those where the fabricator's role was solely that of "steel provider" as opposed to those projects where the fabricator may have been involved in design. Similarly, lump sum contracts were chosen to exclude projects where design was not substantially complete. These limitations were incorporated into the design of this study in order to reduce the effect of potential extraneous variables. The effect of fabricator involvement in design (i.e., design-assist) could provide an opportunity for a comparative follow-up study but was not included in this work.

Any research is interested in accurately measuring what it intends to measure. In the case of measuring construction performance, the use of data from completed projects is commonly used in the investigation of measures related to construction cost and duration. In construction-related research, the use of questionnaires to collect project data for performance measures is also common (Moshini and Davidson, 1992; Griffis, Hogan and Li, 1995; Pocock, Hyun, Liu and Kim, 1996; Konchar and Sanvido, 1998; Hanna, Camlic, Peterson and Nordheim, 2002). RFI documentation found in logs and other communication provides quantitative information to the outside observer. The use of RFI documentation to ascertain RFI variables relating to volume, response time, and other RFI metrics has previously been used by Pugh (1994), Tilley et al. (1997), and Hanna et al. (2002). The construct that performance within the steel fabrication process can be associated with certain RFI variables is based upon previous studies that investigated the effect of RFIs on overall construction project performance (Pugh, 1994; Tilley, 1998). Previous research found that RFI process characteristics are a leading indicator of project performance and that certain measures relative to response time and the number of clarification RFIs could allow for comparisons between projects. The theoretical constructs and operational assumptions used in this study appear consistent with other literature involving RFIs and performance.

A total of 82 project questionnaires were returned with RFI documentation. Due to incomplete information or nonconformance with the aforementioned criteria, 34 projects were rejected. This resulted in a sample consisting of 48 projects from various construction sectors (Figure 2). The size of projects, by project tonnage, included in the sample ranged from 33 to 6,500 tons. The mean value of fabricated steel weight in the sample is 572 tons per project with approximately 67% of the sample projects having fabricated elements weighing in the 100- to 1,000-ton range (Figure 3). Project size appeared related to the volume of clarification RFIs as may be expected. A trend of increasing

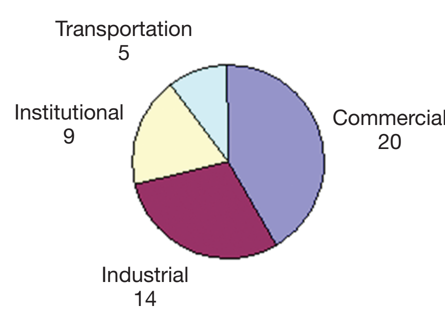

Fig. 2. Sample projects by construction sector.

average number of clarification RFIs as the average weight of fabricated elements increased was apparent in the sample. Figure 4 illustrates the average number of clarification RFI per project in each of the project weight categories.

All submitted data was checked for consistency and reviewed, if necessary, with the fabricator to increase reliability. All projects in the accepted sample were completed during the 2005 to 2006 calendar years.

PERFORMANCE MEASURES

Performance measures for construction projects commonly involve time and cost indicators. The Construction Industry Institute's (CII) Benchmarking and Metrics program has several performance indicators utilizing actual and initial (estimated) values of duration. Measurement of duration-related performance using estimated and actual calendar dates to delineate operationally defined start and stop points for project phases has similarly been used. Griffis et al. (1995), in a CII-sponsored study, investigated cost and duration performance using metrics calculated as ratios of actual-to-estimated values and noted such metrics were "the most widely used and understood."

Using estimated-to-actual duration is the basis of performance measurement in this study. The two performance measures used in this study were the shop drawing production performance (SHOPPERF) and fabrication duration performance (FABDPERF). Using the milestone dates from the fabricator's production schedule, the estimated length of time for shop drawing production and fabrication duration were calculated for each project. Shop drawing production performance was based on a timeframe that commenced with the notice to proceed and ended with the issue date of the last set of shop drawings. Fabrication duration performance was based on a timeframe starting with the issue date of the first batch of shop drawings and ending with the shipment date of the last sequence of steel for the project. The issue date was chosen as the "start" of fabrication as it may lag the actual approval date due to revisions that may be needed. These phases of shop drawing production and fabrication are illustrated in Figure 5. Since each performance measure is expressed as a ratio of estimated to actual time, higher values of each measure indicate increased performance. The formulas for both of these performance measures are as follows:

$$SHOPPERF = \frac{\text{Estimated days in shop drawing phase}}{\text{Actual days in shop drawing phase}}$$

$$FABDPERF = \frac{\text{Estimated days for fabrication duration}}{\text{Actual days for fabrication duration}}$$

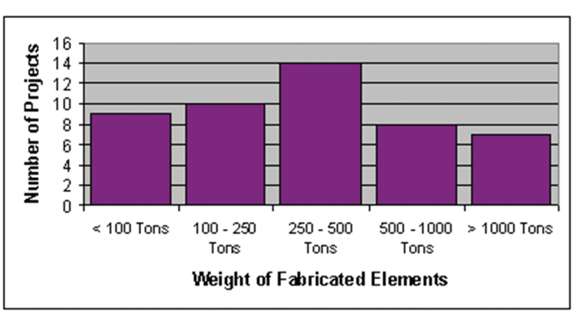

Fig. 3. Sample project categorized by fabricated weight.

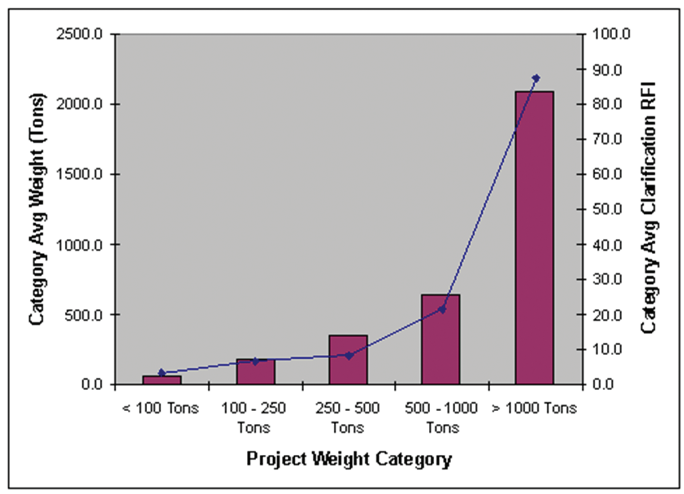

Fig. 4. Relationship of average clarification RFIs to fabricated weight.

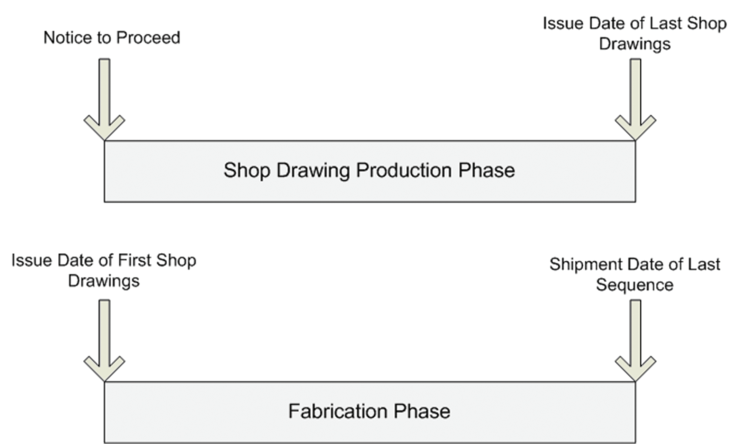

Fig. 5. Start–stop milestones for phases.

RFI VARIABLES

The RFI variables selected for this study were chosen because they were previously identified, readily accessible, and quantitative in nature. Four RFI variables were initially investigated in this study: (1) the average RFI response time, (2) the percentage of RFIs requiring follow-up, (3) the percentage of RFI responses over 7 days, and (4) the RFI performance indicator. These RFI variables comprise elements of RFI volume and timing that are considered important characteristics in a project. These were initially studied for their effect on shop drawing production performance.

RFIs can be generated for a variety of reasons. In this study, RFIs were categorized for their relation to (1) clarification of the design, (2) substitution requests, (3) erection/field issues, or (4) extraneous information/matters. While all categories require time to process, clarification-related RFIs are generally considered most relevant to documentation quality. RFI documentation from the 48 sample projects contained 1,134 RFIs categorized as shown in Figure 6.

The average RFI response time was calculated based on the fabricator's RFI logs which contained the date sent and date returned for each RFI. RFI response time is calculated as the length of time (days) between the date sent and the date returned. Average RFI response time for the project was simply the arithmetic average and outliers more than 3 standard deviations above the mean were removed from the sample project. The next RFI variable, percentage of RFIs requiring follow-up, was again calculated based on an analysis of the RFI logs. If an RFI was generated based on the original response to a previously written RFI it was deemed a "follow-up RFI." The percentage of these follow-up RFIs within a project was calculated to provide this variable. The third RFI variable investigated the effect of extended response times since longer response times could be potentially more detrimental to performance. To consider this characteristic, it was decided to investigate the percentage

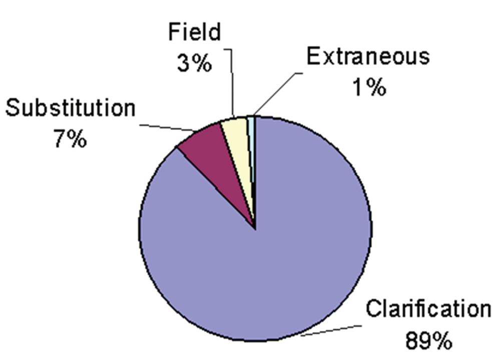

Fig. 6. Categorization of RFIs in sample.

of RFIs in each project that required more than five working days (seven calendar days) to process. This threshold was chosen based on recommended RFI protocol (Andrews, 2005). The final RFI variable investigated for its effect on performance is termed the RFI performance indicator and is based upon previous research (Tilley et al., 1997; Tilley, 1998). This variable provides a numerical value based upon the ratio of clarification-related RFIs to the contract value and duration of fabrication. Contract value and project duration act as proxies for project size and complexity, which would influence the need for clarification. This variable allows comparisons to be made between different projects as it reflects the level of deficiency within the contract documents received by the steel fabricator. The formula for the RFI performance indicator is shown as follows:

$$PI = \left[\frac{N_c}{(CV)D} \right]$$

where

PI = RFI performance indicator
N_c = number of clarification-related RFIs
CV = contract value ($100,000)
D = initial project duration (months)

REGRESSION MODEL AND RESULTS

Multiple regression is a statistical technique that estimates the value of a dependent variable as a function of several independent variables. This analytical tool is used to determine many facets of the relationship between a dependent variable and a set of independent variables. A useful characteristic of this technique is its ability to ascertain the amount of variance in the dependent variable which is accounted for by the independent variables. The coefficient of determination, R^2, of the model ranges between 0 and 1 and represents the percentage of variability in the dependent variable explained by the regression model. Although the R^2 statistic describes the amount of explained variability, it has to be interpreted relative to other factors which comprise the model. Adding more independent variables to a regression model will always increase the R^2 statistic but may be problematic due to interaction between independent variables. Good regression models will use the smallest number of independent variables that still provide practical interpretation of the dependent variable.

