Wood Design

Notation:

a = name for width dimension
A = name for area
$A_{req'd\text{-}adj}$ = area required at allowable stress when shear is adjusted to include self weight
b = width of a rectangle
= name for height dimension
c_1 = coefficient for shear stress for a rectangular bar in torsion
C_C = curvature factor for laminated arches
C_D = load duration factor
C_{fu} = flat use factor for other than decks
C_F = size factor
C_H = shear stress factor
C_i = incising factor
C_L = beam stability factor
C_M = wet service factor
C_p = column stability factor for wood design
C_r = repetitive member factor for wood design
C_V = volume factor for glue laminated timber design
C_t = temperature factor for wood design
d = name for depth
d_{min} = dimension of timber critical for buckling
DL = shorthand for dead load
E = modulus of elasticity
f = stress (strength is a stress limit)
f_b = bending stress
$f_{from\ table}$ = tabular strength (from table)
f_p = bearing stress
f_r = radial stress for a glulam timber
f_v = shear stress
$f_{v\text{-}max}$ = maximum shear stress
F_b = tabular bending strength
= allowable bending stress
F_b' = allowable bending stress (adjusted)
F_c = tabular compression strength parallel to the grain
F_c' = allowable compressive stress (adjusted)
F^*_c = intermediate compressive stress for column design dependent on load duration
F_{cE} = theoretical allowed buckling stress
$F_{c\perp}$ = tabular compression strength perpendicular to the grain
F_p = tabular bearing strength parallel to the grain
= allowable bearing stress
F_R = allowable radial stress
F_t = tabular tensile strength
F_u = ultimate strength
F_v = tabular bending strength
= allowable shear stress
h = height of a rectangle
I = moment of inertia with respect to neutral axis bending
I_{trial} = moment of inertia of trial section
$I_{req'd}$ = moment of inertia required at limiting deflection
I_y = moment of inertia with respect to an y-axis
J = polar moment of inertia
K_{cE} = material factor for wood column design
L_e = effective length that can buckle for column design, as is ℓ_e
L = name for length or span length
LL = shorthand for live load
$LRFD$ = load and resistance factor design
M = internal bending moment
M_{max} = maximum internal bending moment
$M_{max\text{-}adj}$ = maximum bending moment adjusted to include self weight
P = name for axial force vector
R = radius of curvature of a deformed beam
= radius of curvature of a laminated arch
= name for a reaction force
S = section modulus
$S_{req'd}$ = section modulus required at allowable stress

$S_{req'd\text{-}adj}$ = section modulus required at allowable stress when moment is adjusted to include self weight

T = torque (axial moment)

V = internal shear force

V_{max} = maximum internal shear force

$V_{max\text{-}adj}$ = maximum internal shear force adjusted to include self weight

w = name for distributed load

$w_{self\,wt}$ = name for distributed load from self weight of member

$\Delta_{allowable}$ = allowable beam deflection

Δ_{limit} = allowable beam deflection limit

Δ_{max} = maximum beam deflection

κ = slenderness ratio limit for long columns

γ = density or unit weight

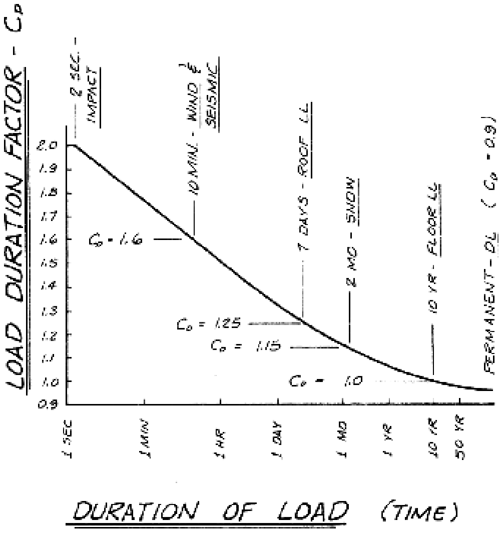
ρ = radial distance

Wood or Timber Design

Structural design standards for wood are established by the *National Design Specification (NDS)* published by the National Forest Products Association. There is a combined specification (from 2005) for **Allowable** Stress Design and limit state design (LRFD).

