CIV102 – Structures and Materials
An Introduction to Engineering Design
Course Notes

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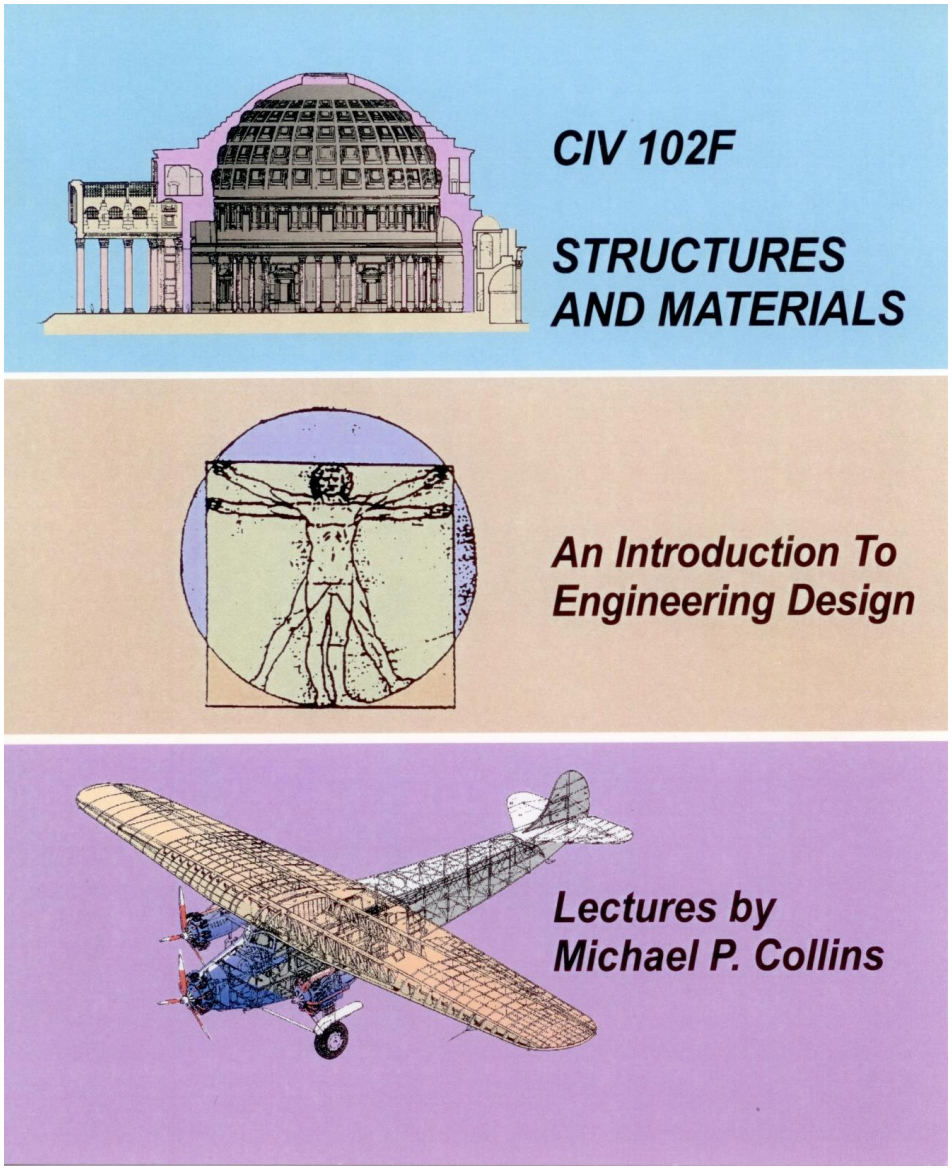

The previous cover of the course notes, used until 2020.

Test of a 4 m deep reinforced concrete slab strip at the University of Toronto in 2015. This remains the largest reinforced concrete shear test ever performed.

CIV102 Course Notes – Appendices

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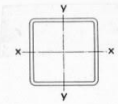
Appendices

Appendix A – Common Material Properties

Average Properties of Some Typical Materials Note that except for density, stiffness and coefficient of thermal expansion, all values have a considerable range

Material	Weight (kN/m^3)	Stiffness E (MPa)	Tensile Strength (MPa)		Compressive Strength (MPa)	Resilience (MJ/m^3)	Toughness (MJ/m^3) tens./comp.	Ductility Max. Elong. (%) Plastic/Elastic	α $10^{-6}/^oC$	Cost $/kg	Comment
			Yield	Ultimate							
Low Alloy Steel	77	200,000	420	560	420	0.44	135	25/0.21	12	0.60	Used in buildings, bridges, cars, etc.
High Tensile Steel	77	200,000	1650	1860	1650	6.8	55	4/0.83	12	1.50	Wire ropes, cables
High Alloy Steel	77	200,000	700	800	700	1.22	200	25/0.35	12	2.00	Pressure Vessels and tanks
Piano Wire	77	200,000	-	3000	-	22	22	0.2/1.50	12	1.50	Brittle material, not used in structures
Cast Iron	70	150,000	-	110	770	0.04	0.06/6	1/0.7	11	0.50	Traditional cast iron, moulded
Wrought Iron	75	185,000	200	350	200	0.11	90	30/0.11	12	1.00	99% pure iron, hammered, fibrous
Aluminum	27	69,000	40	80	60	0.012	19	40/0.06	24	1.80	Light, ductile, non-corrosive, soft metal
Aluminum Alloy	27	73,000	470	580	500	1.51	50	11/0.64	24	2.50	Used for canoes, aircraft, etc.
Copper	88	124,000	70	230	200	0.02	85	55/0.06	20	7.47	Very ductile metal – rounded curve
Bronze	79	105,000	200	390	350	0.2	40	12/0.19	17	2.80	Tin + copper alloy – stronger
Gold	189	82,000	40	220	180	0.01	80	50/0.05	14	40k	Heavy, expensive metal
Granite	26	52,000	-	11	140	0.001	0.01/0.26	0/0.02	8	0.15	Strongest and most durable building stone
Limestone	25	58,000	-	8	62	0.0006	0.01/0.09	0/0.01	6	0.03	Soft, useful building store
Slate	28	95,000	-	60	100	0.019	0.02/0.10	0/0.06		0.08	Stratified rock with high tensile strength
Brick	19	20,000	-	3	20	0.0002	0.01/0.03	0/0.01	9	0.10	Fired clay
Concrete	24	30,000	-	3	35	0.002	0.01/0.10	0/0.01	9	0.12	Mixture of cement, sand, stone, water
Glass	27	69,000	-	100	200	0.072	0.07/0.8	0/0.15	20	1.50	Solidified liquid sand
Oak	7.5	14,000	75	90	60	0.23	0.3/2.5	0.5/0.47	3	3.2	Strong, tough, heavy hardwood
Spruce	4.4	11,000	55	70	50	0.19	0.2/2.2	0.5/0.50	7	2.0	Light, strong, durable softwood
Tendon	10	900	70	80	-	2.7	4	1/7.8		-	Used as tension ties in mammals
Bone	20	17,000	150	180	180	0.66	1	0.5/0.9		-	Used as struts and beams in mammals
Rubber	9.2	7	-	20	20	15	20	4/300	500	2.0	Strange, useful material – low stiffness
Spider's Silk	10	4,000	-	1400	-	160	170	10/35		-	Most resilient material
Carbon Fibre	15	160,000	-	1800	-	10	10	0.1/1.1		50.0	Carbon fibre composites used in aircraft
Nylon Fibre	11	5,500	-	900	-	74	75	2/16	80	8.00	Excellent if stiffness not required
Kevlar Fibre	14	130,000	-	3600	-	50	60	1/2.7		50.00	Super material in many ways