The sample of 48 projects was adequate for the proposed regression technique. Determining this adequacy depends on a number of factors, including the particular statistical test, the desired power level, the significance criterion, and the effect size. To determine the proper sample size, the minimum power level for the regression analysis was set at 0.75, while a medium effect size was posited ($f^2 = 0.15$). A significance level, α, of 0.10 was chosen which is similar to other

Table 1. Correlation of Transformed RFI Variables with Shop Drawing Production Performance Variable.		
		SHOPPERF
LNRFIPER	Pearson Correlation	–0.388
	Significance (2-tailed)	0.006
	N	48
LNRESTME	Pearson Correlation	–0.282
	Significance (2-tailed)	0.052
	N	48

Table 2. Regression Statistics for Shop Drawing Production Performance Model.

		Unstandardized Coefficients		Std. Coefficients			Colinearity Statistics	
Model		*B*	Std. Error	Beta	*t*	Significance	Tolerance	VIF
1	(Constant)	0.666	0.060	—	11.073	0.000	—	—
	LNRFIPER	−0.0913	0.029	−0.411	−3.172	0.003	0.994	1.006
	LNRESTME	−0.0735	0.031	−0.312	−2.409	0.020	0.994	1.006

VIF = variance inflation factor

construction-related research. Using procedures outlined by Cohen (1988), the sample size of 48 exceeded the desired power level in this study.

The initial step of the research analysis sought to determine if any of the RFI variables had a significant effect on the shop drawing performance variable. Scatter plots were examined for linearity as well as outliers. Normality of the independent variables was checked using the observed values of skewness and kurtosis and found to be within a ± 2 standard error of zero. Subsequent correlation analyses revealed the RFI performance indicator and the average RFI response time variables were significantly associated with shop drawing production performance. The other two RFI variables did not have significant correlations and, therefore, were removed from further consideration. Since multiple regression is based on an assumption of linearity, the two significant RFI variables were transformed by applying the natural logarithm to each. This natural log transformation was found to strengthen this correlation between both RFI variables and the shop drawing production performance. The correlation statistics for each can be found in Table 1.

A multiple regression model to estimate the shop drawing production performance based on the RFI performance indicator and the average RFI response time variables was developed. This regression model using the transformed RFI performance indicator (LNRFIPERF) and the transformed average RFI response time (LNRESTME) was found to significantly predict shop drawing production performance ($p = 0.002$). Table 2 provides the inferential statistics for this additive model. The coefficient of determination, R^2, for this model was 0.248, indicating that these two RFI variables together explain almost 25% of the variance in shop drawing production performance for the sample. The model equation is as follows:

$$SHOPPERF = 0.666 - 0.0735(LNRESTME) - 0.0913(LNRFIPERF)$$

This model indicates that as the RFI performance indicator variable and the average RFI response time variable decrease, shop drawing production performance will increase. Although this model explains only 25% of the variance within the sample projects, it must be interpreted with respect to the nature of the shop drawing production process itself as well as the model. Shop drawing production is a complex process because of the communication characteristics involved in producing the final output. The process itself contains various lines of communication involving multiple participants including the fabricator, engineer of record, specialty engineers/designers, and possibly outside detailers. These multiple communication pathways may be exchanging information regarding RFIs using a variety of technologies,

Table 3. Regression Statistics for Fabrication Duration Performance Model.								
		Unstandardized Coefficients		Std. Coefficients			Colinearity Statistics	
Model		*B*	Std. Error	Beta	*t*	Sig.	Tolerance	VIF
1	(Constant)	0.833	0.106	—	7.829	0.000	—	—
	LNRFIPER	–0.145	0.051	–0.386	–2.839	0.007	0.994	1.006
	LNRESTME	–0.0731	0.054	–0.184	–1.355	0.182	0.994	1.006

including e-mail, fax, project management intranets, or some combination of those. Additionally, communication may be influenced by the level of familiarity that participants may have with each other as well as familiarity with the project type and the project delivery system. Instead of exploring the large number of variables that could influence the performance of shop drawing production, this model opted to investigate the aforementioned RFI variables because they were previously identified, readily accessible, and quantitative in nature. The practical nature of this model is reflected in the use of two common RFI variables, the RFI performance indicator variable and the average RFI response time variable, to estimate shop drawing production performance. This statistically significant result is particularly interesting since the sample of 48 projects was obtained from 10 different fabricators, located in various parts of the country, and using projects from various construction sectors.

Although this study quantifies the influence of only several selected RFI variables on the shop drawing production performance, these results are consistent with other studies investigating the impact of RFIs on performance. Other investigations of RFI variables with respect to project performance have concluded that RFI variables are a leading indicator of project performance (Pugh, 1994; Tilley, 1998). These studies also noted the influence of documentation deficiency on the volume of RFIs, while others have associated decreased performance measures with increased documentation deficiency (Shohet and Frydman, 2003; Tilley, McFallan and Tucker, 2000). The effect of RFI response time on steel shop drawing production is congruent with others that have found that increased RFI response time is associated with decreased performance (Mohamed et al, 1999; Tommelein and Ballard, 1997; Pugh, 1994).

The following step in this analysis investigated the association between performance of shop drawing production and the subsequent schedule performance of steel fabrication. In this study, the actual duration of the steel fabrication phase was the number of days between the issue date of the first set of shop drawings and the shipment of the last sequence of steel to the site. Since shop drawing production precedes the fabrication of structural steel, establishing an estimate of fabrication duration performance from performance in the shop drawing phase could serve as an important planning tool.

A correlation analysis was performed between the shop drawing production performance and the fabrication duration performance, that found a significant relationship between these two performance measures (r = 0.375, $\rho = 0.009$). With the finding of a positive association between duration performance in the shop drawing production phase and the subsequent fabrication phase, an additive multiple regression model was investigated to estimate fabrication duration performance using the two RFI variables found to be significant previously. This model, estimating fabrication duration performance based on the RFI performance indicator variable and the average RFI response time variable, was significant at the 0.009 level. Table 3 provides the inferential statistics for this additive model. The coefficient of determination (R^2) for this model was 0.172, indicating that these two RFI variables together explain approximately 17% of the variance in fabrication duration performance in the sample. The regression equation is as follows:

$$FABDPERF = 0.833 - 0.145(LNRFIPERF) - 0.0731(LNRESTME)$$

This model indicates that as the RFI performance indicator and the average RFI response time variable decrease, fabrication duration performance will increase. Again, this model must be again interpreted with respect to the many variables that could possibly affect the fabrication duration as well as the purpose of the model itself. It also indicates that other factors affect fabrication duration in addition to the two RFI variables studied. This should be expected since RFI variables logically share a closer association with the shop drawing production phase. When considered with regard to the number of decisions, deliveries, participants and activities that are involved in getting steel to the project site, it is noteworthy that two basic RFI variables explain roughly one-sixth of the total duration variability in the fabrication phase.

Although fabrication duration could be considered to be insulated from variables within the RFI process, this analysis indicates that fabrication duration performance shares a significant association with the same two RFI variables that were significantly associated with shop drawing production. The results are consistent with the other literature that has asserted that the pace of steel fabrication is driven by the production and approval of shop drawings (Van de Pas, Tinker and Holland, 2005). Timely fabrication of structural steel hinges upon the approval of shop drawings which has been shown to be quantitatively associated with the relative RFI volume and the characteristics of RFI response time. Increasing numbers of RFIs and longer turnaround times invariably produce discontinuities in the fabrication process. Although these discontinuities may originate in the shop drawing production phase, the previous regression equation indicates a ripple effect that occurs in the actual fabrication of the steel components.

CONCLUSION

The widely held belief that increased RFI volume and response time result in negative consequences for the fabrication of structural steel has been quantified. Relative increases in RFI volume lead to discontinuities in the production of shop drawings. Problems in the shop drawing production phase cause a ripple effect in downstream performance relative to the duration of the fabrication phase. The quantitative model developed in this study rests on the theory that shop drawing production and fabrication duration performance can be modeled based upon selected RFI variables. While there are many variables that could influence performance in various stages of steel fabrication, this study opted to investigate RFI variables that have been previously identified and are readily found using typical fabrication documentation. Statistically significant multiple regression equations were developed using two RFI variables to explain approximately 25% of the performance variance in the shop production and 17% of the performance variance in fabrication duration. This significant result occurred in a sample of 48 projects of various sizes and construction types, submitted from 10 different steel fabricators located throughout the United States.

The quality of design documentation is a major attribute of communication at the beginning of the design-fabrication interface. Documentation that is complete, consistent and unambiguous will require less clarification. In this study, the variable found to be statistically significant that reflects the extent of documentation deficiency is the RFI performance indicator (LNRFIPER). This variable, adapted from earlier research work (Tilley et al., 1997; Tilley, 1998), accounts for the number of clarification RFIs generated with respect to a project's size and duration. Higher values of the RFI performance indicator variable indicate a greater usage of RFIs within a given project and portend discontinuities in the shop drawing production process. This variable was found to have the strongest association with both shop drawing production and fabrication duration performance, which is congruent with related research.

While the quality of the design documentation is the primary determinant of the need for RFIs, communication within the process also plays a role in performance. This study has quantitatively established that the average RFI response time variable (LNRESTME) is also associated with shop drawing production performance in steel fabrication. The ability to get answers quickly when seeking clarification on design-related issues is an important factor in the timely completion of the fabricator's work. Longer RFI response times result in discontinuities that are associated with longer durations in the shop drawing production and fabrication phases.

RECOMMENDATIONS

This research identifies specific RFI variables and their statistically significant relationship with shop drawing production and fabrication duration performance. The models developed in this study found that the RFI performance indicator variable and the RFI response time variable have a substantive influence on shop drawing production and fabrication processes. Since the data used in this study represented 48 sample projects from 10 steel fabricators, generalizations to the population of steel fabricators working as steel providers in lump sum projects can be supported. The quantitative foundation of this generalized model can be applied by individual fabricators interested in performance improvement through statistical RFI management. The cataloging of RFI data on past projects could provide the steel fabricator an opportunity to develop robust models incorporating other variables pertaining to project delivery, coordination, and delegation of responsibility. The development of statistical models based on such data would allow individual fabricators to predict confidence intervals using the RFI performance indicator variable. These intervals would identify RFI ranges that would be associated with performance levels for an upcoming project. Information regarding project RFI response time could be combined with historical response time data to develop control processes, similar to control charting, which would allow quantitative, real-time recognition of performance in ongoing projects.

Engineers and designers could also benefit from a database of the RFI variables discussed herein. Such variables could be used as quality service indicators to external parties. Lower values of the RFI performance variable suggest higher levels of quality in design documentation, while lower values of the response time variable would reflect an increased commitment to prompt clarification. Both of these may be useful in documenting a design organization's commitment to quality during qualification-based selection procedures. Similar to contractor's experience modification rate (EMR), the availability of documented indices associated with good performance could be used to further enhance professional reputation.

