Appendix D

Steel Properties

Steel is a high-strength material made of a combination of iron (with a small percentage [usually less than 1 percent] of carbon) and trace percentages of some other elements. Steel has been made for thousands of years, but an economical process for mass production was not developed until the 1800s. Steel's high strength and relatively low weight makes it extremely desirable as a construction material.

ALL-PURPOSE STEEL

D-1. Different grades of steel are available for constructing bridges and buildings. Each has advantages and disadvantages when compared to the type of construction desired. A36 steel is an all-purpose carbon-grade steel. It is widely used in building and bridge construction.

HIGH-STRENGTH, LOW-ALLOY STEEL

D-2. High-strength steels may be used where lighter, stronger members are required. High-strength steels are necessary as a member becomes smaller because of instability, local buckling, deflection, and other similar failures. High-strength steel is frequently used in tension members, in beams of continuous and composite construction where deflection is minimized, and in columns having low slenderness ratios. The following steels are in this category:

- **ASTM A529 structural carbon steel.** These steels have a yield strength of 42 ksi. Their other properties are similar to A36 steel.
- **ASTM A441 and A572 structural steels.** These steels provide yield strengths from 40 to 65 ksi. Some types may be more brittle than A36 steel.
- **ASTM A242 and A588 atmospheric-corrosion-resistant steels.** These steels are suitable for use in a bare (unpainted) condition. Exposure to normal atmospheric conditions cause a tightly adherent oxide (rust) to form on the surface that protects the steel from further, more destructive oxidation. The reduction of maintenance expense for these steels may offset their higher initial cost during peacetime construction.

QUENCH- AND TEMPERED-ALLOY STEEL

D-3. ASTM A514 steel is an example of this type of steel. It provides yield strengths in excess of 90 ksi. As with all high-strength steels, cost is a crucial factor in deciding whether to use them.

STEEL STRENGTHS

D-4. If the type of steel is unknown, use A36 specifications with a minimum yield strength of 36 ksi. If in doubt about the strength of the steel, always use the weakest-strength steel for classification and design purposes.

STRUCTURAL SHAPES

D-5. *Table D-1* lists the standard steel-plate thicknesses, and *Tables D-2* through *D-10, pages D-3* through *D-11*, list the section properties for the most common structural shapes available in the US. I-beams come in two different shapes—wide-flange (W-shaped) and American-standard (S-shaped). W-shaped beams have essentially parallel flange surfaces and are the most common shape used in bridge construction. W-shaped beams are most economical when moment controls the design of a span. S-shaped beams have flanges that are sloped toward the edges and have a larger web area than W-shaped beams. S-shaped beams are more economical when shear controls the design of a span. Steel channels (C-shaped beams) have the same characteristics as the S-shaped beams and are usually used for lateral bracing and as truss-chord components. Equal-leg and unequal-leg angles (L-shaped beams) are also used as lightweight bracing materials. Bearing piles (HP-shaped beams) are used in substructures to provide support for the bridge.

Table D-1. American Institute of Steel Construction (AISC) Plate Thicknesses

Standard Steel-Plate Thicknesses
1/32-inch increments up to 1/2 inch
1/16-inch increments over 1/2 to 1 inch
1/8-inch increments over 1 to 3 inches
1/4-inch increments over 3 inches

Table D-2. Section Properties of Rolled Beams

Nominal Size	Actual Depth (d)	Flange Width (b)	Flange Thickness (t_f)	Web Thickness (t_w)	Section Modulus[3] (S^3)	Unbraced Length (L_m)	Effective Shear Area[2]
Wide-Flange I-Beams (in)							
W36x300	36.72	16.655	1.680	0.945	1,105.1	25.2	31.50
W36x280	36.50	16.595	1.570	0.889	1,031.0	23.6	29.60
W36x260	36.24	16.555	1.440	0.845	951.1	21.7	28.20
W36x245	36.06	16.912	1.350	0.802	892.5	20.4	27.00
W36x230	35.88	16.475	1.260	0.765	835.5	19.1	25.80
W36x194	36.48	12.117	1.260	0.770	663.6	13.8	26.10
W36x182	36.32	12.072	1.180	0.725	621.2	12.9	24.60
W36x170	36.16	12.027	1.100	0.680	579.1	12.1	23.10
W36x160	36.00	12.000	1.020	0.653	541.0	11.2	22.20
W36x150	35.84	11.972	0.940	0.625	502.9	10.3	21.20
W33x200	33.00	15.750	1.150	0.715	669.6	18.1	21.90
W33x141	33.31	11.535	0.960	0.605	446.8	11.0	19.00
W33x130	33.10	11.510	0.855	0.580	404.8	9.8	18.20
W30x124	30.16	10.521	0.930	0.585	354.6	10.7	16.55
W30x116	30.00	10.500	0.850	0.564	327.9	9.8	15.95
W30x108	29.82	10.484	0.760	0.548	299.2	8.8	15.50
W27x102	27.07	10.018	0.827	0.518	266.3	10.1	13.17
W27x94	26.91	9.990	0.747	0.490	242.8	9.1	12.46
W24x100	24.00	12.000	0.775	0.468	248.9	12.8	10.51
W24x94	24.29	9.061	0.872	0.516	220.9	10.7	11.64
W24x84	24.09	9.015	0.772	0.470	196.3	9.5	10.60
W24x76	23.91	8.985	0.682	0.440	175.4	8.4	9.93
W21x73	21.24	8.295	0.740	0.455	150.7	9.5	9.00
W21x68	21.13	8.270	0.685	0.430	139.9	8.8	8.50
W21x62	20.99	8.240	0.615	0.400	126.4	7.9	7.90
W18x60	18.25	7.558	0.695	0.416	107.8	9.4	7.00
W18x55	18.12	7.532	0.630	0.390	98.2	8.6	6.57
W18x50	18.00	7.500	0.570	0.358	89.0	7.8	6.03
W16x50	16.25	7.073	0.628	0.380	80.7	9.0	5.70
W16x45	16.12	7.039	0.563	0.346	72.4	8.1	5.18
W16x40	16.00	7.000	0.503	0.307	64.4	7.3	4.60
W16x36	15.85	6.992	0.428	0.299	56.3	6.2	4.48
W14x34	14.00	6.750	0.453	0.287	48.5	7.2	3.76
W14x30	13.86	6.733	0.383	0.270	41.8	6.1	3.54
W12x27	11.95	6.500	0.400	0.240	34.1	7.1	2.68
W10x25	10.08	5.762	0.430	0.252	26.4	8.1	2.32
W10x21	9.90	5.750	0.340	0.240	21.5	6.9	2.21
W8x20	8.14	5.268	0.378	0.248	17.0	8.1	1.83
W8x17	8.00	5.250	0.308	0.230	14.1	6.6	1.69

Table D-2. Section Properties of Rolled Beams (continued)

