Fast Check for Laterally Supported Beam Capacity

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The purpose of this article is to arrive at a "rule of the thumb" method to determine the total uniform load capacity of a laterally supported simple beam, with the only known data being (a) steel beam designation and (b) span. No other data or references are required. It was found through analysis that the section properties of any rolled steel beam section are "built into" the beam designation, i.e. depth and weight.

ANALYSIS

Derivation of section modulus and load factor

A close approximation of the moment of inertia (I) of a wide-flange beam can be arrived at by considering the combined total moment of inertia of a rectangular section and the negative moment of inertia of the two voids on both sides of the web (see Fig. 1).

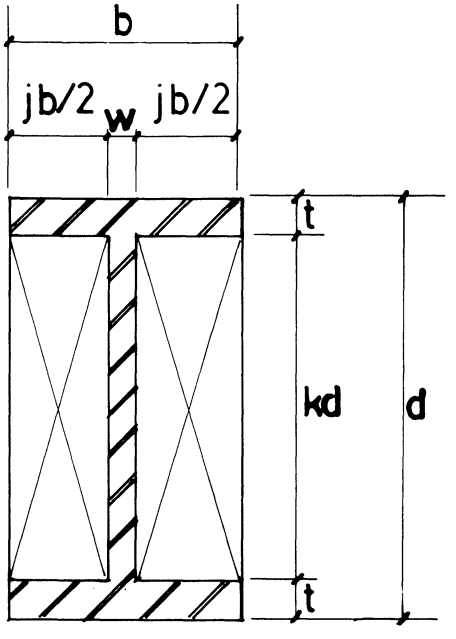

Figure 1

$$I = \frac{bd^3}{12} - \frac{jb \times (kd)^3}{12} = \frac{bd^3}{12}(1-jk^3)$$

$$S = \frac{2I}{d} = \frac{bd^2}{6} \times (1-jk^3)$$

$$= bd^2 \times (m)$$

$$\text{where } m = \frac{1-jk^3}{6}$$

$$bd^2 = \frac{S}{m} \tag{1}$$

$$\text{Beam weight (lbs./ft)} = \text{area} \times 3.4 \text{ lbs./ft/in.}^2$$
$$= [bd - (jb) \times (kd)] \times 3.4$$

$$Wt = bd \times (1-jk) \times (3.4) = bd \times (n)$$
$$\text{where } n = 3.4(1-jk)$$

$$\text{Beam depth} \times \text{weight} = d \times Wt = bd^2 \times (n)$$

$$bd^2 = \frac{d \times Wt}{n} \tag{2}$$

Equate Eq. 1 and Eq. 2

$$\frac{S}{m} = \frac{d \times Wt}{n}$$

$$S = p \times d \times Wt$$

where

$$p = \frac{m}{n} = \frac{1-jk^3}{6} \times \frac{1}{3.4(1-jk)} \tag{3}$$
$$jb = b - w$$
$$j = \frac{b-w}{b} = \left(1 - \frac{w}{b}\right)$$
$$kd = d - 2t$$
$$k = \frac{d-2t}{d} = \left(1 - \frac{2t}{d}\right)$$

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$F_b = \frac{M}{S}$ = 24 ksi for A36 steel with continuous lateral support and

$$M = \frac{WL}{8} \times 12 = 1.5\ WL$$

$$24 = \frac{1.5\ WL}{p\ (d \times Wt)}$$

$$L = 16p\ \frac{(d \times Wt)}{W}$$

Let q = (16p) = load factor

$$W = \frac{q \times d \times Wt}{L} \qquad (4)$$

Note that when L = qd, the beam total load capacity W (kips) is identical to the beam weight in lbs. per ft. Refer to Table 1 for load factor (q) values for various sections.

By examining values of (q) in Table 1 it can be seen that a 100% accurate and universal rule of thumb value does not exist.

Therefore, it was concluded by this writer that an appropriate and simple value of q to use would be 1.5. The choice of a factor of 1.5 was based on the following considerations:

(a) Simple-to-use factor where mental calculations can easily be made
(b) Slightly conservative factors for most beams were chosen (% deviations indicated in Table 1 were kept on the positive side for most beams).

