Chapter 16

STRUCTURAL MATERIALS

1 Proper understanding of structural materials is essential to both structural analysis and to structural design.

2 Characteristics of the most commonly used structural materials will be highlighted.

16.1 Steel

16.1.1 Structural Steel

3 Steel is an **alloy** of iron and carbon. Its properties can be greatly varied by altering the carbon content (always less than 0.5%) or by adding other elements such as silicon, nickel, manganese and copper.

4 Practically all grades of steel have a Young Modulus equal to **29,000 ksi**, density of 490 lb/cu ft, and a coefficient of thermal expansion equal to 0.65×10^{-5} /deg F.

5 The yield stress of steel can vary from 40 ksi to 250 ksi. Most commonly used structural steel are **A36** ($\sigma_{\rm yld} = 36$ ksi) and A572 ($\sigma_{\rm yld} = 50$ ksi), Fig. 16.6

6 Structural steel can be rolled into a wide variety of shapes and sizes. Usually the most desirable members are those which have a large section moduli (S) in proportion to their area (A), Fig. 16.2.

7 Steel can be bolted, riveted or welded.

8 Sections are designated by the shape of their cross section, their depth and their weight. For example W 27× 114 is a W section, 27 in. deep weighing 114 lb/ft.

9 Common sections are:

S sections were the first ones rolled in America and have a slope on their inside flange surfaces of 1 to 6.

W or wide flange sections have a much smaller inner slope which facilitates connections and rivetting. W sections constitute about 50% of the tonnage of rolled structural steel.

C are channel sections

MC Miscellaneous channel which can not be classified as a C shape by dimensions.

HP is a bearing pile section.

M is a miscellaneous section.

L are angle sections which may have equal or unequal sides.

WT is a T section cut from a W section in two.

Properties of structural steel are tabulated in Table 16.1.

ASTM Desig.	**Shapes Available**	**Use**	σ_y **(ksi)**	σ_u **(ksi)**
A36	Shapes and bars	Riveted, bolted, welded; Buildings and bridges	36 up through 8 in. (32 above 8.)	
A500	Cold formed welded and seamless sections;	General structural purpose Riveted, welded or bolted;	Grade A: 33; Grade B: 42; Grade C: 46	
A501	Hot formed welded and seamless sections;	Bolted and welded	36	
A529	Plates and bars $\frac{1}{2}$ in and less thick;	Building frames and trusses; Bolted and welded	42	
A606	Hot and cold rolled sheets;	Atmospheric corrosion resistant	45-50	
A611	Cold rolled sheet in cut lengths	Cold formed sections	Grade C 33; Grade D 40; Grade E 80	
A 709	Structural shapes, plates and bars	Bridges	Grade 36: 36 (to 4 in.); Grade 50: 50; Grade 100: 100 (to 2.5in.) and 90 (over 2.5 to 4 in.)	

Table 16.1: Properties of Major Structural Steels

10 Rolled sections, Fig. 16.3 and welded ones, Fig 16.4 have **residual stresses**. Those originate during the rolling or fabrication of a member. The member is hot just after rolling or welding, it cools unevenly because of varying exposure. The area that cool first become stiffer, resist contraction, and develop compressive stresses. The remaining regions continue to cool and contract in the plastic condition and develop tensile stresses.

11 Due to those residual stresses, the stress-strain curve of a rolled section exhibits a non-linear segment prior to the theoretical yielding, Fig. 16.5. This would have important implications on the flexural and axial strength of beams and columns.

16.1.2 Reinforcing Steel

12 Steel is also used as reinforcing bars in concrete, Table 16.2. Those bars have a deformation on their surface to increase the bond with concrete, and usually have a yield stress of 60 ksi[1].

[1]Stirrups which are used as vertical reinforcement to resist shear usually have a yield stress of only 40 ksi.