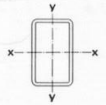
Appendix B – HSS Tables



STEEL

SQUARE Hollow Structural Sections **METRIC Dimensions and Properties**

Designation	Size	Mass	Dead Load	Area	I	S	r	Z	Torsion J	Surface Area	Shear C_{rt}
mm x mm x mm	mm x mm x mm	kg/m	kN/m	mm^2	$10^6\ mm^4$	$10^3\ mm^3$	mm	$10^3\ mm^3$	$10^3\ mm^4$	m^2/m	mm^2
HSS 305x305x13	HSS 305x305x12.7	113	1.110	14 400	202	1 330	118	1 560	324 000	1.18	6 450
x 11	x 11.1	100	0.982	12 800	181	1 190	119	1 390	288 000	1.18	5 790
x 9.5	x 9.53	86.5	0.848	11 000	158	1 040	120	1 210	250 000	1.19	5 080
x 8.0	x 7.95	72.8	0.714	9 280	135	886	121	1 030	211 000	1.19	4 340
x 6.4	x 6.35	58.7	0.576	7 480	110	723	121	833	171 000	1.20	3 550
HSS 254x254x13	HSS 254x254x12.7	93.0	0.912	11 800	113	888	97.6	1 060	183 000	0.972	5 160
x 11	x 11.1	82.4	0.808	10 500	102	799	98.4	945	163 000	0.978	4 660
x 9.5	x 9.53	71.3	0.699	9 090	89.3	703	99.1	825	142 000	0.983	4 110
x 8.0	x 7.95	60.1	0.590	7 660	76.5	602	99.9	702	121 000	0.989	3 530
x 6.4	x 6.35	48.6	0.476	6 190	62.7	494	101	571	97 900	0.994	2 900
HSS 203x203x13	HSS 203x203x12.7	72.7	0.713	9 260	54.7	538	76.8	650	90 700	0.769	3 870
x 11	x 11.1	64.6	0.634	8 230	49.6	488	77.6	584	81 200	0.775	3 530
x 9.5	x 9.53	56.1	0.550	7 150	43.9	432	78.4	513	71 000	0.780	3 150
x 8.0	x 7.95	47.5	0.465	6 050	37.9	373	79.2	438	60 500	0.786	2 730
x 6.4	x 6.35	38.4	0.377	4 900	31.3	308	79.9	359	49 300	0.791	2 260
HSS 178x178x13	HSS 178x178x12.7	62.6	0.614	7 970	35.2	396	66.4	484	59 200	0.668	3 230
x 11	x 11.1	55.7	0.547	7 100	32.1	361	67.2	436	53 200	0.673	2 970
x 9.5	x 9.53	48.5	0.476	6 180	28.6	322	68.0	385	46 700	0.678	2 660
x 8.0	x 7.95	41.1	0.403	5 240	24.8	279	68.8	330	39 900	0.684	2 320
x 6.4	x 6.35	33.4	0.327	4 250	20.6	231	69.6	271	32 700	0.689	1 940
x 4.8	x 4.78	25.5	0.250	3 250	16.1	181	70.3	209	25 200	0.695	1 520
HSS 152x152x13	HSS 152x152x12.7	52.4	0.514	6 680	21.0	275	56.0	341	36 000	0.566	2 580
x 11	x 11.1	46.9	0.460	5 970	19.3	253	56.8	310	32 500	0.571	2 400
x 9.5	x 9.53	40.9	0.401	5 210	17.3	227	57.6	275	28 700	0.577	2 180
x 8.0	x 7.95	34.8	0.341	4 430	15.1	198	58.4	237	24 600	0.582	1 920
x 6.4	x 6.35	28.3	0.278	3 610	12.6	166	59.2	195	20 300	0.588	1 610
x 4.8	x 4.78	21.7	0.213	2 760	9.93	130	59.9	152	15 700	0.593	1 270
HSS 127x127x11	HSS 127x127x11.1	38.0	0.373	4 840	10.4	164	46.4	205	18 000	0.470	1 840
x 9.5	x 9.53	33.3	0.327	4 240	9.47	149	47.2	183	16 000	0.475	1 690
x 8.0	x 7.95	28.4	0.279	3 620	8.35	132	48.0	159	13 900	0.481	1 510
x 6.4	x 6.35	23.2	0.228	2 960	7.05	111	48.8	132	11 500	0.486	1 290
x 4.8	x 4.78	17.9	0.175	2 280	5.60	88.1	49.6	103	8 920	0.492	1 030
HSS 102x102x9.5	HSS 102x102x9.53	25.7	0.252	3 280	4.44	87.4	36.8	110	7 740	0.374	1210
x 8.0	x 7.95	22.1	0.217	2 820	3.98	78.4	37.6	96.6	6 780	0.379	1110
x 6.4	x 6.35	18.2	0.178	2 320	3.42	67.3	38.4	81.3	5 670	0.385	968
x 4.8	x 4.78	14.1	0.138	1 790	2.75	54.2	39.2	64.3	4 450	0.390	789
HSS 89x89x9.5	HSS 88.9x88.9x9.53	21.9	0.215	2 790	2.79	62.7	31.6	80.2	4 970	0.323	968
x 8.0	x 7.95	18.9	0.186	2 410	2.53	57.0	32.4	71.2	4 390	0.328	908
x 6.4	x 6.35	15.6	0.153	1 990	2.20	49.5	33.2	60.5	3 700	0.334	806
x 4.8	x 4.78	12.2	0.119	1 550	1.79	40.3	34.0	48.2	2 930	0.339	667
HSS 76x76x8.0	HSS 76.2x76.2x7.95	15.8	0.155	2 010	1.49	39.0	27.2	49.7	2 630	0.278	706
x 6.4	x 6.35	13.1	0.129	1 670	1.31	34.4	28.0	42.7	2 250	0.283	645
x 4.8	x 4.78	10.3	0.101	1 310	1.08	28.5	28.8	34.4	1 800	0.288	546
HSS 64x64x6.4	HSS 63.5x63.5x6.35	10.6	0.104	1 350	0.701	22.1	22.8	28.0	1 230	0.232	484
x 4.8	x 4.78	8.35	0.082	1 060	0.593	18.7	23.6	22.9	1 000	0.238	424
x 3.8	x 3.81	6.85	0.067	872	0.506	15.9	24.1	19.2	836	0.241	368
x 3.2	x 3.18	5.82	0.057	741	0.441	13.9	24.4	16.5	717	0.243	323
HSS 51x51x6.4	HSS 50.8x50.8x6.35	8.05	0.079	1 030	0.317	12.5	17.6	16.3	580	0.181	323
x 4.8	x 4.78	6.45	0.063	821	0.278	10.9	18.4	13.8	485	0.187	303
x 3.8	x 3.81	5.33	0.052	679	0.242	9.54	18.9	11.7	410	0.190	271
x 3.2	x 3.18	4.55	0.045	580	0.214	8.42	19.2	10.2	355	0.192	242
x 2.8	x 2.79	4.05	0.040	516	0.194	7.64	19.4	9.15	318	0.194	221
HSS 38x38x4.8	HSS 38.1x38.1x4.78	4.54	0.044	578	0.100	5.27	13.2	6.91	184	0.136	181
x 3.8	x 3.81	3.81	0.037	485	0.091	4.77	13.7	6.04	160	0.139	174
x 3.2	x 3.18	3.28	0.032	418	0.082	4.31	14.0	5.34	141	0.141	161
x 2.5	x 2.54	2.71	0.026	345	0.071	3.71	14.3	4.51	118	0.144	142
HSS 32x32x3.8	HSS 31.8x31.8x3.81	3.06	0.030	389	0.048	3.01	11.1	3.92	87.0	0.114	126
x 3.2	x 3.18	2.65	0.026	338	0.044	2.77	11.4	3.51	77.6	0.116	121
x 2.5	x 2.54	2.20	0.022	281	0.039	2.44	11.7	3.01	66.1	0.118	110
HSS 25x25x3.2	HSS 25.4x25.4x3.18	2.01	0.020	257	0.020	1.56	8.79	2.05	36.3	0.091	80.6
x 2.5	x 2.54	1.69	0.017	216	0.018	1.41	9.12	1.79	31.6	0.093	77.4