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Technical Note: Optimum Flexural Design of Steel Members Utilizing Moment Gradient and C_b

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Flexural strength of members based on the limit state of lateral-torsional buckling is a function of the moment gradient of the unbraced length under consideration. The bending modification factor, C_b, accounts for the shape of the moment gradient within the unbraced length and allows for adjustment of the member flexural strength, possibly increasing it by a considerable amount. Therefore, neglecting the impact of C_b on member strength may lead to overdesign. This paper discusses the application of C_b to the design of members subjected to bending including beams as well as members subjected to combined loading (compression and bending, tension and bending, or biaxial bending). The concept of C_b and the formula for determining the modification factor is similar when using Allowable Strength Design (ASD) or the Load and Resistance Factor Design (LRFD) method. However, designers used to the 1989 *Allowable Stress Design and Plastic Design Specification for Structural Steel Buildings* (AISC, 1989a), hereafter referred to as the 1989 ASD *Specification,* and the 9th edition of the AISC *Manual of Steel Construction* (AISC, 1989b) will find more updates in the new formula and method of calculating and using C_b. Numerical examples are presented using both ASD and LRFD methods.

Four limit states apply to bending of steel beams: yielding, lateral-torsional buckling, flange local buckling, and web local buckling. Yura, Galambos and Ravindra (1978) present a thorough discussion of behavior of steel beams under bending and the different controlling limit states. The modification factor, C_b, affects cases in which member unbraced length, L_b, is greater than L_p and thus lateral-torsional buckling (LTB) controls flexural strength.

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A fundamental assumption made in developing the relevant design aids included in the AISC *Steel Construction Manual* (AISC, 2005b) for flexural design when LTB controls is that the critical unbraced segment of the beam has a uniform moment diagram (gradient). If this is not the case, the modification factor, C_b, should be used to adjust the flexural strength of the member. It is noted that every unbraced segment of a beam has its own C_b, which may or may not be equal to that of other segments.

Calculation of C_b has gone through a number of evolutions over the years. Zoruba and Dekker (2005) offer a historic and technical overview of C_b in the AISC Specifications.

The 2005 AISC *Specification for Structural Steel Buildings* (AISC, 2005a), hereafter referred to as the AISC *Specification,* offers Equation 1 for calculation of C_b.

$$C_b = \frac{12.5M_{max}}{2.5M_{max} + 3M_A + 4M_B + 3M_C} R_m \leq 3.0 \tag{1}$$

where

M_{max} = absolute value of maximum moment in the unbraced segment, kip-in. (N-mm)

M_A = absolute value of moment at quarter point of the unbraced segment, kip-in. (N-mm)

M_B = absolute value of moment at centerline of the unbraced beam segment, kip-in. (N-mm)

M_C = absolute value of moment at three-quarter point of the unbraced beam segment, kip-in. (N-mm)

R_m = cross-sectional monosymmetry parameter
= 1.0 for doubly symmetric members
= 1.0 for singly symmetric members subjected to single curvature bending
= $0.5 + 2(I_{yc}/I_y)$ for singly symmetric members subjected to reverse curvature bending

I_y = moment of inertia about the principal y-axis, in.^{4} (mm^4)

I_{yc} = moment of inertia about y-axis referred to the compression flange, or if reverse curvature bending, referred to the smaller flange, in.^{4} (mm^4)

Designers used to the 1989 ASD *Specification* (AISC, 1989a) will find more changes in the new formula and method of calculating and using C_b. This is due to the fact that the 1989 ASD *Specification* had not been updated between 1989 and 2005, while the LRFD *Specification* had gone through a number of revisions to reflect the state-of-the-art in research and practice.

Example 1 illustrates application of Equation 1 to determine C_b for a case not included in Table 3-1 of the AISC *Steel Construction Manual* (AISC, 2005b). It is noted that from this point on, all references in the following examples are made to the 13th Edition AISC *Steel Construction Manual*.

EXAMPLE 1

Given

Simply supported girder shown in Figure 1, laterally braced at ends and load point.
P: 3 kips DL + 10 kips LL
w: 0.35 kips/ft DL (including beam weight) + 1.15 kips/ft LL

Find

Calculate C_b using ASD and LRFD load combinations.

Solution

Using ASD load combinations:
P_a = 3 kips + 10 kips = 13.0 kips
w_a = 0.35 kip/ft + 1.15 kip/ft = 1.50 kip/ft

This beam and loading is a combination of cases 1 and 7 from Table 3-23 of the AISC *Steel Construction Manual* (pages 3-211 and 3-213).

Consider the case of beam with concentrated load at midspan. It can be shown that values of M_{max}, M_A, M_B and M_C are as follows.

M_A = 24.4 kip-ft

M_B = 48.8 kip-ft

M_C = 73.1 kip-ft

M_{max} = 97.5 kip-ft

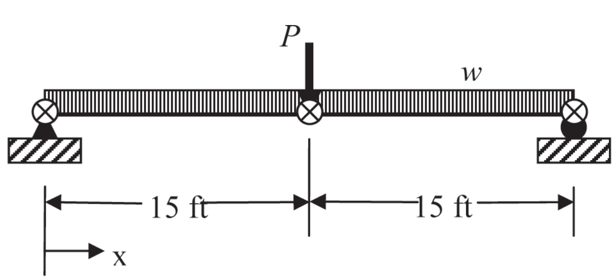

Fig. 1. Simply supported girder for Example 1.

Similarly, it can be shown that for the uniform load,

M_A = 73.8 kip-ft

M_B = 127 kip-ft

M_C = 158 kip-ft

M_{max} = 169 kip-ft

We now calculate C_b using Equation 1 with M_A, M_B, M_C and M_{max} totals from both loading conditions. Note that R_m = 1.0 (single curvature).

M_A = 24.4 kip-ft + 73.8 kip-ft
= 98.2 kip-ft

M_B = 48.8 kip-ft + 127 kip-ft
= 176 kip-ft

M_C = 73.1 kip-ft + 158 kip-ft
= 231 kip-ft

M_{max} = 97.5 kip-ft + 169 kip-ft
= 267 kip-ft

$$C_b = \frac{12.5M_{max}}{2.5M_{max} + 3M_A + 4M_B + 3M_C}R_m$$
$$= \frac{12.5(267\text{ kip-ft})}{2.5(267\text{ kip-ft}) + 3(98.2\text{ kip-ft}) + 4(176\text{ kip-ft}) + 3(231\text{ kip-ft})}$$
$$\times (1.0)$$
$$= 1.41$$

Using LRFD load combinations:

P_u = (1.2)(3 kips) + (1.6)(10 kips)
= 19.6 kips

w_u = (1.2)(0.35 kip/ft) + (1.6)(1.15 kip/ft)
= 2.26 kip/ft

Note the relationship between loads calculated based on the ASD and LRFD load combinations.

$$\frac{P_u}{P_a} = \frac{19.6\text{ kips}}{13.0\text{ kips}} = 1.51$$

and

$$\frac{w_u}{w_a} = \frac{2.26\text{ kip/ft}}{1.50\text{ kip/ft}} = 1.51$$

Therefore, M_{max}, M_A, M_B and M_C for each loading case using the LRFD load combinations will be 1.51 times those found earlier based on the ASD load combinations. This ratio cancels out from top and bottom of the C_b equation and yields the same C_b value for the LRFD load combination as for the ASD approach.

Note that according to Table 3-1 in the AISC *Steel Manual* (page 3-10), C_b for the point load and uniformly distributed loads acting alone are 1.67 and 1.30, respectively.

The modification factor C_b has values ranging from 1.0 to 3.0. The case $C_b = 1.0$ is the most critical. Larger values of C_b may result in increased flexural strength. Section F1 of the AISC *Specification* states that "C_b is permitted to be conservatively taken as 1.0 for all cases." It further states that "For cantilevers or overhangs where the free end is unbraced, $C_b = 1.0$." The reader is encouraged to review the pertinent parts of the 2005 AISC *Specification* (AISC, 2005a) and its commentary for more details and exceptions to the above statements.

FLEXURAL STRENGTH FOR $C_b > 1.0$

Burgett and Tide (1980) offer a method for design of beams with $C_b > 1.0$ for the Allowable Stress Design (ASD) method using the 1989 *ASD Specification* (AISC, 1989a). He recommends using an effective unbraced length (L_e) instead of the original unbraced length (L_x) to select a trial section for $C_b > 1.0$. Burgett suggests use of the formula $L_e = L_x / C_b$ to determine L_e. Once a trial section is selected with L_e, M_u, and $C_b = 1.0$, it must be checked for compliance with the 1989 ASD *Specification* for the original L_x and C_b. This method works well for relatively large unbraced lengths and using the Allowable Stress Design method. The following discussion will cover procedures that are consistent with the unified 2005 AISC *Specification for Structural Steel Buildings* (AISC, 2005a) and apply to both Allowable Strength Design method as well as the Load and Resistance Factor Design methods.

According to the 2005 AISC *Specification* (AISC, 2005a), the nominal flexural strength of beams based on the limit state of lateral torsional buckling with $C_b > 1.0$ is determined using the formula given in Equation 2:

$$\left[M_n\right]_{C_b > 1.0} = \left(C_b\right)\left[M_n\right]_{C_b = 1.0} \leq M_p \text{ or } M_p' \tag{2}$$

ASD and LRFD versions of Equation 2 follow.

$$\left[\frac{M_n}{\Omega}\right]_{C_b > 1.0} = \left(C_b\right)\left[\frac{M_n}{\Omega}\right]_{C_b = 1.0} \leq \frac{M_p}{\Omega} \text{ or } \frac{M_p'}{\Omega} \quad \text{(2-ASD)}$$

$$\left[\phi_b M_n\right]_{C_b > 1.0} = \left(C_b\right)\left[\phi_b M_n\right]_{C_b = 1.0} \leq \phi_b M_p \text{ or } \phi_b M_p' \quad \text{(2-LRFD)}$$

FLEXURAL DESIGN FOR $C_b > 1.0$

Equation 2 and its ASD and LRFD versions form the basis for incorporating C_b in determining flexural strength of members based on the limit state of lateral torsional buckling. As noted earlier, C_b may be conservatively taken to be equal to 1.0 in all cases. However, by doing so the designer is likely to miss gains from $C_b > 1.0$, which may lead to smaller member sizes. Such gains may be quite significant, particularly for beams with relatively large unbraced lengths. Therefore, it makes sense to consider the impact of C_b for unbraced beams. Recall that values of C_b may range from 1.0 to 3.0. Thus, it is possible that member strength after incorporating C_b may be as much as three times that without considering C_b.

The amount of gain or benefit from C_b varies depending on section size, material properties, unbraced length, and value of C_b. Figure 2 graphically illustrates variation of nominal flexural strength versus the unbraced length for compact sections. The chart for non-compact sections would look similar to Figure 2, except that M_p', L_p' and L_m' will be used instead of M_p, L_p and L_m.

Two bending modification factors are utilized in the chart of Figure 2 with $C_{b2} > C_{b1} > 1.0$ to illustrate different possibilities. Note particularly that $C_b M_n$ may not exceed M_p for compact sections and M_p' for non-compact sections.