Nominal Size	Actual Depth (d)	Flange		Web Thickness (t_w)	Section Modulus[3] (S^3)	Unbraced Length (L_m)	Effective Shear Area[2]
		Width (b)	Thickness (t_f)				
Standard-Shaped I-Beams (in)							
S24x120.0	24.00	8.048	1.102	0.798	250.9	12.2	17.39
S24x105.9	24.00	7.875	1.102	0.625	234.3	11.9	13.62
S24x100.0	24.00	7.247	0.871	0.747	197.6	8.6	16.63
S24x90.0	24.00	7.124	0.871	0.624	185.8	8.5	13.89
S24x79.9	24.00	7.000	0.871	0.500	173.9	8.3	11.13
S20x75.0	20.00	6.391	0.789	0.641	126.3	8.3	11.81
S20x65.4	20.00	6.250	0.789	0.500	116.9	8.1	9.21
S18x54.7	18.00	6.000	0.691	0.460	88.4	7.6	7.64
S15x50.0	15.00	5.640	0.622	0.550	64.2	7.7	7.57
S15x42.9	15.00	5.500	0.622	0.410	58.9	7.5	5.64
S12x40.8	12.00	5.250	0.659	0.460	44.8	9.5	4.91
S12x35.0	12.00	5.078	0.544	0.428	37.8	7.6	4.67
S12x31.8	12.00	5.000	0.544	0.350	36.0	7.4	3.82
S10x35.0	10.00	4.944	0.491	0.594	29.2	7.6	5.36
S8x23.0	8.00	4.171	0.425	0.441	16.0	7.3	3.15
S8x18.4	8.00	4.000	0.425	0.270	14.2	7.0	1.93
S7x20.0	7.00	3.860	0.392	0.450	12.0	7.1	2.80
S7x15.3	7.00	3.660	0.392	0.250	10.4	6.7	1.55
S6x17.25	6.00	3.565	0.359	0.465	8.7	7.0	2.46
S6x12.5	6.00	3.330	0.359	0.230	7.3	6.5	1.21

Table D-3. Section Properties of End-Bearing H-Piles (in inches)

Nominal Size	Section Area[2]	Section Depth (d)	Flange		Web Thickness (t_w)	Axis x-x			Axis y-y		
			Width (b_f)	Thick-ness (t_f)		M_i[4]	S^3	r	M_i[4]	S^3	r
HP14x117	34.44	14.23	14.885	0.805	0.805	1,228.5	172.6	5.97	443.1	59.5	3.59
HP14x102	30.01	14.03	14.784	0.704	0.704	1,055.1	150.4	5.93	379.6	51.3	3.56
HP14x89	26.19	13.86	14.696	0.616	0.616	909.1	131.2	5.89	326.2	44.4	3.53
HP14x73	21.46	13.64	14.586	0.506	0.506	733.1	107.5	5.85	261.9	35.9	3.49
HP12x74	21.76	12.12	12.217	0.607	0.607	566.5	93.5	5.10	184.7	30.2	2.91
HP12x53	15.58	11.78	12.046	0.436	0.436	394.8	67.0	5.03	127.3	21.2	2.86
HP10x57	16.76	10.01	10.224	0.564	0.564	294.7	58.9	4.19	100.6	19.7	2.45
HP10x42	12.35	9.72	10.078	0.418	0.418	210.8	43.4	4.13	71.4	14.2	2.40
HP8x36	10.60	8.03	8.158	0.446	0.446	119.8	29.9	3.36	40.4	9.9	1.95

LEGEND:

M_i = moment of inertia
S = section modulus
r = radius of gyration

Table D-4. Section Properties of Rolled Channels

Nominal Size (in)	Weight per Foot (lb)	Actual Depth (d) (in)	Flange (in)		Web Thickness (t_w) (in)	Section Modulus[3] ($S^{3)}$ (in)
			Width (b)	Thickness (t_f)		
18	58.00	18	4.200	0.625	0.700	74.5
	42.70	18	3.950	0.625	0.450	61.0
15	50.00	15	3.716	0.650	0.716	53.6
	33.90	15	3.400	0.650	0.400	41.7
12	30.00	12	3.170	0.501	0.510	26.9
	20.70	12	2.940	0.501	0.280	21.4
10	30.00	10	3.033	0.436	0.673	20.6
	20.00	10	2.739	0.436	0.379	15.7
9	20.00	9	2.648	0.413	0.448	13.5
	13.40	9	2.430	0.413	0.230	10.5
8	18.75	8	2.527	0.390	0.487	10.9
	11.50	8	2.260	0.390	0.220	8.1
7	14.75	7	2.299	0.366	0.419	7.7
	9.80	7	2.090	0.366	0.210	6.0
6	13.00	6	2.157	0.343	0.437	5.8
	8.20	6	1.920	0.343	0.200	4.3
5	6.70	5	1.750	0.320	0.190	3.0
4	5.40	4	1.580	0.296	0.180	1.9
3	4.10	3	1.410	0.273	0.170	1.1

Table D-5. Properties of Reinforcing Bars

Bar Number (see note 1)	Weight per Foot (lb)	Nominal Dimensions (in)		
		D	A_s[2]	Perimeter
2 (see note 2)	0.167	0.250	0.05	0.786
3	0.376	0.375	0.11	1.178
4	0.668	0.500	0.20	1.571
5	1.043	0.625	0.31	1.963
6	1.502	0.750	0.44	2.356
7	2.044	0.875	0.60	2.749
8	2.670	1.000	0.79	3.142
9 (see note 3)	3.400	1.128	1.00	3.544
10 (see note 3)	4.303	1.270	1.27	3.990
11 (see note 3)	5.313	1.410	1.56	4.430

NOTES:

1. Bar numbers are based on the number of eighths of an inch included in the nominal diameter of the bars. The nominal diameter of a deformed bar is equivalent to the diameter of a plain bar having the same weight per foot as the deformed bar.
2. Plain, round 1/4-inch No. 2 bars only.
3. These figures correspond to the former 1-, 1 1/8-, and 1 1/4-inch-square sizes and are equivalent to those former standard bar sizes in weight and nominal cross-sectional area.

