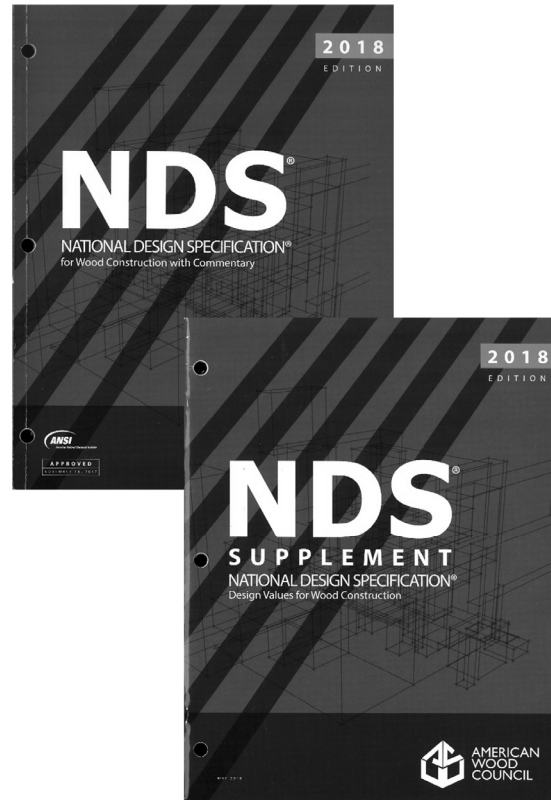


Architecture 544 Wood Structures

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	Design values in pounds per square inch (psi)						Modulus of Elasticity	Specific Gravity ⁴	Grading Rules Agency	
		Bending	Tension parallel to grain	Shear parallel to grain	Compression perpendicular to grain	Compression parallel to grain	E				E _{min}
		F _b	F _t	F _v	F _{c⊥}	F _c					
HEM-FIR											
Select Structural		1,400	925	150	405	1,500	1,600,000	580,000			
No. 1 & Btr		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	0.43	WCLIB WWPA	
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		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		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

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 F_v'

F_v from tables determined by species and grade

$F_v' = F_v$ (usage factors)

usage factors for shear:

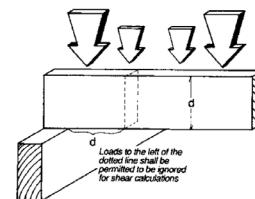
- C_D Load Duration Factor
- C_M Moisture Factor
- C_t Temperature Factor
- C_i Incising Factor

Actual Shear Stress f_v

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

Can use V at d from support as maximum

Shear at Supports



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

$$F_c' = F_c \text{ (usage factors)}$$

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

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

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

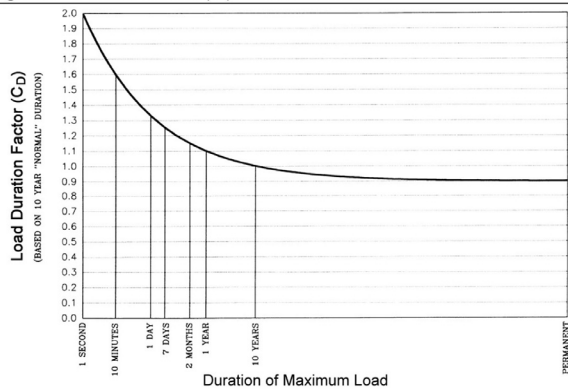
Usage factors for flexure:

C_D Load Duration Factor

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

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



- (1) Actual stress due to (DL) \leq (0.9) (Design value)
- (2) Actual stress due to (DL+LL) \leq (1.0) (Design value)
- (3) Actual stress due to (DL+WL) \leq (1.6) (Design value)
- (4) Actual stress due to (DL+LL+SL) \leq (1.15) (Design value)
- (5) Actual stress due to (DL+LL+WL) \leq (1.6) (Design value)
- (6) Actual stress due to (DL+SL+WL) \leq (1.6) (Design value)
- (7) Actual stress due to (DL+LL+SL+WL) \leq (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		
		$T \leq 100^\circ\text{F}$	$100^\circ\text{F} < T \leq 125^\circ\text{F}$	$125^\circ\text{F} < T \leq 150^\circ\text{F}$
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:

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, $C_M = 1.0$

Size Factors, C_F

Grades	Width (depth)	F_b		F_t	F_c
		Thickness (breadth)			
		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
Stud	12"	1.0	1.1	1.0	1.0
	14" & wider	0.9	1.0	0.9	0.9
	2", 3", & 4"	1.1	1.1	1.1	1.05
Construction, Standard	5" & 6"	1.0	1.0	1.0	1.0
	8" & wider	Use No.3 Grade tabulated design values and size factors			
Utility	2", 3", & 4"	1.0	1.0	1.0	1.0
	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:

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

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

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

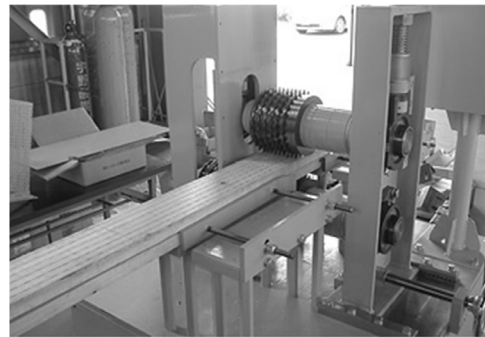
Usage factors for flexure:

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_{ct}	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, $d \leq b$, 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

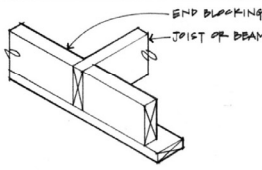
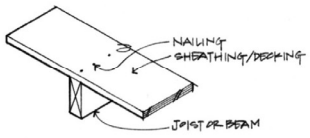
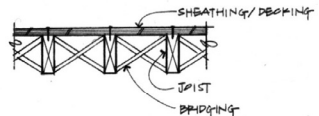
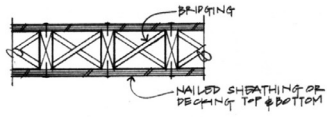
- 2x4 (a) $d/b \leq 2$; no lateral support shall be required.
- 2x6-8 (b) $2 < d/b \leq 4$; the ends shall be held in position, as by full depth solid blocking, bridging, hangers, nailing, or bolting to other framing members, or other acceptable means.
- 2x10 (c) $4 < d/b \leq 5$; the compression edge 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 $\ell_e/d < 7$	when $\ell_e/d \geq 7$
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 ²	when $\ell_e/d < 7$	when $\ell_e/d \geq 7$
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 $\ell_e/d < 7$
 $\ell_e = 1.63 \ell_u + 3d$ when $7 \leq \ell_e/d \leq 14.3$
 $\ell_e = 1.84 \ell_u$ when $\ell_e/d > 14.3$

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:

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

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:

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

where:

F_b^* = reference bending design value multiplied by all applicable adjustment factors except C_{ru} , 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

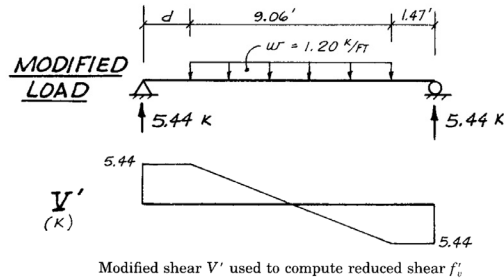
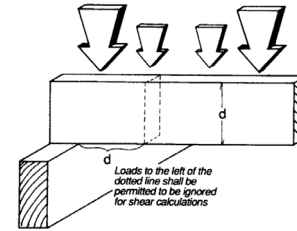
F_v from tables determined by species and grade

$F'_v = F_v$ (usage factors)

Usage factors for shear:

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

Shear at Supports



Analysis Procedure

Given: loading, member size, 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 \leq allowable

- $f_b \leq F'_b$
- $f_v \leq F'_v$

5. Check deflection

6. Check bearing ($F_b = \text{Reaction}/A_{\text{bearing}}$)

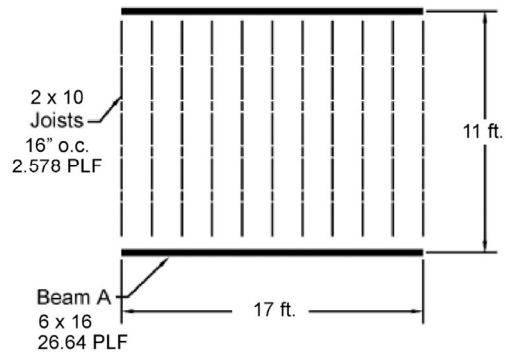
Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in. ²	X-X AXIS		Y-Y AXIS	
			Section Modulus S_{xx} in. ³	Moment of Inertia I_{xx} in. ⁴	Section Modulus S_{yy} in. ³	Moment of Inertia I_{yy} in. ⁴
Boards¹						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
1 x 4	3/4 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



