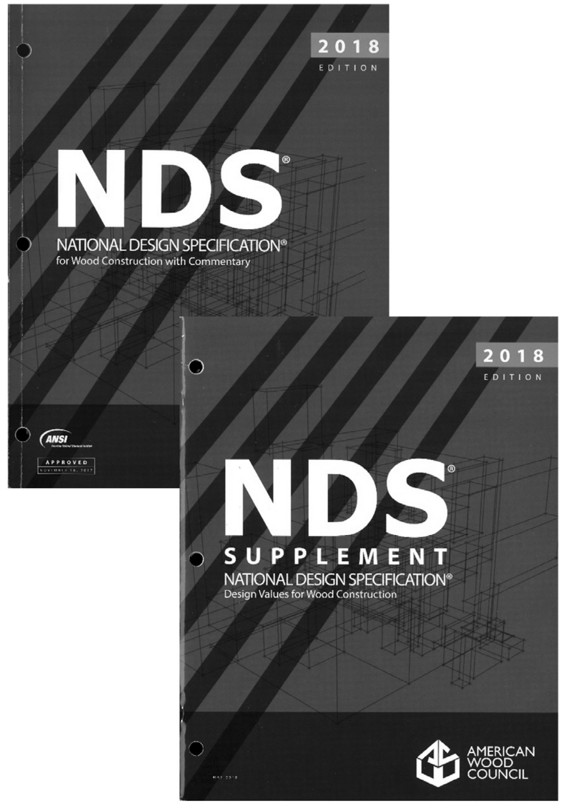
Architecture 544
Wood Structures

Wood Beam Analysis and Design

- ASD approach
- NDS criteria
- Wood Beam Analysis
- Wood Beam Design



Allowable Stresses

From the NDS Supplement

DESIGN VALUES FOR WOOD CONSTRUCTION – NDS SUPPLEMENT 35

Table 4A (Cont.) **Reference Design Values for Visually Graded Dimension Lumber (2" - 4" thick)[1,2,3]**

(All species except Southern Pine — see Table 4B) (Tabulated design values are for normal load duration and dry service conditions. See NDS 4.3 for a comprehensive description of design value adjustment factors.)

USE WITH TABLE 4A ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v	Compression perpendicular to grain $F_{c\perp}$	Compression parallel to grain F_c	Modulus of Elasticity E	Modulus of Elasticity E_{min}	Specific Gravity[4] G	Grading Rules Agency
HEM-FIR										
Select Structural	2" & wider	1,400	925	150	405	1,500	1,600,000	580,000	0.43	WCLIB WWPA
No. 1 & Btr	2" & wider	1,100	725	150	405	1,350	1,500,000	550,000		
No. 1	2" & wider	975	625	150	405	1,350	1,500,000	550,000		
No. 2	2" & wider	850	525	150	405	1,300	1,300,000	470,000		
No. 3	2" & wider	500	300	150	405	725	1,200,000	440,000		
Stud	2" & wider	675	400	150	405	800	1,200,000	440,000		
Construction	2" - 4" wide	975	600	150	405	1,550	1,300,000	470,000		
Standard	2" - 4" wide	550	325	150	405	1,300	1,200,000	440,000		
Utility	2" - 4" wide	250	150	150	405	850	1,100,000	400,000		

Allowable Stress Design by NDS
Flexure

$F_b' \geq f_b$

Allowable Flexure Stress F_b'

F_b from NDS Supplement tables determined by species and grade

$F_b' = F_b$ (usage factors)

usage factors for flexure:

- C_D Load Duration Factor
- C_M Moisture Factor
- C_t Temperature Factor
- C_L Beam Stability Factor
- C_F Size Factor
- C_{fu} Flat Use
- C_i Incising Factor
- C_r Repetitive Member Factor

$\geq$

Actual Flexure Stress f_b

$f_b = Mc/I = M/S$

$S = I/c = bd^2/6$

Allowable Stress Design by NDS
Shear

$F_v' \geq f_v$

Allowable Shear Stress Fv'

F_v from tables determined by species and grade

$F_v' = F_v$ (usage factors)

usage factors for shear:

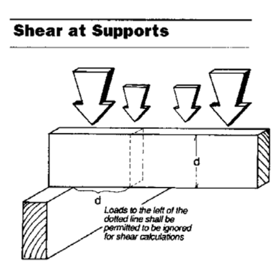
- C_D Load Duration Factor
- C_M Moisture Factor
- C_t Temperature Factor
- C_i Incising Factor

$\geq$

Actual Shear Stress fv

$f_v = VQ / I b = 1.5 V/A$

Can use V at d from support as maximum



Allowable Stress Design by NDS
Compression

$F_c' \geq f_c$

Allowable Compression Stress F_c'

F_c from NDS Supplement tables determined by species and grade

F_c' = F_c (usage factors)

usage factors for flexure:
- C_D Load Duration Factor
- C_M Moisture Factor
- C_t Temperature Factor
- C_F Size Factor
- C_i Incising Factor
- C_P Column Stability Factor

$\geq$

Actual Compression Stress f_c

$f_c = P/A$

Adjustment Factors

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD only	ASD and LRFD										LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Incising Factor	Repetitive Member Factor	Column Stability Factor	Buckling Stiffness Factor	Bearing Area Factor	Format Conversion Factor K_F	Resistance Factor ϕ	Time Effect Factor
$F_b' = F_b$	x	C_D	C_M	C_t	C_L	C_F	C_{fu}	C_i	C_r	-	-	-	2.54	0.85	λ
$F_t' = F_t$	x	C_D	C_M	C_t	-	C_F	-	C_i	-	-	-	-	2.70	0.80	λ
$F_v' = F_v$	x	C_D	C_M	C_t	-	-	-	C_i	-	-	-	-	2.88	0.75	λ
$F_c' = F_c$	x	C_D	C_M	C_t	-	C_F	-	C_i	-	C_P	-	-	2.40	0.90	λ
$F_{c\perp}' = F_{c\perp}$	x	-	C_M	C_t	-	-	-	C_i	-	-	-	C_b	1.67	0.90	-
$E' = E$	x	-	C_M	C_t	-	-	-	C_i	-	-	-	-	-	-	-
$E_{min}' = E_{min}$	x	-	C_M	C_t	-	-	-	C_i	-	-	C_T	-	1.76	0.85	-

Adjustment Factors

Allowable Flexure Stress F_b'

F_b from tables determined by species and grade

$F_b' = F_b (C_D\ C_M\ C_t\ C_L\ C_F\ C_{fu}\ C_i\ C_r)$

Usage factors for flexure:

C_D Load Duration Factor

Figure B1 Load Duration Factors, C_D, for Various Load Durations

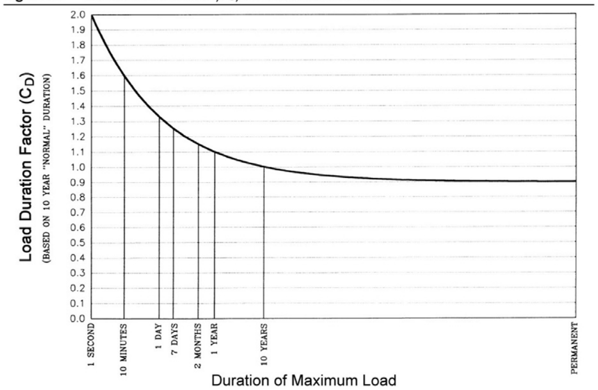


Table 2.3.2 Frequently Used Load Duration Factors, C_D[1]

Load Duration	C_D	Typical Design Loads
Permanent	0.9	Dead Load
Ten years	1.0	Occupancy Live Load
Two months	1.15	Snow Load
Seven days	1.25	Construction Load
Ten minutes	1.6	Wind/Earthquake Load
Impact[2]	2.0	Impact Load

(1) Actual stress due to (DL) ≤ (0.9) (Design value)
(2) Actual stress due to (DL+LL) ≤ (1.0) (Design value)
(3) Actual stress due to (DL+WL) ≤ (1.6) (Design value)
(4) Actual stress due to (DL+LL+SL) ≤ (1.15) (Design value)
(5) Actual stress due to (DL+LL+WL) ≤ (1.6) (Design value)
(6) Actual stress due to (DL+SL+WL) ≤ (1.6) (Design value)
(7) Actual stress due to (DL+LL+SL+WL) ≤ (1.6) (Design value)

Adjustment Factors

Allowable Flexure Stress F_b'

F_b from tables determined by species and grade

$F_b' = F_b (C_D\ C_M\ C_t\ C_L\ C_F\ C_{fu}\ C_i\ C_r)$

Usage factors for flexure:

C_t Temperature Factor

Table 2.3.3 Temperature Factor, C_t

Reference Design Values	In-Service Moisture Conditions[1]	C_t T≤100°F	C_t 100°F<T≤125°F	C_t 125°F<T≤150°F
F_t, E, E_{min}	Wet or Dry	1.0	0.9	0.9
F_b, F_v, F_c, and $F_{c\perp}$	Dry	1.0	0.8	0.7
	Wet	1.0	0.7	0.5

1. Wet and dry service conditions for sawn lumber, structural glued laminated timber, prefabricated wood I-joists, structural composite lumber, wood structural panels and cross-laminated timber are specified in 4.1.4, 5.1.4, 7.1.4, 8.1.4, 9.3.3, and 10.1.5 respectively.

Adjustment Factors

Allowable Flexure Stress F_b'

F_b from NDS tables

$F_b' = F_b (C_D\ C_M\ C_t\ C_L\ C_F\ C_{fu}\ C_i\ C_r)$

Usage factors for flexure:

- **C_M** Moisture Factor
- **C_F** Size Factor

Wet Service Factor, C_M

When dimension lumber is used where moisture content will exceed 19% for an extended time period, design values shall be multiplied by the appropriate wet service factors from the following table:

Wet Service Factors, C_M

F_b	F_t	F_v	$F_{c\perp}$	F_c	E and E_{min}
0.85*	1.0	0.97	0.67	0.8**	0.9

* when $(F_b)(C_F) \le$ 1,150 psi, C_M = 1.0

** when $(F_c)(C_F) \le$ 750 psi, C_M = 1.0

Size Factors, C_F

Grades	Width (depth)	F_b Thickness (breadth) 2" & 3"	F_b Thickness (breadth) 4"	F_t	F_c
Select Structural, No.1 & Btr, No.1, No.2, No.3	2", 3", & 4"	1.5	1.5	1.5	1.15
	5"	1.4	1.4	1.4	1.1
	6"	1.3	1.3	1.3	1.1
	8"	1.2	1.3	1.2	1.05
	10"	1.1	1.2	1.1	1.0
	12"	1.0	1.1	1.0	1.0
	14" & wider	0.9	1.0	0.9	0.9
Stud	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
	8" & wider	Use No.3 Grade tabulated design values and size factors			
Construction, Standard	2", 3", & 4"	1.0	1.0	1.0	1.0
Utility	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	—	0.4	0.6

Adjustment Factors

Allowable Flexure Stress F_b'

F_b from NDS tables

$F_b' = F_b (C_D\ C_M\ C_t\ C_L\ C_F\ C_{fu}\ C_i\ C_r)$

Usage factors for flexure:

- **C_{fu}** Flat Use
- **C_r** Repetitive Member Factor

Flat Use Factor, C_{fu}

Bending design values adjusted by size factors are based on edgewise use (load applied to narrow face). When dimension lumber is used flatwise (load applied to wide face), the bending design value, F_b, shall also be permitted to be multiplied by the following flat use factors:

Flat Use Factors, C_{fu}

Width (depth)	Thickness (breadth) 2" & 3"	Thickness (breadth) 4"
2" & 3"	1.0	—
4"	1.1	1.0
5"	1.1	1.05
6"	1.15	1.05
8"	1.15	1.05
10" & wider	1.2	1.1

Repetitive Member Factor, C_r

Bending design values, F_b, for dimension lumber 2" to 4" thick shall be multiplied by the repetitive member factor, C_r = 1.15, when such members are used as joists, truss chords, rafters, studs, planks, decking, or similar members which are in contact or spaced not more than 24" on center, are not less than 3 in number and are joined by floor, roof, or other load distributing elements adequate to support the design load.

Adjustment Factors

Allowable Flexure Stress F_b'

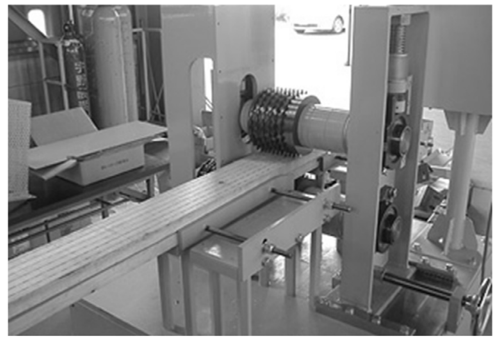
F_b from tables determined by species and grade

$F_b' = F_b (C_D C_M C_t C_L C_F C_{fu} C_i C_r)$

Usage factors for flexure:
C_i Incising Factor

Table 4.3.8 Incising Factors, C_i

Design Value	C_i
E, E_{min}	0.95
F_b, F_t, F_c, F_v	0.80
$F_{c\perp}$	1.00



Adjustment Factors

Allowable Flexure Stress F_b'

F_b from tables determined by species and grade

$F_b' = F_b (C_D C_M C_t C_L C_F C_{fu} C_i C_r)$

Usage factors for flexure:
C_L Beam Stability Factor

3.3.3 Beam Stability Factor, C_L

3.3.3.1 When the depth of a bending member does not exceed its breadth, d ≤ b, no lateral support is required and $C_L = 1.0$.

3.3.3.2 When rectangular sawn lumber bending members are laterally supported in accordance with 4.4.1, $C_L = 1.0$.

3.3.3.3 When the compression edge of a bending member is supported throughout its length to prevent lateral displacement, and the ends at points of bearing have lateral support to prevent rotation, $C_L = 1.0$.

3.3.3.4 Where the depth of a bending member exceeds its breadth, d > b, lateral support shall be provided at points of bearing to prevent rotation.

4.4.1 Stability of Bending Members

2x4 (a) $d/b \leq 2$; no lateral support shall be required.

2x6-8 (b) $2 < d/b \leq 4$; the ends shall be held in position, as by full depth solid blocking, bridging, hangers, nailing, or bolting to other framing members, or other acceptable means.

2x10 (c) $4 < d/b \leq 5$; the compression edge of the member shall be held in line for its entire length to prevent lateral displacement, as by adequate sheathing or subflooring, and ends at point of bearing shall be held in position to prevent rotation and/or lateral displacement.

2x12 (d) $5 < d/b \leq 6$; bridging, full depth solid blocking or diagonal cross bracing shall be installed at intervals not exceeding 8 feet, the compression edge of the member shall be held in line as by adequate sheathing or subflooring, and the ends at points of bearing shall be held in position to prevent rotation and/or lateral displacement.

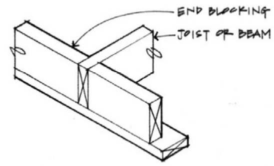
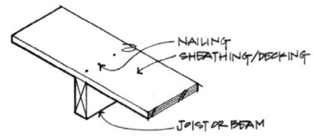
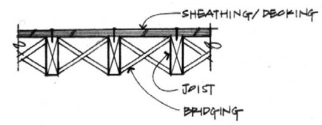
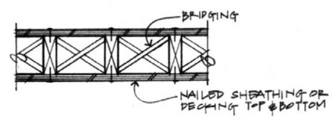
2x14 (e) $6 < d/b \leq 7$; both edges of the member shall be held in line for their entire length and ends at points of bearing shall be held in position to prevent rotation and/or lateral displacement.