We will consider three cases in the following discussion on incorporating C_b in flexural design: beams with relatively small unbraced lengths, beams with relatively large unbraced lengths, and beams with moderate unbraced lengths. For ease of discussion, it is assumed here that all beam sections are compact. Since the AISC *Steel Construction Manual* lists M'_p for non-compact sections the same way in charts and tables as it does M_p for compact sections, there are no procedural differences between the two.

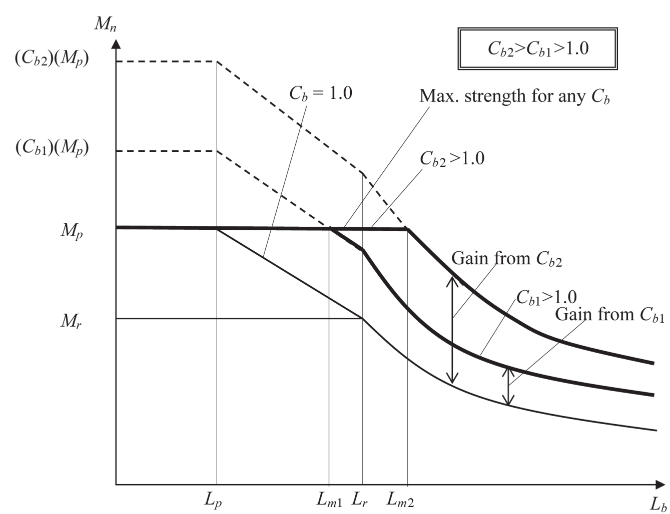

Fig. 2. Impact of C_b *on* M_n *for compact sections.*

For beams with relatively small unbraced length and L_b not exceeding L_p, either yielding or local buckling controls and C_b does not apply. In such cases, the nominal flexural strength is already at the maximum of M_p (M'_p for noncompact sections).

In cases of beams with relatively large unbraced lengths, it is very likely the beam will fully benefit from C_b and therefore Equation 2 may be used as follows for design.

$$M_u \le \left[\frac{M_n}{\Omega}\right]_{C_b > 1.0} = (C_b)\left[\frac{M_n}{\Omega}\right]_{C_b = 1.0} \le \left[\frac{M_p}{\Omega}\right] \qquad \text{(3-ASD)}$$

$$M_u \le \left[\phi_b M_n\right]_{C_b > 1.0} = (C_b)\left[\phi_b M_n\right]_{C_b = 1.0} \le \phi_b M_p \qquad \text{(3-LRFD)}$$

or

$$\frac{M_u}{C_b} \le \left[\frac{M_n}{\Omega}\right]_{C_b = 1.0} \qquad \text{(4-ASD)}$$

$$\frac{M_u}{C_b} \le \left[\phi_b M_n\right]_{C_b = 1.0} \qquad \text{(4-LRFD)}$$

As suggested by Equations 4, for design of beams with relatively large unbraced lengths and $C_b > 1.0$, the designer may select a trial section based on a fictitious required moment of $[M_u]_{C_b = 1.0} = (M_u / C_b)$. This section is then checked for strength using its original M_u and C_b.

For beams with moderate unbraced lengths, one may still follow the approach recommended for relatively large unbraced lengths, but use a smaller C_b to obtain a trial section. Alternatively, the designer may initially neglect the impact of C_b, obtain a trial section based on $C_b = 1.0$, and continue checking smaller sections until a desired section is found. In either case, the trial section must be checked for strength using its original M_u and C_b.

Note that in all cases, the requirement of $\phi_b M_p \ge M_u$ for LRFD and $M_p/\Omega \ge M_u$ for ASD must be checked for all trial sections before any additional work is done.

EXAMPLE 2

Given

Simply supported beam with $L = 50$ ft, $w_D = 0.24$ kip/ft (beam weight included), $w_L = 0.72$ kip/ft, A992 steel. Consider bending only.

Find

Use ASD and LRFD methods to select the lightest W-section if

(a) $L_b = 5$ ft
(b) $L_b = 25$ ft

Solution

ASD Method:

$$\begin{aligned} w_a &= w_D + w_L \\ &= 0.24 \text{ kip/ft} + 0.72 \text{ kip/ft} \\ &= 0.96 \text{ kip/ft} \end{aligned}$$

$$\begin{aligned} M_a &= \frac{w_a L^2}{8} \\ &= \frac{(0.96 \text{ kip/ft})(50 \text{ ft})^2}{8} \\ &= 300 \text{ kip-ft} \end{aligned}$$

Case (a)

$L_b = 5$ ft—relatively small, assume braced beam, C_b not applicable

From Table 3-2 (page 3-17) look for a section with $M_{px}/\Omega \ge M_a = 300$ kip-ft

Try W21×55

$L_b = 5.0$ ft $< L_p = 6.11$ ft, braced beam $\rightarrow$ assumptions about L_b and C_b correct

Therefore, $M_{nx}/\Omega = M_{px}/\Omega = 314$ kip-ft $> M_a = 300$ kip-ft

Use W21×55, A992 steel

Case (b)

$L_b = 25$ ft—relatively large $\rightarrow$ assume full benefit from C_b

Note from Table 3-1 of the AISC *Steel Construction Manual* (page 3-10) that $C_b = 1.30$ for a uniformly loaded simply supported beam braced at midpoint.

Select a trial section based on the following

$$\begin{aligned} [M_a]_{C_b = 1.0} &= \frac{[M_a]_{C_b = 1.30}}{C_b} \\ &= \frac{300 \text{ kip-ft}}{1.30} \\ &= 231 \text{ kip-ft} \end{aligned}$$

Go to page 3-122 of the AISC *Steel Construction Manual* with $L_b = 25$ ft, $M_a = 231$ kip-ft, and $C_b = 1.0$

Try W18×76

From Table 3-2 of the AISC *Steel Construction Manual* (page 3-16):

$M_{px}/\Omega = 407$ kip-ft $> M_a = 300$ kip-ft $\rightarrow$ section may work

$[M_{nx}/\Omega]_{C_b = 1.0} = 273$ kip-ft read directly off of the chart on page 3-122.

$$[M_{nx}/\Omega]_{C_b=1.3} = (C_b)[M_{nx}/\Omega]_{C_b=1.0}$$
$$= (1.30)(273 \text{ kip-ft})$$
$$= 355 \text{ kip-ft} < M_{px}/\Omega = 407 \text{ kip-ft}$$

Note that beam fully benefited from C_b since $[M_{nx}/\Omega]_{C_b=1.3} < M_{px}/\Omega$

$[M_{nx}/\Omega]_{C_b=1.3} = 355$ kip-ft $> M_a = 300$ kip-ft

W18×76 is adequate

For lightest, try W14×74

$M_{px}/\Omega = 314$ kip-ft $> M_a = 300$ kip-ft $\rightarrow$ may work

$[M_{nx}/\Omega]_{C_b=1.0} = 212$ kip-ft read directly off of the chart on page 3-122.

$$[M_{nx}/\Omega]_{C_b=1.3} = (C_b)[M_{nx}/\Omega]_{C_b=1.0}$$
$$= (1.30)(228 \text{ kip-ft})$$
$$= 296 \text{ kip-ft} < M_{px}/\Omega = 314 \text{ kip-ft}$$

Therefore, $[M_{nx}/\Omega]_{C_b=1.3} = 296$ kip-ft $< M_a = 300$ kip-ft $\rightarrow$ Not adequate

Use W18×76, A992 steel

LRFD Method:

$$w_u = 1.2w_D + 1.6w_L$$
$$= 1.2(0.24 \text{ kip/ft}) + 1.6(0.72 \text{ kip/ft})$$
$$= 1.44 \text{ kip/ft}$$

$$M_u = \frac{w_u L^2}{8}$$
$$= \frac{(1.44 \text{ kip/ft})(50 \text{ ft})^2}{8}$$
$$= 450 \text{ kip-ft}$$

Case (a)

$L_b = 5$ ft—relatively small, assume braced beam, C_b not applicable

From Table 3-2 of the AISC *Steel Construction Manual* (page 3-17) look for a section with $\phi_b M_{px} \geq M_u = 450$ kip-ft

Try W21×55

$L_b = 5.0$ ft $< L_p = 6.11$ ft, braced beam $\rightarrow$ assumptions about L_b and C_b correct

Therefore, $\phi_b M_{nx} = \phi_b M_{px} = 473$ kip-ft $> M_u = 450$ kip-ft

Use W21×55, A992 steel

Case (b)

$L_b = 25$ ft—relatively large $\rightarrow$ assume full benefit from C_b

Note from Table 3-1 of the AISC *Steel Construction Manual* (page 3-10) that $C_b = 1.30$ for a uniformly loaded simply supported beam braced at midpoints.

Select a trial section based on the following assumption.

$$[M_u]_{C_b=1.0} = \frac{[M_u]_{C_b=1.30}}{C_b}$$
$$= \frac{450 \text{ kip-ft}}{1.30}$$
$$= 346 \text{ kip-ft}$$

Go to page 3-122 of the AISC *Steel Construction Manual* and select a trial section for $L_b = 25$ ft, $M_u = 346$ kip-ft, and $C_b = 1.0$

Try W18×76

From Table 3-2 of the AISC *Steel Construction Manual* (page 3-16): $\phi_b M_{px} = 611$ kip-ft $> M_u = 450$ kip-ft $\rightarrow$ may work

$[\phi_b M_{nx}]_{C_b=1.0} = 410$ kip-ft (read directly off of the chart on page 3-122)

$$[\phi_b M_{nx}]_{C_b=1.3} = (C_b)[\phi_b M_{nx}]_{C_b=1.0}$$
$$= (1.30)(410 \text{ kip-ft})$$
$$= 533 \text{ kip-ft} < \phi_b M_{px}$$
$$= 611 \text{ kip-ft}$$

Note that beam fully benefited from C_b since $[\phi_b M_{nx}]_{C_b=1.3} < \phi_b M_{px}$

$[\phi_b M_{nx}]_{C_b=1.3} = 533$ kip-ft $> M_u = 450$ kip-ft

W18×76 is adequate

It can be shown that a W14×74 is not adequate. Therefore, use W18×76, A992 steel

Note that if $C_b = 1.0$ were used, a W18×86 would have been selected instead.

It is noted that the focus of this paper and all example problems presented here is on the impact of C_b on member flexural strength. Other criteria, such as deflection, may control the design and must be checked.

Solid lines in the beam design charts of the AISC *Steel Construction Manual* are meant to obtain the lightest section for $C_b = 1.0$. Using them for selecting sections for $C_b > 1.0$ is not quite right, though reasonable. In order to find the lightest section for $C_b > 1.0$, at least two tries are necessary.

IMPACT OF C_b ON THE b_x COEFFICIENT

Part Six of the AISC *Steel Construction Manual* (AISC, 2005b) presents a method and aids for design of members subjected to combined loads (compression and bending, tension and bending, or biaxial bending). This approach, based on Aminmansour (2000 and 2006), utilizes three new coefficients p, b_x and b_y in analysis or design of such members. Following is a discussion on the impact of C_b on the b coefficient.

In addition to design of members subjected to combined loading, the method and aids presented in Part Six of the AISC *Steel Construction Manual* may prove to be helpful in design of beams in certain circumstances as illustrated in some of the examples that follow.