LEGEND:

D = diameter
A_S = cross-sectional area of bar, in square inches

Table D-6. Section Properties of Rolled Angles

Nominal Size (in)	Weight per Foot (lb)	Area[2] (in)	Axes x-x and y-y (in)				Axis z-z (in)
			I[4]	S[3]	r	x or y	r
L8x8x1	51.00	15.00	89.00	15.80	2.44	2.37	1.56
L8x8x$^3/_4$	38.90	11.44	69.70	12.20	2.47	2.28	1.57
L8x8x$^1/_2$	26.40	7.75	48.60	8.40	2.50	2.19	1.59
L6x6x1	37.40	11.00	35.50	8.60	1.80	1.86	1.17
L6x6x$^3/_4$	28.70	8.44	28.20	6.70	1.83	1.78	1.17
L6x6x$^1/_2$	19.60	5.75	19.90	4.60	1.86	1.68	1.18
L6x6x$^3/_8$	14.90	4.36	15.40	3.50	1.88	1.64	1.19
L5x5x$^3/_4$	23.60	6.94	15.70	4.50	1.51	1.52	0.97
L5x5x$^1/_2$	16.20	4.75	11.30	3.20	1.54	1.43	0.98
L5x5x$^3/_8$	12.30	3.61	8.70	2.40	1.56	1.39	0.99
L4x4x$^3/_4$	18.50	5.44	7.70	2.80	1.19	1.27	0.78
L4x4x$^1/_2$	12.80	3.75	5.60	2.00	1.22	1.18	0.78
L4x4x$^3/_8$	9.80	2.86	4.40	1.50	1.23	1.14	0.79
L4x4x$^1/_4$	6.60	1.94	3.00	1.10	1.25	1.09	0.80
L$3^1/_2$x$3^1/_2$x$^1/_2$	11.10	3.25	3.60	1.50	1.06	1.06	0.68
L$3^1/_2$x$3^1/_2$x$^3/_8$	8.50	2.48	2.90	1.20	1.07	1.01	0.69
L$3^1/_2$x$3^1/_2$x$^1/_4$	5.80	1.69	2.00	0.79	1.09	0.97	0.69
L3x3x$^1/_2$	9.40	2.75	2.20	1.10	0.90	0.93	0.58
L3x3x$^3/_8$	7.20	2.11	1.80	0.83	0.91	0.89	0.58
L3x3x$^1/_4$	4.90	1.44	1.20	0.58	0.93	0.84	0.59
L$2^1/_2$x$2^1/_2$x$^1/_2$	7.70	2.25	1.20	0.72	0.74	0.81	0.49
L$2^1/_2$x$2^1/_2$x$^3/_8$	5.90	1.73	0.98	0.57	0.75	0.76	0.49
L$2^1/_2$x$2^1/_2$x$^1/_4$	4.10	1.19	0.70	0.39	0.77	0.72	0.49
L2x2x$^3/_8$	4.70	1.36	0.48	0.35	0.59	0.64	0.39
L2x2x$^1/_4$	3.19	0.94	0.35	0.25	0.61	0.59	0.39

LEGEND:

I = moment of inertia about the x-axis, in inches^4
S = section modulus
r = radius of gyration

Table D-7. Section Properties of Unequal-Leg Angles

Nominal Size (in)	Weight per Foot (lb)	Area[2] (in)	Axis x-x (in)				Axis y-y (in)				Axis z-z	
			I[4]	S[3]	r	y	I[4]	S[3]	r	x	r (in)	tan
L9x4x1	40.8	12.00	97.0	17.60	2.84	3.50	12.0	4.00	1.00	1.00	0.83	0.203
L9x4x$^3/_4$	31.3	9.19	76.1	13.60	2.88	3.41	9.6	3.10	1.02	0.91	0.84	0.212
L9x4x$^1/_2$	21.3	6.25	53.2	9.30	2.92	3.31	6.9	2.20	1.05	0.81	0.85	0.220
L8x6x1	44.2	13.00	80.8	15.10	2.49	2.65	38.8	8.90	1.73	1.65	1.28	0.543
L8x6x$^3/_4$	33.8	9.94	63.4	11.70	2.53	2.56	30.7	6.90	1.76	1.56	1.29	0.551
L8x6x$^1/_2$	23.0	6.75	44.3	8.00	2.56	2.47	21.7	4.80	1.79	1.47	1.30	0.558
L8x4x1	37.4	11.00	69.6	14.10	2.52	3.05	11.6	3.90	1.03	1.05	0.85	0.247
L8x4x$^3/_4$	28.7	8.44	54.9	10.90	2.55	2.95	9.4	3.10	1.05	0.95	0.85	0.258
L8x4x$^1/_2$	19.6	5.75	38.5	7.50	2.59	2.86	6.7	2.20	1.08	0.86	0.86	0.267
L7x4x$^3/_4$	26.2	7.69	37.8	8.40	2.22	2.51	9.1	3.00	1.09	1.01	0.86	0.324
L7x4x$^1/_2$	17.9	5.25	26.7	5.80	2.25	2.42	6.5	2.10	1.11	0.92	0.87	0.335
L7x4x$^3/_8$	13.6	3.98	20.6	4.40	2.27	2.37	5.1	1.60	1.13	0.87	0.88	0.339
L6x4x$^3/_4$	23.6	6.94	24.5	6.30	1.88	2.08	8.7	3.00	1.12	1.08	0.86	0.428
L6x4x$^1/_2$	16.2	4.75	17.4	4.30	1.91	1.99	6.3	2.10	1.15	0.99	0.87	0.440
L6x4x$^3/_8$	12.3	3.61	13.5	3.30	1.93	1.94	4.9	1.60	1.17	0.94	0.88	0.446
L6x3$^1/_2$x$^1/_2$	15.3	4.50	16.6	4.20	1.92	2.08	4.3	1.60	0.97	0.83	0.76	0.344
L6x3$^1/_2$x$^3/_8$	11.7	3.42	12.9	3.20	1.94	2.04	3.3	1.20	0.99	0.79	0.77	0.350
L6x3$^1/_2$x$^1/_4$	7.9	2.31	8.9	2.20	1.96	1.99	2.3	0.85	1.01	0.74	0.78	0.355
L5x3$^1/_2$x$^3/_4$	19.8	5.81	13.9	4.30	1.55	1.75	5.6	2.20	0.98	1.00	0.75	0.464
L5x3$^1/_2$x$^1/_2$	13.6	4.00	10.0	3.00	1.58	1.66	4.1	1.60	1.01	0.91	0.75	0.479
L5x3$^1/_2$x$^3/_8$	10.4	3.05	7.8	2.30	1.60	1.61	3.2	1.20	1.02	0.86	0.76	0.486
L5x3$^1/_2$x$^1/_4$	7.0	2.06	5.4	1.60	1.61	1.56	2.2	0.83	1.04	0.81	0.76	0.492
L5x3x$^1/_2$	12.8	3.75	9.5	2.90	1.59	1.75	2.6	1.10	0.83	0.75	0.65	0.357
L5x3x$^3/_8$	9.8	2.86	7.4	2.20	1.61	1.70	2.0	0.89	0.84	0.70	0.65	0.364
L5x3x$^1/_4$	6.6	1.94	5.1	1.50	1.62	1.66	1.4	0.61	0.86	0.66	0.66	0.371
L4x3$^1/_2$x$^1/_2$	11.9	3.50	5.3	1.90	1.23	1.25	3.8	1.50	1.04	1.00	0.72	0.750
L4x3$^1/_2$x$^3/_8$	9.1	2.67	4.2	1.50	1.25	1.21	3.0	1.20	1.06	0.96	0.73	0.755
L4x3$^1/_2$x$^1/_4$	6.2	1.81	2.9	1.00	1.27	1.16	2.1	0.81	1.07	0.91	0.73	0.759
L4x3x$^1/_2$	11.1	3.25	5.1	1.90	1.25	1.33	2.4	1.10	0.86	0.83	0.64	0.543
L4x3x$^3/_8$	8.5	2.48	4.0	1.50	1.26	1.28	1.9	0.87	0.88	0.78	0.64	0.551
L4x3x$^1/_4$	5.8	1.69	2.8	1.00	1.28	1.24	1.4	0.60	0.90	0.74	0.65	0.558
L3$^1/_2$x3x$^1/_2$	10.2	3.00	3.5	1.50	1.07	1.13	2.3	1.10	0.88	0.88	0.62	0.714
L3$^1/_2$x3x$^3/_8$	7.9	2.30	2.7	1.10	1.09	1.08	1.9	0.85	0.90	0.83	0.62	0.721
L3$^1/_2$x3x$^1/_4$	5.4	1.56	1.9	0.78	1.11	1.04	1.3	0.59	0.91	0.79	0.63	0.727