C_L

C_L = 1.0
when bracing meets 4.4.1
for the depth/width ratio

Otherwise

C_L < 1.0
calculate factor using
section 3.3.3

Beam Depth/ Width Ratio	Type of Lateral Bracing Required	Example
2 to 1	None	
3 to 1 2x6 2x8	The ends of the beam should be held in position	
5 to 1 2x10	Hold compression edge in line (continuously)	
6 to 1 2x12	Diagonal bridging should be used	
7 to 1 2x14	Both edges of the beam should be held in line	

C_L Beam Stability Factor

In the case bracing provisions of 4.4.1 cannot be met,
C_L is calculated using equation 3.3-6

The maximum allowable slenderness, R_B is 50

Table 3.3.3 Effective Length, ℓ_e, for Bending Members

Cantilever[1]	when $\ell_u/d < 7$		when $\ell_u/d \geq 7$
Uniformly distributed load	$\ell_e=1.33\ \ell_u$		$\ell_e=0.90\ \ell_u + 3d$
Concentrated load at unsupported end	$\ell_e=1.87\ \ell_u$		$\ell_e=1.44\ \ell_u + 3d$
Single Span Beam[1,2]	when $\ell_u/d < 7$		when $\ell_u/d \geq 7$
Uniformly distributed load	$\ell_e=2.06\ \ell_u$		$\ell_e=1.63\ \ell_u + 3d$
Concentrated load at center with no intermediate lateral support	$\ell_e=1.80\ \ell_u$		$\ell_e=1.37\ \ell_u + 3d$
Concentrated load at center with lateral support at center		$\ell_e=1.11\ \ell_u$	
Two equal concentrated loads at 1/3 points with lateral support at 1/3 points		$\ell_e=1.68\ \ell_u$	
Three equal concentrated loads at 1/4 points with lateral support at 1/4 points		$\ell_e=1.54\ \ell_u$	
Four equal concentrated loads at 1/5 points with lateral support at 1/5 points		$\ell_e=1.68\ \ell_u$	
Five equal concentrated loads at 1/6 points with lateral support at 1/6 points		$\ell_e=1.73\ \ell_u$	
Six equal concentrated loads at 1/7 points with lateral support at 1/7 points		$\ell_e=1.78\ \ell_u$	
Seven or more equal concentrated loads, evenly spaced, with lateral support at points of load application		$\ell_e=1.84\ \ell_u$	
Equal end moments		$\ell_e=1.84\ \ell_u$	

1. For single span or cantilever bending members with loading conditions not specified in Table 3.3.3:
   $\ell_e = 2.06\ \ell_u$ when $\ell_u/d < 7$
   $\ell_e = 1.63\ \ell_u + 3d$ when $7 \leq \ell_u/d \leq 14.3$
   $\ell_e = 1.84\ \ell_u$ when $\ell_u/d > 14.3$
2. Multiple span applications shall be based on table values or engineering analysis.

3.3.3.6 The slenderness ratio, R_B, for bending members shall be calculated as follows:

$$R_B = \sqrt{\frac{\ell_e d}{b^2}} \quad (3.3\text{-}5)$$

3.3.3.7 The slenderness ratio for bending members, R_B, shall not exceed 50.

3.3.3.8 The beam stability factor shall be calculated as follows:

$$C_L = \frac{1+\left(F_{bE}/F_b^*\right)}{1.9} - \sqrt{\left[\frac{1+\left(F_{bE}/F_b^*\right)}{1.9}\right]^2 - \frac{F_{bE}/F_b^*}{0.95}} \quad (3.3\text{-}6)$$

where:

F_b^* = reference bending design value multiplied by all applicable adjustment factors except C_{fu}, C_V (when $C_V \leq 1.0$), and C_L (see 2.3), psi

$$F_{bE} = \frac{1.20\,E_{min}'}{R_B^2}$$

Adjustment Factors for Shear

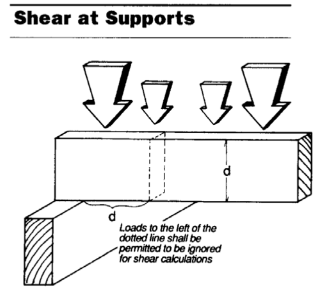
Allowable Flexure Stress F_v'

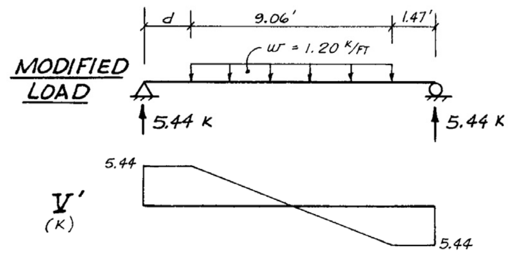
F_v from tables determined by species and grade

$F_v' = F_v$ (usage factors)

Usage factors for shear:

- C_D Load Duration Factor
- C_M Moisture Factor
- C_t Temperature Factor
- C_i Incising Factor





Modified shear V' used to compute reduced shear f'_v

Analysis Procedure

Given: loading, <u>member size</u>, material and span.

Req'd: Safe or Unsafe

1. Find Max Shear & Moment
   - Simple case – equations
   - Complex case - diagrams
2. Determine actual stresses
   - $f_b = M/S$
   - $f_v = 1.5\ V/A$
3. Determine allowable stresses
   - F_b and F_v (from NDS)
   - $F_b' = F_b$ (usage factors)
   - $F_v' = F_v$ (usage factors)
4. Check that actual ≤ allowable
   - $f_b \leq F'_b$
   - $f_v \leq F'_v$
5. Check deflection
6. Check bearing (F_b = Reaction/$A_{bearing}$)

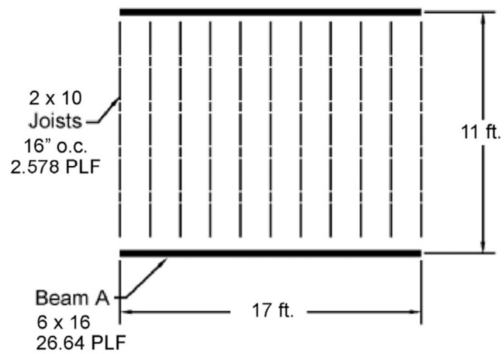
Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.^{2}	X-X AXIS Section Modulus S_{xx} in.^{3}	X-X AXIS Moment of Inertia I_{xx} in.^{4}	Y-Y AXIS Section Modulus S_{yy} in.^{3}	Y-Y AXIS Moment of Inertia I_{yy} in.^{4}
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
1 x 4	3/4 x 3-1/2	2.625	1.531	2.680	0.328	0.123
1 x 6	3/4 x 5-1/2	4.125	3.781	10.40	0.516	0.193
1 x 8	3/4 x 7-1/4	5.438	6.570	23.82	0.680	0.255
1 x 10	3/4 x 9-1/4	6.938	10.70	49.47	0.867	0.325
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396
Dimension Lumber (see NDS 4.1.3.2) and Decking (see NDS 4.1.3.5)						
2 x 3	1-1/2 x 2-1/2	3.750	1.56	1.953	0.938	0.703
2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164
2 x 14	1-1/2 x 13-1/4	19.88	43.89	290.8	4.969	3.727
3 x 4	2-1/2 x 3-1/2	8.75	5.10	8.932	3.646	4.557
3 x 5	2-1/2 x 4-1/2	11.25	8.44	18.98	4.688	5.859
3 x 6	2-1/2 x 5-1/2	13.75	12.60	34.66	5.729	7.161
3 x 8	2-1/2 x 7-1/4	18.13	21.90	79.39	7.552	9.440
3 x 10	2-1/2 x 9-1/4	23.13	35.65	164.9	9.635	12.04
3 x 12	2-1/2 x 11-1/4	28.13	52.73	296.6	11.72	14.65
3 x 14	2-1/2 x 13-1/4	33.13	73.15	484.6	13.80	17.25
3 x 16	2-1/2 x 15-1/4	38.13	96.90	738.9	15.89	19.86
4 x 4	3-1/2 x 3-1/2	12.25	7.15	12.51	7.146	12.51
4 x 5	3-1/2 x 4-1/2	15.75	11.81	26.58	9.188	16.08
4 x 6	3-1/2 x 5-1/2	19.25	17.65	48.53	11.23	19.65
4 x 8	3-1/2 x 7-1/4	25.38	30.66	111.1	14.80	25.90
4 x 10	3-1/2 x 9-1/4	32.38	49.91	230.8	18.89	33.05
4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20
4 x 14	3-1/2 x 13-1/4	46.38	102.41	678.5	27.05	47.34
4 x 16	3-1/2 x 15-1/4	53.38	135.66	1034	31.14	54.49

from *NDS 2012*

Analysis Example

Given:

DATASET: 1	-2-
Span A	17 FT
Span B	11 FT
Joist O.C. Spacing	16 IN
Wood Density	45 PCF
Joist Size	2x10 NOMINAL
Beam Size	6x16 NOMINAL
Floor DL (not including joist)	3 PSF
Occupancy or Use	assembly area - fixed seats



Req'd: pass or fail for floor joist

ASCE-7 Table 4.3-1: Live Load = 60 PSF

ASCE-7 2.4.1 ASD load case: D + L

2x10 Joist + floor load:

D + L

$\left(\text{SELF WEIGHT} + D\,\frac{o.c.}{12}\right) + \left(L\,\frac{o.c.}{12}\right)$

$\left(4.336\text{ PLF} + 3\text{ PSF}\,\frac{16''}{12}\right) + \left(60\text{ PSF}\,\frac{16''}{12}\right)$

8.336 PLF + 80 PLF = 88.336 PLF

Analysis Example (joist)

1. Find Max Shear & Moment on Joist

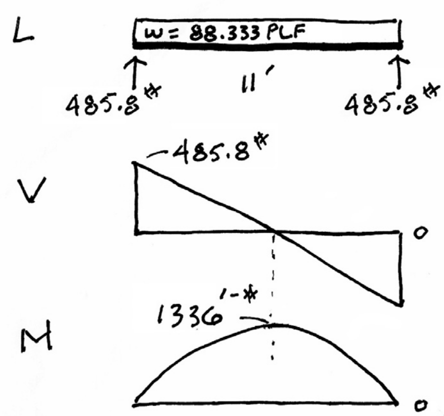
By equations:

Shear:

$$\frac{wl}{2} = \frac{88.336\,(11)}{2} = 485.848 \text{ lbs}$$

Moment:

$$\frac{wl^2}{8} = \frac{88.336\,(11^2)}{8} = 1336.08 \text{ ft-lbs}$$



Analysis Example

2. Determine actual stresses in joists
   - f_b = M/S
   - f_v = 1.5 V/A

$$f_b = \frac{M}{S_x} = \frac{1336'\text{-}\# \,(12)}{21.39 \text{ in}^3} = 749.5 \text{ psi}$$

$$f_v = \frac{3}{2}\frac{V}{A} = \frac{1.5\,(485.8)^{\#}}{13.88 \text{ in}^2} = 52.5 \text{ psi}$$

Species and Grade

3. Determine allowable stresses – NDS Supplement
   - F_b = 875 psi
   - F_v = 135 psi

Table 4A (Cont.) **Reference Design Values for Visually Graded Dimension Lumber (2" - 4" thick)[1,2,3]**

(All species except Southern Pine—see Table 4B) (Tabulated design values are for normal load duration and dry service conditions. See NDS 4.3 for a comprehensive description of design value adjustment factors.)

USE WITH TABLE 4A ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Design values in pounds per square inch (psi)							Specific Gravity[4]	Grading Rules Agency
		Bending	Tension parallel to grain	Shear parallel to grain	Compression perpendicular to grain	Compression parallel to grain	Modulus of Elasticity			
		F_b	F_t	F_v	$F_{c\perp}$	F_c	E	E_{min}	G	
SPRUCE-PINE-FIR										
Select Structural	2" & wider	1,250	700	135	425	1,400	1,500,000	550,000	0.42	NLGA
No. 1/ No. 2		875	450	135	425	1,150	1,400,000	510,000		
No. 3		500	250	135	425	650	1,200,000	440,000		
Stud	2" & wider	675	350	135	425	725	1,200,000	440,000		
Construction	2" - 4" wide	1,000	500	135	425	1,400	1,300,000	470,000		
Standard		550	275	135	425	1,150	1,200,000	440,000		
Utility		275	125	135	425	750	1,100,000	400,000		

Analysis Example

3. Determine allowable stresses – NDS Supplement
   - Adjustment Factors

Determine factors:

CD = ?
CM = 1
Ct = 1
CL = ?
CF = ?
Cfu = 1
Ci = 1
Cr = ?

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD only	ASD and LRFD										LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Incising Factor	Repetitive Member Factor	Column Stability Factor	Buckling Stiffness Factor	Bearing Area Factor	Format Conversion Factor	Resistance Factor	Time Effect Factor
$F_b' = F_b$	x	C_D	C_M	C_t	C_L	C_F	C_{fu}	C_i	C_r	-	-	-	K_F	ϕ_b	λ
$F_v' = F_v$	x	C_D	C_M	C_t	-	-	-	C_i	-	-	-	-	K_F	ϕ_v	λ

Analysis Example

C_D Load duration factor

Occupancy LL (10 years) = 1.0

Table 2.3.2 Frequently Used Load Duration Factors, C_D[1]

Load Duration	C_D	Typical Design Loads
Permanent	0.9	Dead Load
Ten years	1.0	Occupancy Live Load
Two months	1.15	Snow Load
Seven days	1.25	Construction Load
Ten minutes	1.6	Wind/Earthquake Load
Impact[2]	2.0	Impact Load

C_F Size factor

2 x 10
use 1.1

Size Factors, C_F

		F_b		F_t	F_c
		Thickness (breadth)			
Grades	Width (depth)	2" & 3"	4"		
Select Structural, No.1 & Btr, No.1, No.2, No.3	2", 3", & 4"	1.5	1.5	1.5	1.15
	5"	1.4	1.4	1.4	1.1
	6"	1.3	1.3	1.3	1.1
	8"	1.2	1.3	1.2	1.05
	10"	1.1	1.2	1.1	1.0
	12"	1.0	1.1	1.0	1.0
	14" & wider	0.9	1.0	0.9	0.9
Stud	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
	8" & wider	Use No.3 Grade tabulated design values and size factors			
Construction, Standard	2", 3", & 4"	1.0	1.0	1.0	1.0
Utility	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	—	0.4	0.6

Analysis Example

C_r Repetitive Member Factor

16” o.c. : C_r = 1.15

Repetitive Member Factor, C_r

Bending design values, F_b, for dimension lumber 2" to 4" thick shall be multiplied by the repetitive member factor, C_r = 1.15, when such members are used as joists, truss chords, rafters, studs, planks, decking, or similar members which are in contact or spaced not more than 24" on center, are not less than 3 in number and are joined by floor, roof, or other load distributing elements adequate to support the design load.