CONCLUSIONS

The following "rules of thumb" can be used to check or estimate the design load values of steel beams:

(a) Section modulus of any wide flange beam ($in.^3$)

$$= p \times d \times Wt = \frac{q}{16} \times d \times Wt$$
$$= 0.094 \times \text{depth} \times Wt$$

(b) For any span L in feet, total load capacity,

$$W\ (\text{kips}) = \frac{1.5 \times d \times Wt}{L}$$

(c) If the span L (in feet) = (1.5) × d, total load capacity W (in kips) = beam weight,Wt. (in lbs./ft)
(d) Estimated uniform load constant (W_{cc}) in kip/ft., as used in AISC 8th Edition (W_c), is
$W_{cc} = W \times L = (1.5) \times d \times Wt$

VARIATION IN BASIC ASSUMPTIONS

These factors are derived for A36 steel, for simple spans, continuous lateral supports, W shapes and for uniform loading. To account for variations of the above conditions simple conversion factors can be derived, e.g.:

(1) For point loads, use total equivalent uniform load in AISC Manual, in lieu of total uniform load.
(2) For F_y = 50 ksi, use a revised factor q = 1.5 × 50/36 = 2.1. Therefore, use of a load factor of 2.1 in lieu of 1.5.
(3) For M or S shapes, use a load factor q of 1.4 in lieu of 1.5 (see Table 1).

Limitation of this Method

(1) This method is to be used as an approximate check only and should not substitute for detailed design or rolled beams. This is especially true of those engineers who did not develop enough experience to appreciate other factors affecting beam design, such as depth limitations, shear consideration, lack of compression flange lateral support, etc.
(2) This method does not apply to composite or built up sections.

Some Useful Applications for this Method

(1) Engineers can have a "feel" for the load-carrying capacity of any given beam without reference to any tables or any other data.
(2) Supervising engineers can visually check other junior engineers' work without complicated calculations or the use of references. This also applies to building officials checking other engineers' work.
(3) A close approximation of beam carrying capacity can be arrived at in the field as follows:
  (a) measure web and flange dimensions
  (b) calculate approximate area ($in.^2$)
  (c) multiply area × 3.4 = Wt (lbs./ft)
  (d) using total depth (in.), Wt and q factor, method can be used to estimate load-carrying capacity of erected or existing beams.

Note: Results are more accurate if actual depth is used. Nominal depth is used in Table 1 for simplicity.

Remarks: The following are some remarks and observations regarding the load factor q in Table 1:

1. Average q for the entire W, M and S series = 1.58
   Average q for the W series = 1.61
   Average q for the M series = 1.50
   Average q for the S series = 1.45
   Average q for the W36 series = 1.54
   Average q for the W33 series = 1.55
   Average q for the W30 series = 1.55
   Average q for the W27 series = 1.57
   Average q for the W24 series = 1.56
   Average q for the W21 series = 1.56
   Average q for the W18 series = 1.59
   Average q for the W16 series = 1.61
   Average q for the W14 series = 1.69
   Average q for the W12 series = 1.66

Average q for the W10 series = 1.65
Average q for the W8 series = 1.66
Average q for the W5 series = 1.70
Average q for the W4 series = 1.61

2. More accurate results can be arrived at if average q values of individual beam depth series indicated above are used in lieu of the general rule of thumb value of q = 1.5.
3. For a specific beam depth, the use of q = 1.5 yields more conservative results for heavier beams and less conservative results for lighter beams of the same depth.

NOMENCLATURE

b = beam flange width (in.)
d = beam depth (in.)
F_b = allowable bending stress (0.66 F_y = 24 ksi for compact A36 steel sections)
I = moment of inertia (in.^{4})
$j = \frac{b-w}{b}$
$k = \frac{d-2t}{d}$
L = simple span (ft)
$m = (1-jk^3)/6$
M = simple span, uniform load bending moment (kip in.)
$n = 3.4\,(1-jk)$
$p = \frac{m}{n}$
q = 16 × p = load factor
S = section modulus (in.^{3})
t = flange thickness (in.)
w = web thickness (in.)
W = beam total uniform total capacity (kips) for simple span
W_c = W × L (kip-ft) = uniform load constant from AISC tables
W_{cc} = q × d × Wt (kip-ft) = uniform load constant as calculated by the "rule of thumb" formula (q = 1.5 in Table A)
Wt = beam weight (lbs. per ft)

Table 1

% Deviation = $\frac{(w_c - w_{cc})}{w_c} \times 100$ using rule of thumb (negative indicates unconservative estimate)

q = load factor
W_c = WL, taken from AISC tables
W_{cc} = estimated W_c = q × d × Wt (using q = 1.5, d = nominal depth of beam in inches, Wt = weight of beam in lbs./ft.)