LEGEND:

I = moment of inertia about the x-axis, in inches^4
S = section modulus
r = radius of gyration

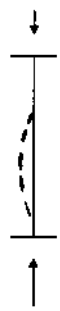
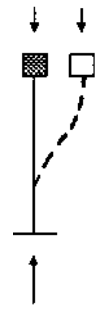
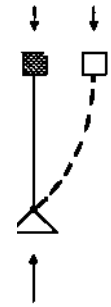
Table D-8. Section Moduli for Composite Steel Stringers

Nominal Size (in)	d (in)	b (in)	S^3 (t_d = 3 in)	S^3 (t_d = 4 in)	S^3 (t_d = 5 in)	S^3 (t_d = 6 in)	S^3 (t_d = 8 in)
W36x300	36.750	16.625	1,105	1,264	1,323	1,380	1,489
W36x230	35.875	16.500	835	972	1,018	1,061	1,145
W36x194	36.500	12.125	663	805	847	887	961
W36x182	36.375	12.125	621	757	796	833	902
W36x170	36.125	12.000	579	709	745	779	844
W36x160	36.000	12.000	541	667	701	733	794
W36x150	35.875	12.000	502	624	656	686	744
W33x220	33.875	15.750	740	868	910	951	1,031
W33x200	33.625	15.750	669	789	828	865	938
W33x141	33.250	11.500	446	555	585	612	666
W33x130	33.125	11.500	404	509	536	561	612
W30x172	30.500	15.000	528	630	663	694	757
W30x124	30.125	10.500	354	449	474	497	546
W30x116	30.000	10.500	327	419	442	464	511
W30x108	29.875	10.500	299	387	409	429	473
W27x161	27.625	14.000	455	537	566	595	655
W27x102	27.125	10.000	267	342	362	381	423
W27x94	26.875	10.000	243	315	333	350	390
W27x84	26.750	10.000	213	279	295	311	347
W24x94	24.250	9.125	222	288	306	323	364
W24x84	24.125	9.000	196	258	274	290	326
W24x76	23.875	9.000	176	233	247	262	295
W21x73	21.250	8.250	151	203	216	231	263
W21x68	21.125	8.250	140	189	202	216	246
W21x62	21.000	8.250	127	172	184	197	224
W18x60	18.250	7.500	108	149	160	173	201
W18x55	18.125	7.500	98	137	147	159	184
W18x50	18.000	7.500	89	124	134	145	168

LEGEND:

b = width
d = depth
S = section modulus
t_d = deck thickness

Table D-9. Effective Length Factors

	(a)	(b)	(c)	(d)	(e)	(f)
Column shape (buckled shape is shown by a dashed line)						
Effective length factor (K) (theoretical value)	0.50	0.70	1.00	1.00	2.00	2.00
Design value of K*	0.65	0.80	1.20	1.00	2.10	2.00
End-condition code		Rotation fixed, translation fixed Rotation free, translation fixed Rotation fixed, translation free Rotation free, translation free				

***When ideal conditions are approximate. For riveted and bolted truss members (partially restrained), *K= 0.75*. For pinned connections in truss members, *K = 0.875* (pin friction).**

Excerpted from the *Standard Specifications for Highway Bridges,* by The American Association of State Highway and Transportation Officials, Washington, DC, Copyright 1996. Note that some of this material may have been superseded by more recent material. Used by permission.

Table D-10. Properties of Steel Stringers (F_y is 36 ksi and f_b is 29 ksi)

Nominal Size (in)	d (in)	b (in)	t_f (in)	t_w (in)	m (kip-feet)	v (kips)	L_m (ft)	S_b (ft)
W39x211*	39.250	11.750	1.438	0.75	1,901	335	93	19.9
W37x206*	37.250	11.750	1.438	0.75	1,779	335	89	21.0
W36x300	36.750	16.625	1.688	0.94	2,670	410	87	35.3
W36x194	36.500	12.125	1.250	0.81	1,602	340	87	19.2
W36x182	36.375	12.125	1.187	0.75	1,500	320	87	18.3
W36x170	36.125	12.000	1.125	1.06	1,398	300	86	17.3
W36x160	36.000	12.000	1.000	1.06	1,307	288	86	15.4
W36x230	35.875	16.500	1.250	0.75	2,018	332	85	26.6
W36x150	35.875	12.000	0.937	0.62	1,215	276	85	14.5
W36x201*	35.375	11.750	1.438	0.75	1,659	317	84	22.1

Table D-10. Properties of Steel Stringers (F_y is 36 ksi and f_b is 29 ksi) (continued)