Analysis Example

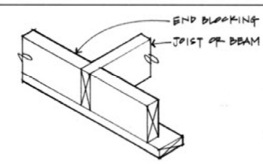
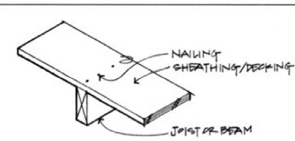
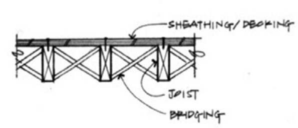
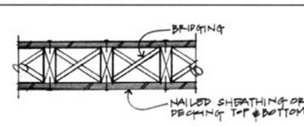
C_L Repetitive Member Factor

2x10 w/ flooring: C_L = 1.0

C_L = 1.0
if depth/width ratio meets criteria in
4.4.1 C_L = 1.0

Otherwise:

C_L < 1.0
calculate factor using section 3.3.3

Beam Depth/ Width Ratio	Type of Lateral Bracing Required	Example
2 to 1	None	
3 to 1 2x6 2x8	The ends of the beam should be held in position	
5 to 1 2x10	Hold compression edge in line (continuously)	
6 to 1 2x12	Diagonal bridging should be used	
7 to 1 2x14	Both edges of the beam should be held in line	

Analysis Example

3. Determine allowable stresses
   - $F_b' = F_b (C_D)(C_L)(C_F)(C_r)$
   - $F_b' = 875\ (1.0)\ (1.0)\ (1.1)\ (1.0)\ (1.15) = 1107$ psi

   - $F_v' = F_v (C_D)$
   - $F_v' = 135\ (1.0) = 135$ psi

4. Check that actual ≤ allowable
   - $f_b < F'_b$
   - $f_v < F'_v$

$$f_b = \frac{M}{S_x} = \frac{1336'\text{-}\# (12)}{21.39\ in^3} = 749.5\ psi$$

$$f_v = \frac{3}{2}\frac{V}{A} = \frac{1.5\,(485.8)^{\#}}{13.88\ in^2} = 52.5\ psi$$

5. Check deflection
6. Check bearing ($F_{cp} = R/A_b$)

Analysis Example

5. Check deflection
   - NDS 3.5
   - Δ_{LT} - Long term
   - Δ_{ST} - Short term
   - K_{cr} – creep factor

$\Delta_T = K_{cr}\,\Delta_{LT} + \Delta_{ST}$ (NDS 3.5-1)

K_{cr}
- 1.5 dry, seasoned lumber
- 2.0 wet service conditions
- 2.0 wood panels
- 2.0 CLT (dry)

$$\Delta_t = \frac{5 w \ell^4}{384 EI} = \frac{5(88.336)\,11^4\,(1728)}{384\,(1400000)(98.93)}$$

$$= 0.210''$$

$$\frac{\ell}{360} = \frac{11'(12)}{360} = 0.367''$$

TABLE 1604.3 DEFLECTION LIMITS[a, b, c, h, i]

CONSTRUCTION	L	S or W[f]	D + L[d, g]
Roof members:[e]			
Supporting plaster or stucco ceiling	l/360	l/360	l/240
Supporting nonplaster ceiling	l/240	l/240	l/180
Not supporting ceiling	l/180	l/180	l/120
Floor members	l/360	—	l/240
Exterior walls:			
With plaster or stucco finishes	—	l/360	—
With other brittle finishes	—	l/240	—
With flexible finishes	—	l/120	—
Interior partitions:[b]			
With plaster or stucco finishes	l/360	—	—
With other brittle finishes	l/240	—	—
With flexible finishes	l/120	—	—
Farm buildings	—	—	l/180
Greenhouses	—	—	l/120

Analysis Example

6. Check bearing : $F_{c\perp} < P/A_b$

$F_{c\perp}$ = 425 psi

P = R = 485.8 lbs
A_b = 1.5" (1") = 1.5 in^2

$f_b = \frac{485.8}{1.5}$ = 323.8 psi < 425 psi ok

3.10.4 Bearing Area Factor, C_b

Reference compression design values perpendicular to grain, $F_{c\perp}$, apply to bearings of any length at the ends of a member, and to all bearings 6" or more in length at any other location. For bearings less than 6" in length and not nearer than 3" to the end of a member, the reference compression design value perpendicular to grain, $F_{c\perp}$, shall be permitted to be multiplied by the following bearing area factor, C_b:

$$C_b = \frac{\ell_b + 0.375}{\ell_b} \quad (3.10\text{-}2)$$

where:

ℓ_b = bearing length measured parallel to grain, in.

Equation 3.10-2 gives the following bearing area factors, C_b, for the indicated bearing length on such small areas as plates and washers:

Table 3.10.4 Bearing Area Factors, C_b

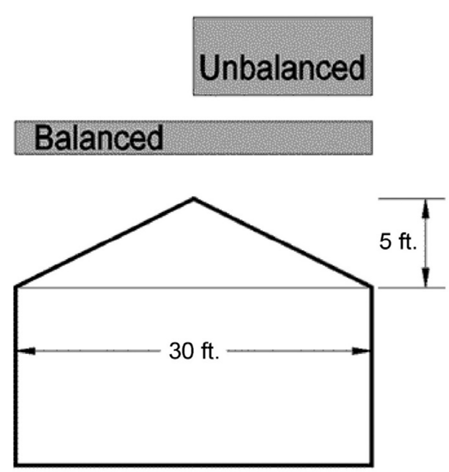
ℓ_b	0.5"	1"	1.5"	2"	3"	4"	6" or more
C_b	1.75	1.38	1.25	1.19	1.13	1.10	1.00

For round bearing areas such as washers, the bearing length, ℓ_b, shall be equal to the diameter.

Design Procedure – Joist or Rafter

Given: loading criteria, wood, span, size
Req'd: controlling load, o.c. spacing

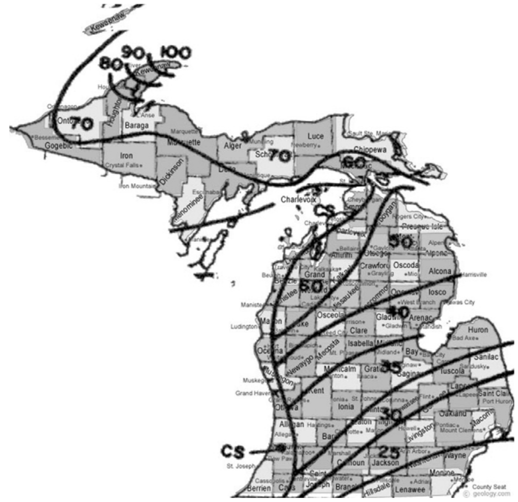
1. Determine each load
   - check applicable load cases
   - determine loads
   - choose controlling load case
2. Find Max Shear & Moment
   - assume o.c. spacing = 12"
3. Calculate actual stresses
4. Calculate allowable stresses
   - find applicable factors
5. Choose spacing
   - determine utilization ratio: fb/Fb
   - divide o.c. spacing by the ratio
   - round down to modular spacing (12, 16 or 24)
6. Check shear stress
7. Check deflection
8. Check bearing



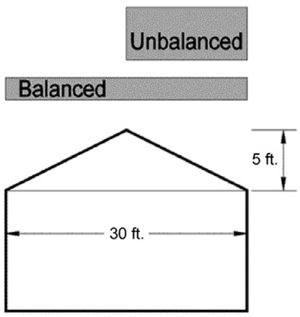
Design Example

Given: 2x10 Hem Fir No. 2 rafter

DATASET: 1	-2-
Location (city in Michigan)	Gaylord
Terrain Category (Sec 26.7)	C
Exposure of Roof (Tab 7.3-1)	Partially Exposed
Thermal Factor, Ct (Tab 7.3-2)	1
Roof Surface	Not Slippery
Risk Category (Tab 1.5-2)	II
Roof Span, L	30 FT
Roof Slope F" in 12"	4 IN/12"



Req'd: rafter spacing



1. Determine Loads:

Dead: ASCE-7 Tab. C3.1-1a → 7 PSF (12" o.c.)
Roof Live: ASCE-7 4.8.2 → 20 PSF
Snow: ASCE-7 Fig. 7.2-1: pg = 50 PSF

ASCE-7 2.4.1 ASD load combinations:

D	$C_D = 0.9$
D + Lr	$C_D = 1.25$
D + S	$C_D = 1.15$

Analysis Example (rafter)

Roof Live Load

- Minimum L_r between 12 PSF and 20 PSF
- $L_r = 20\ R_1\ R_2$
- See 4.9.1

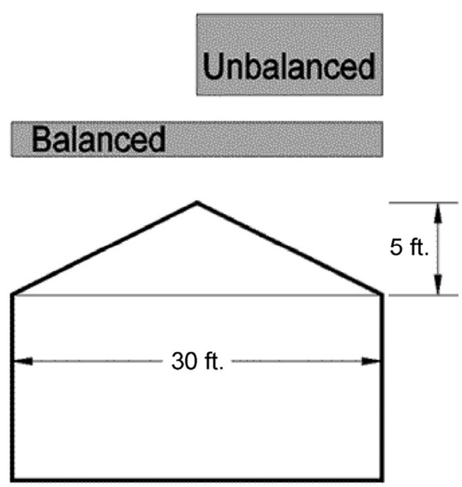
$$R_1 = \begin{cases} 1 & \text{for } A_t \le 200 \text{ ft}^2 (18.58 \text{ m}^2) \\ 1.2 - 0.001A_t & \text{for } 200 \text{ ft}^2 < A_t < 600 \text{ ft}^2 \\ 0.6 & \text{for } A_t \ge 600 \text{ ft}^2 (55.74 \text{ m}^2) \end{cases}$$

where A_t = tributary area in ft^2 (m^2) supported by any structural member and

$$R_2 = \begin{cases} 1 & \text{for } F \le 4 \\ 1.2 - 0.05\,F & \text{for } 4 < F < 12 \\ 0.6 & \text{for } F \ge 12 \end{cases}$$

where, for a pitched roof, F = number of inches of rise per ft.

for an arch or dome, F = rise-to-span ratio multiplied by 32.



Design Example (rafter)

p_g - ground snow (from map)

p_f - flat roof snow load

$p_f = 0.7\ C_e\ C_t\ I_s\ p_g$

- Eq. 7.3-1

Low Slope Roofs

- Monoslope, hip or gable < 15°
- 4/12 = 18.4°

Minimum for Low Slope Roofs

- Minimum where $p_g \leqq 20 = I_S\ p_g$ PSF
- Minimum where $p_g > 20 = I_S\ 20$ PSF

7.3 FLAT ROOF SNOW LOADS, p_f

The flat roof snow load, p_f, shall be calculated in lb/ft^2 (kN/m^2) using the following formula:

$$p_f = 0.7 C_e C_t I_s p_g \qquad (7.3\text{-}1)$$

7.3.1 Exposure Factor, C_e
The value for C_e shall be determined from Table 7-2.

7.3.2 Thermal Factor, C_t
The value for C_t shall be determined from Table 7-3.

7.3.3 Importance Factor, I_s
The value for I_s shall be determined from Table 1.5-2 based on the Risk Category from Table 1.5-1.

7.3.4 Minimum Snow Load for Low-Slope Roofs, p_m
A minimum roof snow load, p_m, shall only apply to monoslope, hip and gable roofs with slopes less than 15°, and to curved roofs where the vertical angle from the eaves to the crown is less than 10°. The minimum roof snow load for low-slope roofs shall be obtained using the following formula:

Where p_g is 20 lb/ft^2 (0.96 kN/m^2) or less:

$p_m = I_s p_g$ (Importance Factor times p_g)

Where p_g exceeds 20 lb/ft^2 (0.96 kN/m^2):

$p_m = 20\ (I_s)$ (20 lb/ft^2 times Importance Factor)

This minimum roof snow load is a separate uniform load case. It need not be used in determining

Design Example (rafter)

C_e – Exposure Factor

- Table 7-2
- Terrain Category C
- Roof Exposure “Partially Exposed”
- Ce = 1.0

EXPOSURE C
FLAT OPEN GRASSLAND WITH SCATTERED OBSTRUCTIONS HAVING HEIGHTS GENERALLY LESS THAN 30 FT

Table 7-2 Exposure Factor, C_e

Terrain Category	Exposure of Roof[a]: Fully Exposed	Partially Exposed	Sheltered
B (see Section 26.7)	0.9	1.0	1.2
C (see Section 26.7)	0.9	1.0	1.1
D (see Section 26.7)	0.8	0.9	1.0
Above the treeline in windswept mountainous areas.	0.7	0.8	N/A
In Alaska, in areas where trees do not exist within a 2-mile (3-km) radius of the site.	0.7	0.8	N/A

The terrain category and roof exposure condition chosen shall be representative of the anticipated conditions during the life of the structure. An exposure factor shall be determined for each roof of a structure.

[a]Definitions: Partially Exposed: All roofs except as indicated in the following text. Fully Exposed: Roofs exposed on all sides with no shelter[b] afforded by terrain, higher structures, or trees. Roofs that contain several large pieces of mechanical equipment, parapets that extend above the height of the balanced snow load (h_b), or other obstructions are not in this category. Sheltered: Roofs located tight in among conifers that qualify as obstructions.

[b]Obstructions within a distance of $10h_o$ provide “shelter,” where h_o is the height of the obstruction above the roof level. If the only obstructions are a few deciduous trees that are leafless in winter, the “fully exposed” category shall be used. Note that these are heights above the roof. Heights used to establish the Exposure Category in Section 26.7 are heights above the ground.

Design Example (rafter)

C_t – Thermal Factor

- Table 7.3-2
- given = 1.0

I_s – Importance Factor

- Table 1.5-2
- given category II : Is = 1.0

Table 1.5-2 Importance Factors by Risk Category of Buildings and Other Structures for Snow, Ice, and Earthquake Loads

Risk Category from Table 1.5-1	Snow Importance Factor, I_s	Ice Importance Factor—Thickness, I_i	Ice Importance Factor—Wind, I_w	Seismic Importance Factor, I_e
I	0.80	0.80	1.00	1.00
II	1.00	1.00	1.00	1.00
III	1.10	1.15	1.00	1.25
IV	1.20	1.25	1.00	1.50

Note: The component importance factor, I_p, applicable to earthquake loads, is not included in this table because it depends on the importance of the individual component rather than that of the building as a whole, or its occupancy. Refer to Section 13.1.3.

Table 7.3-2 Thermal Factor, C_t

Thermal Condition[a]	C_t
All structures except as indicated below	1.0
Structures kept just above freezing and others with cold, ventilated roofs in which the thermal resistance (R-value) between the ventilated space and the heated space exceeds 25°F × h × ft²/Btu (4.4 K × m²/W)	1.1
Unheated and open air structures	1.2
Freezer building	1.3
Continuously heated greenhouses[b] with a roof having a thermal resistance (R-value) less than 2.0°F × h × ft²/Btu (0.4 K × m²/W)	0.85

[a]These conditions shall be representative of the anticipated conditions during winters for the life of the structure.
[b]Greenhouses with a constantly maintained interior temperature of 50°F (10°C) or more at any point 3 ft (0.9 m) above the floor level during winters and having either a maintenance attendant on duty at all times or a temperature alarm system to provide warning in the event of a heating failure.

Design Example (rafter)

p_f - flat roof snow load

$p_f = 0.7\ C_e\ C_t\ I_s\ p_g$

0.7 1.0 1.0 1.0 50 = 35 psf

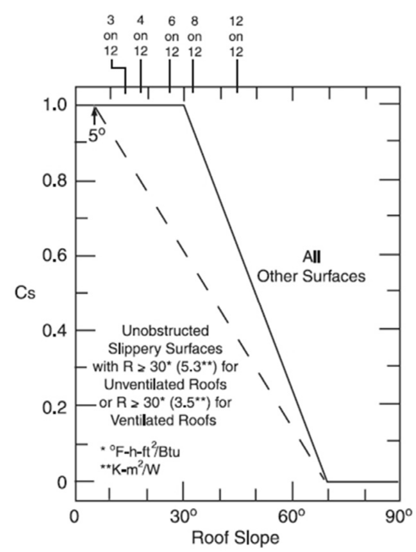
p_s – sloped roof snow load

$p_s = C_s\ p_f$

- Eq. 7.4-1

C_s – Roof Slope Factor

- Figure 7-2
- $C_1 = C_t$
- Equations given in commentary C7.4
- given roof surface "not slippery"
- Cs = 1.0



7-2a: Warm roofs with $C_1<1.0$

p_s

$p_s = C_s\ p_f$ = 1.0 35psf = 35 psf

Design Example (rafter)

Balanced

- p_s = 35 psf

Unbalanced

For W ≤ 20FT

- $I_s \times p_g$ = 1.0 50 = 50 psf

For W > 20FT

- See Fig. 7.6-2

Unbalanced Gable Roof Loads

- **Not** for F > 7 on 12 (30.2°)
- **Not** for F < ½ on 12 (2.38°)

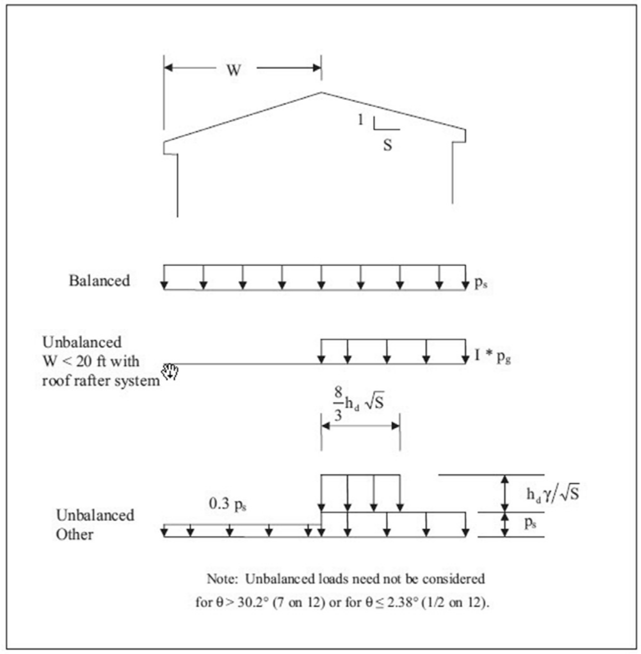


FIGURE 7-5 Balanced and Unbalanced Snow Loads for Hip and Gable Roofs.