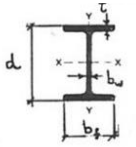
STEEL

RECTANGULAR Hollow Structural Sections **METRIC Dimensions and Properties**

Designation	Size	Mass	Dead Load	Area	I_x	S_x	r_x	Z_x	I_y	S_y	r_y	Z_y	Torsion J	Shear C_{rt}
mm x mm x mm	mm x mm x mm	kg/m	kN/m	mm^2	$10^6\ mm^4$	$10^3\ mm^3$	mm	$10^3\ mm^3$	$10^6\ mm^4$	$10^3\ mm^3$	mm	$10^3\ mm^3$	$10^3\ mm^4$	mm^2
HSS 305x203x13	HSS 305x203x12.7	93.0	0.912	11 800	147	964	111	1 190	78.1	769	81.2	896	167 000	6 450
x 11	x 11.1	82.4	0.808	10 500	132	867	112	1 060	70.5	693	81.9	802	149 000	5 790
x 9.5	x 9.53	71.3	0.699	9 090	116	762	113	925	62.1	611	82.7	701	130 000	5 080
x 8.0	x 7.95	60.1	0.590	7 660	99.4	652	114	787	53.3	524	83.4	596	111 000	4 340
x 6.4	x 6.35	48.6	0.476	6 190	81.5	535	115	640	43.8	431	84.1	486	89 800	3 550
HSS254x152x13	HSS254x152x12.7	72.7	0.713	9 260	75.2	592	90.1	746	33.6	441	60.2	522	78 200	5 160
x 11	x 11.1	64.6	0.634	8 230	68.2	537	91.0	671	30.6	401	61.0	470	70 200	4 660
x 9.5	x 9.53	56.1	0.550	7 150	60.3	475	91.9	589	27.2	357	61.7	413	61 600	4 110
x 8.0	x 7.95	47.5	0.465	6 050	52.0	409	92.7	503	23.5	309	62.4	353	52 600	3 530
x 6.4	x 6.35	38.4	0.377	4 900	42.9	338	93.6	411	19.5	256	63.1	290	43 000	2 900
HSS 203x152x13	HSS 203x152x12.7	62.6	0.614	7 970	43.0	123	73.4	528	27.3	358	58.5	432	56 400	3 870
x 11	x 11.1	55.7	0.547	7 100	39.1	385	74.2	476	24.9	327	59.3	390	50 800	3 530
x 9.5	x 9.53	48.5	0.476	6 180	34.8	343	75.1	419	22.3	292	60.0	344	44 600	3 150
x 8.0	x 7.95	41.1	0.403	5 240	30.2	297	75.9	360	19.3	254	60.7	295	38 200	2 730
x 6.4	x 6.35	33.4	0.327	4 250	25.0	246	76.7	295	16.1	211	61.5	243	31 200	2 260
x 4.8	x 4.78	25.5	0.250	3 250	19.5	192	77.5	228	12.6	165	62.2	188	24 100	1 760
HSS 203x102x13	HSS 203x102x12.7	52.4	0.514	6 680	31.2	307	68.4	405	10.2	201	39.1	246	27 000	3 870
x 11	x 11.1	46.9	0.460	5 970	28.7	282	69.3	367	9.46	186	39.8	224	24 600	3 530
x 9.5	x 9.53	40.9	0.401	5 210	25.8	253	70.3	325	8.56	168	40.5	199	21 900	3 150
x 8.0	x 7.95	34.8	0.341	4 430	22.5	221	71.2	281	7.54	148	41.2	172	18 900	2 730
x 6.4	x 6.35	28.3	0.278	3 610	18.8	185	72.2	232	6.35	125	42.0	143	15 600	2 260
x 4.8	x 4.78	21.7	0.213	2 760	14.7	145	73.1	180	5.03	99.0	42.7	111	12 200	1 760
HSS 178x127x13	HSS 178x127x12.7	52.4	0.514	6 680	26.4	297	62.8	377	15.5	243	48.1	298	33 600	3 230
x 11	x 11.1	46.9	0.460	5 970	24.2	272	63.7	342	14.2	224	48.8	270	30 400	2 970
x 9.5	x 9.53	40.9	0.401	5 210	21.7	244	64.6	303	12.8	202	49.6	240	26 900	2 660
x 8.0	x 7.95	34.8	0.341	4 430	18.9	213	65.4	261	11.2	177	50.3	207	23 100	2 320
x 6.4	x 6.35	28.3	0.278	3 610	15.8	178	66.2	216	9.40	148	51.1	171	19 000	1 940
x 4.8	x 4.78	21.7	0.213	2 760	12.4	140	67.1	167	7.41	117	51.8	133	14 700	1 520
HSS 152x102x11	HSS 152x102x11.1	38.0	0.373	4 840	13.6	179	53.1	230	7.13	140	38.4	172	16 300	2 400
x 9.5	x 9.53	33.3	0.327	4 240	12.4	162	54.0	205	6.50	128	39.1	154	14 500	2 180
x 8.0	x 7.95	28.4	0.279	3 620	10.9	143	54.8	178	5.76	113	39.9	134	12 600	1 920