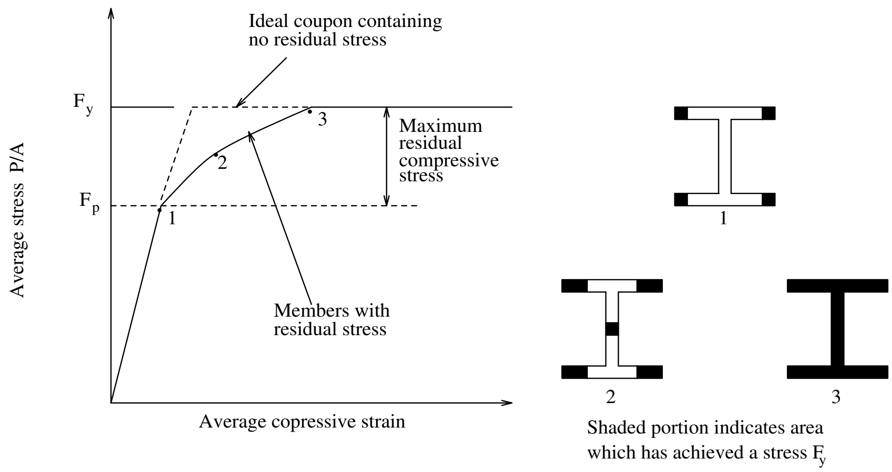


Figure 16.5: Influence of Residual Stress on Average Stress-Strain Curve of a Rolled Section

Bar Designation	Diameter (in.)	Area (in^2)	Perimeter in	Weight lb/ft
No. 2	2/8=0.250	0.05	0.79	0.167
No. 3	3/8=0.375	0.11	1.18	0.376
No. 4	4/8=0.500	0.20	1.57	0.668
No. 5	5/8=0.625	0.31	1.96	1.043
No. 6	6/8=0.750	0.44	2.36	1.5202
No. 7	7/8=0.875	0.60	2.75	2.044
No. 8	8/8=1.000	0.79	3.14	2.670
No. 9	9/8=1.128	1.00	3.54	3.400
No. 10	10/8=1.270	1.27	3.99	4.303
No. 11	11/8=1.410	1.56	4.43	5.313
No. 14	14/8=1.693	2.25	5.32	7.650
No. 18	18/8=2.257	4.00	7.09	13.60

Table 16.2: Properties of Reinforcing Bars

or

$$E = 33\gamma^{1.5}\sqrt{f'_c} \tag{16.2}$$

where both f'_c and E are in psi and γ is in lbs/ft^3.

24 Typical concrete (compressive) strengths range from 3,000 to 6,000 psi; However **high strength concrete** can go up to 14,000 psi.