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

ASCE-7 2.4.1 ASD load case: D + L

2x10 Joist + floor load:

$$\begin{aligned}
 & D + L \\
 & \left(\text{SELF WEIGHT} + D \frac{\text{o.c.}}{12} \right) + \left(L \frac{\text{o.c.}}{12} \right) \\
 & \left(4.336 \text{ PLF} + 3 \text{ PSF} \frac{16''}{12} \right) + \left(60 \text{ PSF} \frac{16''}{12} \right) \\
 & 8.336 \text{ PLF} + 80 \text{ PLF} = 88.336 \text{ PLF}
 \end{aligned}$$

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Analysis Example (joist)

1. Find Max Shear & Moment on Joist

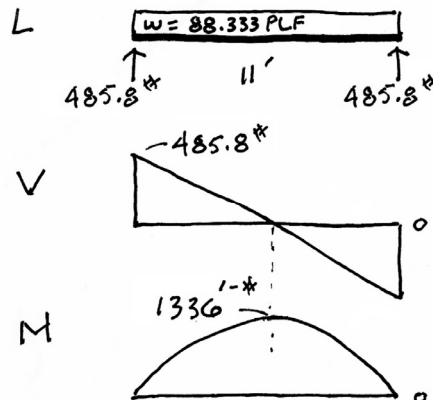
By equations:

Shear:

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

Moment:

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



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Analysis Example

2. Determine actual stresses in joists

- $f_b = M/S$
- $f_v = 1.5 V/A$

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

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

Species and Grade

3. Determine allowable stresses – NDS Supplement

- $F_b = 875 \text{ psi}$
- $F_v = 135 \text{ psi}$



Table 4A 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 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}		
SPRUCE-PINE-FIR										
Select Structural		1,250	700	135	425	1,400	1,500,000	550,000		
No. 1/ No. 2	2" & wider	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	0.42	NLGA
Construction		1,000	500	135	425	1,400	1,300,000	470,000		
Standard	2" - 4" wide	550	275	135	425	1,150	1,200,000	440,000		
Utility		275	125	135	425	750	1,100,000	400,000		

Analysis Example

- Determine allowable stresses – NDS Supplement
 - Adjustment Factors



Determine factors:

- $C_D = ?$
- $C_M = 1$
- $C_t = 1$
- $C_L = ?$
- $C_F = ?$
- $C_{fu} = 1$
- $C_i = 1$
- $C_r = ?$

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

C_F Size factor

2 x 10
use 1.1

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

Size Factors, C_F

Grades	Width (depth)	F_b		F_t	F_c
		Thickness (breadth)			
		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
Stud	14" & wider	0.9	1.0	0.9	0.9
	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
Construction, Standard	8" & wider	Use No.3 Grade tabulated design values and size factors			
	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

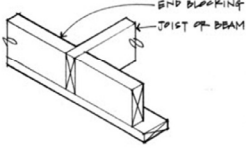
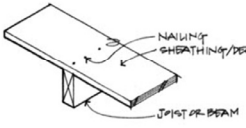
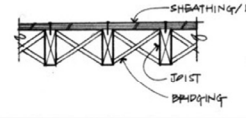
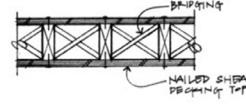
C_L Repetitive Member Factor

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

- $F'_b = F_b (C_D)(C_L)(C_F)(C_T)$
- $F'_b = 875 (1.0) (1.0) (1.1) (1.0) (1.15) = 1107 \text{ psi}$
- $F'_v = F_v (C_D)$
- $F'_v = 135 (1.0) = 135 \text{ psi}$

4. Check that actual \leq allowable

- $f_b < F'_b$
- $f_v < F'_v$

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

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

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

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

K_{cr}

- 1.5 dry, seasoned lumber
- 2.0 wet service conditions
- 2.0 wood panels
- 2.0 CLT (dry)

$$\Delta_t = \frac{5 w l^4}{384 EI} = \frac{5 (88.336) 11^4 (1728)}{384 (1400000) (98.93)} = 0.210''$$

