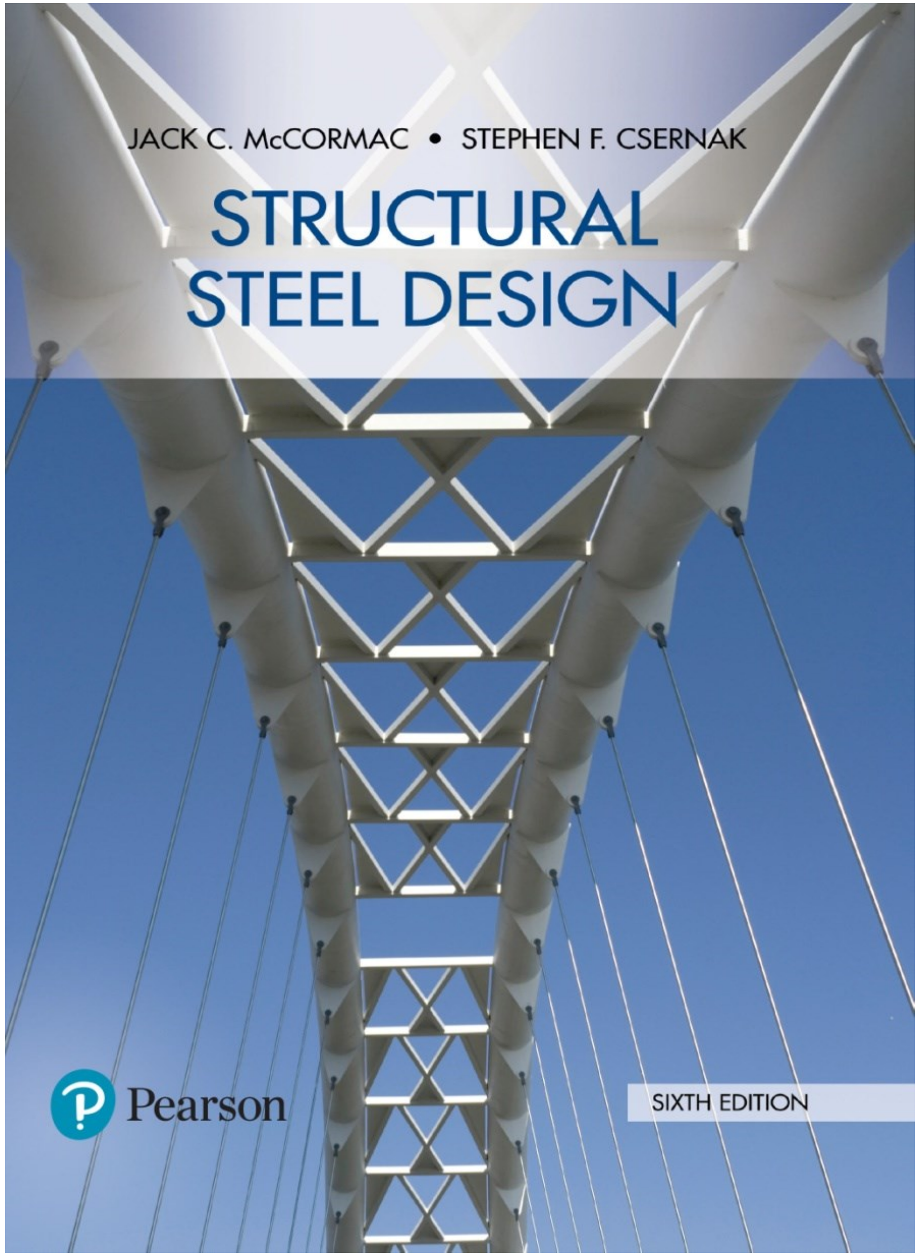
The Hashemite University

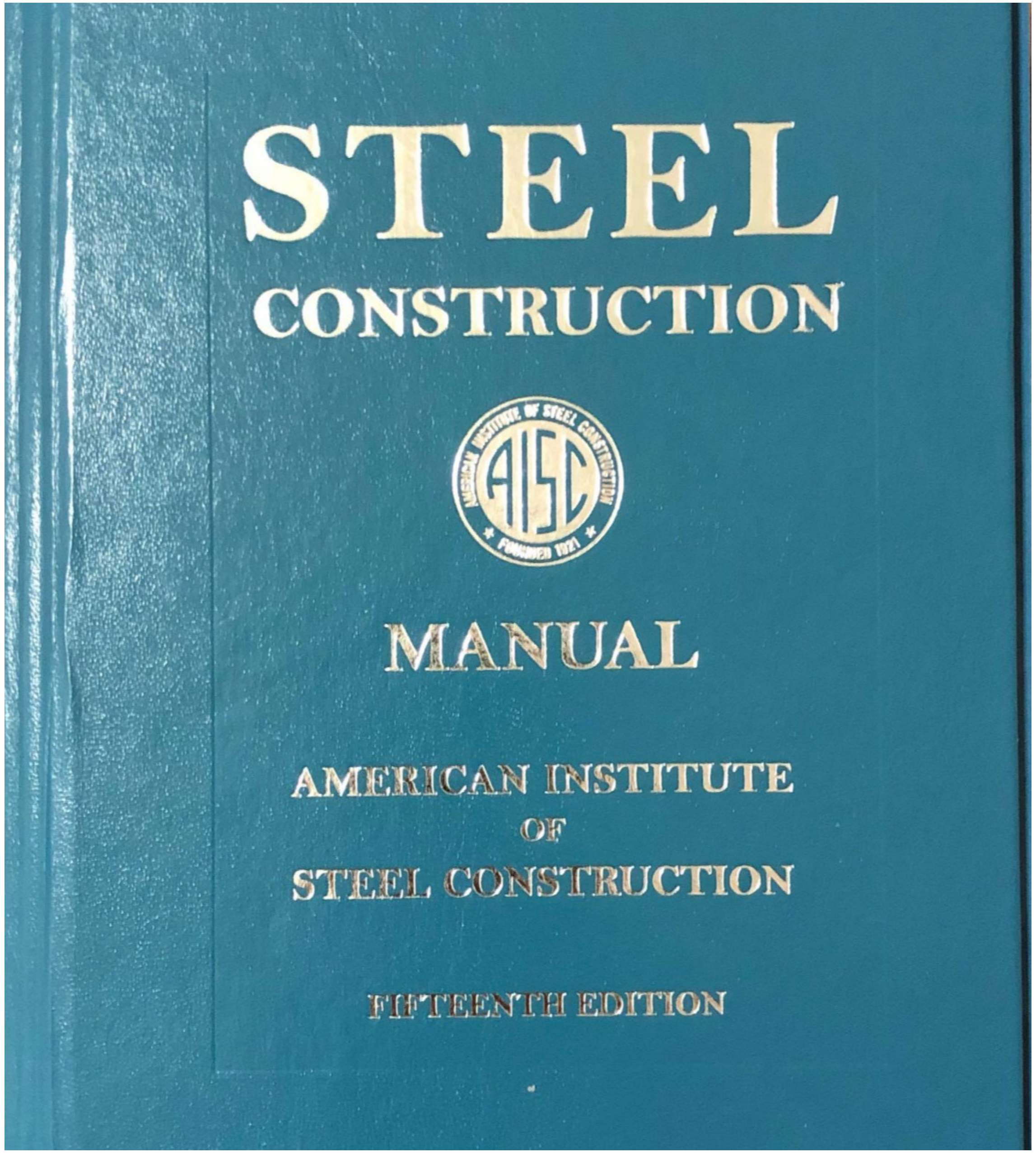
Faculty of Engineering

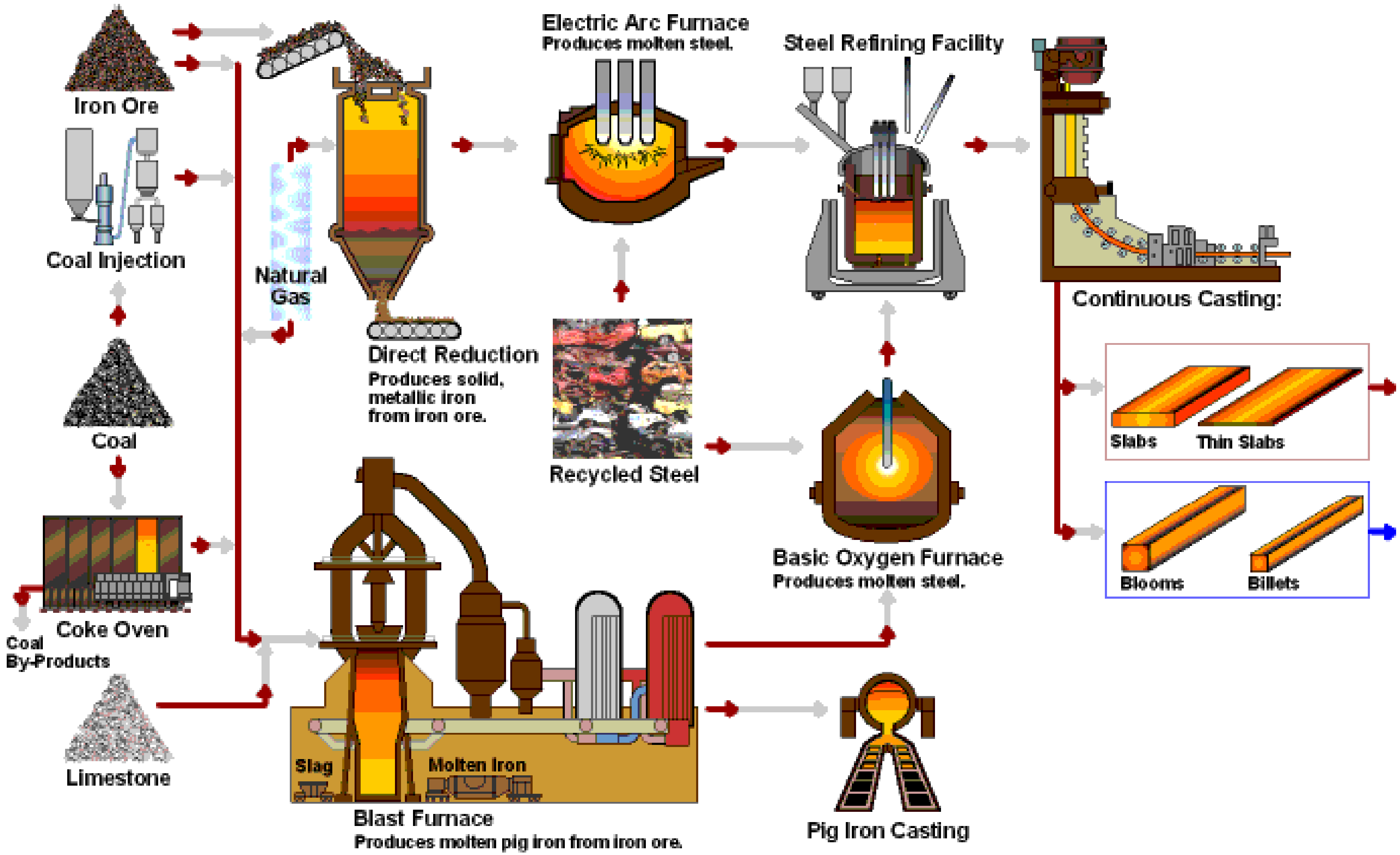
Department of Civil Engineering

Introduction to steel structures

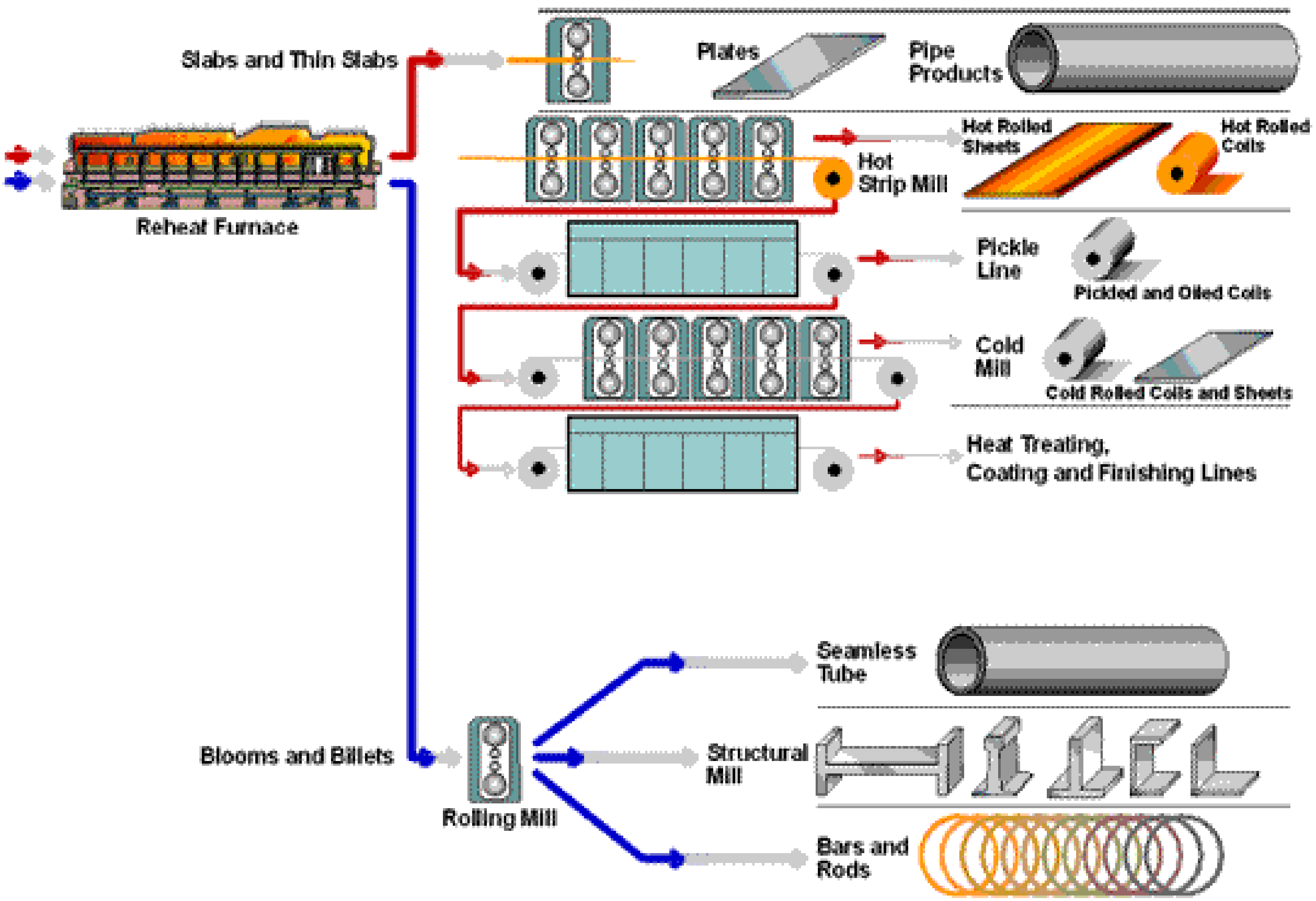
Dr. Ra'ed Al-Mazaidh

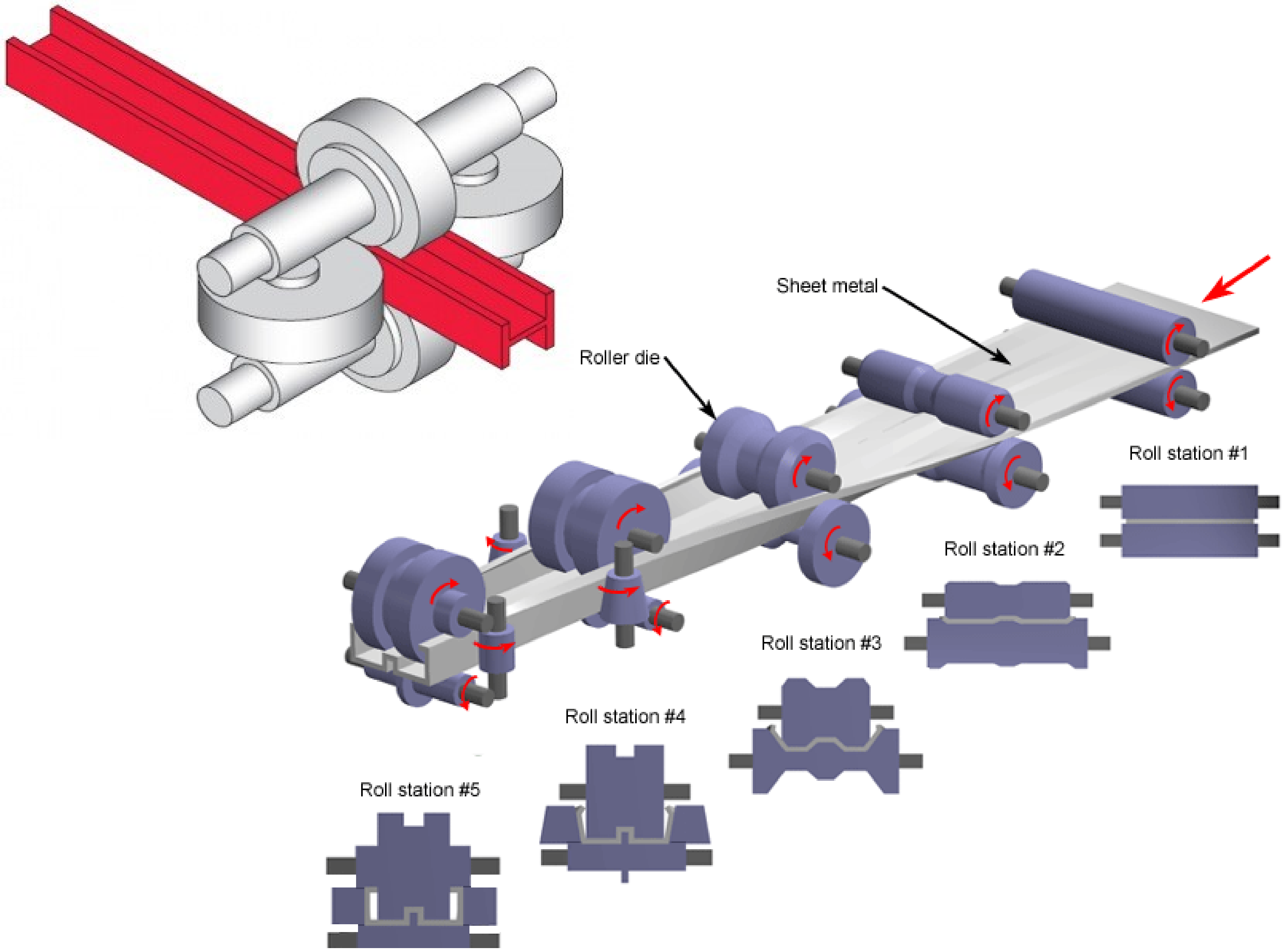

JACK C. McCORMAC • STEPHEN F. CSERNAK
STRUCTURAL STEEL DESIGN
Pearson
SIXTH EDITION

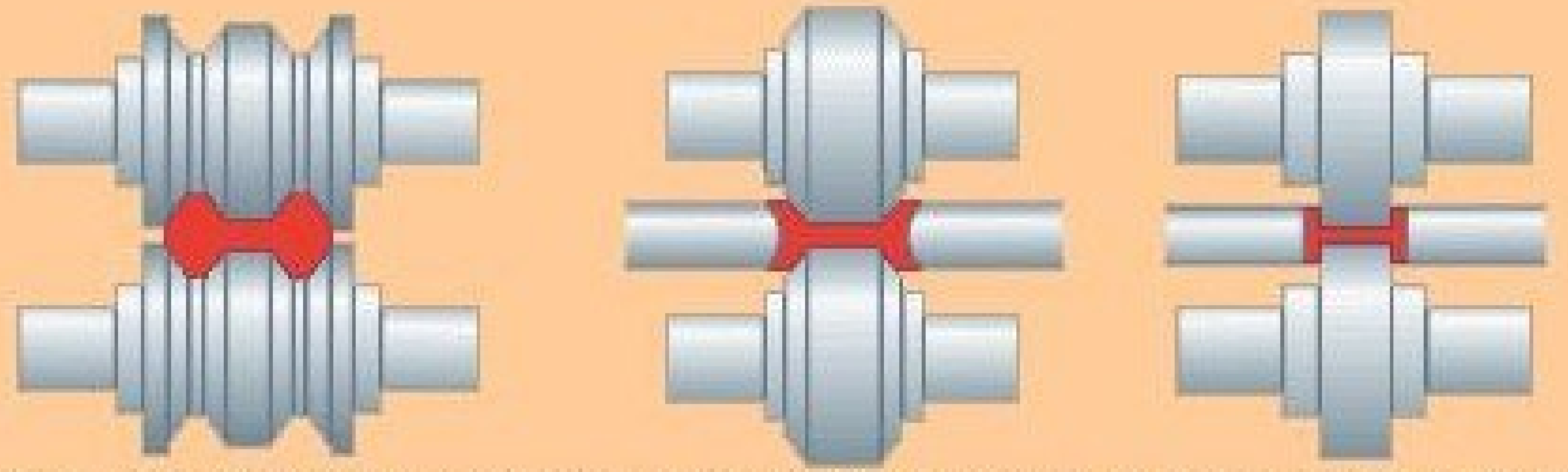

STEEL CONSTRUCTION
MANUAL
AMERICAN INSTITUTE OF STEEL CONSTRUCTION
FIFTEENTH EDITION



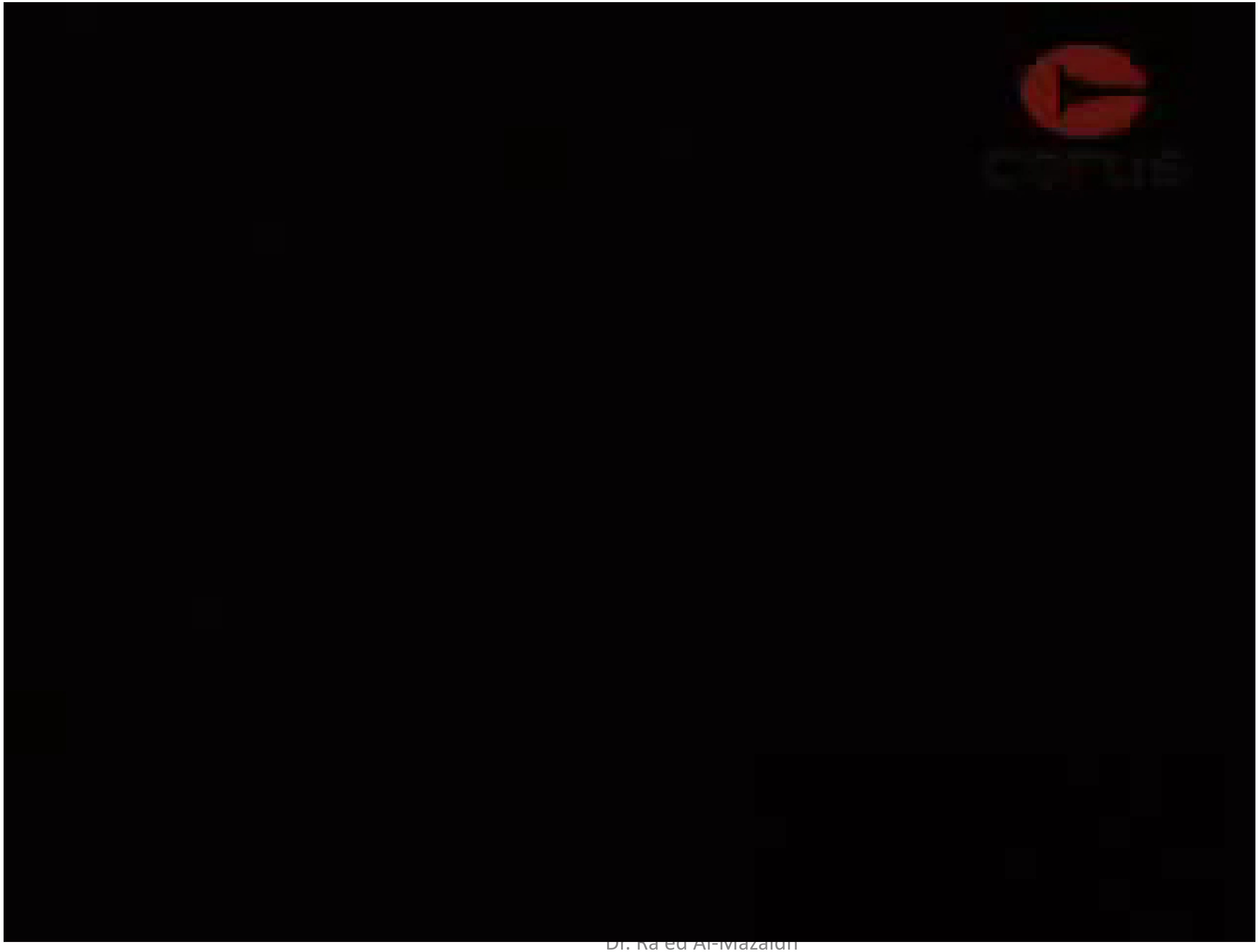
Iron Ore
Coal Injection
Coal
Coke Oven
Coal By-Products
Limestone
Natural Gas
Direct Reduction
Produces solid, metallic iron from iron ore.
Electric Arc Furnace
Produces molten steel.
Recycled Steel
Steel Refining Facility
Basic Oxygen Furnace
Produces molten steel.
Continuous Casting:
Slabs
Thin Slabs
Blooms
Billets
Slag
Molten Iron
Blast Furnace
Produces molten pig iron from iron ore.
Pig Iron Casting


Slabs and Thin Slabs
Plates
Pipe Products
Hot Rolled Sheets
Hot Rolled Coils
Hot Strip Mill
Reheat Furnace
Pickle Line
Pickled and Oiled Coils
Cold Mill
Cold Rolled Coils and Sheets
Heat Treating, Coating and Finishing Lines
Seamless Tube
Structural Mill
Blooms and Billets
Rolling Mill
Bars and Rods

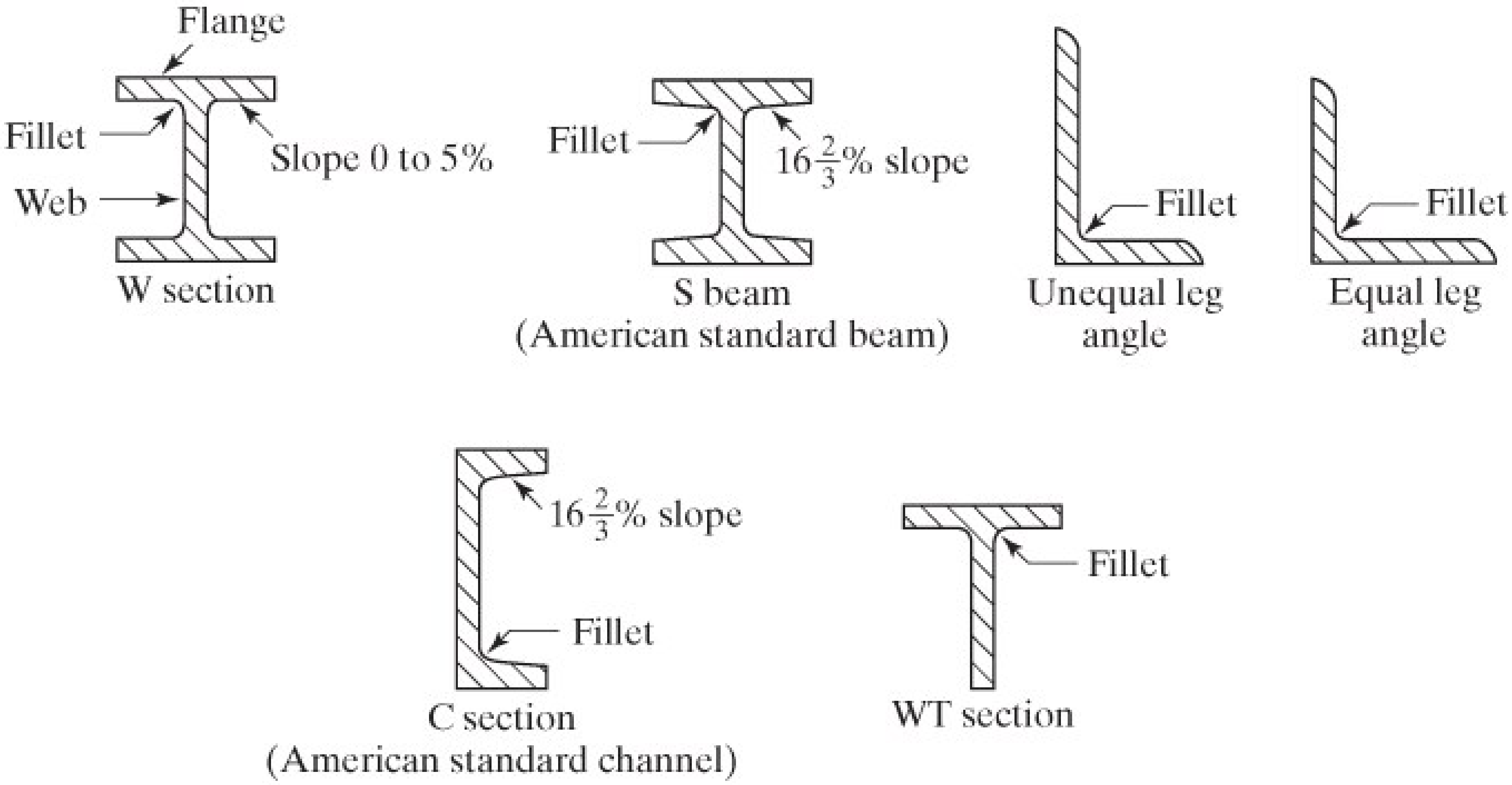

Sheet metal
Roller die
Roll station #1
Roll station #2
Roll station #3
Roll station #4
Roll station #5



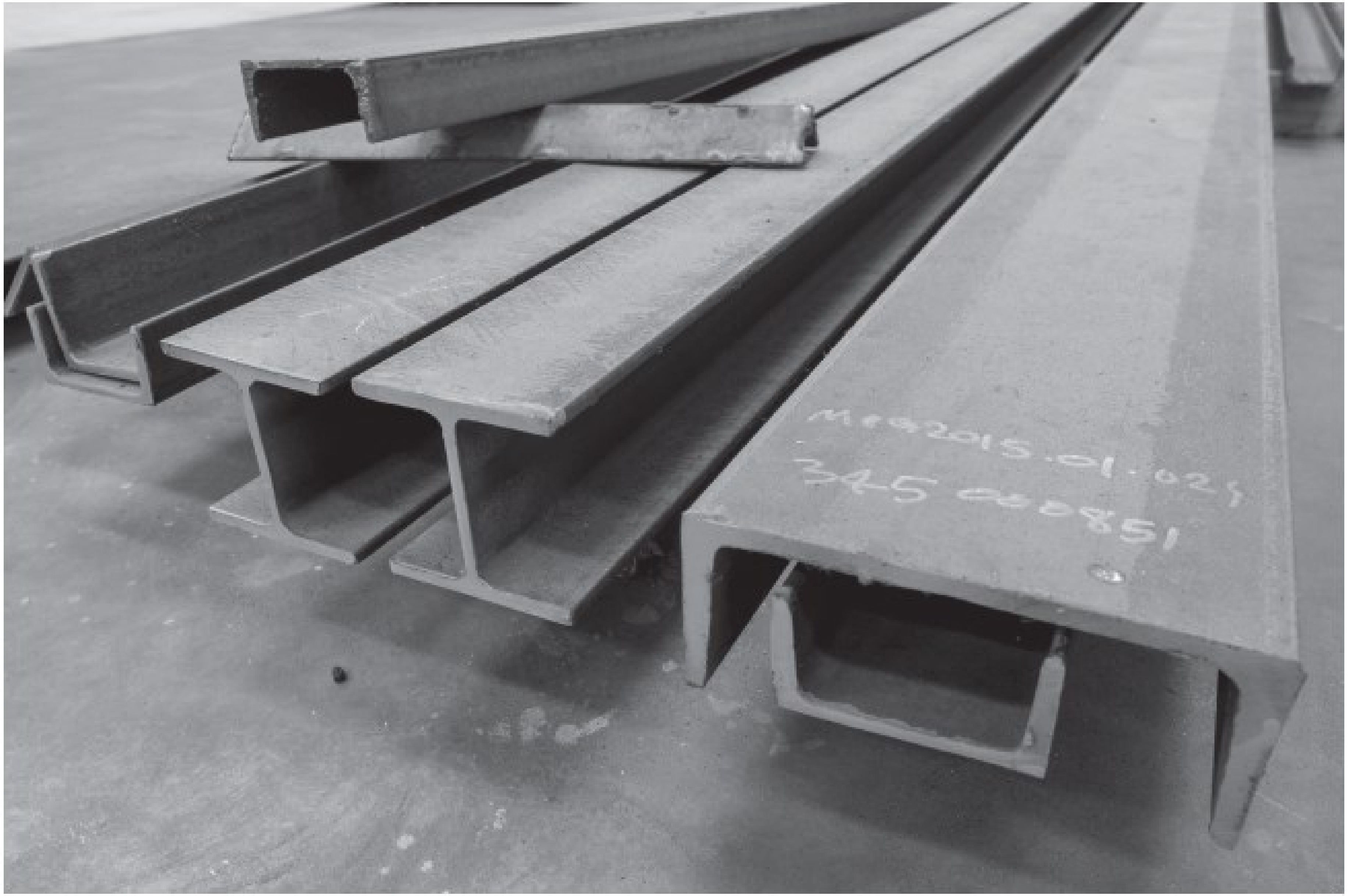
Two-high rolls for shaping of beam blanks into I-beams and H-beams.



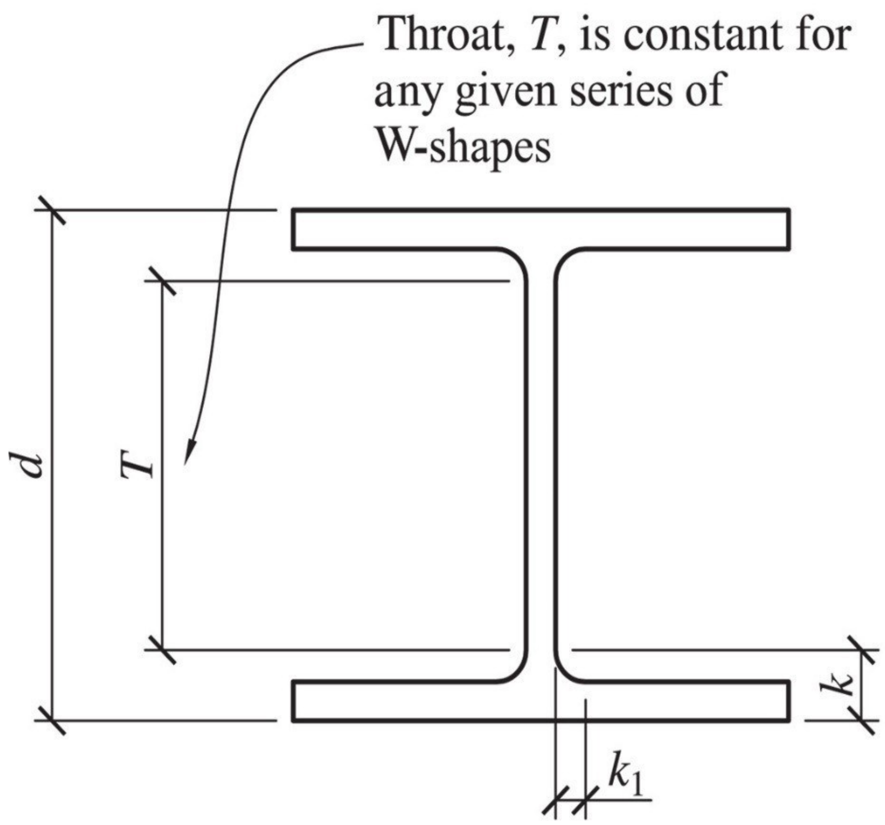
Rolled-steel shapes



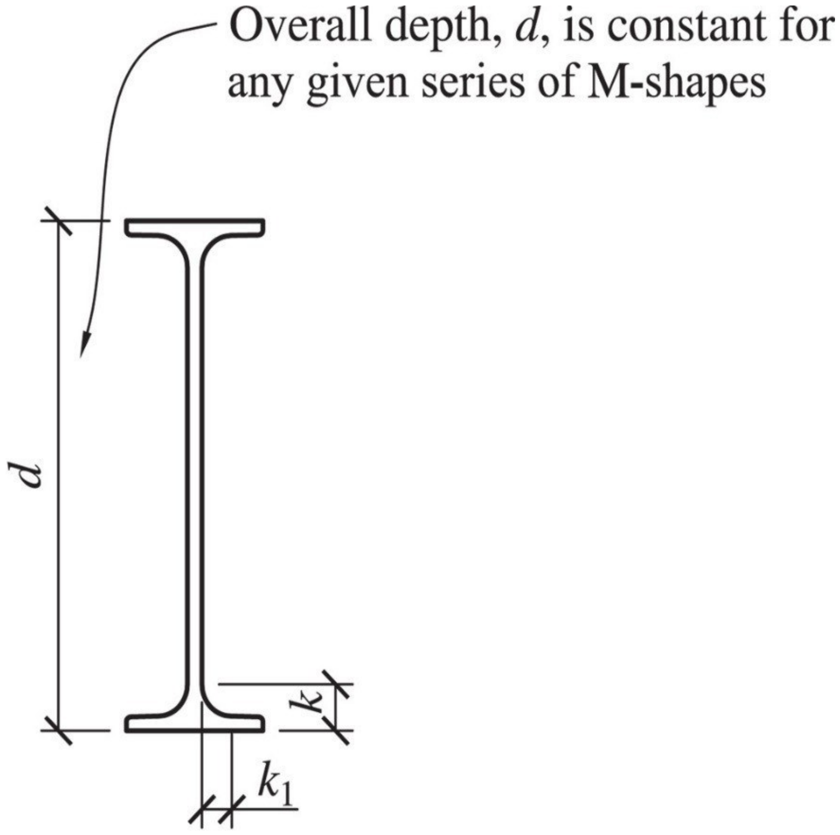
Typical hot-rolled structural steel sections



W-and M-shapes: beams or columns in steel buildings; top and bottom chord members of trusses; diagonal braces in braced frames.

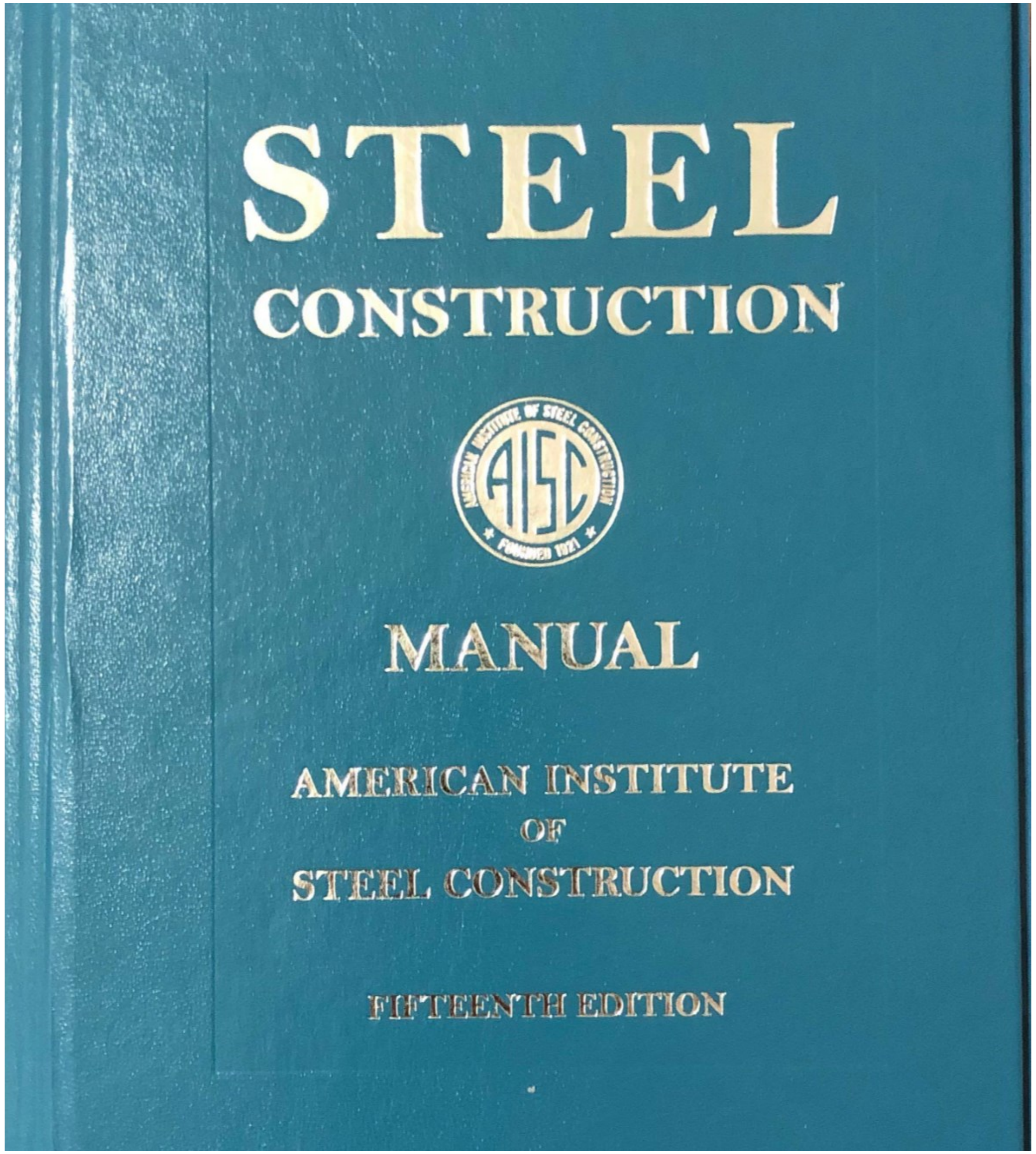


W-shape



M-shape

AISC Manual


STEEL
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FIFTEENTH EDITION

Dimensions and properties **Table 1-1** in the AISC Manual

Example

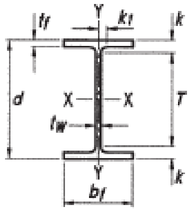


Table 1-1 (continued)
W-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k k_{des}	Distance k k_{det}	Distance k_1	Distance T	Distance Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W14×132	38.8	14.7	14 5/8	0.645	5/8	5/16	14.7	14 3/4	1.03	1	1.63	2 5/16	1 9/16	10	5 1/2
×120	35.3	14.5	14 1/2	0.590	9/16	5/16	14.7	14 5/8	0.940	15/16	1.54	2 1/4	1 1/2		
×109	32.0	14.3	14 3/8	0.525	1/2	1/4	14.6	14 5/8	0.860	7/8	1.46	2 3/16	1 1/2		
×99[f]	29.1	14.2	14 1/8	0.485	1/2	1/4	14.6	14 5/8	0.780	3/4	1.38	2 1/16	1 7/16		
×90[f]	26.5	14.0	14	0.440	7/16	1/4	14.5	14 1/2	0.710	11/16	1.31	2	1 7/16		
W14×82	24.0	14.3	14 1/4	0.510	1/2	1/4	10.1	10 1/8	0.855	7/8	1.45	1 11/16	1 1/16	10 7/8	5 1/2
×74	21.8	14.2	14 1/8	0.450	7/16	1/4	10.1	10 1/8	0.785	13/16	1.38	1 5/8	1 1/16		
×68	20.0	14.0	14	0.415	7/16	1/4	10.0	10	0.720	3/4	1.31	1 9/16	1 1/16		
×61	17.9	13.9	13 7/8	0.375	3/8	3/16	10.0	10	0.645	5/8	1.24	1 1/2	1		
W14×53	15.6	13.9	13 7/8	0.370	3/8	3/16	8.06	8	0.660	11/16	1.25	1 1/2	1	10 7/8	5 1/2
×48	14.1	13.8	13 3/4	0.340	5/16	3/16	8.03	8	0.595	5/8	1.19	1 7/16	1		
×43[c]	12.6	13.7	13 5/8	0.305	5/16	3/16	8.00	8	0.530	1/2	1.12	1 3/8	1		
W14×38[c]	11.2	14.1	14 1/8	0.310	5/16	3/16	6.77	6 3/4	0.515	1/2	0.915	1 1/4	13/16	11 5/8	3 1/2[g]
×34[c]	10.0	14.0	14	0.285	5/16	3/16	6.75	6 3/4	0.455	7/16	0.855	1 3/16	3/4		3 1/2
×30[c]	8.85	13.8	13 7/8	0.270	1/4	1/8	6.73	6 3/4	0.385	3/8	0.785	1 1/8	3/4		3 1/2
W14×26[c]	7.69	13.9	13 7/8	0.255	1/4	1/8	5.03	5	0.420	7/16	0.820	1 1/8	3/4	11 5/8	2 3/4[g]
×22[c]	6.49	13.7	13 3/4	0.230	1/4	1/8	5.00	5	0.335	5/16	0.735	1 1/16	3/4	11 5/8	2 3/4[g]
W12×336[h]	98.9	16.8	16 7/8	1.78	1 3/4	7/8	13.4	13 3/8	2.96	2 15/16	3.55	3 7/8	1 11/16	9 1/8	5 1/2
×305[h]	89.5	16.3	16 3/8	1.63	1 5/8	13/16	13.2	13 1/4	2.71	2 11/16	3.30	3 5/8	1 5/8		
×279[h]	81.9	15.9	15 7/8	1.53	1 1/2	3/4	13.1	13 1/8	2.47	2 1/2	3.07	3 3/8	1 5/8		
×252[h]	74.1	15.4	15 3/8	1.40	1 3/8	11/16	13.0	13	2.25	2 1/4	2.85	3 1/8	1 1/2		
×230[h]	67.7	15.1	15	1.29	1 5/16	11/16	12.9	12 7/8	2.07	2 1/16	2.67	2 15/16	1 1/2		
×210	61.8	14.7	14 3/4	1.18	1 3/16	5/8	12.8	12 3/4	1.90	1 7/8	2.50	2 13/16	1 7/16		
×190	56.0	14.4	14 3/8	1.06	1 1/16	9/16	12.7	12 5/8	1.74	1 3/4	2.33	2 5/8	1 3/8		
×170	50.0	14.0	14	0.960	15/16	1/2	12.6	12 5/8	1.56	1 9/16	2.16	2 7/16	1 5/16		
×152	44.7	13.7	13 3/4	0.870	7/8	7/16	12.5	12 1/2	1.40	1 3/8	2.00	2 5/16	1 1/4		
×136	39.9	13.4	13 3/8	0.790	13/16	7/16	12.4	12 3/8	1.25	1 1/4	1.85	2 1/8	1 1/4		
×120	35.2	13.1	13 1/8	0.710	11/16	3/8	12.3	12 3/8	1.11	1 1/8	1.70	2	1 3/16		
×106	31.2	12.9	12 7/8	0.610	5/8	5/16	12.2	12 1/4	0.990	1	1.59	1 7/8	1 1/8		
×96	28.2	12.7	12 3/4	0.550	9/16	5/16	12.2	12 1/8	0.900	7/8	1.50	1 13/16	1 1/8		
×87	25.6	12.5	12 1/2	0.515	1/2	1/4	12.1	12 1/8	0.810	13/16	1.41	1 11/16	1 1/16		
×79	23.2	12.4	12 3/8	0.470	1/2	1/4	12.1	12 1/8	0.735	3/4	1.33	1 5/8	1 1/16		
×72	21.1	12.3	12 1/4	0.430	7/16	1/4	12.0	12	0.670	11/16	1.27	1 9/16	1 1/16		
×65[f]	19.1	12.1	12 1/8	0.390	3/8	3/16	12.0	12	0.605	5/8	1.20	1 1/2	1		

[c] Shape is slender for compression with $F_y = 50$ ksi.
[f] Shape exceeds compact limit for flexure with $F_y = 50$ ksi.
[g] The actual size, combination and orientation of fastener components should be compared with the geometry of the cross section to ensure compatibility.
[h] Flange thickness greater than 2 in. Special requirements may apply per AISC *Specification* Section A3.1c.

Table 1-1 (continued)
W-Shapes
Properties

W14-W12

Nom-inal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	Compact Section Criteria $\frac{h}{t_w}$	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y Z	r_{ts}	h_o	Torsional Properties J	Torsional Properties C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
132	7.15	17.7	1530	209	6.28	234	548	74.5	3.76	113	4.23	13.7	12.3	25500
120	7.80	19.3	1380	190	6.24	212	495	67.5	3.74	102	4.20	13.6	9.37	22700
109	8.49	21.7	1240	173	6.22	192	447	61.2	3.73	92.7	4.17	13.4	7.12	20200
99	9.34	23.5	1110	157	6.17	173	402	55.2	3.71	83.6	4.14	13.4	5.37	18000
90	10.2	25.9	999	143	6.14	157	362	49.9	3.70	75.6	4.10	13.3	4.06	16000
82	5.92	22.4	881	123	6.05	139	148	29.3	2.48	44.8	2.85	13.4	5.07	6710
74	6.41	25.4	795	112	6.04	126	134	26.6	2.48	40.5	2.83	13.4	3.87	5990
68	6.97	27.5	722	103	6.01	115	121	24.2	2.46	36.9	2.80	13.3	3.01	5380
61	7.75	30.4	640	92.1	5.98	102	107	21.5	2.45	32.8	2.78	13.3	2.19	4710
53	6.11	30.9	541	77.8	5.89	87.1	57.7	14.3	1.92	22.0	2.22	13.2	1.94	2540
48	6.75	33.6	484	70.2	5.85	78.4	51.4	12.8	1.91	19.6	2.20	13.2	1.45	2240
43	7.54	37.4	428	62.6	5.82	69.6	45.2	11.3	1.89	17.3	2.18	13.2	1.05	1950
38	6.57	39.6	385	54.6	5.87	61.5	26.7	7.88	1.55	12.1	1.82	13.6	0.798	1230
34	7.41	43.1	340	48.6	5.83	54.6	23.3	6.91	1.53	10.6	1.80	13.5	0.569	1070
30	8.74	45.4	291	42.0	5.73	47.3	19.6	5.82	1.49	8.99	1.77	13.4	0.380	887
26	5.98	48.1	245	35.3	5.65	40.2	8.91	3.55	1.08	5.54	1.30	13.5	0.358	405
22	7.46	53.3	199	29.0	5.54	33.2	7.00	2.80	1.04	4.39	1.27	13.4	0.208	314
336	2.26	5.47	4060	483	6.41	603	1190	177	3.47	274	4.13	13.8	243	57000
305	2.45	5.98	3550	435	6.29	537	1050	159	3.42	244	4.05	13.6	185	48600
279	2.66	6.35	3110	393	6.16	481	937	143	3.38	220	4.00	13.4	143	42000
252	2.89	6.96	2720	353	6.06	428	828	127	3.34	196	3.93	13.2	108	35800
230	3.11	7.56	2420	321	5.97	386	742	115	3.31	177	3.87	13.0	83.8	31200
210	3.37	8.23	2140	292	5.89	348	664	104	3.28	159	3.81	12.8	64.7	27200
190	3.65	9.16	1890	263	5.82	311	589	93.0	3.25	143	3.77	12.7	48.8	23600
170	4.03	10.1	1650	235	5.74	275	517	82.3	3.22	126	3.70	12.4	35.6	20100
152	4.46	11.2	1430	209	5.66	243	454	72.8	3.19	111	3.66	12.3	25.8	17200
136	4.96	12.3	1240	186	5.58	214	398	64.2	3.16	98.0	3.61	12.2	18.5	14700
120	5.57	13.7	1070	163	5.51	186	345	56.0	3.13	85.4	3.56	12.0	12.9	12400
106	6.17	15.9	933	145	5.47	164	301	49.3	3.11	75.1	3.52	11.9	9.13	10700
96	6.76	17.7	833	131	5.44	147	270	44.4	3.09	67.5	3.49	11.8	6.85	9410
87	7.48	18.9	740	118	5.38	132	241	39.7	3.07	60.4	3.46	11.7	5.10	8270
79	8.22	20.7	662	107	5.34	119	216	35.8	3.05	54.3	3.43	11.7	3.84	7330
72	8.99	22.6	597	97.4	5.31	108	195	32.4	3.04	49.2	3.41	11.6	2.93	6540
65	9.92	24.9	533	87.9	5.28	96.8	174	29.1	3.02	44.1	3.38	11.5	2.18	5780

Dimensions and properties
Table 1-2 in the
AISC Manual

Example

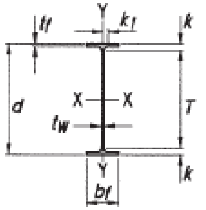


Table 1-2
M-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k	Distance k_1	Distance T	Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.
M12.5×12.4[c,v]	3.63	12.5	12 1/2	0.155	1/8	1/16	3.75	3 3/4	0.228	1/4	9/16	3/8	11 3/8	—
×11.6[c,v]	3.40	12.5	12 1/2	0.155	1/8	1/16	3.50	3 1/2	0.211	3/16	9/16	3/8	11 3/8	—
M12×11.8[c]	3.47	12.0	12	0.177	3/16	1/8	3.07	3 1/8	0.225	1/4	9/16	3/8	10 7/8	—
×10.8[c]	3.18	12.0	12	0.160	3/16	1/8	3.07	3 1/8	0.210	3/16	9/16	3/8	10 7/8	—
M12×10[c,v]	2.95	12.0	12	0.149	1/8	1/16	3.25	3 1/4	0.180	3/16	1/2	3/8	11	—
M10×9[c]	2.65	10.0	10	0.157	3/16	1/8	2.69	2 3/4	0.206	3/16	9/16	3/8	8 7/8	—
×8[c]	2.37	9.95	10	0.141	1/8	1/16	2.69	2 3/4	0.182	3/16	9/16	3/8	8 7/8	—
M10×7.5[c,v]	2.22	9.99	10	0.130	1/8	1/16	2.69	2 3/4	0.173	3/16	7/16	5/16	9 1/8	—
M8×6.5[c]	1.92	8.00	8	0.135	1/8	1/16	2.28	2 1/4	0.189	3/16	9/16	3/8	6 7/8	—
×6.2[c]	1.82	8.00	8	0.129	1/8	1/16	2.28	2 1/4	0.177	3/16	7/16	1/4	7 1/8	—
M6×4.4[c]	1.29	6.00	6	0.114	1/8	1/16	1.84	1 7/8	0.171	3/16	3/8	1/4	5 1/4	—
×3.7[c]	1.09	5.92	5 7/8	0.0980	1/8	1/16	2.00	2	0.129	1/8	5/16	1/4	5 1/4	—
M5×18.9[t]	5.56	5.00	5	0.316	5/16	3/16	5.00	5	0.416	7/16	13/16	1/2	3 3/8	2 3/4[g]
M4×6[f]	1.75	3.80	3 3/4	0.130	1/8	1/16	3.80	3 3/4	0.160	3/16	1/2	3/8	2 3/4	—
×4.08	1.27	4.00	4	0.115	1/8	1/16	2.25	2 1/4	0.170	3/16	9/16	3/8	2 7/8	—
×3.45	1.01	4.00	4	0.0920	1/16	1/16	2.25	2 1/4	0.130	1/8	1/2	3/8	3	—
×3.2	1.01	4.00	4	0.0920	1/16	1/16	2.25	2 1/4	0.130	1/8	1/2	3/8	3	—
M3×2.9	0.914	3.00	3	0.0900	1/16	1/16	2.25	2 1/4	0.130	1/8	1/2	3/8	2	—

[c] Shape is slender for compression with $F_y = 36$ ksi.
[f] Shape exceeds compact limit for flexure with $F_y = 36$ ksi.
[g] The actual size, combination and orientation of fastener components should be compared with the geometry of the cross section to ensure compatibility.
[t] Shape has tapered flanges while other M-shapes have parallel flange surfaces.
[v] Shape does not meet the h/t_w limit for shear in AISC *Specification* Section G2.1(b)(i) with $F_y = 36$ ksi.
— Indicates flange is too narrow to establish a workable gage.