Analysis Example (rafter)

Controlling (greatest) load

- D = 7 psf (on surface)
- S = 50 psf (projected)
- D + S = 57.38 psf (projected)

2. Find Max Shear & Moment

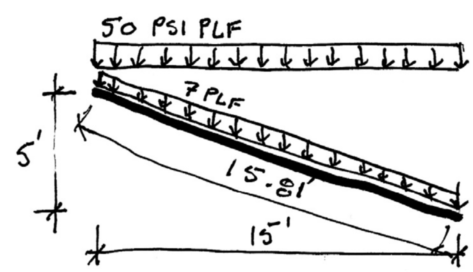
By equations (projected):

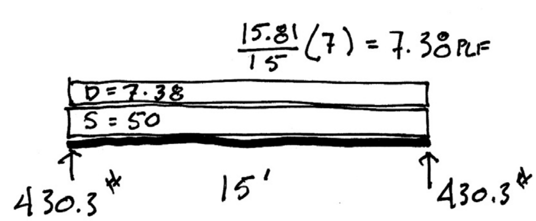
Shear:

$$\frac{wl}{2} = \frac{57.38\,(15)}{2} = 430.3 \text{ lbs}$$

Moment:

$$\frac{wl^2}{8} = \frac{57.38\,(15^2)}{8} = 1614 \text{ ft-lbs}$$





Analysis Example

3. Determine actual stresses
   - $f_b = M/S$
   - $f_v = 1.5\ V/A$

$$f_b = \frac{M}{S_x} = \frac{1614^{\prime\text{-}\#}(12)}{21.39\,\text{in}^3} = 905.4\ \text{psi}$$

$$f_v = \frac{3}{2}\frac{V}{A} = \frac{1.5\,(430.3)}{13.88} = 46.5\ \text{psi}$$

Species and Grade

4. Determine allowable stresses – NDS Supplement
   - F_b = 850 psi
   - F_v = 150 psi

Table 4A (Cont.) Reference Design Values for Visually Graded Dimension Lumber (2" - 4" thick)[1,2,3]

(All species except Southern Pine—see Table 4B) (Tabulated design values are for normal load duration and dry service conditions. See NDS 4.3 for a comprehensive description of design value adjustment factors.)

USE WITH TABLE 4A ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Design values in pounds per square inch (psi)							Specific Gravity[4]	Grading Rules Agency
		Bending	Tension parallel to grain	Shear parallel to grain	Compression perpendicular to grain	Compression parallel to grain	Modulus of Elasticity			
		F_b	F_t	F_v	$F_{c\perp}$	F_c	E	E_{min}	G	
HEM-FIR										
Select Structural	2" & wider	1,400	925	150	405	1,500	1,600,000	580,000	0.43	WCLIB WWPA
No. 1 & Btr		1,100	725	150	405	1,350	1,500,000	550,000		
No. 1		975	625	150	405	1,350	1,500,000	550,000		
No. 2		850	525	150	405	1,300	1,300,000	470,000		
No. 3		500	300	150	405	725	1,200,000	440,000		
Stud	2" & wider	675	400	150	405	800	1,200,000	440,000		
Construction	2" - 4" wide	975	600	150	405	1,550	1,300,000	470,000		
Standard		550	325	150	405	1,300	1,200,000	440,000		
Utility		250	150	150	405	850	1,100,000	400,000		

Analysis Example

4. Determine allowable stresses – NDS Supplement
    - Adjustment Factors

Determine factors:

CD = ?
CM = 1
Ct = 1
CL = ?
CF = ?
Cfu = 1
Ci = 1
Cr = ?

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD only	ASD and LRFD										LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Incising Factor	Repetitive Member Factor	Column Stability Factor	Buckling Stiffness Factor	Bearing Area Factor	Format Conversion Factor	Resistance Factor	Time Effect Factor
$F_b' = F_b$	x	C_D	C_M	C_t	C_L	C_F	C_{fu}	C_i	C_r	-	-	-	K_F	ϕ_b	λ
$F_v' = F_v$	x	C_D	C_M	C_t	-	-	-	C_i	-	-	-	-	K_F	ϕ_v	λ

Analysis Example

Table 2.3.2 Frequently Used Load Duration Factors, C_D[1]

Load Duration	C_D	Typical Design Loads
Permanent	0.9	Dead Load
Ten years	1.0	Occupancy Live Load
Two months	1.15	Snow Load
Seven days	1.25	Construction Load
Ten minutes	1.6	Wind/Earthquake Load
Impact[2]	2.0	Impact Load

C_D Load duration factor

Snow Load (2 months) = 1.15

C_F Size factor

2 x 10
use 1.1

Size Factors, C_F

Grades	Width (depth)	F_b Thickness (breadth) 2" & 3"	F_b Thickness (breadth) 4"	F_t	F_c
Select Structural, No.1 & Btr, No.1, No.2, No.3	2", 3", & 4"	1.5	1.5	1.5	1.15
	5"	1.4	1.4	1.4	1.1
	6"	1.3	1.3	1.3	1.1
	8"	1.2	1.3	1.2	1.05
	10"	1.1	1.2	1.1	1.0
	12"	1.0	1.1	1.0	1.0
	14" & wider	0.9	1.0	0.9	0.9
Stud	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
	8" & wider	Use No.3 Grade tabulated design values and size factors			
Construction, Standard	2", 3", & 4"	1.0	1.0	1.0	1.0
Utility	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	—	0.4	0.6

Analysis Example

C_r Repetitive Member Factor

12” o.c. : C_r = 1.15

Repetitive Member Factor, C_r

Bending design values, F_b, for dimension lumber 2" to 4" thick shall be multiplied by the repetitive member factor, C_r = 1.15, when such members are used as joists, truss chords, rafters, studs, planks, decking, or similar members which are in contact or spaced not more than 24" on center, are not less than 3 in number and are joined by floor, roof, or other load distributing elements adequate to support the design load.

Analysis Example

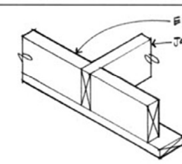
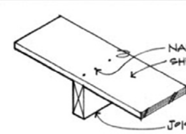
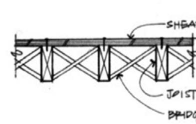
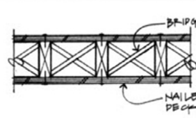
C_L Repetitive Member Factor

2x10 w/ flooring: C_L = 1.0

C_L = 1.0
if depth/width ratio meets criteria in
4.4.1 C_L = 1.0

Otherwise:

C_L < 1.0
calculate factor using section 3.3.3

Beam Depth/ Width Ratio	Type of Lateral Bracing Required	Example
2 to 1	None	
3 to 1 2x6 2x8	The ends of the beam should be held in position	
5 to 1 2x10	Hold compression edge in line (continuously)	
6 to 1 2x12	Diagonal bridging should be used	
7 to 1 2x14	Both edges of the beam should be held in line	

Analysis Example

4. Determine allowable stresses
   - $F_b' = F_b (C_D)(C_L)(C_F)(C_r)$
   - $F_b' = 850 (1.15) (1.0) (1.1) (1.0) (1.15) = 1236$ psi
   - $F_v' = F_v (C_D)$
   - $F_v' = 150 (1.15) = 172.5$ psi
5. Check that actual ≤ allowable
   - $f_b < F'_b$
   - $f_v < F'_v$

$$f_b = \frac{M}{S_x} = \frac{1614^{\prime\text{-}\#}(12)}{21.39\,\text{in}^3} = 905.4\ \text{psi}$$

$$f_v = \frac{3}{2}\frac{V}{A} = \frac{1.5\,(430.3)}{13.88} = 46.5\ \text{psi}$$

6. Utilization Ratio
   - 905.4/1236 = 0.732
   - 12" o.c. / 0.732 = 16.38
   - try 2x10 at 16" o.c.
   - f_b at 16" o.c.= 905.4 (16/12) = 1207 psi
7. Check deflection
8. Check bearing ($F_{cp} = R/A_b$)

Analysis Procedure

Given: member size, material and span.
Req'd: Max. Safe Load (**capacity**)

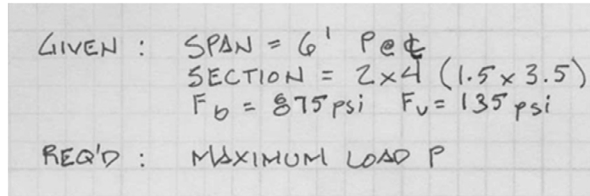
1. Assume f = F
   - Maximum actual = allowable stress
2. Solve stress equations for force
   - $M = F_b S$
   - $V = 0.66 F_v A$
3. Use maximum forces to find loads
   - Back calculate a load from forces
   - Assume moment controls
4. Check Shear
   - Use load found is step 3 to check shear stress.
   - If it fails (fv > F'v), then find load based on shear.
5. Check deflection
6. Check bearing

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.^{2}	X-X AXIS Section Modulus S_{xx} in.^{3}	X-X AXIS Moment of Inertia I_{xx} in.^{4}	Y-Y AXIS Section Modulus S_{yy} in.^{3}	Y-Y AXIS Moment of Inertia I_{yy} in.^{4}
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
1 x 4	3/4 x 3-1/2	2.625	1.531	2.680	0.328	0.123
1 x 6	3/4 x 5-1/2	4.125	3.781	10.40	0.516	0.193
1 x 8	3/4 x 7-1/4	5.438	6.570	23.82	0.680	0.255
1 x 10	3/4 x 9-1/4	6.938	10.70	49.47	0.867	0.325
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396
Dimension Lumber (see NDS 4.1.3.2) and Decking (see NDS 4.1.3.5)						
2 x 3	1-1/2 x 2-1/2	3.750	1.56	1.953	0.938	0.703
2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164
2 x 14	1-1/2 x 13-1/4	19.88	43.89	290.8	4.969	3.727
3 x 4	2-1/2 x 3-1/2	8.75	5.10	8.932	3.646	4.557
3 x 5	2-1/2 x 4-1/2	11.25	8.44	18.98	4.688	5.859
3 x 6	2-1/2 x 5-1/2	13.75	12.60	34.66	5.729	7.161
3 x 8	2-1/2 x 7-1/4	18.13	21.90	79.39	7.552	9.440
3 x 10	2-1/2 x 9-1/4	23.13	35.65	164.9	9.635	12.04
3 x 12	2-1/2 x 11-1/4	28.13	52.73	296.6	11.72	14.65
3 x 14	2-1/2 x 13-1/4	33.13	73.15	484.6	13.80	17.25
3 x 16	2-1/2 x 15-1/4	38.13	96.90	738.9	15.89	19.86
4 x 4	3-1/2 x 3-1/2	12.25	7.15	12.51	7.146	12.51
4 x 5	3-1/2 x 4-1/2	15.75	11.81	26.58	9.188	16.08
4 x 6	3-1/2 x 5-1/2	19.25	17.65	48.53	11.23	19.65
4 x 8	3-1/2 x 7-1/4	25.38	30.66	111.1	14.80	25.90
4 x 10	3-1/2 x 9-1/4	32.38	49.91	230.8	18.89	33.05
4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20
4 x 14	3-1/2 x 13-1/4	46.38	102.41	678.5	27.05	47.34
4 x 16	3-1/2 x 15-1/4	53.38	135.66	1034	31.14	54.49

from *NDS 2012*

Analysis Example

Given: member size, material and span.
load duration = 10 min.
Req'd: Max. Safe Load (capacity)



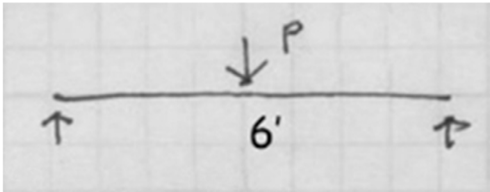


Table 4A (Cont.) **Reference Design Values for Visual (2" - 4" thick)[1,2,3]**

(All species except Southern Pine—see duration and dry service conditions. See NDS adjustment factors.)

USE WITH TABLE 4A AD

Species and commercial grade	Size classification	Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v
SPRUCE-PINE-FIR				
Select Structural	2" & wider	1,250	700	135
No. 1/ No. 2	2" & wider	875	450	135
No. 3	2" & wider	500	250	135
Stud	2" & wider	675	350	135
Construction	2" - 4" wide	1,000	500	135
Standard	2" - 4" wide	550	275	135
Utility	2" - 4" wide	275	125	135

1. Assume f = F'
   - Maximum actual = allowable stress

Analysis Example

Determine allowable stresses – NDS Supplement
- Adjustment Factors

Determine factors:

CD = ?
CM = 1
Ct = 1
CL = 1
CF = ?
Cfu = 1
Ci = 1
Cr = 1

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD only	ASD and LRFD											LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Incising Factor	Repetitive Member Factor	Column Stability Factor	Buckling Stiffness Factor	Bearing Area Factor	Format Conversion Factor	Resistance Factor	Time Effect Factor
$F_b' = F_b$	x	C_D	C_M	C_t	C_L	C_F	C_{fu}	C_i	C_r	-	-	-	K_F	ϕ_b	λ
$F_v' = F_v$	x	C_D	C_M	C_t	-	-	-	C_i	-	-	-	-	K_F	ϕ_v	λ

Analysis Example

Grades	Width (depth)	Size Factors, C_F — F_b — Thickness (breadth) 2" & 3"	4"
Select Structural, No.1 & Btr, No.1, No.2, No.3	2", 3", & 4"	1.5	1.5
	5"	1.4	1.4
	6"	1.3	1.3
	8"	1.2	1.3
	10"	1.1	1.2
	12"	1.0	1.1
	14" & wider	0.9	1.0
Stud	2", 3", & 4"	1.1	1.1
	5" & 6"	1.0	1.0
	8" & wider	Use No.3 Grade tabulated design v	
Construction, Standard	2", 3", & 4"	1.0	1.0
Utility	4"	1.0	1.0
	2" & 3"	0.4	—

Table 2.3.2 Frequently Used Load Duration Factors, C_D[1]

Load Duration	C_D	Typical Design Loads
Permanent	0.9	Dead Load
Ten years	1.0	Occupancy Live Load
Two months	1.15	Snow Load
Seven days	1.25	Construction Load
Ten minutes	1.6	Wind/Earthquake Load
Impact[2]	2.0	Impact Load

$f_b = F'_b = 875(1.6)(1.5)$ (F_b, C_D, C_F)

$F'_b = 2100$ psi

2. Solve stress equation for moment
   - $M = F'_b S_x$ (i.e. moment capacity)

$S_x = 3.063$ in³

$M_{℄} = F'_b S_x = 2100(3.063)$

$= 6432.3$ "-#

$= 536$ '-#

Analysis Example (cont.)

3. Use maximum forces to find loads
   - Back calculate a maximum load from moment capacity

$M_{℄} = PL/4$

$P = M_{℄} 4/L$

$P = 536(4)/6$

$P = 357$ #

4. Check shear
   - Check shear for load capacity from step 3.
   - Use P from moment to find Vmax
   - Check that fv < Fv'

$F'_v = F_v(C_D) = 135_{psi}(1.6) = 216$ psi

$V_{max} = P/2 = 357^{\#}/2 = 178.6^{\#}$

$f_v = \frac{3}{2}\frac{V}{A} = 1.5 \frac{178.6^{\#}}{5.25 \text{ in}^2} = 51$ psi

51 < 216 ∴ ok ✓

4. Check deflection (serviceability)
5. Check bearing (serviceability)

Question …

For the No.2 S-P-F 2x4 section determine the safe center point load capacity with the member flatwise.