x 6.4	x 6.35	23.2	0.228	2 960	9.18	121	55.7	148	4.88	96.1	40.6	112	10 500	1 610
x 4.8	x 4.78	17.9	0.175	2 280	7.28	95.6	56.5	116	3.89	76.6	41.3	87.8	8 160	1 270
HSS 127x76x9.5	HSS 127x76.2x9.53	25.7	0.252	3 280	6.12	96.4	43.2	126	2.69	70.5	28.6	87.5	6 600	1 690
x 8.0	x 7.95	22.1	0.217	2 820	5.49	86.4	44.1	111	2.43	63.8	29.4	77.2	5 810	1 510
x 6.4	x 6.35	18.2	0.178	2 320	4.70	74.0	45.1	93.3	2.10	55.1	30.1	65.2	4 890	1 290
x 4.8	x 4.78	14.1	0.138	1 790	3.78	59.5	45.9	73.8	1.70	44.7	30.8	51.7	3 860	1 030
HSS 127x64x9.5	HSS 127x63.5x9.53	23.8	0.234	3 030	5.28	83.2	41.7	112	1.70	53.6	23.7	67.4	4 640	1 690
x 8.0	x 7.95	20.5	0.201	2 610	4.77	75.1	42.7	98.9	1.56	49.1	24.4	60.0	4 130	1 510
x 6.4	x 6.35	16.9	0.166	2 150	4.11	64.8	43.7	83.6	1.36	42.9	25.1	51.0	3 510	1 290
x 4.8	x 4.78	13.1	0.129	1 670	3.33	52.4	44.6	66.3	1.12	35.2	25.9	40.7	2 800	1 030
HSS 127x51x9.5	HSS 127x50.8x9.53	21.9	0.215	2 790	4.45	70.0	39.9	97.7	0.961	37.8	18.6	48.9	2 930	1 690
x 8.0	x 7.95	18.9	0.186	2 410	4.05	63.8	41.0	86.9	0.897	35.3	19.3	44.0	2 650	1 510
x 6.4	x 6.35	15.6	0.153	1 990	3.53	55.5	42.1	73.8	0.798	31.4	20.0	37.9	2 290	1 290
x 4.8	x 4.78	12.2	0.119	1 550	2.87	45.3	43.1	58.9	0.665	26.2	20.7	30.5	1 850	1 030
HSS 102x76x9.5	HSS 102x76.2x9.53	21.9	0.215	2 790	3.41	67.2	35.0	87.6	2.15	56.3	27.7	71.3	4 710	1 210
x 8.0	x 7.95	18.9	0.186	2 410	3.10	61.0	35.8	77.7	1.96	51.4	28.5	63.5	4 170	1 110
x 6.4	x 6.35	15.6	0.153	1 990	2.68	52.8	36.7	65.9	1.71	44.8	29.3	54.0	3 530	968
x 4.8	x 4.78	12.2	0.119	1 550	2.18	43.0	37.5	52.5	1.39	36.6	30.0	43.1	2 800	789
HSS 102x51x8.0	HSS 102x50.8x7.95	15.8	0.155	2 010	2.21	43.5	33.2	58.8	0.709	27.9	18.8	35.4	1 950	1 110
x 6.4	x 6.35	13.1	0.129	1 670	1.95	38.4	34.2	50.6	0.638	25.1	19.5	30.7	1 690	968
x 4.8	x 4.78	10.3	0.101	1 310	1.61	31.8	35.1	40.8	0.536	21.1	20.3	24.9	1 370	789
x 3.8	x 3.81	8.37	0.082	1 070	1.36	26.8	35.7	33.9	0.456	18.0	20.7	20.8	1 140	658
x 3.2	x 3.18	7.09	0.069	903	1.17	23.1	36.1	29.0	0.397	15.6	21.0	17.9	979	565
HSS 89x64x8.0	HSS 88.9x63.5x7.95	15.8	0.155	2 010	1.87	42.1	30.5	54.9	1.09	34.3	23.3	43.2	2 450	908
x 6.4	x 6.35	13.1	0.129	1 670	1.65	37.1	31.4	47.1	0.966	30.4	24.0	37.2	2 100	806
x 4.8	x 4.78	10.3	0.101	1 310	1.36	32.3	32.3	38.0	0.803	25.3	24.8	30.1	1 690	667
x 3.8	x 3.81	8.37	0.082	1 070	1.15	25.8	32.8	31.5	0.679	21.4	25.2	25.0	1 400	561
x 3.2	x 3.18	7.09	0.069	903	0.990	22.3	33.1	27.0	0.588	18.5	25.5	21.4	1 190	485
HSS 76x51x8.0	HSS 76.2x50.8x7.95	12.6	0.123	1 600	1.01	26.6	25.1	35.9	0.522	20.5	18.0	26.7	1 270	706
x 6.4	x 6.35	10.6	0.104	1 350	0.917	24.1	26.1	31.4	0.477	18.8	18.8	23.5	1 110	645
x 4.8	x 4.78	8.35	0.082	1 060	0.774	20.3	27.0	25.7	0.407	16.0	19.6	19.3	911	546
x 3.8	x 3.81	6.85	0.067	872	0.660	17.3	27.5	21.6	0.349	13.8	20.0	16.3	762	465
HSS 51x25x3.2	HSS 50.8x25.4x3.18	3.28	0.032	418	0.122	4.81	17.1	6.33	0.040	3.14	9.77	3.84	106	242
x 2.5	x 2.54	2.71	0.026	345	0.105	4.15	17.5	5.35	0.035	2.75	10.1	3.27	89.8	206