Values of b_x given in Part Six of the AISC *Steel Construction Manual* and the discussion that follows applies to beam-columns as well as members subjected to combined tension and bending, biaxial bending, or bending alone. Since the limit state of lateral-torsional buckling does not apply to bending of beams about their weak axis, our discussion here will be limited to the b_x coefficient only.

Values of the b_x coefficient given by Equations 5 and listed in Part 6 of the AISC *Steel Construction Manual* are based on $C_b = 1.0$.

$$b_x = \frac{8}{9\left(\dfrac{M_{nx}}{\Omega}\right)} \tag{5-ASD}$$

$$m = \frac{8}{9\left(\phi_b M_{nx}\right)} \tag{5-LRFD}$$

Combining Equations 2 and 5 yields:

$$\begin{aligned}\left[b_x\right]_{C_b>1.0} &= \frac{8}{9\left[\dfrac{M_n}{\Omega}\right]_{C_b>1.0}} \\ &= \frac{8}{9\left(C_b\right)\left[\dfrac{M_n}{\Omega}\right]_{C_b=1.0}} \\ &= \left(\frac{1}{C_b}\right)\left(\frac{8}{9\left[\dfrac{M_n}{\Omega}\right]_{C_b=1.0}}\right) \\ &= \frac{\left[b_x\right]_{C_b=1.0}}{C_b}\end{aligned} \tag{6 ASD}$$

$$\begin{aligned}\left[b_x\right]_{C_b>1.0} &= \frac{8}{9\left[\phi_b M_n\right]_{C_b>1.0}} \\ &= \frac{8}{9\left(C_b\right)\left[\phi_b M_n\right]_{C_b=1.0}} \\ &= \left(\frac{1}{C_b}\right)\left(\frac{8}{9\left[\phi_b M_n\right]_{C_b=1.0}}\right) \\ &= \frac{\left[b_x\right]_{C_b=1.0}}{C_b}\end{aligned} \tag{6 LRFD}$$

Now, apply the upper limit of Equations 2 to Equations 6 to obtain Equation 7 as follows:

$$\left[b_x\right]_{C_b>1.0} = \frac{\left[b_x\right]_{C_b=1.0}}{C_b} \geq \left[b_x\right]_{min} \tag{7}$$

where

$$\left[b_x\right]_{min} = \frac{8}{9\left(\dfrac{M_p}{\Omega} \text{ or } \dfrac{M'_p}{\Omega}\right)} \tag{8-ASD}$$

$$\left[b_x\right]_{min} = \frac{8}{9\left(\phi_b M_p \text{ or } \phi_b M'_p\right)} \tag{8-LRFD}$$

Values of $[b_x]_{\text{min}}$ are listed in Table 6-1 of the AISC *Steel Construction Manual* at $L_b = 0$ ft for a large number of W-sections for both ASD and LRFD methods.

USING b_x IN ANALYSIS AND DESIGN FOR FLEXURE WITH $C_b > 1.0$

The following observations may be used in analysis and design of steel members subjected to bending, including combined loads, with $C_b > 1.0$. Keep in mind that values of b_x listed in Table 6-1 of the AISC *Steel Construction Manual* are for $C_b = 1.0$ and already account for compact/non-compactness.

For laterally braced beams the limit state of yielding (local buckling for non-compact sections) controls and C_b does not apply. Therefore, for such situations, simply use the listed values of b_x.

For beams with relatively large unbraced lengths, it is likely that the member will fully benefit from C_b. Therefore, note that

$$\left[b_x\right]_{C_b>1.0} = \frac{\left[b_x\right]_{C_b=1.0}}{C_b} \geq \left[b_x\right]_{min}$$

For beams with moderately long unbraced length where partial benefit from C_b may be realized, the designer may treat the beam as in the latter case, but use a smaller C_b to obtain a trial section.

In all preceding cases, the trial section must be analyzed exactly based on its L_b and original C_b values to obtain b_x.

Important Note: The reader is reminded that a section with a b_x value equal to or smaller than a required value will be adequate in bending for the conditions given. See Aminmansour (2000 and 2006) for more comprehensive information on this subject.

EXAMPLE 3

Given

W24×76, L_b = 16 ft, C_b = 1.67, A992 steel

Find

Calculate available flexural strength using both ASD and LRFD methods

Solution

ASD Method:

Method I:

From Table 3-2 of the AISC *Steel Construction Manual* (page 3-16):

M_p/Ω = 499 kip-ft
L_p = 6.78 ft
L_r = 19.6 ft
BF = 15.0 kips

L_p = 6.78 ft < L_b = 16 ft < L_r = 19.6 ft

$$\left[\frac{M_n}{\Omega}\right]_{C_b=1.0} = \left(\frac{M_n}{\Omega}\right) - BF\left(L_b - L_p\right)$$
$$= 499\text{ kip-ft} - \left(15.0\text{ kips}\right)\left(16.0\text{ ft} - 6.78\text{ ft}\right)$$
$$= 361\text{ kip-ft}$$

$$\left[\frac{M_n}{\Omega}\right]_{C_b=1.0} = \left(C_b\right)\left[\frac{M_n}{\Omega}\right]_{C_b=1.0}$$
$$= (1.67)(361\text{ kip-ft}) = 603\text{ kip-ft} > \left(\frac{M_p}{\Omega}\right)$$
$$= 499\text{ kip-ft}$$

Therefore, $[M_n/\Omega]_{C_b=1.67} = [M_p/\Omega]$ = 499 kip-ft

Method II:

From Table 6-1 of the AISC *Steel Construction Manual* (page 6-42):
$b_x = 2.46 \times 10^{-3}$ (kip-ft)$^{-1}$ for C_b = 1.0
$[b_x]_{min} = 1.78 \times 10^{-3}$ (kip-ft)$^{-1}$

$$\left[b_x\right]_{C_b>1.0} = \frac{\left[b_x\right]_{C_b=1.0}}{C_b}$$
$$= \frac{2.46\times10^{-3}\text{ (kip-ft)}^{-1}}{1.67}$$
$$= 1.47\times10^{-3}\text{ (kip-ft)}^{-1} < \left[b_x\right]_{min}$$
$$= 1.78\times10^{-3}\text{ (kip-ft)}^{-1}$$

Use $[b_x]_{C_b=1.67} = [b_x]_{min}$
$= 1.78 \times 10^{-3}$ (kip-ft)$^{-1}$

$$\left[\frac{M_n}{\Omega}\right]_{C_b=1.67} = \frac{8}{9\left[b_x\right]_{C_b=1.67}}$$
$$= \frac{8}{9\left[1.78\times10^{-3}\text{ (kip-ft)}^{-1}\right]}$$
$$= 499\text{ kip-ft}$$

LRFD Method:

Method I:

From Table 3-2 of the AISC *Steel Construction Manual* (page 3-16):
$\phi_b M_p$ = 750 kip-ft
L_p = 6.78 ft
L_r = 19.6 ft
BF = 22.5 kips

L_p = 6.78 ft < L_b = 16 ft < L_r = 19.6 ft

$$\left[\phi_b M_n\right]_{C_b=1.0} = \phi_b M_p - BF\left(L_b - L_p\right)$$
$$= 750\text{ kip-ft} - \left(22.5\text{ kips}\right)\left(16.0\text{ ft} - 6.78\text{ ft}\right)$$
$$= 543\text{ kip-ft}$$

$$\left[\phi_b M_n\right]_{C_b>1.0} = \left(C_b\right)\left[\phi_b M_n\right]_{C_b=1.0}$$
$$= (1.67)(543\text{ kip-ft})$$
$$= 907\text{ kip-ft} > \phi_b M_p = 750\text{ kip-ft}$$

Therefore, $[\phi_b M_n]_{C_b=1.67} = \phi_b M_p$ = 750 kip-ft

Method II:

From Table 6-1 of the AISC *Steel Construction Manual* (page 6-42):
$b_x = 1.64 \times 10^{-3}$ (kip-ft)$^{-1}$ for C_b = 1.0
$[b_x]_{min} = 1.19 \times 10^{-3}$ (kip-ft)$^{-1}$

$$\left[b_x\right]_{C_b>1.0} = \frac{\left[b_x\right]_{C_b=1.0}}{C_b}$$
$$= \frac{1.64\times10^{-3}\text{ (kip-ft)}^{-1}}{1.67}$$
$$= 0.982\times10^{-3}\text{ (kip-ft)}^{-1} < \left[b_x\right]_{min} = 1.19\times10^{-3}\text{ (kip-ft)}^{-1}$$

Use $[b_x]_{C_b=1.67} = [b_x]_{min}$
$= 1.19 \times 10^{-3}$ (kip-ft)$^{-1}$

$$\left[\phi_b M_n\right]_{C_b=1.67} = \frac{8}{9\left[b_x\right]_{C_b=1.67}}$$
$$= \frac{8}{9\left[1.19\times10^{-3}\text{ (kip-ft)}^{-1}\right]}$$
$$= 747\text{ kip-ft}$$

EXAMPLE 4

Given

Simply supported beam with $L = L_b = 30$ ft, $w_D = 0.30$ kip/ft, $w_L = 0.90$ kip/ft

Find

Select the lightest W14 of A992 steel. Consider bending only.

Solution

Since Table 6-1 of the AISC *Steel Construction Manual* has a more comprehensive list of W14s, we will use the b_x method in this design.

ASD Method:

$w_u = w_D + w_L = 0.30$ kip/ft + 0.90 kip/ft = 1.20 kip/ft

From Table 3-1 of the AISC *Steel Construction Manual* (page 3-10), $C_b = 1.14$.

$$\begin{aligned} M_u &= \frac{w_u L^2}{8} \\ &= \frac{(1.20\text{ kip/ft})(30\text{ ft})^2}{8} \\ &= 135\text{ kip-ft} \end{aligned}$$

Use Equation 5-ASD and replace (M_{nx}/Ω) with M_u to obtain $(b_x)_{req}$

$$\left[(b_x)_{req}\right]_{C_b = 1.14} = \frac{8}{9(135\text{ kip-ft})} = 6.58 \times 10^{-3}\text{ (kip-ft)}^{-1}$$

From Table 6-1 of the AISC *Steel Construction Manual* (page 6-71), try W14×61 with

$[b_x]_{C_b = 1.0} = 6.20 \times 10^{-3}$ (kip-ft)$^{-1}$ < 6.58×10^{-3} (kip-ft)$^{-1}$

This section is adequate for $C_b = 1.0$; therefore it is adequate for $C_b = 1.14$ as well. However, for illustration purposes, we will verify this fact.

$$\begin{aligned} \left[b_x\right]_{C_b = 1.14} &= \frac{\left[b_x\right]_{C_b = 1.0}}{C_b} \\ &= \frac{6.20 \times 10^{-3}\text{ (kip-ft)}^{-1}}{1.14} \\ &= 5.44 \times 10^{-3}\text{ (kip-ft)}^{-1} > \left[b_x\right]_{min} \\ &= 3.49 \times 10^{-3}\text{ (kip-ft)}^{-1} \end{aligned}$$

Since $[b_x]_{C_b = 1.14} = 5.44 \times 10^{-3}$ (kip-ft)$^{-1}$ < $[b_x]_{req}$
$= 6.58 \times 10^{-3}$ (kip-ft)$^{-1}$

W14×61 is adequate.