Table 1-2 (continued)
M-Shapes
Properties

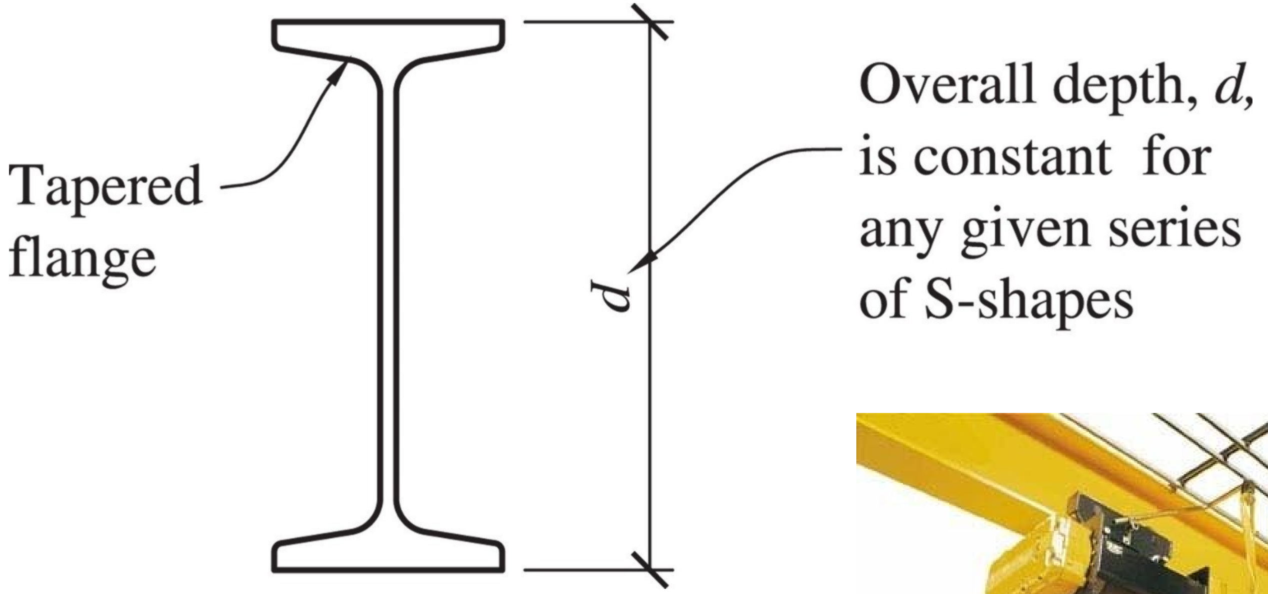
M-SHAPES

Nom-inal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	Compact Section Criteria $\frac{h}{t_w}$	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y Z	r_{ts}	h_o	$\frac{J}{S_x h_o}$	Torsional Properties J	Torsional Properties C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.		in.^{4}	in.^{6}
12.4	8.22	74.8	89.3	14.2	4.96	16.5	2.01	1.07	0.744	1.68	0.933	12.3	0.000283	0.0493	76.0
11.6	8.29	74.8	80.3	12.8	4.86	15.0	1.51	0.864	0.667	1.37	0.852	12.3	0.000263	0.0414	57.1
11.8	6.81	62.5	72.2	12.0	4.56	14.3	1.09	0.709	0.559	1.15	0.731	11.8	0.000355	0.0500	37.7
10.8	7.30	69.2	66.7	11.1	4.58	13.2	1.01	0.661	0.564	1.07	0.732	11.8	0.000300	0.0393	35.0
10	9.03	74.7	61.7	10.3	4.57	12.2	1.03	0.636	0.592	1.02	0.768	11.8	0.000240	0.0292	35.9
9	6.53	58.4	39.0	7.79	3.83	9.22	0.672	0.500	0.503	0.809	0.650	9.79	0.000411	0.0314	16.1
8	7.39	65.0	34.6	6.95	3.82	8.20	0.593	0.441	0.500	0.711	0.646	9.77	0.000328	0.0224	14.2
7.5	7.77	71.0	33.0	6.60	3.85	7.77	0.562	0.418	0.503	0.670	0.646	9.82	0.000289	0.0187	13.5
6.5	6.03	53.8	18.5	4.63	3.11	5.43	0.376	0.329	0.443	0.529	0.563	7.81	0.000509	0.0184	5.73
6.2	6.44	56.5	17.6	4.39	3.10	5.15	0.352	0.308	0.439	0.495	0.560	7.82	0.000455	0.0156	5.38
4.4	5.39	47.0	7.23	2.41	2.36	2.80	0.180	0.195	0.372	0.311	0.467	5.83	0.000707	0.00990	1.53
3.7	7.75	54.7	5.96	2.01	2.34	2.33	0.173	0.173	0.398	0.273	0.499	5.79	0.000459	0.00530	1.45
18.9	6.01	11.2	24.2	9.67	2.08	11.1	8.70	3.48	1.25	5.33	1.44	4.58	0.00709	0.313	45.7
6	11.9	22.0	4.72	2.48	1.64	2.74	1.47	0.771	0.915	1.18	1.04	3.64	0.00208	0.0184	4.87
4.08	6.62	26.4	3.53	1.77	1.67	2.00	0.325	0.289	0.506	0.453	0.593	3.83	0.00218	0.0147	1.19
3.45	8.65	33.9	2.86	1.43	1.68	1.60	0.248	0.221	0.496	0.346	0.580	3.87	0.00148	0.00820	0.930
3.2	8.65	33.9	2.86	1.43	1.68	1.60	0.248	0.221	0.496	0.346	0.580	3.87	0.00148	0.00820	0.930
2.9	8.65	23.6	1.50	1.00	1.28	1.12	0.248	0.221	0.521	0.344	0.597	2.87	0.00275	0.00790	0.511

W- and M-shapes:

W- and M-shapes:

S-shape: hoist beams for the support of monorails



Dimensions and properties Table 1-3 in the AISC Manual

Example →

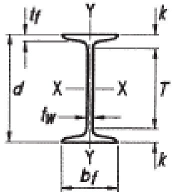


Table 1-3
S-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		$t_w/2$	Flange Width, b_f		Flange Thickness, t_f		Distance k	Distance T	Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.
S24×121	35.5	24.5	24 1/2	0.800	13/16	7/16	8.05	8	1.09	1 1/16	2	20 1/2	4
×106	31.1	24.5	24 1/2	0.620	5/8	5/16	7.87	7 7/8	1.09	1 1/16	2	20 1/2	4
S24×100	29.3	24.0	24	0.745	3/4	3/8	7.25	7 1/4	0.870	7/8	1 3/4	20 1/2	4
×90	26.5	24.0	24	0.625	5/8	5/16	7.13	7 1/8	0.870	7/8	1 3/4	20 1/2	4
×80	23.5	24.0	24	0.500	1/2	1/4	7.00	7	0.870	7/8	1 3/4	20 1/2	4
S20×96	28.2	20.3	20 1/4	0.800	13/16	7/16	7.20	7 1/4	0.920	15/16	1 3/4	16 3/4	4
×86	25.3	20.3	20 1/4	0.660	11/16	3/8	7.06	7	0.920	15/16	1 3/4	16 3/4	4
S20×75	22.0	20.0	20	0.635	5/8	5/16	6.39	6 3/8	0.795	13/16	1 5/8	16 3/4	3 1/2[g]
×66	19.4	20.0	20	0.505	1/2	1/4	6.26	6 1/4	0.795	13/16	1 5/8	16 3/4	3 1/2[g]
S18×70	20.5	18.0	18	0.711	11/16	3/8	6.25	6 1/4	0.691	11/16	1 1/2	15	3 1/2[g]
×54.7	16.0	18.0	18	0.461	7/16	1/4	6.00	6	0.691	11/16	1 1/2	15	3 1/2[g]
S15×50	14.7	15.0	15	0.550	9/16	5/16	5.64	5 5/8	0.622	5/8	1 3/8	12 1/4	3 1/2[g]
×42.9	12.6	15.0	15	0.411	7/16	1/4	5.50	5 1/2	0.622	5/8	1 3/8	12 1/4	3 1/2[g]
S12×50	14.7	12.0	12	0.687	11/16	3/8	5.48	5 1/2	0.659	11/16	1 7/16	9 1/8	3[g]
×40.8	11.9	12.0	12	0.462	7/16	1/4	5.25	5 1/4	0.659	11/16	1 7/16	9 1/8	3[g]
S12×35	10.2	12.0	12	0.428	7/16	1/4	5.08	5 1/8	0.544	9/16	1 3/16	9 5/8	3[g]
×31.8	9.31	12.0	12	0.350	3/8	3/16	5.00	5	0.544	9/16	1 3/16	9 5/8	3[g]
S10×35	10.3	10.0	10	0.594	5/8	5/16	4.94	5	0.491	1/2	1 1/8	7 3/4	2 3/4[g]
×25.4	7.45	10.0	10	0.311	5/16	3/16	4.66	4 5/8	0.491	1/2	1 1/8	7 3/4	2 3/4[g]
S8×23	6.76	8.00	8	0.441	7/16	1/4	4.17	4 1/8	0.425	7/16	1	6	2 1/4[g]
×18.4	5.40	8.00	8	0.271	1/4	1/8	4.00	4	0.425	7/16	1	6	2 1/4[g]
S6×17.25	5.05	6.00	6	0.465	7/16	1/4	3.57	3 5/8	0.359	3/8	13/16	4 3/8	—
×12.5	3.66	6.00	6	0.232	1/4	1/8	3.33	3 3/8	0.359	3/8	13/16	4 3/8	—
S5×10	2.93	5.00	5	0.214	3/16	1/8	3.00	3	0.326	5/16	3/4	3 1/2	—
S4×9.5	2.79	4.00	4	0.326	5/16	3/16	2.80	2 3/4	0.293	5/16	3/4	2 1/2	—
×7.7	2.26	4.00	4	0.193	3/16	1/8	2.66	2 5/8	0.293	5/16	3/4	2 1/2	—
S3×7.5	2.20	3.00	3	0.349	3/8	3/16	2.51	2 1/2	0.260	1/4	5/8	1 3/4	—
×5.7	1.66	3.00	3	0.170	3/16	1/8	2.33	2 3/8	0.260	1/4	5/8	1 3/4	—

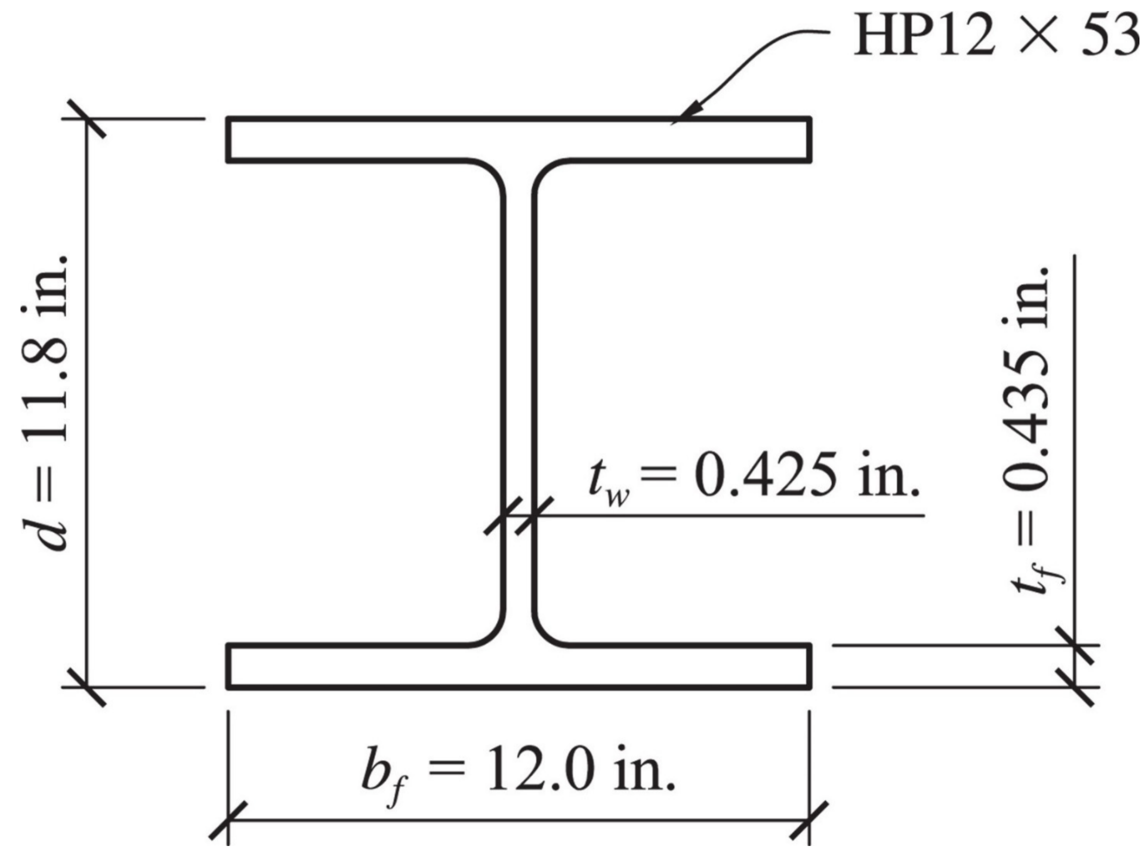
[g] The actual size, combination and orientation of fastener components should be compared with the geometry of the cross section to ensure compatibility.
— Indicates flange is too narrow to establish a workable gage.

Table 1-3 (continued)
S-Shapes
Properties

S-SHAPES

Nom-inal Wt.	Compact Section Criteria $b_f/2t_f$	Compact Section Criteria h/t_w	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y Z	r_{ts}	h_o	Torsional Properties J	Torsional Properties C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
121	3.69	25.9	3160	258	9.43	306	83.0	20.6	1.53	36.3	1.94	23.4	12.8	11400
106	3.61	33.4	2940	240	9.71	279	76.8	19.5	1.57	33.4	1.93	23.4	10.1	10500
100	4.16	27.8	2380	199	9.01	239	47.4	13.1	1.27	24.0	1.66	23.1	7.59	6350
90	4.09	33.1	2250	187	9.21	222	44.7	12.5	1.30	22.4	1.66	23.1	6.05	5980
80	4.02	41.4	2100	175	9.47	204	42.0	12.0	1.34	20.8	1.67	23.1	4.89	5620
96	3.91	21.1	1670	165	7.71	198	49.9	13.9	1.33	24.9	1.71	19.4	8.40	4690
86	3.84	25.6	1570	155	7.89	183	46.6	13.2	1.36	23.1	1.71	19.4	6.65	4370
75	4.02	26.6	1280	128	7.62	152	29.5	9.25	1.16	16.7	1.49	19.2	4.59	2720
66	3.93	33.5	1190	119	7.83	139	27.5	8.78	1.19	15.4	1.49	19.2	3.58	2530
70	4.52	21.5	923	103	6.70	124	24.0	7.69	1.08	14.3	1.42	17.3	4.10	1800
54.7	4.34	33.2	801	89.0	7.07	104	20.7	6.91	1.14	12.1	1.42	17.3	2.33	1550
50	4.53	22.7	485	64.7	5.75	77.0	15.6	5.53	1.03	10.0	1.32	14.4	2.12	805
42.9	4.42	30.4	446	59.4	5.95	69.2	14.3	5.19	1.06	9.08	1.31	14.4	1.54	737
50	4.16	13.7	303	50.6	4.55	60.9	15.6	5.69	1.03	10.3	1.32	11.3	2.77	501
40.8	3.98	20.6	270	45.1	4.76	52.7	13.5	5.13	1.06	8.86	1.30	11.3	1.69	433
35	4.67	23.1	228	38.1	4.72	44.6	9.84	3.88	0.980	6.80	1.22	11.5	1.05	323
31.8	4.60	28.3	217	36.2	4.83	41.8	9.33	3.73	1.00	6.44	1.21	11.5	0.878	306
35	5.03	13.4	147	29.4	3.78	35.4	8.30	3.36	0.899	6.19	1.16	9.51	1.29	188
25.4	4.75	25.6	123	24.6	4.07	28.3	6.73	2.89	0.950	4.99	1.14	9.51	0.603	152
23	4.91	14.1	64.7	16.2	3.09	19.2	4.27	2.05	0.795	3.67	0.999	7.58	0.550	61.2
18.4	4.71	22.9	57.5	14.4	3.26	16.5	3.69	1.84	0.827	3.18	0.985	7.58	0.335	52.9
17.25	4.97	9.67	26.2	8.74	2.28	10.5	2.29	1.28	0.673	2.35	0.859	5.64	0.371	18.2
12.5	4.64	19.4	22.0	7.34	2.45	8.45	1.80	1.08	0.702	1.86	0.831	5.64	0.167	14.3
10	4.61	16.8	12.3	4.90	2.05	5.66	1.19	0.795	0.638	1.37	0.754	4.67	0.114	6.52
9.5	4.77	8.33	6.76	3.38	1.56	4.04	0.887	0.635	0.564	1.13	0.698	3.71	0.120	3.05
7.7	4.54	14.1	6.05	3.03	1.64	3.50	0.748	0.562	0.576	0.970	0.676	3.71	0.0732	2.57
7.5	4.83	5.38	2.91	1.94	1.15	2.35	0.578	0.461	0.513	0.821	0.638	2.74	0.0896	1.08
5.7	4.48	11.0	2.50	1.67	1.23	1.94	0.447	0.383	0.518	0.656	0.605	2.74	0.0433	0.838

HP-shape: bearing pile foundations and soldier piles for lateral support in deep excavations.



Dimensions and properties
Table 1-4 in the
AISC Manual

Example

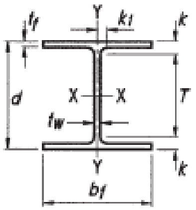


Table 1-4
HP-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k	Distance k_1	Distance T	Distance Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.
HP18×204	60.2	18.3	18 1/4	1.13	1 1/8	9/16	18.1	18 1/8	1.13	1 1/8	2 5/16	1 3/4	13 1/2	7 1/2
×181	53.2	18.0	18	1.00	1	1/2	18.0	18	1.00	1	2 3/16	1 11/16		
×157[f]	46.2	17.7	17 3/4	0.870	7/8	7/16	17.9	17 7/8	0.870	7/8	2 1/16	1 5/8		
×135[f]	39.9	17.5	17 1/2	0.750	3/4	3/8	17.8	17 3/4	0.750	3/4	1 15/16	1 9/16		
HP16×183	54.1	16.5	16 1/2	1.13	1 1/8	9/16	16.3	16 1/2	1.13	1 1/8	2 5/16	1 3/4	11 3/4	5 1/2
×162	47.7	16.3	16 1/4	1.00	1	1/2	16.1	16 1/8	1.00	1	2 3/16	1 11/16		
×141	41.7	16.0	16	0.875	7/8	7/16	16.0	16	0.875	7/8	2 1/16	1 5/8		
×121[f]	35.8	15.8	15 3/4	0.750	3/4	3/8	15.9	15 7/8	0.750	3/4	1 15/16	1 9/16		
×101[f]	29.9	15.5	15 1/2	0.625	5/8	5/16	15.8	15 3/4	0.625	5/8	1 13/16	1 1/2		
×88[c,f]	25.8	15.3	15 3/8	0.540	9/16	5/16	15.7	15 11/16	0.540	9/16	1 3/4	1 7/16		
HP14×117[f]	34.4	14.2	14 1/4	0.805	13/16	7/16	14.9	14 7/8	0.805	13/16	1 1/2	1 1/16	11 1/4	5 1/2
×102[f]	30.1	14.0	14	0.705	11/16	3/8	14.8	14 3/4	0.705	11/16	1 3/8	1		
×89[f]	26.1	13.8	13 7/8	0.615	5/8	5/16	14.7	14 3/4	0.615	5/8	1 5/16	15/16		
×73[c,f]	21.4	13.6	13 5/8	0.505	1/2	1/4	14.6	14 5/8	0.505	1/2	1 3/16	7/8		
HP12×84	24.6	12.3	12 1/4	0.685	11/16	3/8	12.3	12 1/4	0.685	11/16	1 3/8	1	9 1/2	5 1/2
×74[f]	21.8	12.1	12 1/8	0.605	5/8	5/16	12.2	12 1/4	0.610	5/8	1 5/16	15/16		
×63[f]	18.4	11.9	12	0.515	1/2	1/4	12.1	12 1/8	0.515	1/2	1 1/4	7/8		
×53[c,f]	15.5	11.8	11 3/4	0.435	7/16	1/4	12.0	12	0.435	7/16	1 1/8	7/8		
HP10×57	16.7	9.99	10	0.565	9/16	5/16	10.2	10 1/4	0.565	9/16	1 1/4	15/16	7 1/2	5 1/2
×42[f]	12.4	9.70	9 3/4	0.415	7/16	1/4	10.1	10 1/8	0.420	7/16	1 1/8	13/16	7 1/2	5 1/2
HP8×36[f]	10.6	8.02	8	0.445	7/16	1/4	8.16	8 1/8	0.445	7/16	1 1/8	7/8	5 3/4	5 1/2

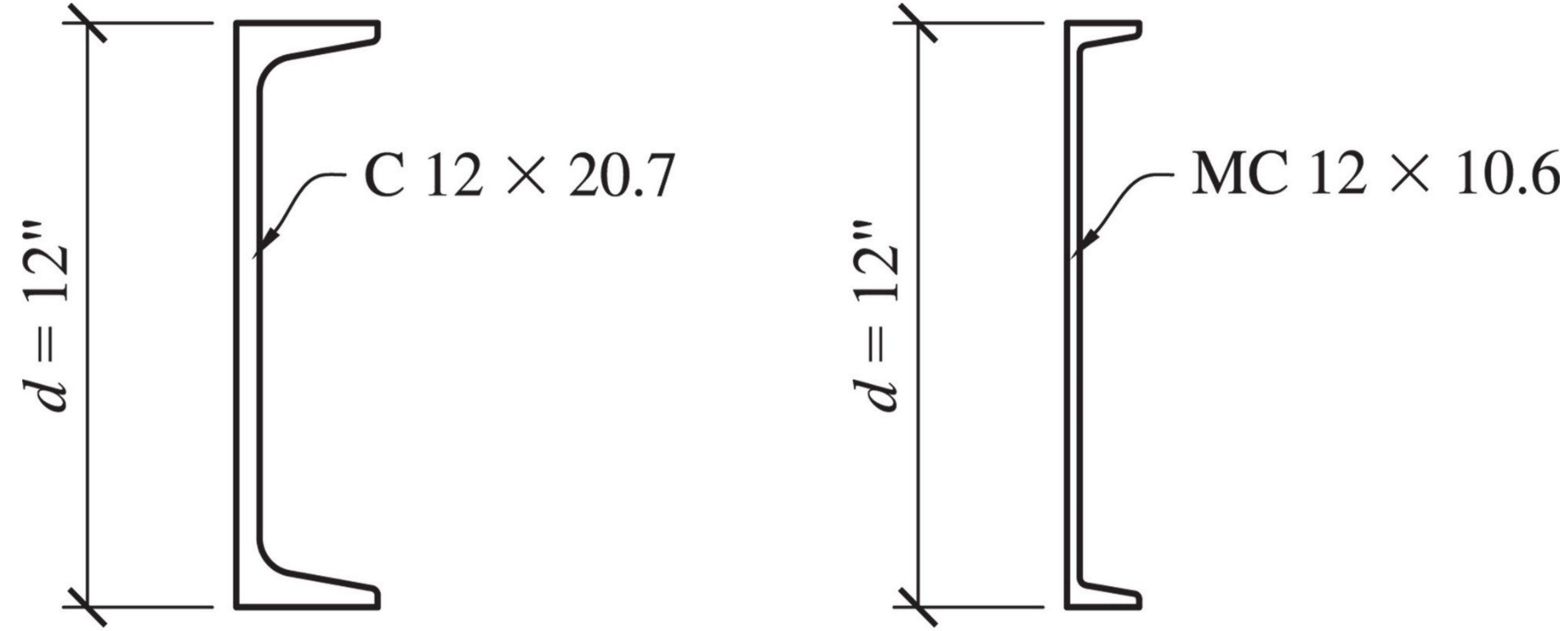
[c] Shape is slender for compression with F_y = 50 ksi.
[f] Shape exceeds compact limit for flexure with F_y = 50 ksi.

Table 1-4 (continued)
HP-Shapes
Properties

HP-SHAPES

Nom-inal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	Compact Section Criteria $\frac{h}{t_w}$	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y Z	r_{ts}	h_o	$\frac{J}{S_x h_o}$	Torsional Properties J	Torsional Properties C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.		in.^{4}	in.^{6}
204	8.01	12.1	3480	380	7.60	433	1120	124	4.31	191	5.03	17.2	0.00451	29.5	82500
181	9.00	13.6	3020	336	7.53	379	974	108	4.28	167	4.96	17.0	0.00362	20.7	70400
157	10.3	15.6	2570	290	7.46	327	833	93.1	4.25	143	4.92	16.8	0.00285	13.9	59000
135	11.9	18.2	2200	251	7.43	281	706	79.3	4.21	122	4.85	16.8	0.00216	9.12	49500
183	7.21	10.5	2510	304	6.81	349	818	100	3.89	156	4.54	15.4	0.00576	26.9	48300
162	8.05	11.9	2190	269	6.78	306	697	86.6	3.82	134	4.45	15.3	0.00457	18.8	40800
141	9.14	13.6	1870	234	6.70	264	599	74.9	3.79	116	4.40	15.1	0.00365	12.9	34300
121	10.6	15.9	1590	201	6.66	226	504	63.4	3.75	97.6	4.34	15.1	0.00275	8.35	28500
101	12.6	19.0	1300	168	6.59	187	412	52.2	3.71	80.1	4.27	14.9	0.00203	5.07	22800
88	14.5	22.0	1110	145	6.56	161	349	44.5	3.68	68.2	4.21	14.8	0.00161	3.45	19000
117	9.25	14.2	1220	172	5.96	194	443	59.5	3.59	91.4	4.15	13.4	0.00348	8.02	19900
102	10.5	16.2	1050	150	5.92	169	380	51.4	3.56	78.8	4.10	13.3	0.00270	5.39	16800
89	11.9	18.5	904	131	5.88	146	326	44.3	3.53	67.7	4.05	13.2	0.00207	3.59	14200
73	14.4	22.6	729	107	5.84	118	261	35.8	3.49	54.6	4.00	13.1	0.00143	2.01	11200
84	8.97	14.2	650	106	5.14	120	213	34.6	2.94	53.2	3.41	11.6	0.00345	4.24	7140
74	10.0	16.1	569	93.8	5.11	105	186	30.4	2.92	46.6	3.38	11.5	0.00276	2.98	6160
63	11.8	18.9	472	79.1	5.06	88.3	153	25.3	2.88	38.7	3.33	11.4	0.00202	1.83	5000
53	13.8	22.3	393	66.7	5.03	74.0	127	21.1	2.86	32.2	3.29	11.4	0.00148	1.12	4080
57	9.03	13.9	294	58.8	4.18	66.5	101	19.7	2.45	30.3	2.84	9.43	0.00355	1.97	2240
42	12.0	18.9	210	43.4	4.13	48.3	71.7	14.2	2.41	21.8	2.77	9.28	0.00202	0.813	1540
36	9.16	14.2	119	29.8	3.36	33.6	40.3	9.88	1.95	15.2	2.26	7.58	0.00341	0.770	578

C- and MC-shapes: beams for light loads



(a) C-shape

(b) MC-shape

Dimensions and properties
Table 1-5 in the AISC Manual

Example

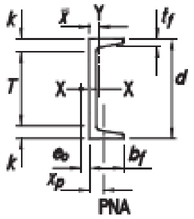


Table 1-5
C-Shapes
Dimensions

Shape	Area, A	Depth, d		Web			Flange				Distance			r_{ts}	h_o
				Thickness, t_w		$\frac{t_w}{2}$	Width, b_f		Average Thickness, t_f		k	T	Workable Gage		
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
C15×50	14.7	15.0	15	0.716	11/16	3/8	3.72	3 3/4	0.650	5/8	1 7/16	12 1/8	2 1/4	1.17	14.4
×40	11.8	15.0	15	0.520	1/2	1/4	3.52	3 1/2	0.650	5/8	1 7/16	12 1/8	2	1.15	14.4
×33.9	10.0	15.0	15	0.400	3/8	3/16	3.40	3 3/8	0.650	5/8	1 7/16	12 1/8	2	1.13	14.4
C12×30	8.81	12.0	12	0.510	1/2	1/4	3.17	3 1/8	0.501	1/2	1 1/8	9 3/4	1 3/4[g]	1.01	11.5
×25	7.34	12.0	12	0.387	3/8	3/16	3.05	3	0.501	1/2	1 1/8	9 3/4	1 3/4[g]	1.00	11.5
×20.7	6.08	12.0	12	0.282	5/16	3/16	2.94	3	0.501	1/2	1 1/8	9 3/4	1 3/4[g]	0.983	11.5
C10×30	8.81	10.0	10	0.673	11/16	3/8	3.03	3	0.436	7/16	1	8	1 3/4[g]	0.924	9.56
×25	7.35	10.0	10	0.526	1/2	1/4	2.89	2 7/8	0.436	7/16	1	8	1 3/4[g]	0.911	9.56
×20	5.87	10.0	10	0.379	3/8	3/16	2.74	2 3/4	0.436	7/16	1	8	1 1/2[g]	0.894	9.56
×15.3	4.48	10.0	10	0.240	1/4	1/8	2.60	2 5/8	0.436	7/16	1	8	1 1/2[g]	0.868	9.56
C9×20	5.87	9.00	9	0.448	7/16	1/4	2.65	2 5/8	0.413	7/16	1	7	1 1/2[g]	0.850	8.59
×15	4.40	9.00	9	0.285	5/16	3/16	2.49	2 1/2	0.413	7/16	1	7	1 3/8[g]	0.825	8.59
×13.4	3.94	9.00	9	0.233	1/4	1/8	2.43	2 3/8	0.413	7/16	1	7	1 3/8[g]	0.814	8.59
C8×18.75	5.51	8.00	8	0.487	1/2	1/4	2.53	2 1/2	0.390	3/8	15/16	6 1/8	1 1/2[g]	0.800	7.61
×13.75	4.03	8.00	8	0.303	5/16	3/16	2.34	2 3/8	0.390	3/8	15/16	6 1/8	1 3/8[g]	0.774	7.61
×11.5	3.37	8.00	8	0.220	1/4	1/8	2.26	2 1/4	0.390	3/8	15/16	6 1/8	1 3/8[g]	0.756	7.61
C7×14.75	4.33	7.00	7	0.419	7/16	1/4	2.30	2 1/4	0.366	3/8	7/8	5 1/4	1 1/4[g]	0.738	6.63
×12.25	3.59	7.00	7	0.314	5/16	3/16	2.19	2 1/4	0.366	3/8	7/8	5 1/4	1 1/4[g]	0.722	6.63
×9.8	2.87	7.00	7	0.210	3/16	1/8	2.09	2 1/8	0.366	3/8	7/8	5 1/4	1 1/4[g]	0.698	6.63
C6×13	3.82	6.00	6	0.437	7/16	1/4	2.16	2 1/8	0.343	5/16	13/16	4 3/8	1 3/8[g]	0.689	5.66
×10.5	3.07	6.00	6	0.314	5/16	3/16	2.03	2	0.343	5/16	13/16	4 3/8	1 1/8[g]	0.669	5.66
×8.2	2.39	6.00	6	0.200	3/16	1/8	1.92	1 7/8	0.343	5/16	13/16	4 3/8	1 1/8[g]	0.643	5.66
C5×9	2.64	5.00	5	0.325	5/16	3/16	1.89	1 7/8	0.320	5/16	3/4	3 1/2	1 1/8[g]	0.616	4.68
×6.7	1.97	5.00	5	0.190	3/16	1/8	1.75	1 3/4	0.320	5/16	3/4	3 1/2	—	0.584	4.68
C4×7.25	2.13	4.00	4	0.321	5/16	3/16	1.72	1 3/4	0.296	5/16	3/4	2 1/2	1[g]	0.563	3.70
×6.25	1.77	4.00	4	0.247	1/4	1/8	1.65	1 3/4	0.272	5/16	3/4	2 1/2	—	0.546	3.73
×5.4	1.58	4.00	4	0.184	3/16	1/8	1.58	1 5/8	0.296	5/16	3/4	2 1/2	—	0.528	3.70
×4.5	1.38	4.00	4	0.125	1/8	1/16	1.58	1 5/8	0.296	5/16	3/4	2 1/2	—	0.524	3.70
C3×6	1.76	3.00	3	0.356	3/8	3/16	1.60	1 5/8	0.273	1/4	11/16	1 5/8	—	0.519	2.73
×5	1.47	3.00	3	0.258	1/4	1/8	1.50	1 1/2	0.273	1/4	11/16	1 5/8	—	0.496	2.73
×4.1	1.20	3.00	3	0.170	3/16	1/8	1.41	1 3/8	0.273	1/4	11/16	1 5/8	—	0.469	2.73
×3.5	1.09	3.00	3	0.132	1/8	1/16	1.37	1 3/8	0.273	1/4	11/16	1 5/8	—	0.456	2.73

[g] The actual size, combination and orientation of fastener components should be compared with the geometry of the cross section to ensure compatibility.
— Indicates flange is too narrow to establish a workable gage.

Table 1-5 (continued)
C-Shapes
Properties

C-SHAPES

Nom-inal Wt.	Shear Ctr, e_o	Axis X-X				Axis Y-Y						Torsional Properties			
		I	S	r	Z	I	S	r	$\bar{x}$	Z	x_p	J	C_w	$\bar{r}_o$	H
lb/ft	in.	in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{6}	in.	
50	0.583	404	53.8	5.24	68.5	11.0	3.77	0.865	0.799	8.14	0.490	2.65	492	5.49	0.937
40	0.767	348	46.5	5.43	57.5	9.17	3.34	0.883	0.778	6.84	0.392	1.45	410	5.71	0.927
33.9	0.896	315	42.0	5.61	50.8	8.07	3.09	0.901	0.788	6.19	0.332	1.01	358	5.94	0.920
30	0.618	162	27.0	4.29	33.8	5.12	2.05	0.762	0.674	4.32	0.367	0.861	151	4.54	0.919
25	0.746	144	24.0	4.43	29.4	4.45	1.87	0.779	0.674	3.82	0.306	0.538	130	4.72	0.909
20.7	0.870	129	21.5	4.61	25.6	3.86	1.72	0.797	0.698	3.47	0.253	0.369	112	4.93	0.899
30	0.368	103	20.7	3.43	26.7	3.93	1.65	0.668	0.649	3.78	0.441	1.22	79.5	3.63	0.921
25	0.494	91.1	18.2	3.52	23.1	3.34	1.47	0.675	0.617	3.18	0.367	0.687	68.3	3.76	0.912
20	0.636	78.9	15.8	3.67	19.4	2.80	1.31	0.690	0.606	2.70	0.294	0.368	56.9	3.93	0.900
15.3	0.796	67.3	13.5	3.88	15.9	2.27	1.15	0.711	0.634	2.34	0.224	0.209	45.5	4.19	0.884
20	0.515	60.9	13.5	3.22	16.9	2.41	1.17	0.640	0.583	2.46	0.326	0.427	39.4	3.46	0.899
15	0.681	51.0	11.3	3.40	13.6	1.91	1.01	0.659	0.586	2.04	0.245	0.208	31.0	3.69	0.882
13.4	0.742	47.8	10.6	3.48	12.6	1.75	0.954	0.666	0.601	1.94	0.219	0.168	28.2	3.79	0.875
18.75	0.431	43.9	11.0	2.82	13.9	1.97	1.01	0.598	0.565	2.17	0.344	0.434	25.1	3.05	0.894
13.75	0.604	36.1	9.02	2.99	11.0	1.52	0.848	0.613	0.554	1.73	0.252	0.186	19.2	3.26	0.874
11.5	0.697	32.5	8.14	3.11	9.63	1.31	0.775	0.623	0.572	1.57	0.211	0.130	16.5	3.41	0.862
14.75	0.441	27.2	7.78	2.51	9.75	1.37	0.772	0.561	0.532	1.63	0.309	0.267	13.1	2.75	0.875
12.25	0.538	24.2	6.92	2.59	8.46	1.16	0.696	0.568	0.525	1.42	0.257	0.161	11.2	2.86	0.862
9.8	0.647	21.2	6.07	2.72	7.19	0.957	0.617	0.578	0.541	1.26	0.205	0.0996	9.15	3.02	0.845
13	0.380	17.3	5.78	2.13	7.29	1.05	0.638	0.524	0.514	1.35	0.318	0.237	7.19	2.37	0.858
10.5	0.486	15.1	5.04	2.22	6.18	0.860	0.561	0.529	0.500	1.14	0.256	0.128	5.91	2.48	0.842
8.2	0.599	13.1	4.35	2.34	5.16	0.687	0.488	0.536	0.512	0.987	0.199	0.0736	4.70	2.65	0.824
9	0.427	8.89	3.56	1.84	4.39	0.624	0.444	0.486	0.478	0.913	0.264	0.109	2.93	2.10	0.815
6.7	0.552	7.48	2.99	1.95	3.55	0.470	0.372	0.489	0.484	0.757	0.215	0.0549	2.22	2.26	0.790
7.25	0.386	4.58	2.29	1.47	2.84	0.425	0.337	0.447	0.459	0.695	0.266	0.0817	1.24	1.75	0.767
6.25	0.434	4.00	2.00	1.50	2.43	0.345	0.284	0.441	0.435	0.569	0.221	0.0487	1.03	1.79	0.764
5.4	0.501	3.85	1.92	1.56	2.29	0.312	0.277	0.444	0.457	0.565	0.231	0.0399	0.921	1.88	0.742
4.5	0.587	3.65	1.83	1.63	2.12	0.289	0.265	0.457	0.493	0.531	0.321	0.0322	0.871	2.01	0.710
6	0.322	2.07	1.38	1.09	1.74	0.300	0.263	0.413	0.455	0.543	0.294	0.0725	0.462	1.40	0.690
5	0.392	1.85	1.23	1.12	1.52	0.241	0.228	0.405	0.439	0.464	0.245	0.0425	0.379	1.45	0.673
4.1	0.461	1.65	1.10	1.18	1.32	0.191	0.196	0.398	0.437	0.399	0.262	0.0269	0.307	1.53	0.655
3.5	0.493	1.57	1.04	1.20	1.24	0.169	0.182	0.394	0.443	0.364	0.296	0.0226	0.276	1.57	0.646

Dimensions and properties
Table 1-6 in the
AISC Manual

Example ➡

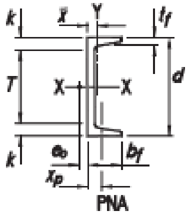
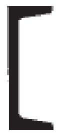


Table 1-6
MC-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Average Thickness, t_f		Distance k	Distance T	Distance Workable Gage	r_{ts}	h_o
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
MC18×58	17.1	18.0	18	0.700	11/16	3/8	4.20	4 1/4	0.625	5/8	1 7/16	15 1/8	2 1/2	1.35	17.4
×51.9	15.3	18.0	18	0.600	5/8	5/16	4.10	4 1/8	0.625	5/8	1 7/16	↓	↓	1.35	17.4
×45.8	13.5	18.0	18	0.500	1/2	1/4	4.00	4	0.625	5/8	1 7/16			1.34	17.4
×42.7	12.6	18.0	18	0.450	7/16	1/4	3.95	4	0.625	5/8	1 7/16			1.34	17.4
MC13×50	14.7	13.0	13	0.787	13/16	7/16	4.41	4 3/8	0.610	5/8	1 7/16	10 1/8	2 1/2	1.41	12.4
×40	11.7	13.0	13	0.560	9/16	5/16	4.19	4 1/8	0.610	5/8	1 7/16	↓	↓	1.38	12.4
×35	10.3	13.0	13	0.447	7/16	1/4	4.07	4 1/8	0.610	5/8	1 7/16			1.35	12.4
×31.8	9.35	13.0	13	0.375	3/8	3/16	4.00	4	0.610	5/8	1 7/16			1.34	12.4
MC12×50	14.7	12.0	12	0.835	13/16	7/16	4.14	4 1/8	0.700	11/16	1 5/16	9 3/8	2 1/2	1.37	11.3
×45	13.2	12.0	12	0.710	11/16	3/8	4.01	4	0.700	11/16	1 5/16	↓	↓	1.35	11.3
×40	11.8	12.0	12	0.590	9/16	5/16	3.89	3 7/8	0.700	11/16	1 5/16			1.33	11.3
×35	10.3	12.0	12	0.465	7/16	1/4	3.77	3 3/4	0.700	11/16	1 5/16			1.30	11.3
×31	9.12	12.0	12	0.370	3/8	3/16	3.67	3 5/8	0.700	11/16	1 5/16		2 1/4	1.28	11.3
MC12×14.3	4.18	12.0	12	0.250	1/4	1/8	2.12	2 1/8	0.313	5/16	3/4	10 1/2	1 1/4[g]	0.672	11.7
MC12×10.6[c]	3.10	12.0	12	0.190	3/16	1/8	1.50	1 1/2	0.309	5/16	3/4	10 1/2	—	0.478	11.7
MC10×41.1	12.1	10.0	10	0.796	13/16	7/16	4.32	4 3/8	0.575	9/16	1 5/16	7 3/8	2 1/2[g]	1.44	9.43
×33.6	9.87	10.0	10	0.575	9/16	5/16	4.10	4 1/8	0.575	9/16	1 5/16	7 3/8	2 1/2[g]	1.40	9.43
×28.5	8.37	10.0	10	0.425	7/16	1/4	3.95	4	0.575	9/16	1 5/16	7 3/8	2 1/2[g]	1.36	9.43
MC10×25	7.34	10.0	10	0.380	3/8	3/16	3.41	3 3/8	0.575	9/16	1 5/16	7 3/8	2[g]	1.17	9.43
×22	6.45	10.0	10	0.290	5/16	3/16	3.32	3 3/8	0.575	9/16	1 5/16	7 3/8	2[g]	1.14	9.43
MC10×8.4[c]	2.46	10.0	10	0.170	3/16	1/8	1.50	1 1/2	0.280	1/4	3/4	8 1/2	—	0.486	9.72
×6.5[c]	1.95	10.0	10	0.152	1/8	1/16	1.17	1 1/8	0.202	3/16	9/16	8 7/8	—	0.363	9.80
MC9×25.4	7.47	9.00	9	0.450	7/16	1/4	3.50	3 1/2	0.550	9/16	1 1/4	6 1/2	2[g]	1.20	8.45
×23.9	7.02	9.00	9	0.400	3/8	3/16	3.45	3 1/2	0.550	9/16	1 1/4	6 1/2	2[g]	1.18	8.45
MC8×22.8	6.70	8.00	8	0.427	7/16	1/4	3.50	3 1/2	0.525	1/2	1 3/16	5 5/8	2[g]	1.20	7.48
×21.4	6.28	8.00	8	0.375	3/8	3/16	3.45	3 1/2	0.525	1/2	1 3/16	5 5/8	2[g]	1.18	7.48
MC8×20	5.87	8.00	8	0.400	3/8	3/16	3.03	3	0.500	1/2	1 1/8	5 3/4	2[g]	1.03	7.50
×18.7	5.50	8.00	8	0.353	3/8	3/16	2.98	3	0.500	1/2	1 1/8	5 3/4	2[g]	1.02	7.50
MC8×8.5	2.50	8.00	8	0.179	3/16	1/8	1.87	1 7/8	0.311	5/16	13/16	6 3/8	1 1/8[g]	0.624	7.69

[c] Shape is slender for compression with $F_y = 36$ ksi.
[g] The actual size, combination and orientation of fastener components should be compared with the geometry of the cross section to ensure compatibility.
— Indicates flange is too narrow to establish a workable gage.