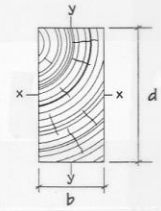
Appendix C – Steel Wide Flange Beams and Sawn Timber Section Tables

Wide Flange Rolled Steel Beams
Dimensions and Section Properties



Designation	Dimensions				Dead Load	Area	Strong Axis x-x			Weak Axis y-y			Torsion Constant	Shear Depth
	d	b_f	t	b_w			I_x	S_x	r_x	I_y	S_y	r_y	J	I_x/Q
mm × kg/m	mm	mm	mm	mm	kN/m	mm²	10^6 mm⁴	10^3 mm³	mm	10^6 mm⁴	10^3 mm³	mm	10^3 mm⁴	mm
W920 × 446	933	423	43	24.0	4.38	57000	8470	18200	385	540	2550	97.3	26800	822
× 365	916	419	34	20.3	3.57	46400	6710	14600	380	421	2010	95.3	14400	813
× 313	932	309	34	21.1	3.06	39800	5480	11800	371	170	1100	65.4	11600	806
× 238	915	305	26	16.5	2.33	30400	4060	8880	365	123	806	63.6	5140	796
W840 × 329	862	401	32	19.7	3.23	42000	5350	12400	357	349	1740	91.2	11500	764
× 210	846	293	24	15.4	2.06	26800	3110	7340	341	103	700	62.0	4050	738
× 176	835	292	19	14.0	1.72	22400	2460	5900	331	78.2	536	59.1	2220	722
W760 × 257	773	381	27	16.6	2.52	32800	3420	8840	323	250	1310	87.3	6380	689
× 173	762	267	22	14.4	1.70	22100	2060	5400	305	68.7	515	55.8	2690	663
× 147	753	265	17	13.2	1.44	18700	1660	4410	298	52.9	399	53.2	1560	651
W690 × 217	695	355	25	15.4	2.13	27700	2340	6740	291	185	1040	81.7	4560	618
× 152	688	254	21	13.1	1.49	19400	1510	4380	279	57.8	455	54.6	2200	604
× 125	678	253	16	11.7	1.23	16000	1190	3500	273	44.1	349	52.5	1180	594
W610 × 195	622	327	24	15.4	1.91	24900	1680	5400	260	142	871	75.5	3970	554
× 155	611	324	19	12.7	1.51	19700	1290	4220	256	108	666	74.0	1950	545
× 125	612	229	20	11.9	1.22	15900	985	3220	249	39.3	343	49.7	1540	537
× 101	603	228	15	10.5	0.99	13000	764	2530	242	29.5	259	47.6	781	527
W530 × 182	551	315	24	15.2	1.78	23100	1240	4480	232	127	808	74.1	3740	492
× 150	543	312	20	12.7	1.47	19200	1010	3710	229	103	659	73.2	2160	487
× 109	539	211	19	11.6	1.06	13900	667	2480	219	29.5	280	46.1	1260	471
× 82	528	209	13	9.5	0.81	10500	479	1810	214	20.3	194	44.0	530	463
W460 × 144	472	283	22	13.6	1.41	18400	726	3080	199	83.6	591	67.4	2440	421
× 97	466	193	19	11.4	0.95	12300	445	1910	190	22.8	237	43.1	1130	408
× 82	460	191	16	9.9	0.80	10400	370	1610	189	18.6	195	42.3	691	404
× 61	450	189	11	8.1	0.60	7760	259	1150	183	12.2	129	39.7	289	395
W410 × 114	420	261	19	11.6	1.12	14600	462	2200	178	57.2	439	62.6	1490	376
× 74	413	180	16	9.7	0.73	9550	275	1330	170	15.6	173	40.4	637	364
× 60	407	178	13	7.7	0.58	7580	216	1060	169	12.0	135	39.8	328	363
× 39	399	140	9	6.4	0.38	4990	127	634	160	4.0	57.7	28.5	111	348
W360 × 314	399	401	40	24.9	3.07	39900	1100	5530	166	426	2120	103	18500	345
× 122	363	257	22	13.0	1.19	15500	365	2010	153	61.5	478	63.0	2100	322
× 79	354	205	17	9.4	0.78	10100	227	1280	150	24.2	236	48.9	814	317
× 64	347	203	14	7.7	0.63	8140	178	1030	148	18.8	186	48.1	438	312
× 45	352	171	10	6.9	0.44	5730	122	691	146	8.18	95.7	37.8	160	313
× 33	349	127	8	5.8	0.32	4170	82.7	474	141	2.91	45.8	26.4	85.9	305
W310 × 253	356	319	40	24.4	2.48	32200	682	3830	146	215	1350	81.7	14800	304
× 118	314	307	19	11.9	1.15	15000	275	1750	135	90.2	588	77.5	1600	282
× 79	306	254	15	8.8	0.77	10100	177	1160	132	39.9	314	62.9	657	277
× 60	303	203	13	7.5	0.59	7590	129	849	130	18.3	180	49.1	397	274
× 39	310	165	10	5.8	0.38	4940	85.1	549	131	7.27	88.1	38.4	126	279
× 21	303	101	6	5.1	0.21	2690	37.0	244	117	0.983	19.5	19.1	29.4	258
W250 × 115	269	259	22	13.5	1.12	14600	189	1410	114	64.1	495	66.3	2130	236
× 49	247	202	11	7.4	0.48	6250	70.6	572	106	15.1	150	49.2	241	223
× 33	258	146	9	6.1	0.32	4170	48.9	379	108	4.73	64.7	33.7	98.5	231
W200 × 59	210	205	14	9.1	0.58	7560	61.1	582	89.9	20.4	199	51.9	465	187
× 36	201	165	10	6.2	0.35	4580	34.4	342	86.7	7.64	92.6	40.8	146	181
× 27	207	133	8	5.8	0.26	3390	25.8	249	87.2	3.30	49.6	31.2	71.3	185
W150 × 30	157	153	9	6.6	0.29	3790	17.2	219	67.4	5.56	72.6	38.3	101	141
× 14	150	100	6	4.3	0.13	1730	6.87	91.5	63.0	0.92	18.4	23.0	17.0	133