$F_b' = F_b (C_D\, C_M\, C_t\, C_L\, C_F\, C_{fu}\, C_i\, C_r)$

$C_D=1.6$

$C_F=1.5$

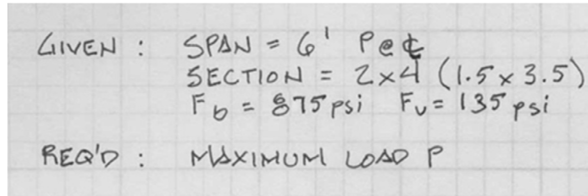
$C_{fu}=1.1$

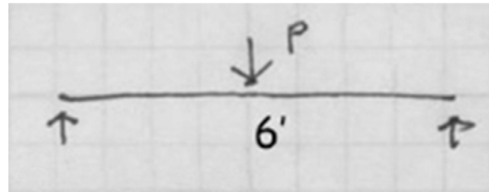
$F_v' = F_v (C_D\, C_M\, C_t\, C_i)$

$M = F'_b\, S_y \qquad P = M\, 4 / L$

$S_y=1.313\ in^3$

Check that $f_v < F'_v$





Flat Use Factor, C_{fu}

Bending design values adjusted by size factors are based on edgewise use (load applied to narrow face). When dimension lumber is used flatwise (load applied to wide face), the bending design value, F_b, shall also be permitted to be multiplied by the following flat use factors:

Flat Use Factors, C_{fu}

Width (depth)	Thickness (breadth) 2" & 3"	4"
2" & 3"	1.0	—
4"	1.1	1.0
5"	1.1	1.05
6"	1.15	1.05
8"	1.15	1.05
10" & wider	1.2	1.1

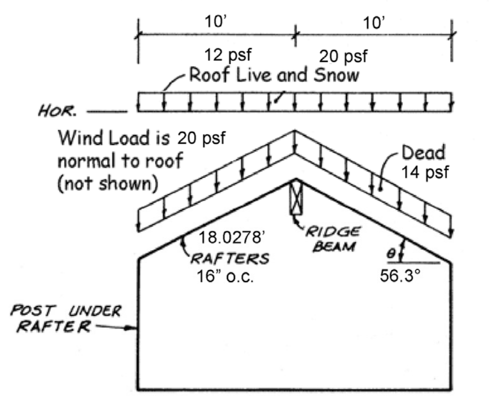
Analysis Example 3

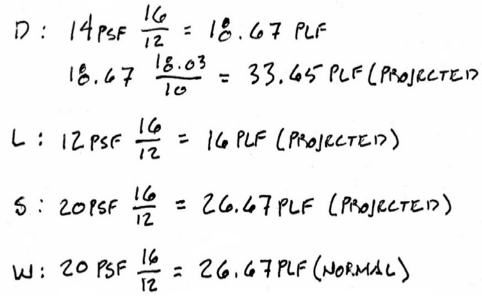
3. Sawn Lumber - Rafters

Analyze the simple roof rafter system to determine safety in flexure. Determine the controlling load combination (see ASCE-7 2.4). Consider all load cases which include D, Lr, S and W together with the corresponding CD. Assume adequate bracing to give CL=1. Also CM, Ct, Cfu and Ci should be taken as 1.

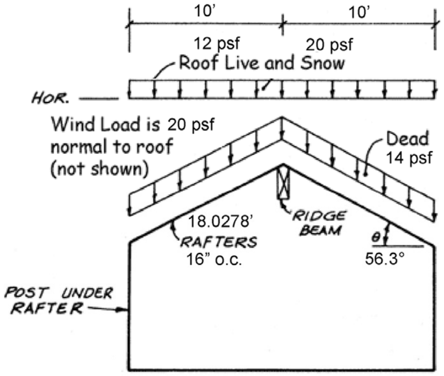
DATASET: 1 -2-

Wood Species	Western Cedars
Wood Grade	No.2
Rafter Size	2x10
Rafter O.C. Spacing	16 IN
Rafter Span	10 FT
Roof Slope	18 IN/FT
Dead Load (includes selfweight)	14 PSF
Roof Live Load	12 PSF
Snow Load	20 PSF
Wind Load (+ is pressure inward)	20 PSF





Analysis Example 3



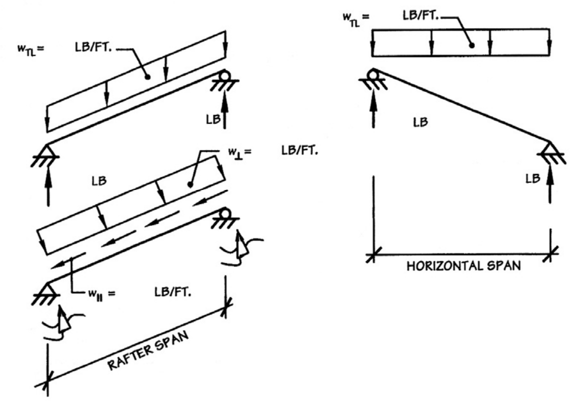
D: $14\text{ PSF}\ \frac{16}{12} = 18.67\text{ PLF}$

$18.67\ \frac{18.03}{10} = 33.65\text{ PLF (PROJECTED)}$

L: $12\text{ PSF}\ \frac{16}{12} = 16\text{ PLF (PROJECTED)}$

S: $20\text{ PSF}\ \frac{16}{12} = 26.67\text{ PLF (PROJECTED)}$

W: $20\text{ PSF}\ \frac{16}{12} = 26.67\text{ PLF (NORMAL)}$



Analysis Example 3

D: $14\text{ PSF}\ \frac{16}{12} = 18.67\text{ PLF}$

$18.67\ \frac{18.03}{10} = 33.65\text{ PLF (PROJECTED)}$

L: $12\text{ PSF}\ \frac{16}{12} = 16\text{ PLF (PROJECTED)}$

S: $20\text{ PSF}\ \frac{16}{12} = 26.67\text{ PLF (PROJECTED)}$

W: $20\text{ PSF}\ \frac{16}{12} = 26.67\text{ PLF (NORMAL)}$

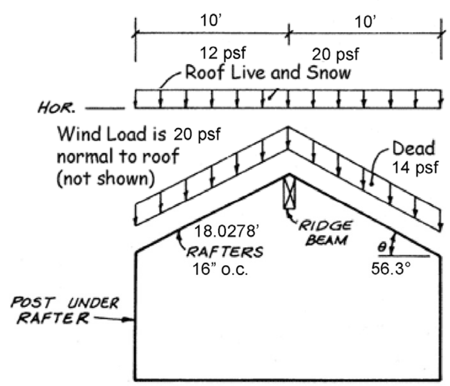
MOMENTS: $\frac{wl^2}{8}$

D: $\frac{33.65(10)^2}{8} = 420.6\text{ FT-LBS}$

L: $\frac{16(10)^2}{8} = 200\text{ FT-LBS}$

S: $\frac{26.67(10)^2}{8} = 333.3\text{ FT-LBS}$

W: $\frac{26.67(18.0278)^2}{8} = 1083.5\text{ FT-LBS}$



Analysis Example 3

ASCE 7 2.4
ASD Load Combinations

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. $0.6D + 0.6W$

MOMENTS: $\frac{wl^2}{8}$

D: $\frac{33.65(10)^2}{8} = 420.6$ FT-LBS

L: $\frac{16(10)^2}{8} = 200$ FT-LBS

S: $\frac{26.67(10)^2}{8} = 333.3$ FT-LBS

W: $\frac{26.67(18.0278)^2}{8} = 1083.5$ FT-LBS

To find the controlling case :

Sum moments / C_D
the largest controls

LOAD CASES:

D: $\frac{420.6}{0.9} = 467.4$

D+Lr: $\frac{420.6+200}{1.0} = 496.5$

D+S: $\frac{420.6+333.3}{1.15} = 655.6$

D+.6W: $\frac{420.6+.6(1083.5)}{1.6} = 669.2$

D+.75(.6W)+.75Lr:
$\frac{420.6+.75(.6(1083.5))+.75(200)}{1.6} = 661.3$

D+.75(.6W)+.75S:
$\frac{420.6+.75(.6(1083.5)+.75(333.3)}{1.6} = 723.8$

LARGEST CONTROLS

∴ LOAD CASE IS
D+.75(.6W)+.75S

$M_{℄} = 1158$ FT-LBS

Analysis Example 3

Other stress adjustment factors:

C_F C_r

for 16" o.c.
$C_r = 1.15$

Repetitive Member Factor, C_r

Bending design values, F_b, for dimension lumber 2" to 4" thick shall be multiplied by the repetitive member factor, $C_r = 1.15$, when such members are used as joists, truss chords, rafters, studs, planks, decking, or similar members which are in contact or spaced not more than 24" on center, are not less than 3 in number and are joined by floor, roof, or other load distributing elements adequate to support the design load.

C_F Size factor

2 x 10
use 1.1

Size Factors, C_F

Grades	Width (depth)	F_b Thickness (breadth) 2" & 3"	F_b Thickness (breadth) 4"	F_t	F_c
Select Structural, No.1 & Btr, No.1, No.2, No.3	2", 3", & 4"	1.5	1.5	1.5	1.15
	5"	1.4	1.4	1.4	1.1
	6"	1.3	1.3	1.3	1.1
	8"	1.2	1.3	1.2	1.05
	10"	1.1	1.2	1.1	1.0
	12"	1.0	1.1	1.0	1.0
	14" & wider	0.9	1.0	0.9	0.9
Stud	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
	8" & wider	Use No.3 Grade tabulated design values and size factors			
Construction, Standard	2", 3", & 4"	1.0	1.0	1.0	1.0
Utility	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	—	0.4	0.6

Analysis Example 3

Tabulated allowable stress:

F_b = 700 psi

USE WITH TABLE 4A ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Design values in pounds per square inch (psi)							Specific Gravity[4]
		Bending	Tension parallel to grain	Shear parallel to grain	Compression perpendicular to grain	Compression parallel to grain	Modulus of Elasticity		
		F_b	F_t	F_v	$F_{c\perp}$	F_c	E	E_{min}	G
WESTERN CEDARS									
Select Structural	2" & wider	1,000	600	155	425	1,000	1,100,000	400,000	0.36
No. 1		725	425	155	425	825	1,000,000	370,000	
No. 2		700	425	155	425	650	1,000,000	370,000	
No. 3		400	250	155	425	375	900,000	330,000	
Stud	2" & wider	550	325	155	425	400	900,000	330,000	
Construction	2" - 4" wide	800	475	155	425	850	900,000	330,000	
Standard		450	275	155	425	650	800,000	290,000	
Utility		225	125	155	425	425	800,000	290,000	

Analysis Example 3

allowable stress:

F_b = 700 psi

$F'_b = F_b\,(C_D\ C_M\ C_t\ C_L\ C_F\ C_{fu}\ C_i\ C_r)$

F'_b = 700 psi (1.6 1.1 1.15) = 1416.8 psi

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD only	ASD and LRFD										LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Incising Factor	Repetitive Member Factor	Column Stability Factor	Buckling Stiffness Factor	Bearing Area Factor	Format Conversion Factor	Resistance Factor	Time Effect Factor
$F_b' = F_b$	x	C_D	C_M	C_t	C_L	C_F	C_{fu}	C_i	C_r	-	-	-	K_F	ϕ_b	λ
$F_v' = F_v$	x	C_D	C_M	C_t	-	-	-	C_i	-	-	-	-	K_F	ϕ_v	λ

Analysis Example 3

actual stress:

$f_b = M / S_x$

$f_b = 1158.15 \text{ ft.-lbs. } (12) / 21.39 \text{ in}^3$
$f_b = 649.7 \text{ psi}$

$F'_b = 1416.8 \text{ psi} > 649 \text{ psi}$ … OK

try 24" o.c. ?

check shear

Analysis Example

Given: loading, member size, material and span.

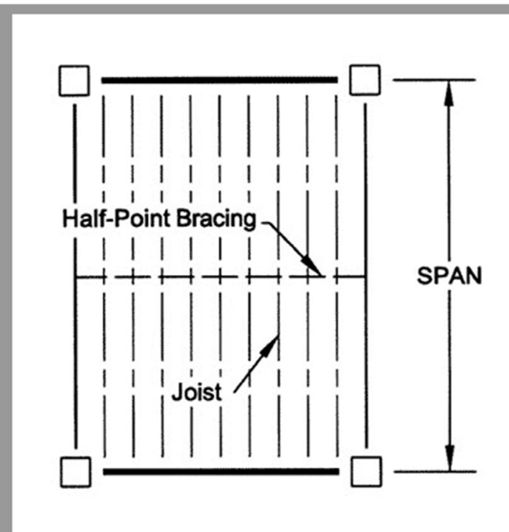
Req'd: LL capacity in psf

4. Sawn Lumber - Joists

Analyze the given floor system for live + dead load. Determine the maximum capacity for the floor based on the flexural strength of the joists. Check the joists for shear strength. Assume that the flooring does not supply bracing (i.e. braced at C.L. and ends as shown). Assume M.C. < 19%

DATASET: 1 -2-

Wood Species	Douglas Fir-South
Wood Grade	No.2
Wood Size	2x10
Joist o.c. spacing	24 IN
Joist Span	10 FT
Floor D load including joists	13 PSF



Analysis Example

Find Fb, Fv and Emin for Douglas Fir – South No2.

- (from NDS Supplement)

DESIGN VALUES FOR WOOD CONSTRUCTION – NDS SUPPLEMENT 35

Table 4A (Cont.) **Reference Design Values for Visually Graded Dimension Lumber (2" - 4" thick)[1,2,3]**

(All species except Southern Pine—see Table 4B) (Tabulated design values are for normal load duration and dry service conditions. See NDS 4.3 for a comprehensive description of design value adjustment factors.)

USE WITH TABLE 4A ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Design values in pounds per square inch (psi)							Specific Gravity[4]	Grading Rules Agency
		Bending	Tension parallel to grain	Shear parallel to grain	Compression perpendicular to grain	Compression parallel to grain	Modulus of Elasticity			
		F_b	F_t	F_v	$F_{c\perp}$	F_c	E	E_{min}	G	
DOUGLAS FIR-SOUTH										
Select Structural	2" & wider	1,350	900	180	520	1,600	1,400,000	510,000	0.46	WWPA
No. 1		925	600	180	520	1,450	1,300,000	470,000		
No. 2		850	525	180	520	1,350	1,200,000	440,000		
No. 3		500	300	180	520	775	1,100,000	400,000		
Stud	2" & wider	675	425	180	520	850	1,100,000	400,000		
Construction	2" - 4" wide	975	600	180	520	1,650	1,200,000	440,000		
Standard		550	350	180	520	1,400	1,100,000	400,000		
Utility		250	150	180	520	900	1,000,000	370,000		

Analysis Example

Section Properties:

2 x 10 (3.5” x 11.25”)

Area = 13.88 in^2

Sx = 21.39 in^3

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.^{2}	X-X AXIS Section Modulus S_{xx} in.^{3}	X-X AXIS Moment of Inertia I_{xx} in.^{4}	Y-Y AXIS Section Modulus S_{yy} in.^{3}	Y-Y AXIS Moment of Inertia I_{yy} in.^{4}
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
1 x 4	3/4 x 3-1/2	2.625	1.531	2.680	0.328	0.123
1 x 6	3/4 x 5-1/2	4.125	3.781	10.40	0.516	0.193
1 x 8	3/4 x 7-1/4	5.438	6.570	23.82	0.680	0.255
1 x 10	3/4 x 9-1/4	6.938	10.70	49.47	0.867	0.325
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396
Dimension Lumber (see NDS 4.1.3.2) and Decking (see NDS 4.1.3.5)						
2 x 3	1-1/2 x 2-1/2	3.750	1.56	1.953	0.938	0.703
2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164
		19.88	43.89	290.8	4.969	3.727
		8.75	5.10	8.932	3.646	4.557
		11.25	8.44	18.98	4.688	5.859
		13.75	12.60	34.66	5.729	7.161
		18.13	21.90	79.39	7.552	9.440
		23.13	35.65	164.9	9.635	12.04
		28.13	52.73	296.6	11.72	14.65
		33.13	73.15	484.6	13.80	17.25
		38.13	96.90	738.9	15.89	19.86
		12.25	7.15	12.51	7.146	12.51
		15.75	11.81	26.58	9.188	16.08
		19.25	17.65	48.53	11.23	19.65
		25.38	30.66	111.1	14.80	25.90
		32.38	49.91	230.8	18.89	33.05
		39.38	73.83	415.3	22.97	40.20
		46.38	102.41	678.5	27.05	47.34
		53.38	135.66	1034	31.14	54.49

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD only	ASD and LRFD											LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Incising Factor	Repetitive Member Factor	Column Stability Factor	Buckling Stiffness Factor	Bearing Area Factor	Format Conversion Factor	Resistance Factor	Time Effect Factor
$F_b' = F_b$	x	C_D	C_M	C_t	C_L	C_F	C_{fu}	C_i	C_r	-	-	-	K_F	ϕ_b	λ
$F_v' = F_v$	x	C_D	C_M	C_t	-	-	-	C_i	-	-	-	-	K_F	ϕ_v	λ

Design Example

2x10 Doug Fir S No2 M.C.<19%

Determine Adjustment Factors

C_r = 1.15
C_F = 1.1
C_M = 1.0

Table 4A Adjustment Factors

Repetitive Member Factor, C_r

Bending design values, F_b, for dimension lumber 2" to 4" thick shall be multiplied by the repetitive member factor, C_r = 1.15, when such members are used as joists, truss chords, rafters, studs, planks, decking, or similar members which are in contact or spaced not more than 24" on center, are not less than 3 in number and are joined by floor, roof, or other load distributing elements adequate to support the design load.