25 All concrete fail at an ultimate strain of 0.003, Fig. 16.6.

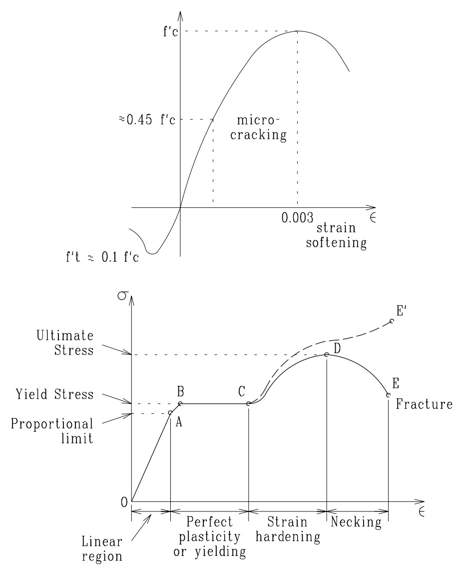


Figure 16.6: Concrete Stress-Strain curve

26 Pre-peak nonlinearity is caused by micro-cracking Fig. 16.7.

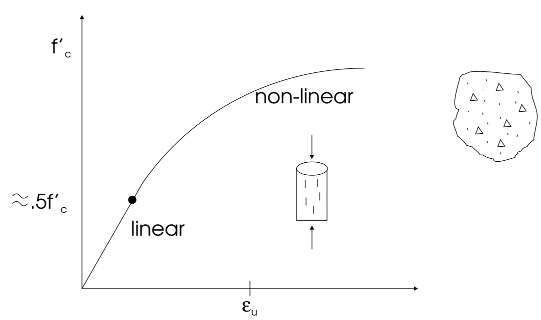


Figure 16.7: Concrete microcracking

27 The tensile strength of concrete f'_t is about 10% of the compressive strength.

28 Density of normal weight concrete is 145 lbs/ft^3 and 100 lbs/ft^3 for lightweight concrete.

Designation	A	d	t_w	b_f	t_f	$\frac{b_f}{2t_f}$	$\frac{h_c}{t_w}$	I_x	S_x	r_x	I_y	S_y	r_y	Z_x	Z_y	J
	in^2	in	in	in	in			in^4	in^3	in	in^4	in^3	in	in^3	in^3	in^4
WT 8.x 50.	14.7	8.48	0.585	10.425	0.985	0	12.1	76.8	11.4	2.28	93.10	17.90	2.51	20.70	27.40	3.85
WT 8.x 45.	13.1	8.38	0.525	10.365	0.875	0	13.5	67.2	10.1	2.27	81.30	15.70	2.49	18.10	24.00	2.72
WT 8.x 39.	11.3	8.26	0.455	10.295	0.760	0	15.6	56.9	8.6	2.24	69.20	13.40	2.47	15.30	20.50	1.78
WT 8.x 34.	9.8	8.16	0.395	10.235	0.665	0	18.0	48.6	7.4	2.22	59.50	11.60	2.46	13.00	17.70	1.19
WT 8.x 29.	8.4	8.22	0.430	7.120	0.715	0	16.5	48.7	7.8	2.41	21.60	6.06	1.60	13.80	9.43	1.10
WT 8.x 25.	7.4	8.13	0.380	7.070	0.630	0	18.7	42.3	6.8	2.40	18.60	5.26	1.59	12.00	8.16	0.76
WT 8.x 23.	6.6	8.06	0.345	7.035	0.565	0	20.6	37.8	6.1	2.39	16.40	4.67	1.57	10.80	7.23	0.65
WT 8.x 20.	5.9	8.01	0.305	6.995	0.505	0	23.3	33.1	5.3	2.37	14.40	4.12	1.57	9.43	6.37	0.40
WT 8.x 18.	5.3	7.93	0.295	6.985	0.430	0	24.1	30.6	5.1	2.41	12.20	3.50	1.52	8.93	5.42	0.27
WT 8.x 16.	4.6	7.94	0.275	5.525	0.440	0	25.8	27.4	4.6	2.45	6.20	2.24	1.17	8.27	3.52	0.23
WT 8.x 13.	3.8	7.84	0.250	5.500	0.345	0	28.4	23.5	4.1	2.47	4.80	1.74	1.12	8.12	2.74	0.13
WT 7.x365.	107.0	11.21	3.070	17.890	4.910	0	1.9	739.0	95.4	2.62	2360.00	264.00	4.69	211.00	408.00	714.00
WT 7.x333.	97.8	10.82	2.830	17.650	4.520	0	2.0	622.0	82.1	2.52	2080.00	236.00	4.62	182.00	365.00	555.00
WT 7.x303.	88.9	10.46	2.595	17.415	4.160	0	2.2	524.0	70.6	2.43	1840.00	211.00	4.55	157.00	326.00	430.00
WT 7.x275.	80.9	10.12	2.380	17.200	3.820	0	2.4	442.0	60.9	2.34	1630.00	189.00	4.49	136.00	292.00	331.00
WT 7.x250.	73.5	9.80	2.190	17.010	3.500	0	2.6	375.0	52.7	2.26	1440.00	169.00	4.43	117.00	261.00	255.00
WT 7.x228.	66.9	9.51	2.015	16.835	3.210	0	2.8	321.0	45.9	2.19	1280.00	152.00	4.38	102.00	234.00	196.00
WT 7.x213.	62.6	9.34	1.875	16.695	3.035	0	3.0	287.0	41.4	2.14	1180.00	141.00	4.34	91.70	217.00	164.00