Sawn Timber Sections
Dimensions and Section Properties



Size and Designation $b \times d$	Nominal Dimensions	Dead Load	Area	Strong Axis x-x			Weak Axis y-y			Torsion Constant
				I_x	S_x	r_x	I_y	S_y	r_y	J
mm	in.	kN/m	mm²	10^6 mm⁴	10^3 mm³	mm	10^6 mm⁴	10^3 mm³	mm	10^6 mm⁴
292 × 495	12 × 20	0.907	145000	2950	11900	143	1030	7030	84.3	2570
× 445	× 18	0.816	130000	2140	9640	129	923	6320	84.3	2190
× 394	× 16	0.722	115000	1490	7550	114	817	5600	84.3	1760
× 343	× 14	0.629	100000	982	5730	99.0	712	4870	84.3	1370
× 292	× 12	0.535	85300	606	4150	84.3	606	4150	84.3	1030
241 × 495	10 × 20	0.749	119000	2440	9840	143	577	4790	69.9	1600
× 445	× 18	0.673	107000	1770	7950	129	519	4310	69.6	1360
× 394	× 16	0.596	95000	1230	6240	114	460	3810	69.6	1130
× 343	× 14	0.519	82700	810	4730	99.0	400	3320	69.6	900
× 292	× 12	0.442	70400	500	3420	84.3	341	2830	69.6	671
× 241	× 10	0.365	58100	281	2330	69.6	281	2330	69.6	476
191 × 495	8 × 20	0.594	94600	1930	7800	143	287	3010	55.1	868
× 445	× 18	0.534	85000	1400	6300	129	258	2710	55.1	751
× 394	× 16	0.472	75300	974	4940	114	229	2400	55.1	636
× 343	× 14	0.411	65500	642	3750	99.0	199	2090	55.1	515
× 292	× 12	0.350	55800	396	2710	84.3	170	1780	55.1	403
× 241	× 10	0.289	46000	223	1850	69.6	140	1470	55.1	285
× 191	× 8	0.229	36500	111	1160	55.1	111	1160	55.1	188
140 × 445	6 × 18	0.391	62300	1030	4620	129	102	1450	40.4	325
× 394	× 16	0.346	55200	714	3620	114	90.1	1290	40.4	279
× 343	× 14	0.301	48000	471	2750	99.0	78.4	1120	40.4	232
× 292	× 12	0.257	40900	290	1990	84.3	66.8	954	40.4	186
× 241	× 10	0.212	33700	163	1360	69.6	55.1	787	40.4	139
× 191	× 8	0.168	26700	81.3	851	55.1	43.7	624	40.4	94.9
× 140	× 6	0.123	19600	32.0	457	40.4	32.0	457	40.4	54.2
89 × 387	4 × 16	0.216	34400	430	2220	112	22.7	511	25.7	77.5
× 337	× 14	0.188	30000	284	1680	97.3	19.8	445	25.7	65.9
× 286	× 12	0.160	25500	174	1210	82.6	16.8	378	25.7	53.8
× 235	× 10	0.131	20900	96.3	819	67.8	13.8	310	25.7	41.9
× 184	× 8	0.103	16400	46.2	502	53.1	10.8	243	25.7	30.1
× 140	× 6	0.078	12500	20.4	291	40.4	8.22	185	25.7	19.8
× 114	× 5	0.064	10200	11.0	193	32.9	6.70	151	25.7	13.8
× 89	× 4	0.050	7920	5.23	118	25.7	5.23	117	25.7	8.85
64 × 337	3 × 14	0.135	21600	204	1210	97.3	7.36	230	18.5	25.8
× 286	× 12	0.115	18300	125	872	82.6	6.25	195	18.5	21.4
× 235	× 10	0.094	15000	69.2	589	67.8	5.13	160	18.5	17.0
× 184	× 8	0.074	11800	33.2	361	53.1	4.02	126	18.5	12.5
× 140	× 6	0.056	8960	14.6	209	40.4	3.06	95.6	18.5	8.68
× 114	× 5	0.046	7300	7.90	139	32.9	2.49	77.8	18.5	6.41
× 89	× 4	0.036	5700	3.76	84.5	25.7	1.94	60.8	18.5	4.29
38 × 337	2 × 14	0.071	12800	121	719	97.3	1.54	81.1	11.0	5.72
× 286	× 12	0.060	10900	74.1	518	82.6	1.31	68.8	11.0	4.79
× 235	× 10	0.049	8930	41.1	350	67.8	1.07	56.6	11.0	3.87
× 184	× 8	0.038	6990	19.7	214	53.1	0.84	44.3	11.0	2.91
× 140	× 6	0.029	5320	8.69	124	40.4	0.64	33.7	11.0	2.11
× 114	× 5	0.024	4330	4.69	82.3	32.9	0.52	27.4	11.0	1.65
× 89	× 4	0.019	3380	2.23	50.2	25.7	0.41	21.4	11.0	1.19
× 64	× 3	0.013	2430	0.83	25.9	18.5	0.29	15.4	11.0	0.73
× 38	× 2	0.008	1440	0.17	9.15	11.0	0.17	9.15	11.0	0.29

Appendix D – Wood Properties

Section 9 | Wood Structures

5th Percentile estimates of strength under one month loading. For safe working stresses reduce these breaking stresses by factor of safety of 1.5.