Wet Service Factor, C_M

When dimension lumber is used where moisture content will exceed 19% for an extended time period, design values shall be multiplied by the appropriate wet service factors from the following table:

Wet Service Factors, C_M

F_b	F_t	F_v	$F_{c\perp}$	F_c	E and E_{min}
0.85*	1.0	0.97	0.67	0.8**	0.9

* when $(F_b)(C_F) \le 1{,}150$ psi, $C_M = 1.0$
** when $(F_c)(C_F) \le 750$ psi, $C_M = 1.0$

Flat Use Factor, C_{fu}

Bending design values adjusted by size factors are based on edgewise use (load applied to narrow face). When dimension lumber is used flatwise (load applied to wide face), the bending design value, F_b, shall also be multiplied by the following flat use factors:

Flat Use Factors, C_{fu}

Width	Thickness (breadth)	
(depth)	2" & 3"	4"
2" & 3"	1.0	—
4"	1.1	1.0
5"	1.1	1.05
6"	1.15	1.05
8"	1.15	1.05
10" & wider	1.2	1.1

NOTE
To facilitate the use of Table 4A, shading has been employed to distinguish design values based on a 4" nominal width (Construction, Standard, and Utility grades) or a 6" nominal width (Stud grade) from design values based on a 12" nominal width (Select Structural, No.1 & Btr, No.1, No.2, and No.3 grades).

Size Factor, C_F

Tabulated bending, tension, and compression parallel to grain design values for dimension lumber 2" to 4" thick shall be multiplied by the following size factors:

Size Factors, C_F

		F_b		F_t	F_c
		Thickness (breadth)			
Grades	Width (depth)	2" & 3"	4"		
Select Structural, No.1 & Btr, No.1, No.2, No.3	2", 3", & 4"	1.5	1.5	1.5	1.15
	5"	1.4	1.4	1.4	1.1
	6"	1.3	1.3	1.3	1.1
	8"	1.2	1.3	1.2	1.05
	10"	1.1	1.2	1.1	1.0
	12"	1.0	1.1	1.0	1.0
	14" & wider	0.9	1.0	0.9	0.9
Stud	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
	8" & wider	Use No.3 Grade tabulated design values and size factors			
Construction, Standard	2", 3", & 4"	1.0	1.0	1.0	1.0
Utility	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	—	0.4	0.6

C_L Beam Stability Factor

In the case bracing provisions of 4.4.1 cannot be met, C_L is calculated using equation 3.3-6
The maximum allowable slenderness, R_B is 50

Table 3.3.3 Effective Length, ℓ_e, for Bending Members

Cantilever[1]	when $\ell_u/d < 7$		when $\ell_u/d \ge 7$
Uniformly distributed load	ℓ_e=1.33 ℓ_u		ℓ_e=0.90 ℓ_u + 3d
Concentrated load at unsupported end	ℓ_e=1.87 ℓ_u		ℓ_e=1.44 ℓ_u + 3d
Single Span Beam[1,2]	when $\ell_u/d < 7$		when $\ell_u/d \ge 7$
Uniformly distributed load	ℓ_e=2.06 ℓ_u		ℓ_e=1.63 ℓ_u + 3d
Concentrated load at center with no intermediate lateral support	ℓ_e=1.80 ℓ_u		ℓ_e=1.37 ℓ_u + 3d
Concentrated load at center with lateral support at center		ℓ_e=1.11 ℓ_u	
Two equal concentrated loads at 1/3 points with lateral support at 1/3 points		ℓ_e=1.68 ℓ_u	
Three equal concentrated loads at 1/4 points with lateral support at 1/4 points		ℓ_e=1.54 ℓ_u	
Four equal concentrated loads at 1/5 points with lateral support at 1/5 points		ℓ_e=1.68 ℓ_u	
Five equal concentrated loads at 1/6 points with lateral support at 1/6 points		ℓ_e=1.73 ℓ_u	
Six equal concentrated loads at 1/7 points with lateral support at 1/7 points		ℓ_e=1.78 ℓ_u	
Seven or more equal concentrated loads, evenly spaced, with lateral support at points of load application		ℓ_e=1.84 ℓ_u	
Equal end moments		ℓ_e=1.84 ℓ_u	

1. For single span or cantilever bending members with loading conditions not specified in Table 3.3.3:
   $\ell_e = 2.06\ \ell_u$ when $\ell_u/d < 7$
   $\ell_e = 1.63\ \ell_u + 3d$ when $7 \le \ell_u/d \le 14.3$
   $\ell_e = 1.84\ \ell_u$ when $\ell_u/d > 14.3$
2. Multiple span applications shall be based on table values or engineering analysis.

ℓ_u = 5' = 60"
d = 9.25"

ℓ_u / d = 6.48 < 7

ℓ_e = 2.06 ℓ_u = 123.6"

C_L Beam Stability Factor

In the case bracing provisions of 4.4.1 cannot be met, C_L is calculated using equation 3.3-6
The maximum allowable slenderness, R_B is 50

3.3.3.6 The slenderness ratio, R_B, for bending members shall be calculated as follows:

$$R_B = \sqrt{\frac{\ell_e d}{b^2}} \quad (3.3\text{-}5)$$

3.3.3.7 The slenderness ratio for bending members, R_B, shall not exceed 50.

3.3.3.8 The beam stability factor shall be calculated as follows:

$$C_L = \frac{1+(F_{bE}/F_b^*)}{1.9} - \sqrt{\left[\frac{1+(F_{bE}/F_b^*)}{1.9}\right]^2 - \frac{F_{bE}/F_b^*}{0.95}} \quad (3.3\text{-}6)$$

where:

F_b^* = reference bending design value multiplied by all applicable adjustment factors except C_{fu}, C_V (when $C_V \le 1.0$), and C_L (see 2.3), psi

$$F_{bE} = \frac{1.20\, E_{min}'}{R_B^2}$$

$\ell_e = 123.6$

$$R_B = \sqrt{\frac{\ell_e d}{b^2}} = \sqrt{\frac{123.6\,(9.25)}{1.5^2}}$$

$$R_B = \sqrt{508.1} = 22.54$$

$$F_b^* = 850(\overset{C_F}{1.1}\ \overset{C_r}{1.15}) = 1075.25 \text{ psi}$$

$$F_{bE} = \frac{1.20\, E_{min}'}{R_B^2} = \frac{1.20\,(440\,000)}{22.54^2}$$

$$F_{bE} = 1039.1 \text{ psi}$$

$$F_{bE}/F_b^* = \frac{1039.1}{1075.2} = 0.9664$$

$$C_L = \frac{1+0.9664}{1.9} - \sqrt{\left[\frac{1+0.9664}{1.9}\right]^2 - \frac{0.9664}{0.95}}$$

$$C_L = 1.0349 - \sqrt{1.0349^2 - 1.0172}$$

$$C_L = 1.0349 - 0.23198 = 0.8029$$

Analysis Example

Determine the Factored Allowable Stress

F'b = Fb (adjustment factors)

C_D = 1.0
C_r = 1.15
C_F = 1.1
C_M = 1.0
C_L = 0.8029

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD only	ASD and LRFD										LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Incising Factor	Repetitive Member Factor	Column Stability Factor	Buckling Stiffness Factor	Bearing Area Factor	Format Conversion Factor	Resistance Factor	Time Effect Factor
$F_b' = F_b$	x	C_D	C_M	C_t	C_L	C_F	C_{fu}	C_i	C_r	-	-	-	K_F	ϕ_b	λ
$F_v' = F_v$	x	C_D	C_M	C_t	-	-	-	C_i	-	-	-	-	K_F	ϕ_v	λ

F'b = 850(1.15 x 1.1 x 0.8029) = 863.3 psi

F'v = 180(C_D C_M C_t C_i) = 180 psi

Analysis Example

Allowable Stresses

F'b = 863.3 psi

F'v = 180 psi

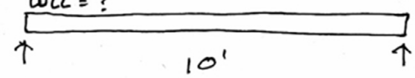
Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.^{2}	X-X AXIS Section Modulus S_{xx} in.^{3}	X-X AXIS Moment of Inertia I_{xx} in.^{4}	Y-Y AXIS Section Modulus S_{yy} in.^{3}	Y-Y AXIS Moment of Inertia I_{yy} in.^{4}
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
1 x 4	3/4 x 3-1/2	2.625	1.531	2.680	0.328	0.123
1 x 6	3/4 x 5-1/2	4.125	3.781	10.40	0.516	0.193
1 x 8	3/4 x 7-1/4	5.438	6.570	23.82	0.680	0.255
1 x 10	3/4 x 9-1/4	6.938	10.70	49.47	0.867	0.325
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396
Dimension Lumber (see NDS 4.1.3.2) and Decking (see NDS 4.1.3.5)						
2 x 3	1-1/2 x 2-1/2	3.750	1.56	1.953	0.938	0.703
2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164
2 x 14	1-1/2 x 13-1/4	19.88	43.89	290.8	4.969	3.727
3 x 4	2-1/2 x 3-1/2	8.75	5.10	8.932	3.646	4.557
3 x 5	2-1/2 x 4-1/2	11.25	8.44	18.98	4.688	5.859
3 x 6	2-1/2 x 5-1/2	13.75	12.60	34.66	5.729	7.161
3 x 8	2-1/2 x 7-1/4	18.13	21.90	79.39	7.552	9.440
3 x 10	2-1/2 x 9-1/4	23.13	35.65	164.9	9.635	12.04
3 x 12	2-1/2 x 11-1/4	28.13	52.73	296.6	11.72	14.65
3 x 14	2-1/2 x 13-1/4	33.13	73.15	484.6	13.80	17.25
3 x 16	2-1/2 x 15-1/4	38.13	96.90	738.9	15.89	19.86
4 x 4	3-1/2 x 3-1/2	12.25	7.15	12.51	7.146	12.51
4 x 5	3-1/2 x 4-1/2	15.75	11.81	26.58	9.188	16.08
4 x 6	3-1/2 x 5-1/2	19.25	17.65	48.53	11.23	19.65
4 x 8	3-1/2 x 7-1/4	25.38	30.66	111.1	14.80	25.90
4 x 10	3-1/2 x 9-1/4	32.38	49.91	230.8	18.89	33.05
4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20
4 x 14	3-1/2 x 13-1/4	46.38	102.41	678.5	27.05	47.34
4 x 16	3-1/2 x 15-1/4	53.38	135.66	1034	31.14	54.49

Determine LL capacity

M = F'b Sx

$w_{DL} = 13\text{ PSF}\ \frac{24}{12} = 26\text{ PLF}$

$w_{LL} = ?$



$M = F_b' S_x = 863.3\,(21.39) = 18466 \text{ in-lb}$
$= 1538.8 \text{ FT-LB}$

$M = \frac{w\ell^2}{8} = 1538.8 = \frac{w(10)^2}{8}$

$w_{TOTAL} = 123.11 \text{ PLF}$

$w_{LL} = 123.11 - 26 = 97.11 \text{ PLF}$

$w_{LL} = 97.11 \frac{12}{24} = 48.55 \text{ PSF}$

ACTUAL V_{max}

$V = \frac{w\ell}{2} = \frac{(26 + 97.11)\,10'}{2} = 615.5 \text{ LB}$

$f_v = \frac{3}{2}\frac{V}{A} = 1.5\,\frac{615.5}{13.88} = 66.5 \text{ psi} < 180$

Design Procedure

Given: load, wood, span

Req'd: <u>member size</u>

1. Find Max Shear & Moment
   - Simple case – equations
   - Complex case - diagrams
2. Estimate allowable stresses
3. Solve $S=M/F_b'$
4. Choose a section from Table 1B
   - Revise DL and F_b'
5. Check shear stress
   - First for V max (easier)
   - If that fails try V at d distance from support.
   - If the section still fails, choose a new section with $A=1.5V/F_v'$
6. Check deflection
7. Check bearing

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.^{2}	X-X AXIS Section Modulus S_{xx} in.^{3}	X-X AXIS Moment of Inertia I_{xx} in.^{4}	Y-Y AXIS Section Modulus S_{yy} in.^{3}	Y-Y AXIS Moment of Inertia I_{yy} in.^{4}
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
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1 x 6	3/4 x 5-1/2	4.125	3.781	10.40	0.516	0.193
1 x 8	3/4 x 7-1/4	5.438	6.570	23.82	0.680	0.255
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Dimension Lumber (see NDS 4.1.3.2) and Decking (see NDS 4.1.3.5)						
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2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164
2 x 14	1-1/2 x 13-1/4	19.88	43.89	290.8	4.969	3.727
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3 x 16	2-1/2 x 15-1/4	38.13	96.90	738.9	15.89	19.86
4 x 4	3-1/2 x 3-1/2	12.25	7.15	12.51	7.146	12.51
4 x 5	3-1/2 x 4-1/2	15.75	11.81	26.58	9.188	16.08
4 x 6	3-1/2 x 5-1/2	19.25	17.65	48.53	11.23	19.65
4 x 8	3-1/2 x 7-1/4	25.38	30.66	111.1	14.80	25.90
4 x 10	3-1/2 x 9-1/4	32.38	49.91	230.8	18.89	33.05
4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20
4 x 14	3-1/2 x 13-1/4	46.38	102.41	678.5	27.05	47.34
4 x 16	3-1/2 x 15-1/4	53.38	135.66	1034	31.14	54.49

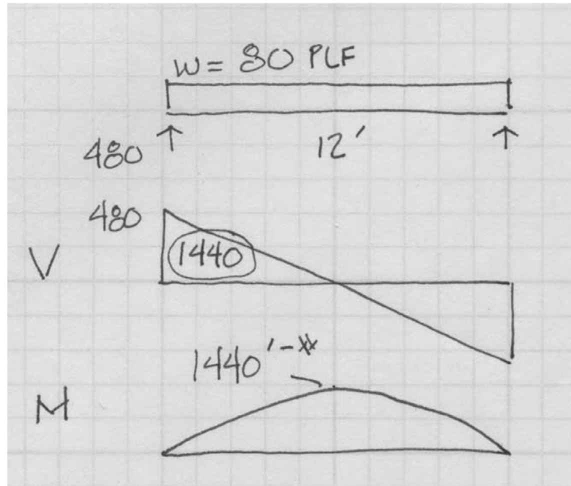
Design Example (joist)