Tabulated wood strength values are used as the base allowable strength (ASD) and modified by appropriate adjustment factors:

$$f = C_D C_M C_F \ldots \times f_{from\,table}$$



Adjustment Factors

C_D	load duration factor
C_M	wet service factor (1.0 dry < 16% moisture content)
C_t	temperature factor (at high temperatures strength decreases)
C_L	beam stability factor (for beams without full lateral support)
C_F	size factor for visually graded sawn lumber and round timber > 12" depth

$$C_F = (12/d)^{1/9} \leq 1.0$$

C_V	volume factor for glued laminated timber (similar to C_F)
C_{fu}	flat use factor (excluding decking)
C_r	repetitive member factor (1.15 for three or more parallel members of Dimension lumber spaced not more than 24 in. on center, connected together by a load-distributing element such as roof, floor, or wall sheathing)
C_c	curvature factor for glued laminated timber (1.0 straight & cambered)

t/R ≤ 1/100 for hardwoods & southern pine or 1/125 other softwoods

$$C_c = 1 - 2000(t/R)^2$$

C_i	incising factor (0.85 incised sawn lumber, 1 for sawn lumber not incised and glulam)
C_H	shear stress factor (amount of splitting)
C_P	column stability factor (1.0 for fully supported columns)

Design Values

F_b: bending stress
F_t: tensile stress
F_v: horizontal shear stress
$F_{c\perp}$: compression stress (perpendicular to grain)
F_c: compression stress (parallel to grain)
E: modulus of elasticity
F_p: bearing stress (parallel to grain)

Wood is significantly weakest in shear and strongest along the direction of the grain (tension and compression).

Load Combinations and Deflection

The critical load combination is determined by the largest of either:

$$\frac{dead\ load}{0.9} \ or \ \frac{(dead\ load + any\ combination\ of\ live\ load\ )}{C_D}$$

The deflection limits may be increased for less stiffness with total load: LL + 0.5(DL)

Criteria for Beam Design

Allowable normal stress or normal stress from LRFD should not be exceeded:

Knowing M and F_b, the minimum section modulus fitting the limit is: $S_{req'd} \geq \frac{M}{F_b}$

Besides strength, we also need to be concerned about *serviceability*. This involves things like limiting deflections & cracking, controlling noise and vibrations, preventing excessive settlements of foundations and durability. When we know about a beam section and its material, we can determine beam deformations.

Determining Maximum Bending Moment

Drawing V and M diagrams will show us the maximum values for design. Computer applications are very helpful.

Determining Maximum Bending Stress

For a prismatic member (constant cross section), the maximum normal stress will occur at the maximum moment.

For a *non-prismatic* member, the stress varies with the cross section AND the moment.

Deflections

Elastic curve equations can be found in handbooks, textbooks, design manuals, etc...Computer programs can be used as well.

Elastic curve equations can be superpositioned ONLY if the stresses are in the elastic range. *The deflected shape is roughly the same shape flipped as the bending moment diagram but is constrained by supports and geometry.*

Allowable Deflection Limits

All building codes and design codes limit deflection for beam types and damage that could happen based on service condition and severity.

Use	LL only	DL+LL
Roof beams:		
Industrial	L/180	L/120
Commercial		
plaster ceiling	L/240	L/180
no plaster	L/360	L/240
Floor beams:		
Ordinary Usage	L/360	L/240
Roof or floor (damageable elements)		L/480

Lateral Buckling

With compression stresses in the top of a beam, a sudden "popping" or buckling can happen even at low stresses. In order to prevent it, we need to brace it along the top, or laterally brace it, or provide a bigger I_y.

Beam Loads & Load Tracing

In order to determine the loads on a beam (or girder, joist, column, frame, foundation...) we can start at the top of a structure and determine the *tributary area* that a load acts over and the beam needs to support. Loads come from material weights, people, and the environment. This area is assumed to be from half the distance to the next beam over to halfway to the next beam.

The reactions must be supported by the next lower structural element *ad infinitum*, to the ground.

Design Procedure

The intent is to find the most light weight member satisfying the section modulus size.