Beam	q	W_c	W_{cc}	% Deviation
W36x300	1.60	17800	16200	+ 9.0
W36x280	1.61	16500	15120	+ 8.4
W36x260	1.61	15200	14040	+ 7.6
W36x245	1.62	14300	13230	+ 7.5
W36x230	1.62	13400	12420	+ 7.3
	(1.61) average q for this grouping			
W36x210	1.49	11500	11340	+ 1.4
W36x194	1.50	10600	10476	+ 1.2
W36x182	1.50	9970	9828	+ 1.4
W36x170	1.50	9280	9180	+ 1.1
W36x160	1.50	8670	8640	+ 0.3
W36x150	1.49	8060	8100	− 0.5
W36x135	1.45	7020	7290	− 3.8
	(1.49) average q for this grouping			
	(1.54) average q for 36-in. series			
W33x241	1.61	13300	11930	+10.3
W33x221	1.61	12100	10940	+ 9.6
W33x201	1.62	10900	9950	+ 8.7
	(1.61) average q for this grouping			
W33x152	1.52	7790	7524	+ 3.4
W33x141	1.52	7170	6980	+ 2.7
W33x130	1.50	6500	6435	+ 1.0
W33x118	1.48	5740	5841	− 1.8
	(1.51) average q for this grouping			
	(1.55) average q for 33-in. series			

Beam	q	W_c	W_{cc}	% Deviation
W30x211	1.62	10600	9495	+10.4
W30x191	1.63	9570	8595	+10.2
W30x173	1.64	8620	7785	+ 9.7
	(1.63) average q for this grouping			
W30x132	1.52	6080	5940	+ 2.3
W30x124	1.51	5680	5580	+ 1.8
W30x116	1.50	5260	5220	+ 0.8
W30x108	1.48	4780	4860	− 1.7
W30x99	1.46	4300	4455	− 3.6
	(1.49) average q for this grouping			
	(1.55) average q for 30-in. series			
W27x178	1.62	8030	7209	+10.2
W27x161	1.64	7280	6521	+10.4
W27x146	1.64	6580	5913	+10.1
	(1.63) average q for this grouping			
W27x114	1.54	4780	4617	+ 3.4
W27x102	1.54	4270	4131	+ 3.3
W27x94	1.53	3890	3807	+ 2.1
W27x84	1.51	3410	3402	+ 0.2
	(1.53) average q for this grouping			
	(1.57) average q for 27-in. series			
W24x162	1.63	6620	5832	+11.9
W24x146	1.64	5940	5256	+11.5
W24x131	1.64	5260	4716	+10.3
W24x117	1.64	4660	4212	+ 9.6
W24x104	1.65	4130	3744	+ 9.3
	(1.64) average q for this grouping			
W24x94	1.55	3550	3384	+ 4.7
W24x84	1.55	3140	3024	+ 3.7
W24x76	1.54	2820	2736	+ 3.0
W24x68	1.52	2460	2448	+ 0.5
	(1.54) average q for this grouping			
W24x62	1.41	2100	2232	− 6.3
W24x55	1.40	1820	1980	− 8.8
	(1.41) average q for this grouping			
	(1.56) average q for 24-in. series			
W21x147	1.62	5260	4631	+12.0
W21x132	1.64	4720	4158	+11.9
W21x122	1.65	4370	3843	+12.1
W21x111	1.66	3980	3497	+12.1
W21x101	1.68	3630	3182	+12.4
	(1.65) average q for this grouping			
W21x93	1.52	3070	2930	; 4.6
W21x83	1.54	2740	2615	+ 4.6
W21x73	1.55	2420	2300	+ 5.0
W21x68	1.55	2240	2142	+ 4.4
W21x62	1.55	2030	1953	+ 3.8
	(1.54) average q for this grouping			
W21x57	1.47	1780	1796	− 0.9
W21x50	1.44	1510	1575	− 4.3
W21x44	1.42	1310	1386	− 5.8
	(1.44) average q for this grouping			
	(1.56) average q for 21-in. series			
W18x119	1.63	3700	3213	+13.2
W18x106	1.65	3260	2862	+12.2
W18x97	1.67	3010	2619	+13.0
W18x86	1.68	2660	2322	+12.7