Given: total load, wood, span
Req'd: <u>member size</u>

GIVEN: $F'_b = 1000$ PSI
$F'_v = 100$ PSI
SPAN = 12'
DL + LL = 80 PLF

REQ'D: SECTION SIZE

1. Find Max Shear & Moment
   - Simple case – equations
   - Complex case - diagrams



Design Example

2. Estimate allowable stresses
   (given in this example)
   $F'_b = 1000$ psi
   $F'_v = 100$ psi

3. Solve $S=M/F_b'$

$$F'_b = M/S_x \qquad S_x = M/F'_b$$

$$S_x = \frac{1440(12)}{1000} = 17.28 \text{ in}^3$$

4. Choose a section from S table
   - Revise DL and F_b'

2 x 10 $S_x = 21.39 > 17.28$ ✓
$A = 13.88 \text{ in}^2$

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.²	X-X AXIS Section Modulus S_{xx} in.³	X-X AXIS Moment of Inertia I_{xx} in.⁴	Y-Y AXIS Section Modulus S_{yy} in.³	Y-Y AXIS Moment of Inertia I_{yy} in.⁴
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
1 x 4	3/4 x 3-1/2	2.625	1.531	2.680	0.328	0.123
1 x 6	3/4 x 5-1/2	4.125	3.781	10.40	0.516	0.193
1 x 8	3/4 x 7-1/4	5.438	6.570	23.82	0.680	0.255
1 x 10	3/4 x 9-1/4	6.938	10.70	49.47	0.867	0.325
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396
Dimension Lumber (see NDS 4.1.3.2) and Decking (see NDS 4.1.3.5)						
2 x 3	1-1/2 x 2-1/2	3.750	1.56	1.953	0.938	0.703
2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164
2 x 14	1-1/2 x 13-1/4	19.88	43.89	290.8	4.969	3.727
3 x 4	2-1/2 x 3-1/2	8.75	5.10	8.932	3.646	4.557
3 x 5	2-1/2 x 4-1/2	11.25	8.44	18.98	4.688	5.859
3 x 6	2-1/2 x 5-1/2	13.75	12.60	34.66	5.729	7.161
3 x 8	2-1/2 x 7-1/4	18.13	21.90	79.39	7.552	9.440
3 x 10	2-1/2 x 9-1/4	23.13	35.65	164.9	9.635	12.04
3 x 12	2-1/2 x 11-1/4	28.13	52.73	296.6	11.72	14.65
3 x 14	2-1/2 x 13-1/4	33.13	73.15	484.6	13.80	17.25
3 x 16	2-1/2 x 15-1/4	38.13	96.90	738.9	15.89	19.86
4 x 4	3-1/2 x 3-1/2	12.25	7.15	12.51	7.146	12.51
4 x 5	3-1/2 x 4-1/2	15.75	11.81	26.58	9.188	16.08
4 x 6	3-1/2 x 5-1/2	19.25	17.65	48.53	11.23	19.65
4 x 8	3-1/2 x 7-1/4	25.38	30.66	111.1	14.80	25.90
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4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20
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4 x 16	3-1/2 x 15-1/4	53.38	135.66	1034	31.14	54.49

Design Example

$2 \times 10 \quad S_x = 21.39 > 17.28$ ✓
$A = 13.88 \text{ in}^2$

5. Check shear stress
   - First for V max (easier)
   - If that fails try V at d distance (remove load d from support)
   - If the section still fails, choose a new section with $A=1.5V/F_v'$

$$f_v = \frac{3}{2}\frac{V}{A} = \frac{1.5(480^{\#})}{13.88 \text{ in}^2} = 51.87$$

$51.87 \text{ psi} < 100 \text{ psi}$ ✓ OK

6. Check deflection
7. Check bearing

Design Example (joist)

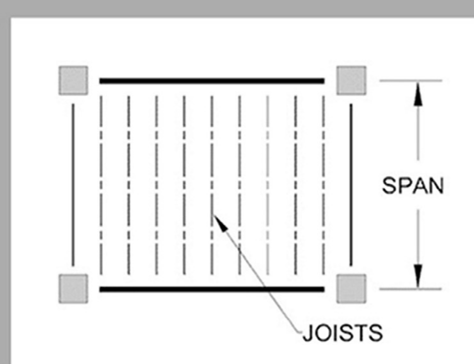
Given: load, wood, span
Req'd: <u>member size</u>

4. Wood Beam Design

Design a 2x dimensioned lumber floor joist to carry the given dead + live floor load. Assume the floor meets conditions of 4.4.1 so CL=1.0. Also Ct, Cfu, and Ci = 1.0. Find the short term deflection of your chosen beam under live load only (100% LL is short term). Compare your LL deflection with the code limit of L/360.

DATASET: 1 -2- -3-

Wood Species	HEM-FIR
Wood Grade	No.1
Span	20 FT
Joist Spacing, o.c.	12 IN
Moisture Content, m.c.	15 %
Floor DL	7 PSF
Floor LL	35 PSF



Design Example

Determine allowable stresses

- F_b and F_v (from NDS)

Table 4A (Cont.) **Reference Design Values for Visually Graded Dimension Lumber (2" - 4" thick)[1,2,3]**

(All species except Southern Pine — see Table 4B) (Tabulated design values are for normal load duration and dry service conditions. See NDS 4.3 for a comprehensive description of design value adjustment factors.)

USE WITH TABLE 4A ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v	Compression perpendicular to grain $F_{c\perp}$	Compression parallel to grain F_c	Modulus of Elasticity E	E_{min}	Specific Gravity[4] G	Grading Rules Agency
HEM-FIR										
Select Structural	2" & wider	1,400	925	150	405	1,500	1,600,000	580,000	0.43	WCLIB WWPA
No. 1 & Btr		1,100	725	150	405	1,350	1,500,000	550,000		
No. 1		975	625	150	405	1,350	1,500,000	550,000		
No. 2		850	525	150	405	1,300	1,300,000	470,000		
No. 3		500	300	150	405	725	1,200,000	440,000		
Stud	2" & wider	675	400	150	405	800	1,200,000	440,000		
Construction	2" - 4" wide	975	600	150	405	1,550	1,300,000	470,000		
Standard		550	325	150	405	1,300	1,200,000	440,000		
Utility		250	150	150	405	850	1,100,000	400,000		

Design Example

Determine allowable stresses

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.²	X-X AXIS Section Modulus S_{xx} in.³	X-X AXIS Moment of Inertia I_{xx} in.⁴	Y-Y AXIS Section Modulus S_{yy} in.³	Y-Y AXIS Moment of Inertia I_{yy} in.⁴
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
1 x 4	3/4 x 3-1/2	2.625	1.531	2.680	0.328	0.123
1 x 6	3/4 x 5-1/2	4.125	3.781	10.40	0.516	0.193
1 x 8	3/4 x 7-1/4	5.438	6.570	23.82	0.680	0.255
1 x 10	3/4 x 9-1/4	6.938	10.70	49.47	0.867	0.325
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396
Dimension Lumber (see NDS 4.1.3.2) and Decking (see NDS 4.1.3.5)						
2 x 3	1-1/2 x 2-1/2	3.750	1.56	1.953	0.938	0.703
2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547
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3 x 5	2-1/2 x 4-1/2	11.25	8.44	18.98	4.688	5.859
3 x 6	2-1/2 x 5-1/2	13.75	12.60	34.66	5.729	7.161
3 x 8	2-1/2 x 7-1/4	18.13	21.90	79.39	7.552	9.440
3 x 10	2-1/2 x 9-1/4	23.13	35.65	164.9	9.635	12.04
3 x 12	2-1/2 x 11-1/4	28.13	52.73	296.6	11.72	14.65
3 x 14	2-1/2 x 13-1/4	33.13	73.15	484.6	13.80	17.25
3 x 16	2-1/2 x 15-1/4	38.13	96.90	738.9	15.89	19.86
4 x 4	3-1/2 x 3-1/2	12.25	7.15	12.51	7.146	12.51
4 x 5	3-1/2 x 4-1/2	15.75	11.81	26.58	9.188	16.08
4 x 6	3-1/2 x 5-1/2	19.25	17.65	48.53	11.23	19.65
4 x 8	3-1/2 x 7-1/4	25.38	30.66	111.1	14.80	25.90
4 x 10	3-1/2 x 9-1/4	32.38	49.91	230.8	18.89	33.05
4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20
4 x 14	3-1/2 x 13-1/4	46.38	102.41	678.5	27.05	47.34
4 x 16	3-1/2 x 15-1/4	53.38	135.66	1034	31.14	54.49

Table 4A Adjustment Factors

Repetitive Member Factor, C_r

Bending design values, F_b, for dimension lumber 2" to 4" thick shall be multiplied by the repetitive member factor, $C_r = 1.15$, when such members are used as joists, truss chords, rafters, studs, planks, decking, or similar members which are in contact or spaced not more than 24" on center, are not less than 3 in number and are joined by floor, roof, or other load distributing elements adequate to support the design load.

Wet Service Factor, C_M

When dimension lumber is used where moisture content will exceed 19% for an extended time period, design values shall be multiplied by the appropriate wet service factors from the following table:

Wet Service Factors, C_M

F_b	F_t	F_v	$F_{c\perp}$	F_c	E and E_{min}
0.85*	1.0	0.97	0.67	0.8**	0.9

* when $(F_b)(C_F) \leq 1{,}150$ psi, $C_M = 1.0$

** when $(F_c)(C_F) \leq 750$ psi, $C_M = 1.0$

Flat Use Factor, C_{fu}

Bending design values adjusted by size factors are based on edgewise use (load applied to narrow face). When dimension lumber is used flatwise (load applied to wide face), the bending design value, F_b, shall also be multiplied by the following flat use factors:

Flat Use Factors, C_{fu}

Width (depth)	Thickness (breadth) 2" & 3"	Thickness (breadth) 4"
2" & 3"	1.0	—
4"	1.1	1.0
5"	1.1	1.05
6"	1.15	1.05
8"	1.15	1.05
10" & wider	1.2	1.1

NOTE

To facilitate the use of Table 4A, shading has been employed to distinguish design values based on a 4" nominal width (Construction, Standard, and Utility grades) or a 6" nominal width (Stud grade) from design values based on a 12" nominal width (Select Structural, No.1 & Btr, No.1, No.2, and No.3 grades).

Size Factor, C_F

Tabulated bending, tension, and compression parallel to grain design values for dimension lumber 2" to 4" thick shall be multiplied by the following size factors:

Size Factors, C_F

Grades	Width (depth)	F_b Thickness (breadth) 2" & 3"	F_b Thickness (breadth) 4"	F_t	F_c
Select Structural, No.1 & Btr, No.1, No.2, No.3	2", 3", & 4"	1.5	1.5	1.5	1.15
	5"	1.4	1.4	1.4	1.1
	6"	1.3	1.3	1.3	1.1
	8"	1.2	1.3	1.2	1.05
	10"	1.1	1.2	1.1	1.0
	12"	1.0	1.1	1.0	1.0
	14" & wider	0.9	1.0	0.9	0.9
Stud	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
	8" & wider	Use No.3 Grade tabulated design values and size factors			
Construction, Standard	2", 3", & 4"	1.0	1.0	1.0	1.0
Utility	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	—	0.4	0.6

Design Example

Determine allowable stresses.

Since the size is not known you have to skip C_F (or make a guess).

$$F_b' = F_b(\text{FACTORS})$$

$$= 975(1.0 \times 1.15 \times 1.0 \times C_F?) \approx 1121 \text{ psi}$$

C_D C_r C_M

$$F_v' = F_v(C_D, C_M, C_t, C_i)$$

$$= 150(1.0 \times 1.0 \times 1.0 \times 1.0) = 150 \text{ psi}$$

Design Example

Determine moment from loading.

First find the uniform beam load, w, from the floor loading.

$$w = (\text{PSF})\frac{\text{O.C.}}{12} = \text{PLF}$$

$$(7+35)\frac{12}{12} = 42 \text{ PLF}$$

With the beam loading, calculate the maximum moment.

$$M = \frac{w l^2}{8} = \frac{42(20')^2}{8} = 2100 \text{ 1-\#}$$

Design Example

Estimate the Required Section Modulus.

$$S_x = \frac{M}{F'_b} = \frac{2100(12)}{1121} = 22.47 \text{ in}^3$$

Compare this required Sx to the actual Sx of available sections in NDS Table 1B. Remember CF will be multiplied which may make some pass which at first fail.

FROM TABLE 1B (NDS)

	S_x	
2×10	21.39	($C_F = 1.1$) MIGHT WORK
2×12	31.64	($C_F = 1.0$)

Design Example

Choose a section and test it (by analysis with all factors including C_F)

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.²	X-X AXIS Section Modulus S_{xx} in.³	X-X AXIS Moment of Inertia I_{xx} in.⁴	Y-Y AXIS Section Modulus S_{yy} in.³	Y-Y AXIS Moment of Inertia I_{yy} in.⁴
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
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3 x 10	2-1/2 x 9-1/4	23.13	35.65	164.9	9.635	12.04
3 x 12	2-1/2 x 11-1/4	28.13	52.73	296.6	11.72	14.65
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4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20
4 x 14	3-1/2 x 13-1/4	46.38	102.41	678.5	27.05	47.34
4 x 16	3-1/2 x 15-1/4	53.38	135.66	1034	31.14	54.49

TRY 2×10 $C_F = 1.1$

$$F'_b = 975(1.15 \; 1.1) = 1233.3 \text{ psi}$$

$$f_b = M/S_x = \frac{2100(12)}{21.39} = 1178 \text{ psi} < 1233 \text{ psi} \checkmark \text{OK}$$

$$f_v = \frac{3}{2}\frac{V}{A} = \frac{1.5(420)}{13.88} = 45.39 \text{ psi} < 150 \text{ psi} \checkmark \text{OK}$$

∴ USE 2×10

Design Example

Check Deflection

In this case LL only against IBC code limit of L/360
For short term load there is no creep factor Kcr

TABLE 1604.3 DEFLECTION LIMITS[a, b, c, h, i]

CONSTRUCTION	L	S or W[f]	D + L[d, g]
Roof members:[e]			
Supporting plaster or stucco ceiling	l/360	l/360	l/240
Supporting nonplaster ceiling	l/240	l/240	l/180
Not supporting ceiling	l/180	l/180	l/120
Floor members	l/360	—	l/240
Exterior walls:			
With plaster or stucco finishes	—	l/360	—
With other brittle finishes	—	l/240	—
With flexible finishes	—	l/120	—
Interior partitions:[b]			
With plaster or stucco finishes	l/360	—	—
With other brittle finishes	l/240	—	—
With flexible finishes	l/120	—	—
Farm buildings	—	—	l/180
Greenhouses	—	—	l/120

International Building Code (IBC)

LL = 35 PSF = 35 PLF

$$\Delta_{LL} = \frac{5 w \ell^4}{384 EI} = \frac{5(35)(20)^4(1728)}{384(1500000)(98.93)} = 0.849''$$

$$\Delta_{LIMIT} \quad \frac{L}{360} = \frac{20'(12)}{360} = 0.667''$$

$0.849 > 0.667 \therefore$ FAILS

Timber Beam Design

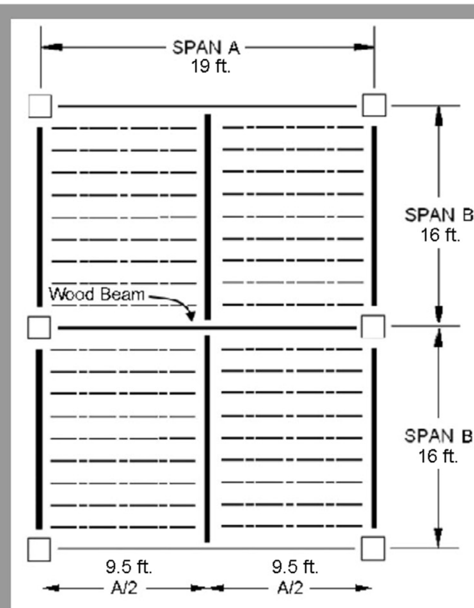
Given: load, wood, span
Req'd: <u>member size</u> (in this example both b and d)

5. Sawn Lumber - Beams

Design the central timber beam shown in the floor system using the given species and grade. Use the given floor D+L load plus the beam selfweight based on the given wood density (moisture is already included). Assume dry conditions (M.C. < 19%) and normal temperatures. Find the timber section with the least area to pass the adjusted allowable stress. Finally, calculate the total D+L deflection including creep. Assume 30% of the Live Load is sustained (long-term).