1. Know F_{all} for the material or F_U for LRFD.
2. Draw V & M, finding M_{max}.

3. Calculate $S_{req'd}$. This step is equivalent to determining $f_b = \frac{M_{\max}}{S} \le F_b'$
4. For rectangular beams $S = \frac{bh^2}{6}$
    - For timber: use the section charts to find S that will work *and remember that the beam self weight will increase* $S_{req'd.}$

*****Determine the "updated"* V_{max} *and* M_{max} *including the beam self weight, and verify that the updated* $S_{req'd}$ *has been met.*******

5. Consider lateral stability.

6. Evaluate horizontal shear stresses using $V_{\max}$ to determine if $f_v \le F_v'$

   For rectangular beams $$f_{v-\max} = \frac{3V}{2A} = 1.5\frac{V}{A}$$

7. Provide adequate bearing area at supports: $$f_p = \frac{P}{A} \le F_p'$$

8. Evaluate shear due to torsion $$f_v = \frac{T\rho}{J} \text{ or } \frac{T}{c_1 ab^2} \le F_v'$$
   (circular section or rectangular)

9. Evaluate the deflection to determine if $\Delta_{maxLL} \le \Delta_{LL-allowed}$ and/or $\Delta_{\max Total} \le \Delta_{Total-allowed}$

***** note: when* $\Delta_{calculated} > \Delta_{limit}$, $I_{required}$ *can be found with:*
and $S_{req'd}$ *will be satisfied for similar self weight ****** $$I_{req'd} \ge \frac{\Delta_{too\,big}}{\Delta_{limit}} I_{trial}$$

FOR ANY EVALUATION:

> Redesign (with a new section) at any point that a stress or serviceability criteria is NOT satisfied and re-evaluate each condition until it is satisfactory.

Column Design

National Design Specification for Wood Construction (1992):

Any slenderness ratio, $l_e/d \le 50$:

$$f_c = \frac{P}{A} \le F_c' \qquad F_c' = F_c(C_D)(C_M)(C_t)(C_F)(C_p)$$

For preliminary column design:

$$F_c' = F_c^* C_p = (F_c C_D) C_p$$

Procedure

1. Obtain F'$_c$

   find l_e/d or assume ($l_e/d \le 50$)

   compute $F_{cE} = \dfrac{K_{cE}E}{\left(\frac{l_e}{d}\right)^2}$ with K$_{cE}$ =0.3 for sawn, = 0.418 for glu-lam

   compute $F_c^* \cong F_c C_D$ with C$_D$ = 1, normal, C$_D$ =1.25 for 7 day roof...

   find F_{cE}/F_c^* and get C$_p$

2. Select a section

   If the load and area of the column are known, set the stress equal to the allowable stress, and solve for l_e, l, or d$_{min}$

   If the load and length of the column are known, set the stress equal to the allowable stress, and solve for A or d$_{min}$ and select a section that satisfies the values found.

3. Continue from 2 until F_c' is satisfied: $F_c' = F_c^* C_p$

Alternate Column Allowable Stress

For *intermediate length* columns with 11<L/d<κ, where $\kappa = 0.67\sqrt{E/F_c}$:

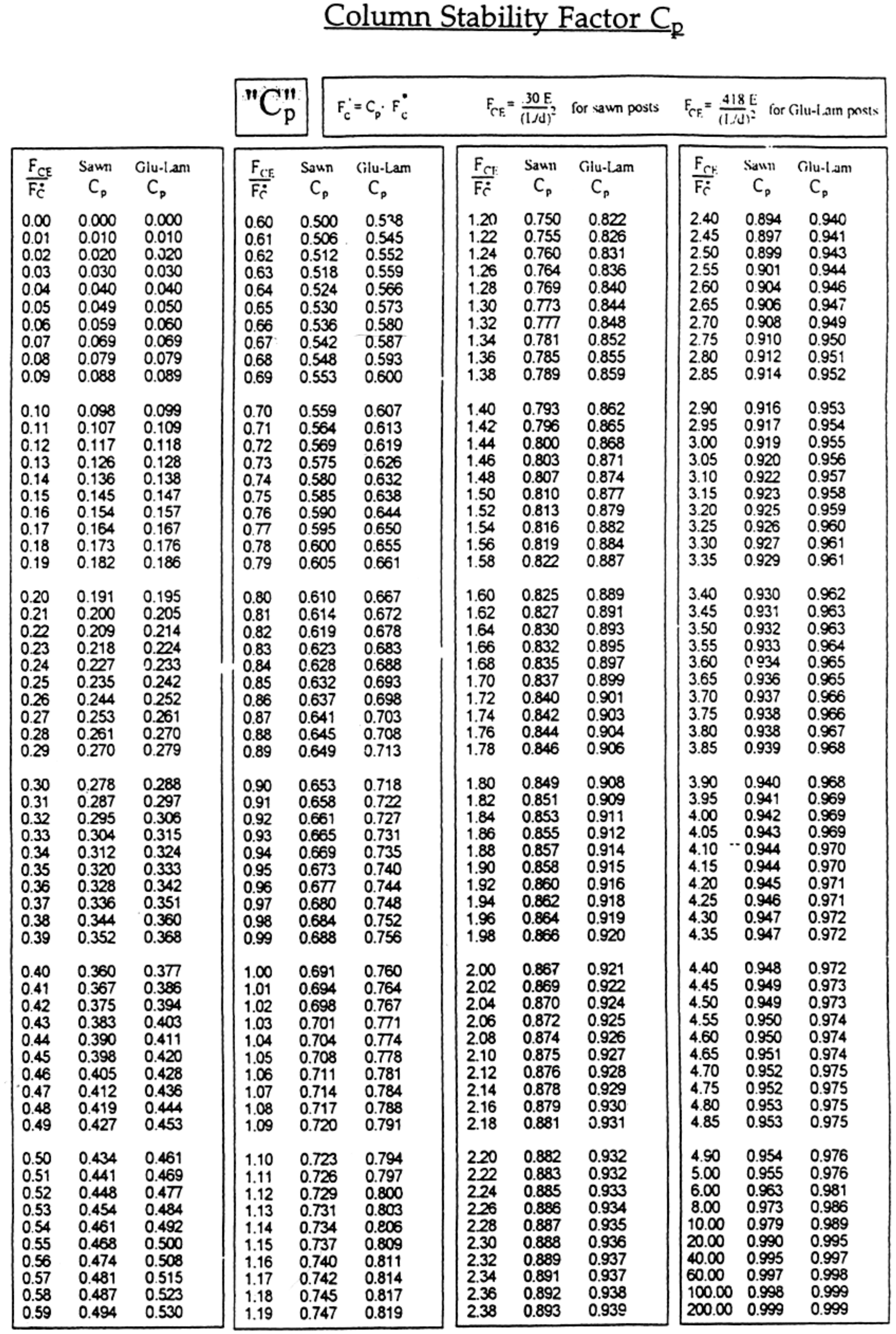
$$F_c' = F_c\left\{1 - \left(\tfrac{1}{3}\right)\left[\left(\frac{L_e}{d}\right)\kappa\right]^4\right\}$$

For *long* columns with L/d>κ, and an assumed safety factor of 2.73: the allowable stress is:

$$F_c = \frac{0.3E}{\left(\frac{L_e}{d}\right)^2}$$

Table 9.3 *Column stability factor* C_p.

Statics and Strength of Materials for Architecture and Building Construction, 2nd ed., Onouye & Kane



Column Stability Factor C_p

"C_p"

$F_c' = C_p \cdot F_c^*$ $F_{CE} = \frac{.30\,E}{(L/d)^2}$ for sawn posts $F_{CE} = \frac{.418\,E}{(L/d)^2}$ for Glu-Lam posts