Nominal Size (in)	d (in)	b (in)	t_f (in)	t_w (in)	m (kip-feet)	v (kips)	L_m (ft)	S_b (ft)
W33x196*	33.375	11.750	1.438	0.75	1,539	297	79	23.4
W33x220*	33.250	15.750	1.250	0.81	1,784	309	79	27.4
W33x141	33.250	11.500	0.937	0.62	1,079	247	79	15.0
W33x200	33.000	15.750	1.125	0.56	978	236	79	14.1
W31x180	31.500	11.750	1.312	0.75	1,618	285	79	24.9
W30x124	30.125	10.500	0.937	0.68	1,425	258	75	22.7
W30x116	30.000	10.500	0.875	0.62	856	215	72	15.1
W30x108	29.875	10.500	0.750	0.56	793	207	71	14.2
W30x175*	29.500	11.750	1.312	0.56	723	201	71	12.2
W27x171*	27.500	11.750	1.312	0.68	1,242	240	70	24.2
W27x102	27.125	10.000	0.812	0.68	1,137	222	65	26.0
W27x94	26.875	10.000	0.750	0.50	643	171	65	13.9
W26x157*	25.500	11.750	1.250	0.50	586	162	64	12.9
W24x94	24.250	9.000	0.875	0.62	983	187	61	26.7
W24x84	24.125	9.000	0.750	0.50	534	150	58	15.0
W24x100	24.000	12.000	0.750	0.50	475	137	57	12.4
S24x120	24.000	8.000	1.125	0.50	601	136	57	17.4
S24x106	24.000	7.875	1.125	1.18	606	225	57	17.4
S24x80	24.000	7.000	0.875	0.62	566	176	57	17.1
W24x76	23.875	9.000	0.687	0.50	420	144	57	11.8
W24x153*	23.625	11.750	0.250	0.43	423	128	57	12.0
S24x134*	23.625	8.500	1.250	0.62	889	171	26	28.8
S22x75*	22.000	7.000	0.812	0.81	681	223	26	20.8
W21x139*	21.625	11.750	1.187	0.50	331	132	52	12.0
S21x112*	21.625	7.875	1.187	0.62	751	156	52	30.0
W21x73	21.250	8.250	0.750	0.75	532	188	52	20.0
W21x68	21.125	8.250	0.687	0.50	363	117	51	13.5
W21x62	21.000	8.250	0.625	0.43	338	110	50	12.4
S20x85	20.000	7.125	0.937	0.37	305	102	50	11.4
S21x65*	20.000	6.500	0.812	0.68	362	154	48	15.5
W20x134*	19.625	11.750	1.187	0.43	263	104	48	12.2
W18x60	18.250	7.500	0.687	0.62	667	139	47	32.9
S18x86*	18.250	7.000	1.000	0.43	261	91	43	13.1
S18x55	18.125	7.500	0.625	0.37	236	85	43	12.0
S18x80*	18.000	8.000	0.937	0.50	314	104	43	19.3
W18x50	18.000	7.500	0.562	0.37	215	78	43	10.9
S18x55	18.000	6.000	0.687	0.50	214	99	43	10.6
S18x122*	17.750	11.750	1.062	0.56	696	114	42	32.6
S18x62*	17.750	6.875	0.750	0.37	256	79	42	3.4
S18x77*	17.750	6.625	0.937	0.62	302	128	42	16.2
W16x112*	16.750	11.750	1.000	0.56	483	107	40	32.5
S16x70*	16.750	6.500	0.937	0.62	256	115	40	16.8
W16x50	16.250	7.125	0.625	0.37	194	74	39	12.7
W16x45	16.125	7.000	0.562	0.37	175	67	38	1.3

Table D-10. Properties of Steel Stringers (F_y is 36 ksi and f_b is 29 ksi) (continued)

Nominal Size (in)	d (in)	b (in)	t_f (in)	t_w (in)	m (kip-feet)	v (kips)	L_m (ft)	S_b (ft)
W16x64	16.000	8.500	0.687	0.43	251	84	38	16.9
W16x40	16.000	7.000	0.500	0.31	156	59	38	10.1
S16x50*	16.000	6.000	0.687	0.43	166	83	38	11.9
W16x36	15.875	7.000	0.437	0.31	136	58	38	8.9
W16x110*	15.750	11.750	1.000	0.56	371	100	37	34.5
S16x62*	15.750	6.125	0.875	0.56	215	101	37	15.8
S16x45*	15.750	5.375	0.625	0.43	161	82	37	9.9
W15x103*	15.000	11.750	0.937	0.56	396	95	36	34.0
S15x56	15.000	5.875	0.812	0.50	186	87	36	14.7
S15x43	15.000	5.500	0.625	0.43	142	73	36	0.6
W14x101*	14.250	11.750	0.937	0.56	369	90	34	35.8
S14x40*	14.250	5.375	0.375	0.37	128	65	34	6.5
S14x51*	14.125	5.625	0.750	0.50	161	82	34	13.8
S14x70*	14.000	8.000	0.937	0.43	219	69	33	24.8
S14x57*	14.000	6.000	0.875	0.50	164	80	33	17.4
W14x34	14.000	6.750	0.437	0.31	117	48	33	9.8
W14x30	13.875	6.750	0.375	0.25	101	46	33	8.4
W14x92*	13.375	11.750	0.875	0.50	319	76	32	35.6
S14x46*	13.375	5.375	0.687	0.50	135	78	32	12.8
S13x35*	13.000	5.000	0.625	0.37	91	57	31	11.1
S13x41*	12.625	5.125	0.687	0.56	116	82	30	12.9
W12x36	12.250	6.625	0.562	0.31	111	44	29	14.1
S12x65*	12.000	8.000	0.937	0.43	195	58	29	28.9
W12x57	12.000	6.500	0.375	1.25	82	35	29	9.4
S12x50	12.000	5.500	0.687	0.68	121	96	29	14.6
S12x32	12.000	5.000	0.562	0.37	87	49	29	10.9
S12x34*	11.250	4.750	0.625	0.43	87	57	27	13.5
W11x76*	11.000	11.000	0.812	0.50	217	61	26	37.6
S10x29*	10.625	4.750	0.562	0.31	72	38	25	10.4
W10x25	10.125	5.750	0.437	0.25	63	30	24	10.5
S10x40	10.000	6.000	0.687	0.37	99	42	24	19.1
S10x35	10.000	5.000	0.500	0.62	70	69	24	11.6

***Available in Europe; not a standard US shape.**

LEGEND:

b = width
d = depth
L_m = maximum span length
m = moment capacity
S_b = brace spacing
t_f = flange thickness
t_w = web thickness
v = shear capacity

UNLISTED-BEAMS SECTION PROPERTIES

D-6. *Tables D-2, D-3, D-4, D-6,* and *D-7, pages D-3* through *D-7,* do not list the section properties for all beam types. These properties can be determined by using the external dimensions of the unlisted beams and calculating each of the section properties. Important properties to consider include the—

- Effective shear area.
- Neutral axis.
- Moment of inertia.
- Section modulus.
- Radius of gyration.