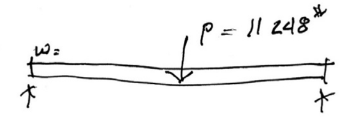
DATASET: 1 -2-

Wood Species	COAST SITKA SPRUCE
Wood Grade	No.2
Span A	19 FT
Span B	16 FT
Dead Load	19 PSF
Live Load	55 PSF
Wood density, D	30 PCF
actual section width, b	13.5 IN



Timber Beam Design

Find applied load and force

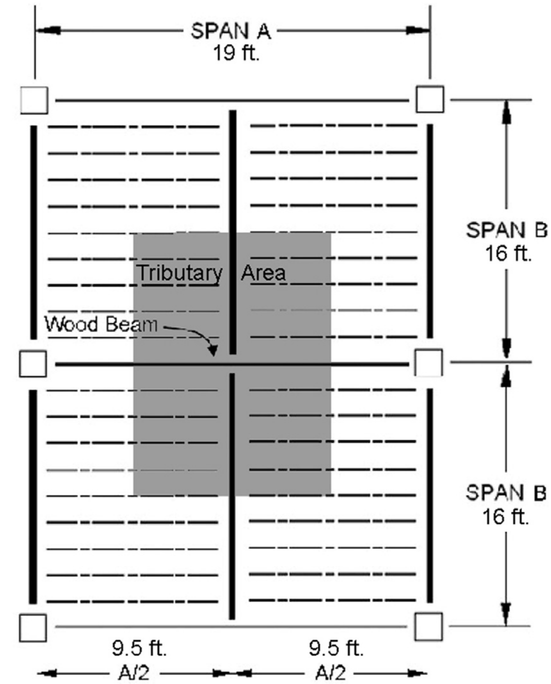


COAST SITKA SPRUCE
No2
DENSITY 30 PCF
M.C. 15%
DL 19 PSF
LL 55 PSF

$P_{D+L} = (19+55)(152\ SF)$
$= 11248\ LBS$
$w = $ BEAM SELFWEIGHT

$M_P = \frac{P l}{4} = \frac{11248(19)}{4} = 53428$ 1-#

$M_w = \frac{w l^2}{8} =$



Timber Beam Design

Find allowable stress

From NDS Supplement:
Coast Sitka Spruce No2

$F_b = 625$ PSI
$F_v = 115$ PSI
$E = 1200000$ PSI
$E_{min} = 440000$ PSI

Table 4D Reference Design Values for Visually Graded Timbers (5" x 5" and larger)[1,3]

(Tabulated design values are for normal load duration and dry service conditions, unless specified otherwise. See NDS 4.3 for a comprehensive description of design value adjustment factors.)

USE WITH TABLE 4D ADJUSTMENT FACTORS

Species and commercial Grade	Size classification	Design values in pounds per square inch (psi)							Specific Gravity[4]	Grading Rules Agency
		Bending	Tension parallel to grain	Shear parallel to grain	Compression perpendicular to grain	Compression parallel to grain	Modulus of Elasticity			
		F_b	F_t	F_v	$F_{c\perp}$	F_c	E	E_{min}	G	
COAST SITKA SPRUCE										
Select Structural	Beams and Stringers	1,150	675	115	455	775	1,500,000	550,000	0.43	NLGA
No.1	Beams and Stringers	950	475	115	455	650	1,500,000	550,000	0.43	NLGA
No.2	Beams and Stringers	625	325	115	455	425	1,200,000	440,000	0.43	NLGA
Select Structural	Posts and Timbers	1,100	725	115	455	825	1,500,000	550,000	0.43	NLGA
No.1	Posts and Timbers	875	575	115	455	725	1,500,000	550,000	0.43	NLGA
No.2	Posts and Timbers	525	350	115	455	500	1,200,000	440,000	0.43	NLGA

Timber Beam Design

Trial 1:
choose Sx and size

Sx = M / Fb

TRY 1

$F'_b \approx F_b = 625$ psi

$S_x = M/F = \frac{53428(12)}{625} = 1025 \text{ in}^3$

12 x 24

$S_x = 1058 \text{ in}^2$

$A = 270 \text{ in}^2$

Table 1B Section Properties of Standard Dressed (S4S) Sawn Lumber (Cont.)

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.^{2}	X-X AXIS Section Modulus S_{xx} in.^{3}	X-X AXIS Moment of Inertia I_{xx} in.^{4}	Y-Y AXIS Section Modulus S_{yy} in.^{3}	Y-Y AXIS Moment of Inertia I_{yy} in.^{4}	25 lbs/ft^3	30 lbs/ft^3	35 lbs/ft^3	40 lbs/ft^3	45 lbs/ft^3	50 lbs/ft^3
							Approximate weight in pounds per linear foot (lbs/ft) of piece when density of wood equals:					
Beams & Stringers (see NDS 4.1.3.3 and NDS 4.1.5.3)												
10 x 14	9-1/2 x 13-1/2	128.3	288.6	1948	203.1	964.5	22.27	26.72	31.17	35.63	40.08	44.53
10 x 16	9-1/2 x 15-1/2	147.3	380.4	2948	233.1	1107	25.56	30.68	35.79	40.90	46.02	51.13
10 x 18	9-1/2 x 17-1/2	166.3	484.9	4243	263.2	1250	28.86	34.64	40.41	46.18	51.95	57.73
10 x 20	9-1/2 x 19-1/2	185.3	602.1	5870	293.3	1393	32.16	38.59	45.03	51.46	57.89	64.32
10 x 22	9-1/2 x 21-1/2	204.3	731.9	7868	323.4	1536	35.46	42.55	49.64	56.74	63.83	70.92
10 x 24	9-1/2 x 23-1/2	223.3	874.4	10274	353.5	1679	38.76	46.51	54.26	62.01	69.77	77.52
12 x 16	11-1/2 x 15-1/2	178.3	460.5	3569	341.6	1964	30.95	37.14	43.32	49.51	55.70	61.89
12 x 18	11-1/2 x 17-1/2	201.3	587.0	5136	385.7	2218	34.94	41.93	48.91	55.90	62.89	69.88
12 x 20	11-1/2 x 19-1/2	224.3	728.8	7106	429.8	2471	38.93	46.72	54.51	62.29	70.08	77.86
12 x 22	11-1/2 x 21-1/2	247.3	886.0	9524	473.9	2725	42.93	51.51	60.10	68.68	77.27	85.85
12 x 24	11-1/2 x 23-1/2	270.3	1058	12437	518.0	2978	46.92	56.30	65.69	75.07	84.45	93.84
14 x 18	13-1/2 x 17-1/2	236.3	689.1	6029	531.6	3588	41.02	49.22	57.42	65.63	73.83	82.03
14 x 20	13-1/2 x 19-1/2	263.3	855.6	8342	592.3	3998	45.70	54.84	63.98	73.13	82.27	91.41
14 x 22	13-1/2 x 21-1/2	290.3	1040	11181	653.1	4408	50.39	60.47	70.55	80.63	90.70	100.8
14 x 24	13-1/2 x 23-1/2	317.3	1243	14600	713.8	4818	55.08	66.09	77.11	88.13	99.14	110.2

Timber Beam Design

Trial 1: 12 x 24 m.c. < 19% not flat use

Table 4D Adjustment Factors

Size Factor, C_F

When visually graded timbers are subjected to loads applied to the narrow face, tabulated design values shall be multiplied by the following size factors:

Size Factors, C_F

Depth	F_b	F_t	F_c
d > 12"	$(12/d)^{1/9}$	1.0	1.0
d ≤ 12"	1.0	1.0	1.0

Flat Use Factor, C_{fu}

When members classified as Beams and Stringers* in Table 4D are subjected to loads applied to the wide face, tabulated design values shall be multiplied by the following flat use factors:

Flat Use Factor, C_{fu}

Grade	F_b	E and E_{min}	Other Properties
Select Structural	0.86	1.00	1.00
No.1	0.74	0.90	1.00
No.2	1.00	1.00	1.00

*"Beams and Stringers" are defined in NDS 4.1.3 (also see Table 1B).

Wet Service Factor, C_M

When timbers are used where moisture content will exceed 19% for an extended time period, design values shall be multiplied by the appropriate wet service factors from the following table (for Southern Pine and Mixed Southern Pine, use tabulated design values without further adjustment):

Wet Service Factors, C_M

F_b	F_t	F_v	$F_{c\perp}$	F_c	E and E_{min}
1.00	1.00	1.00	0.67	0.91	1.00

$C_F = (12/23.5)^{1/9} = 0.928$

Timber Beam Design

Trial 1: 12 x 24

Adjustment Factors:

C_L

Table 3.3.3
"Concentrated load at center with lateral support at center"
le = 1.11 lu

C_L:

$l_u = 9.5' = 114''$ $\quad l_u/d = 4.851$

$l_e = 1.11(l_u) = 1.11(114) = 126.5$

$R_B = \sqrt{\frac{l_e d}{b^2}} = 4.74$

$F_{bE} = \frac{1.2\ E_{min}}{R_B^2} = \frac{1.2(440000)}{4.74^2} = 23482$ psi

$F_b^* = F_b(C_F) = 65\ (0.928) = 580$

$\frac{F_{bE}}{F_b^*} = 40.5$

$C_L = 0.999$

Timber Beam Design

Trial 1: 12 x 24 Sx = 1058 in^3 A = 270 in^2

TRY 1 CONT.

12 x 24 $\quad C_F = 0.928 \quad C_L = 0.999 \quad C_D = 1.0$

$F_b' = F_b(C_D\ C_F\ C_L) = 625(1\ \ 0.928\ \ 0.999) = 579.3$ psi

$w_{SELF} = D\ \frac{AREA}{144} = 30\ \frac{270\ in^2}{144} = 56.25$ PLF

$M_w = \frac{w l^2}{8} = \frac{56.25\ (19)^2}{8} = 2538$ FT-LB

$M_{TOTAL} = M_P + M_w = 53428 + 2538 = 55969$ FT-LB

$S'_{REQ} = M/F = \frac{55969\ (12)}{579.3} = 1159.4\ in^3$

1159.4 > 1058 so 12 x 24 is too small

Timber Beam Design

Trial 2: Sx req'd = 1159 in^3

Table 1B Section Properties of Standard Dressed (S4S) Sawn Lumber (Cont.)

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.^{2}	X-X AXIS Section Modulus S_{xx} in.^{3}	X-X AXIS Moment of Inertia I_{xx} in.^{4}	Y-Y AXIS Section Modulus S_{yy} in.^{3}	Y-Y AXIS Moment of Inertia I_{yy} in.^{4}	Approximate weight in pounds per linear foot (lbs/ft) of piece when density of wood equals: 25 lbs/ft^3	30 lbs/ft^3	35 lbs/ft^3	40 lbs/ft^3	45 lbs/ft^3	50 lbs/ft^3
Beams & Stringers (see NDS 4.1.3.3 and NDS 4.1.5.3)												
10 x 14	9-1/2 x 13-1/2	128.3	288.6	1948	203.1	964.5	22.27	26.72	31.17	35.63	40.08	44.53
10 x 16	9-1/2 x 15-1/2	147.3	380.4	2948	233.1	1107	25.56	30.68	35.79	40.90	46.02	51.13
10 x 18	9-1/2 x 17-1/2	166.3	484.9	4243	263.2	1250	28.86	34.64	40.41	46.18	51.95	57.73
10 x 20	9-1/2 x 19-1/2	185.3	602.1	5870	293.3	1393	32.16	38.59	45.03	51.46	57.89	64.32
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14 x 22	13-1/2 x 21-1/2	290.3	1040	11181	653.1	4408	50.39	60.47	70.55	80.63	90.70	100.8
14 x 24	13-1/2 x 23-1/2	317.3	1243	14600	713.8	4818	55.08	66.09	77.11	88.13	99.14	110.2
16 x 20	15-1/2 x 19-1/2	302.3	982.3	9578	780.8	6051	52.47	62.97	73.46	83.96	94.45	104.9
16 x 22	15-1/2 x 21-1/2	333.3	1194	12837	860.9	6672	57.86	69.43	81.00	92.57	104.1	115.7
16 x 24	15-1/2 x 23-1/2	364.3	1427	16763	941.0	7293	63.24	75.89	88.53	101.2	113.8	126.5

try 14 x 24 Sx = 1243 in^3

Timber Beam Design

Trial 2: 14 x 24 (13 ½ x 23 ½) Sx = 1243 in^3

revise adjustment factors:

$$C_F = \left(\frac{12}{23.5}\right)^{1/9} = 0.928$$

C_L $l_e = 126.5''$

$$R_B = \sqrt{\frac{l_e d}{b^2}} = \sqrt{\frac{126.5(23.5)}{13.5^2}} = 4.039$$

$$F_{bE} = \frac{1.2(440000)}{4.039^2} = 32359.8 \text{ psi}$$

$$F^* = 625(0.928) = 580.0 \text{ psi}$$

$$F_{bE}/F^* = \frac{32359.8}{580} = 55.79$$

$$C_L = 0.999$$

Timber Beam Design

Trial 2: 14 x 24 A = 317.3 in^2 Sx = 1243 in^3

check stresses:

w = 66.1 PLF

TRY 2

14 x 24 $A = 317.3\ in^2$ $S_x = 1242.6\ in^3$

$F'_b = 625(1.0\ \ 0.928\ \ 0.999) = 579.5\ psi$

REVISE $M_w = 944.8$ FT-LB

CHECK $f_b = M/S_x = \frac{56410}{1242.6} = 544.8\ psi < 579.5 = F'_b$

CHECK SHEAR: $V_{MAX} = \frac{w\ell}{2} + \frac{P}{2} = \frac{66.1(19)}{2} + \frac{11248}{2} = 6251.9\ LB$

$f_v = \frac{3}{2}\frac{V}{A} = \frac{3}{2}\frac{6251.9}{317.3} = 29.56\ psi < 115 = F'_v$ ✓

∴ USE 14x 24

Timber Beam Design

Trial 2: 14 x 24 Ix = 14600 in^4

check deflection:
assume 30% of LL is sustained

see NDS 3.5
Kcr = 1.5 “seasoned lumber”

TABLE 1604.3 DEFLECTION LIMITS[a, b, c, h, i]

CONSTRUCTION	L	S or W[f]	D + L[d, g]
Roof members:[e]			
Supporting plaster or stucco ceiling	l/360	l/360	l/240
Supporting nonplaster ceiling	l/240	l/240	l/180
Not supporting ceiling	l/180	l/180	l/120
Floor members	l/360	—	l/240
Exterior walls:			
With plaster or stucco finishes	—	l/360	—
With other brittle finishes	—	l/240	—
With flexible finishes	—	l/120	—
Interior partitions:[b]			
With plaster or stucco finishes	l/360	—	—
With other brittle finishes	l/240	—	—
With flexible finishes	l/120	—	—
Farm buildings	—	—	l/180
Greenhouses	—	—	l/120

L/240 = 19(12)/240 = 0.95”

DEFLECTION

LONG-TERM: w_D P_D 30% P_L

$$\Delta_{w_D} = \frac{5 w_D \ell^4}{384 EI} = \frac{5(66.1)(19)^4(1728)}{384(1200000)(14600)} = 0.011''$$

$$\Delta_{P_D} = \frac{P_D \ell^3}{48 EI} = \frac{2888(19)^3(1728)}{48(1200000)(14600)} = 0.0407''$$

$$\Delta_{P_{L\,30\%}} = \frac{0.3(P_L)\ell^3}{48 EI} = \frac{0.3(8360)(19)^3(1728)}{48(1200000)(14600)} = 0.035''$$

$$\Delta_{LT} = 0.0867''$$

SHORT-TERM: 70% P_L

$$\Delta_{P_{L\,70\%}} = \frac{0.7(P_L)\ell^3}{48 EI} = \frac{0.7(8360)(19)^3(1728)}{48(1200000)(14600)} = 0.0825''$$

TOTAL DEFLECTION:

$$\Delta_T = K_{cr}\Delta_{LT} + \Delta_{ST}$$

$$= 1.5(0.0867) + 0.0825 = 0.213''$$