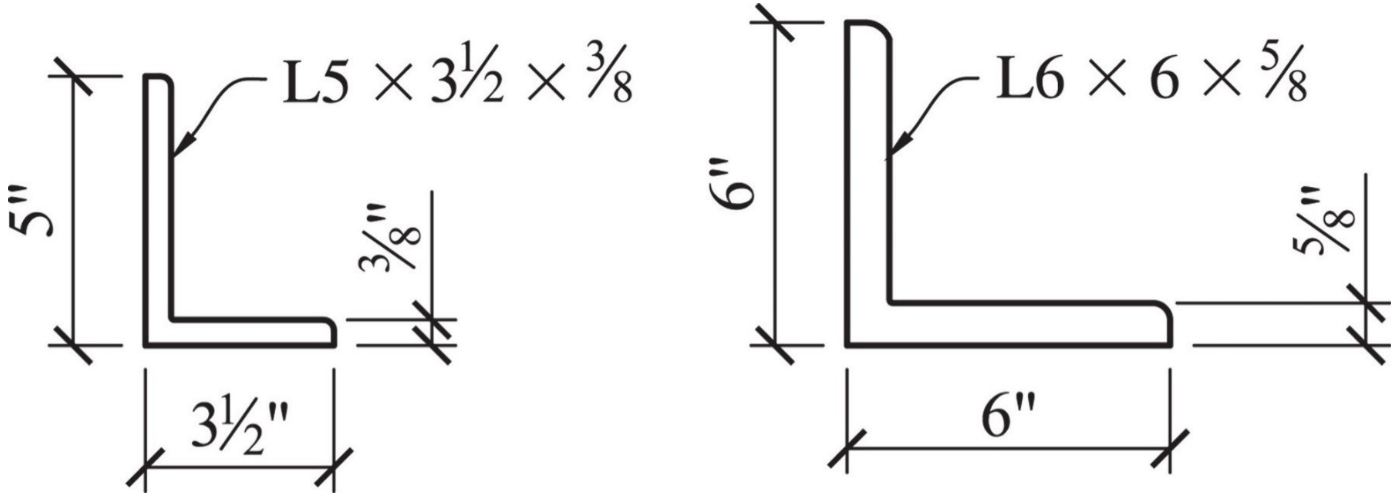
Table 1-6 (continued)
MC-Shapes
Properties



MC18-MC8

Nominal Wt.	Shear Ctr, e_o	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y $\bar{x}$	Axis Y-Y Z	Axis Y-Y x_p	Torsional J	Torsional C_w	Torsional $\bar{r}_o$	Torsional H
lb/ft	in.	in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{6}	in.	
58	0.695	675	75.0	6.29	95.4	17.6	5.28	1.02	0.862	10.7	0.474	2.81	1070	6.56	0.944
51.9	0.797	627	69.6	6.41	87.3	16.3	5.02	1.03	0.858	9.86	0.424	2.03	985	6.70	0.939
45.8	0.909	578	64.2	6.55	79.2	14.9	4.77	1.05	0.866	9.14	0.374	1.45	897	6.87	0.933
42.7	0.969	554	61.5	6.64	75.1	14.3	4.64	1.07	0.877	8.82	0.349	1.23	852	6.97	0.930
50	0.815	314	48.3	4.62	60.8	16.4	4.77	1.06	0.974	10.2	0.566	2.96	558	5.07	0.875
40	1.03	273	41.9	4.82	51.2	13.7	4.24	1.08	0.963	8.66	0.452	1.55	462	5.32	0.859
35	1.16	252	38.8	4.95	46.5	12.3	3.97	1.09	0.980	8.04	0.396	1.13	412	5.50	0.849
31.8	1.24	239	36.7	5.05	43.4	11.4	3.79	1.10	1.00	7.69	0.360	0.937	380	5.64	0.842
50	0.741	269	44.9	4.28	56.5	17.4	5.64	1.09	1.05	10.9	0.613	3.23	411	4.77	0.859
45	0.844	251	41.9	4.36	52.0	15.8	5.30	1.09	1.04	10.1	0.550	2.33	373	4.88	0.851
40	0.952	234	39.0	4.46	47.7	14.2	4.98	1.10	1.04	9.31	0.490	1.69	336	5.01	0.842
35	1.07	216	36.0	4.59	43.2	12.6	4.64	1.11	1.05	8.62	0.428	1.24	297	5.18	0.831
31	1.17	202	33.7	4.71	39.7	11.3	4.37	1.11	1.08	8.15	0.425	1.00	267	5.34	0.822
14.3	0.435	76.1	12.7	4.27	15.9	1.00	0.574	0.489	0.377	1.21	0.174	0.117	32.8	4.37	0.965
10.6	0.284	55.3	9.22	4.22	11.6	0.378	0.307	0.349	0.269	0.635	0.129	0.0596	11.7	4.27	0.983
41.1	0.864	157	31.5	3.61	39.3	15.7	4.85	1.14	1.09	9.49	0.604	2.26	269	4.26	0.790
33.6	1.06	139	27.8	3.75	33.7	13.1	4.35	1.15	1.09	8.28	0.494	1.20	224	4.47	0.770
28.5	1.21	126	25.3	3.89	30.0	11.3	3.99	1.16	1.12	7.59	0.419	0.791	193	4.68	0.752
25	1.03	110	22.0	3.87	26.2	7.25	2.96	0.993	0.953	5.65	0.367	0.638	124	4.46	0.803
22	1.12	102	20.5	3.99	23.9	6.40	2.75	0.997	0.990	5.29	0.467	0.510	110	4.62	0.791
8.4	0.332	31.9	6.39	3.61	7.92	0.326	0.268	0.364	0.284	0.548	0.123	0.0413	7.00	3.68	0.972
6.5	0.182	22.9	4.59	3.43	5.90	0.133	0.137	0.262	0.194	0.284	0.0975	0.0191	2.76	3.46	0.988
25.4	0.986	87.9	19.5	3.43	23.5	7.57	2.99	1.01	0.970	5.70	0.415	0.691	104	4.08	0.770
23.9	1.04	84.9	18.9	3.48	22.5	7.14	2.89	1.01	0.981	5.51	0.390	0.599	98.0	4.15	0.763
22.8	1.04	63.8	15.9	3.09	19.1	7.01	2.81	1.02	1.01	5.37	0.419	0.572	75.2	3.84	0.715
21.4	1.09	61.5	15.4	3.13	18.2	6.58	2.71	1.02	1.02	5.18	0.452	0.495	70.8	3.91	0.707
20	0.843	54.4	13.6	3.04	16.4	4.42	2.02	0.867	0.840	3.86	0.367	0.441	47.8	3.58	0.779
18.7	0.889	52.4	13.1	3.09	15.6	4.15	1.95	0.868	0.849	3.72	0.344	0.380	45.0	3.65	0.773
8.5	0.542	23.3	5.82	3.05	6.95	0.624	0.431	0.500	0.428	0.875	0.156	0.0587	8.21	3.24	0.910

Angle shapes: lintels to support brick cladding and block wall cladding; members in trusses



Dimensions and properties Table 1-7 in the AISC Manual

Example

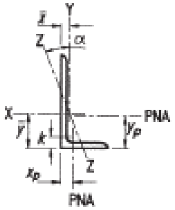


Table 1-7
Angles
Properties

Shape	k	Wt.	Area, A	Axis X-X						Flexural-Torsional Properties		
				I	S	r	$\bar{y}$	Z	y_p	J	C_w	$\bar{r}_o$
	in.	lb/ft	in.^{2}	in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{6}	in.
L8×8×$1\frac{1}{8}$	$1\frac{3}{4}$	56.9	16.8	98.1	17.5	2.41	2.40	31.6	1.05	7.13	32.5	4.29
×1	$1\frac{5}{8}$	51.0	15.1	89.1	15.8	2.43	2.36	28.5	0.944	5.08	23.4	4.32
×$\frac{7}{8}$	$1\frac{1}{2}$	45.0	13.3	79.7	14.0	2.45	2.31	25.3	0.831	3.46	16.1	4.36
×$\frac{3}{4}$	$1\frac{3}{8}$	38.9	11.5	69.9	12.2	2.46	2.26	22.0	0.719	2.21	10.4	4.39
×$\frac{5}{8}$	$1\frac{1}{4}$	32.7	9.69	59.6	10.3	2.48	2.21	18.6	0.606	1.30	6.16	4.42
×$\frac{9}{16}$	$1\frac{3}{16}$	29.6	8.77	54.2	9.33	2.49	2.19	16.8	0.548	0.961	4.55	4.43
×$\frac{1}{2}$	$1\frac{1}{8}$	26.4	7.84	48.8	8.36	2.49	2.17	15.1	0.490	0.683	3.23	4.45
L8×6×1	$1\frac{1}{2}$	44.2	13.1	80.9	15.1	2.49	2.65	27.3	1.45	4.34	16.3	3.88
×$\frac{7}{8}$	$1\frac{3}{8}$	39.1	11.5	72.4	13.4	2.50	2.60	24.3	1.43	2.96	11.3	3.92
×$\frac{3}{4}$	$1\frac{1}{4}$	33.8	9.99	63.5	11.7	2.52	2.55	21.1	1.34	1.90	7.28	3.95
×$\frac{5}{8}$	$1\frac{1}{8}$	28.5	8.41	54.2	9.86	2.54	2.50	17.9	1.27	1.12	4.33	3.98
×$\frac{9}{16}$	$1\frac{1}{16}$	25.7	7.61	49.4	8.94	2.55	2.48	16.2	1.24	0.823	3.20	3.99
×$\frac{1}{2}$	1	23.0	6.80	44.4	8.01	2.55	2.46	14.6	1.20	0.584	2.28	4.01
×$\frac{7}{16}$	$\frac{15}{16}$	20.2	5.99	39.3	7.06	2.56	2.43	12.9	1.15	0.396	1.55	4.02
L8×4×1	$1\frac{1}{2}$	37.4	11.1	69.7	14.0	2.51	3.03	24.3	2.45	3.68	12.9	3.75
×$\frac{7}{8}$	$1\frac{3}{8}$	33.1	9.79	62.6	12.5	2.53	2.99	21.7	2.41	2.51	8.89	3.78
×$\frac{3}{4}$	$1\frac{1}{4}$	28.7	8.49	55.0	10.9	2.55	2.94	18.9	2.34	1.61	5.75	3.80
×$\frac{5}{8}$	$1\frac{1}{8}$	24.2	7.16	47.0	9.20	2.56	2.89	16.1	2.27	0.955	3.42	3.83
×$\frac{9}{16}$	$1\frac{1}{16}$	21.9	6.49	42.9	8.34	2.57	2.86	14.6	2.23	0.704	2.53	3.84
×$\frac{1}{2}$	1	19.6	5.80	38.6	7.48	2.58	2.84	13.1	2.20	0.501	1.80	3.86
×$\frac{7}{16}$	$\frac{15}{16}$	17.2	5.11	34.2	6.59	2.59	2.81	11.6	2.16	0.340	1.22	3.87
L7×4×$\frac{3}{4}$	$1\frac{1}{4}$	26.2	7.74	37.8	8.39	2.21	2.50	14.8	1.84	1.47	3.97	3.31
×$\frac{5}{8}$	$1\frac{1}{8}$	22.1	6.50	32.4	7.12	2.23	2.45	12.5	1.80	0.868	2.37	3.34
×$\frac{1}{2}$	1	17.9	5.26	26.6	5.79	2.25	2.40	10.2	1.74	0.456	1.25	3.37
×$\frac{7}{16}$	$\frac{15}{16}$	15.7	4.63	23.6	5.11	2.26	2.38	9.03	1.71	0.310	0.851	3.38
×$\frac{3}{8}$	$\frac{7}{8}$	13.6	4.00	20.5	4.42	2.27	2.35	7.81	1.67	0.198	0.544	3.40
L6×6×1	$1\frac{1}{2}$	37.4	11.0	35.4	8.55	1.79	1.86	15.4	0.917	3.68	9.24	3.18
×$\frac{7}{8}$	$1\frac{3}{8}$	33.1	9.75	31.9	7.61	1.81	1.81	13.7	0.813	2.51	6.41	3.21
×$\frac{3}{4}$	$1\frac{1}{4}$	28.7	8.46	28.1	6.64	1.82	1.77	11.9	0.705	1.61	4.17	3.24
×$\frac{5}{8}$	$1\frac{1}{8}$	24.2	7.13	24.1	5.64	1.84	1.72	10.1	0.594	0.955	2.50	3.28
×$\frac{9}{16}$	$1\frac{1}{16}$	21.9	6.45	22.0	5.12	1.85	1.70	9.18	0.538	0.704	1.85	3.29
×$\frac{1}{2}$	1	19.6	5.77	19.9	4.59	1.86	1.67	8.22	0.481	0.501	1.32	3.31
×$\frac{7}{16}$	$\frac{15}{16}$	17.2	5.08	17.6	4.06	1.86	1.65	7.25	0.423	0.340	0.899	3.32
×$\frac{3}{8}$	$\frac{7}{8}$	14.9	4.38	15.4	3.51	1.87	1.62	6.27	0.365	0.218	0.575	3.34
×$\frac{5}{16}$	$\frac{13}{16}$	12.4	3.67	13.0	2.95	1.88	1.60	5.26	0.306	0.129	0.338	3.35

Note: For workable gages, refer to Table 1-7A. For compactness criteria, refer to Table 1-7B.

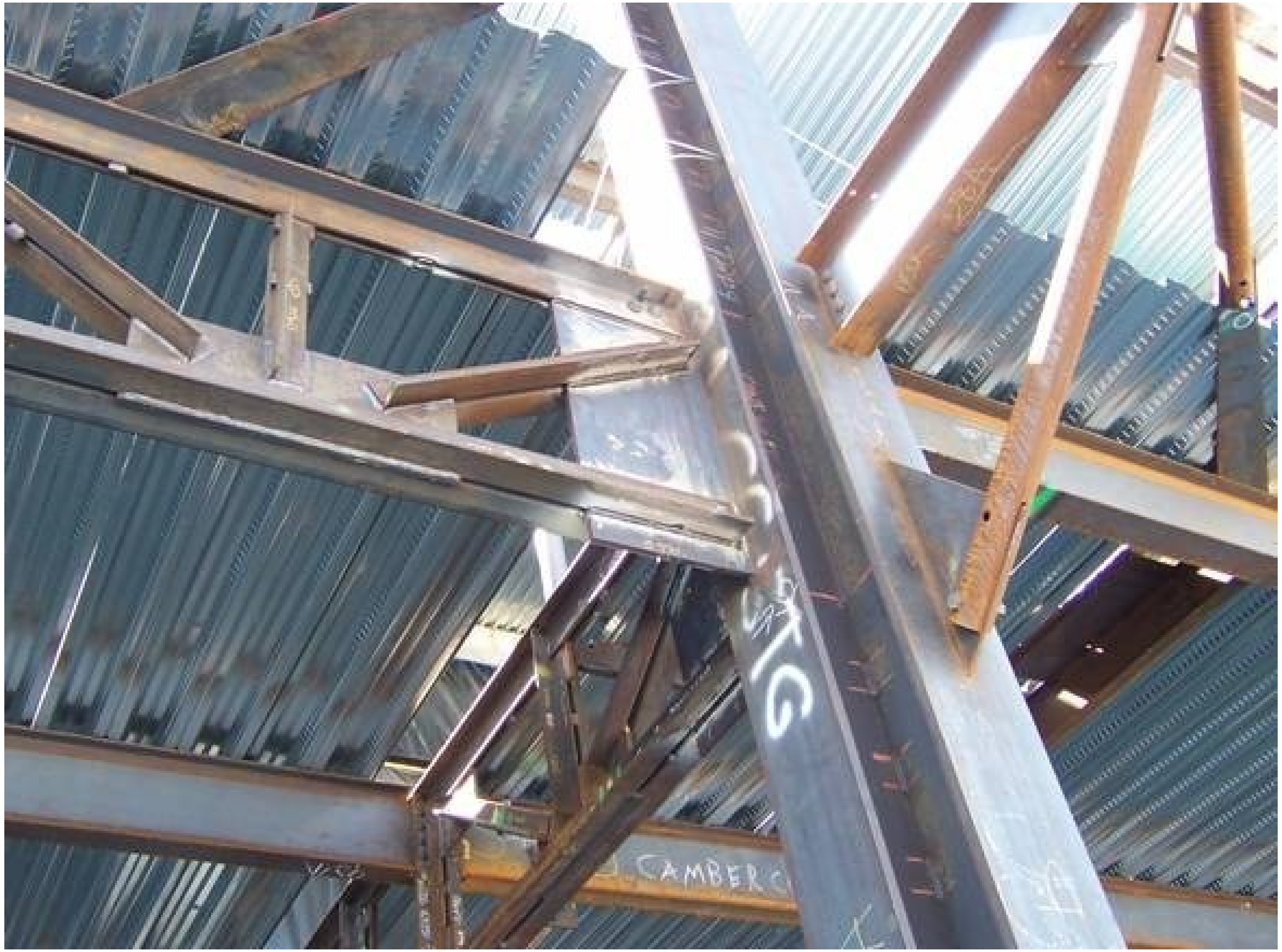
Table 1-7 (continued)
Angles
Properties

L8-L6

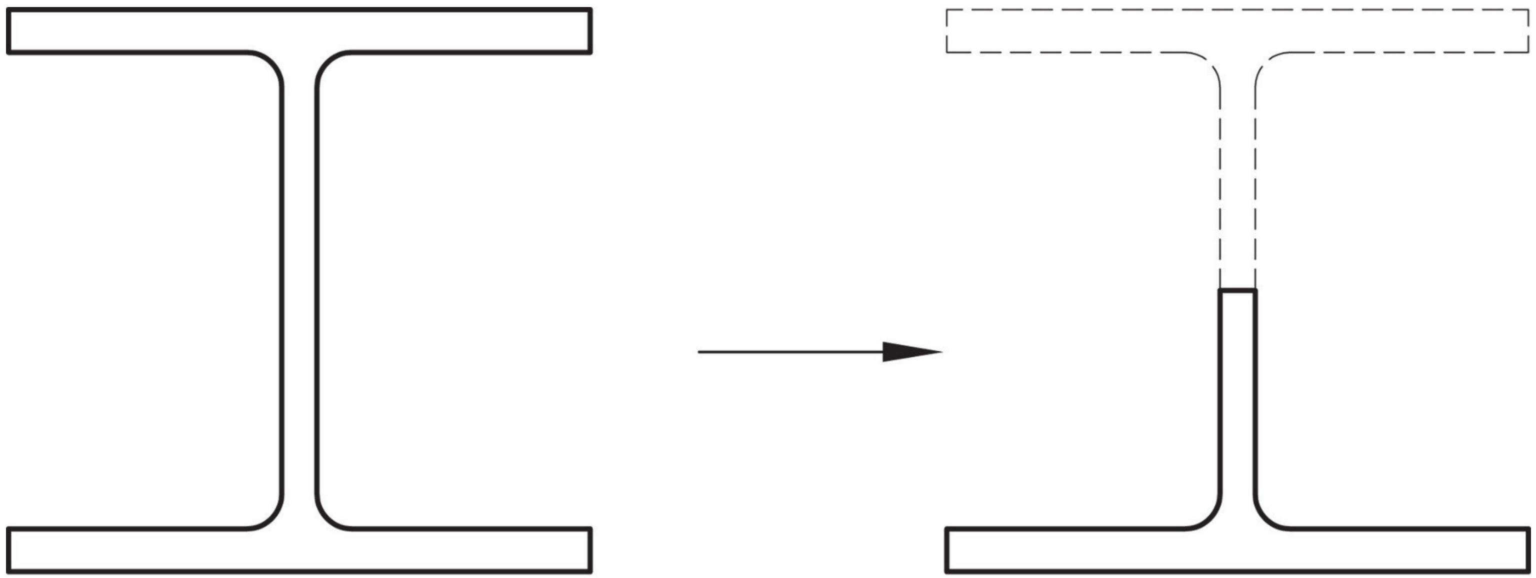
Shape	Axis Y-Y						Axis Z-Z				Q_s
	I	S	r	$\bar{x}$	Z	x_p	I	S	r	Tan α	F_y = 36 ksi
	in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{3}	in.		
L8×8×$1\frac{1}{8}$	98.1	17.5	2.41	2.40	31.6	1.05	40.7	12.0	1.56	1.00	1.00
×1	89.1	15.8	2.43	2.36	28.5	0.944	36.8	11.0	1.56	1.00	1.00
×$\frac{7}{8}$	79.7	14.0	2.45	2.31	25.3	0.831	32.7	10.0	1.57	1.00	1.00
×$\frac{3}{4}$	69.9	12.2	2.46	2.26	22.0	0.719	28.5	8.90	1.57	1.00	1.00
×$\frac{5}{8}$	59.6	10.3	2.48	2.21	18.6	0.606	24.2	7.72	1.58	1.00	0.997
×$\frac{9}{16}$	54.2	9.33	2.49	2.19	16.8	0.548	21.9	7.09	1.58	1.00	0.959
×$\frac{1}{2}$	48.8	8.36	2.49	2.17	15.1	0.490	19.8	6.44	1.59	1.00	0.912
L8×6×1	38.8	8.92	1.72	1.65	16.2	0.819	21.3	7.60	1.28	0.542	1.00
×$\frac{7}{8}$	34.9	7.94	1.74	1.60	14.4	0.719	18.9	6.71	1.28	0.546	1.00
×$\frac{3}{4}$	30.8	6.92	1.75	1.56	12.5	0.624	16.6	5.82	1.29	0.550	1.00
×$\frac{5}{8}$	26.4	5.88	1.77	1.51	10.5	0.526	14.1	4.91	1.29	0.554	0.997
×$\frac{9}{16}$	24.1	5.34	1.78	1.49	9.52	0.476	12.8	4.45	1.30	0.556	0.959
×$\frac{1}{2}$	21.7	4.79	1.79	1.46	8.52	0.425	11.5	3.98	1.30	0.557	0.912
×$\frac{7}{16}$	19.3	4.23	1.80	1.44	7.50	0.374	10.2	3.51	1.31	0.559	0.850
L8×4×1	11.6	3.94	1.03	1.04	7.73	0.694	7.83	3.48	0.844	0.247	1.00
×$\frac{7}{8}$	10.5	3.51	1.04	0.997	6.77	0.612	6.97	3.06	0.846	0.252	1.00
×$\frac{3}{4}$	9.37	3.07	1.05	0.949	5.82	0.531	6.14	2.65	0.850	0.257	1.00
×$\frac{5}{8}$	8.11	2.62	1.06	0.902	4.86	0.448	5.24	2.24	0.856	0.262	0.997
×$\frac{9}{16}$	7.44	2.38	1.07	0.878	4.39	0.406	4.78	2.03	0.859	0.264	0.959
×$\frac{1}{2}$	6.75	2.15	1.08	0.854	3.91	0.363	4.32	1.82	0.863	0.266	0.912
×$\frac{7}{16}$	6.03	1.90	1.09	0.829	3.42	0.319	3.84	1.61	0.867	0.268	0.850
L7×4×$\frac{3}{4}$	9.00	3.01	1.08	1.00	5.60	0.553	5.63	2.57	0.855	0.324	1.00
×$\frac{5}{8}$	7.79	2.56	1.10	0.958	4.69	0.464	4.81	2.16	0.860	0.329	1.00
×$\frac{1}{2}$	6.48	2.10	1.11	0.910	3.77	0.376	3.94	1.76	0.866	0.334	0.965
×$\frac{7}{16}$	5.79	1.86	1.12	0.886	3.31	0.331	3.50	1.55	0.869	0.337	0.912
×$\frac{3}{8}$	5.06	1.61	1.12	0.861	2.84	0.286	3.04	1.34	0.873	0.339	0.840
L6×6×1	35.4	8.55	1.79	1.86	15.4	0.917	14.9	5.70	1.17	1.00	1.00
×$\frac{7}{8}$	31.9	7.61	1.81	1.81	13.7	0.813	13.3	5.18	1.17	1.00	1.00
×$\frac{3}{4}$	28.1	6.64	1.82	1.77	11.9	0.705	11.6	4.63	1.17	1.00	1.00
×$\frac{5}{8}$	24.1	5.64	1.84	1.72	10.1	0.594	9.81	4.04	1.17	1.00	1.00
×$\frac{9}{16}$	22.0	5.12	1.85	1.70	9.18	0.538	8.90	3.73	1.18	1.00	1.00
×$\frac{1}{2}$	19.9	4.59	1.86	1.67	8.22	0.481	8.06	3.40	1.18	1.00	1.00
×$\frac{7}{16}$	17.6	4.06	1.86	1.65	7.25	0.423	7.05	3.05	1.18	1.00	0.973
×$\frac{3}{8}$	15.4	3.51	1.87	1.62	6.27	0.365	6.21	2.69	1.19	1.00	0.912
×$\frac{5}{16}$	13.0	2.95	1.88	1.60	5.26	0.306	5.20	2.30	1.19	1.00	0.826

Note: For workable gages, refer to Table 1-7A. For compactness criteria, refer to Table 1-7B.

Angle shapes



WT-shapes: brace members and top/bottom chords of trusses



W14 × 90

WT 7 × 45

Dimensions and properties
Table 1-8 in the AISC Manual

Example

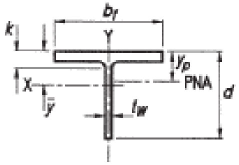


Table 1-8
WT-Shapes
Dimensions

Shape	Area, A	Depth, d		Stem Thickness, t_w		Stem $\frac{t_w}{2}$	Stem Area	Flange Width, b_f		Flange Thickness, t_f		Distance k k_{des}	Distance k k_{det}	Distance Workable Gage
	in.^{2}	in.		in.		in.	in.^{2}	in.		in.		in.	in.	in.
WT22×167.5[c]	49.2	22.0	22	1.03	1	1/2	22.6	15.9	16	1.77	1 3/4	2.56	2 5/8	5 1/2
×145[c]	42.6	21.8	21 3/4	0.865	7/8	7/16	18.9	15.8	15 7/8	1.58	1 9/16	2.36	2 7/16	
×131[c]	38.5	21.7	21 5/8	0.785	13/16	7/16	17.0	15.8	15 3/4	1.42	1 7/16	2.20	2 1/4	
×115[c,v]	33.9	21.5	21 1/2	0.710	11/16	3/8	15.2	15.8	15 3/4	1.22	1 1/4	2.01	2 1/16	
WT20×296.5[h]	87.2	21.5	21 1/2	1.79	1 13/16	15/16	38.5	16.7	16 3/4	3.23	3 1/4	4.41	4 1/2	7 1/2
×251.5[h]	74.0	21.0	21	1.54	1 9/16	13/16	32.3	16.4	16 3/8	2.76	2 3/4	3.94	4	
×215.5[h]	63.3	20.6	20 5/8	1.34	1 5/16	11/16	27.6	16.2	16 1/4	2.36	2 3/8	3.54	3 5/8	
×198.5[h]	58.3	20.5	20 1/2	1.22	1 1/4	5/8	25.0	16.1	16 1/8	2.20	2 3/16	3.38	3 1/2	
×186[h]	54.7	20.3	20 3/8	1.16	1 3/16	5/8	23.6	16.1	16 1/8	2.05	2 1/16	3.23	3 5/16	
×181[c,h]	53.2	20.3	20 1/4	1.12	1 1/8	9/16	22.7	16.0	16	2.01	2	3.19	3 1/4	
×162[c]	47.7	20.1	20 1/8	1.00	1	1/2	20.1	15.9	15 7/8	1.81	1 13/16	2.99	3 1/16	
×148.5[c]	43.6	19.9	19 7/8	0.930	15/16	1/2	18.5	15.8	15 7/8	1.65	1 5/8	2.83	2 15/16	
×138.5[c]	40.7	19.8	19 7/8	0.830	13/16	7/16	16.5	15.8	15 7/8	1.58	1 9/16	2.76	2 7/8	
×124.5[c]	36.7	19.7	19 3/4	0.750	3/4	3/8	14.8	15.8	15 3/4	1.42	1 7/16	2.60	2 11/16	
×107.5[c,v]	31.8	19.5	19 1/2	0.650	5/8	5/16	12.7	15.8	15 3/4	1.22	1 1/4	2.40	2 1/2	
×99.5[c,v]	29.2	19.3	19 3/8	0.650	5/8	5/16	12.6	15.8	15 3/4	1.07	1 1/16	2.25	2 5/16	
WT20×196[h]	57.8	20.8	20 3/4	1.42	1 7/16	3/4	29.4	12.4	12 3/8	2.52	2 1/2	3.70	3 13/16	7 1/2
×165.5[h]	48.8	20.4	20 3/8	1.22	1 1/4	5/8	24.9	12.2	12 1/8	2.13	2 1/8	3.31	3 3/8	
×163.5[h]	47.9	20.4	20 3/8	1.18	1 3/16	5/8	24.1	12.1	12 1/8	2.13	2 1/8	3.31	3 3/8	
×147[c]	43.1	20.2	20 1/4	1.06	1 1/16	9/16	21.4	12.0	12	1.93	1 15/16	3.11	3 3/16	
×139[c]	41.0	20.1	20 1/8	1.03	1	1/2	20.6	12.0	12	1.81	1 13/16	2.99	3 1/16	
×132[c]	38.7	20.0	20	0.960	15/16	1/2	19.2	11.9	11 7/8	1.73	1 3/4	2.91	3	
×117.5[c]	34.6	19.8	19 7/8	0.830	13/16	7/16	16.5	11.9	11 7/8	1.58	1 9/16	2.76	2 7/8	
×105.5[c]	31.1	19.7	19 5/8	0.750	3/4	3/8	14.8	11.8	11 3/4	1.42	1 7/16	2.60	2 11/16	
×91.5[c,v]	26.7	19.5	19 1/2	0.650	5/8	5/16	12.7	11.8	11 3/4	1.20	1 3/16	2.38	2 1/2	
×83.5[c,v]	24.5	19.3	19 1/4	0.650	5/8	5/16	12.5	11.8	11 3/4	1.03	1	2.21	2 5/16	
×74.5[c,v]	21.9	19.1	19 1/8	0.630	5/8	5/16	12.0	11.8	11 3/4	0.830	13/16	2.01	2 1/8	

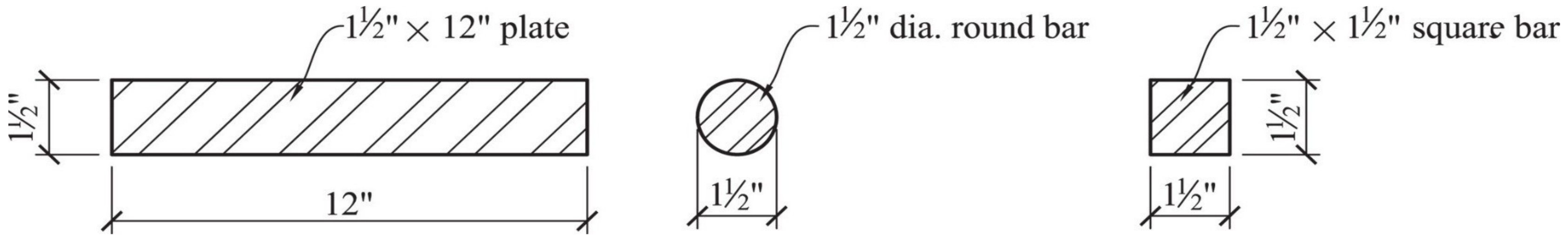
[c] Shape is slender for compression with $F_y = 50$ ksi.
[h] Flange thickness greater than 2 in. Special requirements may apply per AISC *Specification* Section A3.1c.
[v] Shear strength controlled by buckling effects ($C_v < 1.0$) with $F_y = 50$ ksi.

Table 1-8 (continued)
WT-Shapes
Properties

WT22-WT20

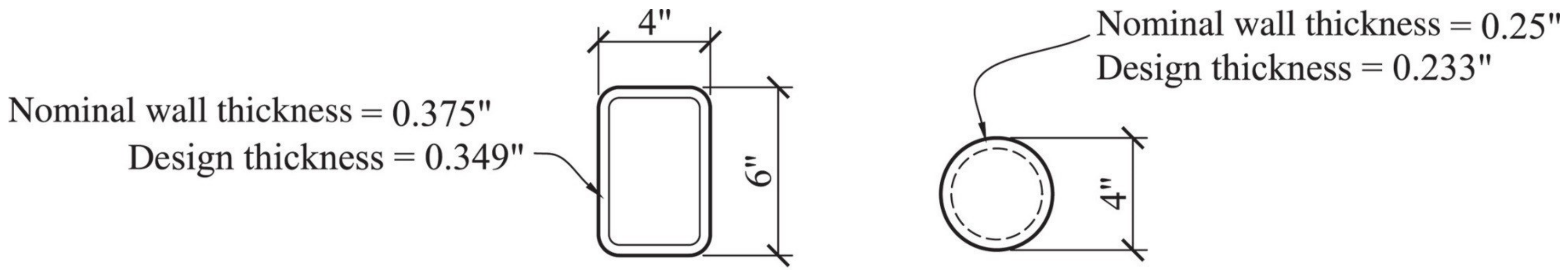
Nom-inal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	Compact Section Criteria $\frac{d}{t_w}$	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X $\bar{y}$	Axis X-X Z	Axis X-X y_p	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y Z	Q_s $F_y = 50$ ksi	Torsional Properties J	Torsional Properties C_w
lb/ft			in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{3}	in.	in.^{3}		in.^{4}	in.^{6}
167.5	4.50	21.4	2170	131	6.63	5.53	234	1.54	600	75.2	3.49	118	0.824	37.2	438
145	5.02	25.2	1830	111	6.54	5.26	196	1.35	521	65.9	3.49	102	0.630	25.4	275
131	5.57	27.6	1640	99.4	6.53	5.19	176	1.22	462	58.6	3.47	90.9	0.525	18.6	200
115	6.45	30.3	1440	88.6	6.53	5.17	157	1.07	398	50.5	3.43	78.3	0.436	12.4	139
296.5	2.58	12.0	3310	209	6.16	5.66	379	2.61	1260	151	3.80	240	1.00	221	2340
251.5	2.98	13.6	2730	174	6.07	5.38	314	2.25	1020	124	3.72	197	1.00	138	1400
215.5	3.44	15.4	2290	148	6.01	5.18	266	1.95	843	104	3.65	164	1.00	88.2	881
198.5	3.66	16.8	2070	134	5.96	5.03	240	1.81	771	95.7	3.63	150	1.00	70.6	677
186	3.93	17.5	1930	126	5.95	4.98	225	1.70	709	88.3	3.60	138	1.00	57.7	558
181	3.99	18.1	1870	122	5.92	4.91	217	1.66	691	86.3	3.60	135	0.991	54.2	511
162	4.40	20.1	1650	108	5.88	4.77	192	1.50	609	76.6	3.57	119	0.890	39.6	362
148.5	4.80	21.4	1500	98.9	5.87	4.71	176	1.38	546	69.0	3.54	107	0.824	30.5	279
138.5	5.03	23.9	1360	88.6	5.78	4.50	157	1.29	522	65.9	3.58	102	0.697	25.7	218
124.5	5.55	26.3	1210	79.4	5.75	4.41	140	1.16	463	58.8	3.55	90.8	0.579	19.0	158
107.5	6.45	30.0	1030	68.0	5.71	4.28	120	1.01	398	50.5	3.54	77.8	0.445	12.4	101
99.5	7.39	29.7	988	66.5	5.81	4.47	117	0.929	347	44.1	3.45	68.2	0.454	9.12	83.5
196	2.45	14.6	2270	153	6.27	5.94	275	2.33	401	64.9	2.64	106	1.00	85.4	796
165.5	2.86	16.7	1880	128	6.21	5.74	231	2.00	322	52.9	2.57	85.7	1.00	52.5	484
163.5	2.85	17.3	1840	125	6.19	5.66	224	1.98	320	52.7	2.58	85.0	1.00	51.4	449
147	3.11	19.1	1630	111	6.14	5.51	199	1.80	281	46.7	2.55	75.0	0.940	38.2	322
139	3.31	19.5	1550	106	6.14	5.51	191	1.71	261	43.5	2.52	69.9	0.920	32.4	282
132	3.45	20.8	1450	99.2	6.11	5.41	178	1.63	246	41.3	2.52	66.0	0.854	27.9	233
117.5	3.77	23.9	1260	85.7	6.04	5.17	153	1.45	222	37.3	2.54	59.0	0.697	20.6	156
105.5	4.17	26.3	1120	76.7	6.01	5.08	137	1.31	195	33.0	2.51	52.1	0.579	15.2	113
91.5	4.92	30.0	955	65.7	5.98	4.97	117	1.13	165	28.0	2.49	44.0	0.445	9.65	71.2
83.5	5.76	29.7	899	63.7	6.05	5.19	115	1.10	141	23.9	2.40	37.8	0.454	6.99	62.9
74.5	7.11	30.3	815	59.7	6.10	5.45	108	1.72	114	19.4	2.29	30.9	0.436	4.66	51.9

Plates and bars



Hollow structural section (HSS) and structural pipes:

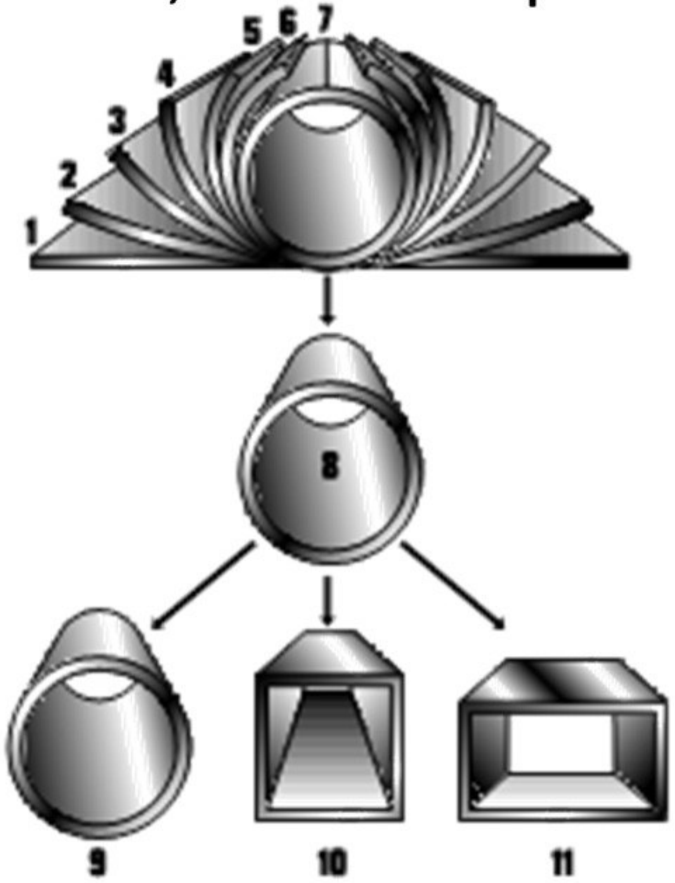
Commonly uses for columns hangers, and braced-frame members.



(a) HSS 6 × 4 × ⅜ (b) HSS 4.000 × 0.250

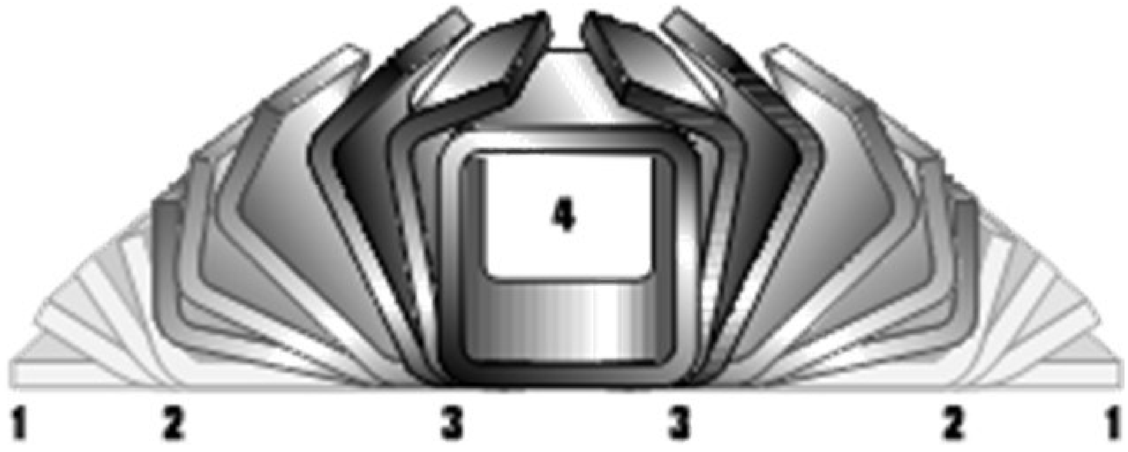
Manufacturing Process

Weld - Round, Form - Square



Manufacturing Process

Form - Square, Weld - Square



Submerged Arc Welding

105D1
4393

Dimensions and properties Table 1-11 in the AISC Manual

Example

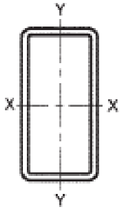
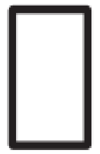


Table 1-11
Rectangular HSS
Dimensions and Properties

Shape	Design Wall Thickness, t	Nominal Wt.	Area, A	b/t	h/t	Axis X-X			
						I	S	r	Z
	in.	lb/ft	in.^{2}			in.^{4}	in.^{3}	in.	in.^{3}
HSS20×12×5/8	0.581	127.37	35.0	17.7	31.4	1880	188	7.33	230
×1/2	0.465	103.30	28.3	22.8	40.0	1550	155	7.39	188
×3/8	0.349	78.52	21.5	31.4	54.3	1200	120	7.45	144
×5/16	0.291	65.87	18.1	38.2	65.7	1010	101	7.48	122
HSS20×8×5/8	0.581	110.36	30.3	10.8	31.4	1440	144	6.89	185
×1/2	0.465	89.68	24.6	14.2	40.0	1190	119	6.96	152
×3/8	0.349	68.31	18.7	19.9	54.3	926	92.6	7.03	117
×5/16	0.291	57.36	15.7	24.5	65.7	786	78.6	7.07	98.6
HSS20×4×1/2	0.465	76.07	20.9	5.60	40.0	838	83.8	6.33	115
×3/8	0.349	58.10	16.0	8.46	54.3	657	65.7	6.42	89.3
×5/16	0.291	48.86	13.4	10.7	65.7	560	56.0	6.46	75.6
×1/4	0.233	39.43	10.8	14.2	82.8	458	45.8	6.50	61.5
HSS18×6×5/8	0.581	93.34	25.7	7.33	28.0	923	103	6.00	135
×1/2	0.465	76.07	20.9	9.90	35.7	770	85.6	6.07	112
×3/8	0.349	58.10	16.0	14.2	48.6	602	66.9	6.15	86.4
×5/16	0.291	48.86	13.4	17.6	58.9	513	57.0	6.18	73.1
×1/4	0.233	39.43	10.8	22.8	74.3	419	46.5	6.22	59.4
HSS16×12×5/8	0.581	110.36	30.3	17.7	24.5	1090	136	6.00	165
×1/2	0.465	89.68	24.6	22.8	31.4	904	113	6.06	135
×3/8	0.349	68.31	18.7	31.4	42.8	702	87.7	6.12	104
×5/16	0.291	57.36	15.7	38.2	52.0	595	74.4	6.15	87.7
HSS16×8×5/8	0.581	93.34	25.7	10.8	24.5	815	102	5.64	129
×1/2	0.465	76.07	20.9	14.2	31.4	679	84.9	5.70	106
×3/8	0.349	58.10	16.0	19.9	42.8	531	66.3	5.77	82.1
×5/16	0.291	48.86	13.4	24.5	52.0	451	56.4	5.80	69.4
×1/4	0.233	39.43	10.8	31.3	65.7	368	46.1	5.83	56.4
HSS16×4×5/8	0.581	76.33	21.0	3.88	24.5	539	67.3	5.06	92.9
×1/2	0.465	62.46	17.2	5.60	31.4	455	56.9	5.15	77.3
×3/8	0.349	47.90	13.2	8.46	42.8	360	45.0	5.23	60.2
×5/16	0.291	40.35	11.1	10.7	52.0	308	38.5	5.27	51.1
×1/4	0.233	32.63	8.96	14.2	65.7	253	31.6	5.31	41.7
×3/16	0.174	24.73	6.76	20.0	89.0	193	24.2	5.35	31.7

Note: For compactness criteria, refer to Table 1-12A.

Table 1-11 (continued)
Rectangular HSS
Dimensions and Properties



HSS20-HSS16

Shape	Axis Y-Y				Workable Flat		Torsion		Surface Area
	I	S	r	Z	Depth	Width	J	C	
	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{3}	ft^2/ft
HSS20×12×5/8	851	142	4.930	162	17 3/16	9 3/16	1890	257	5.17
×1/2	705	117	4.99	132	17 3/4	9 3/4	1540	209	5.20
×3/8	547	91.1	5.04	102	18 5/16	10 5/16	1180	160	5.23
×5/16	464	77.3	5.07	85.8	18 5/8	10 5/8	997	134	5.25
HSS20×8×5/8	338	84.6	3.34	96.4	17 3/16	5 3/16	916	167	4.50
×1/2	283	70.8	3.39	79.5	17 3/4	5 3/4	757	137	4.53
×3/8	222	55.6	3.44	61.5	18 5/16	6 5/16	586	105	4.57
×5/16	189	47.4	3.47	52.0	18 5/8	6 5/8	496	88.3	4.58
HSS20×4×1/2	58.7	29.3	1.68	34.0	17 3/4	—	195	63.8	3.87
×3/8	47.6	23.8	1.73	26.8	18 5/16	2 5/16	156	49.9	3.90
×5/16	41.2	20.6	1.75	22.9	18 5/8	2 5/8	134	42.4	3.92
×1/4	34.3	17.1	1.78	18.7	18 7/8	2 7/8	111	34.7	3.93
HSS18×6×5/8	158	52.7	2.48	61.0	15 3/16	3 3/16	462	109	3.83
×1/2	134	44.6	2.53	50.7	15 3/4	3 3/4	387	89.9	3.87
×3/8	106	35.5	2.58	39.5	16 5/16	4 5/16	302	69.5	3.90
×5/16	91.3	30.4	2.61	33.5	16 9/16	4 9/16	257	58.7	3.92
×1/4	75.1	25.0	2.63	27.3	16 7/8	4 7/8	210	47.7	3.93
HSS16x12×5/8	700	117	4.80	135	13 3/16	9 3/16	1370	204	4.50
×1/2	581	96.8	4.86	111	13 3/4	9 3/4	1120	166	4.53
×3/8	452	75.3	4.91	85.5	14 5/16	10 5/16	862	127	4.57
×5/16	384	64.0	4.94	72.2	14 5/8	10 5/8	727	107	4.58
HSS16×8×5/8	274	68.6	3.27	79.2	13 3/16	5 3/16	681	132	3.83
×1/2	230	57.6	3.32	65.5	13 3/4	5 3/4	563	108	3.87
×3/8	181	45.3	3.37	50.8	14 5/16	6 5/16	436	83.4	3.90
×5/16	155	38.7	3.40	43.0	14 5/8	6 5/8	369	70.4	3.92
×1/4	127	31.7	3.42	35.0	14 7/8	6 7/8	300	57.0	3.93
HSS16×4×5/8	54.1	27.0	1.60	32.5	13 3/16	—	174	60.5	3.17
×1/2	47.0	23.5	1.65	27.4	13 3/4	—	150	50.7	3.20
×3/8	38.3	19.1	1.71	21.7	14 5/16	2 5/16	120	39.7	3.23
×5/16	33.2	16.6	1.73	18.5	14 5/8	2 5/8	103	33.8	3.25
×1/4	27.7	13.8	1.76	15.2	14 7/8	2 7/8	85.2	27.6	3.27
×3/16	21.5	10.8	1.78	11.7	15 3/16	3 3/16	65.5	21.1	3.28

— Indicates flat depth or width is too small to establish a workable flat.

Dimensions and properties Table 1-12 in the AISC Manual

Example

HSS16-HSS8

Table 1-12

Square HSS

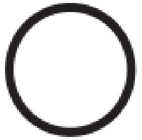
Dimensions and Properties

Shape	Design Wall Thickness, t	Nominal Wt.	Area, A	b/t	h/t	I	S	r	Z	Workable Flat	Torsion J	Torsion C	Surface Area
	in.	lb/ft	in.^{2}			in.^{4}	in.^{3}	in.	in.^{3}	in.	in.^{4}	in.^{3}	ft^2/ft
HSS16×16×5/8	0.581	127.37	35.0	24.5	24.5	1370	171	6.25	200	13 3/16	2170	276	5.17
×1/2	0.465	103.30	28.3	31.4	31.4	1130	141	6.31	164	13 3/4	1770	224	5.20
×3/8	0.349	78.52	21.5	42.8	42.8	873	109	6.37	126	14 5/16	1350	171	5.23
×5/16	0.291	65.87	18.1	52.0	52.0	739	92.3	6.39	106	14 5/8	1140	144	5.25
HSS14×14×5/8	0.581	110.36	30.3	21.1	21.1	897	128	5.44	151	11 3/16	1430	208	4.50
×1/2	0.465	89.68	24.6	27.1	27.1	743	106	5.49	124	11 3/4	1170	170	4.53
×3/8	0.349	68.31	18.7	37.1	37.1	577	82.5	5.55	95.4	12 5/16	900	130	4.57
×5/16	0.291	57.36	15.7	45.1	45.1	490	69.9	5.58	80.5	12 5/8	759	109	4.58
HSS12×12×5/8	0.581	93.34	25.7	17.7	17.7	548	91.4	4.62	109	9 3/16	885	151	3.83
×1/2	0.465	76.07	20.9	22.8	22.8	457	76.2	4.68	89.6	9 3/4	728	123	3.87
×3/8	0.349	58.10	16.0	31.4	31.4	357	59.5	4.73	69.2	10 5/16	561	94.6	3.90
×5/16	0.291	48.86	13.4	38.2	38.2	304	50.7	4.76	58.6	10 5/8	474	79.7	3.92
×1/4	0.233	39.43	10.8	48.5	48.5	248	41.4	4.79	47.6	10 7/8	384	64.5	3.93
×3/16	0.174	29.84	8.15	66.0	66.0	189	31.5	4.82	36.0	11 3/16	290	48.6	3.95
HSS10×10×5/8	0.581	76.33	21.0	14.2	14.2	304	60.8	3.80	73.2	7 3/16	498	102	3.17
×1/2	0.465	62.46	17.2	18.5	18.5	256	51.2	3.86	60.7	7 3/4	412	84.2	3.20
×3/8	0.349	47.90	13.2	25.7	25.7	202	40.4	3.92	47.2	8 5/16	320	64.8	3.23
×5/16	0.291	40.35	11.1	31.4	31.4	172	34.5	3.94	40.1	8 5/8	271	54.8	3.25
×1/4	0.233	32.63	8.96	39.9	39.9	141	28.3	3.97	32.7	8 7/8	220	44.4	3.27
×3/16	0.174	24.73	6.76	54.5	54.5	108	21.6	4.00	24.8	9 3/16	167	33.6	3.28
HSS9×9×5/8	0.581	67.82	18.7	12.5	12.5	216	47.9	3.40	58.1	6 3/16	356	81.6	2.83
×1/2	0.465	55.66	15.3	16.4	16.4	183	40.6	3.45	48.4	6 3/4	296	67.4	2.87
×3/8	0.349	42.79	11.8	22.8	22.8	145	32.2	3.51	37.8	7 5/16	231	52.1	2.90
×5/16	0.291	36.10	9.92	27.9	27.9	124	27.6	3.54	32.1	7 5/8	196	44.0	2.92
×1/4	0.233	29.23	8.03	35.6	35.6	102	22.7	3.56	26.2	7 7/8	159	35.8	2.93
×3/16	0.174	22.18	6.06	48.7	48.7	78.2	17.4	3.59	20.0	8 3/16	121	27.1	2.95
×1/8	0.116	14.96	4.09	74.6	74.6	53.5	11.9	3.62	13.6	8 7/16	82.0	18.3	2.97
HSS8×8×5/8	0.581	59.32	16.4	10.8	10.8	146	36.5	2.99	44.7	5 3/16	244	63.2	2.50
×1/2	0.465	48.85	13.5	14.2	14.2	125	31.2	3.04	37.5	5 3/4	204	52.4	2.53
×3/8	0.349	37.69	10.4	19.9	19.9	100	24.9	3.10	29.4	6 5/16	160	40.7	2.57
×5/16	0.291	31.84	8.76	24.5	24.5	85.6	21.4	3.13	25.1	6 5/8	136	34.5	2.58
×1/4	0.233	25.82	7.10	31.3	31.3	70.7	17.7	3.15	20.5	6 7/8	111	28.1	2.60
×3/16	0.174	19.63	5.37	43.0	43.0	54.4	13.6	3.18	15.7	7 3/16	84.5	21.3	2.62
×1/8	0.116	13.26	3.62	66.0	66.0	37.4	9.34	3.21	10.7	7 7/16	57.3	14.4	2.63

Note: For compactness criteria, refer to Table 1-12A.