EFFECTIVE SHEAR AREA

D-7. Compute the effective shear area as follows:

$$A_v = t_w d_i \qquad \text{(D-1)}$$

where—

A_v = *effective shear area, in square inches*
t_w = *web thickness, in inches*
d_i = *internal flange depth, in inches. Measure this distance from the inside of the top flange to the inside of the bottom flange.*

NEUTRAL AXIS

D-8. The neutral axis is the plane that splits the area of a shape in half. The beam is unaffected by compression or tension along this axis. There is no stress in the beam along this axis. Determine the location of the neutral axis as follows:

- **Simple shapes (squares, rectangles, triangles, and circles).** Divide the depth of the shape by two or three, as appropriate *(Figure D-1).*
- **Symmetrical, complex shapes.** Divide the depth of the member by two *(Figure D-2).*
- **Unsymmetrical, complex shapes.** Use the following procedure:
  - Divide the complex shape into simple shapes and determine the location of the neutral axes in these sections *(Figure D-3, page D-14).*
  - Find the distance from an arbitrary baseline (normally the bottom of the complex shape) to the neutral axis of each of the simple shapes *(Figure D-4, page D-14).*
  - Determine the area of each of the simple shapes *(Figure D-5, page D-14).*
  - Determine the distance from the baseline to the neutral axis of the complex shape by using *Figure D-6, page D-15,* and the following equation:

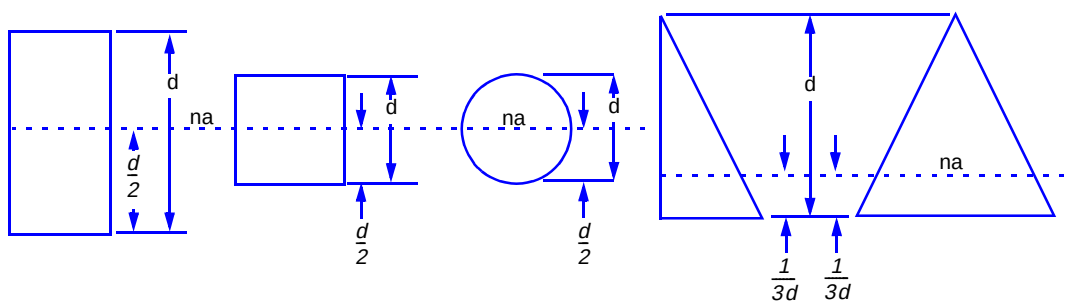
$$y = \frac{\Sigma A\bar{y}}{\Sigma A} \qquad \text{(D-2)}$$

where—

y = *distance from the baseline to the neutral axis of the complex shape, in inches*

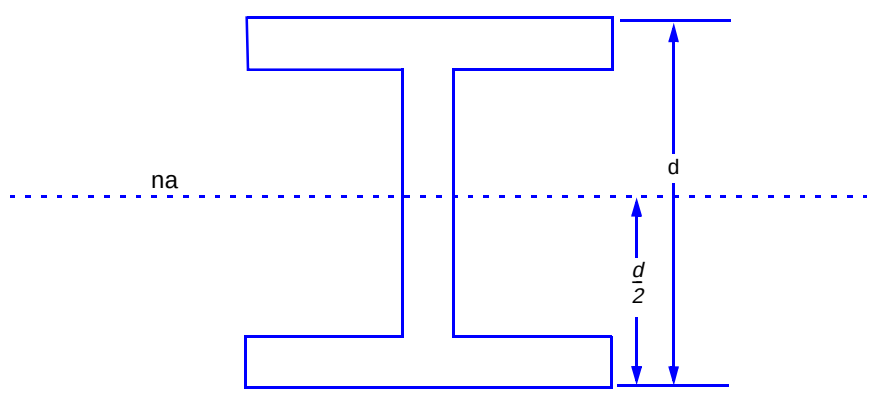
A = *area of the simple shape, in square inches*

$\bar{y}$ = *distance from the baseline to the neutral axis of the simple shape, in inches*