WT 7.x199.	58.5	9.15	1.770	16.590	2.845	0	3.2	257.0	37.6	2.10	1090.00	131.00	4.31	82.90	201.00	135.00
WT 7.x185.	54.4	8.96	1.655	16.475	2.660	0	3.4	229.0	33.9	2.05	994.00	121.00	4.27	74.40	185.00	110.00
WT 7.x171.	50.3	8.77	1.540	16.360	2.470	0	3.7	203.0	30.4	2.01	903.00	110.00	4.24	66.20	169.00	88.30
WT 7.x156.	45.7	8.56	1.410	16.230	2.260	0	4.0	176.0	26.7	1.96	807.00	99.40	4.20	57.70	152.00	67.50
WT 7.x142.	41.6	8.37	1.290	16.110	2.070	0	4.4	153.0	23.5	1.92	722.00	89.70	4.17	50.40	137.00	51.80
WT 7.x129.	37.8	8.19	1.175	15.995	1.890	0	4.9	133.0	20.7	1.88	645.00	80.70	4.13	43.90	123.00	39.30
WT 7.x117.	34.2	8.02	1.070	15.890	1.720	0	5.3	116.0	18.2	1.84	576.00	72.50	4.10	38.20	110.00	29.60
WT 7.x106.	31.0	7.86	0.980	15.800	1.560	0	5.8	102.0	16.2	1.81	513.00	65.00	4.07	33.40	99.00	22.20
WT 7.x 97.	28.4	7.74	0.890	15.710	1.440	0	6.4	89.8	14.4	1.78	466.00	59.30	4.05	29.40	90.20	17.30
WT 7.x 88.	25.9	7.61	0.830	15.650	1.310	0	6.9	80.5	13.0	1.76	419.00	53.50	4.02	26.30	81.40	13.20
WT 7.x 80.	23.4	7.49	0.745	15.565	1.190	0	7.7	70.2	11.4	1.73	374.00	48.10	4.00	22.80	73.00	9.84
WT 7.x 73.	21.3	7.39	0.680	15.500	1.090	0	8.4	62.5	10.2	1.71	338.00	43.70	3.98	20.20	66.30	7.56
WT 7.x 66.	19.4	7.33	0.645	14.725	1.030	0	8.8	57.8	9.6	1.73	274.00	37.20	3.76	18.60	56.60	6.13
WT 7.x 60.	17.7	7.24	0.590	14.670	0.940	0	9.7	51.7	8.6	1.71	247.00	33.70	3.74	16.50	51.20	4.67
WT 7.x 55.	16.0	7.16	0.525	14.605	0.860	0	10.9	45.3	7.6	1.68	223.00	30.60	3.73	14.40	46.40	3.55
WT 7.x 50.	14.6	7.08	0.485	14.565	0.780	0	11.8	40.9	6.9	1.67	201.00	27.60	3.71	12.90	41.80	2.68
WT 7.x 45.	13.2	7.01	0.440	14.520	0.710	0	13.0	36.4	6.2	1.66	181.00	25.00	3.70	11.50	37.80	2.03
WT 7.x 41.	12.0	7.16	0.510	10.130	0.855	0	11.2	41.2	7.1	1.85	74.20	14.60	2.48	13.20	22.40	2.53
WT 7.x 37.	10.9	7.09	0.450	10.070	0.785	0	12.7	36.0	6.3	1.82	66.90	13.30	2.48	11.50	20.30	1.94
WT 7.x 34.	10.0	7.02	0.415	10.035	0.720	0	13.7	32.6	5.7	1.81	60.70	12.10	2.46	10.40	18.50	1.51
WT 7.x 31.	9.0	6.95	0.375	9.995	0.645	0	15.2	28.9	5.1	1.80	53.70	10.70	2.45	9.16	16.40	1.10
WT 7.x 27.	7.8	6.96	0.370	8.060	0.660	0	15.4	27.6	4.9	1.88	28.80	7.16	1.92	8.87	11.00	0.97
WT 7.x 24.	7.1	6.89	0.340	8.030	0.595	0	16.8	24.9	4.5	1.87	25.70	6.40	1.91	8.00	9.82	0.73
WT 7.x 22.	6.3	6.83	0.305	7.995	0.530	0	18.7	21.9	4.0	1.86	22.60	5.65	1.89	7.05	8.66	0.52
WT 7.x 19.	5.6	7.05	0.310	6.770	0.515	0	19.8	23.3	4.2	2.04	13.30	3.94	1.55	7.45	6.07	0.40