$\frac{F_{CE}}{F_c^*}$	Sawn C_p	Glu-Lam C_p
0.00	0.000	0.000
0.01	0.010	0.010
0.02	0.020	0.020
0.03	0.030	0.030
0.04	0.040	0.040
0.05	0.049	0.050
0.06	0.059	0.060
0.07	0.069	0.069
0.08	0.079	0.079
0.09	0.088	0.089
0.10	0.098	0.099
0.11	0.107	0.109
0.12	0.117	0.118
0.13	0.126	0.128
0.14	0.136	0.138
0.15	0.145	0.147
0.16	0.154	0.157
0.17	0.164	0.167
0.18	0.173	0.176
0.19	0.182	0.186
0.20	0.191	0.195
0.21	0.200	0.205
0.22	0.209	0.214
0.23	0.218	0.224
0.24	0.227	0.233
0.25	0.235	0.242
0.26	0.244	0.252
0.27	0.253	0.261
0.28	0.261	0.270
0.29	0.270	0.279
0.30	0.278	0.288
0.31	0.287	0.297
0.32	0.295	0.306
0.33	0.304	0.315
0.34	0.312	0.324
0.35	0.320	0.333
0.36	0.328	0.342
0.37	0.336	0.351
0.38	0.344	0.360
0.39	0.352	0.368
0.40	0.360	0.377
0.41	0.367	0.386
0.42	0.375	0.394
0.43	0.383	0.403
0.44	0.390	0.411
0.45	0.398	0.420
0.46	0.405	0.428
0.47	0.412	0.436
0.48	0.419	0.444
0.49	0.427	0.453
0.50	0.434	0.461
0.51	0.441	0.469
0.52	0.448	0.477
0.53	0.454	0.484
0.54	0.461	0.492
0.55	0.468	0.500
0.56	0.474	0.508
0.57	0.481	0.515
0.58	0.487	0.523
0.59	0.494	0.530
0.60	0.500	0.538
0.61	0.506	0.545
0.62	0.512	0.552
0.63	0.518	0.559
0.64	0.524	0.566
0.65	0.530	0.573
0.66	0.536	0.580
0.67	0.542	0.587
0.68	0.548	0.593
0.69	0.553	0.600
0.70	0.559	0.607
0.71	0.564	0.613
0.72	0.569	0.619
0.73	0.575	0.626
0.74	0.580	0.632
0.75	0.585	0.638
0.76	0.590	0.644
0.77	0.595	0.650
0.78	0.600	0.655
0.79	0.605	0.661
0.80	0.610	0.667
0.81	0.614	0.672
0.82	0.619	0.678
0.83	0.623	0.683
0.84	0.628	0.688
0.85	0.632	0.693
0.86	0.637	0.698
0.87	0.641	0.703
0.88	0.645	0.708
0.89	0.649	0.713
0.90	0.653	0.718
0.91	0.658	0.722
0.92	0.661	0.727
0.93	0.665	0.731
0.94	0.669	0.735
0.95	0.673	0.740
0.96	0.677	0.744
0.97	0.680	0.748
0.98	0.684	0.752
0.99	0.688	0.756
1.00	0.691	0.760
1.01	0.694	0.764
1.02	0.698	0.767
1.03	0.701	0.771
1.04	0.704	0.774
1.05	0.708	0.778
1.06	0.711	0.781
1.07	0.714	0.784
1.08	0.717	0.788
1.09	0.720	0.791
1.10	0.723	0.794
1.11	0.726	0.797
1.12	0.729	0.800
1.13	0.731	0.803
1.14	0.734	0.806
1.15	0.737	0.809
1.16	0.740	0.811
1.17	0.742	0.814
1.18	0.745	0.817
1.19	0.747	0.819
1.20	0.750	0.822
1.22	0.755	0.826
1.24	0.760	0.831
1.26	0.764	0.836
1.28	0.769	0.840
1.30	0.773	0.844
1.32	0.777	0.848
1.34	0.781	0.852
1.36	0.785	0.855
1.38	0.789	0.859
1.40	0.793	0.862
1.42	0.796	0.865
1.44	0.800	0.868
1.46	0.803	0.871
1.48	0.807	0.874
1.50	0.810	0.877
1.52	0.813	0.879
1.54	0.816	0.882
1.56	0.819	0.884
1.58	0.822	0.887
1.60	0.825	0.889
1.62	0.827	0.891
1.64	0.830	0.893
1.66	0.832	0.895
1.68	0.835	0.897
1.70	0.837	0.899
1.72	0.840	0.901
1.74	0.842	0.903
1.76	0.844	0.904
1.78	0.846	0.906
1.80	0.849	0.908
1.82	0.851	0.909
1.84	0.853	0.911
1.86	0.855	0.912
1.88	0.857	0.914
1.90	0.858	0.915
1.92	0.860	0.916
1.94	0.862	0.918
1.96	0.864	0.919
1.98	0.866	0.920
2.00	0.867	0.921
2.02	0.869	0.922
2.04	0.870	0.924
2.06	0.872	0.925
2.08	0.874	0.926
2.10	0.875	0.927
2.12	0.876	0.928
2.14	0.878	0.929
2.16	0.879	0.930
2.18	0.881	0.931
2.20	0.882	0.932
2.22	0.883	0.932
2.24	0.885	0.933
2.26	0.886	0.934
2.28	0.887	0.935
2.30	0.888	0.936
2.32	0.889	0.937
2.34	0.891	0.937
2.36	0.892	0.938
2.38	0.893	0.939
2.40	0.894	0.940
2.45	0.897	0.941
2.50	0.899	0.943
2.55	0.901	0.944
2.60	0.904	0.946
2.65	0.906	0.947
2.70	0.908	0.949
2.75	0.910	0.950
2.80	0.912	0.951
2.85	0.914	0.952
2.90	0.916	0.953
2.95	0.917	0.954
3.00	0.919	0.955
3.05	0.920	0.956
3.10	0.922	0.957
3.15	0.923	0.958
3.20	0.925	0.959
3.25	0.926	0.960
3.30	0.927	0.961
3.35	0.929	0.961
3.40	0.930	0.962
3.45	0.931	0.963
3.50	0.932	0.963
3.55	0.933	0.964
3.60	0.934	0.965
3.65	0.936	0.965
3.70	0.937	0.966
3.75	0.938	0.966
3.80	0.938	0.967
3.85	0.939	0.968
3.90	0.940	0.968
3.95	0.941	0.969
4.00	0.942	0.969
4.05	0.943	0.969
4.10	0.944	0.970
4.15	0.944	0.970
4.20	0.945	0.971
4.25	0.946	0.971
4.30	0.947	0.972
4.35	0.947	0.972
4.40	0.948	0.972
4.45	0.949	0.973
4.50	0.949	0.973
4.55	0.950	0.974
4.60	0.950	0.974
4.65	0.951	0.974
4.70	0.952	0.975
4.75	0.952	0.975
4.80	0.953	0.975
4.85	0.953	0.975
4.90	0.954	0.976
5.00	0.955	0.976
6.00	0.963	0.981
8.00	0.973	0.986
10.00	0.979	0.989
20.00	0.990	0.995
40.00	0.995	0.997
60.00	0.997	0.998
100.00	0.998	0.999
200.00	0.999	0.999