Table 1 *(continued)*

Beam	q	W_c	W_{cc}	% Deviation
W18x76	1.69	2340	2052	+12.3
	(1.66) average q for this grouping			
W18x71	1.55	2030	1917	+ 5.6
W18x65	1.56	1870	1755	+ 6.1
W18x60	1.58	1730	1620	+ 6.4
W18x55	1.57	1570	1485	+ 5.4
W18x50	1.58	1420	1350	+ 4.9
	(1.57) average q for this grouping			
W18x46	1.51	1260	1242	+ 1.4
W18x40	1.52	1090	1080	+ 0.9
W18x35	1.48	922	945	− 2.5
	(1.50) average q for this grouping			
	(1.59) average q for 18-in. series			
W16x100	1.65	2800	2400	+14.3
W16x89	1.67	2480	2136	+13.9
W16x77	1.69	2140	1848	+13.6
W16x67	1.71	1870	1608	+14.0
	(1.68) average q for this grouping			
W16x57	1.57	1480	1368	+ 7.6
W16x50	1.59	1300	1200	+ 7.7
W16x45	1.60	1160	1080	+ 6.9
W16x40	1.61	1040	960	+ 7.7
W16x36	1.58	904	864	+ 4.4
	(1.59) average q for this grouping			
W16x31	1.52	755	744	+ 1.5
W16x26	1.49	614	624	− 1.6
	(1.51) average q for this grouping			
	(1.61) average q for 16-in. series			
W14x132	1.73	3340	2772	+17.0
W14x120	1.75	3040	2520	+17.1
W14x109	1.77	2770	2289	+17.4
W14x99	1.79	2510	2079	+17.2
W14x90	1.81	2290	1890	+17.5
	(1.77) average q for this grouping			
W14x82	1.68	1970	1722	+12.6
W14x74	1.71	1790	1554	+13.2
W14x68	1.72	1650	1428	+13.5
W14x61	1.74	1480	1281	+13.4
	(1.71) average q for this grouping			
W14x53	1.68	1240	1113	+10.2
W14x48	1.69	1120	1008	+10.0
W14x43	1.70	1000	903	+ 9.7
	(1.69) averge q for this grouping			
W14x38	1.63	874	798	+ 8.7
W14x34	1.63	778	714	+ 8.2
W14x30	1.61	672	630	+ 6.3
	(1.62) average q for this grouping			
W14x26	1.54	565	546	+ 3.4
W14x22	1.52	464	462	+ 0.4
	(1.53) average q for this grouping			
	(1.69) average q for 14-in. series			
W12x87	1.74	1890	1566	+17.1
W12x79	1.75	1710	1422	+16.8
W12x72	1.77	1560	1296	+16.9
W12x65	1.79	1410	1170	+17.0
	(1.76) average q for this grouping			

Beam	q	W_c	W_{cc}	% Deviation
W12x58	1.77	1250	1044	+16.5
W12x53	1.77	1130	954	+15.6
	(1.77) average q for this grouping			
W12x50	1.70	1040	900	+13.5
W12x45	1.71	930	810	+12.9
W12x40	1.73	830	720	+13.3
	(1.71) average q for this grouping			
W12x35	1.66	730	630	+13.7
W12x30	1.67	618	540	+12.6
W12x26	1.68	534	468	+12.4
	(1.67) average q for this grouping			
W12x22	1.49	406	396	+ 2.5
W12x19	1.47	341	342	− 0.3
W12x16	1.42	274	288	− 5.1
W12x14	1.40	238	252	− 5.9
	(1.45) average q for this grouping			
	(1.66) average q for 12-in. series			
W10x112	1.59	2020	1680	+16.8
W10x100	1.62	1790	1500	+16.2
W10x88	1.65	1580	1320	+16.5
W10x77	1.69	1370	1155	+15.7
W10x68	1.72	1210	1020	+15.7
W10x60	1.74	1070	900	+15.9
W10x54	1.77	960	810	+15.6
W10x49	1.78	874	735	+15.9
	(1.70) average q for this grouping			
W10x45	1.73	786	675	+14.1
W10x39	1.74	674	585	+13.2
W10x33	1.74	560	495	+11.6
	(1.74) average q for this grouping			
W10x30	1.65	518	450	+13.1
W10x26	1.67	446	390	+12.6
W10x22	1.65	371	330	+11.1
	(1.66) average q for this grouping			
W10x19	1.53	301	285	+ 5.3
W10x17	1.50	259	255	+ 1.5
W10x15	1.46	227	225	+ 0.9
W10x12	1.46	174	180	− 3.4
	(1.49) average q for this grouping			
	(1.65) average q for 10-in. series			
W8x67	1.61	966	804	+16.8
W8x58	1.64	832	696	+16.3
W8x48	1.70	693	576	+16.9
W8x40	1.72	568	480	+15.5
W8x35	1.76	499	420	+15.8
W8x31	1.77	440	372	+15.5
	(1.70) average q for this grouping			
W8x28	1.72	389	336	+13.6
W8x24	1.75	334	288	+13.8
	(1.74) average q for this grouping			
W8x21	1.67	291	252	+13.4
W8x18	1.67	243	216	+11.1
	(1.67) average q for this grouping			
W8x15	1.54	189	180	+ 4.8
W8x13	1.51	159	156	+ 1.9
W8x10	1.56	125	120	+ 4.0
	(1.54) average q for this grouping			
	(1.66) average q for 8-in. series			