Dimensions and properties Table 1-13 in the AISC Manual

Example



HSS6.625-HSS5

Table 1-13 (continued)

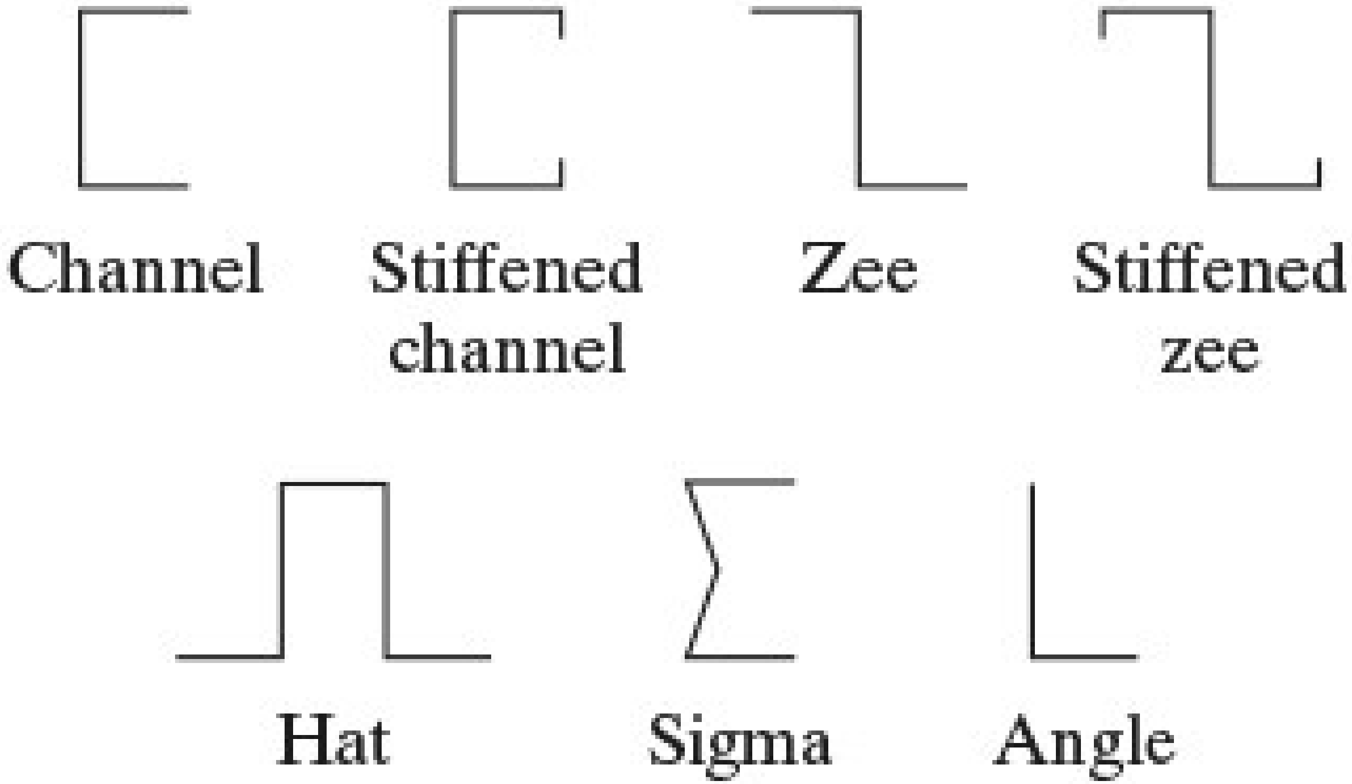
Round HSS

Dimensions and Properties

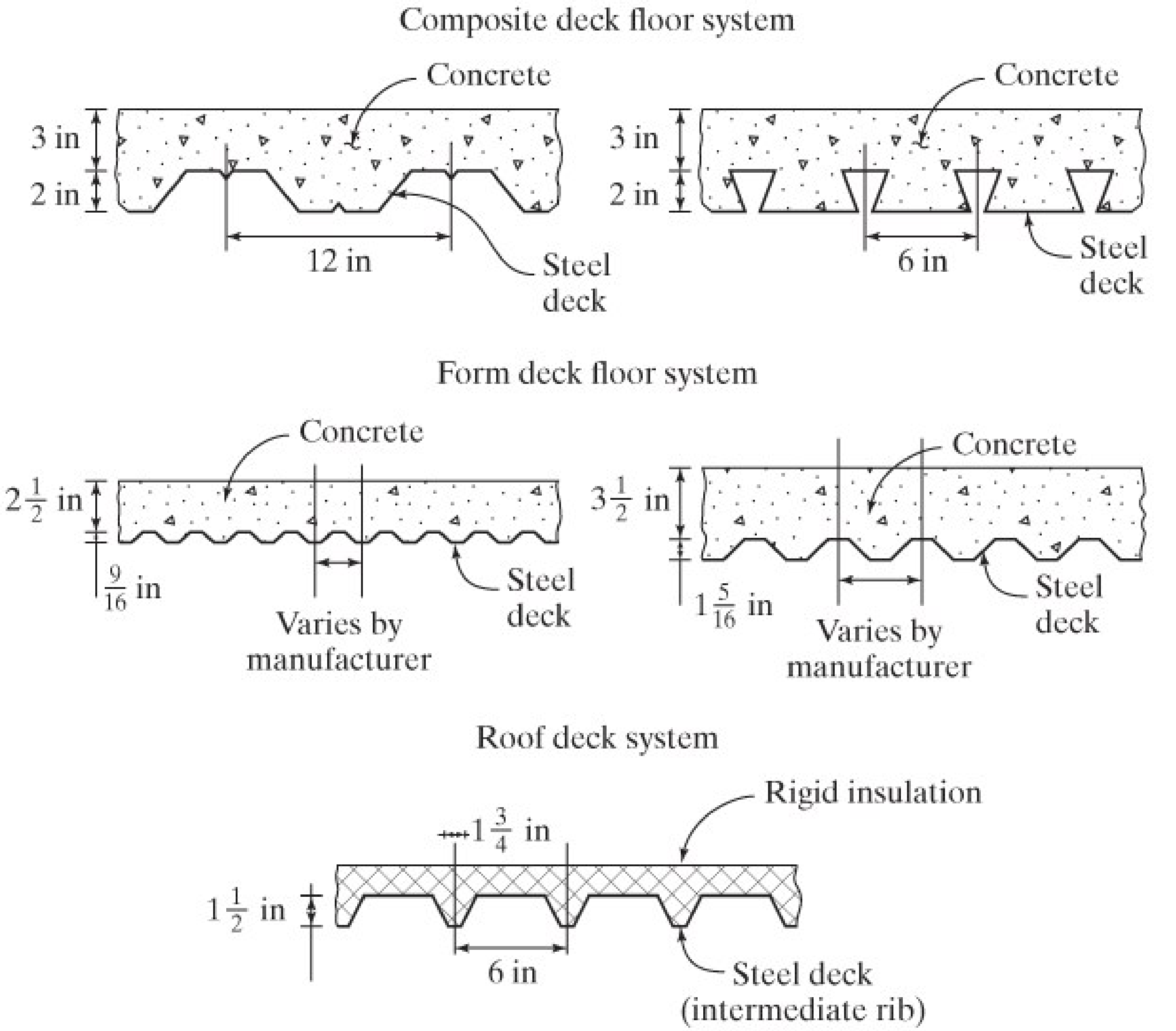
Shape	Design Wall Thickness, t	Nominal Wt.	Area, A	D/t	I	S	r	Z	Torsion J	Torsion C
	in.	lb/ft	in.^{2}		in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}
HSS6.625×0.500	0.465	32.74	9.00	14.2	42.9	13.0	2.18	17.7	85.9	25.9
×0.432	0.402	28.60	7.86	16.5	38.2	11.5	2.20	15.6	76.4	23.1
×0.375	0.349	25.06	6.88	19.0	34.0	10.3	2.22	13.8	68.0	20.5
×0.312	0.291	21.06	5.79	22.8	29.1	8.79	2.24	11.7	58.2	17.6
×0.280	0.260	18.99	5.20	25.5	26.4	7.96	2.25	10.5	52.7	15.9
×0.250	0.233	17.04	4.68	28.4	23.9	7.22	2.26	9.52	47.9	14.4
×0.188	0.174	12.94	3.53	38.1	18.4	5.54	2.28	7.24	36.7	11.1
×0.125[f]	0.116	8.69	2.37	57.1	12.6	3.79	2.30	4.92	25.1	7.59
HSS6×0.500	0.465	29.40	8.09	12.9	31.2	10.4	1.96	14.3	62.4	20.8
×0.375	0.349	22.55	6.20	17.2	24.8	8.28	2.00	11.2	49.7	16.6
×0.312	0.291	18.97	5.22	20.6	21.3	7.11	2.02	9.49	42.6	14.2
×0.280	0.260	17.12	4.69	23.1	19.3	6.45	2.03	8.57	38.7	12.9
×0.250	0.233	15.37	4.22	25.8	17.6	5.86	2.04	7.75	35.2	11.7
×0.188	0.174	11.68	3.18	34.5	13.5	4.51	2.06	5.91	27.0	9.02
×0.125[f]	0.116	7.85	2.14	51.7	9.28	3.09	2.08	4.02	18.6	6.19
HSS5.563×0.500	0.465	27.06	7.45	12.0	24.4	8.77	1.81	12.1	48.8	17.5
×0.375	0.349	20.80	5.72	15.9	19.5	7.02	1.85	9.50	39.0	14.0
×0.258	0.240	14.63	4.01	23.2	14.2	5.12	1.88	6.80	28.5	10.2
×0.188	0.174	10.80	2.95	32.0	10.7	3.85	1.91	5.05	21.4	7.70
×0.134	0.124	7.78	2.12	44.9	7.84	2.82	1.92	3.67	15.7	5.64
HSS5.500×0.500	0.465	26.73	7.36	11.8	23.5	8.55	1.79	11.8	47.0	17.1
×0.375	0.349	20.55	5.65	15.8	18.8	6.84	1.83	9.27	37.6	13.7
×0.258	0.240	14.46	3.97	22.9	13.7	5.00	1.86	6.64	27.5	10.0
HSS5×0.500	0.465	24.05	6.62	10.8	17.2	6.88	1.61	9.60	34.4	13.8
×0.375	0.349	18.54	5.10	14.3	13.9	5.55	1.65	7.56	27.7	11.1
×0.312	0.291	15.64	4.30	17.2	12.0	4.79	1.67	6.46	24.0	9.58
×0.258	0.240	13.08	3.59	20.8	10.2	4.08	1.69	5.44	20.4	8.15
×0.250	0.233	12.69	3.49	21.5	9.94	3.97	1.69	5.30	19.9	7.95
×0.188	0.174	9.67	2.64	28.7	7.69	3.08	1.71	4.05	15.4	6.15
×0.125	0.116	6.51	1.78	43.1	5.31	2.12	1.73	2.77	10.6	4.25

[f] Shape exceeds compact limit for flexure with F_y = 42 ksi.

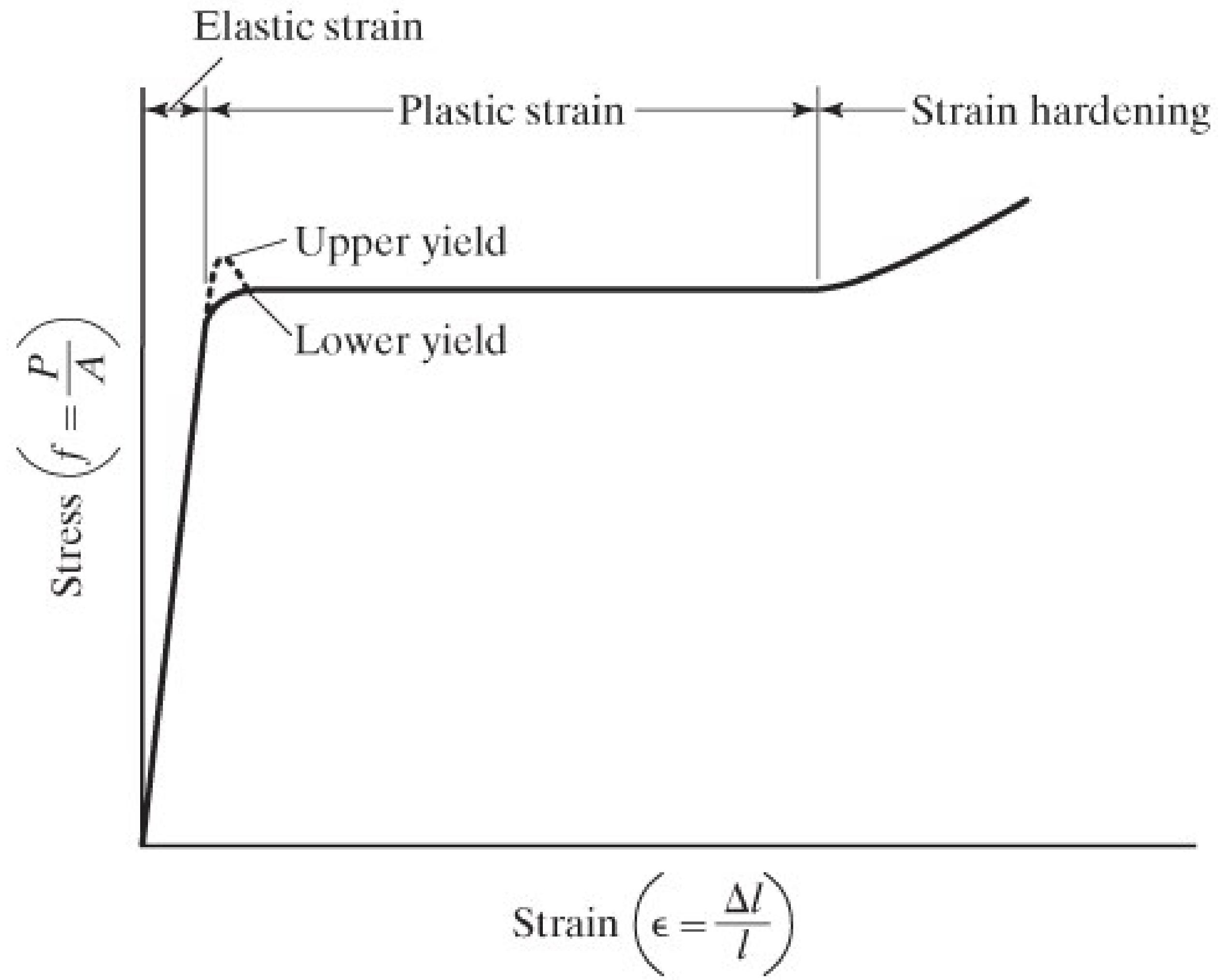
Cold-formed shapes



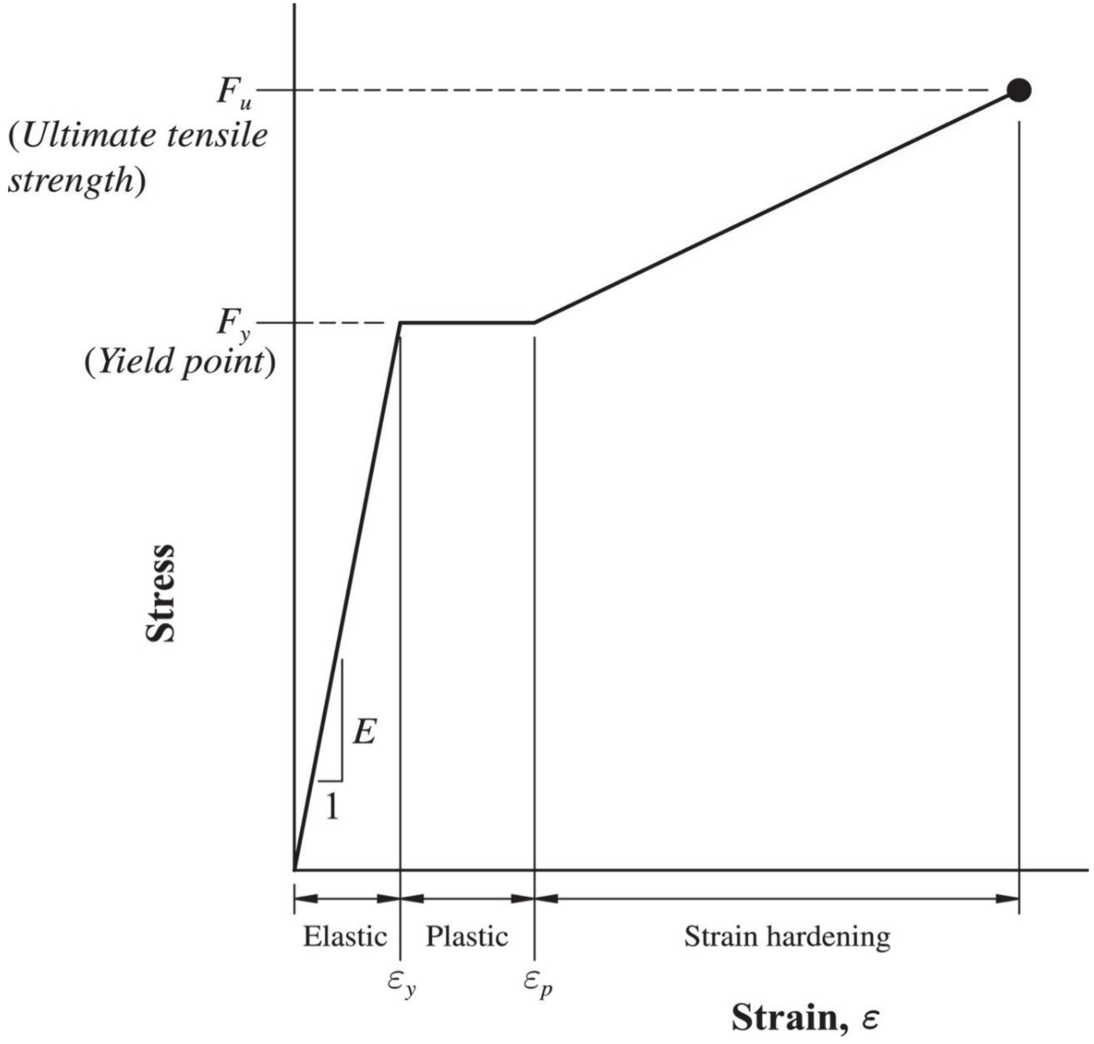
Some types of steel decks



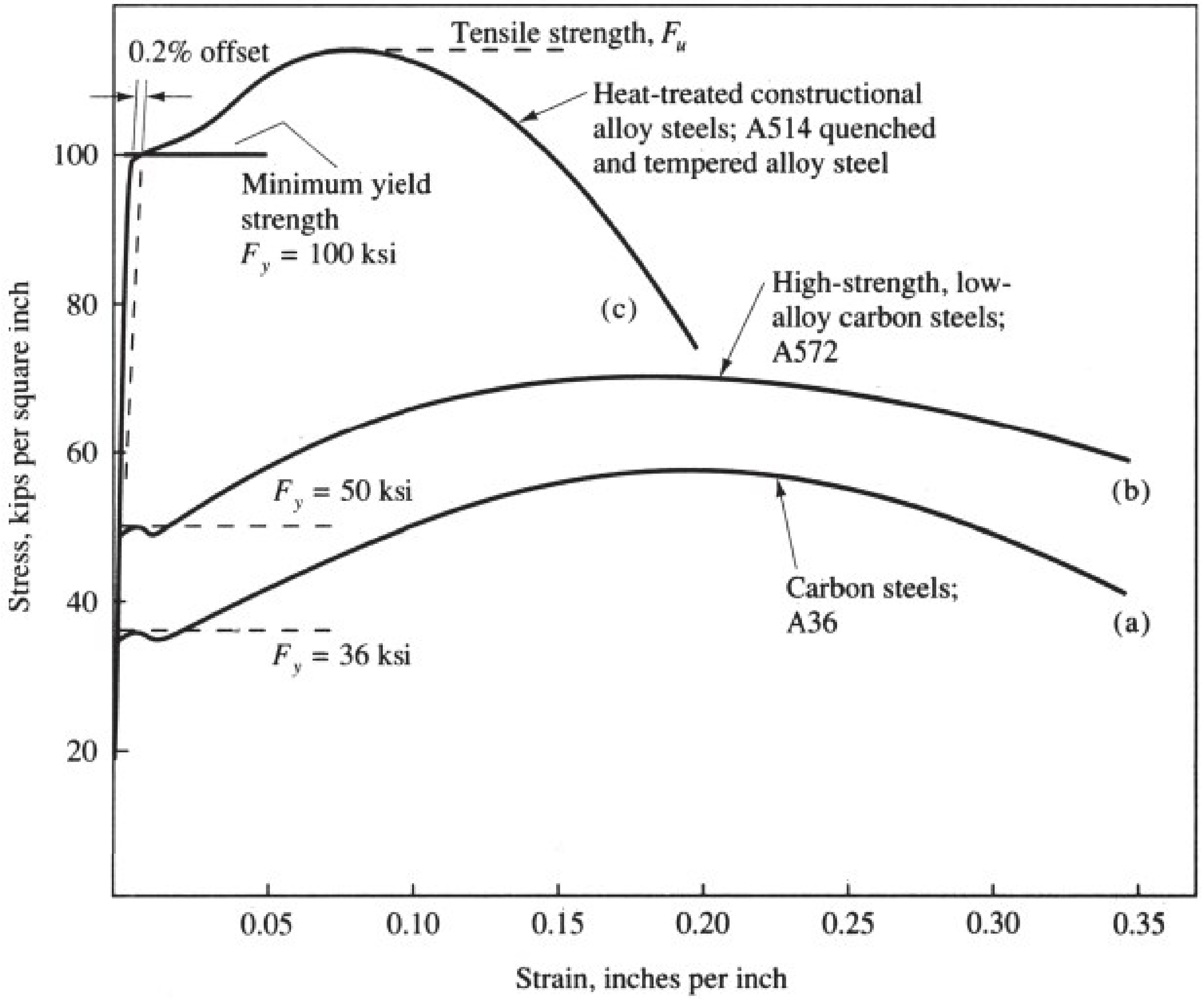
Typical stress–strain diagram for a mild- or low-carbon structural steel at room temperature



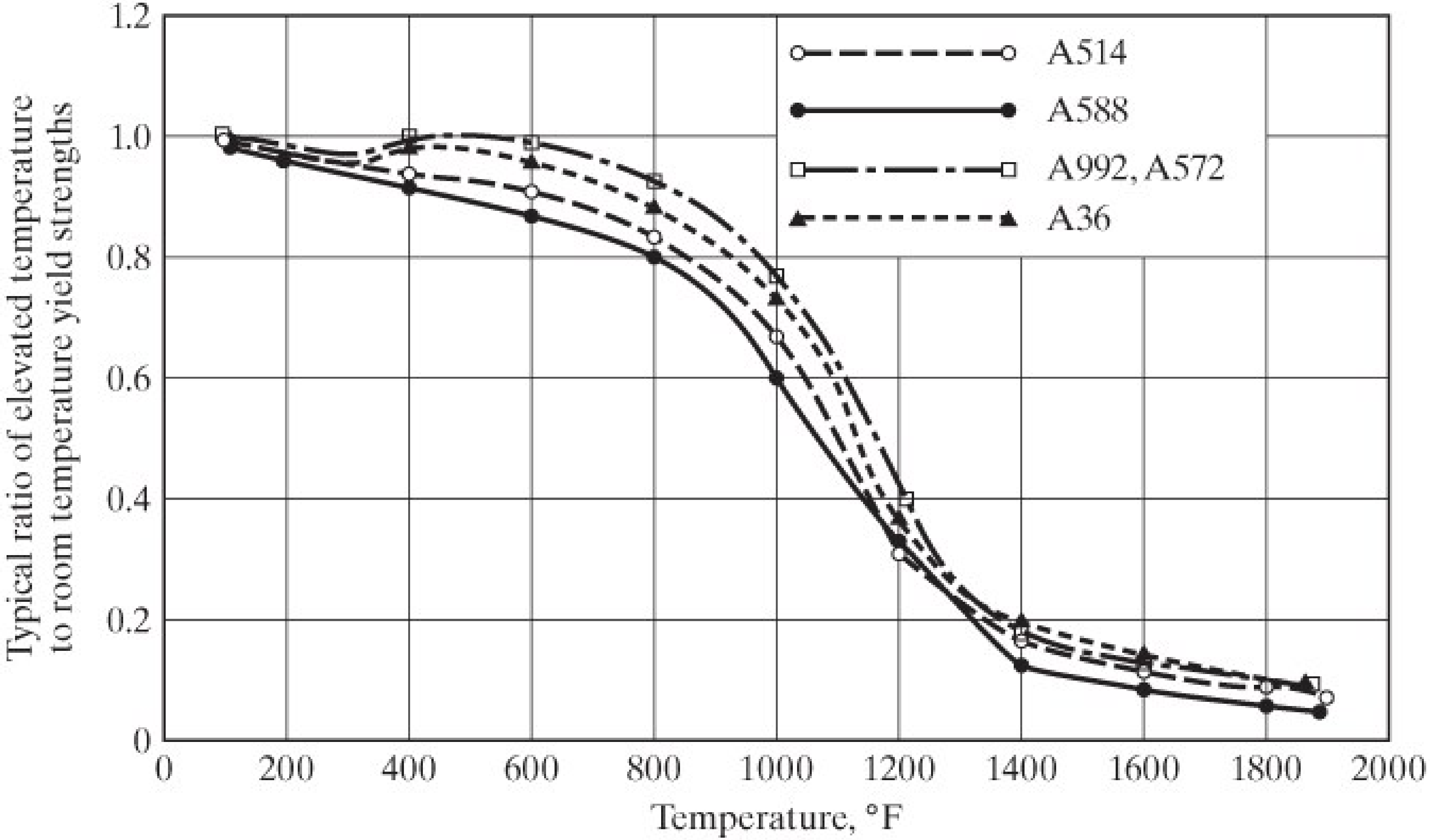
Idealized stress–strain diagram for structural steel



Typical stress–strain curves



Effect of temperature on yield strengths



Steel Types

1. Carbon Steels:

i. Low Carbon Steel (Carbon < 0.15%)

ii. Mild Carbon (Structural) (Carbon 0.15%-0.29%)

iii. Medium Carbon Steel (Carbon 0.3%-0.59%)

iv. High Carbon Steel (Carbon 0.6%-1.7%)

- F_y = 35-65 Ksi
- The Carbon steels A36, A53, A500, A 501,A529,A709,A1043 and A1085

2. High Strength Low Alloy Steel:

- F_y = 42-70 Ksi
- Corrosive resistance.
- The High Strength Low Alloy Steel are A572, A618,A709,A913, A992, A1065

Table 2-4
Applicable ASTM Specifications for Various Structural Shapes

Steel Typ	ASTM Designatio		F_y Yield Stress[a] (ksi)	F_u Tensile Stress[a] (ksi)	Applicable Shape Series W	M	S	HP	C	MC	L	HSS Rect.	HSS Round	Pipe
Carbon	A36		36	58–80[b]	▒	■	■	▒	■	■	■			
	A53 Gr. B		35	60										■
	A500	Gr. B	42	58									▒	
			46	58								▒		
		Gr. C	46	62									■	
			50	62								■		
	A501	Gr. A	36	58								▒	▒	
		Gr. B	50	70								▒	▒	
	A529[c]	Gr. 50	50	65–100	▒	▒	▒	▒	▒	▒	▒			
		Gr. 55	55	70–100	▒	▒	▒	▒	▒	▒	▒			
	A709	36	36	58–80[b]	▒	▒	▒	▒	▒	▒	▒			
	A1043[d,k]	36	36–52	58	▒									
		50	50–65	65	▒									
	A1085	Gr.A	50	65								▒	▒	
High-Strength Low-Alloy	A572	Gr.42	42	60	▒	▒	▒	▒	▒	▒	▒			
		Gr.50	50	65	▒	▒	▒	■	▒	▒	▒			
		Gr.55	55	70	▒	▒	▒	▒	▒	▒	▒			
		Gr. 60[e]	60	75	▒	▒	▒	▒	▒	▒	▒			
		Gr. 65[e]	65	80	▒	▒	▒	▒	▒	▒	▒			
	A618[f]	Gr. Ia[k], Ib & II	50[g]	70[g]								▒	▒	
		Gr. III	50	65								▒	▒	
	A709	50	50	65	▒	▒	▒	▒	▒	▒	▒			
		50S	50–65	65	▒	▒	▒	▒	▒	▒	▒			
		50W	50	70	▒	▒	▒	▒	▒	▒	▒			
	A913	50	50[h]	65[h]	▒	▒	▒	▒	▒	▒	▒			
		60	60	75	▒	▒	▒	▒	▒	▒	▒			
		65	65	80	▒	▒	▒	▒	▒	▒	▒			
		70	70	90	▒	▒	▒	▒	▒	▒	▒			
	A992		50[i]	65[i]	■	▒	▒	▒	▒	▒	▒			
	A1065[k]	Gr. 50[j]	50	60								▒		

■ = Preferred material specification.
▒ = Other applicable material specification, the availability of which should be confirmed prior to specification.
□ = Material specification does not apply.

Footnotes on facing page.

3. Corrosion Resistant High Strength Low Alloy Steel :

- Fy = 50 ksi
- Corrosive resistance.
- The Alloy Steels are A588,A847,A1065 and Gr.50W

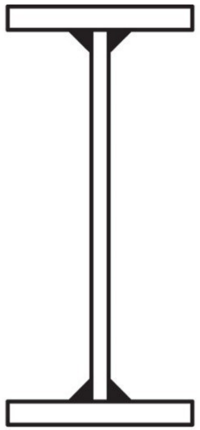
Table 2-4 (continued)
Applicable ASTM Specifications for Various Structural Shapes

Steel Typ	ASTM Designatio		F_y Yield Stress[a] (ksi)	F_u Tensile Stress[a] (ksi)	Applicable Shape Series									
					W	M	S	HP	C	MC	L	HSS Rect.	HSS Round	HSS Pipe
Corrosion Resistant High-Strength Low-Alloy	A588													
	A847[k]		50	70										
	A1065[k]	Gr. 50W[j]	50	70										

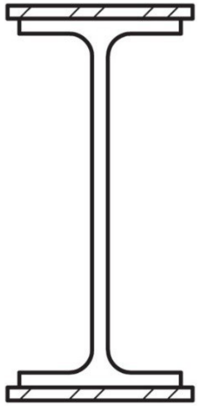
■ = Preferred material specification.
▨ = Other applicable material specification, the availability of which should be confirmed prior to specification.
□ = Material specification does not apply.

[a] Minimum, unless a range is shown.
[b] For wide-flange shapes with flange thicknesses over 3 in., only the minimum of 58 ksi applies.
[c] For shapes with a flange or leg thickness less than or equal to 1½ in. only. To improve weldability, a maximum carbon equivalent can be specified (per ASTM A529 Supplementary Requirement S78). If desired, maximum tensile stress of 90 ksi can be specified (per ASTM A529 Supplementary Requirement S79).
[d] For shape profiles with a flange width of 6 in. or greater.
[e] For shapes with a flange thickness less than or equal to 2 in. only.
[f] ASTM A618 can also be specified as corrosion-resistant; see ASTM A618.
[g] Minimum applies for walls nominally ¾ in. thick and under. For wall thickness over ¾ in., $F_y = 46$ ksi and $F_u = 67$ ksi.
[h] If desired, maximum yield stress of 65 ksi and maximum yield-to-tensile strength ratio of 0.85 can be specified (per ASTM A913 Supplementary Requirement S75).
[i] A maximum yield-to-tensile strength ratio of 0.85 and carbon equivalent formula are included as mandatory, and some variation is allowed, including for shapes tested with coupons cut from the web; see ASTM A992. If desired, maximum tensile stress of 90 ksi can be specified (per ASTM A992 Supplementary Requirement S79).
[j] The grades of ASTM A1065 may not be interchanged without approval of the purchaser.
[k] This specification is not a prequalified base metal per AWS D1.1/D1.1M:2015.

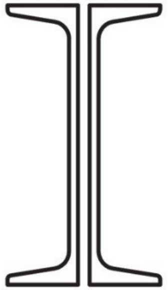
Built-up sections



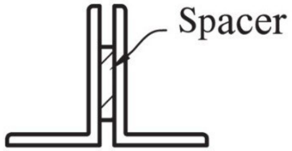
(a) Plate Girder



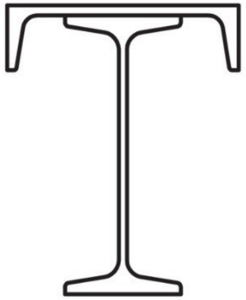
(b) Reinforced W-Section



(c) (2)–C12 × 25



(d) (2)–L6 × 4 × 3⁄8



(e) S12 × 31.8 with
C10 × 15.3 Cap Channel

Advantages of Steel as a Structural Material

- Steel exhibits desirable physical properties that makes it one of the most versatile structural material in use.
- Its great strength, uniformity, light weight, ease of use, and many other desirable properties makes it the material of choice for numerous structures such as steel bridges, high rise buildings, towers, and other structures.
- The many advantages of steel can be summarized as follows:
  - **High Strength**
    - This means that the weight of structure that made of steel will be **small**.
  - **Uniformity**
    - Properties of steel do not change as oppose to concrete.
  - **Elasticity**
    - Steel follows Hooke's Law very accurately.

Advantages of Steel as a Structural Material

– **Ductility**

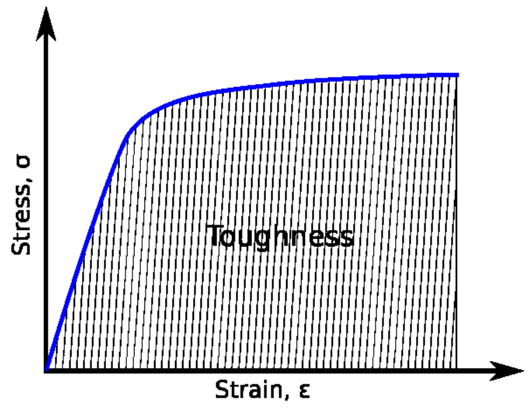
- A very desirable of property of steel in which steel can withstand extensive deformation without failure under high tensile stresses, i.e., it gives warning before failure takes place.

– **Toughness**

- Steel has both strength and ductility.

– **Additions to Existing Structures**

- Example: new bays or even entire new wings can be added to existing frame buildings, and steel bridges may easily be widened.



Toughness is the ability of a material to absorb energy and plastically deform without fracturing

Disadvantages of Steel as a Structural Material

- Although steel has all this advantages as structural material, it also has **many disadvantages** that make reinforced concrete as a replacement for construction purposes.
- For example, steel columns sometimes can not provide the necessary strength because of **buckling**, whereas R/C columns are generally sturdy and massive, i.e., no buckling problems occurs.

❑ **The many disadvantages of steel can be summarized as follows:**

- **Maintenance Cost**
- Steel structures are susceptible to corrosion when exposed to air, water, and humidity. They must be painted periodically.
- **Fireproofing Cost**

  Although steel is incombustible material, however, its strength is reduced extremely at high temperatures due to common fires.
- **Fatigue**

  The strength of structural steel member can be reduced if this member is subjected to cyclic loading.

Design Methods

- Allowable Strength Design (ASD)

  Allowable Stress Design prior to 2005

  "working stress design"

- Load and Resistance Factor Design (LRFD)

  "limit states design"

  Failure condition is considered

◆ Allowable Strength Design (ASD)

required strength ≤ allowable strength

$$\boxed{R_a} \le \frac{\boxed{R_n}}{\boxed{\Omega}}$$

Nominal Strength

Factor of Safety

Required Strength (ASD)

□ Load combinations specified by the ASCE 7-16 Standard

1. D
2. $D + L$
3. $D + (L_r \text{ or } S \text{ or } R)$
4. $D + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$
5. $D + (0.6W)$
6. $D + 0.75L + 0.75(0.6W) + 0.75(L_r \text{ or } S \text{ or } R)$
7. $0.6D + 0.6W$

Load and Resistance Factor Design (LRFD)

required strength ≤ design strength

Load factor $\boxed{> 1}$

$$R_u = \sum \gamma_i Q_{ni} \le \phi R_n$$

Required Strength (LRFD)

Load

Resistance Factor $\boxed{< 1}$

Nominal Strength/ Resistance

- This method uses load factors to the loads or combination of loads

1. $1.4D$
2. $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
3. $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W)$
4. $1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R)$
5. $0.9D + 1.0W$
6. $1.2D + E_v + E_h + L + 0.2S$
7. $0.9D - E_v + E_h$

The Hashemite University

Faculty of Engineering

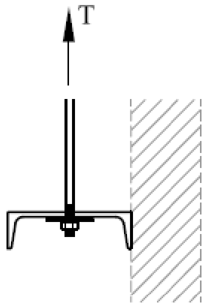
Department of Civil Engineering

Analysis and design of tension members

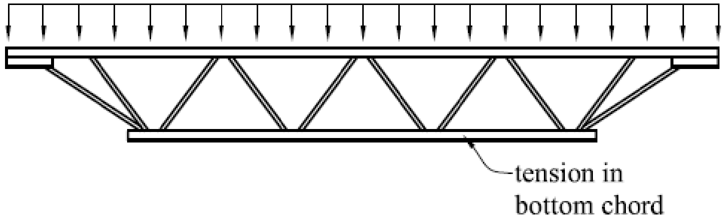
Dr. Ra’ed Al-Mazaidh

Tension Members

- **Tension members** are axially loaded members stressed in **tension**.
- They are used in steel structures in various forms; they occur as web and chord members in roof and floor trusses, and as hangers and sag rods, diagonal braces for lateral stability, lap splices, and in moment connections.

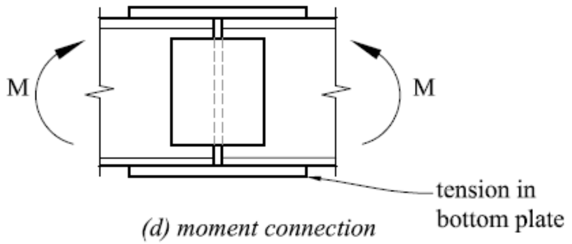


(a) sag rod

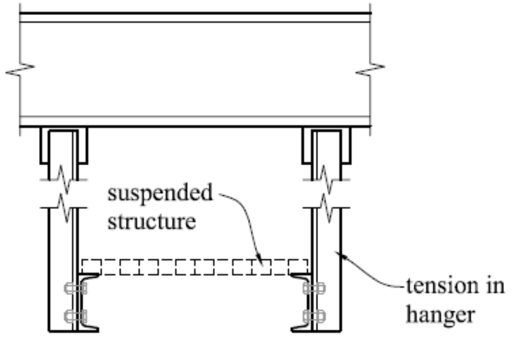


(b) truss chord

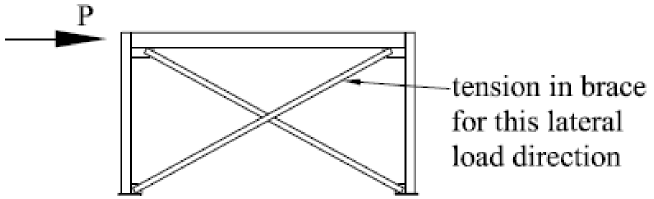
(c) lap splice



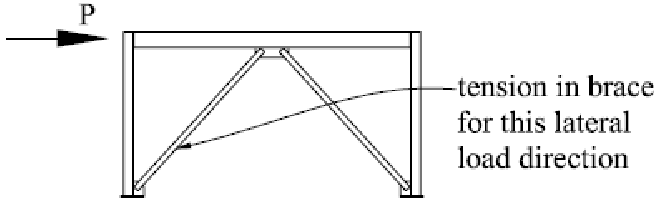
(d) moment connection



(e) hanger



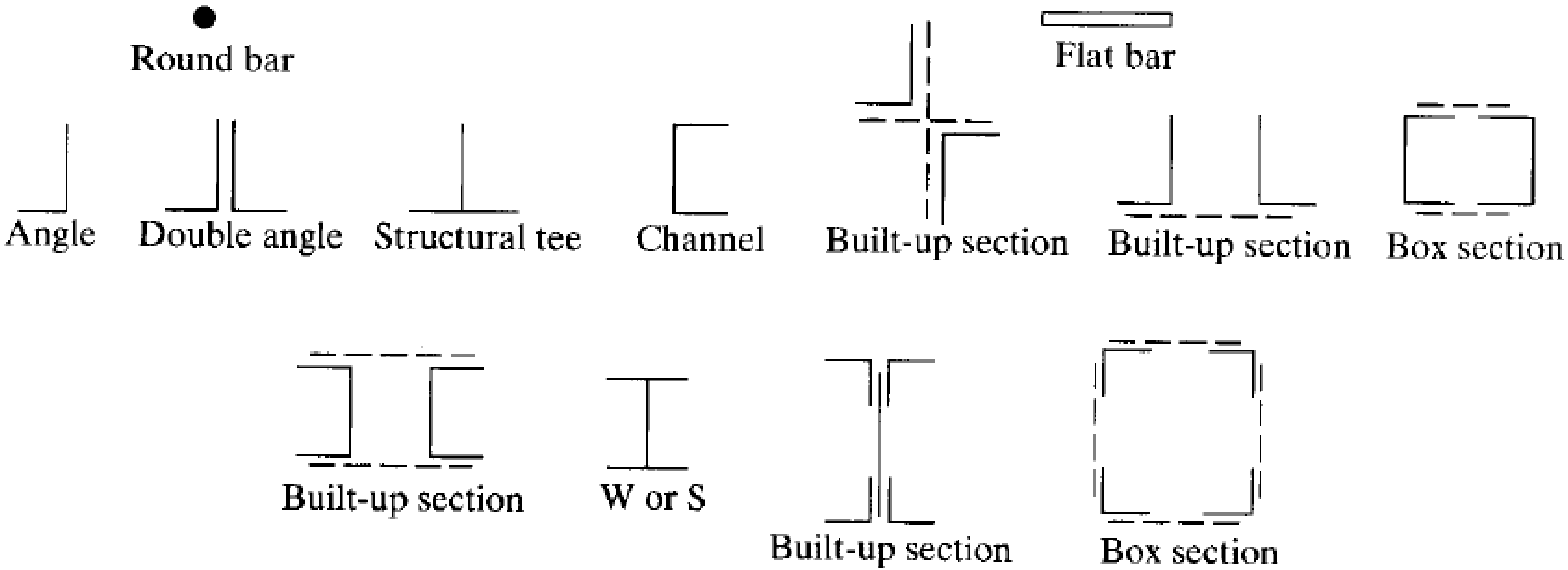
(f) X-brace



(g) Chevron brace

Types of Sections used in steel tension members

- ✓ <u>Hot rolled Steel Sections</u>: (W, S, WT, ST, C, L)
- ✓ <u>Special Sections</u>: (Flat bar, Rods and Cables)
- ✓ <u>Built up Sections</u>:



Failure modes and analysis of tension members

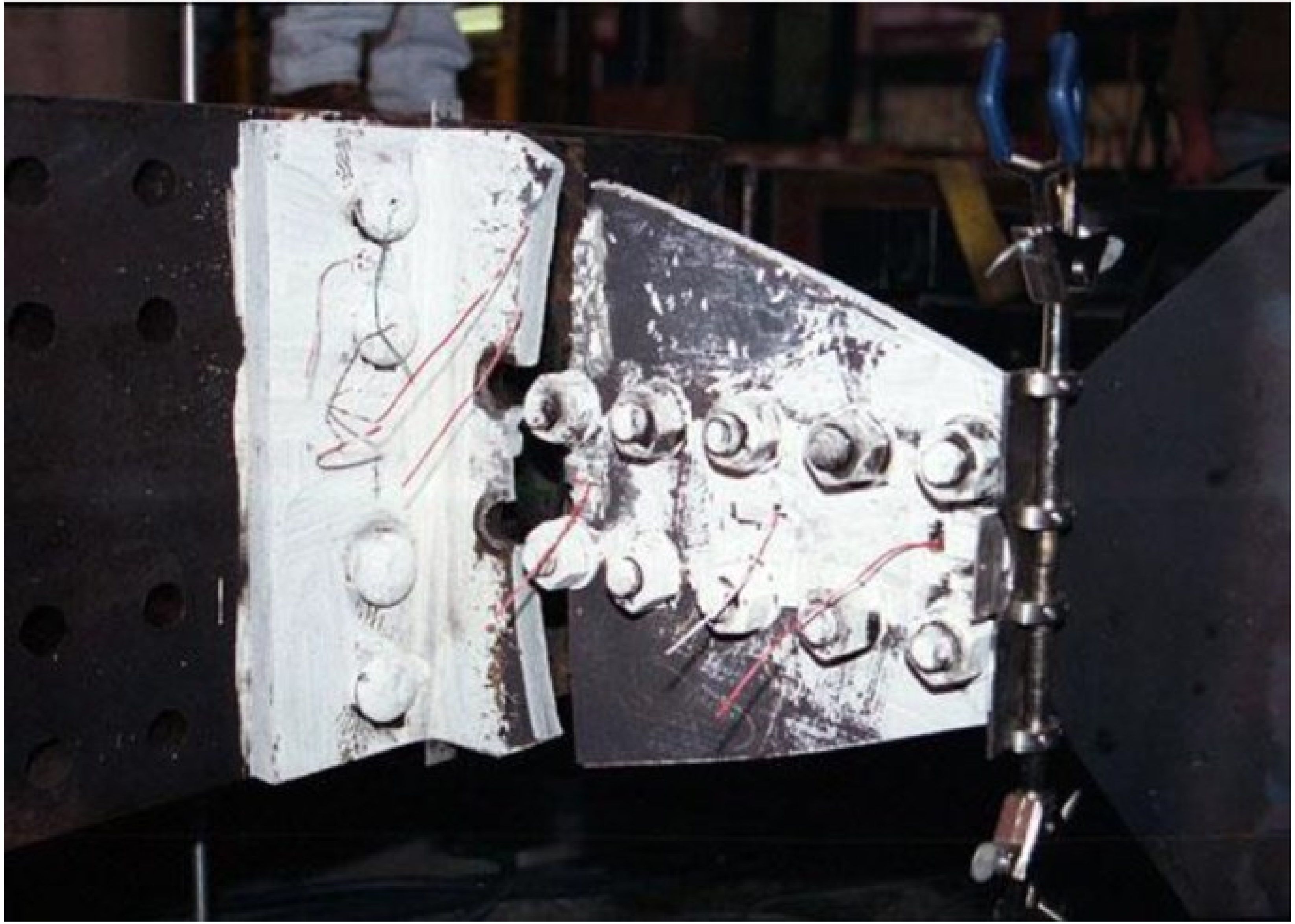
❖ For members subjected to tension, the two most basic modes of failure are:

1. **Tensile yielding** on the gross section.
2. **Tensile rupture** at the net section.

➢ **Tensile yielding** occurs when the **stress on the gross area** of the section is large enough to cause excessive deformation.

➢ **Tensile rupture** occurs when the **stress on the effective area of the net cross-section** is large enough to cause the member **to fracture or rupture** (perpendicular to the tension force), which usually occurs across a line of bolts where the tension member is weakest.

Yielding failure in Tension member



Rupture failure in Tension member

Tensile Yielding on the Gross Section:

Failure occurs in this mode by **tensile yielding** of the member at the gross cross-section. In the **LRFD method**, the ultimate tension capacity or design tensile strength, $\emptyset P_n$, for the failure mode of tensile yielding in the gross section is given as

$$\boxed{\phi_t P_n = \phi_t F_y A_g\,,}$$

Eq. (D2-1)....AISCM-15th ed.

where

$\phi_t = 0.90$,

P_n = Nominal tensile yield strength = $F_y A_g$

F_y = Minimum yield stress, and

A_g = Gross cross-sectional area of the tension member.

Part 16 (AISCM)

16.1-28

CHAPTER D

DESIGN OF MEMBERS FOR TENSION

This chapter applies to members subject to axial tension.

The chapter is organized as follows:

Tensile Rupture in the Net Section

Failure occurs in this mode by **tensile yielding** of the member at the gross cross-section. In the LRFD method, the ultimate tension capacity or design tensile strength, $\emptyset P_n$ for the failure mode of tensile yielding in the gross section is given as

$$\boxed{\phi_R P_n = \phi_R F_u A_e}$$ Eq. (D2-2)....AISCM-15th ed.

where

$\phi_R = 0.75$,

P_n = Nominal tensile strength in fracture or rupture = $F_u A_e$,

F_u = Minimum tensile strength, and

A_e = Effective cross-sectional area of the tension member.

The **design tensile strength of a tension member** is the **smaller** of the two expressions (yielding and tensile strengths)

$$\phi P_n \geq P_u$$

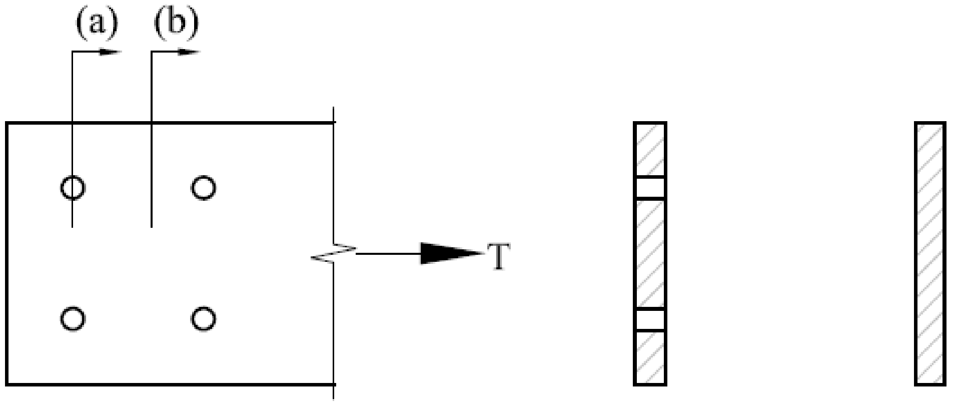
Gross cross-sectional area (A_g), Net Area (A_n)

- **The gross cross-sectional area (A_g)** of a tension member is simply the total cross-sectional area of the member.
- **The net area (A_n)** of a member is the sum of the products of the thickness and the net width of each element.

$$\boxed{A_n = A_g - \sum A_{\text{holes}},}$$

$$\sum A_{\text{holes}} = n(d_b + 1/8)t$$

n = Number of bolt holes along the failure plane (perpendicular to the tension force),
d_b = Bolt diameter, and
t = Material thickness



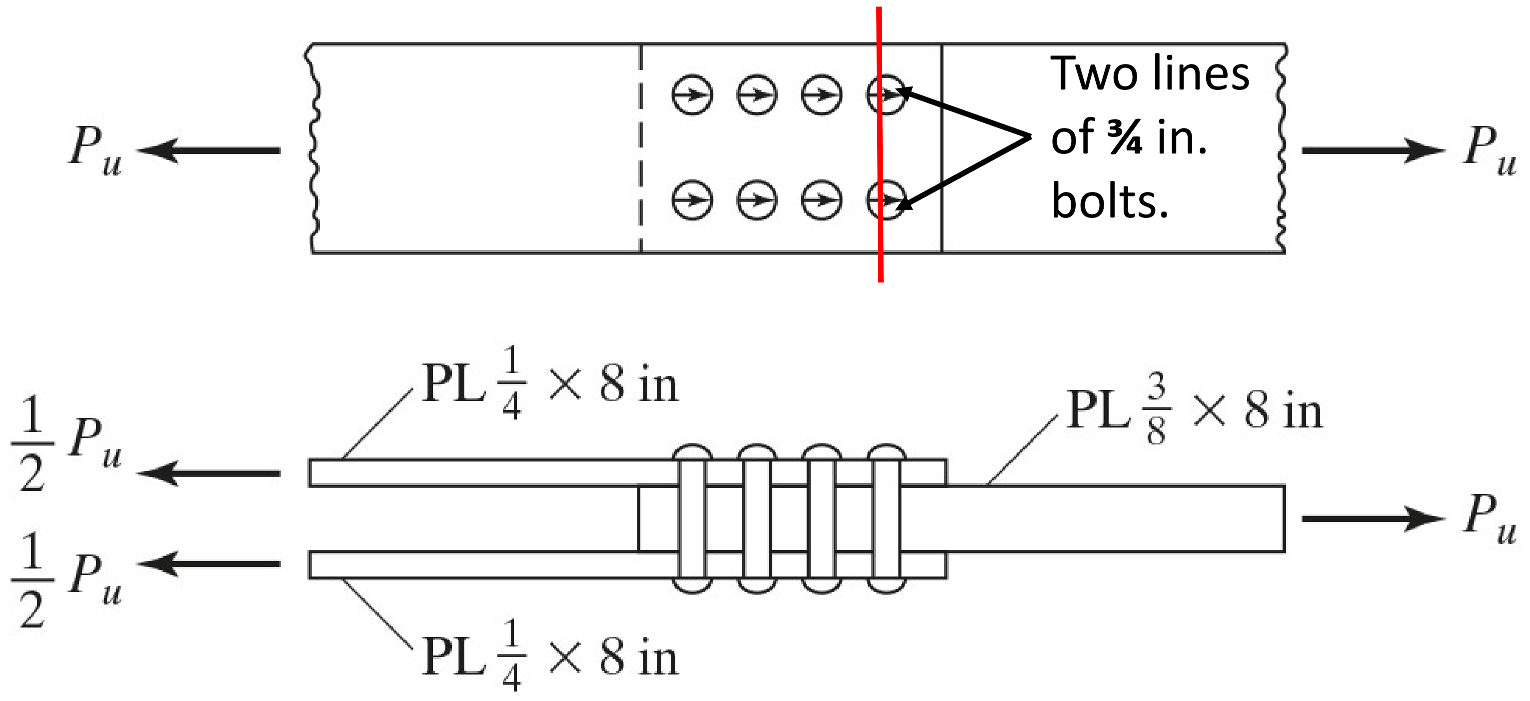
(a) net area (b) gross area

What is the (1/8) in the equation?

1. The long used practice was to punch holes with a diameter **1/16** inch larger than that of the bolts diameter.
2. Punching damages **1/16** inch more of the surrounding metal.

$$\frac{1}{16} + \frac{1}{16} = \frac{1}{8}$$

Example :



- $A_g = \left(\frac{3}{8} in.\right)(8\ in.) = 3\ in^2.$

$$A_n = A_g - \sum A_{\text{holes}}, \quad \sum A_{\text{holes}} = n(d_b + {}^1\!/_8)t$$

- $A_n = \left(\frac{3}{8} in.\right)(8\ in.) - 2\left(\frac{3}{4}\ in. + \frac{1}{8} in.\right)\left(\frac{3}{8} in.\right) = 2.34\ in^2$

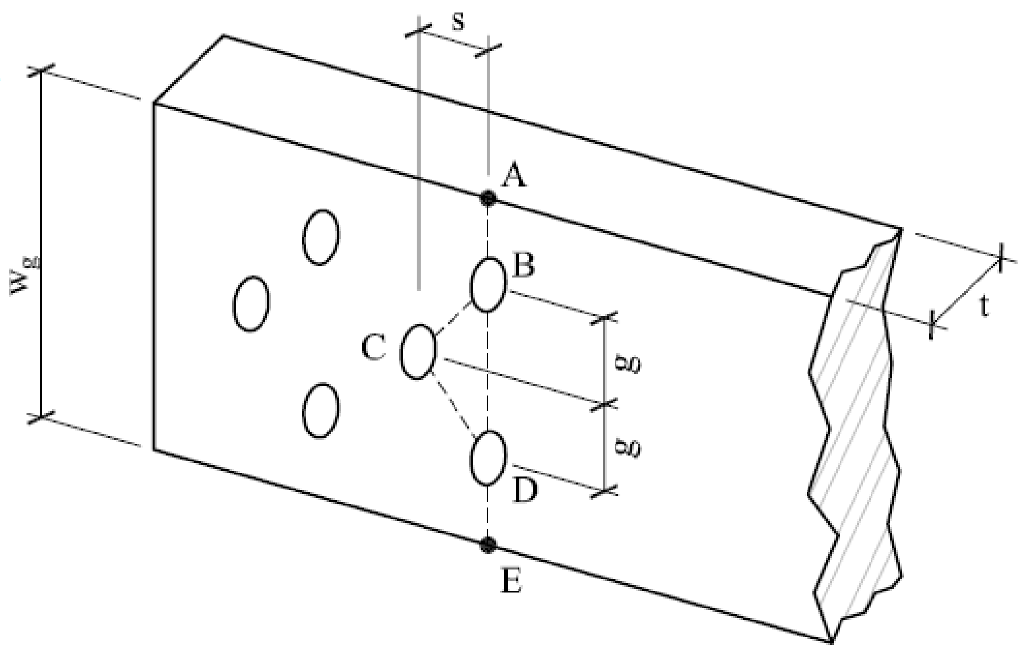
Staggered Holes

$$\frac{s^2}{4g},$$

where

s = Longitudinal center-to-center spacing or pitch between two consecutive holes, and

g = Transverse center-to-center spacing or gage between two consecutive holes.