WT 7.x 17.	5.0	6.99	0.285	6.745	0.455	0	21.5	20.9	3.8	2.04	11.70	3.45	1.53	6.74	5.32	0.28
WT 7.x 15.	4.4	6.92	0.270	6.730	0.385	0	22.7	19.0	3.5	2.07	9.79	2.91	1.49	6.25	4.49	0.19
WT 7.x 13.	3.8	6.95	0.255	5.025	0.420	0	24.1	17.3	3.3	2.12	4.45	1.77	1.08	5.89	2.77	0.18
WT 7.x 11.	3.3	6.87	0.230	5.000	0.335	0	26.7	14.8	2.9	2.14	3.50	1.40	1.04	5.20	2.19	0.10
WT 6.x168.	49.4	8.41	1.775	13.385	2.955	0	2.7	190.0	31.2	1.96	593.00	88.60	3.47	68.40	137.00	120.00
WT 6.x153.	44.8	8.16	1.625	13.235	2.705	0	3.0	162.0	27.0	1.90	525.00	79.30	3.42	59.10	122.00	92.00
WT 6.x140.	41.0	7.93	1.530	13.140	2.470	0	3.2	141.0	24.1	1.86	469.00	71.30	3.38	51.90	110.00	70.90
WT 6.x126.	37.0	7.70	1.395	13.005	2.250	0	3.5	121.0	20.9	1.81	414.00	63.60	3.34	44.80	97.90	53.50
WT 6.x115.	33.9	7.53	1.285	12.895	2.070	0	3.8	106.0	18.5	1.77	371.00	57.50	3.31	39.40	88.40	41.60
WT 6.x105.	30.9	7.36	1.180	12.790	1.900	0	4.1	92.1	16.4	1.73	332.00	51.90	3.28	34.50	79.70	32.20
WT 6.x 95.	27.9	7.19	1.060	12.670	1.735	0	4.6	79.0	14.2	1.68	295.00	46.50	3.25	29.80	71.30	24.40
WT 6.x 85.	25.0	7.01	0.960	12.570	1.560	0	5.1	67.8	12.3	1.65	259.00	41.20	3.22	25.60	63.00	17.70
WT 6.x 76.	22.4	6.86	0.870	12.480	1.400	0	5.6	58.5	10.8	1.62	227.00	36.40	3.19	22.00	55.60	12.80
WT 6.x 68.	20.0	6.70	0.790	12.400	1.250	0	6.1	50.6	9.5	1.59	199.00	32.10	3.16	19.00	49.00	9.22
WT 6.x 60.	17.6	6.56	0.710	12.320	1.105	0	6.8	43.4	8.2	1.57	172.00	28.00	3.13	16.20	42.70	6.43
WT 6.x 53.	15.6	6.45	0.610	12.220	0.990	0	8.0	36.3	6.9	1.53	151.00	24.70	3.11	13.60	37.50	4.55
WT 6.x 48.	14.1	6.36	0.550	12.160	0.900	0	8.8	32.0	6.1	1.51	135.00	22.20	3.09	11.90	33.70	3.42
WT 6.x 44.	12.8	6.26	0.515	12.125	0.810	0	9.4	28.9	5.6	1.50	120.00	19.90	3.07	10.70	30.20	2.54
WT 6.x 40.	11.6	6.19	0.470	12.080	0.735	0	10.3	25.8	5.0	1.49	108.00	17.90	3.05	9.49	27.20	1.92
WT 6.x 36.	10.6	6.13	0.430	12.040	0.670	0	11.3	23.2	4.5	1.48	97.50	16.20	3.04	8.48	24.60	1.46
WT 6.x 33.	9.5	6.06	0.390	12.000	0.605	0	12.4	20.6	4.1	1.47	87.20	14.50	3.02	7.50	22.00	1.09
WT 6.x 29.	8.5	6.09	0.360	10.010	0.640	0	13.5	19.1	3.8	1.50	53.50	10.70	2.51	6.97	16.30	1.05
WT 6.x 27.	7.8	6.03	0.345	9.995	0.575	0	14.1	17.7	3.5	1.51	47.90	9.58	2.48	6.46	14.60	0.79
WT 6.x 25.	7.3	6.09	0.370	8.080	0.640	0	13.1	18.7	3.8	1.60	28.20	6.97	1.96	6.90	10.70	0.89
WT 6.x 23.	6.6	6.03	0.335	8.045	0.575	0	14.5	16.6	3.4	1.58	25.00	6.21	1.94	6.12	9.50	0.66