Table developed and permission for use granted by Professor Ed Lebert, Dept. of Architecture, University of Washington.

SECTION PROPERTIES / STANDARD SIZES To the extent that other considerations will permit, the finished sizes of structural glued laminated timber as given in **Table B constitute** normal industry practice. Industry standards do, however, permit the use of any depth or width of glued laminated timber. Dimension lumber of 1½ in. net thickness is normally used for laminating straight members. **The modified section modulus includes size factor (C_F), and no further reduction of bending stress for size is needed.**

DEPTH, d in.	AREA, A in.^{2}	MODIFIED SECTION MODULUS, SC_F in.^{3}	MOMENT OF INERTIA, I in.^{4}
3⅛" WIDTH			
6.0	18.8	18.8	56
7.5	23.4	29.3	110
9.0	28.1	42.2	190
10.5	32.8	57.4	302
12.0	37.5	75.0	450
13.5	42.2	93.7	641
15.0	46.9	114.3	879
16.5	51.6	136.9	1,170
18.0	56.3	161.3	1,519
19.5	60.9	187.6	1,931
21.0	65.6	215.8	2,412
22.5	70.3	245.9	2,966
24.0	75.0	277.8	3,600
5⅛" WIDTH			
7.5	38.4	48.0	180
9.0	46.1	69.2	311
10.5	53.8	94.2	494
12.0	61.5	123.0	738
13.5	69.2	153.6	1,051
15.0	76.9	187.5	1,441
16.5	84.6	224.5	1,919
18.0	92.3	264.6	2,491
19.5	99.9	307.7	3,167
21.0	107.6	354.0	3,955
22.5	115.3	403.2	4,865
24.0	123.0	455.5	5,904
25.5	130.7	510.8	7,082
27.0	138.4	569.0	8,406
28.5	146.1	630.2	9,887
30.0	153.8	694.3	11,531
31.5	161.4	761.4	13,349
33.0	169.1	831.3	15,348
34.5	176.8	904.1	17,538
36.0	184.5	979.8	19,926
6¾" WIDTH			
12.0	81.0	162.0	972
13.5	91.1	202.4	1,384
15.0	101.3	246.9	1,898
16.5	111.4	295.6	2,527
18.0	121.5	348.4	3,280
19.5	131.6	405.3	4,171
21.0	141.8	466.2	5,209
22.5	151.9	531.1	6,407
24.0	162.0	600.0	7,776
25.5	172.1	672.8	9,327
27.0	182.3	749.5	11,072
28.5	192.4	830.0	13,021
30.0	202.5	914.5	15,188
31.5	212.6	1,002.8	17,581
33.0	222.8	1,094.9	20,215
34.5	232.9	1,190.8	23,098
36.0	243.0	1,290.5	26,244
37.5	253.1	1,393.9	29,663
39.0	263.3	1,501.1	33,367
40.5	273.4	1,612.0	37,367
42.0	283.5	1,726.6	41,674
43.5	293.6	1,845.0	46,301
45.0	303.8	1,967.0	51,258
46.5	313.9	2,092.6	56,556
48.0	324.0	2,222.0	62,208
8¾" WIDTH			
12.0	105.0	210.0	1,260
13.5	118.1	262.3	1,794
15.0	131.3	320.1	2,461
16.5	144.4	383.2	3,276
18.0	157.5	451.7	4,252
19.5	170.6	525.4	5,407
21.0	183.8	604.4	6,753
22.5	196.9	688.5	8,306
24.0	210.0	777.7	10,080
25.5	223.1	872.1	12,091
27.0	236.3	971.5	14,352
28.5	249.4	1,076.0	16,880
30.0	262.5	1,185.5	19,688
31.5	275.6	1,299.9	22,791
33.0	288.8	1,419.3	26,204