For lightest, try W14×53 with $b_x = 9.56 \times 10^{-3}$ (kip-ft)$^{-1}$

It can be shown that this section has a larger b_x than $[b_x]_{req} = 6.58 \times 10^{-3}$ (kip-ft)$^{-1}$ after incorporating the impact of C_b. Therefore, W14×53 is not adequate.

Use W14×61, A992 steel

LRFD Method:

$w_u = 1.2w_D + 1.6w_L = 1.2(0.30$ kip/ft$) + 1.6(0.90$ kip/ft$)$
$= 1.80$ kip/ft

From Table 3-1 of the AISC *Steel Construction Manual* (page 3-10), $C_b = 1.14$.

$$\begin{aligned} M_u &= \frac{w_u L^2}{8} \\ &= \frac{(1.80\text{ kip/ft})(30\text{ ft})^2}{8} \\ &= 203\text{ kip-ft} \end{aligned}$$

Use Equation 5-LRFD and replace $\phi_b M_{nx}$ with M_u to obtain $(b_x)_{req}$

$$\begin{aligned} \left[(b_x)_{req.}\right]_{C_b = 1.0} &= \frac{8}{9(203\text{ kip-ft})} \\ &= 4.38 \times 10^{-3}\text{ (kip-ft)}^{-1} \end{aligned}$$

From Table 6-1 of the AISC *Steel Construction Manual* (page 6-71), try W14×61 with

$[b_x]_{C_b = 1.0} = 4.12 \times 10^{-3}$ (kip-ft)$^{-1}$ < 4.38×10^{-3} (kip-ft)$^{-1}$

This section is adequate for $C_b = 1.0$; therefore it is adequate for $C_b = 1.14$ as well. However, for illustration purposes, we will verify this fact.

$$\begin{aligned} \left[b_x\right]_{C_b = 1.14} &= \frac{\left[b_x\right]_{C_b = 1.0}}{C_b} \\ &= \frac{4.12 \times 10^{-3}\text{ (kip-ft)}^{-1}}{1.14} \\ &= 3.61 \times 10^{-3}\text{ (kip-ft)}^{-1} > \left[b_x\right]_{min} \\ &= 2.32 \times 10^{-3}\text{ (kip-ft)}^{-1} \end{aligned}$$

Since $[b_x]_{C_b = 1.14} = 3.61 \times 10^{-3}$ (kip-ft)$^{-1}$ < $[b_x]_{req}$
$= 4.38 \times 10^{-3}$ (kip-ft)$^{-1}$

W14×61 is adequate.

For lightest, try W14×53 with $b_x = 6.36 \times 10^{-3}$ (kip-ft)$^{-1}$

It can be shown that this section has a larger b_x than $[b_x]_{req} = 4.38 \times 10^{-3}$ (kip-ft)$^{-1}$. Therefore, W14×53 is not adequate.

Use W14×61, A992 steel

Note that if $[b_x]_{C_b > 1.0} > [b_x]_{min}$, the beam fully benefits from $C_b > 1.0$. Otherwise, the benefit is partial.

EXAMPLE 5

Given

W18×86 member as shown in Figure 3, A992 steel, braced frame, bending about the x-axis only
P_u = 630 kips
M_{ux} = 210 kip-ft
$(KL)_x$ = 26 ft
$(KL)_y = L_b$ = 13 ft

Find

Determine if this section adequate per AISC *Specification* for the given conditions.

Solution

LRFD Method:

Obtain the following information for a W18×86 from Table 6-1 of the AISC *Steel Construction Manual* (page 6-54):
$[b_x]_{C_b = 1.0} = 1.37 \times 10^{-3}$ (kip-ft)$^{-1}$
$[b_x]_{min} = 1.27 \times 10^{-3}$ (kip-ft)$^{-1}$
$(r_x / r_y) = 2.95$

Determine $(KL)_{y\,eq}$

$$(KL)_{y\,eq} = \frac{(KL)_x}{\left(\dfrac{r_x}{r_y}\right)}$$
$$= \frac{26 \text{ ft}}{2.95}$$
$$= 8.81 \text{ ft} < (KL)_y$$
$$= 13.0 \text{ ft}$$

Use $KL = (KL)_y$ = 13.0 ft

Therefore, $p = 1.14 \times 10^{-3}$ kips^{-1}

Note that in this case, C_b = 1.30 (braced at ends and midspan)

$$[b_x]_{C_b = 1.30} = \frac{[b_x]_{C_b = 1.0}}{1.30}$$
$$= \frac{1.37 \times 10^{-3} \text{ (kip-ft)}^{-1}}{1.30}$$
$$= 1.05 \times 10^{-3} \text{ (kip-ft)}^{-1} < [b_x]_{min}$$
$$= 1.27 \times 10^{-3} \text{ (kip-ft)}^{-1}$$

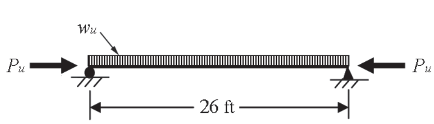

Fig. 3. Beam-column for Example 5.

Therefore, $[b_x]_{C_b = 1.30} = [b_x]_{min} = 1.27 \times 10^{-3}$ (kip-ft)$^{-1}$

$pP_u = (1.14 \times 10^{-3}$ kips^{-1})(630 kips) = 0.718 > 0.200

Use $bP_u + mM_{ux} + nM_{uy} \leq 1.0$

$0.718 + [1.27 \times 10^{-3}$ (kip-ft)$^{-1}$](210 kip-ft) + 0
= 0.718 + 0.267 + 0
= 0.985 < 1.00

W18×86, A992 steel is adequate for the given conditions.

Note that the impact of C_b = 1.3 in this case is not significant. However, the example problem is presented as an illustration of the method.

Reader is encouraged to repeat this problem using the ASD method.

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Current Steel Structures Research

REIDAR BJORHOVDE

Sustainability has become a major world issue over the past few years. Due to the impact of the construction market on the gross domestic product (GDP)—approximately 12 to 13% for the United States—sustainability is becoming a key consideration in all architectural designs. By direct extension, this is now affecting the work of structural engineers in general, although much of the current influence is almost hidden among the many and complex issues of construction. Various rating schemes, such as the Leadership in Energy and Environmental Design (LEED) system in the United States, are used extensively to assess architectural and engineering designs; but, of course, the issue goes much beyond the efforts of the design profession, insofar as structures are concerned.

However, it is a fact that codes and standards will be significantly affected, and structural engineers need to recognize the importance of the subject and take a proactive role in the overall design process. Since steel is the most recycled of all materials, the industry and AISC alike have long recognized the critical nature of the subject and are on record as pursuing sustainability aggressively. Intensive research efforts are now under way in a number of countries, and it is already clear that construction techniques and materials are changing significantly to meet the needs of future societies. There is no question that steel and steel structures occupy a central and advantageous position in all of these undertakings.

A major international research and development effort on the part of the world steel industry is under way in several locales, and one of the projects reported in this paper reflects current European approaches and where the developments may lead. In many ways, the sustainability work is also tied to seismic research efforts, since such studies must take into account efficient construction techniques and economies, and that goes hand-in-hand with sustainability. A seismic study that is examined in this paper focuses on effective composite construction for members and frames, and another study looks at the development of novel and innovative fastening solutions for steel in combination with structures using other materials. Of course, bridges have major effects on local and regional communities, and two studies discussed in the paper examine the improvements that can be achieved by advanced load analyses as well as different structural systems and details.

References are provided throughout the paper, whenever such are available in the public domain. However, much of the work is still in progress, and reports or publications have not yet been prepared for public dissemination.

Reidar Bjorhovde is the Research Editor of the AISC *Engineering Journal*.

SUSTAINABILITY OF STEEL STRUCTURES

Sustainability of Steel Structures: This is a major, long-term project that is being conducted at the Institute for Sustainability and Innovation in Structural Engineering (ISISE) at the University of Coimbra in Coimbra, Portugal, with Professor Luis da Silva as the director.

In addition to the development of a sustainability assessment protocol for a variety of practical construction cases, the project aims at expanding, identifying and quantifying the influence of the following features (Gervásio, 2008):

- The key advantages of steel and steel construction
- Energy efficiency of steel production
- The effects of various structural and non-structural details
- The time needed for high-quality and safe fabrication and construction
- Functional requirements and potential changes over life cycle
- Construction material waste and recyclability
- Durability of steel, the life span of the structure, and the eventual rehabilitation or demolition

Construction provides approximately 7% of world employment and 28% of industry employment. At the same time, it is known that the construction industry consumes nearly 50% of all resources extracted from the earth, and a significant percentage of the total energy consumption and greenhouse gas emissions (GHG) (= CO_2) can be identified as related to construction. Construction and demolition waste account for a large percentage of the total waste, and it is especially high in wealthier nations.

It is recognized that the influence of several of the preceding features has been documented reasonably well, but not always in the context of steel construction. For example, addressing steelmaking by itself, it is essential to note the shift from basic oxygen furnaces (BOF) to electric arc furnaces (EAF) that has taken place in the United States over the past 20 years. Specifically, all American structural shape producers now use EAF and ladle metallurgy technology, along with continuous casting, to give the most efficient steel production in the world. In Europe and other areas of the world this is much less so, to the effect that BOF production is still used for approximately two-thirds of worldwide steel production.

Considering energy consumption and CO_2 emissions for BOF and EAF illustrates in part how far the industry has come. Based on data from the International Iron and Steel Institute (IISI), the energy consumption is reduced by 67% and the CO_2 emissions are reduced by 82% when the change is made from BOF to EAF. Further, another European research project is aiming at the development of steel production with ultra-low CO_2 emissions, with a reduction of 50% compared to the numbers of today.

The efficiency of steel construction is a major advantage, in terms of significantly reduced fabrication and construction time, construction site organization, high-quality workmanship, and reduced construction site waste. But the greatest advantages of steel for sustainability are the facts that

1. Steel is 100% recyclable.
2. EAF-based products are based on steel scrap rather than iron ore and coke, hence reducing the environmental and natural resource impacts of steel construction.
3. Steel has a high strength-to-weight ratio, for high construction efficiency.
4. Steel frames are highly adaptable to changes in functional requirements over the life span of the structure.

The current rating systems for steel structures, including the American-based LEED, all emphasize (1) materials and resources (MR) and (2) innovation and design processes (ID). In these respects, the MR advantages of steel as outlined earlier are very clear. For ID, the ability of steel to adapt to a variety of uses, including changes that are needed during the life cycle of the structure are major advantages. So is the use of cold-formed elements and pre-engineered buildings, as well as composite construction and other systems that make the most efficient use of different materials. And finally, the relative ease with which a steel structure can be taken down and the elements reused for other structures or simply recycled is a plus that does not enter into most considerations at the pre-construction stage.

In essence, therefore, the full sustainability capacity of structures can only be assessed realistically by considering the complete life cycle. As would be expected, the recommendations of the researchers focus on the eminent performance of steel in all elements of the life cycle analyses.