Table 1 *(continued)*

Beam	q	W_c	W_{cc}	% Deviation
W6x25	1.68	267	225	+15.7
W6x20	1.73	214	180	+15.9
W6x15	1.72	152	135	+11.2
	(1.71) average q for this grouping			
W6x16	1.62	163	144	+11.7
W6x12	1.60	117	108	+ 7.7
W6x9	1.65	89	81	+ 9.0
	(1.62) average q for this grouping			
	(1.67) average q for 6-in. series			
W5x19	1.68	163	143	+12.6
W5x16	1.71	136	120	+11.8
	(1.70) average q for this grouping			
	(1.70) average q for 5-in. series			
W4x13	1.61	87	78	+10.3
	(1.61) average q for this series			
	(1.61) average q for 4-in. series			
M14x18	1.38	338	378	−11.8
M12x11.8	1.35	192	212	−10.6
M10x9	1.37	124	135	− 8.9
M8x6.5	1.41	74	78	− 5.4
M6x20	1.74	208	180	+13.5
M6x4.4	1.45	38	40	− 4.2
M5x18.9	1.64	154	142	+ 8.0
M4x13	1.63	84	78	+ 7.1
	(1.50) average q for this grouping			
S24x121	1.39	4130	4356	− 5.5
S24x106	1.48	3840	3816	+ 0.6
S24x100	1.33	3180	3600	−13.2
S24x90	1.39	2990	3240	− 8.4
S24x80	1.46	2800	2880	− 2.9
	(1.41) average q for this grouping			
S20x96	1.36	2640	2880	− 9.1
S20x86	1.42	2480	2580	− 4.0
S20x75	1.36	2050	2250	− 9.8
S20x66	1.44	1900	1980	− 4.2
	(1.40) average q for this grouping			
S18x70	1.31	1650	1890	−14.5
S18x54.7	1.45	1430	1477	− 3.3
	(1.38) average q for this grouping			
S15x50	1.38	1040	1125	− 8.2
S15x42.5	1.48	954	956	− 0.2
	(1.43) average q for this grouping			
S12x50	1.36	813	900	−10.7
S12x40.8	1.49	726	734	− 1.2
	(1.43) average q for this grouping			
S12x35	1.46	611	630	− 3.1
S12x31.8	1.53	582	572	+ 1.6
	(1.50) average q for this grouping			
S10x35	1.35	470	525	−11.7
S10x25.4	1.56	395	381	+ 3.5
	(1.46) average q for this grouping			
S8x23	1.41	259	276	− 6.6
S8x18.4	1.57	230	221	+ 4.0
	(1.49) average q for this grouping			

Beam	q	W_c	W_{cc}	% Deviation
S7x20	1.39	194	210	− 8.2
S7x15.3	1.58	168	161	+ 4.4
	(1.49) average q for this grouping			
S6x17.25	1.37	140	155	−10.9
S6x12.5	1.58	118	113	+ 4.7
	(1.48) average q for this grouping			
S5x14.75	1.33	97	111	−14.0
S5x10	1.59	79	75	+ 5.1
	(1.46) average q for this grouping			
S4x9.5	1.44	54	57	− 5.6
S4x7.7	1.59	49	46	+ 5.7
	(1.52) average q for this grouping			
S3x7.5	1.40	31	34	− 8.9
S3x5.7	1.55	27	26	+ 5.0
	(1.48) average q for this grouping			