9 – 11.2 (a) Specified strength and modulus of elasticity for dimension lumber, thickness 38 to 77 mm, MPa**

Species or Species Combination	Grade	Bending f_{bu}	Shear Longitudinal f_{vu}	Compression Parallel to Grain f_{pu}	Compression Perpendicular to Grain f_{qu}	Tension Parallel to Grain f_{tu}	Modulus of Elasticity E_{50}	Modulus of Elasticity E_{05}
Douglas Fir-Larch	Select Structural	17.5	1.1	16.5	3.6	13.5	11,000	8,000
	No. 1 and No. 2	10.0	1.1	9.0	3.6	9.0	9,500	6,000
Hem-Fir	Select Structural	16.0	0.8	14.5	1.9	13.5	11,000	7,500
	No. 1 and No. 2	11.5	0.8	10.5	1.9	9.0	10,500	7,000
Lodgepole Pine, or Ponderosa Pine	Select Structural	16.0	1.0	14.5	1.9	13.5	10,000	7,000
	No. 1 and No 2	11.5	1.0	10.5	1.9	9.0	9,000	6,000
Jack Pine	Select Structural	16.0	1.0	14.5	2.6	13.5	10,500	7,000
	No. 1 and No. 2	11.5	1.0	10.5	2.6	9.0	9,500	6,000
Red Pine	Select Structural	11.5	0.8	10.0	1.9	10.0	7,000	5,000
	No. 1 and No. 2	8.0	0.8	7.0	1.9	7.0	6,000	4,000
White Pine*	Select Structural	6.0	0.8	–	1.9	–	5,500	4,000
	No. 1 and No. 2	4.5	0.8	–	1.9	–	4,500	3,500

* *For use in stress-laminated decks only.*

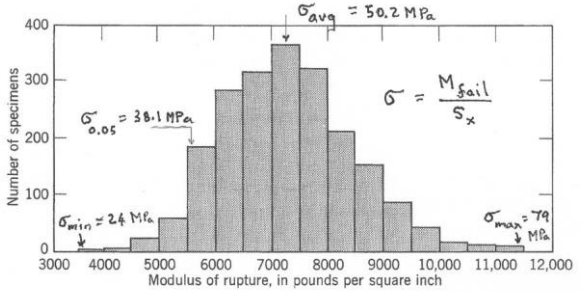
** *Dimension lumber with thickness of 89 mm or greater shall have specified strengths in accordance with Table 13–11.2 (b).*

9 – 11.2 (b) Specified strength and modulus of elasticity for beams & stringers, post & timbers, minimum dimension 140 mm, MPa

Species or Species Combination	Grade	Bending f_{bu}	Shear Longitudinal f_{vu}	Compression Parallel to Grain f_{pu}	Compression Perpendicular to Grain f_{qu}	Tension Parallel to Grain f_{tu}	Modulus of Elasticity E_{50}	Modulus of Elasticity E_{05}
Douglas Fir-Larch	Select Structural	24.0	1.1	16.5	3.6	13.0	11,000	7,500
	No. 1	20.0	1.1	9.0	3.6	9.0	9,500	6,500
Hem-Fir	Select Structural	20.0	0.8	14.5	1.9	13.0	11,000	7,500
	No. 1	18.0	0.8	10.5	1.9	9.0	10,500	7,000
Lodgepole Pine, or Ponderosa Pine	Select Structural	18.5	1.0	14.5	1.9	13.0	10,000	7,000
	No. 1	13.0	1.0	10.5	1.9	9.0	9,000	6,000
Jack Pine	Select Structural	18.5	1.0	14.5	2.6	13.0	10,500	7,000
	No. 1	13.0	1.0	10.5	2.6	9.0	9,500	6,000
Red Pine	Select Structural	13.0	0.8	10.0	1.9	10.0	7,000	5,000
	No. 1	9.0	0.8	7.0	1.9	7.0	6,000	4,000

Table 4.3 *Average clear-wood strength values* for commercial species in air-dry condition*

Species	Relative density† Nominal	Relative density† Oven-dry	Shrinkage, green to air-dry based on dimensions when green (%) Radial	Tangential	Volumetric	Modulus of rupture (MPa)	Modulus of elasticity (MPa)	Compression parallel to grain, crushing strength max. (MPa)	Shear strength (MPa)	Compression perpendicular to grain, fiber stress at proportional limit (MPa)	Tension perpendicular to grain (MPa)
SOFTWOODS											
Cedar											
Eastern white	0.30	0.31	–	–	3.8	42.3	4 380	24.8	6.93	2.68	2.63
Western red	0.34	0.34	–	–	4.8	53.8	8 270	33.9	5.58	3.43	1.46
Yellow	0.43	0.46	–	–	5.0	79.7	11 000	45.9	9.21	4.74	3.49
Douglas-fir	0.49	0.51	–	–	7.0	88.6	13 500	50.1	9.53	6.01	3.06
Fir											
Amabilis (Pacific silver)	0.39	0.41	–	–	7.5	68.9	11 400	40.8	7.54	3.61	3.06
Balsam	0.35	0.37	1.2	4.3	5.7	58.3	9 650	34.3	6.25	3.14	2.08
Hemlock											
Eastern	0.43	0.45	2.4	4.7	6.2	67.1	9 720	41.0	8.75	4.28	2.06
Western	0.43	0.47	–	–	8.1	81.1	12 300	46.7	6.48	4.53	2.93
Tamarack	0.51	0.54	–	–	7.1	76.0	9 380	44.8	9.00	6.15	3.47
Larch, western	0.58	0.64	–	–	8.0	107.0	14 300	60.9	9.25	7.31	3.62
Pine											
Eastern white	0.37	0.38	–	–	4.5	65.0	9 380	36.2	6.10	3.39	2.63
Jack	0.44	0.45	2.1	3.8	5.7	77.9	10 200	40.5	8.23	5.70	3.65
Lodgepole	0.41	0.46	–	–	6.6	76.0	10 900	43.2	8.54	3.65	3.78
Ponderosa	0.46	0.49	–	–	6.1	73.3	9 510	42.3	7.03	5.22	3.47
Red	0.40	0.42	1.9	4.1	6.5	69.7	9 450	37.9	7.50	4.96	3.54
Western white	0.37	0.40	–	–	6.0	64.1	10 100	36.1	6.34	3.23	2.64
Spruce											
Black	0.43	0.44	1.7	4.0	6.5	78.3	10 400	41.5	8.65	4.25	3.43
Engelmann	0.40	0.42	–	–	6.8	69.5	10 700	42.4	7.55	3.70	2.72
Red	0.40	0.42	–	–	6.2	71.5	11 000	38.5	9.20	3.77	3.70
Sitka	0.39	0.39	–	–	6.0	69.8	11 200	37.8	6.78	4.10	2.48
White	0.37	0.39	1.4	4.0	6.8	62.7	9 930	36.9	6.79	3.45	3.28
HARDWOODS											
Aspen, trembling	0.41	–	2.7	5.7	8.3	67.6	11 200	36.3	6.76	3.52	4.19
Birch, yellow	0.61	–	–	–	9.9	106.0	14 100	52.1	14.67	7.24	7.52
Maple, sugar	0.66	–	2.9	6.4	9.3	115.0	14 100	56.4	16.71	9.72	9.21
Oak, red	0.61	–	–	–	6.9	98.7	11 900	49.8	14.38	8.89	6.52