STRUCTURAL BEHAVIOR AND STRENGTH UNDER SEISMIC LOADS

Seismic Design and Analysis of Rectangular Concrete-Filled Steel Tube (RCFT) Members and Frames: This project is conducted at the University of Illinois at Urbana, with Professor Jerome F. Hajjar as the director. It has been funded by the National Science Foundation and the University of Minnesota (Tort and Hajjar, 2004, 2008).

The study aims at developing a performance-based design technique for structures with RCFT columns and steel girders and includes a reliability assessment procedure. The work is very advanced, specifically by incorporating two- and three-dimensional evaluations with seismic and nonseismic loads, as well as nonlinear time-history analyses. The mechanisms of load transfer and composite interaction have been examined in comparison with experimental data from other studies, and the correlation with the finite element formulation was found to be very good. Using the ground motions from a range of earthquake records, the researchers were able to establish realistic assessments of the progression of damage in a series of RCFT structures. This is critical for an eventual, practice-oriented, performance-based design approach.

It will be useful to see how these results compare to some previous studies of damage and damage accumulation in structures (for example, Bažant and Cedolin, 1991; Chi, Deierlein and Ingraffea, 2000). Extensive damage accumulation studies have been conducted at numerous locations, particularly in France by Lemaitre, Pijaudier-Cabot and others.

PERFORMANCE OF NOVEL FASTENING SYSTEMS

Market Opportunities for Innovative Fastening Solutions for Steel Structures: This is a major three-year (2007–2010) project undertaken jointly by three European universities and three European companies. Funding is provided by the Research Fund for Coal and Steel under the auspices of the European Union. The lead effort is taking place at the University of Stuttgart in Stuttgart, Germany, with Professor Ulrike Kuhlmann as the director. The other two universities are the Czech Technical University in Prague, the Czech Republic, and the University of Coimbra in Coimbra, Portugal.

The primary emphasis of the project is to provide fastening techniques and solutions for structures where reinforced concrete has been the traditional choice of material. Economical approaches focus on connections between steel elements and concrete structures, with the fairly large construction tolerances for the latter creating significant problems at the construction sites. Specifically, the connection details that are being developed provide for easy fabrication, quick and accurate erection in the structure, high load capacity, and sufficient ductility. The primary focus is on methods that can be readily adopted by practicing engineers. Two examples are shown in Figures 1 and 2, with steel beams attached to a concrete wall with simple and practical connections.

It is important and interesting to note that the European codes that address steel and concrete structures, EC3 and EC2, respectively, both have to accept the proposed solutions.

PERFORMANCE OF BRIDGE STRUCTURES

Size Effects in the Fatigue Behavior of Tubular Bridge Connections: This study is part of a major, long-term project that has been conducted at the Federal Institute of Technology (EPFL) in Lausanne, Switzerland, with Professors Alain Nussbaumer and Manfred Hirt as the directors.

Bridges such as the one shown in Figure 3 have become very common in Europe. This has happened in spite of the complex tubular connections, difficult welding fabrication, and fatigue considerations in design that require extremely detailed evaluations. But the elegance and simplicity of these solutions and the long-term successful construction and service record have made these structures into signature bridges.

One of the major considerations in the design of tubular bridges is the fatigue resistance and service life of the connections. Early studies found that connections for tubes with a larger wall thickness tended to fail earlier than small thickness members. This is referred to as the size effect, and a variety of solutions were developed over the years. Part of the problem was that very few studies of the size effect had actually been conducted. Even more troublesome is the fact that today's projects have typically been based on geometries that are typical for offshore structure, since bridges utilize entirely different sizes and geometries. This is especially the case for the lower chords of the tubular trusses. Further, many current design recommendations are based on the stress at the weld toe of the failing member, the so-called hot-spot, a number of which are illustrated in Figure 4. The hot-spot approach tends to be very punitive for the thicker wall tubes that are used in bridges. Finally, designs based on static loads produce member sizes that are outside the range of the current design recommendations.

The primary aim of the EPFL research project was to establish the fatigue behavior of K-joints with circular hollow sections (CHS) (Costa Borges, 2008). Specifically, the influences of the various geometric parameters on the fatigue strength had to be determined. To that end, a number of full-scale tests were conducted where crack depths were monitored and measured. An advanced three-dimensional crack propagation model was also developed to establish a broad base for the design criteria that would be forthcoming. The model was based on linear elastic fracture mechanics, using an incremental crack growth strategy.

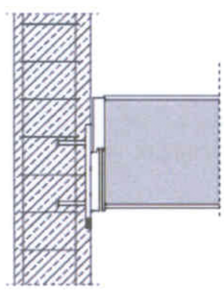

Fig. 1. Steel beam connected to concrete wall with anchor plate and shear studs.

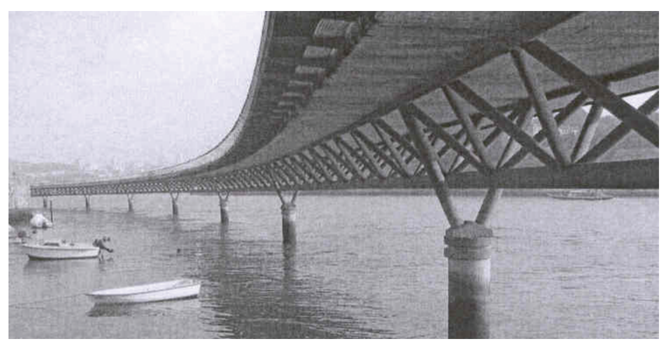

Fig. 3. The Cas das Piedras Bridge in Portugal (photograph courtesy of Alain Nussbaumer).

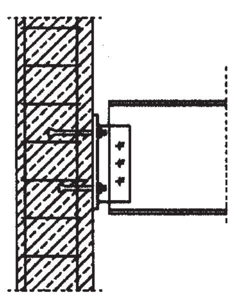

Fig. 2. Steel beam connected to concrete wall with anchor plate and shear tab.

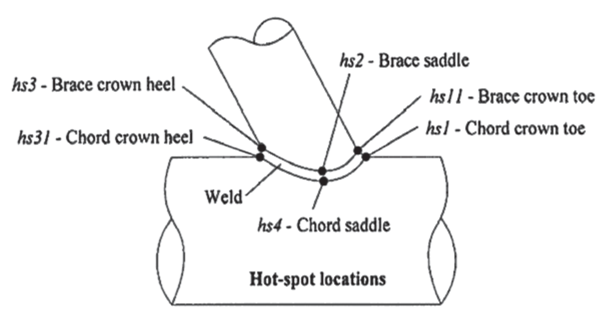

Fig. 4. Definitions of hot-spot locations for a tubular connection (courtesy of Alain Nussbaumer).

A full-blown parametric study was conducted, using typical bridge connection details and three basic load cases. Specifically, the connections had a low chord radius-to-wall thickness ratio. A geometry correction factor that is a function of the relative crack depth for such joints has been introduced, whereby the absolute size of the connection is accounted for. The absolute size of the joint is also known as the "size effect." Finally, the researchers have shown that the size correction factors for the fatigue strength can be expressed as a function of the non-dimensional geometric parameters, the chord wall thickness, and the load cases that have been used.

A Methodology for an Integral Life Cycle Analysis of Bridges in View of Sustainability: This study is currently going on at the Institute for Sustainability and Innovation in Structural Engineering at the University of Coimbra in Coimbra, Portugal. The project director is Professor Luis da Silva.

The study was started relatively recently, following the project that addresses sustainability for building structures, as reported earlier in this paper. The procedures are similar insofar as the steel is concerned; extensive simulation studies will be conducted to assess life cycle considerations and the factors that are unique to bridge structures. These will include risk analyses.

Finally, two case studies will be done, focusing on a composite highway bridge and a bridge with integral abutments.

Load Rating of Curved Composite Steel I-Girder Bridges through Load Testing with Heavy Trucks: This project has been conducted at the University of Minnesota, with financial support provided by the Minnesota Department of Transportation and the Center for Transportation Studies. Professor Jerome F. Hajjar directed the project.

Load rating of bridges is a major and very important effort on the part of all U.S. states, and the procedures for such ratings have been developed by the American Association for State Highway and Transportation Officials (AASHTO, 2003). The ratings are used extensively by transportation officials and the trucking industry. Curved girders are particularly difficult to rate under the current provisions, since these are based on straight-line girder evaluations with a correction factor for the curvature as well as a reduction of the flange yield stress. Improved methods that are based on grillage analyses have been developed, and these are now being applied to curved girders. The purpose of the analyses and the heavy truck testing of the project was to assess the accuracy of the grillage analysis and to develop rating procedure recommendations for these types of bridges (Krzmarzick and Hajjar, 2006).

Extensive parametric evaluations of a range of bridges and models were conducted, finding that the predicted bending stresses were very accurate, whereas warping normal stresses were less so, although still acceptable. The final rating recommendations include how to take composite action into account in the stiffness and stress computations, determining effective widths and modular ratios, and how to incorporate lateral bracing effects. Finally, work is continuing to develop rating procedures that can be used with and without load testing.

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Suggested Readings from Other Publishers

The following abstracts summarize papers published by others on the subject of steel design and construction that may be of interest to *Engineering Journal* readers.

From Volume 86, Number 11, 3 June 2008 of *The Structural Engineer* published by The Institution of Structural Engineers, London:

Refurbishment of St Pancras—Justification of Cast Iron Columns
Ian Brooks, Alan Browne, David Gration and Andrew McNulty

This paper presents the results of an extensive programme of material and full-scale laboratory tests undertaken on existing cast iron columns from St Pancras Railway Station in London. The original station, which was constructed during the 1860s, has been upgraded to form the international terminus for the Channel Tunnel Rail Link. The current use will impose greater vertical loads and horizontal displacements on the cast iron columns than they previously experienced. A preliminary assessment suggested that it would be prudent to undertake a program of tests to determine the material properties and understand the structural behavior under load with more confidence. A total of five columns were made available for full-scale testing to destruction; these were made redundant by the introduction of escalator slots and light wells. In addition, coupons were obtained from columns for material tests. The coupon tests provided sufficient information to determine a reliable materials model suitable for a nonlinear finite element analysis of the columns. The full-scale tests confirmed that the presence of cast-in features affects the overall structural behavior of the column. The results from the material and full-scale tests are compared. It is concluded that there is consistency between the material and full-scale tests. Back analysis of the full-scale tests using the material model developed from the material tests confirmed that the model is reliable for analysis in the permissible stress domain and gives reasonable assessments of the failure mode and load when lack-of-fit conditions can be properly assessed.