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

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	//360	//360	//240
Supporting nonplaster ceiling	//240	//240	//180
Not supporting ceiling	//180	//180	//120
Floor members	//360	—	//240
Exterior walls:			
With plaster or stucco finishes	—	//360	—
With other brittle finishes	—	//240	—
With flexible finishes	—	//120	—
Interior partitions: ^b			
With plaster or stucco finishes	//360	—	—
With other brittle finishes	//240	—	—
With flexible finishes	//120	—	—
Farm buildings	—	—	//180
Greenhouses	—	—	//120

Analysis Example

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

$$F_{c\perp} = 425 \text{ psi}$$

$$P = R = 485.8 \text{ lbs}$$

$$A_b = 1.5" (1") = 1.5 \text{ in}^2$$

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

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 :

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

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

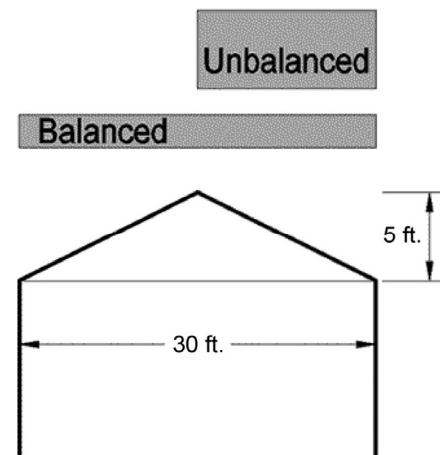
For round bearing areas such as washers, the bearing length, ℓ_b , shall be equal to the diameter.

Design Procedure – Joist or Rafter

Given: loading criteria, wood, span, size

Req'd: controlling load, o.c. spacing

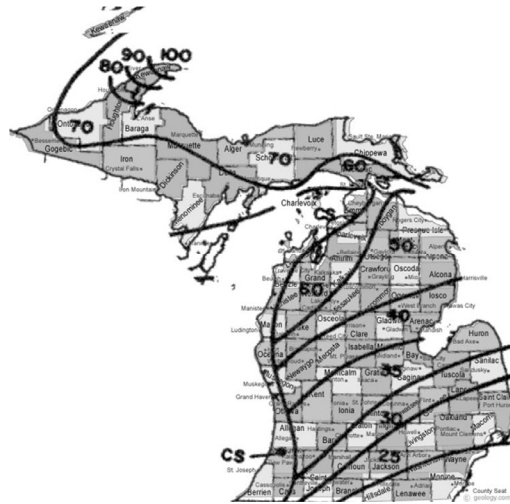
- Determine each load
 - check applicable load cases
 - determine loads
 - choose controlling load case
- Find Max Shear & Moment
 - assume o.c. spacing = 12"
- Calculate actual stresses
- Calculate allowable stresses
 - find applicable factors
- Choose spacing
 - determine utilization ratio: f_b/F_b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



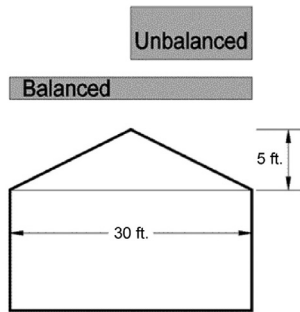
Design Example

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



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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 + L _r	$C_D = 1.25$
D + S	$C_D = 1.15$

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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

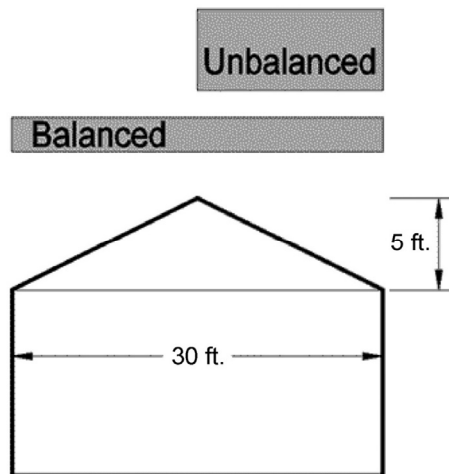
$$R_1 = \begin{cases} 1 & \text{for } A_t \leq 200 \text{ ft}^2 (18.58 \text{ m}^2) \\ 1.2 - 0.001A_t & \text{for } 200 \text{ ft}^2 < A_t < 600 \text{ ft}^2 \\ 0.6 & \text{for } A_t \geq 600 \text{ ft}^2 (55.74 \text{ m}^2) \end{cases}$$

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

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

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.