WT 6.x 20.	5.9	5.97	0.295	8.005	0.515	0	16.5	14.4	3.0	1.57	22.00	5.51	1.93	5.30	8.41	0.48
WT 6.x 18.	5.2	6.25	0.300	6.560	0.520	0	18.1	16.0	3.2	1.76	12.20	3.73	1.54	5.71	5.73	0.37
WT 6.x 15.	4.4	6.17	0.260	6.520	0.440	0	20.9	13.5	2.8	1.75	10.20	3.12	1.52	4.83	4.78	0.23
WT 6.x 13.	3.8	6.11	0.230	6.490	0.380	0	23.6	11.7	2.4	1.75	8.66	2.67	1.51	4.20	4.08	0.15
WT 6.x 11.	3.2	6.16	0.260	4.030	0.425	0	20.9	11.7	2.6	1.90	2.33	1.16	0.85	4.63	1.83	0.15
WT 6.x 10.	2.8	6.08	0.235	4.005	0.350	0	23.1	10.1	2.3	1.90	1.88	0.94	0.82	4.11	1.49	0.09
WT 6.x 8.	2.4	5.99	0.220	3.990	0.265	0	24.7	8.7	2.0	1.92	1.41	0.71	0.77	3.72	1.13	0.05
WT 6.x 7.	2.1	5.95	0.200	3.970	0.225	0	27.2	7.7	1.8	1.92	1.18	0.59	0.75	3.32	0.95	0.04
WT 5.x 56.	16.5	5.68	0.755	10.415	1.250	0	5.2	28.6	6.4	1.32	118.00	22.60	2.68	13.40	34.60	7.50
WT 5.x 50.	14.7	5.55	0.680	10.340	1.120	0	5.8	24.5	5.6	1.29	103.00	20.00	2.65	11.40	30.50	5.41
WT 5.x 44.	12.9	5.42	0.605	10.265	0.990	0	6.5	20.8	4.8	1.27	89.30	17.40	2.63	9.65	26.50	3.75
WT 5.x 39.	11.3	5.30	0.530	10.190	0.870	0	7.4	17.4	4.0	1.24	76.80	15.10	2.60	8.06	22.90	2.55
WT 5.x 34.	10.0	5.20	0.470	10.130	0.770	0	8.4	14.9	3.5	1.22	66.80	13.20	2.59	6.85	20.00	1.78
WT 5.x 30.	8.8	5.11	0.420	10.080	0.680	0	9.4	12.9	3.0	1.21	58.10	11.50	2.57	5.87	17.50	1.23
WT 5.x 27.	7.9	5.05	0.370	10.030	0.615	0	10.6	11.1	2.6	1.19	51.70	10.30	2.56	5.05	15.70	0.91
WT 5.x 25.	7.2	4.99	0.340	10.000	0.560	0	11.6	10.0	2.4	1.18	46.70	9.34	2.54	4.52	14.20	0.69
WT 5.x 23.	6.6	5.05	0.350	8.020	0.620	0	11.2	10.2	2.5	1.24	26.70	6.65	2.01	4.65	10.10	0.75
WT 5.x 20.	5.7	4.96	0.315	7.985	0.530	0	12.5	8.8	2.2	1.24	22.50	5.64	1.98	3.99	8.59	0.49
WT 5.x 17.	4.8	4.86	0.290	7.960	0.435	0	13.6	7.7	1.9	1.26	18.30	4.60	1.94	3.48	7.01	0.29
WT 5.x 15.	4.4	5.24	0.300	5.810	0.510	0	14.8	9.3	2.2	1.45	8.35	2.87	1.37	4.01	4.42	0.31
WT 5.x 13.	3.8	5.16	0.260	5.770	0.440	0	17.0	7.9	1.9	1.44	7.05	2.44	1.36	3.39	3.75	0.20
WT 5.x 11.	3.2	5.09	0.240	5.750	0.360	0	18.4	6.9	1.7	1.46	5.71	1.99	1.33	3.02	3.05	0.12
WT 5.x 10.	2.8	5.12	0.250	4.020	0.395	0	17.7	6.7	1.7	1.54	2.15	1.07	0.87	3.10	1.68	0.12
WT 5.x 9.	2.5	5.05	0.240	4.010	0.330	0	18.4	6.1	1.6	1.56	1.78	0.89	0.84	2.90	1.40	0.08
WT 5.x 8.	2.2	4.99	0.230	4.000	0.270	0	19.2	5.4	1.5	1.57	1.45	0.72	0.81	3.03	1.15	0.05
WT 5.x 6.	1.8	4.93	0.190	3.960	0.210	0	23.3	4.3	1.2	1.57	1.09	[illegible]	0.79	2.50	0.87	0.03