From Volume 134, Issue 7 of the *Journal of Structural Engineering* published by the American Society of Civil Engineers:

Macromodel-Based Simulation of Progressive Collapse: Steel Frame Structures
Kapil Khandelwal, Sherif El-Tawil, Sashi K. Kunnath and H.S. Lew

Computationally efficient macromodels are developed for investigating the progressive collapse resistance of seismically designed steel moment frame buildings. The developed models are calibrated using detailed finite-element models of beam-column subassemblages and account for the most important physical phenomena associated with progressive collapse. The models are utilized to compare the collapse resistance of two-dimensional, 10-story steel moment frames designed for moderate and high seismic risk according to current design specifications and practices. The simulation results show that the frame designed for high seismic risk has somewhat better resistance to progressive collapse than the system designed for moderate seismic risk. The better performance is attributed to layout and system strength rather than the influence of improved ductile detailing. The alternate path method is shown to be useful for judging the ability of a system to absorb the loss of a critical member. However, it is pointed out that the method does not provide information about the reserve capacity of the system and so its results should be carefully evaluated.

Physical Theory Hysteretic Model for Steel Braces
Murat Dicleli and Ertugrul Emre Calik

This paper presents a simple yet efficient physical theory model that can be used to simulate the inelastic cyclic axial force—axial deformation and axial force—transverse deformation relationships of steel braces. The model consists of a brace idealized as a pin-ended member with a plastic hinge located at its midlength. Input parameters of the model are based only on the properties of the brace. The model combines analytical formulations based on the nonlinear behavior of the brace with some semiempirical normalized formulas developed on the basis of a study of available experimental data. The model realistically accounts for growth effect and degradation of buckling capacity due to Baushinger effects and residual kink present within the brace and it is broadly applicable to steel braces with various section types and slenderness ratios. It is observed that the analytically obtained axial force versus axial displacement as well as axial force versus transverse displacement hysteresis loops compare reasonably well with the experimental ones.

Gusset Plate Connections to Circular Hollow Section Braces under Inelastic Cyclic Loading
Gilberto Martinez-Saucedo, Jeffrey A. Packer and Constantin Christopoulos

Braces are commonly used to provide lateral stiffness and strength to steel-framed buildings subjected to wind or earthquake loading. Of the structural sections that can be employed as brace members, hollow structural sections represent a very good solution due to their excellent structural properties in compression. Nevertheless, their use has been hitherto compromised for seismic applications mainly due to a lack of simplified connection details that avoid brittle failures. At present, slotted hollow structural section connections are popular in seismic zones, but the hollow section is typically reinforced with steel cover plates to increase the net area at the critical location to avoid premature fracture under tension loading cycles. This reinforcing practice can likely be avoided, for circular hollow sections, if both the tube and the plate are slotted in such a manner that the weld terminates at the tube gross cross section. The potential of this innovative detail is demonstrated by means of three large-scale specimen tests under pseudodynamic loading.

From Volume 134, Issue 8 of the *Journal of Structural Engineering* published by the American Society of Civil Engineers:

Cyclic Behavior of Steel Wide-Flange Columns Subjected to Large Drift
James D. Newell and Chia-Ming Uang

During an earthquake, steel braced-frame columns can be subjected to high axial forces combined with inelastic rotation demand resulting from story drift. Cyclic testing of nine full-scale W14 column specimens representing a practical range of flange and web width-to-thickness ratios were subjected to different levels of axial force demand (35, 55 and 75% of nominal axial yield strength) combined with up to 10% story drift. No global buckling was observed in all test specimens. Flange local buckling was the dominant buckling mode. Specimens achieved interstory drift capacities of 0.07 to 0.09 rad. These large deformation capacities were, in part, achieved due to the delay in flange local buckling resulting from the stabilizing effect provided by the stocky column web of the W14 section specimens. Testing indicated that the ASCE 41 predicted plastic rotation capacities are very conservative. The ASCE 41 criteria do not specify plastic rotation capacity at axial load ratios greater than 0.5; however, tested specimens exhibited significant plastic rotation capacities of approximately 15 to 25 times the member yield rotation.

Low-Rise Steel Structures under Directional Winds: Mean Recurrence Interval of Failure
D. Duthinh, J.A. Main, A.P. Wright and E. Simiu

The Commentary to the American Society of Civil Engineers (ASCE) Standard 7-05 states that the nominal mean recurrence interval (MRI) of the wind speed inducing the design strength is about 500 years if the specified load factor is 1.5, as in early versions of ASCE 7, and "somewhat higher than 500 years" if the specified load factor is 1.6, as in ASCE 7-05. However, the Commentary also states, "it is not likely that the 500-year event is the actual speed at which engineered structures are expected to fail, due to resistance factors in materials, due to conservative design procedures that do not always analyze all load capacity, and due to a lack of a precise definition of failure." In this paper, we propose a working definition of failure for steel structures using nonlinear finite-element analysis, and we present a methodology for estimating the MRI of failure under wind loads that accounts in a detailed and rigorous manner for nonlinear structural behavior and for the directionality of the wind speeds and the aerodynamic effects. The methodology uses databases of wind tunnel pressure (database-assisted design), nonlinear finite-element analysis, and directional wind speeds from the National Institute of Standards and Technology (NIST) hurricane database augmented by statistical techniques. As a case study to illustrate the methodology, we consider a single frame of a steel industrial building. Under the assumption that uncertainties with respect to the parameters that determine the wind loading and to the material behavior are negligible, the minimum MRI of failure for the steel frame being investigated was found to be of the order of 100,000 years, which corresponds to a probability of 1/2,000 that the frame will fail during a 50-year lifetime.

Volume 134, Issue 9 of the *Journal of Structural Engineering* contains a Special Section on Behavior and Design of Steel I-Section Members. Also from Volume 134, Issue 9 of the *Journal of Structural Engineering* published by the American Society of Civil Engineers:

Ductility and Energy Dissipation Capacity of Shear-Dominated Steel Plate Walls
In-Rak Choi and Hong-Gun Park

An experimental study was performed to investigate the potential maximum ductility and energy dissipation capacity of steel plate walls with thin infill plates. Three specimens of a three-story steel plate wall were tested. A concentrically braced frame (CBF) and a moment-resisting frame (MRF) were also tested for comparison. To maximize the ductility and energy dissipation capacity of the steel plate walls, ductile details were used. The test parameters were the aspect ratio of the infill plate and the shear strength of the column. The steel plate walls exhibited much better ductility and energy dissipation capacity as compared to the CBF and MRF. This result indicates that unlike conventional reinforced concrete walls and CBFs, shear-dominated steel plate walls with thin infill plates possess excellent ductility capacity as well as high strength and stiffness. Based on the results of previous studies and the present study, the variations in the ductility and the energy dissipation capacity of the steel plate walls according to the design parameters were investigated.

Direct Analysis and Design of Steel Frames Accounting for Partially Restrained Column Base Conditions
Murat Eröz, Donald W. White and Reginald DesRoches

The 2005 AISC specification provides a new method for stability design of steel frame structures termed the direct analysis method (DM). This paper addresses the consideration of partial base fixity using the DM. A refined model of the column base moment-rotation response is developed using an adaptation of the component method (CM) of Eurocode 3 plus a representation of the foundation stiffness. The paper also summarizes and applies an extension of the DM for frames containing web-tapered members. An example clear-span gable frame is checked using several models of its nominally simple four-bolt base detail: ideally pinned, elastic based on $G = 10$ from the AISC sidesway-uninhibited alignment chart, and elastic-perfectly plastic using the CM. It is demonstrated that the member strength unity checks and the frame deflections obtained by modeling of the column bases as elastic based on $G = 10$ are accurate to slightly optimistic compared to the refined base model. It is found that the contribution of the significant initial stiffness of typical bases to the overall frame response is limited by the connection strength.

Validation of Cyclic Void Growth Model for Fracture Initiation in Blunt Notch and Dogbone Steel Specimens
A.M. Kanvinde and G.G. Deierlein

Tests and finite-element analyses of blunt notch and dogbone specimens are presented to demonstrate the application and validation of the cyclic void growth model (CVGM) to evaluate the initiation of ductile fracture under cyclic loading in steel structures. Modeling concepts and procedures for characterizing the CVGM material parameters using notched bar tests are described. Accuracy of the model is validated through a series of cyclic tests of 14 blunt notch compact fracture specimens and four dogbone specimens. Four types of moderate to high strength structural steels are investigated (two types of A572-Grade 50, A514-Grade 110, HPS70W). The test specimens reflect stress and strain conditions encountered in structural steel components and provide sufficiently strong stress and strain gradients to validate the characteristic length assumptions in the model. Detailed finite-element analyses that employ the CVGM criterion are shown to predict fracture with good accuracy across the specimen geometries, steel types, and loading histories.

From Volume 134, Issue 10 of the *Journal of Structural Engineering* published by the American Society of Civil Engineers:

Pushover Response of a Braced Frame with Suspended Zipper Struts
Chuang-Sheng Yang, Roberto T. Leon and Reginald DesRoches

This paper presents the results from an experimental pushover test on a one-third-scale model of a special inverted-V-braced steel frame with zipper struts. Zipper elements are vertical elements added at the intersections of the braces above the first floor and designed to carry upward the unbalanced loads resulting from buckling of the braces. As far as the writers know, this is the first test on such a configuration that has been suggested as an alternate to conventional braced frames in the American Institute of Steel Construction seismic specification for many years. The model was pushed to a target roof drift ratio of +3.58%, which was achieved without strength degradation and followed a trilinear backbone curve. The load was then reversed until the bottom story brace in tension fractured at a drift of −0.78%. After this fracture, the frame still carried about 37% of the maximum base shear. The zipper elements demonstrated their ability to activate buckling in all stories except the top one, redistributing the loads in the structure and minimizing strength losses. Two-dimensional and one three-dimensional frame models were analyzed and found to reproduce satisfactorily the experimental results up to the beginning of tearing in the tension brace.

ERRATA

Reduced Beam Section Spring Constants

Paper by BART MORTENSEN, JANICE J. CHAMBERS and TONY C. BARTLEY
(2nd Quarter, 2008)

The last sentence under the heading, "RELATIONSHIP BETWEEN THE SPRING CONSTANT AND MINIMUM PLASTIC SECTION MODULUS OF RBS BEAMS" should read, "Note that '% flange reduction' is equal to the total flange reduction, $2c/b_f \times 100$."

Design Aid for Triangular Bracket Plates Using AISC Specifications

Paper by SHILAK SHAKYA and SRIRAMULU VINNAKOTA
(3rd Quarter, 2008)

On page 189, the heading for Table 1 should read, "Values of t^*/b for a/b equal to."

On page 189, the last sentence in the paragraph following Equation 12 should read, "The location of this boundary denoted by z_1 (measured from the inside 90° corner) can be determined from Equations 11 and 12 by setting λ_{cz} equal to 1.5 and is given here:"

On page 189, Equation 15 should be replaced with

$$\frac{t^*}{b} = \frac{4}{\sqrt{3}} \frac{K}{\pi} \sqrt{\frac{F_y}{E}} \sqrt{1+\left(\frac{a}{b}\right)^2}$$

GUIDE FOR AUTHORS

SCOPE: The ENGINEERING JOURNAL is dedicated to the improvement and advancement of steel construction. Its pages are open to all who wish to report on new developments or techniques in steel design, research, the design and/or construction of new projects, steel fabrication methods, or new products of significance to the uses of steel in construction. Only original papers should be submitted.

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Doe, J.H. (1992), "Structural Steel," *Engineering Journal*, AISC, Vol. 100, No. 1, 1st Quarter, pp. 2–10.

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