LEGEND:
d = depth of the stringer

Figure D-1. Neutral Axis in Simple Shapes



LEGEND:
d = depth of the stringer

Figure D-2. Neutral Axis in Symmetrical, Complex Shapes

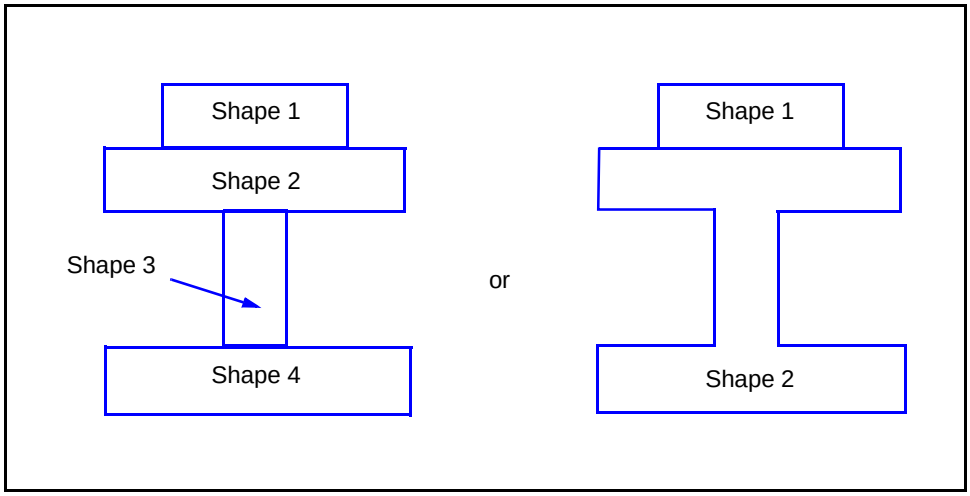


Figure D-3. Sectioning Complex Shapes

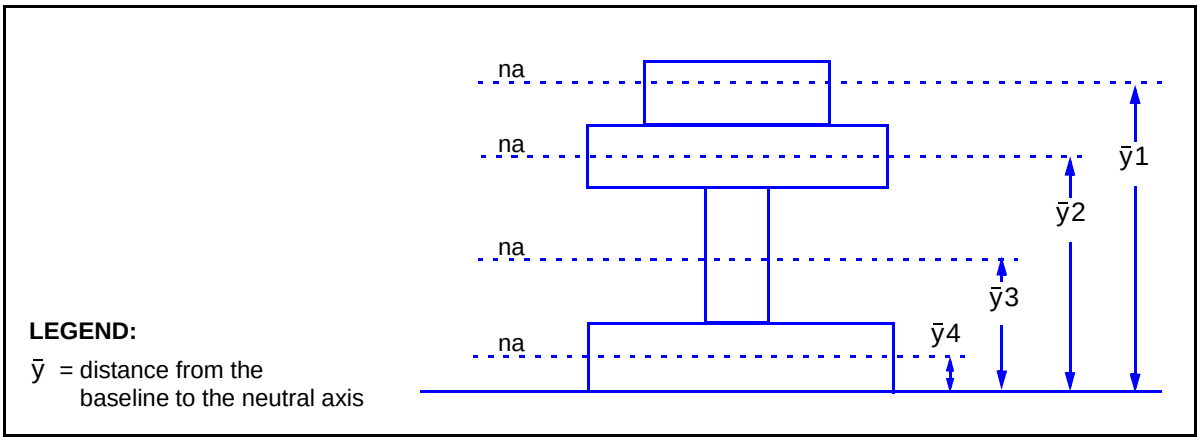


Figure D-4. Determining Baseline-to-Neutral-Axis Distances

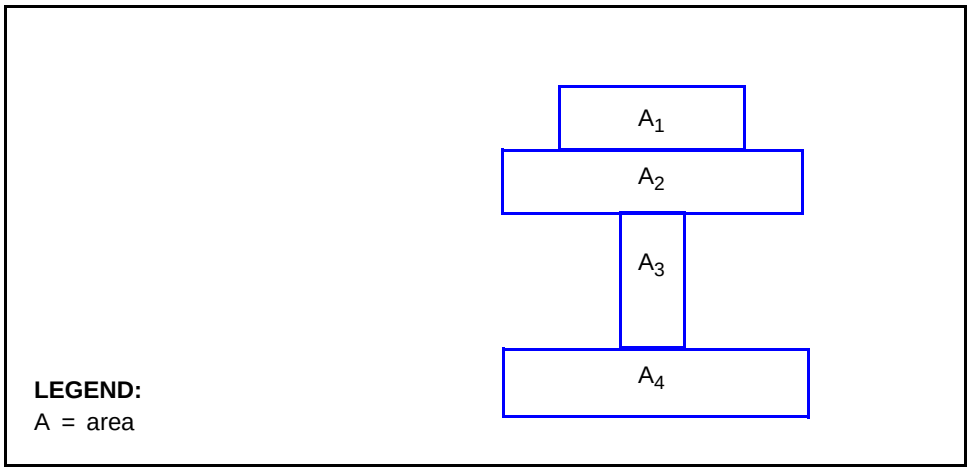


Figure D-5. Areas of the Simple Shapes

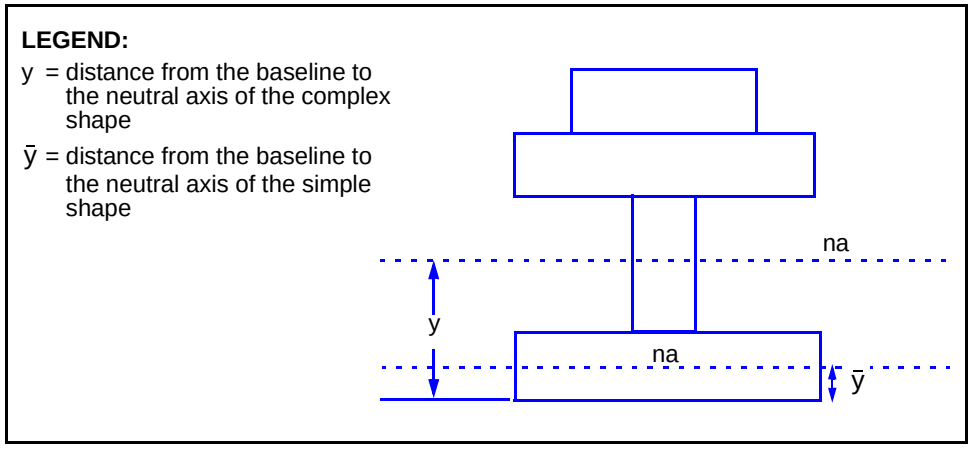


Figure D-6. Example Tabulation of Neutral Axis

MOMENT OF INERTIA

D-9. Compute the moment of inertia of a shape (with respect to the axis) using *Figure D-6* and the following equation:

$$M_i = \int_0^d y^2 dA \qquad \text{(D-3)}$$

where—

M_i = *moment of inertia, in inches*^{4}
d = *distance over which integration occurs, in inches*
y = *distance from the baseline to the element of area, in inches*
dA = *element of area, in square inches*

D-10. The moment of inertia of a given shape changes with the differing locations and orientations of the axis chosen. The axis normally chosen is the neutral axis of the cross section of the beam that is perpendicular to the load being applied *(Figure D-7, page D-16)*. Compute as follows:

- **Simple shapes *(Figure D-8, page D-16)*.**
- **Complex shapes.** Use the parallel-axis theorem, which dictates the use of *Figure D-9, page D-16,* and the following equation:

$$M_{iC} = \Sigma M_{iS} + \Sigma A y^2 \qquad \text{(D-4)}$$

where—

M_{iC} = *moment of inertia of the complex shape about its neutral axis, in inches*^{4}
M_{iS} = *moment of inertia for each simple shape about its neutral axis, in inches*^{4}
A = *area for each simple shape, in square inches*
y = *distance of the neutral axis of each simple shape to the neutral axis of the complex shape, in inches*