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Design Example (rafter)

p_f - flat roof snow load = 50 psf

$$p_f = 0.7 C_e C_t I_s p_g$$

- Eq. 7.3-1

Low Slope Roofs

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

Minimum for Low Slope Roofs

- Minimum where $p_g \leq 20 = I_s p_g$ 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/ft² (kN/m²) using the following formula:

$$p_f = 0.7 C_e C_t I_s p_g \quad (7.3-1)$$

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/ft² (0.96 kN/m²) or less:

$$p_m = I_s p_g \quad (\text{Importance Factor times } p_g)$$

Where p_g exceeds 20 lb/ft² (0.96 kN/m²):

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

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”
- $C_e = 1.0$



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.

^aDefinitions: 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.

^bObstructions 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 : $I_s = 1.0$

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_t	Ice Importance Factor—Wind, I_w	Seismic Importance Factor, I_p
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 $25^\circ\text{F} \times h \times \text{ft}^2/\text{Btu}$ ($4.4 \text{ K} \times \text{m}^2/\text{W}$)	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 $2.0^\circ\text{F} \times h \times \text{ft}^2/\text{Btu}$ ($0.4 \text{ K} \times \text{m}^2/\text{W}$)	0.85

^aThese conditions shall be representative of the anticipated conditions during winters for the life of the structure.

^bGreenhouses 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

$$p_f = 0.7 C_e C_t I_s p_g$$

$$0.7 \cdot 1.0 \cdot 1.0 \cdot 1.0 \cdot 50 = 35 \text{ psf}$$

p_s – sloped roof snow load

$$p_s = C_s p_f$$

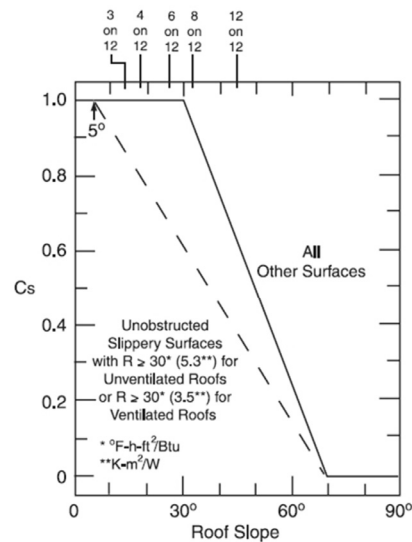
- Eq. 7.4-1

C_s – Roof Slope Factor

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

p_s

$$p_s = C_s p_f = 1.0 \cdot 35 \text{ psf} = 35 \text{ psf}$$



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

Design Example (rafter)

Balanced

- $p_s = 35 \text{ psf}$

Unbalanced

For $W \leq 20\text{FT}$

- $I_s \times p_g = 1.0 \times 50 = 50 \text{ psf}$

For $W > 20\text{FT}$

- See Fig. 7.6-2

Unbalanced Gable Roof Loads

- Not** for $F > 7$ on 12 (30.2°)
- Not** for $F < \frac{1}{2}$ on 12 (2.38°)

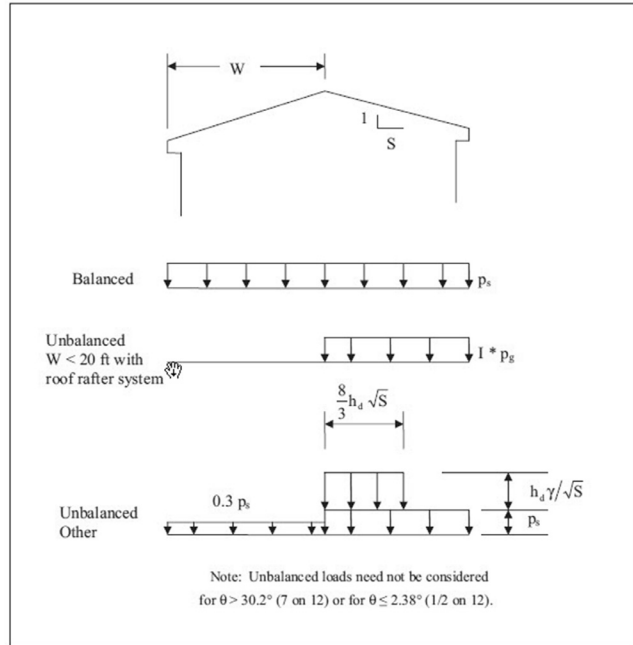


FIGURE 7-5 Balanced and Unbalanced Snow Loads for Hip and Gable Roofs.