The failure plane ***ABCDE*** has two diagonal failure planes: *BC* and *CD*. The expression for the net width then becomes:

$$w_n = w_g - \sum d_h + \sum \frac{s^2}{4g},$$

Where:

w_n = Net width,

w_g = Gross width, and

d_h = Hole diameter.

Multiplying the equation by the thickness of the member yields

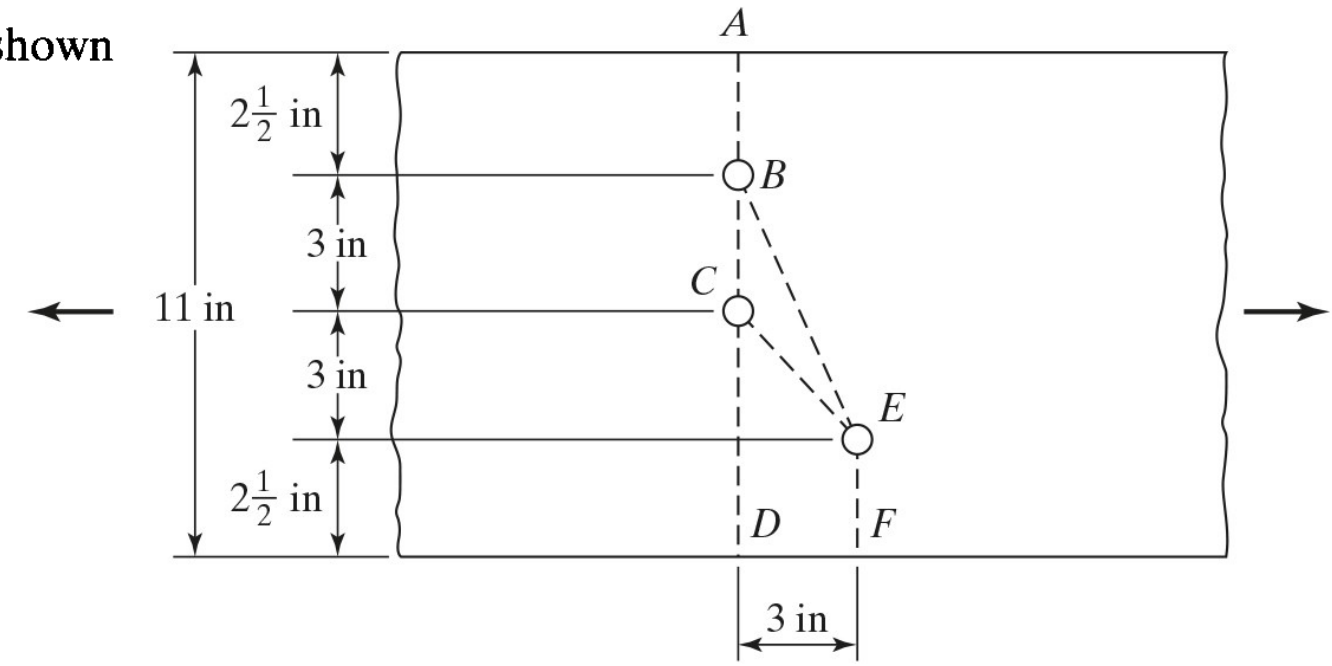
$$w_n t = w_g t - \sum d_h t + \sum \frac{s^2}{4g} t.$$

Since $A_n = W_n t$ and $A_g = W_g t$, the equation can be simplified as follows:

$$\boxed{A_n = A_g - \sum d_h t + \sum \frac{s^2}{4g} t}$$

Example :

Determine the critical net area of the 1/2-in-thick plate shown



Diameter of bolts = 3/4 in.

Solution:

$$A_n = A_g - \sum d_h t + \sum \frac{s^2}{4g} t$$

$$t = \frac{1}{2}\ in. \qquad d_h = \frac{3}{4}\ in.$$

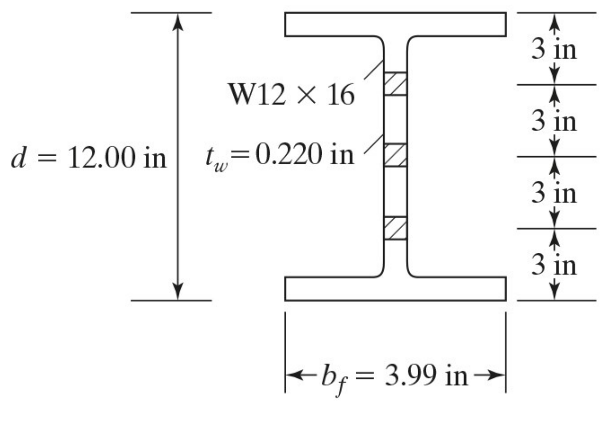
$$ABCD = (11\text{ in})\left(\frac{1}{2}\text{ in}\right) - 2\left(\frac{7}{8}\text{ in}\right)\left(\frac{1}{2}\text{ in}\right) = 4.63\text{ in}^2$$

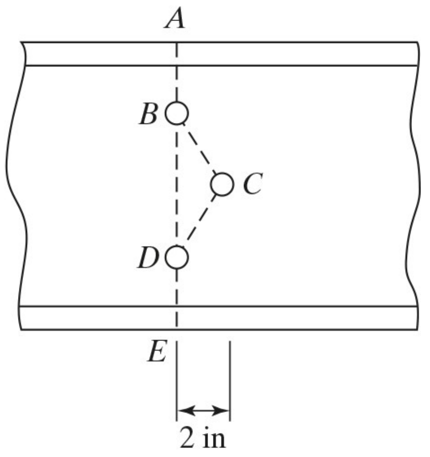
$$ABCEF = (11\text{ in})\left(\frac{1}{2}\text{ in}\right) - 3\left(\frac{7}{8}\text{ in}\right)\left(\frac{1}{2}\text{ in}\right) + \frac{(3\text{ in})^2}{4(3\text{ in})}\left(\frac{1}{2}\text{ in}\right) = 4.56\text{ in}^2 \longleftarrow$$ Critical section (smallest area)

$$ABEF = (11\text{ in})\left(\frac{1}{2}\text{ in}\right) - 2\left(\frac{7}{8}\text{ in}\right)\left(\frac{1}{2}\text{ in}\right) + \frac{(3\text{ in})^2}{4(6\text{ in})}\left(\frac{1}{2}\text{ in}\right) = 4.81\text{ in}^2$$

Example :

Determine the net area of the W12X16 shown below, assuming that the holes for 1-in bolts





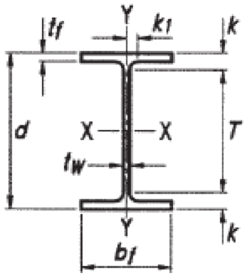


Table 1-1 (continued)
W-Shapes
Dimensions

Shape	Area, A	Depth, d		Web			Flange				Distance				
				Thickness, t_w		$\frac{t_w}{2}$	Width, b_f		Thickness, t_f		k		k_1	T	Workable Gage
											k_{des}	k_{det}			
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W12×58	17.0	12.2	12 1/4	0.360	3/8	3/16	10.0	10	0.640	5/8	1.24	1 1/2	15/16	9 1/4	5 1/2
×53	15.6	12.1	12	0.345	3/8	3/16	10.0	10	0.575	9/16	1.18	1 3/8	15/16	9 1/4	5 1/2
W12×50	14.6	12.2	12 1/4	0.370	3/8	3/16	8.08	8 1/8	0.640	5/8	1.14	1 1/2	15/16	9 1/4	5 1/2
×45	13.1	12.1	12	0.335	5/16	3/16	8.05	8	0.575	9/16	1.08	1 3/8	15/16	↓	↓
×40	11.7	11.9	12	0.295	5/16	3/16	8.01	8	0.515	1/2	1.02	1 3/8	7/8		
W12×35[c]	10.3	12.5	12 1/2	0.300	5/16	3/16	6.56	6 1/2	0.520	1/2	0.820	1 3/16	3/4	10 1/8	3 1/2
×30[c]	8.79	12.3	12 3/8	0.260	1/4	1/8	6.52	6 1/2	0.440	7/16	0.740	1 1/8	3/4	↓	↓
×26[c]	7.65	12.2	12 1/4	0.230	1/4	1/8	6.49	6 1/2	0.380	3/8	0.680	1 1/16	3/4		
W12×22[c]	6.48	12.3	12 1/4	0.260	1/4	1/8	4.03	4	0.425	7/16	0.725	15/16	5/8	10 3/8	2 1/4[g]
×19[c]	5.57	12.2	12 1/8	0.235	1/4	1/8	4.01	4	0.350	3/8	0.650	7/8	9/16	↓	↓
×16[c]	4.71	12.0	12	0.220	1/4	1/8	3.99	4	0.265	1/4	0.565	13/16	9/16		
×14[c,v]	4.16	11.9	11 7/8	0.200	3/16	1/8	3.97	4	0.225	1/4	0.525	3/4	9/16		

Solution :

$$A_n = A_g - \sum d_h t + \sum \frac{s^2}{4g} t$$

$$ABDE = 4.71 in^2 - 2\left(1 + \frac{1}{8}\right) in.(0.22\ in.) = 4.21\ in^2.$$

$$ABCDE = 4.71 in^2 - 3\left(1 + \frac{1}{8}\right) in.(0.22\ in.) + (2)\frac{(2 in)^2}{4(3\ in)}(0.22\ in) = 4.11\ in^2. \longleftarrow$$ Critical section (smallest area)

Effective Area, A_e:

The effective net area, A_e, of a tension member is a product of the net cross-sectional area which accounts for the presence of bolt holes, if any, at the critical section, and the shear lag factor, U

$$\boxed{A_e = A_n U}$$

where

A_n = Net cross-sectional area of the tension member, and

U = Shear lag factor.

Shear lag factor (U)

Shear lag in tension members is a phenomenon that occurs due to the non-uniform axial tension stress distribution at the connections of the tension member because all of the elements of the tension member are not connected or attached to the supporting member or gusset plate, such as a single or WT member.

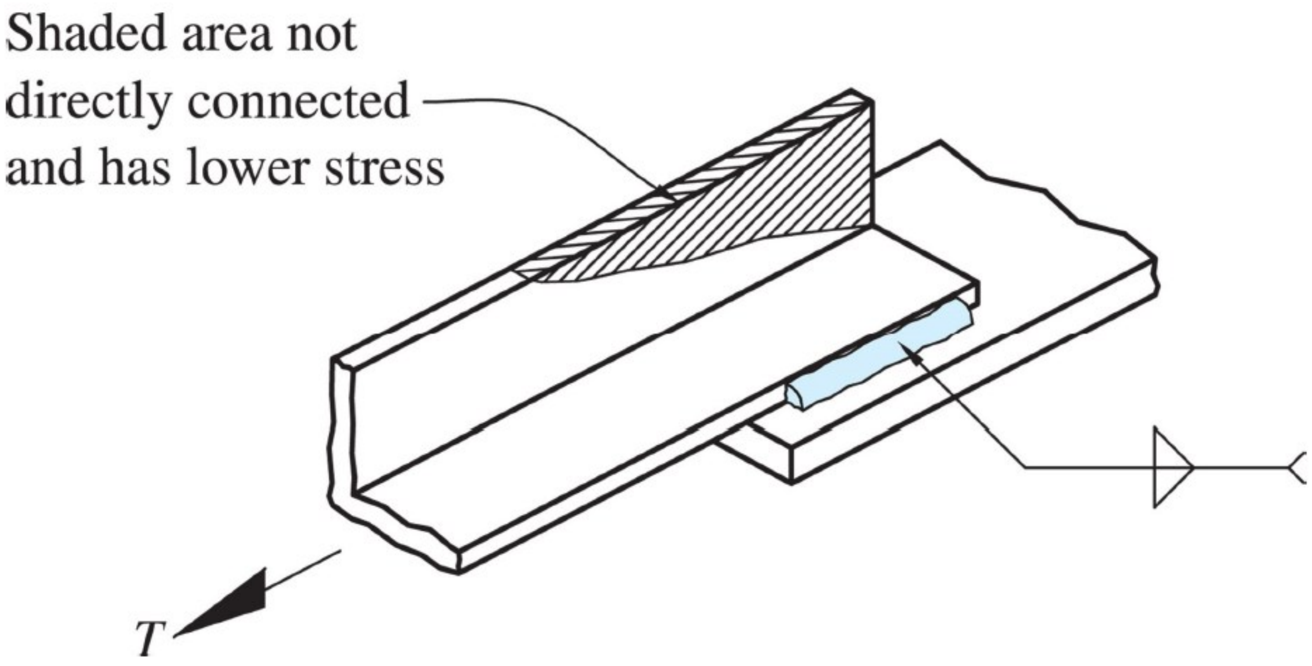
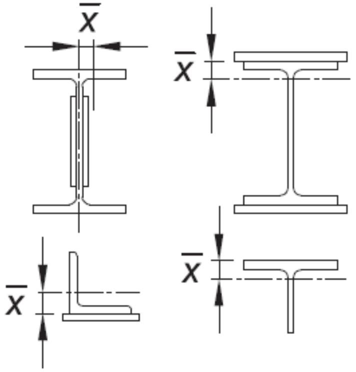


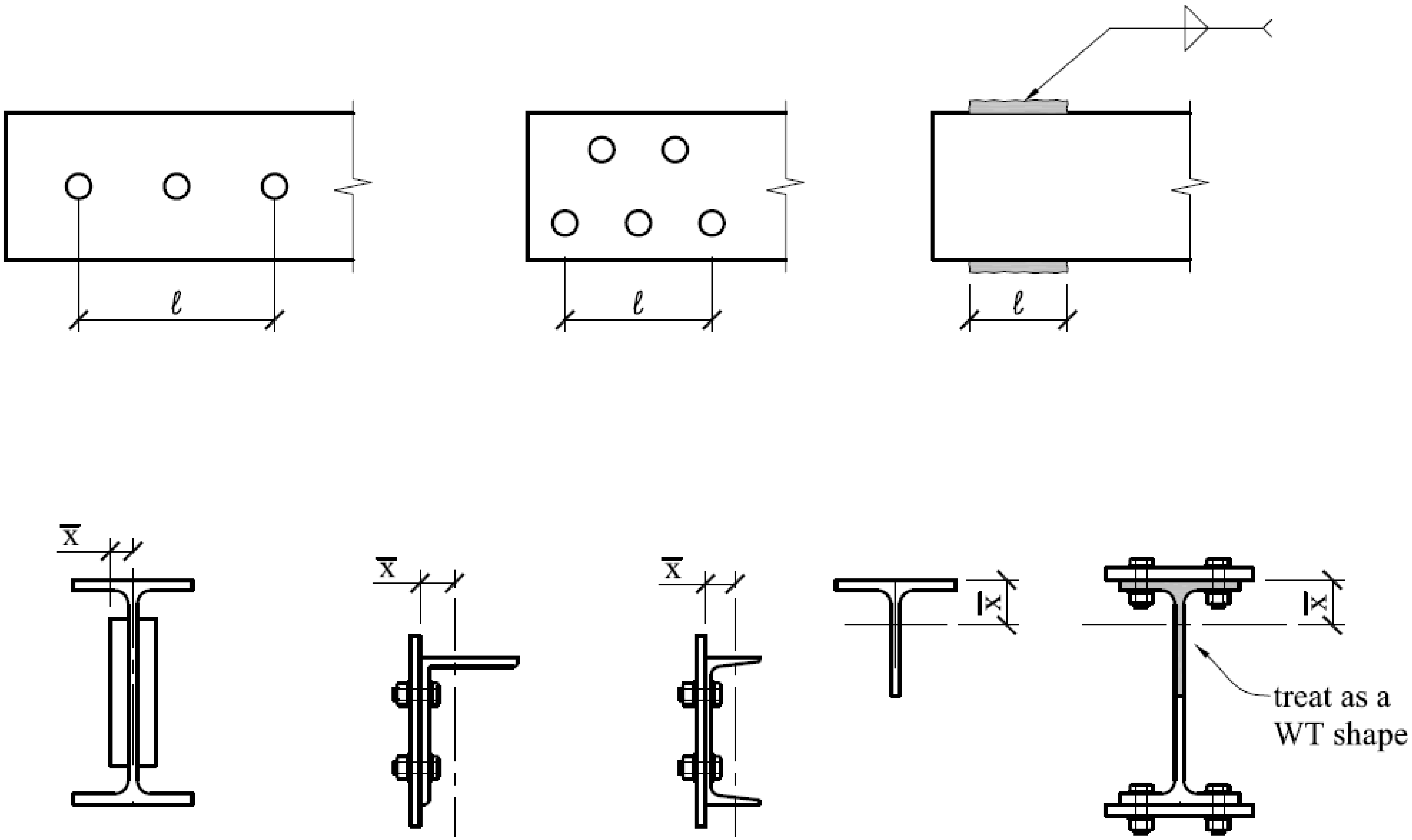
Table D3.1 of the **AISCM** gives the values of the shear lag factor, U, for various connection configurations

TABLE D3.1
Shear Lag Factors for Connections to Tension Members

Case	Description of Element	Shear Lag Factor, U	Example
1	All tension members where the tension load is transmitted directly to each of the cross-sectional elements by fasteners or welds (except as in Cases 4, 5 and 6).	$U = 1.0$	–
2	All tension members, except HSS, where the tension load is transmitted to some but not all of the cross-sectional elements by fasteners or by longitudinal welds in combination with transverse welds. Alternatively, Case 7 is permitted for W, M, S and HP shapes. (For angles, Case 8 is permitted to be used.)	$U = 1 - \frac{\bar{x}}{l}$	

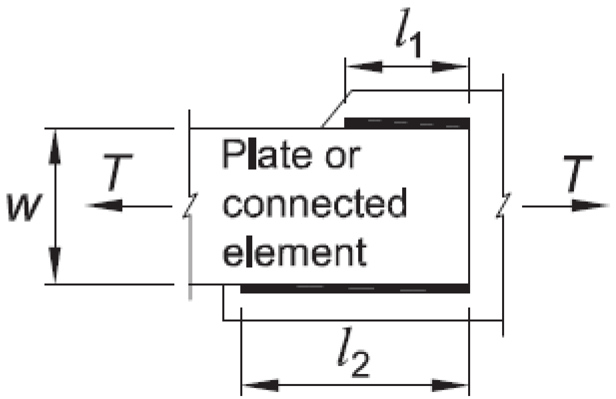
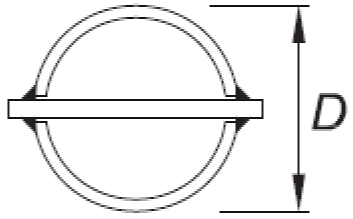
$\bar{x}$= Distance between the centroid of the connected member and the connection plane.

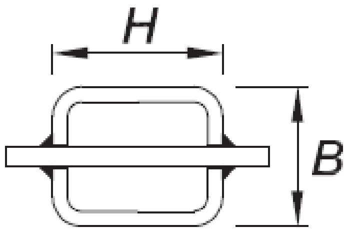
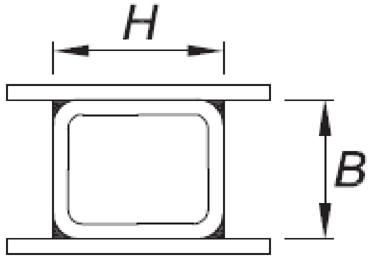
l = Connection length measured parallel to the tension load (for bolts, it is the out-to-out distance between extreme bolts).



Determination of $\bar{x}$ and ℓ

$$l = \frac{l_1 + l_2}{2}$$, where l_1 and l_2 shall not be less than 4 times the weld size.

4[a]	Plates, angles, channels with welds at heels, tees, and W-shapes with connected elements, where the tension load is transmitted by longitudinal welds only. See Case 2 for definition of $\bar{x}$.	$U = \frac{3l^2}{3l^2 + w^2}\left(1 - \frac{\bar{x}}{l}\right)$	
5	Round HSS with a single concentric gusset plate through slots in the HSS.	$l \geq 1.3D,\ U = 1.0$ $D \leq l < 1.3D,\ U = 1 - \frac{\bar{x}}{l}$ $\bar{x} = \frac{D}{\pi}$	

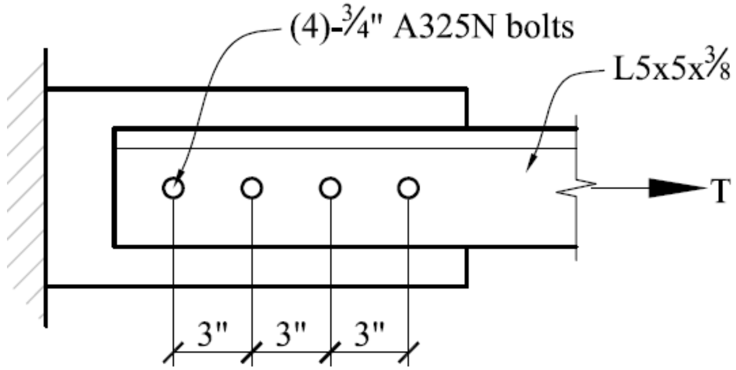
6	Rectangular HSS.	with a single concentric gusset plate	$l \ge H,\ U = 1 - \frac{\bar{x}}{l}$ $\bar{x} = \frac{B^2 + 2BH}{4(B+H)}$	
		with two side gusset plates	$l \ge H,\ U = 1 - \frac{\bar{x}}{l}$ $\bar{x} = \frac{B^2}{4(B+H)}$	
7	W-, M-, S- or HP-shapes, or tees cut from these shapes. (If U is calculated per Case 2, the larger value is permitted to be used.)	with flange connected with three or more fasteners per line in the direction of loading	$b_f \ge \frac{2}{3}d,\ U = 0.90$ $b_f < \frac{2}{3}d,\ U = 0.85$	–
		with web connected with four or more fasteners per line in the direction of loading	$U = 0.70$	–

B = overall width of rectangular HSS member, measured 90° to the plane of the connection, in. (mm); D = outside diameter of round HSS, in. (mm); H = overall height of rectangular HSS member, measured in the plane of the connection, in. (mm); d = depth of section, in. (mm); for tees, d = depth of the section from which the tee was cut, in. (mm); l = length of connection, in. (mm); w = width of plate, in. (mm); $\bar{x}$ = eccentricity of connection, in. (mm).

8	Single and double angles. (If U is calculated per Case 2, the larger value is permitted to be used.)	with four or more fasteners per line in the direction of loading	$U = 0.80$	–
		with three fasteners per line in the direction of loading (with fewer than three fasteners per line in the direction of loading, use Case 2)	$U = 0.60$	–

Example :

For the bolted tension member shown **below,** determine the shear lag factor, U; the net area, A_n; and the effective area, A_e.



Solution

From the section property tables in part 1 of the *AISCM*, we find that for an $L5 \times 5 \times {}^3\!/_8$,

$$\bar{x} = 1.37 \text{ in.}$$

$$A_g = 3.65 \text{ in.}^2$$

Total length of the connection (i.e., distance between extreme bolts), $\ell = 9$ in.

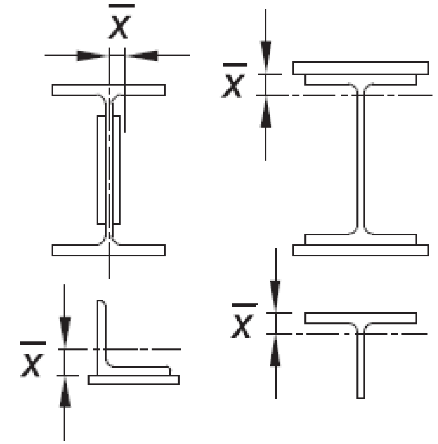
Shear Lag Factor: See next slide

$$U = 1 - \frac{\bar{x}}{\ell} \quad \text{Case 2}$$

$$= 1 - \frac{1.37 \text{ in.}}{9 \text{ in.}} = 0.848$$

Alternatively, $U = 0.80$ from **Table D3.1** The larger value of $U = 0.848$ can be used.

Case 8 (a)

2	All tension members, except HSS, where the tension load is transmitted to some but not all of the cross-sectional elements by fasteners or by longitudinal welds in combination with transverse welds. Alternatively, Case 7 is permitted for W, M, S and HP shapes. (For angles, Case 8 is permitted to be used.)	$\boxed{U = 1 - \frac{\bar{x}}{l}}$	

8	Single and double angles. (If U is calculated per Case 2, the larger value is permitted to be used.)	with four or more fasteners per line in the direction of loading	$\boxed{U = 0.80}$	–
		with three fasteners per line in the direction of loading (with fewer than three fasteners per line in the direction of loading, use Case 2)	$U = 0.60$	–

Net Area of the Angle:

At any critical section where rupture may occur perpendicular to the tension load, there is only one hole. Therefore, the net area is

$$A_n = A_g - \sum A_{\text{holes}}$$

$$= 3.65 - (1)\left(\frac{3}{4} + \frac{1}{8}\right)(0.375) = 3.32 \text{ in.}^2$$

Effective Area:

$$A_e = A_n U$$

$$= (3.32)(0.848) = 2.82 \text{ in.}^2$$

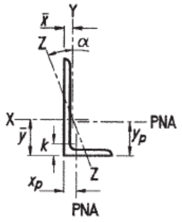


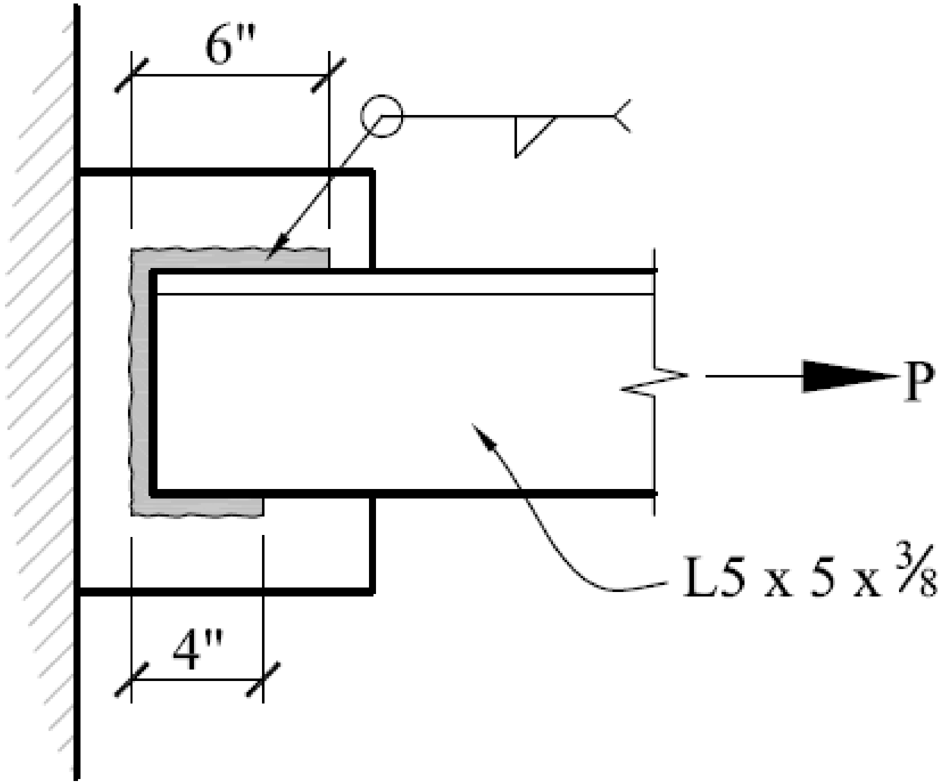
Table 1-7 (continued)
Angles
Properties

Shape	k	Wt.	Area, A	Axis X-X I	S	r	$\bar{y}$	Z	y_p	Flexural-Torsional Properties J	C_w	$\bar{r}_o$
	in.	lb/ft	in.^{2}	in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{6}	in.
L6×4×7/8	1 3/8	27.2	8.00	27.7	7.13	1.86	2.12	12.7	1.43	2.03	4.04	2.82
×3/4	1 1/4	23.6	6.94	24.5	6.23	1.88	2.07	11.1	1.37	1.31	2.64	2.85
×5/8	1 1/8	20.0	5.86	21.0	5.29	1.89	2.03	9.44	1.31	0.775	1.59	2.88
×9/16	1 1/16	18.1	5.31	19.2	4.81	1.90	2.00	8.59	1.28	0.572	1.18	2.90
×1/2	1	16.2	4.75	17.3	4.31	1.91	1.98	7.71	1.25	0.407	0.843	2.91
×7/16	15/16	14.3	4.18	15.4	3.81	1.92	1.95	6.81	1.22	0.276	0.575	2.93
×3/8	7/8	12.3	3.61	13.4	3.30	1.93	1.93	5.89	1.19	0.177	0.369	2.94
×5/16	13/16	10.3	3.03	11.4	2.77	1.94	1.90	4.96	1.15	0.104	0.217	2.96
L6×3 1/2×1/2	1	15.3	4.50	16.6	4.23	1.92	2.07	7.49	1.50	0.386	0.779	2.88
×3/8	7/8	11.7	3.44	12.9	3.23	1.93	2.02	5.74	1.41	0.168	0.341	2.90
×5/16	13/16	9.80	2.89	10.9	2.72	1.94	2.00	4.84	1.38	0.0990	0.201	2.92
L5×5×7/8	1 3/8	27.2	8.00	17.8	5.16	1.49	1.56	9.31	0.800	2.07	3.53	2.64
×3/4	1 1/4	23.6	6.98	15.7	4.52	1.50	1.52	8.14	0.698	1.33	2.32	2.67
×5/8	1 1/8	20.0	5.90	13.6	3.85	1.52	1.47	6.93	0.590	0.792	1.40	2.70
×1/2	1	16.2	4.79	11.3	3.15	1.53	1.42	5.66	0.479	0.417	0.744	2.73
×7/16	15/16	14.3	4.22	10.0	2.78	1.54	1.40	5.00	0.422	0.284	0.508	2.74
×3/8	7/8	12.3	3.65	8.76	2.41	1.55	1.37	4.33	0.365	0.183	0.327	2.76

Shape	Axis Y-Y I	S	r	$\bar{x}$	Z	x_p	Axis Z-Z I	S	r	Tan α	Q_s $F_y = 36$ ksi
	in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{3}	in.		
L6×4×7/8	9.70	3.37	1.10	1.12	6.26	0.667	5.82	2.91	0.854	0.421	1.00
×3/4	8.63	2.95	1.12	1.07	5.42	0.578	5.08	2.51	0.856	0.428	1.00
×5/8	7.48	2.52	1.13	1.03	4.56	0.488	4.32	2.12	0.859	0.435	1.00
×9/16	6.86	2.29	1.14	1.00	4.13	0.443	3.93	1.92	0.861	0.438	1.00
×1/2	6.22	2.06	1.14	0.981	3.69	0.396	3.54	1.72	0.864	0.440	1.00
×7/16	5.56	1.83	1.15	0.957	3.24	0.348	3.14	1.51	0.867	0.443	0.973
×3/8	4.86	1.58	1.16	0.933	2.79	0.301	2.73	1.31	0.870	0.446	0.912
×5/16	4.13	1.34	1.17	0.908	2.33	0.253	2.31	1.10	0.874	0.449	0.826
L6×3 1/2×1/2	4.24	1.59	0.968	0.829	2.88	0.375	2.59	1.34	0.756	0.343	1.00
×3/8	3.33	1.22	0.984	0.781	2.18	0.287	2.01	1.02	0.763	0.349	0.912
×5/16	2.84	1.03	0.991	0.756	1.82	0.241	1.70	0.859	0.767	0.352	0.826
L5×5×7/8	17.8	5.16	1.49	1.56	9.31	0.800	7.60	3.43	0.971	1.00	1.00
×3/4	15.7	4.52	1.50	1.52	8.14	0.698	6.55	3.08	0.972	1.00	1.00
×5/8	13.6	3.85	1.52	1.47	6.93	0.590	5.62	2.70	0.975	1.00	1.00
×1/2	11.3	3.15	1.53	1.42	5.66	0.479	4.64	2.29	0.980	1.00	1.00
×7/16	10.0	2.78	1.54	1.40	5.00	0.422	4.04	2.06	0.983	1.00	1.00
×3/8	8.76	2.41	1.55	1.37	4.33	0.365	3.55	1.83	0.986	1.00	0.983

Example :

For the welded tension member shown below, determine the shear lag factor, U; the net area, A_n; and the effective area, A_e.



Solution

Shear Lag Factor:

The average length of the longitudinal welds, $\ell = \dfrac{6\text{ in.} + 4\text{ in.}}{2} = 5\text{ in.}$

$$U = 1 - \frac{\bar{x}}{\ell}$$ Case 2

$$= 1 - \frac{1.37\text{ in.}}{5\text{ in.}} = 0.726$$

There is not an alternate value to use from **Table D3.1** so $U = 0.726$.

Since there are no holes, $A_n = A_g = 3.65\text{ in.}^2$.

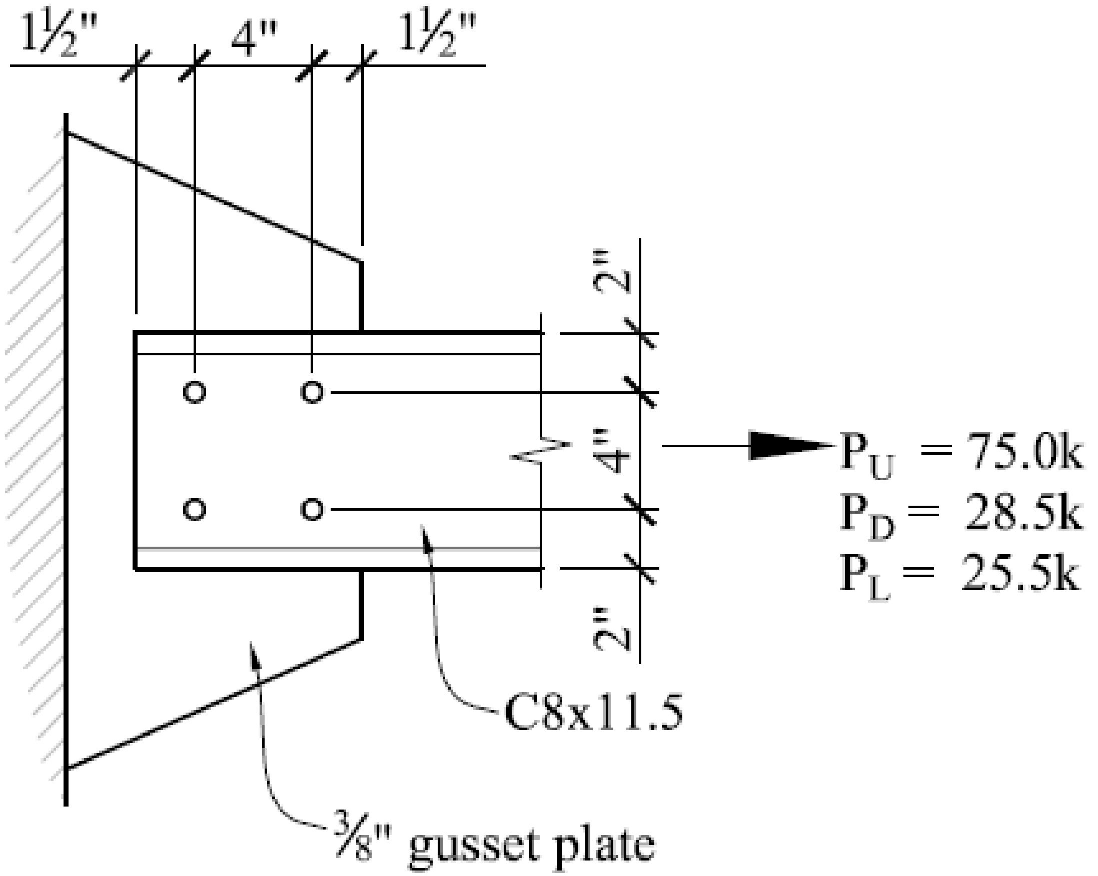
Effective Area:

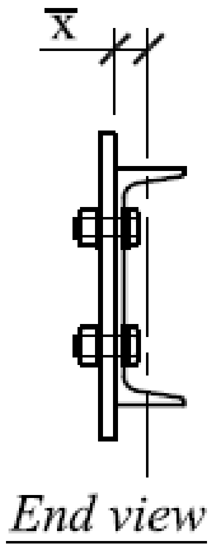
$$A_e = A_n U$$

$$= (3.65)(0.726) = 2.65\text{ in.}^2$$

Example :

Determine if the channel is adequate for the applied tension load shown **below.** . The channel is ASTM A36 steel and is connected with four $^5/_8$-in. diameter bolts. The tension member is subjected to service dead and live loads of 28.5 kips and 25.5 kips, respectively. Neglect block shear.





Solution

From the *AISCM*, Table 1-5:

$$A_g = 3.37 \text{ in.}^2$$

$$\bar{x} = 0.572$$

$$t_w = 0.220 \text{ in.}$$

From the *AISCM* Table (2-4)

$$F_y = 36 \text{ ksi}$$

$$F_u = 58 \text{ ksi to } 80 \text{ ksi} \ (\text{use } F_u = 58 \text{ ksi})$$

Net Area of the Channel:

$$A_n = A_g - \sum A_{\text{holes}}$$

$$= 3.37 - \left[(2)\left(\frac{5}{8}+\frac{1}{8}\right)(0.220)\right] = 3.04 \text{ in.}^2$$

Effective Area of the Channel:

From **Table D3.1** the shear lag factor is

$$U = 1 - \frac{\bar{x}}{\ell} \qquad \text{Case 2}$$

$$= 1 - \frac{0.572 \text{ in.}}{4 \text{ in.}} = 0.857$$

$$A_e = A_n U$$

$$= (3.04)(0.857) = 2.61 \text{ in.}^2$$

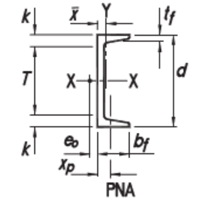


Table 1-5
C-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Average Thickness, t_f		Distance k	Distance T	Workable Gage	r_{ts}	h_o
	in.²	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
C15×50	14.7	15.0	15	0.716	11/16	3/8	3.72	3 3/4	0.650	5/8	1 7/16	12 1/8	2 1/4	1.17	14.4
×40	11.8	15.0	15	0.520	1/2	1/4	3.52	3 1/2	0.650	5/8	1 7/16	12 1/8	2	1.15	14.4
×33.9	10.0	15.0	15	0.400	3/8	3/16	3.40	3 3/8	0.650	5/8	1 7/16	12 1/8	2	1.13	14.4
C12×30	8.81	12.0	12	0.510	1/2	1/4	3.17	3 1/8	0.501	1/2	1 1/8	9 3/4	1 3/4[g]	1.01	11.5
×25	7.34	12.0	12	0.387	3/8	3/16	3.05	3	0.501	1/2	1 1/8	9 3/4	1 3/4[g]	1.00	11.5
×20.7	6.08	12.0	12	0.282	5/16	3/16	2.94	3	0.501	1/2	1 1/8	9 3/4	1 3/4[g]	0.983	11.5
C10×30	8.81	10.0	10	0.673	11/16	3/8	3.03	3	0.436	7/16	1	8	1 3/4[g]	0.924	9.56
×25	7.35	10.0	10	0.526	1/2	1/4	2.89	2 7/8	0.436	7/16	1	8	1 3/4[g]	0.911	9.56
×20	5.87	10.0	10	0.379	3/8	3/16	2.74	2 3/4	0.436	7/16	1	8	1 1/2[g]	0.894	9.56
×15.3	4.48	10.0	10	0.240	1/4	1/8	2.60	2 5/8	0.436	7/16	1	8	1 1/2[g]	0.868	9.56
C9×20	5.87	9.00	9	0.448	7/16	1/4	2.65	2 5/8	0.413	7/16	1	7	1 1/2[g]	0.850	8.59
×15	4.40	9.00	9	0.285	5/16	3/16	2.49	2 1/2	0.413	7/16	1	7	1 3/8[g]	0.825	8.59
×13.4	3.94	9.00	9	0.233	1/4	1/8	2.43	2 3/8	0.413	7/16	1	7	1 3/8[g]	0.814	8.59
C8×18.75	5.51	8.00	8	0.487	1/2	1/4	2.53	2 1/2	0.390	3/8	15/16	6 1/8	1 1/2[g]	0.800	7.61
×13.75	4.03	8.00	8	0.303	5/16	3/16	2.34	2 3/8	0.390	3/8	15/16	6 1/8	1 3/8[g]	0.774	7.61
×11.5	3.37	8.00	8	0.220	1/4	1/8	2.26	2 1/4	0.390	3/8	15/16	6 1/8	1 3/8[g]	0.756	7.61

Nom-inal Wt.	Shear Ctr, e_o	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y $\bar{x}$	Axis Y-Y Z	Axis Y-Y x_p	Torsional Properties J	Torsional Properties C_w	Torsional Properties $\bar{r}_o$	Torsional Properties H
lb/ft	in.	in.⁴	in.³	in.	in.³	in.⁴	in.³	in.	in.	in.³	in.	in.⁴	in.⁶	in.	
50	0.583	404	53.8	5.24	68.5	11.0	3.77	0.865	0.799	8.14	0.490	2.65	492	5.49	0.937
40	0.767	348	46.5	5.43	57.5	9.17	3.34	0.883	0.778	6.84	0.392	1.45	410	5.71	0.927
33.9	0.896	315	42.0	5.61	50.8	8.07	3.09	0.901	0.788	6.19	0.332	1.01	358	5.94	0.920
30	0.618	162	27.0	4.29	33.8	5.12	2.05	0.762	0.674	4.32	0.367	0.861	151	4.54	0.919
25	0.746	144	24.0	4.43	29.4	4.45	1.87	0.779	0.674	3.82	0.306	0.538	130	4.72	0.909
20.7	0.870	129	21.5	4.61	25.6	3.86	1.72	0.797	0.698	3.47	0.253	0.369	112	4.93	0.899
30	0.368	103	20.7	3.43	26.7	3.93	1.65	0.668	0.649	3.78	0.441	1.22	79.5	3.63	0.921
25	0.494	91.1	18.2	3.52	23.1	3.34	1.47	0.675	0.617	3.18	0.367	0.687	68.3	3.76	0.912
20	0.636	78.9	15.8	3.67	19.4	2.80	1.31	0.690	0.606	2.70	0.294	0.368	56.9	3.93	0.900
15.3	0.796	67.3	13.5	3.88	15.9	2.27	1.15	0.711	0.634	2.34	0.224	0.209	45.5	4.19	0.884
20	0.515	60.9	13.5	3.22	16.9	2.41	1.17	0.640	0.583	2.46	0.326	0.427	39.4	3.46	0.899
15	0.681	51.0	11.3	3.40	13.6	1.91	1.01	0.659	0.586	2.04	0.245	0.208	31.0	3.69	0.882
13.4	0.742	47.8	10.6	3.48	12.6	1.75	0.954	0.666	0.601	1.94	0.219	0.168	28.2	3.79	0.875
18.75	0.431	43.9	11.0	2.82	13.9	1.97	1.01	0.598	0.565	2.17	0.344	0.434	25.1	3.05	0.894
13.75	0.604	36.1	9.02	2.99	11.0	1.52	0.848	0.613	0.554	1.73	0.252	0.186	19.2	3.26	0.874
11.5	0.697	32.5	8.14	3.11	9.63	1.31	0.775	0.623	0.572	1.57	0.211	0.130	16.5	3.41	0.862

Table 2-4
Applicable ASTM Specifications for Various Structural Shapes

Steel Typ	ASTM Designatio		F_y Yield Stress[a] (ksi)	F_u Tensile Stress[a] (ksi)	Applicable Shape Series W	M	S	HP	C	MC	L	HSS Rect.	HSS Round	Pipe
Carbon	A36		36	58–80[b]	▒	■	■	▒	■	■	■			
	A53 Gr. B		35	60										■
	A500	Gr. B	42	58									▒	
			46	58								▒		
		Gr. C	46	62									■	
			50	62								■		
	A501	Gr. A	36	58								▒	▒	
		Gr. B	50	70								▒	▒	
	A529[c]	Gr. 50	50	65–100	▒	▒	▒	▒	▒	▒	▒			
		Gr. 55	55	70–100	▒	▒	▒	▒	▒	▒	▒			
	A709	36	36	58–80[b]	▒	▒	▒	▒	▒	▒	▒			
	A1043[d,k]	36	36–52	58	▒									
		50	50–65	65	▒									
	A1085	Gr. A	50	65								▒	▒	
High-Strength Low-Alloy	A572	Gr.42	42	60	▒	▒	▒	▒	▒	▒	▒			
		Gr.50	50	65	▒	▒	▒	■	▒	▒	▒			
		Gr.55	55	70	▒	▒	▒	▒	▒	▒	▒			
		Gr. 60[e]	60	75	▒	▒	▒	▒	▒	▒	▒			
		Gr. 65[e]	65	80	▒	▒	▒	▒	▒	▒	▒			
	A618[f]	Gr. Ia[k], Ib & II	50[g]	70[g]								▒	▒	
		Gr. III	50	65								▒	▒	
	A709	50	50	65	▒	▒	▒	▒	▒	▒	▒			
		50S	50–65	65	▒	▒	▒	▒	▒	▒	▒			
		50W	50	70	▒	▒	▒	▒	▒	▒	▒			
	A913	50	50[h]	65[h]	▒	▒	▒	▒	▒	▒	▒			
		60	60	75	▒	▒	▒	▒	▒	▒	▒			
		65	65	80	▒	▒	▒	▒	▒	▒	▒			
		70	70	90	▒	▒	▒	▒	▒	▒	▒			
	A992		50[i]	65[i]	■	▒	▒	▒	▒	▒	▒			
	A1065[k]	Gr. 50[j]	50	60								▒		

■ – Preferred material specification.
▒ = Other applicable material specification, the availability of which should be confirmed prior to specification.
□ = Material specification does not apply.

Footnotes on facing page.

LRFD Method:

Pu=1.2 DL+1.6 LL

$$P_u = 1.2(28.5) + 1.6(25.5) = 75 \text{ kips}$$

the nominal tensile strength due to tensile yielding on the gross area is

$$P_n = F_y A_g = (36)(3.37) = 121.3 \text{ kips}$$

The design tensile strength due to yielding is :

$$\phi_t P_n = (0.9)(121.3) = 109 \text{ kips} > P_u = 75 \text{ kips. OK.}$$ ← **Controls**

the nominal tensile strength due to fracture or rupture on the effective area is

$$P_n = F_u A_e = (58)(2.61 \text{ in.}^2) = 151.4 \text{ kips}$$

The design tensile strength due to fracture or rupture on the effective area is

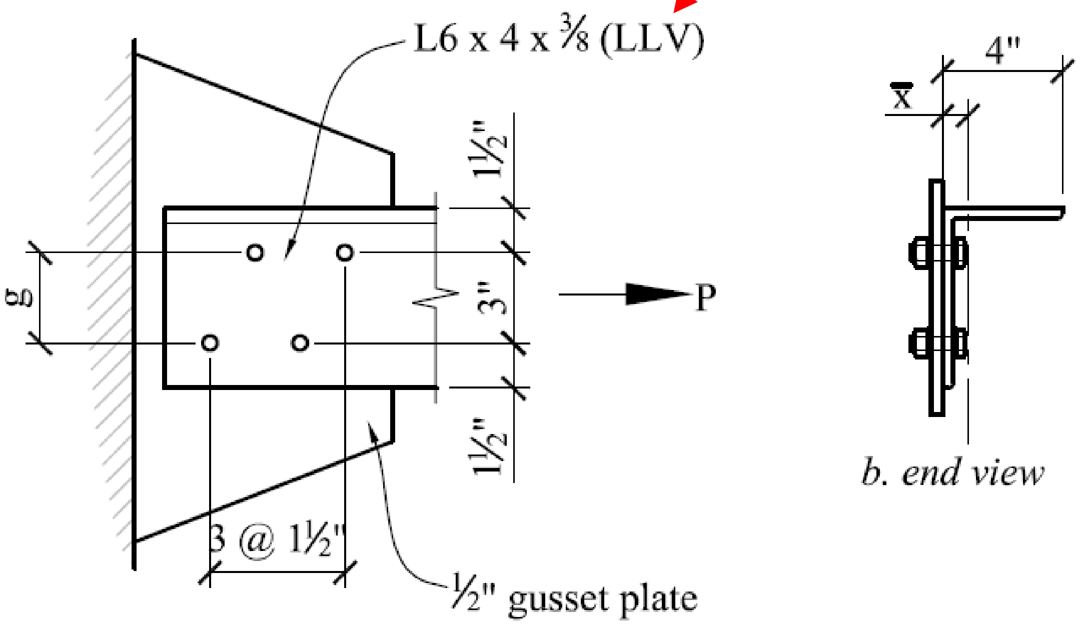
$$\phi_R P_n = (0.75)(151.4) = 113.6 \text{ kips} > P_u = 75 \text{ kips. OK.}$$

The design tensile strength of the tension member is the smaller of the two values calculated above. Thus, the design strength, $\phi P_n = 109 \text{ kips} > P_u = 75 \text{ kips.}$ OK.

Example :

Determine the maximum factored load that can be applied in tension to the angle shown **below.** The angle is ASTM A36 steel and is connected with four 3⁄4-in. diameter bolts. Neglect block shear.

Long leg is vertical



Solution

From the *AISCM* Table 1-7:

$$A_g = 3.61 \text{ in.}^2$$

$$\bar{x} = 0.933 \text{ in.}$$

$$t = 0.375 \text{ in.}$$

$$\frac{3}{8} = 0.375''$$

From the *AISCM*, Table (2-4)

$$F_y = 36 \text{ ksi}$$

$$F_u = 58 \text{ ksi to } 80 \text{ ksi } \left(\text{use } F_u = 58 \text{ ksi}\right)$$

Table 2-4
Applicable ASTM Specifications for Various Structural Shapes

Steel Typ	ASTM Designatio		F_y Yield Stress[a] (ksi)	F_u Tensile Stress[a] (ksi)	Applicable Shape Series: W	M	S	HP	C	MC	L	HSS: Rect.	HSS: Round	Pipe
Carbon	A36		36	58–80[b]	▒	■	■	▒	■	■	■			
	A53 Gr. B		35	60										■
	A500	Gr. B	42	58									▒	
			46	58								▒		
		Gr. C	46	62									■	
			50	62								■		
	A501	Gr. A	36	58								▒	▒	
		Gr. B	50	70								▒	▒	
	A529[c]	Gr. 50	50	65–100	▒	▒	▒	▒	▒	▒	▒			
		Gr. 55	55	70–100	▒	▒	▒	▒	▒	▒	▒			
	A709	36	36	58–80[b]	▒	▒	▒	▒	▒	▒	▒			
	A1043[d,e]	36	36–52	58	▒									
		50	50–65	65	▒									
	A1085	Gr.A	50	65								▒	▒	
High-Strength Low-Alloy	A572	Gr.42	42	60	▒	▒	▒	▒	▒	▒	▒			
		Gr.50	50	65	▒	▒	▒	■	▒	▒	▒			
		Gr.55	55	70	▒	▒	▒	▒	▒	▒	▒			
		Gr. 60[e]	60	75	▒	▒	▒	▒	▒	▒	▒			
		Gr. 65[e]	65	80	▒	▒	▒	▒	▒	▒	▒			
	A618[f]	Gr.Ia[k],Ib&II	50[g]	70[g]								▒	▒	
		Gr. III	50	65								▒	▒	
	A709	50	50	65	▒	▒	▒	▒	▒	▒	▒			
		50S	50–65	65	▒	▒	▒	▒	▒	▒	▒			
		50W	50	70	▒	▒	▒	▒	▒	▒	▒			
	A913	50	50[h]	65[h]	▒	▒	▒	▒	▒	▒	▒			
		60	60	75	▒	▒	▒	▒	▒	▒	▒			
		65	65	80	▒	▒	▒	▒	▒	▒	▒			
		70	70	90	▒	▒	▒	▒	▒	▒	▒			
	A992		50[i]	65[i]	■	▒	▒	▒	▒	▒	▒			
	A1065[k]	Gr. 50[j]	50	60								▒		

■ = Preferred material specification.
▒ = Other applicable material specification, the availability of which should be confirmed prior to specification.
□ = Material specification does not apply.