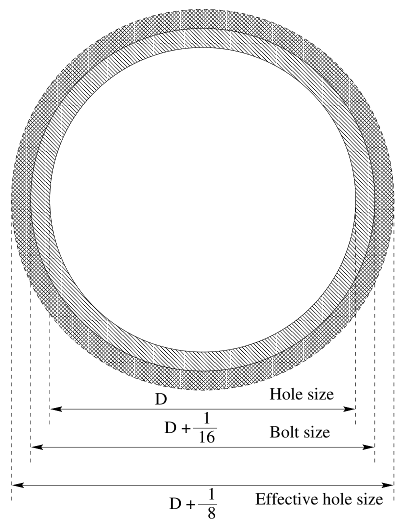


Figure 17.2: Hole Sizes

17 Accordingly, for a plate of width w and thickness t, and with a single hole which accomodates a bolt of diameter D, the net area would be

$$\boxed{A_n = wt - \left(D + \frac{1}{8}\right) t} \tag{17.2}$$

18 Whenever there is a need for more than two rivets or bolts, the holes are not aligned but rather **staggered**. Thus there is more than one potential failure line which can be used to determine the net area.

19 For staggered holes, we define the net are in terms of, Fig. 17.3,

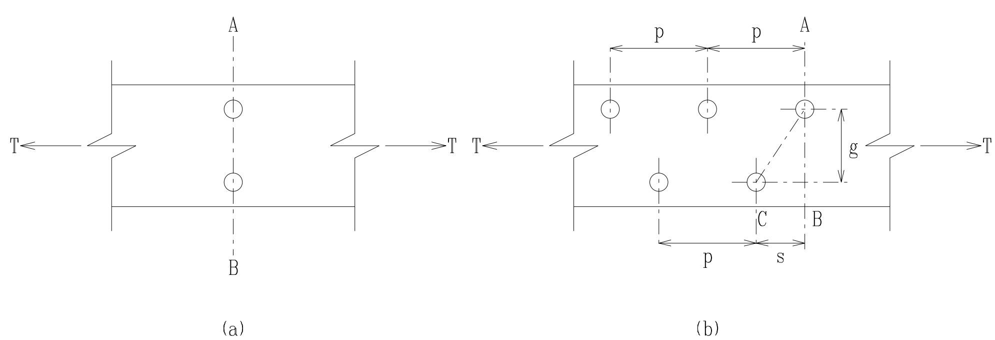
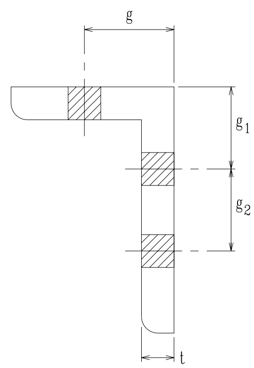


Figure 17.3: Effect of Staggered Holes on Net Area

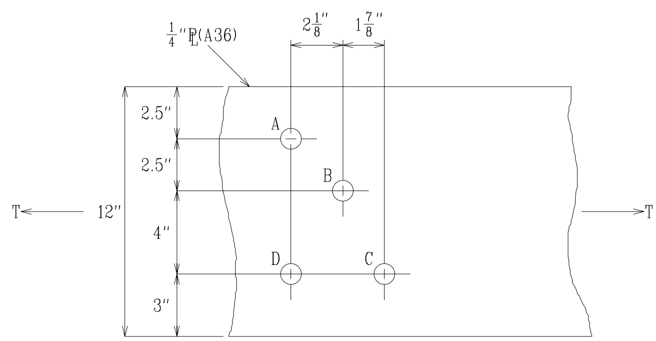
pitch s, longitudinal center to center spacing between two consecutive holes.

gage g, transverse center to center spacing between two adjacent holes.



Leg	8	7	6	5	4	$3\frac{1}{2}$	3	$2\frac{1}{2}$	2	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	1
g	$4\frac{1}{2}$	4	$3\frac{1}{2}$	3	$2\frac{1}{2}$	2	$1\frac{3}{4}$	$1\frac{3}{8}$	$1\frac{1}{8}$	1	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$
g_1	3	$2\frac{1}{2}$	$2\frac{1}{4}$	2										
g_2	3	3	$2\frac{1}{2}$	$1\frac{3}{4}$										