Analysis Example (rafter)

Controlling (greatest) load

- $D = 7 \text{ psf}$ (on surface)
- $S = 50 \text{ psf}$ (projected)
- $D + S = 57.38 \text{ psf}$ (projected)

2. Find Max Shear & Moment

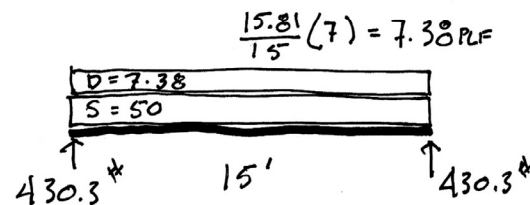
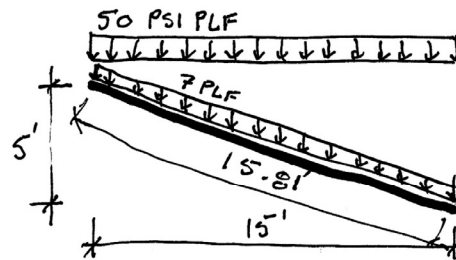
By equations (projected):

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

- $f_b = M/S$
- $f_v = 1.5 V/A$

$$f_b = \frac{M}{S_x} = \frac{1614' \cdot (12)}{21.39 \text{ in}^3} = 905.4 \text{ psi}$$

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

Species and Grade

4. Determine allowable stresses – NDS Supplement

- $F_b = 850 \text{ psi}$
- $F_v = 150 \text{ psi}$

DESIGN VALUES FOR WOOD CONSTRUCTION – NDS SUPPLEMENT

35

Table 4A 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 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}		
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 Standard	2" - 4" wide	975	600	150	405	1,550	1,300,000	470,000		
Utility		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 and LRFD											LRFD only		
		ASD 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
$F_b' = F_b$	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

Snow Load (2 months) = 1.15

Table 2.3.2 Frequently Used Load Duration Factors, C_D¹

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

Grades	Width (depth)	F _b		F _t	F _c
		Thickness (breadth)			
		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
Stud	14" & wider	0.9	1.0	0.9	0.9
	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
Construction, Standard	8" & wider	Use No.3 Grade tabulated design values and size factors			
	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

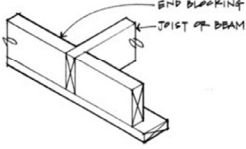
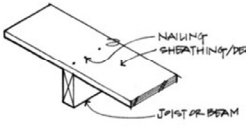
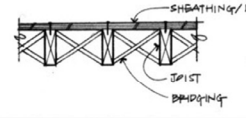
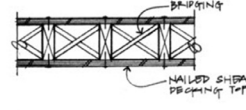
C_L Repetitive Member Factor

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

- $F'_b = F_b (C_D)(C_L)(C_F)(C_r)$
- $F'_b = 850 (1.15) (1.0) (1.1) (1.0) (1.15) = 1236 \text{ psi}$
- $F'_v = F_v (C_D)$
- $F'_v = 150 (1.15) = 172.5 \text{ psi}$

5. Check that actual \leq allowable

- $f_b < F'_b$
- $f_v < F'_v$

$$f_b = \frac{M}{S_x} = \frac{1614 \text{ ft} \cdot \text{lb}}{21.39 \text{ in}^3} = 905.4 \text{ psi}$$

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

6. Utilization Ratio

- $905.4/1236 = 0.732$
- $12'' \text{ o.c.} / 0.732 = 16.38$
- try 2x10 at 16'' o.c.
- $f_b \text{ at } 16'' \text{ o.c.} = 905.4 (16/12) = 1207 \text{ psi}$

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 in step 3 to check shear stress.
- If it fails ($f_v > F'_v$), then find load based on shear.