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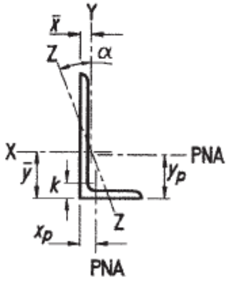


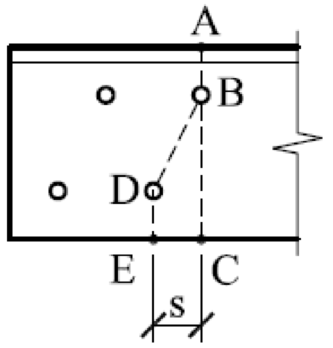
Table 1-7 (continued)
Angles
Properties

Shape	k (in.)	Wt. (lb/ft)	Area, A (in.^{2})	Axis X-X: I (in.^{4})	S (in.^{3})	r (in.)	$\bar{y}$ (in.)	Z (in.^{3})	y_p (in.)	Flexural-Torsional Properties: J (in.^{4})	C_w (in.^{6})	$\bar{r}_o$ (in.)
L6×4×7/8	1 3/8	27.2	8.00	27.7	7.13	1.86	2.12	12.7	1.43	2.03	4.04	2.82
×3/4	1 1/4	23.6	6.94	24.5	6.23	1.88	2.07	11.1	1.37	1.31	2.64	2.85
×5/8	1 1/8	20.0	5.86	21.0	5.29	1.89	2.03	9.44	1.31	0.775	1.59	2.88
×9/16	1 1/16	18.1	5.31	19.2	4.81	1.90	2.00	8.59	1.28	0.572	1.18	2.90
×1/2	1	16.2	4.75	17.3	4.31	1.91	1.98	7.71	1.25	0.407	0.843	2.91
×7/16	15/16	14.3	4.18	15.4	3.81	1.92	1.95	6.81	1.22	0.276	0.575	2.93
×3/8	7/8	12.3	3.61	13.4	3.30	1.93	1.93	5.89	1.19	0.177	0.369	2.94
×5/16	13/16	10.3	3.03	11.4	2.77	1.94	1.90	4.96	1.15	0.104	0.217	2.96

Shape	Axis Y-Y: I (in.^{4})	S (in.^{3})	r (in.)	$\bar{x}$ (in.)	Z (in.^{3})	x_p (in.)	Axis Z-Z: I (in.^{4})	S (in.^{3})	r (in.)	Tan α	Q_s: $F_y = 36$ ksi
L6×4×7/8	9.70	3.37	1.10	1.12	6.26	0.667	5.82	2.91	0.854	0.421	1.00
×3/4	8.63	2.95	1.12	1.07	5.42	0.578	5.08	2.51	0.856	0.428	1.00
×5/8	7.48	2.52	1.13	1.03	4.56	0.488	4.32	2.12	0.859	0.435	1.00
×9/16	6.86	2.29	1.14	1.00	4.13	0.443	3.93	1.92	0.861	0.438	1.00
×1/2	6.22	2.06	1.14	0.981	3.69	0.396	3.54	1.72	0.864	0.440	1.00
×7/16	5.56	1.83	1.15	0.957	3.24	0.348	3.14	1.51	0.867	0.443	0.973
×3/8	4.86	1.58	1.16	0.933	2.79	0.301	2.73	1.31	0.870	0.446	0.912
×5/16	4.13	1.34	1.17	0.908	2.33	0.253	2.31	1.10	0.874	0.449	0.826
L6×3 1/2×1/2	4.24	1.50	0.968	0.829	2.88	0.375	2.50	1.34	0.756	0.343	1.00

Failure Plane *ABC*:

$$A_n = 3.61 - \left[\left(\frac{3}{4} + \frac{1}{8}\right)(0.375)\right] + 0 = 3.28 \text{ in.}^2$$



a. failure planes

Failure Plane *ABDE*:

$s = 1.5$ in. and $g = 3$ in.

$$A_n = 3.61 - \left[(2)\left(\frac{3}{4} + \frac{1}{8}\right)(0.375)\right] + \left[\frac{(1.5)^2}{(4)(3)}(0.375)\right] = 3.02 \text{ in.}^2$$

The failure plane along *ABDE* controls, since it has a smaller net cross-sectional area.

Effective Area of the Angle:

The shear lag factor, $U = 1 - \frac{\bar{x}}{\ell}$ Case 2

$$= 1 - \frac{0.933}{(3)(1.5)} = 0.792$$

Alternatively, $U = 0.60$ from **Table D3.1** The larger value is permitted to be used, so $U = 0.792$.

Case 8 (b)

$$A_e = A_n U$$

$$= (3.02)(0.792) = 2.39 \text{ in.}^2$$

8	Single and double angles. (If U is calculated per Case 2, the larger value is permitted to be used.)	with four or more fasteners per line in the direction of loading	$U = 0.80$	–
		with three fasteners per line in the direction of loading (with fewer than three fasteners per line in the direction of loading, use Case 2)	$\boxed{U = 0.60}$	–

the tensile strength based on tensile yielding on the gross area is

$$\phi_t P_n = \phi_t F_y A_g$$

$$= (0.9)(36)(3.61) = 116 \text{ kips}$$

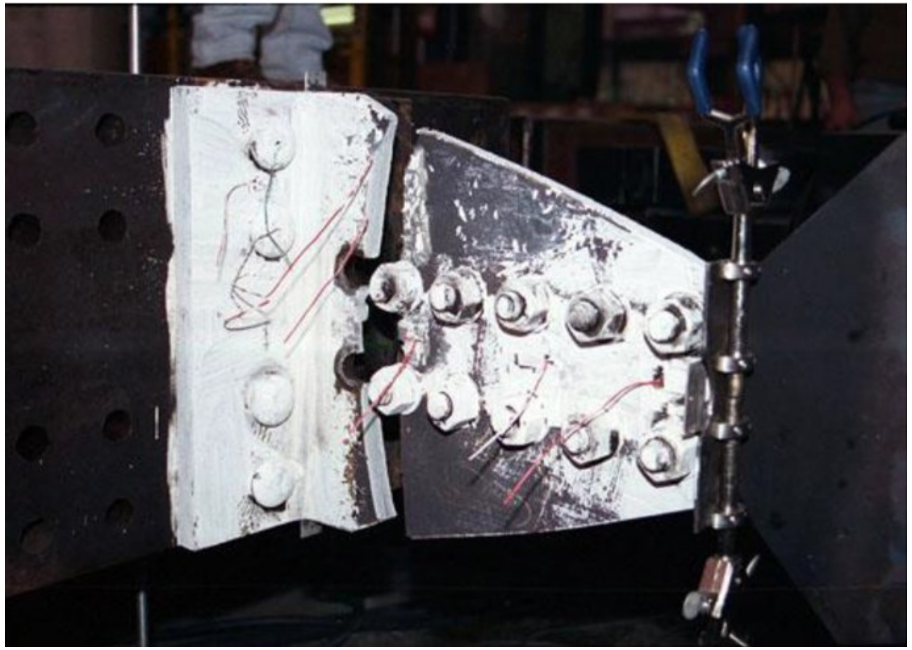
the tensile strength based on the tensile rupture on the effective area is

$$\phi_R P_n = \phi_R F_u A_e$$

$$= (0.75)(58)\left(2.39 \text{ in.}^2\right) = 104 \text{ kips} \longleftarrow \textbf{Controls}$$

The smaller value controls, therefore, the maximum factored tension load, $\boldsymbol{P_u}$ **= 104 kips**.

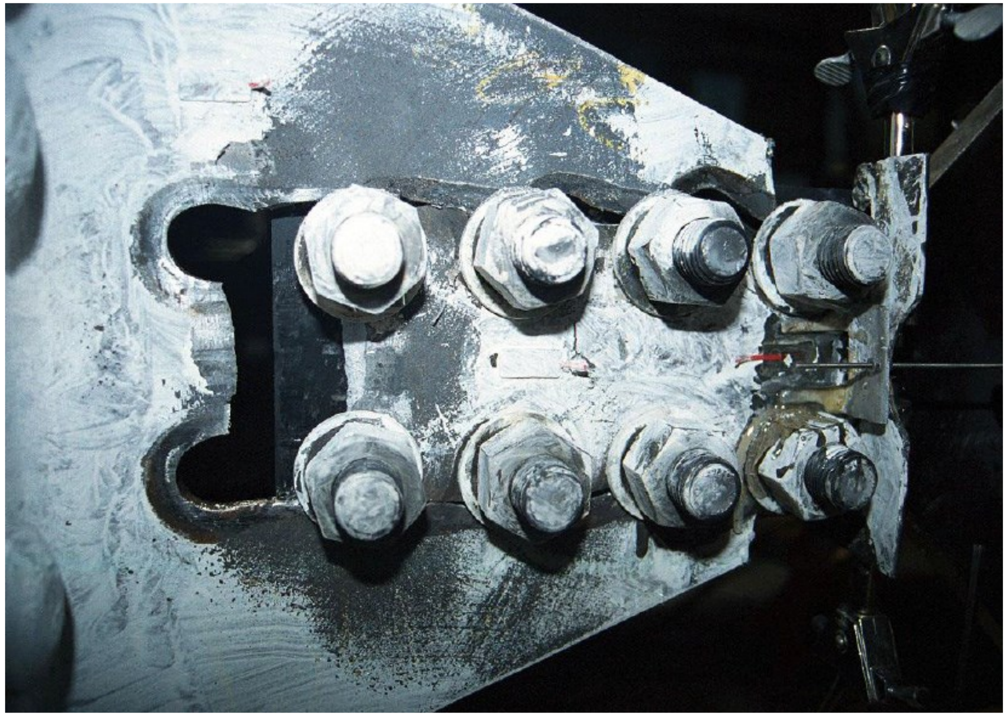
Yielding failure

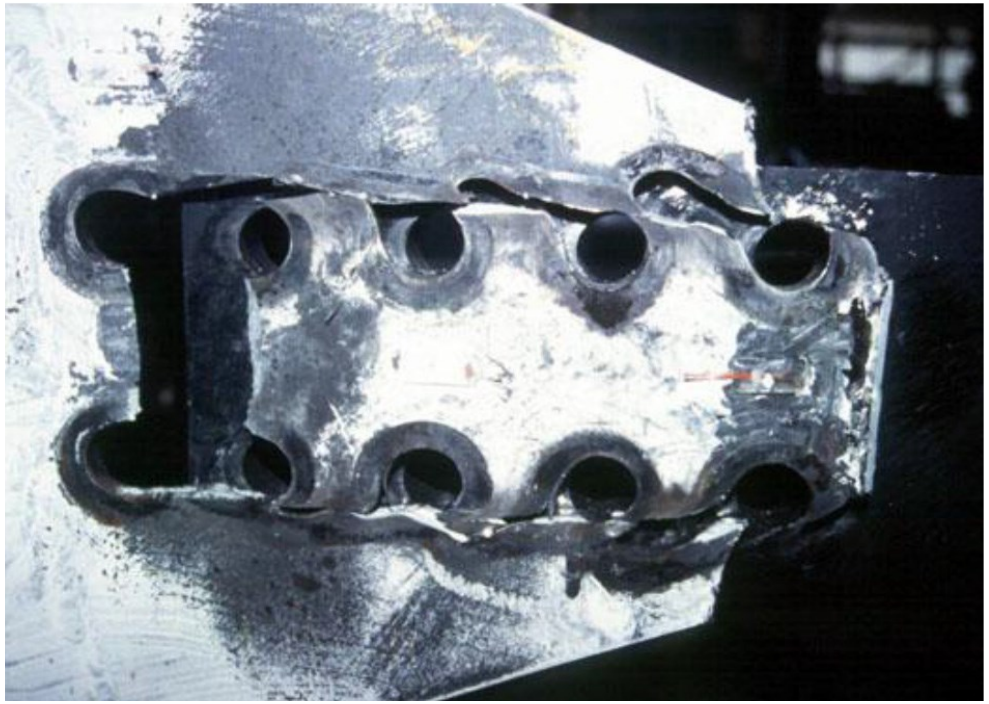


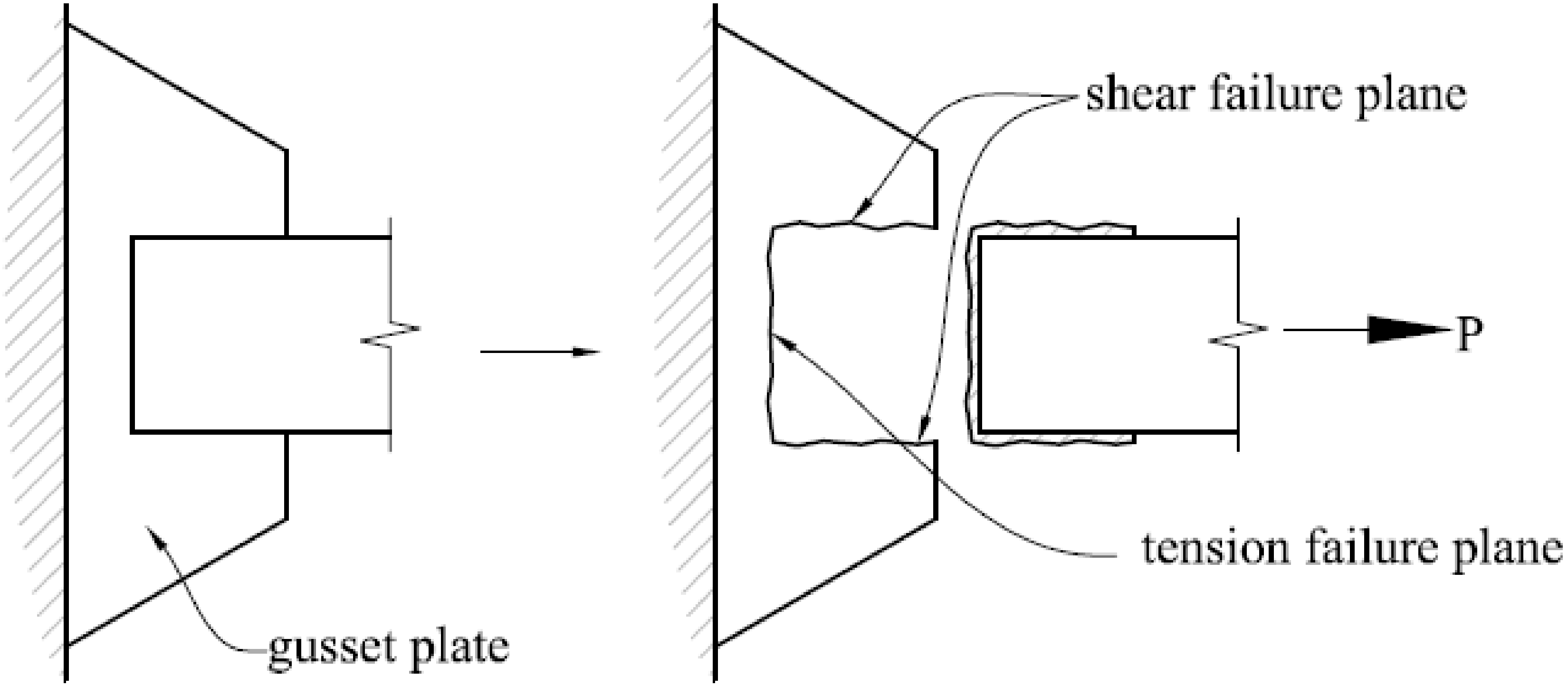
Rupture failure

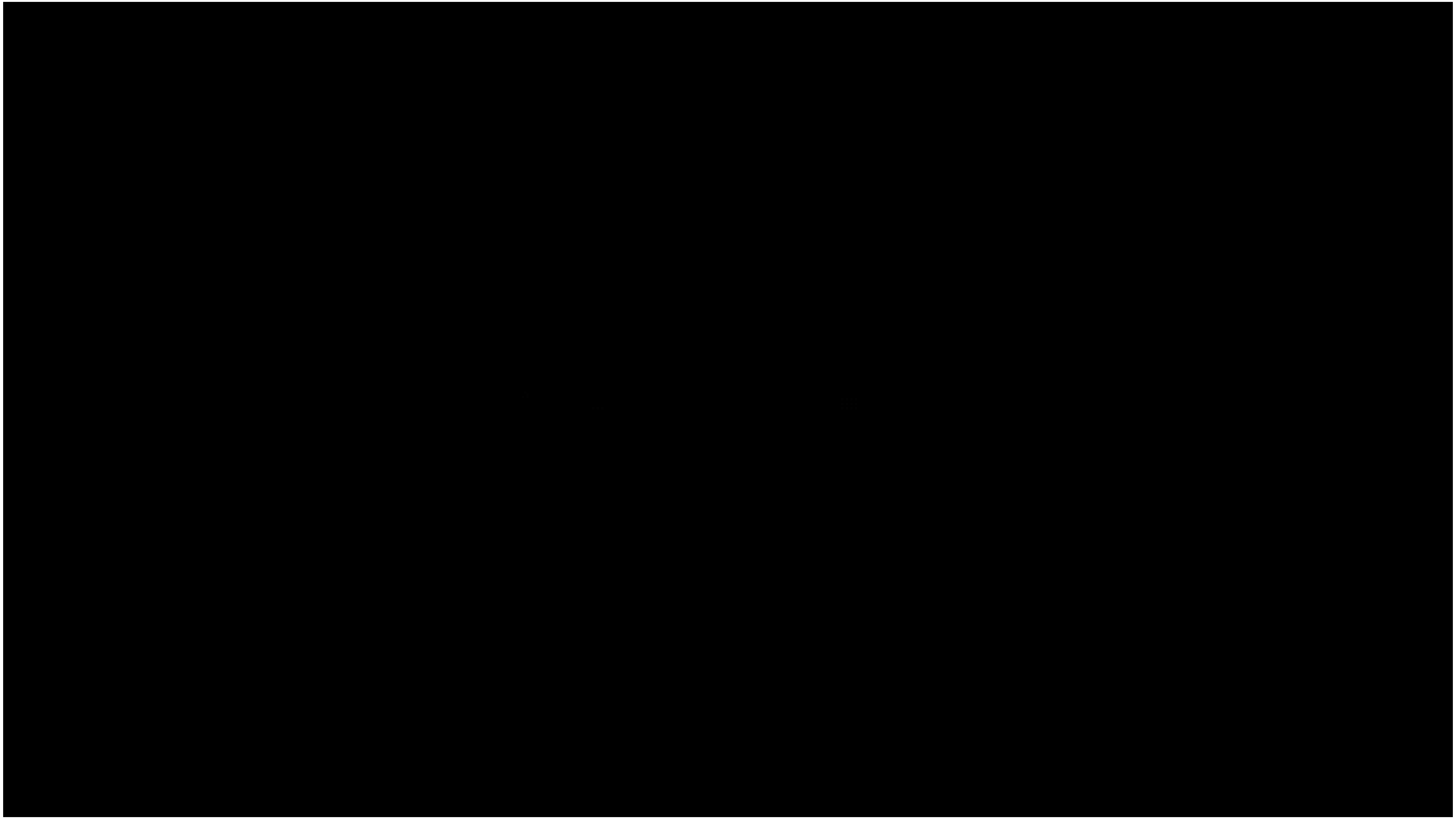
Block Shear Failure Mode:

- This failure occurs due to the **tearing out** of a segment of the tension member or the connecting element from the rest of the connection.
- The failure planes usually occur:
  1. Along the centerlines of the bolt holes for bolted connections.
  2. Along the outline of the welds for welded connections.



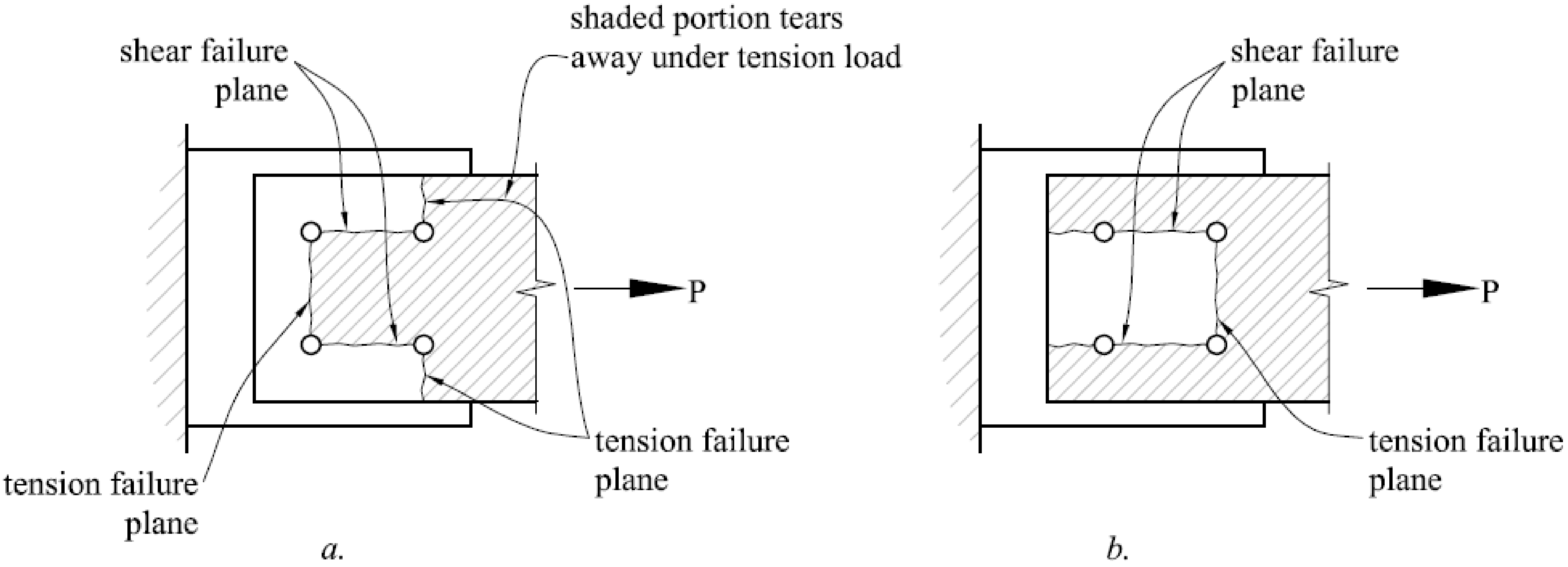


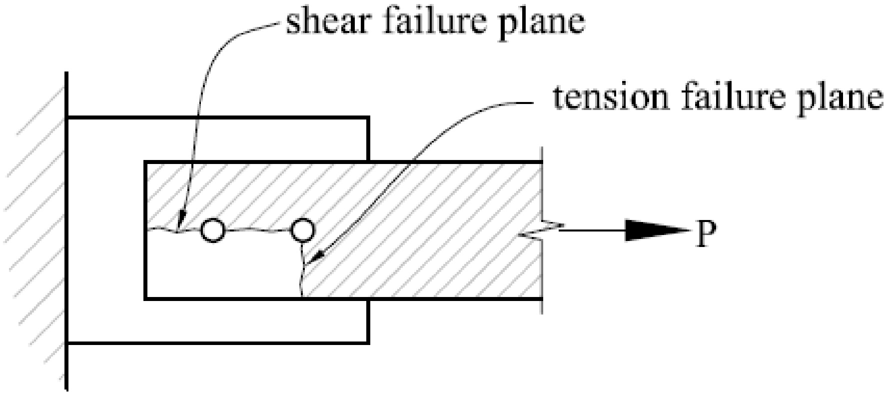

shear failure plane
P
tension failure plane
gusset plate



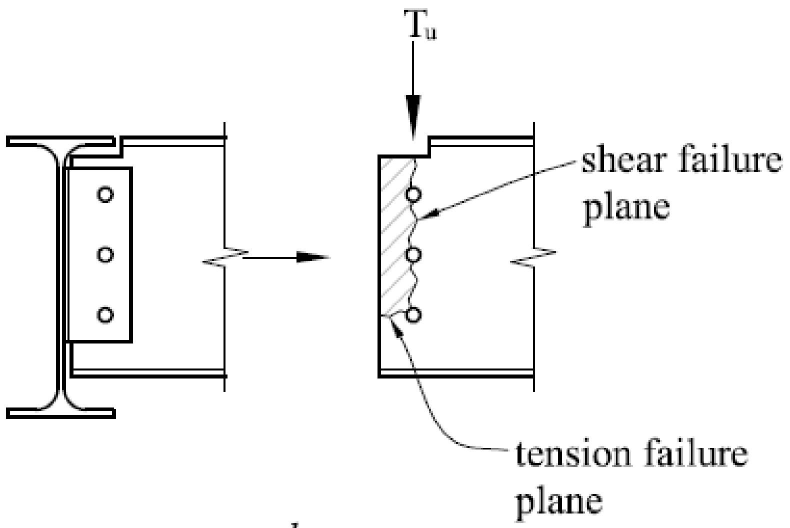
- Failure in block shear can occur by:

1. A combination of shear yielding plus tensile rupture.
2. **OR** by a combination of shear rupture plus tensile rupture.

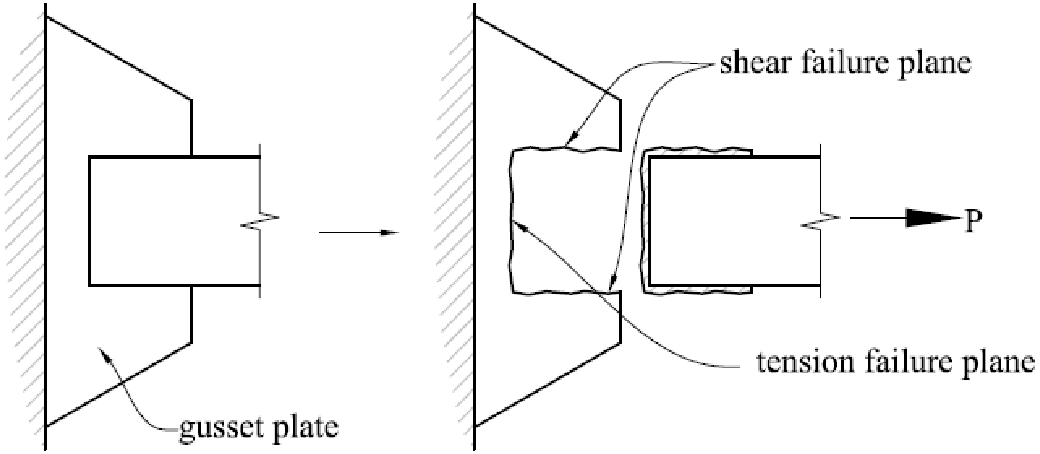



shear failure plane
tension failure plane
P

c.


T_u
shear failure plane
tension failure plane

d.


gusset plate
shear failure plane
tension failure plane
P

e.

Block shear failure

From AISCM Section J4.2

- The nominal strength based on **shear yielding** is

$$R_n = 0.6\ F_y A_{gv}$$

- The nominal strength based on **shear rupture** is

$$R_n = 0.6\ F_u A_{nv}.$$

Where,

A_{gv} = Gross area subject

A_{nv} = Net area subject to shear

From AISCM Section J4.3

$$\boxed{\phi P_n = \phi\Big(\underbrace{0.6F_uA_{nv}}_{\text{Shear rupture}} + \underbrace{U_{bs}F_uA_{nt}}_{\text{Tensile rupture}}\Big) \le \phi\Big(\underbrace{0.6F_yA_{gv}}_{\text{Shear yielding}} + \underbrace{U_{bs}F_uA_{nt}}_{\text{Tensile rupture}}\Big)}$$

Shear rupture + Tensile rupture

Shear yielding + Tensile rupture

Smallest controls

where

$\phi = 0.75$,

F_u = Minimum tensile stress,

F_y = Minimum yield stress,

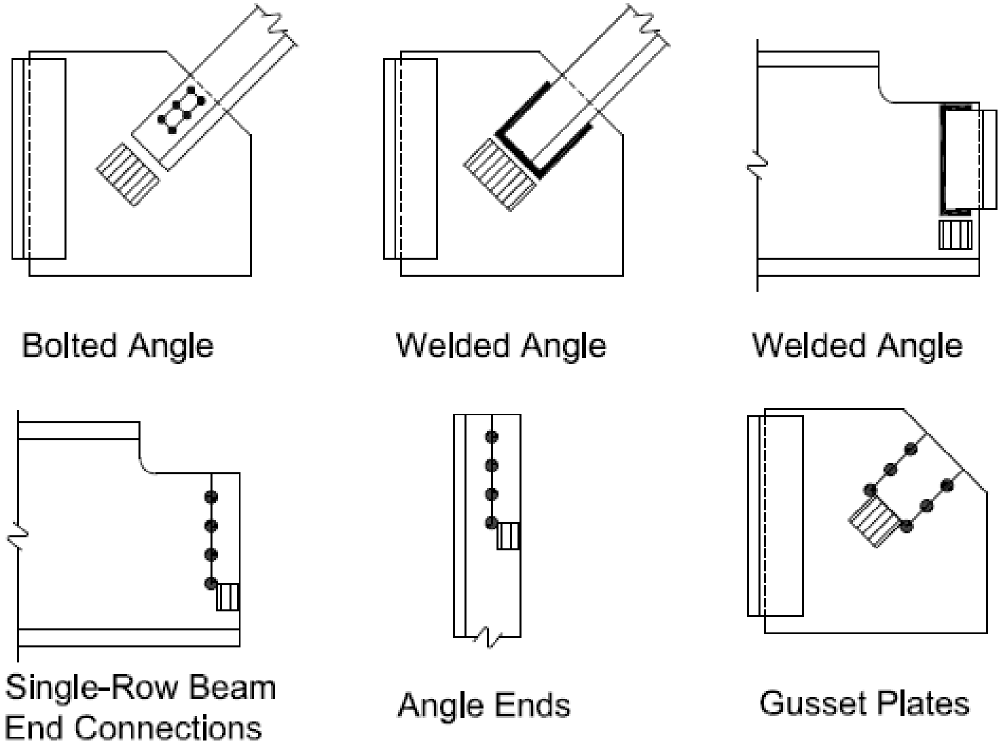
A_{gv} = Gross area subjected to shear,

A_{nt} = Net area subjected to tension (see equation (4-4)),

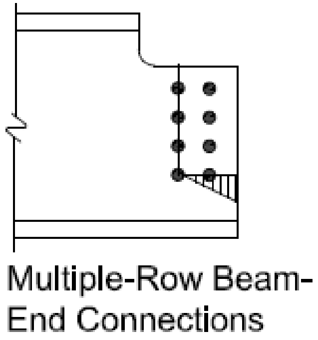
A_{nv} = Net area subjected to shear (see equation (4-4)), and

U_{bs} = 1.0 for uniform tension stress

= 0.50 for nonuniform tension stress.

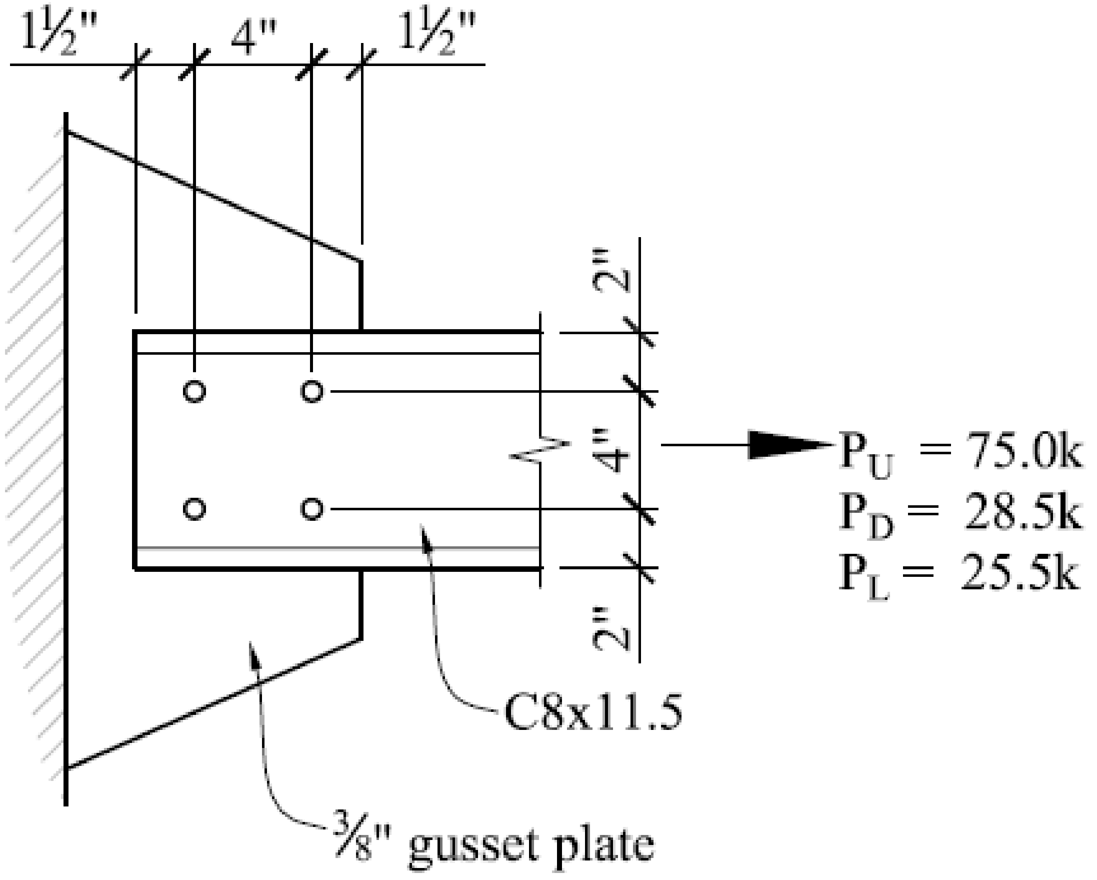


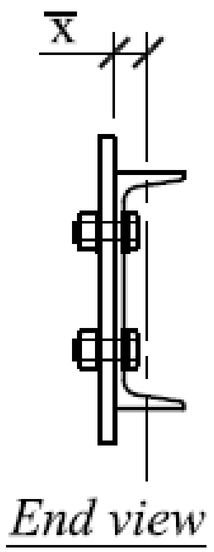
(a) Cases for which $U_{bs} = 1.0$



(b) Cases for which $U_{bs} = 0.5$

Determine if the channel is adequate for the applied tension load shown **below.** The channel is ASTM A36 steel and is connected with four $^5/_8$-in. diameter bolts. The tension member is subjected to service dead and live loads of 28.5 kips and 25.5 kips, respectively. <u>**Consider**</u> block shear.



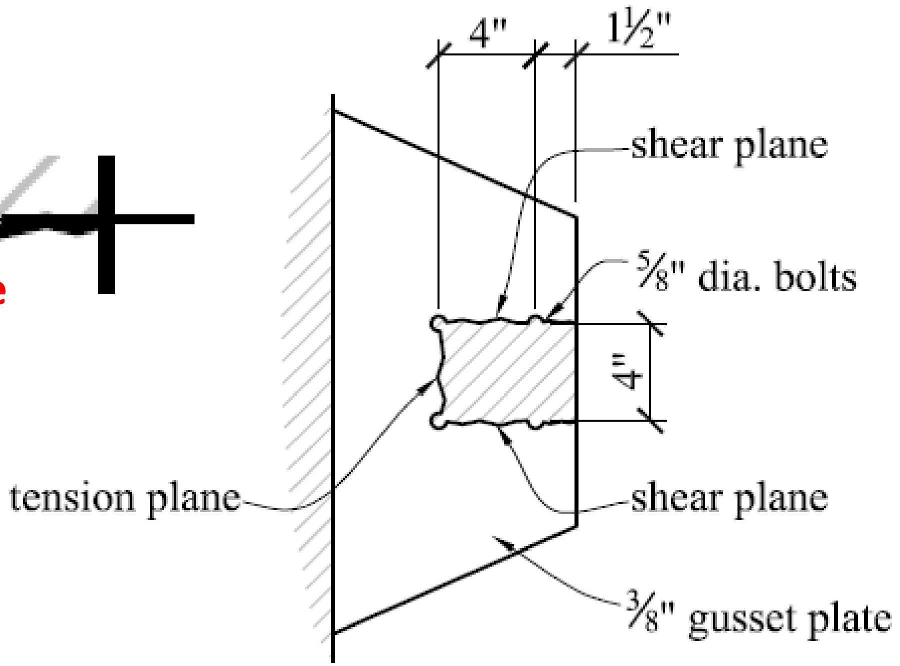


SOLUTION

From the *AISCM* Table 2-4

$$F_y = 36 \text{ ksi}$$

$$F_u = 58 \text{ ksi to } 80 \text{ ksi } (\text{use } F_u = 58 \text{ ksi})$$



block shear in plate

Gusset Plate Dimensions:

Shear plane:

$$A_{gv} = (2 \text{ shear planes})(4 \text{in.} + 1.5 \text{in.})(0.375 \text{in.}) = 4.12 \text{ in.}^2$$

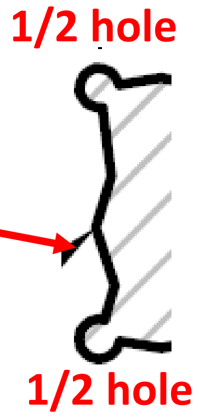
$$A_{nv} = A_{gv} - \sum A_{\text{holes}}$$

$$= 4.12 - \left[(2 \text{ sides})(1.5 \text{ holes})\left(\frac{5}{8} + \frac{1}{8}\right)(0.375 \text{in.})\right] = 3.28 \text{ in.}^2$$

Tension plane:

$$A_{nt} = A_{gt} - \sum A_{\text{holes}}$$

$$= [(4 \text{in.})(0.375 \text{in.})] - \left(\frac{1}{2} \text{ hole} + \frac{1}{2} \text{ hole}\right)\left[\left(\frac{5}{8} + \frac{1}{8}\right)(0.375 \text{in.})\right] = 1.21 \text{ in.}^2$$



Channel Dimensions:

$t_w = 0.22\ in\ (AISCM\ Table\ 1-5\ Section\ C8X11.5$

Shear plane:

$$A_{gv} = (2\text{ shear planes})(4\text{ in.} + 1.5\text{ in.})\boxed{(0.220\text{ in.})} = 2.42\text{ in.}^2$$

$$A_{nv} = A_{gv} - \sum A_{\text{holes}}$$

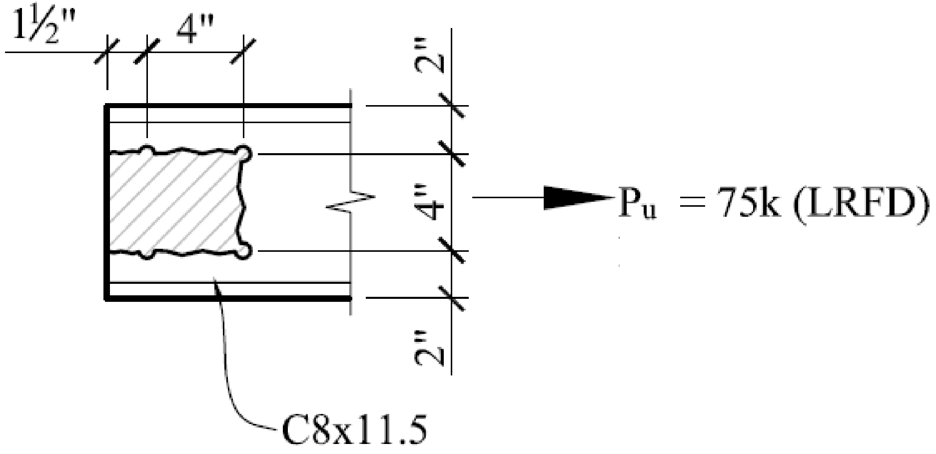
$$= 2.42 - \left[(2\text{ shear planes})(1.5\text{ holes})\left(\frac{5}{8}+\frac{1}{8}\right)(0.220\text{ in.})\right] = 1.92\text{ in.}^2$$

Tension plane:

$$A_{nt} = A_{gt} - \sum A_{\text{holes}}$$

$$= \left[(4\text{ in.})(0.220\text{ in.})\right] - \left(\frac{1}{2}\text{ hole} + \frac{1}{2}\text{ hole}\right)\left[\left(\frac{5}{8}+\frac{1}{8}\right)(0.220\text{ in.})\right] = 0.715\text{ in.}^2$$

$$U_{bs} = 1.0\ \ (\text{tension stress is uniform})$$



block shear in channel

$$\phi P_n = \phi(0.6F_u A_{nv} + U_{bs} F_u A_{nt}) \leq \phi(0.6F_y A_{gv} + U_{bs} F_u A_{nt})$$

For the *Gusset Plate*, the tensile strength in block shear is

$$\phi P_n = 0.75[(0.6)(58)(3.28) + (1.0)(58)(1.21)]$$

$$\leq 0.75[(0.6)(36)(4.12) + (1.0)(58)(1.21)]$$

$$= 138 \text{ kips} \leq \underline{119 \text{ kips}}.$$

Controls

$$\emptyset P_n = 119\ Kips\ > P_u = 75\ Kips\ \ldots\ldots.\ Okay$$

For the ***Channel*** (t_w = 0.22 in.), the tensile strength in block shear is

$$\phi P_n = 0.75[(0.60)(58)(1.92) + (1.0)(58)(0.715)]$$

$$\leq 0.75[(0.60)(36)(2.42) + (1.0)(58)(0.715)]$$

$$= 81.2 \text{ kips} \leq \underline{70.3 \text{ kips}}.$$

Controls

$$\emptyset P_n = 70.3\ Kips\ < P_u = 75\ Kips$$

The channel is NOT adequate in block shear

DESIGN OF TENSION MEMBERS

1. Calculate the maximum factored tension loads on the member, P_u.

2. Determine the minimum gross area from the tensile yielding failure mode equation

$$A_g \geq \frac{P_u}{0.9F_y}$$

3. Determine the minimum net area from the tensile rupture failure mode equation

$$A_n \geq \frac{P_u}{0.75F_u U}$$

where the net area is found from equation

$$A_n = A_g - \sum A_{\text{holes}}$$

Therefore, the required gross area for the tensile rupture failure mode is:

$$A_g \geq \frac{P_u}{0.75F_u U} + \sum A_{\text{holes}}$$

4. Use the larger A_g value from step (2) and step (3), and select a trial member size based on the larger value of A_g.

5. For tension members, AISC specification Section D1 suggests that the slenderness ratio $\frac{L_C}{r_{min}} = \frac{KL}{r_{min}}$

should be less than 300 to prevent flapping or flutter of the member,

Where:

K = Effective length factor (usually assumed to be 1.0 for tension members),

L = Unbraced length of the tension member, and

r_{min} = Smallest radius of gyration of the member.

The smallest radius of gyration for rolled sections can be obtained from part 1 (tables) of the AISCM

6. Determine the block shear capacity of the selected tension member

$$\phi P_n = \phi\left(0.6F_u A_{nv} + U_{bs} F_u A_{nt}\right) \le \phi\left(0.6F_y A_{gv} + U_{bs} F_u A_{nt}\right)$$

If ϕP_n (block shear) is greater than or equal to P_u, the member is adequate.

If ϕP_n (block shear) is less than P_u, increase the member size and repeat step 5 until ϕP_n (block shear) $\ge P_u$.

Example:

Using the LRFD method, design a tension member given the following parameters:

- Service loads: $P_D = 40$ kips, $P_L = 66$ kips;
- Single angle required;
- Unbraced length, $L = 20$ ft.;
- ASTM A36 steel; and
- Two lines of four $^3\!/_4$-in.-diameter bolts.

Solution

$$P_u = 1.2\ P_D + 1.6\ P_L = \left[(1.2)(40)\right] + \left[(1.6)(66)\right] = 154 \text{ kips}$$

1. $A_g \geq \dfrac{P_u}{0.9F_y} \qquad \left(\text{assume slenderness ratio,} \dfrac{K\ell}{r} < 300\right)$

$$A_g \geq \frac{(154)}{(0.9)(36)} = 4.75 \text{ in.}^2$$

Case 8- (a)

2. Shear lag factor, U, is 0.80 for single angles (from Table D3.1 Alternatively, U may be calculated using $\ell = (3)(3 \text{ in.}) = 9$ in. (three spaces at 3 in.), but an angle size would have to be assumed.

$$A_g \geq \frac{P_u}{0.75 F_u U} + \Sigma A_{\text{holes}}$$

$$A_g \geq \frac{(154)}{(0.75)(58)(0.80)} + (2 \text{ holes})\left(\frac{3}{4} + \frac{1}{8}\right)(t)$$

$A_{g \text{ required}} = 4.43 + 1.75t,$ where t is the thickness of the angle

$$r_{\min} = \frac{L}{300} = \frac{(20)(12)}{300} = 0.80 \text{ in.}$$

From AISCM Table (1-7)

1. All angles with thickness (t=1/4 in) have Ag< 4.86 in^2
2. All angles with thickness (t=5/16 in) have Ag< 4.97 in^2
3. All angles with thickness (t=3/8 in) have Ag< 5.08 in^2

Summary of angle selection

t	A_g Required			
	A_g (Step 1)	A_g (Step 2)	Selected Angle	r_z
$^1/_4$ in.	4.75 in.^{2}	4.86 in.^{2}	None worked	–
$^5/_{16}$ in.	4.75 in.^{2}	4.97 in.^{2}	None worked	–
$^3/_8$ in.	4.75 in.^{2}	5.08 in.^{2}	None worked	–
$^7/_{16}$ in.	4.75 in.^{2}	5.19 in.^{2}	L8 × 6 × $^7/_{16}$ (wt. = 20.2 lb./ft.)	1.31 in.
$^1/_2$ in.	4.75 in.^{2}	5.30 in.^{2}	L6 × 6 × $^1/_2$ (wt. = 19.6 lb./ft.)	1.18 in.
			L8 × 4 × $^1/_2$ (wt. = 19.6 lb./ft.)	0.863 in.

Ag= 5.99 in^2>5.19 in^2 ok.

Ag= 5.77 in^2>5.3 in^2 ok.

Ag= 5.80 in^2>5.3 in^2 ok.

From AISCM Table (1-7) see next slides

Minimum of r_x, r_y, r_z for each section

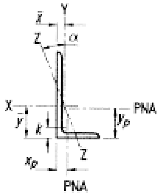


Table 1-7
Angles
Properties

Shape	k	Wt.	Area, A	Axis X-X						Flexural-Torsional Properties		
				I	S	r	$\bar{y}$	Z	y_p	J	C_w	$\bar{r}_o$
	in.	lb/ft	in.^{2}	in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{6}	in.
L8×8×1 1/8	1 3/4	56.9	16.8	98.1	17.5	2.41	2.40	31.6	1.05	7.13	32.5	4.29
×1	1 5/8	51.0	15.1	89.1	15.8	2.43	2.36	28.5	0.944	5.08	23.4	4.32
×7/8	1 1/2	45.0	13.3	79.7	14.0	2.45	2.31	25.3	0.831	3.46	16.1	4.36
×3/4	1 3/8	38.9	11.5	69.9	12.2	2.46	2.26	22.0	0.719	2.21	10.4	4.39
×5/8	1 1/4	32.7	9.69	59.6	10.3	2.48	2.21	18.6	0.606	1.30	6.16	4.42
×9/16	1 3/16	29.6	8.77	54.2	9.33	2.49	2.19	16.8	0.548	0.961	4.55	4.43
×1/2	1 1/8	26.4	7.84	48.8	8.36	2.49	2.17	15.1	0.490	0.683	3.23	4.45
L8×6×1	1 1/2	44.2	13.1	80.9	15.1	2.49	2.65	27.3	1.45	4.34	16.3	3.88
×7/8	1 3/8	39.1	11.5	72.4	13.4	2.50	2.60	24.3	1.43	2.96	11.3	3.92
×3/4	1 1/4	33.8	9.99	63.5	11.7	2.52	2.55	21.1	1.34	1.90	7.28	3.95
×5/8	1 1/8	28.5	8.41	54.2	9.86	2.54	2.50	17.9	1.27	1.12	4.33	3.98
×9/16	1 1/16	25.7	7.61	49.4	8.94	2.55	2.48	16.2	1.24	0.823	3.20	3.99
×1/2	1	23.0	6.80	44.4	8.01	2.55	2.46	14.6	1.20	0.584	2.28	4.01
×7/16	15/16	20.2	5.99	39.3	7.06	2.56	2.43	12.9	1.15	0.396	1.55	4.02
L8×4×1	1 1/2	37.4	11.1	69.7	14.0	2.51	3.03	24.3	2.45	3.68	12.9	3.75
×7/8	1 3/8	33.1	9.79	62.6	12.5	2.53	2.99	21.7	2.41	2.51	8.89	3.78
×3/4	1 1/4	28.7	8.49	55.0	10.9	2.55	2.94	18.9	2.34	1.61	5.75	3.80
×5/8	1 1/8	24.2	7.16	47.0	9.20	2.56	2.89	16.1	2.27	0.955	3.42	3.83
×9/16	1 1/16	21.9	6.49	42.9	8.34	2.57	2.86	14.6	2.23	0.704	2.53	3.84
×1/2	1	19.6	5.80	38.6	7.48	2.58	2.84	13.1	2.20	0.501	1.80	3.86
×7/16	15/16	17.2	5.11	34.2	6.59	2.59	2.81	11.6	2.16	0.340	1.22	3.87
L7×4×3/4	1 1/4	26.2	7.74	37.8	8.39	2.21	2.50	14.8	1.84	1.47	3.97	3.31
×5/8	1 1/8	22.1	6.50	32.4	7.12	2.23	2.45	12.5	1.80	0.868	2.37	3.34
×1/2	1	17.9	5.26	26.6	5.79	2.25	2.40	10.2	1.74	0.456	1.25	3.37
×7/16	15/16	15.7	4.63	23.6	5.11	2.26	2.38	9.03	1.71	0.310	0.851	3.38
×3/8	7/8	13.6	4.00	20.5	4.42	2.27	2.35	7.81	1.67	0.198	0.544	3.40
L6×6×1	1 1/2	37.4	11.0	35.4	8.55	1.79	1.86	15.4	0.917	3.68	9.24	3.18
×7/8	1 3/8	33.1	9.75	31.9	7.61	1.81	1.81	13.7	0.813	2.51	6.41	3.21
×3/4	1 1/4	28.7	8.46	28.1	6.64	1.82	1.77	11.9	0.705	1.61	4.17	3.24
×5/8	1 1/8	24.2	7.13	24.1	5.64	1.84	1.72	10.1	0.594	0.955	2.50	3.28
×9/16	1 1/16	21.9	6.45	22.0	5.12	1.85	1.70	9.18	0.538	0.704	1.85	3.29
×1/2	1	19.6	5.77	19.9	4.59	1.86	1.67	8.22	0.481	0.501	1.32	3.31
×7/16	15/16	17.2	5.08	17.6	4.06	1.86	1.65	7.25	0.423	0.340	0.899	3.32
×3/8	7/8	14.9	4.38	15.4	3.51	1.87	1.62	6.27	0.365	0.218	0.575	3.34
×5/16	13/16	12.4	3.67	13.0	2.95	1.88	1.60	5.26	0.306	0.129	0.338	3.35

Note: For workable gages, refer to Table 1-7A. For compactness criteria, refer to Table 1-7B.