34.5	301.9	1,543.6	29,942
36.0	315.0	1,672.8	34,020
37.5	328.1	1,806.9	38,452
39.0	341.3	1,945.9	43,253
40.5	354.4	2,089.6	48,439
42.0	367.5	2,238.2	54,022
43.5	380.6	2,391.6	60,020
45.0	393.8	2,549.8	66,445
46.5	406.9	2,712.7	73,314
48.0	420.0	2,880.3	80,640
49.5	433.1	3,052.7	88,439
51.0	446.3	3,229.8	96,725
52.5	459.4	3,411.6	105,513
54.0	472.5	3,598.0	114,818
55.5	485.6	3,789.1	124,654
57.0	498.8	3,984.9	135,037
58.5	511.9	4,185.3	145,980
60.0	525.0	4,390.3	157,500
10¾" WIDTH			
15.0	161.3	393.3	3,023
16.5	177.4	470.8	4,024
18.0	193.5	554.9	5,224
19.5	209.6	645.5	6,642
21.0	225.8	742.5	8,296
22.5	241.9	845.8	10,204
24.0	258.0	955.5	12,384
25.5	274.1	1,071.4	14,854
27.0	290.3	1,193.6	17,633
28.5	306.4	1,321.9	20,738
30.0	322.5	1,456.4	24,188
31.5	338.6	1,597.0	28,000
33.0	354.8	1,743.7	32,194
34.5	370.9	1,896.4	36,786
36.0	387.0	2,055.2	41,796
37.5	403.1	2,219.9	47,241
39.0	419.3	2,390.6	53,140
40.5	435.4	2,567.3	59,510
42.0	451.5	2,749.8	66,370
43.5	467.6	2,938.3	73,739
45.0	483.8	3,132.6	81,633
46.5	499.9	3,332.7	90,071
48.0	516.0	3,538.7	99,072
49.5	532.1	3,750.5	108,653
51.0	548.3	3,968.0	118,833
52.5	564.4	4,191.4	129,630
54.0	580.5	4,420.4	141,062
55.5	596.6	4,655.2	153,146
57.0	612.8	4,895.7	165,902
58.5	628.9	5,141.9	179,347
60.0	645.0	5,398.8	193,500
61.5	661.1	5,651.4	208,379
63.0	677.3	5,914.5	224,000
64.5	693.4	6,183.3	240,384
66.0	709.5	6,457.8	257,548
67.5	725.6	6,737.8	275,511
69.0	741.8	7,023.4	294,289
70.5	757.9	7,314.6	313,902
72.0	774.0	7,611.3	334,368
73.5	790.1	7,913.6	355,704

Glue Laminated Timber

These members come in nominal widths of 3, 4, 6, 8, 10, 12, 14 and 16 inches. The depth can exceed 12 inches, so the size factor, C_F must be used. The formula is based on a uniformly loaded beam, simply supported with an l/d ratio of 21. With a single midspan load, multiply C_F by 1.078. With two loads at third points, multiply C_F by 0.968. (Note: the table on page 4 provides section modulus that include C_F).

$$C_F = (12/d)^{1/9} \le 1.0$$

If a glulam is subject to lateral buckling, the slenderness factor is used, and the size factor is not.

Bending of a curved glulam causes radial stresses (like membrane pressures) in tension and compression which can be evaluated for an arc with a radius of R at the neutral axis from:

$$f_r = \frac{3M}{2Rbd}$$ for constant rectangular cross section

$$f_r \le F_R \quad \text{where} \quad F_R = \begin{cases} F_{C\perp} \\ \tfrac{1}{3} F_V \end{cases}$$

ASD Beam Design Flow Chart