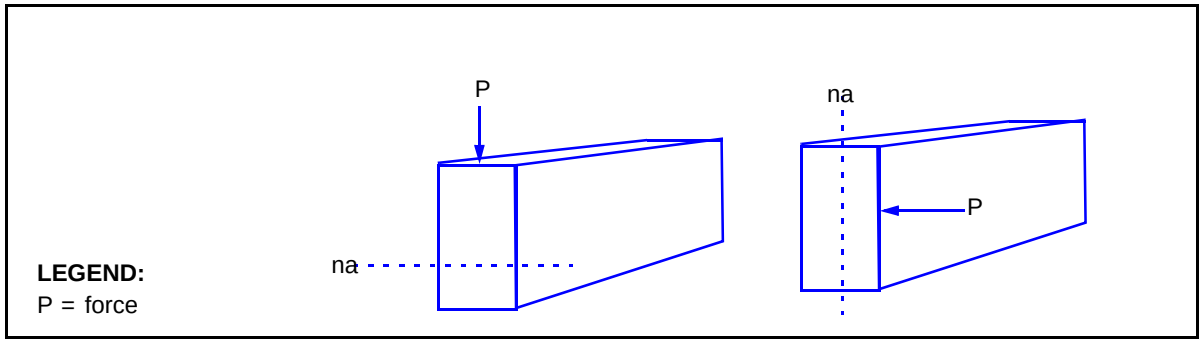


Figure D-7. Axis Orientations Based on Loading

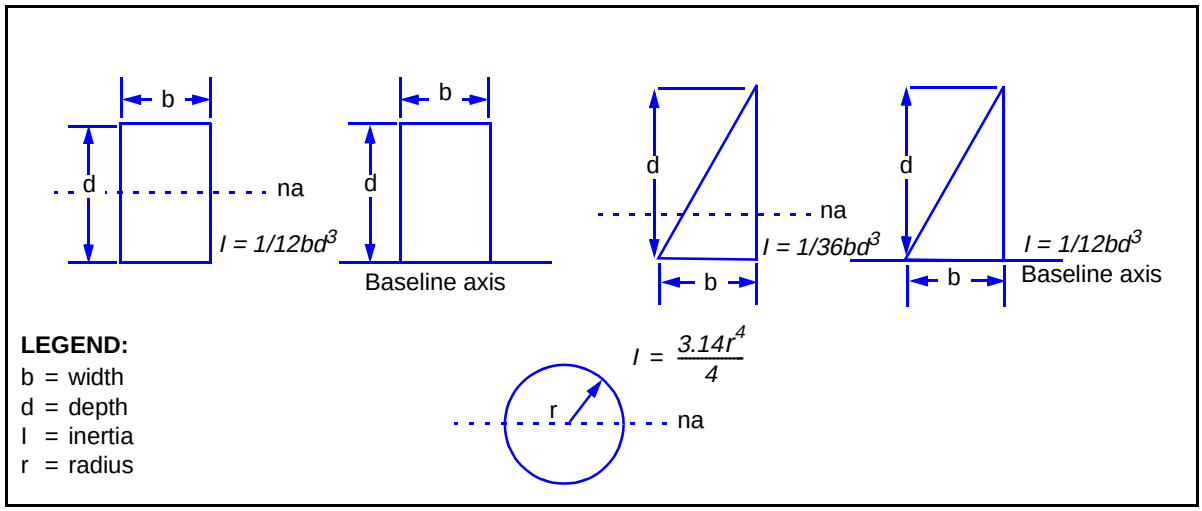


Figure D-8. Moments of Inertia for Simple Shapes

Section	A	y	Ay^2	I_o
	A_1	y1	A_1y1^2	I_{o1}
	A_2	y2	A_2y2^2	I_{o2}
	A_3	y3	A_3y3^2	I_{o3}
	A_4	y4	A_4y4^2	I_{o4}
			$\Sigma Ay^2 = A_1y1^2 + A_2y2^2 + A_3y3^2 + A_4y4^2$	$\Sigma I_o = I_{o1} + I_{o2} + I_{o3} + I_{o4}$

LEGEND:
A = area for each simple shape
y = distance of the neutral axis of each simple shape to the neutral axis of the complex shape
I_o = moment of inertia

Figure D-9. Sample Tabulation of Moments of Inertia

SECTION MODULUS

D-11. Compute the stress induced in the extreme fiber of a given shape as follows. The value of M_i/y_e is defined as the section modulus of the shape. It is a measure of the ability of the shape to resist bending moments about a given axis.

$$F_b = M\frac{M_i}{y_e} = \frac{M}{S} \qquad \text{(D-5)}$$

where—

F_b = *induced stress in the extreme fiber of the shape, in ksi*
M = *moment force applied to the shape, in kip-inches*
M_i = *moment of inertia of the shape, in inches*^{4}
y_e = *distance from the neutral axis to the extreme fiber of the shape, in inches*
S = *section modulus of the shape, in cubic inches*

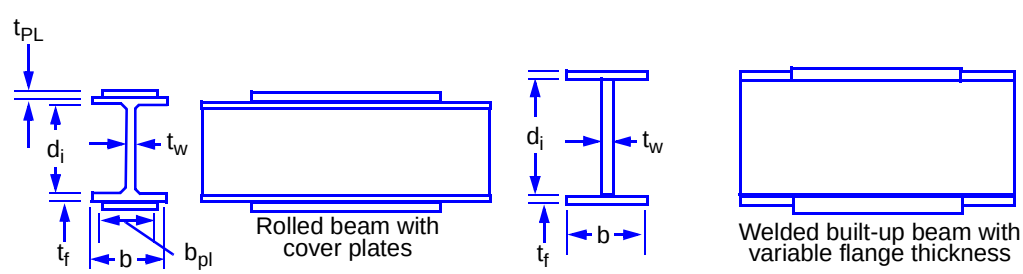
Symmetrical, Welded Beams and Girders

D-12. Use *Figure D-10* and the following equation (based on the parallel-axis theorem) to approximate the section modulus for symmetrical, built-up beams and girders that have been welded within 5 percent of the true section modulus:

$$S = d_i\left(A_f + \frac{A_w}{6}\right) \qquad \text{(D-6)}$$

where—

S = *section modulus, in cubic inches*
d_i = *interior depth of the beam, in inches*
A_f = *area of one flange, in square inches*
A_w = *area of the web, in square inches*



LEGEND:

t_{PL} = thickness of the plate
d_i = interior depth of the beam
t_w = web thickness
t_f = flange thickness
b = width
b_{pl} = width of the cover plate

Figure D-10. Built-up Beams

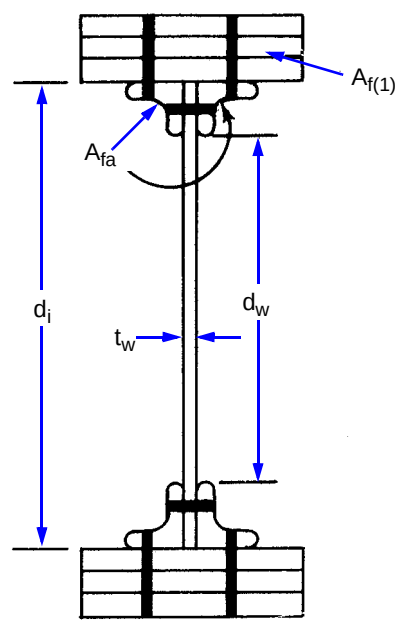
Symmetrical, Riveted Beams and Girders

D-13. Use the following equation and *Figure D-11* to approximate the section modulus of these beams and girders (deduct the area of the rivet holes from the used areas):

$$S = d_w\left(A_f + \frac{A_w}{6}\right) + d_i A_{fa} \qquad \text{(D-7)}$$

where—

S = *section modulus, in cubic inches*
d_w = *web depth measured from angle to angle, in inches*
A_f = *area of one flange, in square inches*
A_w = *area of the web, in square inches*
d_i = *interior depth of the beam, in inches*
A_{fa} = *net area of one set of flange angles, in square inches*



LEGEND:
A_{fa} = net area of one set of flange angles
$A_{f(1)}$ = area of one flange
d_i = interior depth of the beam
d_w = web depth measured from angle to angle
t_w = web thickness

Figure D-11. Riveted Beam or Girder

All Shapes (Symmetrical and Unsymmetrical)

D-14. Compute the section modulus of all types of shapes as follows:

- Determine the location of the neutral axis as described earlier.
- Determine the moment of inertia of the shape about the neutral axis as described earlier.
- Determine the distance from the neutral axis to the point on the section that is the farthest away from the neutral axis.
- Divide the moment of inertia by the neutral axis.

RADIUS OF GYRATION

D-15. The radius of gyration for a shape is the distance from a given axis (usually the neutral axis) where the concentrated mass of the shape would have the same moment of inertia as the actual shape. This value is a measure of how the shape reacts to rotational forces. The purpose of computing the radius of gyration is to determine the capacity of the shape to resist buckling that is induced from compressive and bending forces. Compute the radius of gyration as follows:

$$r = \sqrt{\frac{M_i}{A}} \qquad \text{(D-8)}$$

where—

r = *radius of gyration, in inches*

M_i = *moment of inertia, in inches*^{4}

A = *area of the shape, in square inches*