Table 1-7 (continued)
Angles
Properties

L8-L6

Shape	Axis Y-Y						Axis Z-Z				Q_s
	I	S	r	$\bar{x}$	Z	x_p	I	S	r	Tan α	$F_y = 36$ ksi
	in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{3}	in.		
L8×8×1 1/8	98.1	17.5	2.41	2.40	31.6	1.05	40.7	12.0	1.56	1.00	1.00
×1	89.1	15.8	2.43	2.36	28.5	0.944	36.8	11.0	1.56	1.00	1.00
×7/8	79.7	14.0	2.45	2.31	25.3	0.831	32.7	10.0	1.57	1.00	1.00
×3/4	69.9	12.2	2.46	2.26	22.0	0.719	28.5	8.90	1.57	1.00	1.00
×5/8	59.6	10.3	2.48	2.21	18.6	0.606	24.2	7.72	1.58	1.00	0.997
×9/16	54.2	9.33	2.49	2.19	16.8	0.548	21.9	7.09	1.58	1.00	0.959
×1/2	48.8	8.36	2.49	2.17	15.1	0.490	19.8	6.44	1.59	1.00	0.912
L8×6×1	38.8	8.92	1.72	1.65	16.2	0.819	21.3	7.60	1.28	0.542	1.00
×7/8	34.9	7.94	1.74	1.60	14.4	0.719	18.9	6.71	1.28	0.546	1.00
×3/4	30.8	6.92	1.75	1.56	12.5	0.624	16.6	5.82	1.29	0.550	1.00
×5/8	26.4	5.88	1.77	1.51	10.5	0.526	14.1	4.91	1.29	0.554	0.997
×9/16	24.1	5.34	1.78	1.49	9.52	0.476	12.8	4.45	1.30	0.556	0.959
×1/2	21.7	4.79	1.79	1.46	8.52	0.425	11.5	3.98	1.30	0.557	0.912
×7/16	19.3	4.23	1.80	1.44	7.50	0.374	10.2	3.51	1.31	0.559	0.850
L8×4×1	11.6	3.94	1.03	1.04	7.73	0.694	7.83	3.48	0.844	0.247	1.00
×7/8	10.5	3.51	1.04	0.997	6.77	0.612	6.97	3.06	0.846	0.252	1.00
×3/4	9.37	3.07	1.05	0.949	5.82	0.531	6.14	2.65	0.850	0.257	1.00
×5/8	8.11	2.62	1.06	0.902	4.86	0.448	5.24	2.24	0.856	0.262	0.997
×9/16	7.44	2.38	1.07	0.878	4.39	0.406	4.78	2.03	0.859	0.264	0.959
×1/2	6.75	2.15	1.08	0.854	3.91	0.363	4.32	1.82	0.863	0.266	0.912
×7/16	6.03	1.90	1.09	0.829	3.42	0.319	3.84	1.61	0.867	0.268	0.850
L7×4×3/4	9.00	3.01	1.08	1.00	5.60	0.553	5.63	2.57	0.855	0.324	1.00
×5/8	7.79	2.56	1.10	0.958	4.69	0.464	4.81	2.16	0.860	0.329	1.00
×1/2	6.48	2.10	1.11	0.910	3.77	0.376	3.94	1.76	0.866	0.334	0.965
×7/16	5.79	1.86	1.12	0.886	3.31	0.331	3.50	1.55	0.869	0.337	0.912
×3/8	5.06	1.61	1.12	0.861	2.84	0.286	3.04	1.34	0.873	0.339	0.840
L6×6×1	35.4	8.55	1.79	1.86	15.4	0.917	14.9	5.70	1.17	1.00	1.00
×7/8	31.9	7.61	1.81	1.81	13.7	0.813	13.3	5.18	1.17	1.00	1.00
×3/4	28.1	6.64	1.82	1.77	11.9	0.705	11.6	4.63	1.17	1.00	1.00
×5/8	24.1	5.64	1.84	1.72	10.1	0.594	9.81	4.04	1.17	1.00	1.00
×9/16	22.0	5.12	1.85	1.70	9.18	0.538	8.90	3.73	1.18	1.00	1.00
×1/2	19.9	4.59	1.86	1.67	8.22	0.481	8.06	3.40	1.18	1.00	1.00
×7/16	17.6	4.06	1.86	1.65	7.25	0.423	7.05	3.05	1.18	1.00	0.973
×3/8	15.4	3.51	1.87	1.62	6.27	0.365	6.21	2.69	1.19	1.00	0.912
×5/16	13.0	2.95	1.88	1.60	5.26	0.306	5.20	2.30	1.19	1.00	0.826

Note: For workable gages, refer to Table 1-7A. For compactness criteria, refer to Table 1-7B.

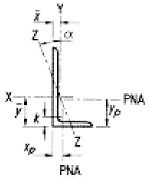


Table 1-7
Angles
Properties

Shape	k	Wt.	Area, A	Axis X-X						Flexural-Torsional Properties		
				I	S	r	$\bar{y}$	Z	y_p	J	C_w	$\bar{r}_o$
	in.	lb/ft	in.^{2}	in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{6}	in.
L8×8×1 1/8	1 3/4	56.9	16.8	98.1	17.5	2.41	2.40	31.6	1.05	7.13	32.5	4.29
×1	1 5/8	51.0	15.1	89.1	15.8	2.43	2.36	28.5	0.944	5.08	23.4	4.32
×7/8	1 1/2	45.0	13.3	79.7	14.0	2.45	2.31	25.3	0.831	3.46	16.1	4.36
×3/4	1 3/8	38.9	11.5	69.9	12.2	2.46	2.26	22.0	0.719	2.21	10.4	4.39
×5/8	1 1/4	32.7	9.69	59.6	10.3	2.48	2.21	18.6	0.606	1.30	6.16	4.42
×9/16	1 3/16	29.6	8.77	54.2	9.33	2.49	2.19	16.8	0.548	0.961	4.55	4.43
×1/2	1 1/8	26.4	7.84	48.8	8.36	2.49	2.17	15.1	0.490	0.683	3.23	4.45
L8×6×1	1 1/2	44.2	13.1	80.9	15.1	2.49	2.65	27.3	1.45	4.34	16.3	3.88
×7/8	1 3/8	39.1	11.5	72.4	13.4	2.50	2.60	24.3	1.43	2.96	11.3	3.92
×3/4	1 1/4	33.8	9.99	63.5	11.7	2.52	2.55	21.1	1.34	1.90	7.28	3.95
×5/8	1 1/8	28.5	8.41	54.2	9.86	2.54	2.50	17.9	1.27	1.12	4.33	3.98
×9/16	1 1/16	25.7	7.61	49.4	8.94	2.55	2.48	16.2	1.24	0.823	3.20	3.99
×1/2	1	23.0	6.80	44.4	8.01	2.55	2.46	14.6	1.20	0.584	2.28	4.01
×7/16	15/16	20.2	5.99	39.3	7.06	2.56	2.43	12.9	1.15	0.396	1.55	4.02
L8×4×1	1 1/2	37.4	11.1	69.7	14.0	2.51	3.03	24.3	2.45	3.68	12.9	3.75
×7/8	1 3/8	33.1	9.79	62.6	12.5	2.53	2.99	21.7	2.41	2.51	8.89	3.78
×3/4	1 1/4	28.7	8.49	55.0	10.9	2.55	2.94	18.9	2.34	1.61	5.75	3.80
×5/8	1 1/8	24.2	7.16	47.0	9.20	2.56	2.89	16.1	2.27	0.955	3.42	3.83
×9/16	1 1/16	21.9	6.49	42.9	8.34	2.57	2.86	14.6	2.23	0.704	2.53	3.84
×1/2	1	19.6	5.80	38.6	7.48	2.58	2.84	13.1	2.20	0.501	1.80	3.86
×7/16	15/16	17.2	5.11	34.2	6.59	2.59	2.81	11.6	2.16	0.340	1.22	3.87
L7×4×3/4	1 1/4	26.2	7.74	37.8	8.39	2.21	2.50	14.8	1.84	1.47	3.97	3.31
×5/8	1 1/8	22.1	6.50	32.4	7.12	2.23	2.45	12.5	1.80	0.868	2.37	3.34
×1/2	1	17.9	5.26	26.6	5.79	2.25	2.40	10.2	1.74	0.456	1.25	3.37
×7/16	15/16	15.7	4.63	23.6	5.11	2.26	2.38	9.03	1.71	0.310	0.851	3.38
×3/8	7/8	13.6	4.00	20.5	4.42	2.27	2.35	7.81	1.67	0.198	0.544	3.40
L6×6×1	1 1/2	37.4	11.0	35.4	8.55	1.79	1.86	15.4	0.917	3.68	9.24	3.18
×7/8	1 3/8	33.1	9.75	31.9	7.61	1.81	1.81	13.7	0.813	2.51	6.41	3.21
×3/4	1 1/4	28.7	8.46	28.1	6.64	1.82	1.77	11.9	0.705	1.61	4.17	3.24
×5/8	1 1/8	24.2	7.13	24.1	5.64	1.84	1.72	10.1	0.594	0.955	2.50	3.28
×9/16	1 1/16	21.9	6.45	22.0	5.12	1.85	1.70	9.18	0.538	0.704	1.85	3.29
×1/2	1	19.6	5.77	19.9	4.59	1.86	1.67	8.22	0.481	0.501	1.32	3.31
×7/16	15/16	17.2	5.08	17.6	4.06	1.86	1.65	7.25	0.423	0.340	0.899	3.32
×3/8	7/8	14.9	4.38	15.4	3.51	1.87	1.62	6.27	0.365	0.218	0.575	3.34
×5/16	13/16	12.4	3.67	13.0	2.95	1.88	1.60	5.26	0.306	0.129	0.338	3.35

Note: For workable gages, refer to Table 1-7A. For compactness criteria, refer to Table 1-7B.

Table 1-7 (continued)
Angles
Properties

L8-L6

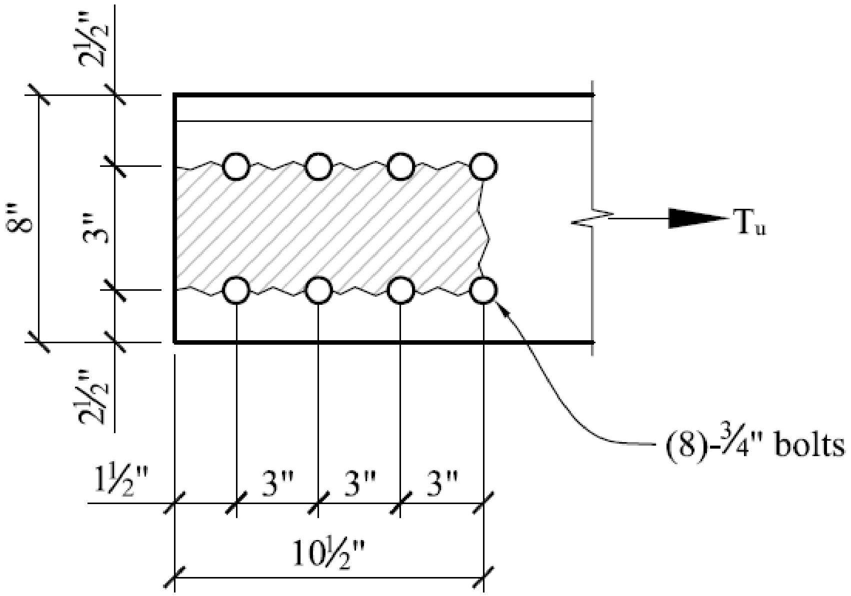
Shape	Axis Y-Y						Axis Z-Z				Q_s
	I	S	r	$\bar{x}$	Z	x_p	I	S	r	Tan α	F_y = 36 ksi
	in.^{4}	in.^{3}	in.	in.	in.^{3}	in.	in.^{4}	in.^{3}	in.		
L8×8×1 1/8	98.1	17.5	2.41	2.40	31.6	1.05	40.7	12.0	1.56	1.00	1.00
×1	89.1	15.8	2.43	2.36	28.5	0.944	36.8	11.0	1.56	1.00	1.00
×7/8	79.7	14.0	2.45	2.31	25.3	0.831	32.7	10.0	1.57	1.00	1.00
×3/4	69.9	12.2	2.46	2.26	22.0	0.719	28.5	8.90	1.57	1.00	1.00
×5/8	59.6	10.3	2.48	2.21	18.6	0.606	24.2	7.72	1.58	1.00	0.997
×9/16	54.2	9.33	2.49	2.19	16.8	0.548	21.9	7.09	1.58	1.00	0.959
×1/2	48.8	8.36	2.49	2.17	15.1	0.490	19.8	6.44	1.59	1.00	0.912
L8×6×1	38.8	8.92	1.72	1.65	16.2	0.819	21.3	7.60	1.28	0.542	1.00
×7/8	34.9	7.94	1.74	1.60	14.4	0.719	18.9	6.71	1.28	0.546	1.00
×3/4	30.8	6.92	1.75	1.56	12.5	0.624	16.6	5.82	1.29	0.550	1.00
×5/8	26.4	5.88	1.77	1.51	10.5	0.526	14.1	4.91	1.29	0.554	0.997
×9/16	24.1	5.34	1.78	1.49	9.52	0.476	12.8	4.45	1.30	0.556	0.959
×1/2	21.7	4.79	1.79	1.46	8.52	0.425	11.5	3.98	1.30	0.557	0.912
×7/16	19.3	4.23	1.80	1.44	7.50	0.374	10.2	3.51	1.31	0.559	0.850
L8×4×1	11.6	3.94	1.03	1.04	7.73	0.694	7.83	3.48	0.844	0.247	1.00
×7/8	10.5	3.51	1.04	0.997	6.77	0.612	6.97	3.06	0.846	0.252	1.00
×3/4	9.37	3.07	1.05	0.949	5.82	0.531	6.14	2.65	0.850	0.257	1.00
×5/8	8.11	2.62	1.06	0.902	4.86	0.448	5.24	2.24	0.856	0.262	0.997
×9/16	7.44	2.38	1.07	0.878	4.39	0.406	4.78	2.03	0.859	0.264	0.959
×1/2	6.75	2.15	1.08	0.854	3.91	0.363	4.32	1.82	0.863	0.266	0.912
×7/16	6.03	1.90	1.09	0.829	3.42	0.319	3.84	1.61	0.867	0.268	0.850
L7×4×3/4	9.00	3.01	1.08	1.00	5.60	0.553	5.63	2.57	0.855	0.324	1.00
×5/8	7.79	2.56	1.10	0.958	4.69	0.464	4.81	2.16	0.860	0.329	1.00
×1/2	6.48	2.10	1.11	0.910	3.77	0.376	3.94	1.76	0.866	0.334	0.965
×7/16	5.79	1.86	1.12	0.886	3.31	0.331	3.50	1.55	0.869	0.337	0.912
×3/8	5.06	1.61	1.12	0.861	2.84	0.286	3.04	1.34	0.873	0.339	0.840
L6×6×1	35.4	8.55	1.79	1.86	15.4	0.917	14.9	5.70	1.17	1.00	1.00
×7/8	31.9	7.61	1.81	1.81	13.7	0.813	13.3	5.18	1.17	1.00	1.00
×3/4	28.1	6.64	1.82	1.77	11.9	0.705	11.6	4.63	1.17	1.00	1.00
×5/8	24.1	5.64	1.84	1.72	10.1	0.594	9.81	4.04	1.17	1.00	1.00
×9/16	22.0	5.12	1.85	1.70	9.18	0.538	8.90	3.73	1.18	1.00	1.00
×1/2	19.9	4.59	1.86	1.67	8.22	0.481	8.06	3.40	1.18	1.00	1.00
×7/16	17.6	4.06	1.86	1.65	7.25	0.423	7.05	3.05	1.18	1.00	0.973
×3/8	15.4	3.51	1.87	1.62	6.27	0.365	6.21	2.69	1.19	1.00	0.912
×5/16	13.0	2.95	1.88	1.60	5.26	0.306	5.20	2.30	1.19	1.00	0.826

Note: For workable gages, refer to Table 1-7A. For compactness criteria, refer to Table 1-7B.

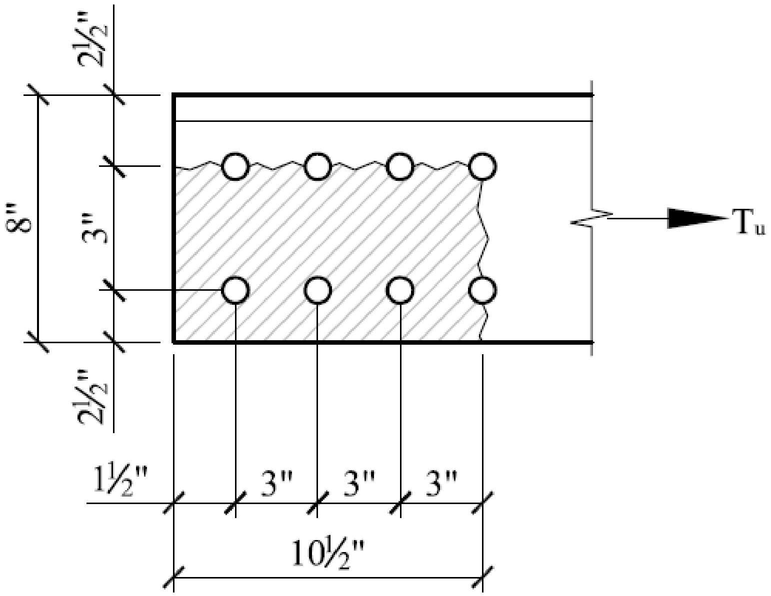
3. Select L8 × 4 × $\frac{1}{2}$ because of its lighter weight; also, it would have greater block shear capacity than the L6 × 6 × $\frac{1}{2}$ (same weight).

4. The minimum slenderness ratio calculated = 0.8 in.; r_{zz} for L8 × 4 × $\frac{1}{2}$ = **0.863 in.** > 0.8 in. OK.

5. Check block shear capacity. The spacing of the bolts will have to be assumed.



a. mode 1



b. mode 2

Mode 1 Block Shear:

Shear plane:

$$A_{gv} = (2\text{ shear planes})(10.5)\,(0.5) = 10.5\text{ in.}^2$$

$$A_{nv} = A_{gv} - \Sigma A_{\text{holes}}$$

$$= 10.5 - (2\text{ shear planes})(3.5\text{ holes})\left(\frac{3}{4}+\frac{1}{8}\right)(0.5\text{ in.}) = 7.43\text{ in.}^2$$

Tension plane:

$$A_{gt} = (3\text{ in.})(0.5\text{ in.}) = 1.5\text{ in.}^2$$

$$A_{nt} = A_{gt} - \Sigma A_{\text{holes}}$$

$$= 1.5 - (2)(0.5\text{ hole})\left(\frac{3}{4}+\frac{1}{8}\right)(0.5\text{ in.})\,(0.5\text{ in.}) = 1.06\text{ in.}^2$$

The design tension strength for the block shear failure mode is

$$\phi P_n = \phi\left(0.60F_uA_{nv} + U_{bs}F_u\ A_{nt}\right) \le \phi\left(0.60F_yA_{gv} + U_{bs}F_uA_{nt}\right)$$

$$= 0.75\left[(0.60)(58)(7.43) + (1.0)(58)(1.06)\right]$$

$$\le 0.75\left[(0.60)(36)(10.5) + (1.0)(58)(1.06)\right]$$

$$= 240\text{ kips} \le\ 216\text{ kips}$$

Therefore, $\phi P_n = 216\text{ kips}$ $(\text{mode \#1 block shear capacity}) > T_u = 154\text{ kips}$ OK.

Mode 2 Block Shear:

Shear plane:

$$A_{gv} = (10.5 \text{ in.})(0.5 \text{ in.}) = 5.25 \text{ in.}^2$$

$$A_{nv} = A_{gv} - \sum A_{\text{holes}}$$

$$= 5.25 - (3.5 \text{ holes})\left(\frac{3}{4} + \frac{1}{8}\right)(0.5 \text{ in.}) = 3.72 \text{ in.}^2$$

Tension plane:

$$A_{gt} = (3 \text{ in.} + 2.5 \text{ in.})(0.5 \text{ in.}) = 2.75 \text{ in.}^2$$

$$A_{nt} = A_{gt} - \Sigma A_{\text{holes}}$$

$$= 2.75 - (1.5 \text{ holes})\left(\frac{3}{4} + \frac{1}{8}\right)(0.5 \text{ in.}) = 2.09 \text{ in.}^2$$

The design tension strength for the block shear failure mode is

$$\phi P_n = \phi(0.60 F_u A_{nv} + U_{bs} F_u A_{nt}) \le \phi(0.60 F_y A_{gv} + U_{bs} F_u A_{nt})$$

$$= 0.75[(0.60)(58)(3.72) + (1.0)(58)(2.09)]$$

$$\le 0.75[(0.60)(36)(5.25) + (1.0)(58)(2.09)]$$

$$= 188 \text{ kips} \le 175 \text{ kips}$$

Therefore, $\phi P_n = 175$ kips (mode #2 block shear capacity) $> T_u = 154$ kips OK.

The block shear capacity is the smaller of the block shear capacities for block shear failure modes 1 and 2. Therefore, $\phi P_n = 175$ kips.

Select an $L8 \times 4 \times {}^1\!/_2$ with two lines of four ${}^3\!/_4$-in.-diameter bolts.

The Hashemite University

Faculty of Engineering

Department of Civil Engineering

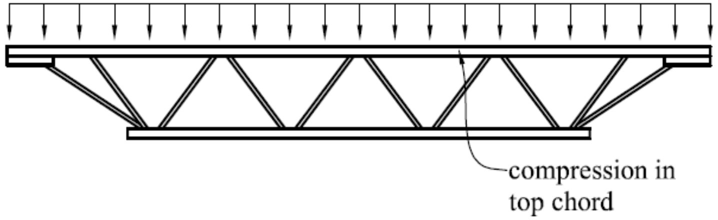
Analysis and design of axially loaded compression members

Dr. Ra'ed Al-Mazaidh

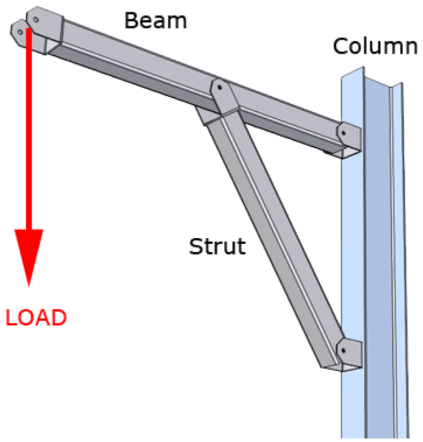
INTRODUCTION

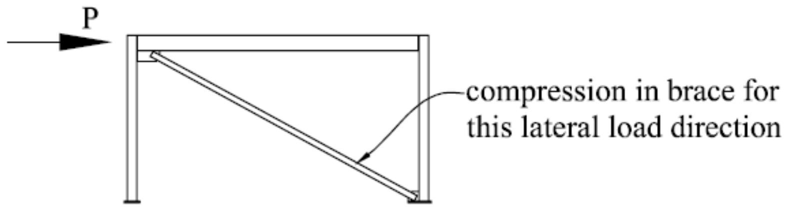
Structural steel elements are sometimes subjected to concentric compressive axial loads without any accompanying bending moment; Some examples include:

- Truss web members, compression chords of some trusses
- Struts
- compression members in concentric and eccentric braced frames such as X-braces and Chevron braces, and some columns in buildings

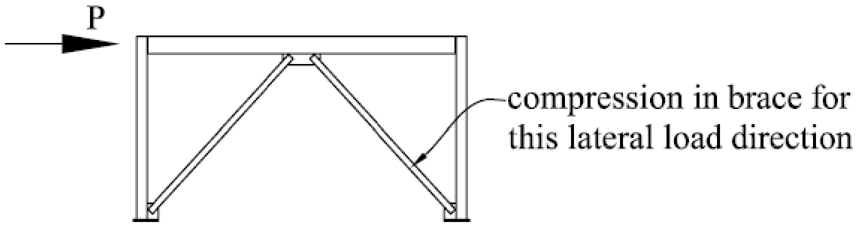


(ii) truss chord

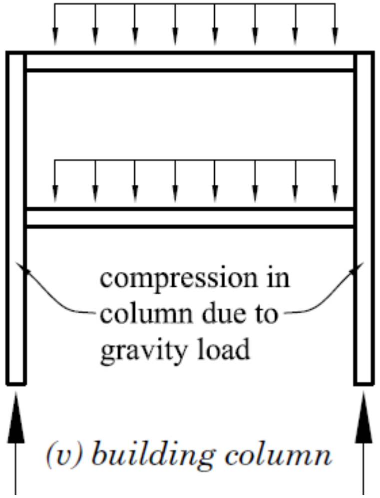




(iii) diagonal brace



(iv) Chevron brace

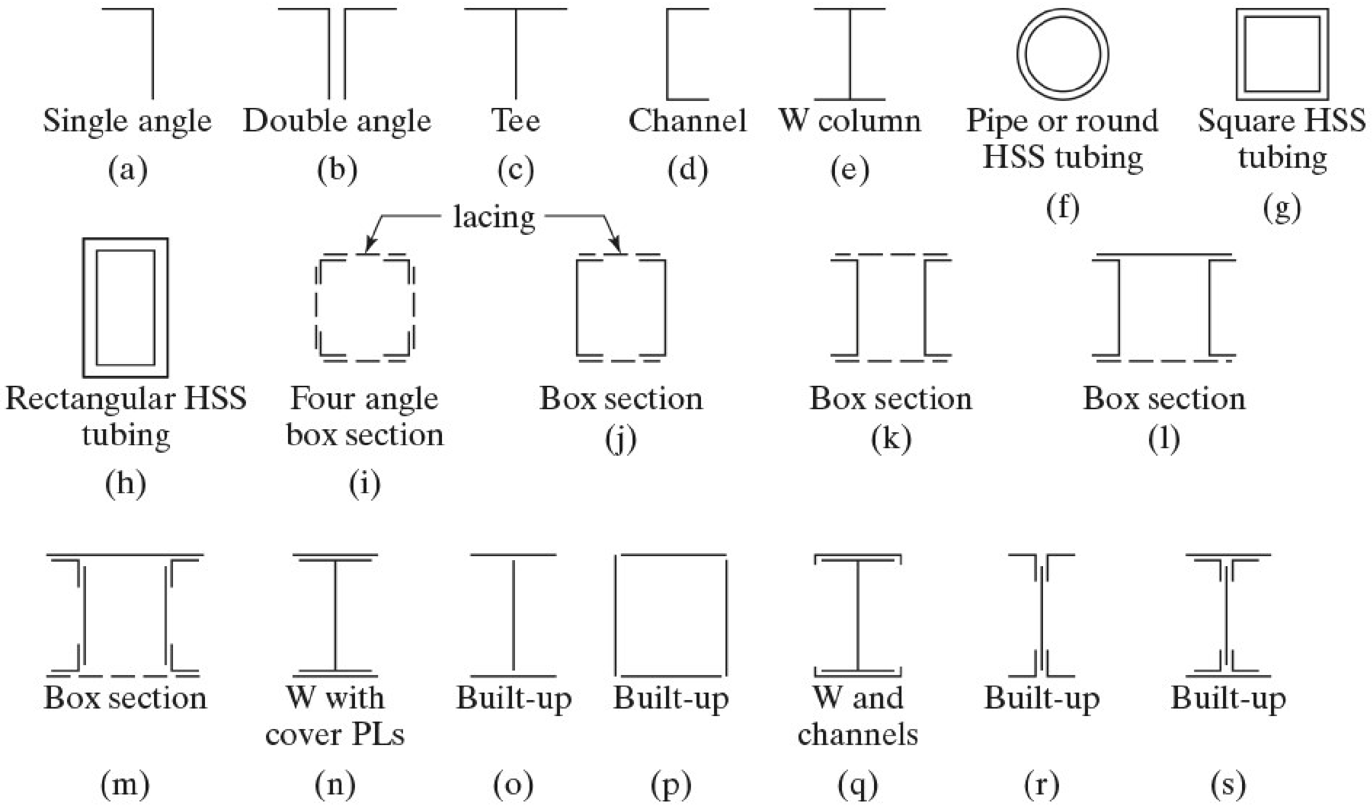


(v) building column

Struts, tie rods, and columns at an airport entrance canopy

The common shapes used for columns are:

- Wide flange sections (i.e., I-shapes)
- Round and square hollow structural sections (HSS).
- Built-up sections (e.g., box sections) are used as columns in high-rise buildings

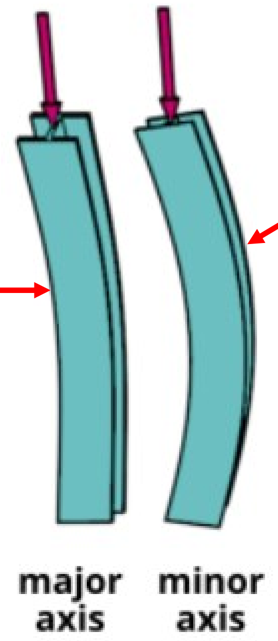


Failure modes of compression members

- **Flexural buckling:**

➢ In this failure mode, the member bends globally between lateral supports and **buckles about its weaker axis** (i.e., the axis with the larger slenderness ratio) because of the presence of the axial compression load.

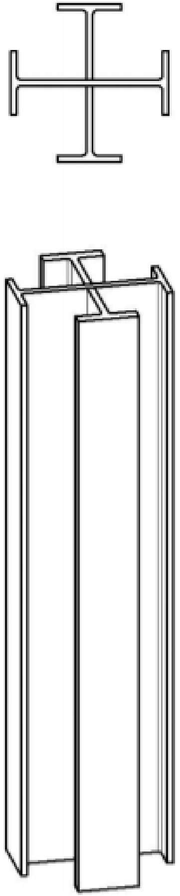
➢ This limit state is usually applicable to compression members comprised of non-slender elements, and **the failure mode can be either elastic buckling or inelastic buckling** depending on the slenderness ratio of the member. This limit state is covered in AISC Specification Section E3.

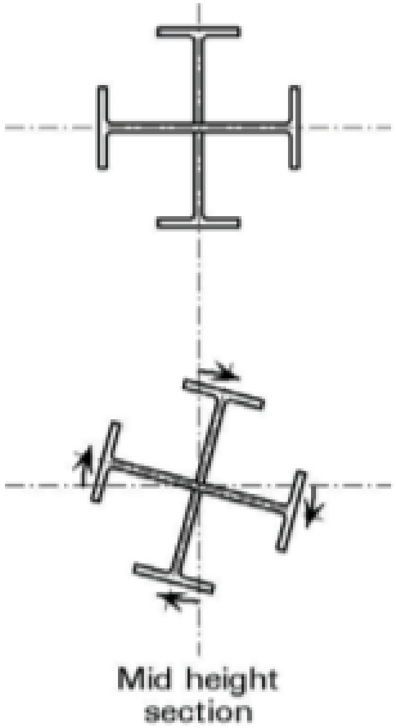


❑ Torsional buckling

- It involves **twisting about the longitudinal axis of the member without any lateral displacement**.

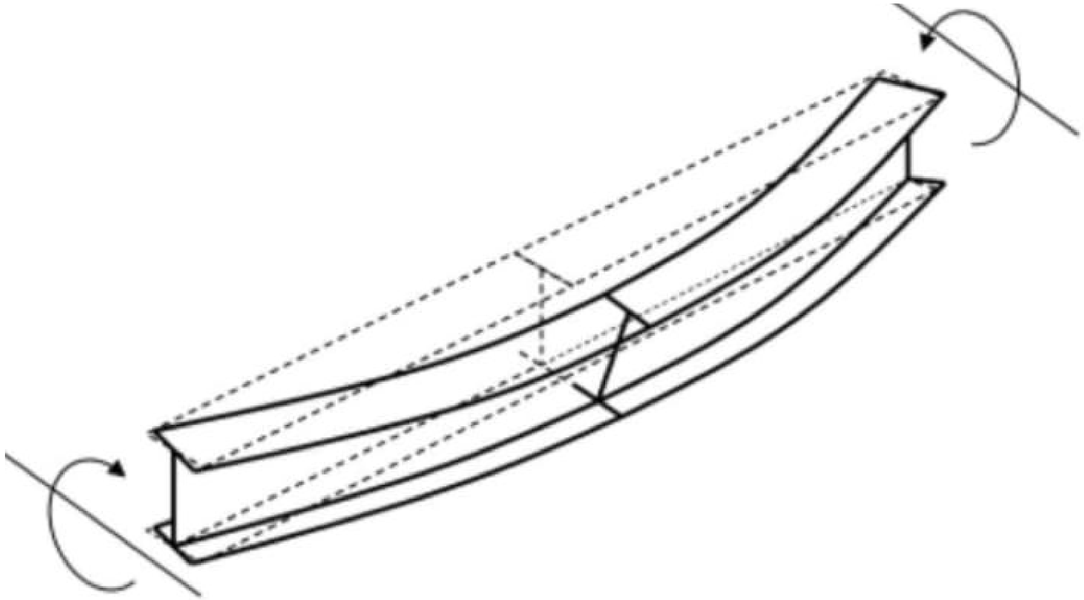
  Examples of sections susceptible to torsional buckling include cruciform shapes. See AISC Specification E4.





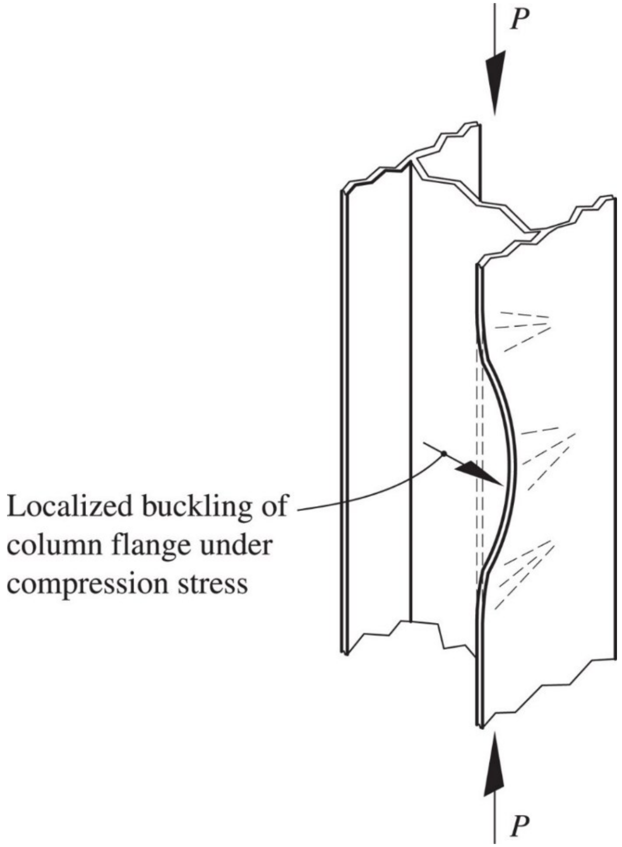
❑ Lateral-torsional or flexural-torsional buckling:

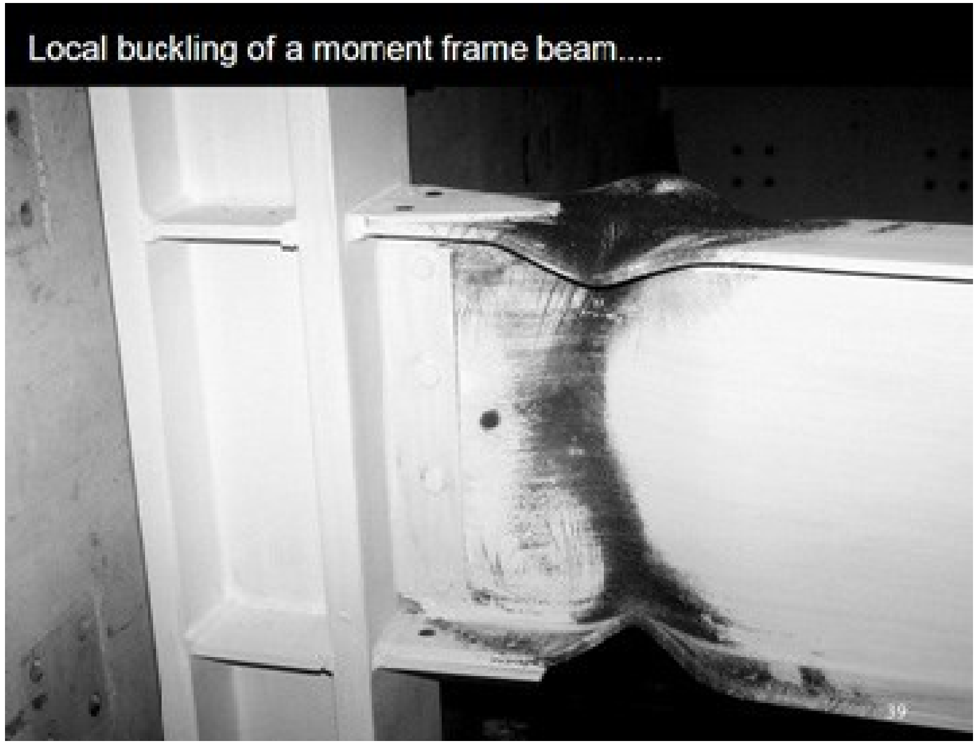
- It is a combination of the above two failure modes.
- It is common in wide flange sections.
- It is caused by the flexural compression stresses on the **compression flange** of a beam or column with large unbraced lengths.
- Torsional and flexural buckling limit state applies to singly symmetric and non-symmetric members and some doubly symmetric members such as cruciform-shaped columns with non-slender elements.
- The flexural and torsional buckling limit state for members with non-slender elements is covered in AISC Specification Section E4.



❑ Local buckling

- It occurs where the component elements of the structural member such as the web and the flanges are slender and can buckle locally (i.e., web local buckling and flange local buckling) in contrast to the global buckling that occurs in the first three failure modes discussed previously (see AISC Specification Section E7).




Local buckling of a moment frame beam.....

EULER CRITICAL BUCKLING LOAD

Summing moments about point C in Figure yields

$$-Py + M = 0$$

Therefore, $M = Py$ ....(1)

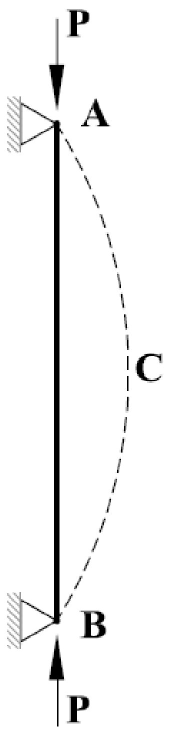
$$\frac{d^2y}{dx^2} = -\frac{M}{EI} \quad \text{..........(2)}$$

Substituting equation (2) into equation (1) and rearranging yields the second order differential equation

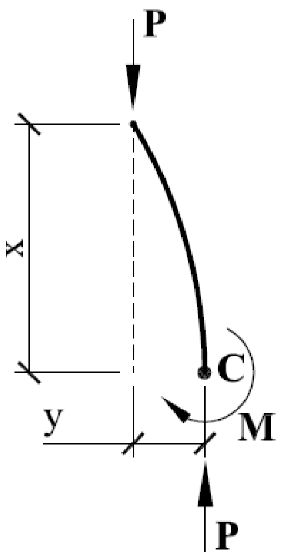
$$\frac{d^2y}{dx^2} + \frac{Py}{EI} = 0 \quad \text{..........(3)}$$

The solution to equation (3) is as follows

$$y = A_1 \sin\left(\sqrt{\frac{P}{EI}}x\right) + A_2 \cos\left(\sqrt{\frac{P}{EI}}x\right) \quad \text{..........(4)}$$



(a) Pin ended column subject to axial compression load



(b) Free body diagram

The boundary conditions for the pin-ended column are as follows:

At $x = 0$, the deflection, $y = 0$

At $x = L$, the deflection, $y = 0$

Substituting the first boundary condition into equation (4) means that the constant, $A_2 = 0$, which reduces equation (4) to

$$y = A_1 \sin\left(\sqrt{\frac{P}{EI}}\,x\right) \quad \text{..........(5)}$$

Substituting the second boundary condition into equation (5) leads to the following equation:

$$0 = A_1 \sin\left(\sqrt{\frac{P}{EI}}\,L\right)$$

The non-trivial solution to the preceding equation is obtained from

$\sin\left(\sqrt{\frac{P}{EI}}\,L\right) = 0$, which yields the following solution:

$$\left(\sqrt{\frac{P}{EI}}\,L\right) = n\pi,$$

Where, n = the number of deflection waves in the column between lateral supports = 1, 2, 3…

Therefore, the solution is $P = \dfrac{n^2\pi^2 EI}{L^2}$

The smallest value of n (i.e., $n = 1$), which indicates a single half-sine wave between the column lateral supports, gives the Euler critical load of the column, P_e,

$$\boxed{P_e = \frac{\pi^2 EI}{L^2}}$$

Where,

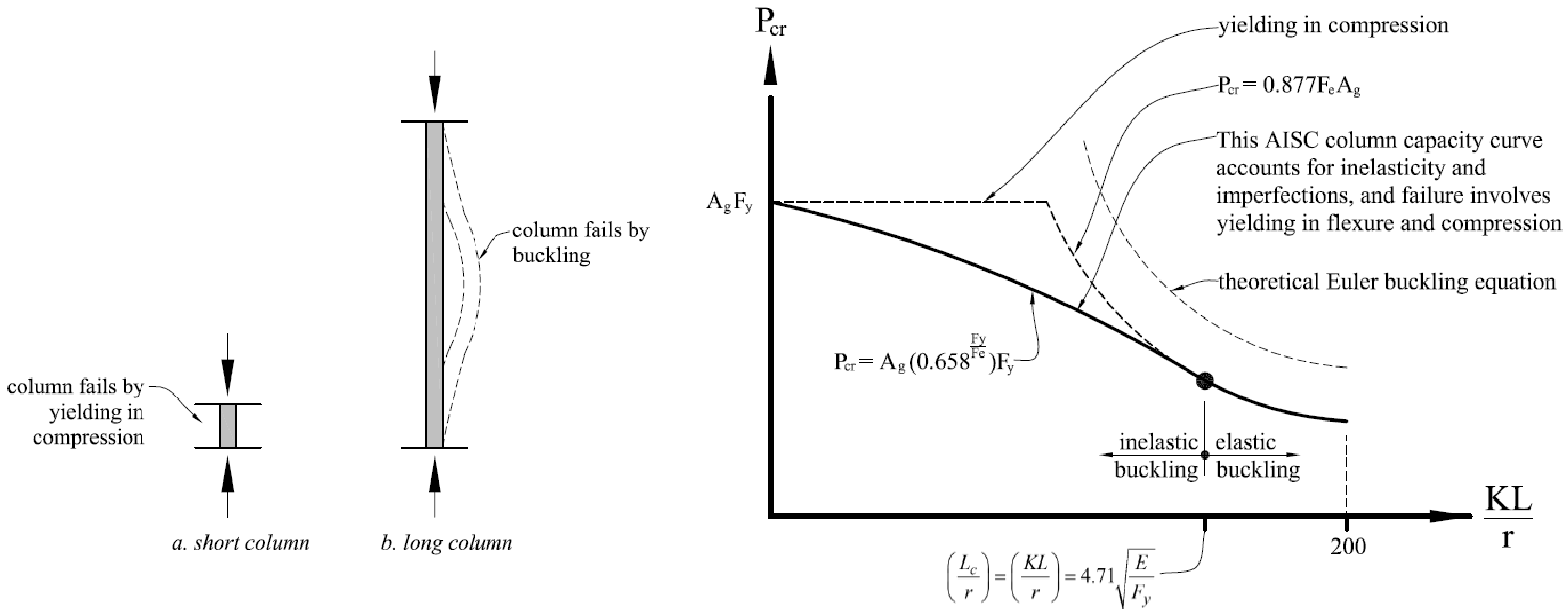
and,

P_e = Euler critical buckling load, lb.,

E = Modulus of elasticity (for steel, $E = 29 \times 10^6$ psi),

I = Moment of inertia, in.^{4}, and

L = Length of the column between lateral supports or brace points, in.



c. column capacity curve

$$P_e = \frac{\pi^2 EI}{L^2}$$

$$I = Ar^2, \qquad P_e = \frac{\pi^2 EAr^2}{L^2}$$

$$\sigma = \frac{P}{A}$$

$$F_e = \frac{P_e}{A} = \frac{\pi^2 E}{(L/r)^2}$$

where

F_e = Euler elastic critical buckling stress, psi,

A = Cross-sectional area, in.^{2}, and

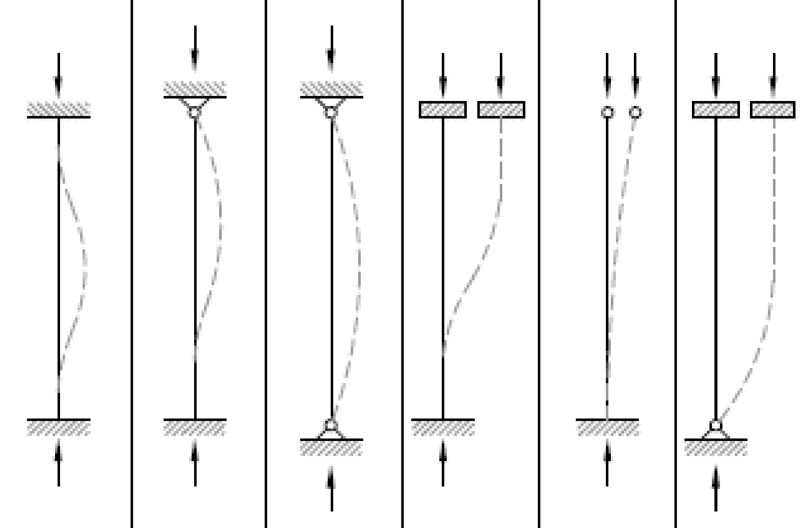
r = Radius of gyration, in

This equation assumes that the ends of the column are **pinned**. For other end conditions, an adjustment or ***effective length factor, K,*** is applied to the column length

$$P_e = \frac{\pi^2 EI}{(KL)^2} = \frac{\pi^2 EI}{(L_c)^2}$$

$$F_e = \frac{\pi^2 E}{(KL/r)^2} = \frac{\pi^2 E}{(L_c/r)^2}$$

$$\frac{KL}{r} = \frac{L_c}{r} \le 200 \text{ for compression members.}$$

	(a)	(b)	(c)	(d)	(e)	(f)
Buckling modes						
Theoretical K value	0.50	0.70	1.0	1.0	2.0	2.0
Recommended design K when ideal conditions are approximated	0.65	0.80	1.0	1.2	2.1	2.4
End condition legend	Rotation fixed, translation fixed Rotation free, translation fixed Rotation fixed, translation free Rotation free, translation free					

Adapted from AISCM Table C-A-7.1 [1].

Effective length factors, *K*, for idealized support conditions

COMPRESSION MEMBER STRENGTH

The AISC Specification defines the design compressive strength of a column for the flexural buckling limit state as follows :

The nominal axial compression strength is given as:

$$P_n = F_{cr} A_g$$

Where,

P_n = Nominal compressive strength $\left(= F_{cr} A_g\right)$, kips,

F_{cr} = Flexural buckling stress (see below), ksi

A_g = Gross cross-sectional area of the column, in.^{2}

For the LRFD method, the design axial compressive strength is given as

$$\phi_c P_n = \phi_c F_{cr} A_g$$

ϕ_c = strength reduction factor for compression = 0.90,

The slenderness ratio at which the behavior of the compression member changes from inelastic buckling to elastic buckling is

$$\frac{KL}{r} = \frac{L_c}{r} = 4.71\sqrt{\frac{E}{F_y}}$$

- Therefore, the member buckles *elastically* when $\frac{KL}{r} = \frac{L_c}{r} > 4.71\sqrt{\frac{E}{F_y}}$, and
- The column buckles *inelastically* when $\frac{KL}{r} = \frac{L_c}{r} \leq 4.71\sqrt{\frac{E}{F_y}}$

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

When $\frac{KL}{r} = \frac{L_c}{r} \leq 4.71\sqrt{\frac{E}{F_y}}$ $\quad$ (or when $F_y \leq 2.25F_e$ or $F_e \geq 0.44F_y$),

$$F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right]F_y$$

AISC equation E3-2

When $\frac{KL}{r} = \frac{L_c}{r} > 4.71\sqrt{\frac{E}{F_y}}$ $\quad$ (or when $F_y > 2.25F_e$ or $F_e < 0.44F_y$),

$$F_{cr} = 0.877F_e$$

AISC equation E3-3

$$F_e = \frac{P_e}{A} = \frac{\pi^2 E}{(L/r)^2}$$

LOCAL BUCKLING OF COMPRESSION MEMBERS

- Local buckling due to the slenderness of the **component elements a compression member** leads to a **reduction in the strength** of the member and prevents it from reaching its full axial compression capacity

- To avoid or prevent local buckling, the AISC specification prescribes limits to the **width-to-thickness ratios** (λ_p) of the plate elements that make up the compression member. These limits are given in **section B4** of the AISC Specification.

- In Section B4 of the AISC Specification, compression members subject to axial compression can be classified with regard to local stability as follows (**see Table 5-1 or AISCM Table B4.1a**):
  - Nonslender elements, or
  - Slender element sections.

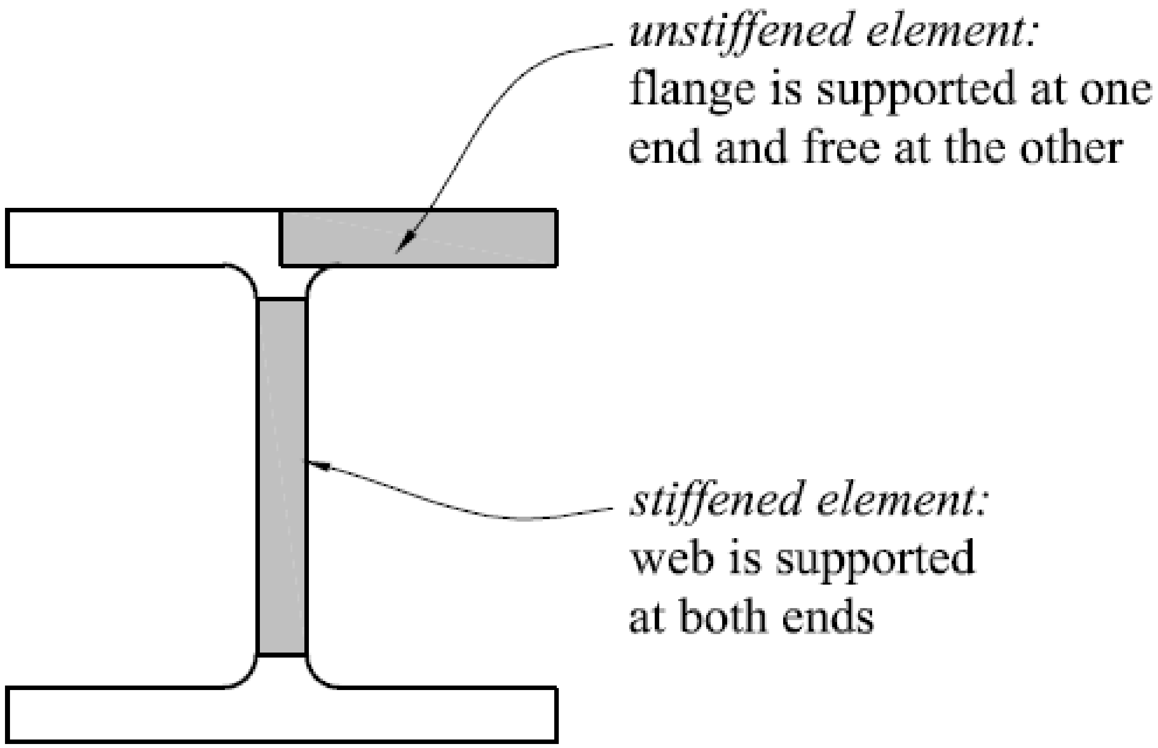
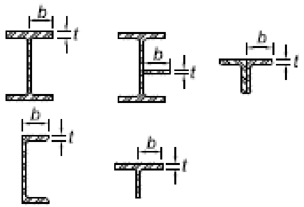
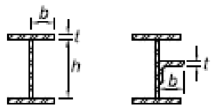
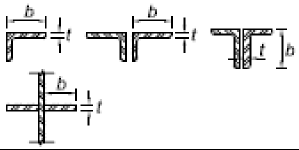
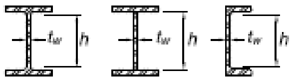
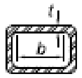
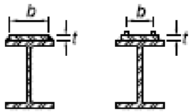
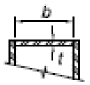
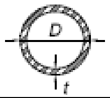

unstiffened element:
flange is supported at one
end and free at the other
stiffened element:
web is supported
at both ends

TABLE B4.1a
Width-to-Thickness Ratios: Compression Elements
Members Subject to Axial Compression

	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio λ_r (nonslender/slender)	Examples
Unstiffened Elements	1	Flanges of rolled I-shaped sections, plates projecting from rolled I-shaped sections, outstanding legs of pairs of angles connected with continuous contact, flanges of channels, and flanges of tees	b/t	$0.56\sqrt{\frac{E}{F_y}}$	
	2	Flanges of built-up I-shaped sections and plates or angle legs projecting from built-up I-shaped sections	b/t	$0.64\sqrt{\frac{k_c E}{F_y}}$ [a]	
	3	Legs of single angles, legs of double angles with separators, and all other unstiffened elements	b/t	$0.45\sqrt{\frac{E}{F_y}}$	
	4	Stems of tees	d/t	$0.75\sqrt{\frac{E}{F_y}}$	
Stiffened Elements	5	Webs of doubly symmetric rolled and built-up I-shaped sections and channels	h/t_w	$1.49\sqrt{\frac{E}{F_y}}$	
	6	Walls of rectangular HSS	b/t	$1.40\sqrt{\frac{E}{F_y}}$	
	7	Flange cover plates and diaphragm plates between lines of fasteners or welds	b/t	$1.40\sqrt{\frac{E}{F_y}}$	
	8	All other stiffened elements	b/t	$1.49\sqrt{\frac{E}{F_y}}$	
	9	Round HSS	D/t	$0.11\frac{E}{F_y}$	

[a] $k_c = 4/\sqrt{h/t_w}$, but shall not be taken less than 0.35 nor greater than 0.76 for calculation purposes.