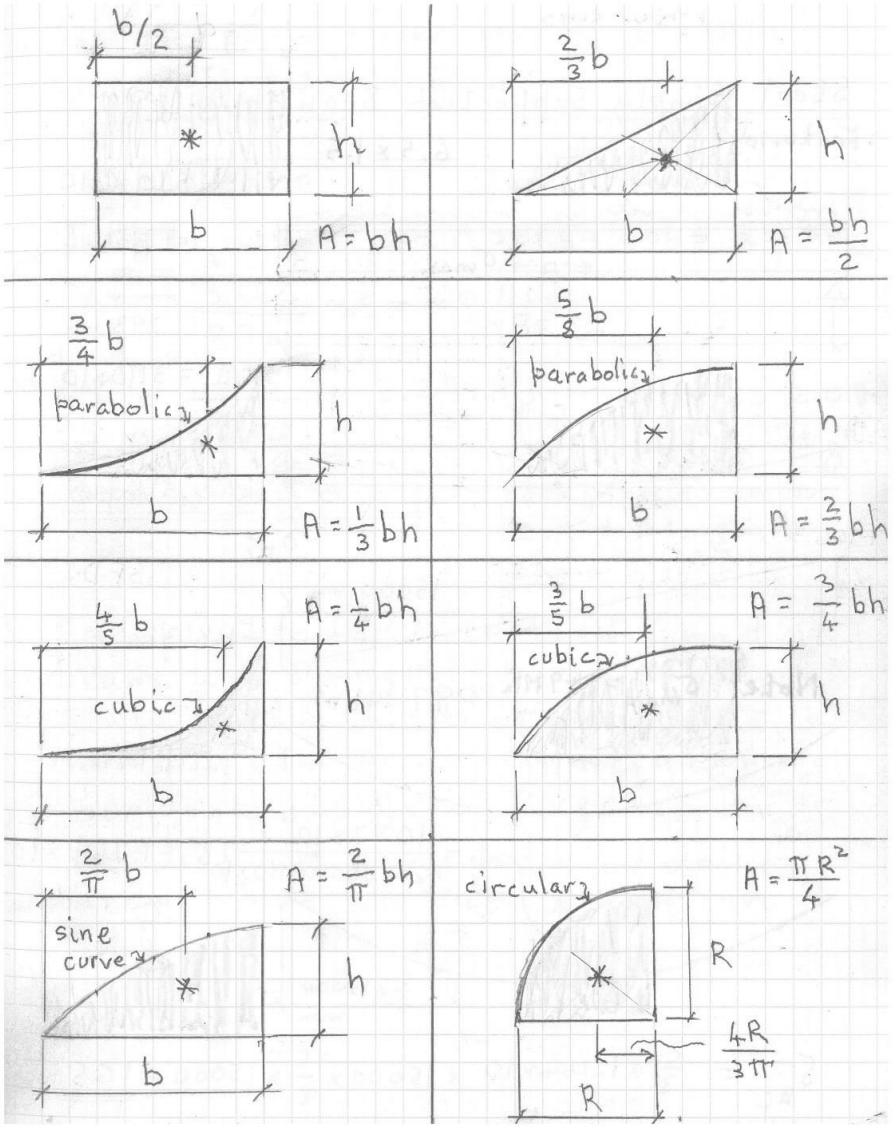


(b) Frequency distribution of bending strength of green Douglas fir. 2110 small clear specimens cut from a single tree. Short-term loading.

Appendix E – Common Unit Conversions

Working with SI units		
Lengths, Strains and Curvatures	Pressures and Stresses	Forces and Moments
1 m = 1,000 mm 1 m^2 = 10^6 mm^2 1 m^3 = 10^9 mm^3 1 mm/m = 10^3 mm/mm 1 rad/m = 10^6 mrad/mm	1 Pa = 1 N/m^2 1 kPa = 1 kN/m^2 1 MPa = 1 MN/m^2 1 MPa = 1 N/mm^2	1 kN = 1,000 N 1 MN = 10^6 N 1 Nm = 1,000 Nmm 1 kNm = 10^6 Nmm
Working with other unit systems and other miscellaneous quantities		
1 foot = 12 inches 1 cubit = 18 inches 1 yard = 3 feet 1 chain = 22 yards 1 furlong = 10 chains 1 mile = 8 furlongs 1 mile = 1,760 yards 1 acre = 10 square chains 1 square mile = 640 acres 1 ha = 10,000 square m	1 inch = 25.4 mm 1 foot = 304.8 mm 1 mile = 1609 m 1 ha = 2.47 acres 1 kg = 2.20 lbs 1 stone = 14.0 lbs 1 lbs/ ft^3 = 16.02 kg/ m^3 100 lbs/ft^3 = 15.72 kN/m^3 1 N = 0.225 lbs (force) 1 kip = 4.45 kN	9.81 m/s^2 = 32.2 $feet/s^2$ 1 kNm = 0.738 kip ft 1 kNm = 8.85 kip in 1 hp = 746 Watt 1 km/h = 0.278 m/s 1 km/h = 0.621 miles/h 1 knot = 1.852 km/h 1 MPa = 145.0 psi 1 kN/m^2 = 20.9 lbs/ft^2

Appendix F – Areas and Centroids of Common Shapes



Appendix G – Common Canadian Reinforcing Bar Information

Designation	Linear Density (kg/m)	Nominal Diameter (mm)	Cross-Sectional Area (mm^2)
10M	0.785	11.3	100
15M	1.570	16.0	200
20M	2.355	19.6	300
25M	3.925	25.2	500
30M	5.495	29.9	700
35M	7.850	35.7	1000
45M	11.775	43.7	1500
55M	19.625	56.4	2500