Table 17.1: Usual Gage Lengths g, g_1, g_2



Solution:
We consider various paths:

$$A-D: \quad \left[12 - 2\left(\frac{15}{16} + \frac{1}{16}\right)\right](0.25) = 2.50 \text{ in}^2 \quad (17.5\text{-a})$$

$$A-B-D: \quad \left[12 - 3\left(\frac{15}{16} + \frac{1}{16}\right) + \frac{(2.125)^2}{4(2.5)} + \frac{(2.125)^2}{4(4)}\right](0.25) = 2.43 \text{ in}^2 \quad (17.5\text{-b})$$

$$A-B-C: \quad \left[12 - 3\left(\frac{15}{16} + \frac{1}{16}\right) + \frac{(2.125)^2}{4(2.5)} + \frac{(1.875)^2}{4(4)}\right](0.25) = \boxed{2.4 \text{ in}^2} \quad (17.5\text{-c})$$

Thus path A-B-C controls. ■

■ Example 17-2: Net Area, Angle

Determine the net area A_n for the angle shown below if $\frac{15}{16}$ in. diameter holes are used.

Type of members	Minimum Number of Fasteners/line	Special Requirements	A_e
Fastened Rolled Sections			
Members having all cross sectional elements connected to transmit tensile force	1 (or welds)		A_n
W, M, or S shapes with flange widths not less than 2/3 the depth, and structural tees cut from these shapes, provided the connection is to the flanges. Bolted or riveted connections shall have no fewer than three fasteners per line in the direction of stress	3 (or welds)	$\frac{b}{d} \geq 0.67$	$0.9A_n$
W, M, or S not meeting above conditions, structural tees cut from these shapes and all other shapes, including built-up cross-sections. Bolted or riveted connections shall have no fewer than three fasteners per line in the direction of stress	3 (or welds)		$0.85A_n$
Structural tees cut from W, M, or S connected at flanges only	3 (or welds)	$\frac{b}{d} \geq 0.67$	$0.9A_n$
All members with bolted or riveted connections having only two fasteners per line in the direction of stress	2		$0.75A_n$
Welded Plates			
	Welds	$l > 2w$	A_g
	Welds	$2w > l > 1.5w$	$0.87A_g$
	Welds	$l/w.1$	$0.75A_g$

b Flange width; d section depth; l Weld length; w Plate width;

Table 17.2: Effective Net Area A_e for Bolted and Welded Connections

where Φ_t = resistance factor relating to tensile strength
T_n = nominal strength of a tension member
T_u = factored load on a tension member

30 From Table 14.3, Φ_t is 0.75 and 0.9 for fracture and yielding failure respectively.

17.3.1 Tension Failure

31 The design strength $\Phi_t T_n$ is the smaller of that based on, Fig. 17.5

1. **Yielding in the gross section:** We can not allow yielding of the gross section, because this will result in unacceptable elongation of the entire member.

$$\boxed{\Phi_t T_n = \Phi_t F_y A_g = 0.90 F_y A_g} \tag{17.12}$$

or

2. **Fracture in the net section:** Yielding is locally allowed, because A_e is applicable only on a small portion of the element. Local excessive elongation is allowed, however fracture must be prevented. This mode of failure usually occurs if there is insufficient distance behind the pin.

$$\boxed{\Phi_t T_n = \Phi_t F_u A_e = 0.75 F_u A_e} \tag{17.13}$$

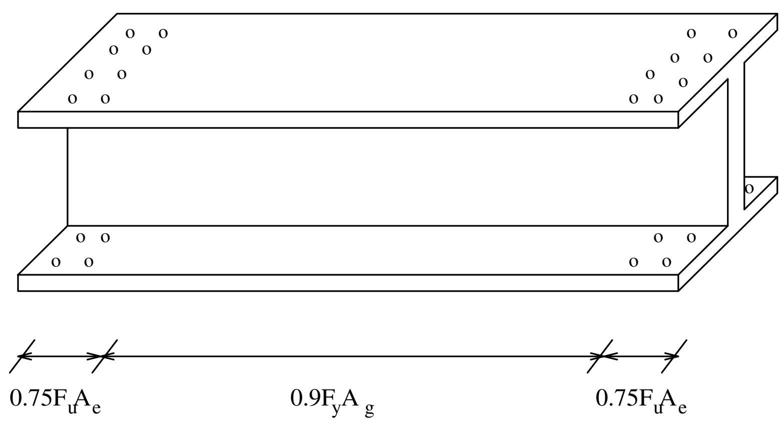


Figure 17.5: Net and Gross Areas

17.3.2 Block Shear Failure

32 For bolted connections, **tearing failure** may occur and control the strength of the tension member.

33 For instance, with reference to Fig. 17.6 the angle tension member attached to the **gusset**