ANALYSIS PROCEDURES FOR COMPRESSION MEMBERS

Method 1: Using slenderness ratios and the AISC equations

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

When $\frac{KL}{r} = \frac{L_c}{r} \leq 4.71\sqrt{\frac{E}{F_y}}$ (or when $F_y \leq 2.25F_e$ or $F_e \geq 0.44F_y$),

$$F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right]F_y$$

AISC equation E3-2

using the larger of $\frac{L_{cx}}{r_x}$ *or* $\frac{K_x L_x}{r_x}$ and $\frac{L_{cy}}{r_y}$ *or* $\frac{K_y L_y}{r_y}$.

When $\frac{KL}{r} = \frac{L_c}{r} > 4.71\sqrt{\frac{E}{F_y}}$ (or when $F_y > 2.25F_e$ or $F_e < 0.44F_y$),

$$F_{cr} = 0.877F_e$$

AISC equation E3-3

$$\phi P_n = \phi F_{cr} A_g$$

where A_g is the gross cross-sectional area of the compression member.

Method 2: Using slenderness ratios and AISC Available Critical Stress Tables (*AISCM*, Table **(4-22)**

This table gives the critical buckling stress, $\phi_c F_{cr}$ (for LRFD) and as a function of $\frac{L_c}{r}$ *or* $\frac{KL}{r}$ for different values of F_y (35 ksi, 36 ksi, 46 ksi 50 ksi, 65 ksi, and 70 ksi).

For a given $\frac{L_c}{r}$ *or* $\frac{KL}{r}$, determine $\phi_c F_{cr}$ (for LRFD) from the table using the larger of $\frac{L_{cx}}{r_x}$ *or* $\frac{K_x L_x}{r_x}$ and $\frac{L_{cy}}{r_y}$ *or* $\frac{K_y L_y}{r_y}$.

(e.g., when $\frac{L_c}{r} = \frac{KL}{r} = 97$ and F_y = 36 ksi, *AISCM* Table **(4-22)** gives $\phi_c F_{cr}$ = 19.7

Knowing the critical buckling stress, the axial design capacity for the LRFD method can be calculated from the equation

$$\phi P_n = \phi F_{cr} A_g$$

where A_g is the gross cross-sectional area of the compression member.

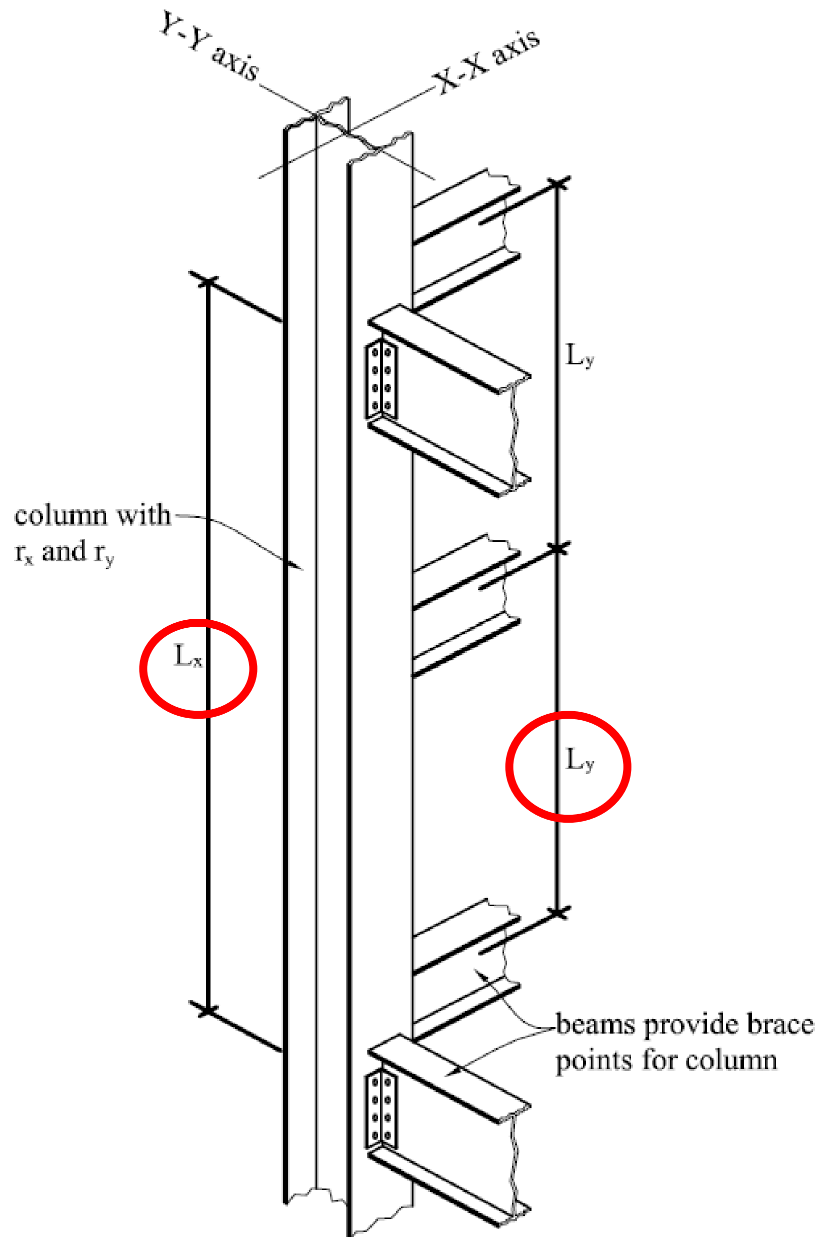


Table 4-22 (continued)
Available Critical Stress for Compression Members

KL/r	F_y = 35 ksi F_{cr}/Ω_c ksi ASD	F_y = 35 ksi $\phi_c F_{cr}$ ksi LRFD	KL/r	F_y = 36 ksi F_{cr}/Ω_c ksi ASD	F_y = 36 ksi $\phi_c F_{cr}$ ksi LRFD	KL/r	F_y = 42 ksi F_{cr}/Ω_c ksi ASD	F_y = 42 ksi $\phi_c F_{cr}$ ksi LRFD	KL/r	F_y = 46 ksi F_{cr}/Ω_c ksi ASD	F_y = 46 ksi $\phi_c F_{cr}$ ksi LRFD	KL/r	F_y = 50 ksi F_{cr}/Ω_c ksi ASD	F_y = 50 ksi $\phi_c F_{cr}$ ksi LRFD
81	15.0	22.5	81	15.3	22.9	81	16.8	25.3	81	17.7	26.6	81	18.5	27.9
82	14.9	22.3	82	15.1	22.7	82	16.6	25.0	82	17.5	26.3	82	18.3	27.5
83	14.7	22.1	83	15.0	22.5	83	16.5	24.8	83	17.3	26.0	83	18.1	27.2
84	14.6	22.0	84	14.9	22.3	84	16.3	24.5	84	17.1	25.8	84	17.9	26.9
85	14.5	21.8	85	14.7	22.1	85	16.1	24.3	85	16.9	25.5	85	17.7	26.5
86	14.4	21.6	86	14.6	22.0	86	16.0	24.0	86	16.7	25.2	86	17.4	26.2
87	14.2	21.4	87	14.5	21.8	87	15.8	23.7	87	16.6	24.9	87	17.2	25.9
88	14.1	21.2	88	14.3	21.6	88	15.6	23.5	88	16.4	24.6	88	17.0	25.5
89	14.0	21.0	89	14.2	21.4	89	15.5	23.2	89	16.2	24.3	89	16.8	25.2
90	13.8	20.8	90	14.1	21.2	90	15.3	23.0	90	16.0	24.0	90	16.6	24.9
91	13.7	20.6	91	13.9	21.0	91	15.1	22.7	91	15.8	23.7	91	16.3	24.6
92	13.6	20.4	92	13.8	20.8	92	15.0	22.5	92	15.6	23.4	92	16.1	24.2
93	13.5	20.2	93	13.7	20.5	93	14.8	22.2	93	15.4	23.1	93	15.9	23.9
94	13.3	20.0	94	13.5	20.3	94	14.6	22.0	94	15.2	22.8	94	15.7	23.6
95	13.2	19.9	95	13.4	20.1	95	14.4	21.7	95	15.0	22.6	95	15.5	23.3
96	13.1	19.7	96	13.3	19.9	96	14.3	21.5	96	14.8	22.3	96	15.3	22.9
97	13.0	19.5	97	13.1	19.7	97	14.1	21.2	97	14.6	22.0	97	15.0	22.6

Method 3: AISCM Available Strength in Axial Compression Tables (*AISCM* Tables 4-1 through 4-12) – also known as the column load capacity tables.

These column load capacity tables give the design strength, $\phi_c P_n$ (for the LRFD method) for selected shapes at various effective lengths, L_c *or* KL, and for selected values of the yield strength, F_y. Enter the appropriate "Available Strength in Axial Compression" table (i.e., the column load capacity table) with the value of L_c *or* KL, using the larger of

$$\frac{K_x L_x}{\left(\frac{r_x}{r_y}\right)} \text{ and } K_y L_y \text{ (i.e., the larger of } \frac{L_{cx}}{\left(\frac{r_x}{r_y}\right)} \text{ and } L_{cy}\text{)}$$

F_y = 50 ksi

Table 4-1 (continued)
Available Strength in Axial Compression, kips
W-Shapes

W14

Shape		W14×											
lb/ft		426^h		398^h		370^h		342^h		311^h		283^h	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Effective length, KL (ft), with respect to least radius of gyration, r_y	0	3740	5620	3500	5260	3260	4900	3020	4540	2740	4110	2490	3750
	11	3500	5260	3270	4920	3040	4570	2820	4230	2550	3830	2320	3480
	12	3450	5190	3230	4850	3000	4510	2780	4180	2510	3770	2290	3440
	13	3410	5120	3180	4780	2960	4450	2740	4120	2470	3720	2250	3380
	14	3350	5040	3130	4710	2910	4380	2700	4050	2430	3660	2210	3330
	15	3300	4960	3080	4630	2870	4310	2650	3980	2390	3600	2180	3270
	16	3240	4870	3030	4550	2810	4230	2600	3910	2350	3530	2140	3210
	17	3180	4790	2970	4470	2760	4150	2550	3840	2300	3460	2090	3150
	18	3120	4690	2920	4380	2710	4070	2500	3760	2260	3390	2050	3080
	19	3060	4600	2850	4290	2650	3980	2450	3680	2210	3320	2000	3010
	20	2990	4500	2790	4200	2590	3890	2390	3600	2160	3240	1960	2940
	22	2860	4290	2660	4000	2470	3710	2280	3420	2050	3080	1860	2800
	24	2710	4080	2530	3800	2340	3520	2160	3240	1940	2920	1760	2640
	26	2560	3850	2390	3590	2210	3320	2040	3060	1830	2750	1660	2490
	28	2410	3630	2250	3380	2080	3120	1910	2870	1710	2580	1550	2330
	30	2260	3400	2100	3160	1940	2920	1790	2680	1600	2400	1450	2170
	32	2110	3170	1960	2950	1810	2720	1660	2500	1490	2230	1340	2020
	34	1960	2950	1820	2730	1670	2520	1540	2310	1370	2060	1240	1860
	36	1810	2730	1680	2530	1540	2320	1420	2130	1260	1900	1140	1710
	38	1670	2510	1550	2320	1420	2130	1300	1950	1160	1740	1040	1560
	40	1530	2300	1410	2130	1300	1950	1180	1780	1050	1580	945	1420
	42	1390	2090	1290	1930	1180	1770	1070	1610	954	1430	857	1290
	44	1270	1910	1170	1760	1070	1610	979	1470	869	1310	781	1170
	46	1160	1750	1070	1610	980	1470	896	1350	795	1200	715	1070
	48	1070	1600	985	1480	900	1350	823	1240	730	1100	656	986
	50	983	1480	907	1360	830	1250	758	1140	673	1010	605	909

EXAMPLE 1

Using the LRFD method, calculate the design compressive strength of a W12 × 65 column, 20 ft. long, and pinned at both ends. Use ASTM A992 Grade 50 steel.

Solution

Method 1: Using slenderness ratios and the AISC equations

Solution

$L_x = L_y = 20$ ft.

$K = 1.0$ Both ends are pinned

$F_y = 50$ ksi Table 2-4

For W12 × 65, $A_g = 19.1$ in.^{2} Table 1-1 AISCM

Compute the slenderness ratio about the *x-x* and *y-y* axes and use the larger of the two values (i.e., the larger of $\frac{KL_x}{r_x}$ *or* $\frac{KL_y}{r_y}$). Alternatively, since $L_x = L_y$ and therefore $KL_x = KL_y$, the smaller radius of gyration will control.

For W12 × 65 from *AISCM*, part 1, the radius of gyration about both orthogonal axes are as follows:

$r_x = 5.28$ in., and

$r_y = 3.02$ in., (smaller value controls).

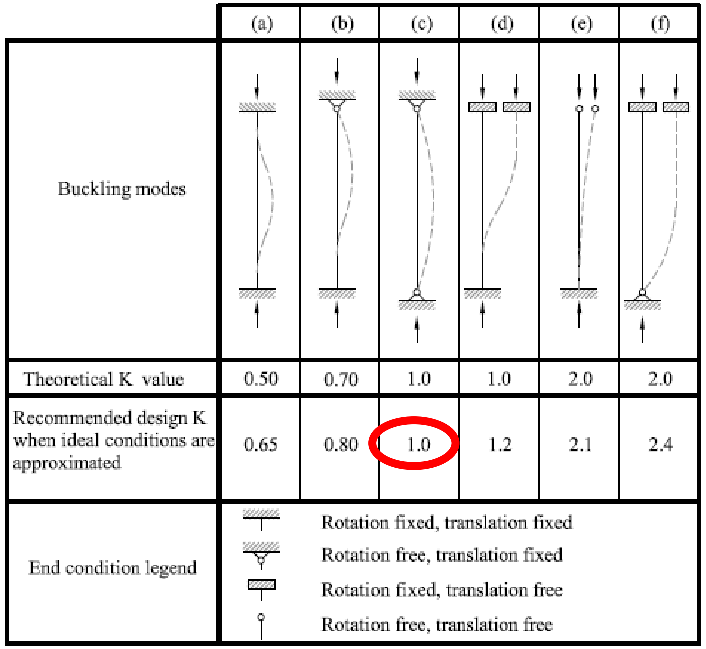


FIGURE 5-4 Effective length factors, *K*, for idealized support conditions

Table 2-4
Applicable ASTM Specifications for Various Structural Shapes

Steel Typ	ASTM Designatio		F_y Yield Stress[a] (ksi)	F_u Tensile Stress[a] (ksi)	Applicable Shape Series: W	M	S	HP	C	MC	L	HSS: Rect.	HSS: Round	Pipe
Carbon	A36		36	58–80[b]	▒	■	■	▒	■	■	■			
	A53 Gr. B		35	60										■
	A500	Gr. B	42	58									▒	
			46	58								▒		
		Gr. C	46	62									■	
			50	62								■		
	A501	Gr. A	36	58								▒	▒	
		Gr. B	50	70								▒	▒	
	A529[c]	Gr. 50	50	65–100	▒	▒	▒	▒	▒	▒	▒			
		Gr. 55	55	70–100	▒	▒	▒	▒	▒	▒	▒			
	A709	36	36	58–80[b]	▒	▒	▒	▒	▒	▒	▒			
	A1043[d,k]	36	36–52	58	▒									
		50	50–65	65	▒									
	A1085	Gr.A	50	65								▒	▒	
High-Strength Low-Alloy	A572	Gr.42	42	60	▒	▒	▒	▒	▒	▒	▒			
		Gr.50	50	65	▒	▒	▒	■	▒	▒	▒			
		Gr.55	55	70	▒	▒	▒	▒	▒	▒	▒			
		Gr. 60[e]	60	75	▒	▒	▒	▒	▒	▒	▒			
		Gr. 65[e]	65	80	▒	▒	▒	▒	▒	▒	▒			
	A618[f]	Gr. Ia[k], Ib & II	50[g]	70[g]								▒	▒	
		Gr. III	50	65								▒	▒	
	A709	50	50	65	▒	▒	▒	▒	▒	▒	▒			
		50S	50–65	65	▒	▒	▒	▒	▒	▒	▒			
		50W	50	70	▒	▒	▒	▒	▒	▒	▒			
	A913	50	50[h]	65[h]	▒	▒	▒	▒	▒	▒	▒			
		60	60	75	▒	▒	▒	▒	▒	▒	▒			
		65	65	80	▒	▒	▒	▒	▒	▒	▒			
		70	70	90	▒	▒	▒	▒	▒	▒	▒			
	A992		50[i]	65[i]	■	▒	▒	▒	▒	▒	▒			
	A1065[k]	Gr. 50[j]	50	60								▒		

■ = Preferred material specification.
▒ = Other applicable material specification, the availability of which should be confirmed prior to specification.
□ = Material specification does not apply.

Footnotes on facing page.

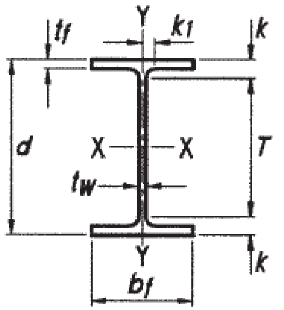


Table 1-1 (continued)
W-Shapes
Dimensions

Shape	Area, A	Depth, d		Web			Flange				Distance				
				Thickness, t_w		$\frac{t_w}{2}$	Width, b_f		Thickness, t_f		k		k_1	T	Workable Gage
											k_{des}	k_{det}			
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W12×336[h]	98.9	16.8	16 7/8	1.78	1 3/4	7/8	13.4	13 3/8	2.96	2 15/16	3.55	3 7/8	1 11/16	9 1/8	5 1/2
×305[h]	89.5	16.3	16 3/8	1.63	1 5/8	13/16	13.2	13 1/4	2.71	2 11/16	3.30	3 5/8	1 5/8		
×279[h]	81.9	15.9	15 7/8	1.53	1 1/2	3/4	13.1	13 1/8	2.47	2 1/2	3.07	3 3/8	1 5/8		
×252[h]	74.1	15.4	15 3/8	1.40	1 3/8	11/16	13.0	13	2.25	2 1/4	2.85	3 1/8	1 1/2		
×230[h]	67.7	15.1	15	1.29	1 5/16	11/16	12.9	12 7/8	2.07	2 1/16	2.67	2 15/16	1 1/2		
×210	61.8	14.7	14 3/4	1.18	1 3/16	5/8	12.8	12 3/4	1.90	1 7/8	2.50	2 13/16	1 7/16		
×190	56.0	14.4	14 3/8	1.06	1 1/16	9/16	12.7	12 5/8	1.74	1 3/4	2.33	2 5/8	1 3/8		
×170	50.0	14.0	14	0.960	15/16	1/2	12.6	12 5/8	1.56	1 9/16	2.16	2 7/16	1 5/16		
×152	44.7	13.7	13 3/4	0.870	7/8	7/16	12.5	12 1/2	1.40	1 3/8	2.00	2 5/16	1 1/4		
×136	39.9	13.4	13 3/8	0.790	13/16	7/16	12.4	12 3/8	1.25	1 1/4	1.85	2 1/8	1 1/4		
×120	35.2	13.1	13 1/8	0.710	11/16	3/8	12.3	12 3/8	1.11	1 1/8	1.70	2	1 3/16		
×106	31.2	12.9	12 7/8	0.610	5/8	5/16	12.2	12 1/4	0.990	1	1.59	1 7/8	1 1/8		
×96	28.2	12.7	12 3/4	0.550	9/16	5/16	12.2	12 1/8	0.900	7/8	1.50	1 13/16	1 1/8		
×87	25.6	12.5	12 1/2	0.515	1/2	1/4	12.1	12 1/8	0.810	13/16	1.41	1 11/16	1 1/16		
×79	23.2	12.4	12 3/8	0.470	1/2	1/4	12.1	12 1/8	0.735	3/4	1.33	1 5/8	1 1/16		
×72	21.1	12.3	12 1/4	0.430	7/16	1/4	12.0	12	0.670	11/16	1.27	1 9/16	1 1/16		
×65[f]	19.1	12.1	12 1/8	0.390	3/8	3/16	12.0	12	0.605	5/8	1.20	1 1/2	1		

Table 1-1 (continued)

W-Shapes

Properties

W14-W12

Nom-inal Wt.	Compact Section Criteria		Axis X-X				Axis Y-Y				r_{ts}	h_o	Torsional Properties	
	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	I	S	r	Z	I	S	r	Z			J	C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
336	2.26	5.47	4060	483	6.41	603	1190	177	3.47	274	4.13	13.8	243	57000
305	2.45	5.98	3550	435	6.29	537	1050	159	3.42	244	4.05	13.6	185	48600
279	2.66	6.35	3110	393	6.16	481	937	143	3.38	220	4.00	13.4	143	42000
252	2.89	6.96	2720	353	6.06	428	828	127	3.34	196	3.93	13.2	108	35800
230	3.11	7.56	2420	321	5.97	386	742	115	3.31	177	3.87	13.0	83.8	31200
210	3.37	8.23	2140	292	5.89	348	664	104	3.28	159	3.81	12.8	64.7	27200
190	3.65	9.16	1890	263	5.82	311	589	93.0	3.25	143	3.77	12.7	48.8	23600
170	4.03	10.1	1650	235	5.74	275	517	82.3	3.22	126	3.70	12.4	35.6	20100
152	4.46	11.2	1430	209	5.66	243	454	72.8	3.19	111	3.66	12.3	25.8	17200
136	4.96	12.3	1240	186	5.58	214	398	64.2	3.16	98.0	3.61	12.2	18.5	14700
120	5.57	13.7	1070	163	5.51	186	345	56.0	3.13	85.4	3.56	12.0	12.9	12400
106	6.17	15.9	933	145	5.47	164	301	49.3	3.11	75.1	3.52	11.9	9.13	10700
96	6.76	17.7	833	131	5.44	147	270	44.4	3.09	67.5	3.49	11.8	6.85	9410
87	7.48	18.9	740	118	5.38	132	241	39.7	3.07	60.4	3.46	11.7	5.10	8270
79	8.22	20.7	662	107	5.34	119	216	35.8	3.05	54.3	3.43	11.7	3.84	7330
72	8.99	22.6	597	97.4	5.31	108	195	32.4	3.04	49.2	3.41	11.6	2.93	6540
65	9.92	24.9	533	87.9	5.28	96.8	174	29.1	3.02	44.1	3.38	11.5	2.18	5780

$$\frac{L_{cy}}{r_y}=\frac{KL_y}{r_y}=\frac{(1.0)(20\text{ ft.})(12)}{3.02}=79.5 \quad \text{(controls)}$$

$$< 200 \quad \text{OK.}$$

$$\frac{L_{cx}}{r_x}=\frac{KL_x}{r_x}=\frac{(1.0)(20\text{ ft.})(12)}{5.28\text{ in.}}=45.5 \quad < 200 \quad \text{OK.}$$

The larger $\frac{L_c}{r}$ value governs.

Check the slenderness criteria for compression elements:
For W12×65,

$$\left.\begin{aligned} b_f &= 12\text{ in. } \left(b=b_f/2=12/2=6\text{ in.}\right)\\ t_f &= 0.605\text{ in.}\\ t_w &= 0.39\text{ in.}\end{aligned}\right\} \text{(Table 1-1 AISCM)}$$

$$h = d - 2k_{\text{des}} = 12.1-(2)(1.20)=9.7\text{ in.}$$

$$\boxed{\frac{b}{t}\le 0.56\sqrt{\frac{E}{F_y}};} \quad \frac{b}{t}=\frac{6}{0.605}=9.92 < 0.56\sqrt{\frac{29{,}000}{50}}=13.48 \quad \text{OK.} \quad \text{Flange}$$

$$\boxed{\frac{h}{t_w}\le 1.49\sqrt{\frac{E}{F_y}}} \quad \frac{h}{t_w}=\frac{9.7}{0.39}=24.88 < 1.49\sqrt{\frac{29{,}000}{50}}=35.88 \quad \text{OK.} \quad \text{Web}$$

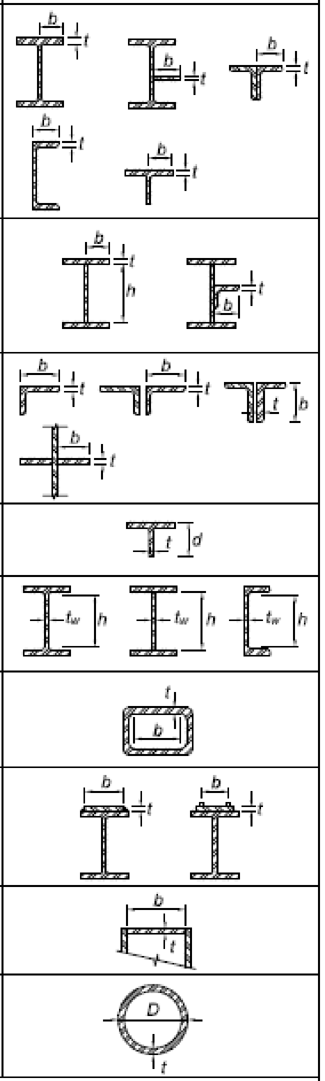
You can also get these values from table 1-1 AISCM……See previous slide

TABLE B4.1a

Width-to-Thickness Ratios: Compression Elements Members Subject to Axial Compression

	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio λ_r (nonslender/slender)
Unstiffened Elements	1	Flanges of rolled I-shaped sections, plates projecting from rolled I-shaped sections, outstanding legs of pairs of angles connected with continuous contact, flanges of channels, and flanges of tees	b/t	$0.56\sqrt{\frac{E}{F_y}}$
	2	Flanges of built-up I-shaped sections and plates or angle legs projecting from built-up I-shaped sections	b/t	$0.64\sqrt{\frac{k_c E}{F_y}}$ [a]
	3	Legs of single angles, legs of double angles with separators, and all other unstiffened elements	b/t	$0.45\sqrt{\frac{E}{F_y}}$
	4	Stems of tees	d/t	$0.75\sqrt{\frac{E}{F_y}}$
Stiffened Elements	5	Webs of doubly symmetric rolled and built-up I-shaped sections and channels	h/t_w	$1.49\sqrt{\frac{E}{F_y}}$
	6	Walls of rectangular HSS	b/t	$1.40\sqrt{\frac{E}{F_y}}$
	7	Flange cover plates and diaphragm plates between lines of fasteners or welds	b/t	$1.40\sqrt{\frac{E}{F_y}}$
	8	All other stiffened elements	b/t	$1.49\sqrt{\frac{E}{F_y}}$
	9	Round HSS	D/t	$0.11\frac{E}{F_y}$

Examples



[a] $k_c = 4/\sqrt{h/t_w}$, but shall not be taken less than 0.35 nor greater than 0.76 for calculation purposes.

Therefore, the component elements are non-slender.

Determine the flexural buckling stress, F_{cr}:

The maximum slenderness ratio for inelastic buckling is

$$4.71\sqrt{\frac{E}{F_y}} = 4.71\sqrt{\frac{29{,}000}{50}} = 113.4$$

Since $\frac{L_c}{r} = \frac{KL}{r} = 79.5 < 113.4$, this indicates that the failure mode is by inelastic flexural

$$F_e = \frac{\pi^2 E}{(KL/r)^2} = \frac{(\pi^2)(29{,}000)}{(79.5)^2} = 45.3 \text{ ksi}$$

the flexural buckling stress is

$$F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right] F_y = \left[0.658^{\frac{50}{45.3}}\right](50) = 31.5 \text{ ksi}$$

The nominal axial compressive strength of the column is

$$P_n = F_{cr} A_g = (31.5)(19.1) = 601.6 \text{ kips}$$

The design compressive strength of the column is determined:

$$\phi_c P_n = (0.90)(601.6) = 541 \text{ kips}$$

Method 2: Using slenderness ratios and AISC Available Critical Stress Tables (*AISCM*, Table **(4-22)**

From *AISCM* Table **(4-22)** the critical compression stress, ϕF_{cr}, could be obtained directly by entering the table with $\frac{L_c}{r} = \frac{KL}{r} = 79.5$ and $F_y = 50$ ksi. A value of $\phi_c F_{cr} = 28.4$ ksi is obtained, which confirms the design axial compression strength as

$$\phi_c F_{cr} A_g = (28.4\,\text{ksi})(19.1\,\text{in.}^2) = 542\ \text{kips}.$$

Table 4-22 (continued)

Available Critical Stress for Compression Members

$Fy = 35$ ksi			$Fy = 36$ ksi			$Fy = 42$ ksi			$Fy = 46$ ksi			$Fy = 50$ ksi		
$\frac{KL}{r}$	F_{cr}/Ω_c	$\phi_c F_{cr}$	$\frac{KL}{r}$	F_{cr}/Ω_c	$\phi_c F_{cr}$	$\frac{KL}{r}$	F_{cr}/Ω_c	$\phi_c F_{cr}$	$\frac{KL}{r}$	F_{cr}/Ω_c	$\phi_c F_{cr}$	$\frac{KL}{r}$	F_{cr}/Ω_c	$\phi_c F_{cr}$
	ksi	ksi		ksi	ksi		ksi	ksi		ksi	ksi		ksi	ksi
	ASD	LRFD		ASD	LRFD		ASD	LRFD		ASD	LRFD		ASD	LRFD
78	15.4	23.1	78	15.6	23.5	78	17.3	26.0	78	18.3	27.5	78	19.2	28.8
79	15.2	22.9	79	15.5	23.3	79	17.1	25.8	79	18.1	27.2	79	19.0	28.5
80	15.1	22.7	80	15.4	23.1	80	17.0	25.5	80	17.9	26.9	80	18.8	28.2

ASD	LRFD
$\Omega_c = 1.67$	$\phi_c = 0.90$

Method 3: *AISCM* Available Strength in Axial Compression Tables (*AISCM* Tables 4-1 through 4-12)

WF sections (Table 4-1)

Alternatively, the design axial compression strength could be obtained directly from Table 4-1 of the *AISCM* (i.e., the column load capacity tables). Enter the table with $L_{cy} = KL_y = 20$ ft. and obtain $\phi_c P_n = 542$ kips.

F_y = 50 ksi

Table 4-1 (continued)
Available Strength in Axial Compression, kips
W-Shapes

W12

Shape		W12×									
lb/ft		96		87		79		72		65	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Effective length, KL (ft), with respect to least radius of gyration, r_y	0	844	1270	766	1150	695	1040	632	949	572	859
	6	811	1220	736	1110	667	1000	606	911	549	825
	7	800	1200	726	1090	657	988	597	898	540	812
	8	787	1180	714	1070	646	971	587	883	531	798
	9	772	1160	700	1050	634	953	576	866	521	783
	10	756	1140	685	1030	620	932	564	847	510	766
	11	739	1110	670	1010	606	910	550	827	497	747
	12	720	1080	653	981	590	887	536	806	484	728
	13	701	1050	635	954	574	862	521	783	470	707
	14	680	1020	616	925	556	836	505	759	456	685
	15	659	990	596	896	538	809	489	735	441	663
	16	637	957	576	865	520	781	472	709	426	640
	17	614	923	555	834	501	753	455	683	410	616
	18	591	888	534	802	481	723	437	656	393	591
	19	567	852	512	770	462	694	419	629	377	567
	20	543	816	490	737	442	664	401	602	360	542
	22	495	744	446	671	402	604	364	547	327	492
	24	447	672	403	605	362	544	328	493	294	442
	26	401	602	360	541	323	486	292	440	262	394
	28	356	535	319	480	286	430	259	389	231	348
	30	312	469	280	421	250	376	226	340	202	304
	32	274	413	246	370	220	331	199	299	178	267
	34	243	365	218	327	195	293	176	265	157	236
	36	217	326	194	292	174	261	157	236	140	211
	38	195	293	174	262	156	234	141	212	126	189
	40	176	264	157	237	141	212	127	191	114	171

Example

Using the LRFD method, determine the design compressive strength for a pin-ended HSS 8 × 8 × $^3/_8$ column of **Fy= 46 Ksi** steel with an unbraced length of 13.5 ft.

Solution

Unbraced column length, L = 13.5 ft.

Pin-ended column : $K = 1.0$,

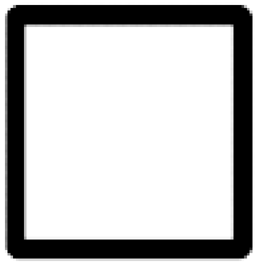
$$L_c = KL = (1.0)\ (13.5) = 13.5 \text{ ft.}$$

For HSS 8 × 8 × $^3/_8$ from **AISCM Table (1-12)** we find the cross-sectional properties as follows:

$A_g = 10.4 \text{ in.}^2$

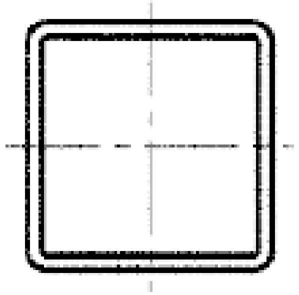
$r_x = r_y = 3.10 \text{ in.}$

$$\frac{L_c}{r} = \frac{KL}{r} = \frac{(1.0)\ (13.5 \text{ ft.})(12)}{3.10} = \mathbf{52.26 < 200} \quad \text{OK.}$$



HSS16-HSS8

Table 1-12
Square HSS
Dimensions and Properties



Shape	Design Wall Thickness, *t*	Nominal Wt.	Area, *A*	*b/t*	*h/t*	*I*	*S*	*r*	*Z*	Workable Flat	Torsion		Surface Area
											J	*C*	
	in.	lb/ft	$in.^2$			$in.^4$	$in.^3$	in.	$in.^3$	in.	$in.^4$	$in.^3$	ft^2/ft
HSS8×8×5/8	0.581	59.32	16.4	10.8	10.8	146	36.5	2.99	44.7	5 3/16	244	63.2	2.50
×1/2	0.465	48.85	13.5	14.2	14.2	125	31.2	3.04	37.5	5 3/4	204	52.4	2.53
×3/8	0.349	37.69	10.4	19.9	19.9	100	24.9	3.10	29.4	6 5/16	160	40.7	2.57
×5/16	0.291	31.84	8.76	24.5	24.5	85.6	21.4	3.13	25.1	6 5/8	136	34.5	2.58
×1/4	0.233	25.82	7.10	31.3	31.3	70.7	17.7	3.15	20.5	6 7/8	111	28.1	2.60
×3/16	0.174	19.63	5.37	43.0	43.0	54.4	13.6	3.18	15.7	7 3/16	84.5	21.3	2.62
×1/8	0.116	13.26	3.62	66.0	66.0	37.4	9.34	3.21	10.7	7 7/16	57.3	14.4	2.63

Method 1: Using slenderness ratios and the AISC equations

Check the slenderness criteria for compression elements:

$$\frac{b}{t} \le 1.40\sqrt{\frac{E}{F_y}}; \qquad \text{i.e. } 19.9 \le 1.40\sqrt{\frac{29{,}000}{46}} = 35.1 \text{ OK}$$

$\left(\frac{b}{t} = 19.9 \text{ from } \right.$ **AISCM Table (1-12)** $\left.\right)$

Therefore, there are no slender elements in this column section.

Determine the flexural buckling stress, F_{cr}:

The maximum slenderness ratio for inelastic buckling is

$$4.71\sqrt{\frac{E}{F_y}} = 4.71\sqrt{\frac{29{,}000}{46}} = 118.2$$

Since $\frac{L_c}{r} = \frac{KL}{r} =$ **52.26<118.2**

therefore,

The Euler critical buckling stress is

$$F_e = \frac{\pi^2 E}{(KL/r)^2} = \frac{(\pi^2)(29{,}000)}{(52.26)^2} = 104.80 \text{ Ksi}$$

The flexural buckling stress is:

$$F_{cr} = \left(0.658^{\frac{F_y}{F_e}}\right) F_y = \left(0.658^{\left(\frac{46}{104.8}\right)}\right)(46) = 38.28 \text{ Ksi}$$

The nominal axial compressive strength is

$$P_n = F_{cr} A_g = (38.28)(10.4) = 398.11 \text{ Kips}$$

$$\phi_c P_n = (0.9)(398.11) = \mathbf{358.3\ Kips}$$

Recall

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

When $\frac{KL}{r} = \frac{L_c}{r} \le 4.71\sqrt{\frac{E}{F_y}}$ (or when $F_y \le 2.25F_e$ or $F_e \ge 0.44F_y$),

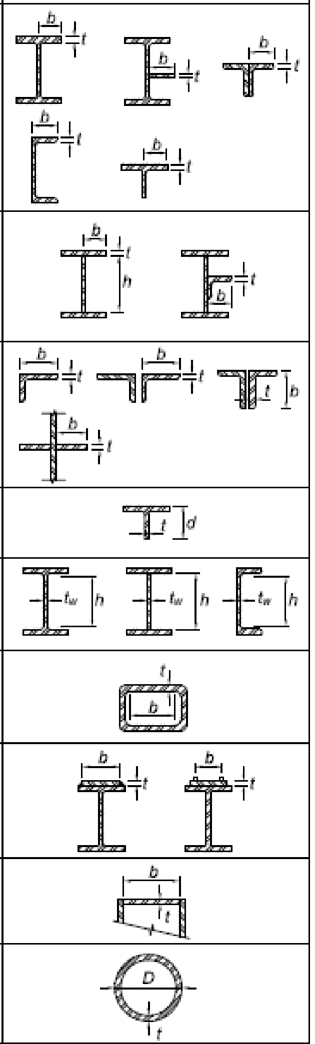
$$F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right] F_y \qquad \text{AISC equation E3-2}$$

When $\frac{KL}{r} = \frac{L_c}{r} > 4.71\sqrt{\frac{E}{F_y}}$ (or when $F_y > 2.25F_e$ or $F_e < 0.44F_y$),

$$F_{cr} = 0.877F_e \qquad \text{AISC equation E3-3}$$

TABLE B4.1a
Width-to-Thickness Ratios: Compression Elements
Members Subject to Axial Compression

	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio λ_r (nonslender/slender)	Examples
Unstiffened Elements	1	Flanges of rolled I-shaped sections, plates projecting from rolled I-shaped sections, outstanding legs of pairs of angles connected with continuous contact, flanges of channels, and flanges of tees	b/t	$0.56\sqrt{\frac{E}{F_y}}$	
	2	Flanges of built-up I-shaped sections and plates or angle legs projecting from built-up I-shaped sections	b/t	$0.64\sqrt{\frac{k_c E}{F_y}}$ [a]	
	3	Legs of single angles, legs of double angles with separators, and all other unstiffened elements	b/t	$0.45\sqrt{\frac{E}{F_y}}$	
	4	Stems of tees	d/t	$0.75\sqrt{\frac{E}{F_y}}$	
Stiffened Elements	5	Webs of doubly symmetric rolled and built-up I-shaped sections and channels	h/t_w	$1.49\sqrt{\frac{E}{F_y}}$	
	6	Walls of rectangular HSS	b/t	$1.40\sqrt{\frac{E}{F_y}}$	
	7	Flange cover plates and diaphragm plates between lines of fasteners or welds	b/t	$1.40\sqrt{\frac{E}{F_y}}$	
	8	All other stiffened elements	b/t	$1.49\sqrt{\frac{E}{F_y}}$	
	9	Round HSS	D/t	$0.11\frac{E}{F_y}$	



[a] $k_c = 4/\sqrt{h/t_w}$, but shall not be taken less than 0.35 nor greater than 0.76 for calculation purposes.

Method 2: Using slenderness ratios and AISC Available Critical Stress Tables (*AISCM*, Table **(4-22)**

From *AISCM* Table **(4-22)** he critical compression stress for LRFD, $\phi_c F_{cr}$, is obtained directly by entering the table with $\frac{L_c}{r} = \frac{KL}{r} =$ **52.26 and Fy=46 Ksi** . A value of $\phi_c F_{cr} =$ **34.45 Ksi is obtained** therefore, the design axial compressive strength is

$$\phi_c P_n = \phi_c F_{cr} A_g = \mathbf{(34.45)\ (10.4) = 355.3\ Kips}$$

Table 4-22 (continued)
Available Critical Stress for Compression Members

$F_y = 35$ ksi			$F_y = 36$ ksi			$F_y = 42$ ksi			$F_y = 46$ ksi			$F_y = 50$ ksi		
$\frac{KL}{r}$	F_{cr}/Ω_c	$\phi_c F_{cr}$	$\frac{KL}{r}$	F_{cr}/Ω_c	$\phi_c F_{cr}$	$\frac{KL}{r}$	F_{cr}/Ω_c	$\phi_c F_{cr}$	$\frac{KL}{r}$	F_{cr}/Ω_c	$\phi_c F_{cr}$	$\frac{KL}{r}$	F_{cr}/Ω_c	$\phi_c F_{cr}$
	ksi	ksi		ksi	ksi		ksi	ksi		ksi	ksi		ksi	ksi
	ASD	LRFD		ASD	LRFD		ASD	LRFD		ASD	LRFD		ASD	LRFD
41	19.2	28.9	41	19.7	29.7	41	22.7	34.1	41	24.6	37.0	41	26.5	39.8
42	19.2	28.8	42	19.6	29.5	42	22.6	33.9	42	24.5	36.8	42	26.3	39.5
43	19.1	28.7	43	19.6	29.4	43	22.5	33.7	43	24.3	36.6	43	26.2	39.3
44	19.0	28.5	44	19.5	29.3	44	22.3	33.6	44	24.2	36.3	44	26.0	39.1
45	18.9	28.4	45	19.4	29.1	45	22.2	33.4	45	24.0	36.1	45	25.8	38.8
46	18.8	28.3	46	19.3	29.0	46	22.1	33.2	46	23.9	35.9	46	25.6	38.5
47	18.7	28.1	47	19.2	28.9	47	22.0	33.0	47	23.8	35.7	47	25.5	38.3
48	18.6	28.0	48	19.1	28.7	48	21.8	32.8	48	23.6	35.4	48	25.3	38.0
49	18.5	27.9	49	19.0	28.5	49	21.7	32.6	49	23.4	35.2	49	25.1	37.7
50	18.4	27.7	50	18.9	28.4	50	21.6	32.4	50	23.3	35.0	50	24.9	37.5
51	18.3	27.6	51	18.8	28.3	51	21.4	32.2	51	23.1	34.8	51	24.8	37.2
52	18.3	27.4	52	18.7	28.1	52	21.3	32.0	52	23.0	34.5	52	24.6	36.9
53	18.2	27.3	53	18.6	28.0	53	21.2	31.8	53	22.8	34.3	53	24.4	36.7

52.26 34.45

Method 3: AISCM Available Strength in Axial Compression Tables (*AISCM* Tables 4-1 through 4-12)

HSS sections (Table 4-4)

Alternatively, the design strength could be obtained directly from the *AISCM* column load capacity tables (Table 4-4), but these are only listed for F_y=46 Ksi Enter the table with $KL =$ 13.5 ft. and interpolate to obtain $\phi_c P_n =$ **358 Kips** for F_y=46 Ksi

Table 4-4 (continued)
Available Strength in Axial Compression, kips

HSS9-HSS8

F_y = 46 ksi

Square HSS

Shape		HSS9×9×				HSS8×8×							
		$^3/_{16}{}^c$		$^1/_8{}^c$		$^5/_8$		$^1/_2$		$^3/_8$		$^5/_{16}$	
t_{design}, in.		0.174		0.116		0.581		0.465		0.349		0.291	
lb/ft		22.2		15.0		59.3		48.9		37.7		31.8	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
dius of gyration, r_y	0	134	201	64.4	96.8	452	679	372	559	286	431	241	363
	6	132	198	63.8	95.9	434	653	358	538	276	415	233	350
	7	131	197	63.6	95.6	428	644	353	531	273	410	230	346
	8	130	196	63.4	95.2	421	633	348	523	269	404	226	340
	9	130	195	63.1	94.8	414	622	342	513	264	397	223	335
	10	129	193	62.8	94.4	405	609	335	503	259	389	219	329
	11	128	192	62.4	93.9	396	596	328	492	254	381	214	322
	12	126	190	62.1	93.3	386	581	320	481	248	372	209	315
	13	125	188	61.7	92.7	376	565	311	468	242	363	204	307
	14	124	186	61.2	92.0	365	549	303	455	235	353	199	299
	15	122	184	60.7	91.3	354	532	294	441	228	343	193	290

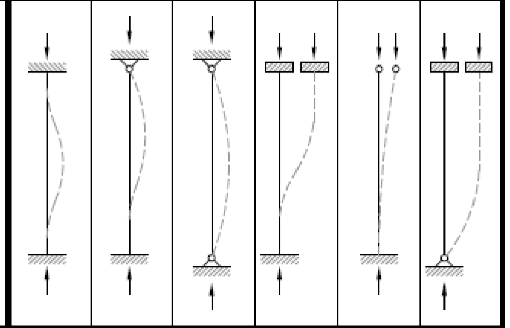
DESIGN PROCEDURES FOR COMPRESSION MEMBERS

a) calculate the factored axial load on the column, P_u.

b) Obtain the recommended effective length factor, K, from and calculate the effective length, $L_c = KL$, for buckling about each axis.

c) Enter the column load capacity tables (i.e., *AISCM*, Tables 4-1 through 4-12) with $L_c = KL$ which is the larger of $\dfrac{K_x L_x}{\left(\dfrac{r_x}{r_y}\right)}$ and $K_y L_y$, and find the *lightest* column section that has a design strength, $\phi_c P_n \geq$ the factored load, P_u for the LRFD method

Buckling modes (a)–(f):



	(a)	(b)	(c)	(d)	(e)	(f)
Theoretical K value	0.50	0.70	1.0	1.0	2.0	2.0
Recommended design K when ideal conditions are approximated	0.65	0.80	1.0	1.2	2.1	2.4

End condition legend:
- Rotation fixed, translation fixed
- Rotation free, translation fixed
- Rotation fixed, translation free
- Rotation free, translation free

FIGURE 5-4 Effective length factors, *K*, for idealized support conditions

EXAMPLE

Using LRFD Method, select a W14 column of ASTM A992, Grade 50 steel, 14 ft. long, pinned at both ends, and subjected to the following service loads:

$$P_D = 160 \text{ kips}$$
$$P_L = 330 \text{ kips}$$

Solution

- A992, Grade 50 steel: $F_y = 50$ ksi **AISCM Table (2-4)**
- Pinned at both ends, $K = 1.0$
- $L = 14$ ft.; $L_c = KL = (1.0)(14) = 14$ ft.

The factored load, $P_u = 1.2P_D + 1.6P_L = 1.2(160) + 1.6(330) = 720$ kips.

From the column load capacity tables in part 4 of the *AISCM*, find the W14 tables for $F_y = 50$ ksi (i.e., *AISCM* Table 4-1a).

Enter these tables with $L_c = KL = 14$ ft. and find the lightest W14 that has a design compression strength, $\phi P_n \geq P_u$.

We obtain a **W14 × 82** with an axial compression strength, $\phi_c P_n = 774$ kips $> P_u = 720$ kips.

(*Note:* $\phi_c P_n = 701$ kips for W14 × 74, so the W14 × 74 column size is not adequate.)

EXAMPLE

Select a W12 column of an ASTM A992, Grade 50 steel column to resist a factored compression load, $P_u = 780$ kips. The unbraced lengths are $L_x = 25$ ft. and $L_y = 12.5$ ft. and the column is pinned at each end.

Solution

1. $P_u = 780$ kip

2. $L_{cx} = K_x L_x = (1.0)(25 \text{ ft.}) = 25$ ft. (strong axis)

$L_{cy} = K_y L_y = (1.0)(12.5 \text{ ft.}) = 12.5$ ft. (weak axis)

3. Initially, assume that the *weak* axis governs, that is, $L_c = KL = K_y L_y$. Enter the column load capacity table (*AISCM* Table 4-1) with $L_c = KL = K_y L_y = 12.5$ ft.

Select W12X72 $\phi_c P_n =$ 794.5 Kips (**see the next slide -red color circles**)

4. W12X72, the radius of gyration about x-axes are:

r_x=5.31 in., r_y=5.31 in. , and

r_x/r_y=1.75 (from AISCM Table 4-1);

thus, the effective length for buckling about the x- and

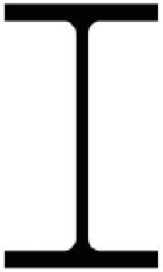
y-axes, respectively, are:

$$\frac{K_x L_x}{\left(\frac{r_x}{r_y}\right)} = \frac{25 \text{ ft.}}{1.75} = 14.3 \text{ ft.} \quad \text{(the larger value controls)}$$

$$K_y L_y = 12.5 \text{ ft.}$$

F_y = 50 ksi

Table 4-1 (continued)
Available Strength in Axial Compression, kips
W-Shapes



W12

Shape		W12×									
lb/ft		96		87		79		72		65	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
o least radius of gyration, r_y	0	844	1270	766	1150	695	1040	632	949	572	859
	6	811	1220	736	1110	667	1000	606	911	549	825
	7	800	1200	726	1090	657	988	597	898	540	812
	8	787	1180	714	1070	646	971	587	883	531	798
	9	772	1160	700	1050	634	953	576	866	521	783
	10	756	1140	685	1030	620	932	564	847	510	766
	11	739	1110	670	1010	606	910	550	827	497	747
12.5 ft	12	720	1080	653	981	590	887	536	806	484	728
	13	701	1050	635	954	574	862	521	783	470	707
14.3 ft	14	680	1020	616	925	556	836	505	759	456	685
	15	659	990	596	896	538	809	489	735	441	663

Therefore, the original assumption in step 3—that the weak axis (i.e., y-axis) controls—was incorrect; the strong axis (i.e., the x-axis) actually controls.

5. Enter the W12X72 column load capacity tables (*AISCM* Table 4-1a) with $\frac{K_x L_x}{\left(\frac{r_x}{r_y}\right)} = 14.3$ ft. and we obtain the following allowable compression loads for the unbraced lengths of 14 ft and 15 ft, from which the allowable compression load for the unbraced length of 14.3 ft. can be obtained by linear interpolation:

$L_c = KL$ (ft.)	$\phi_c P_n$, (kips)
14.0	759
14.3	752
15.0	735

See the previous slide (blue color circles)

For W12 X 72, $\phi_c P_n$ = **752 Kips <** $P_u = 780$ kips **NOT OKAY**

Select another section heavier than W12X72

Select W12X79

For W12 × 79, the radius of gyration about the *x*- and *y*-axes are

$r_x = 5.34$ in.,

$r_y = 3.05$ in., and

$r_x / r_y = 1.75$ (from *AISCM* Table 4-1);

thus, the effective length for buckling about the *x*- and *y*-axes, respectively, are

$$\frac{K_x L_x}{\left(\frac{r_x}{r_y}\right)} = \frac{25 \text{ ft.}}{1.75} = 14.3 \text{ ft.} \quad \text{(the larger value controls)}$$

$$K_y L_y = 12.5 \text{ ft.}$$

Enter the W12 × 79 column load capacity tables (*AISCM* Table 4-1a) with

$$\frac{K_x L_x}{\left(\frac{r_x}{r_y}\right)} = 14.3 \text{ ft.}$$

and we obtain the following allowable compression loads for the unbraced lengths of 14 ft and 15 ft, from which the allowable compression load for the unbraced length of 14.3 ft. can be obtained by linear interpolation:

$L_c = KL$ (ft.)	$\phi_c P_n$, (kips)
14.0	836
14.3	**827**
15.0	809

See next slide

For W12 × 79, $\phi_c P_n = 827$ kips $> P_u = 780$ kips OK.
Use a W12 × 79 column.

F_y = 50 ksi

Table 4-1 (continued)
Available Strength in Axial Compression, kips
W-Shapes

W12

Shape		W12×									
lb/ft		96		87		79		72		65	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
o least radius of gyration, r_y	0	844	1270	766	1150	695	1040	632	949	572	859
	6	811	1220	736	1110	667	1000	606	911	549	825
	7	800	1200	726	1090	657	988	597	898	540	812
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	10	756	1140	685	1030	620	932	564	847	510	766
	11	739	1110	670	1010	606	910	550	827	497	747
	12	720	1080	653	981	590	887	536	806	484	728
	13	701	1050	635	954	574	862	521	783	470	707
	14	680	1020	616	925	556	836	505	759	456	685
	15	659	990	596	896	538	809	489	735	441	663

14.3 ft