5. Check deflection

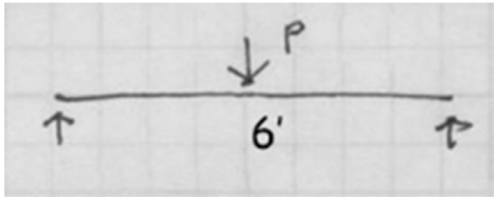
6. Check bearing

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in. ²	X-X AXIS		Y-Y AXIS	
			Section Modulus S_{xx} in. ³	Moment of Inertia I_{xx} in. ⁴	Section Modulus S_{yy} in. ³	Moment of Inertia I_{yy} in. ⁴
Boards¹						
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)



- Assume $f = F'$
 - Maximum actual = allowable stress

GIVEN : SPAN = 6' P@C
 SECTION = 2x4 (1.5x3.5)
 $F_b = 875 \text{ psi}$ $F_v = 135 \text{ psi}$
 REQ'D : MAXIMUM LOAD P

Table 4A 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 A1

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

Analysis Example

Determine allowable stresses – NDS Supplement

- Adjustment Factors



Determine factors:

- $C_D = ?$
- $C_M = 1$
- $C_t = 1$
- $C_L = 1$
- $C_F = ?$
- $C_{fu} = 1$
- $C_i = 1$
- $C_r = 1$

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

Size Factors, C_F			
Grades	Width (depth)	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" & wider	1.0	1.1
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

$$f_b = F'_b = \frac{F_b}{C_D} = 875 (1.6)(1.5)$$

$$F'_b = 2100 \text{ PSI}$$

$$S_x = 3.063 \text{ in}^3$$

$$M_d = F'_b S_x = 2100 (3.063)$$

$$= 6432.3 \text{ in} \cdot \text{lb}$$

$$= 536 \text{ ft} \cdot \text{lb}$$

2. Solve stress equation for moment

- $M = F'_b S_x$ (i.e. moment capacity)

Analysis Example (cont.)

3. Use maximum forces to find loads

- Back calculate a maximum load from moment capacity

$$M_d = \frac{PL}{4}$$

$$P = \frac{M_d 4}{L}$$

$$P = \frac{536 (4)}{16}$$

$$P = 357 \text{ lb}$$

4. Check shear

- Check shear for load capacity from step 3.
- Use P from moment to find V_{max}
- Check that $f_v < F'_v$

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

$$V_{max} = \frac{P}{2} = \frac{357}{2} = 178.5 \text{ lb}$$

$$f_v = \frac{3}{2} \frac{V}{A} = 1.5 \frac{178.5}{5.25 \text{ in}^2} = 51 \text{ psi}$$

4. Check deflection (serviceability)

5. Check bearing (serviceability)

$$51 < 216 \therefore \text{OK} \checkmark$$

Question ...

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

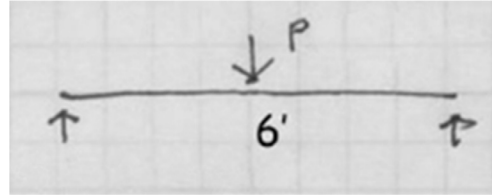
$$F_b' = F_b (C_D C_M C_t C_L C_F C_{fu} C_i C_r)$$

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

$$M = F_b' S_y \quad P = M 4 / L$$

Check that $f_v < F_v'$

GIVEN : SPAN = 6' P @ ϕ
SECTION = 2x4 (1.5x3.5)
 $F_b = 875 \text{ psi}$ $F_v = 135 \text{ psi}$
REQ'D : MAXIMUM LOAD P



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

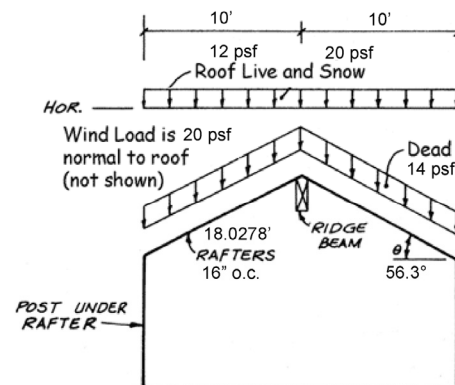
Analysis Example 3

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 , C_t , C_{fu} and C_i 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



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

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

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

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

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

Analysis Example 3

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

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

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

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

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

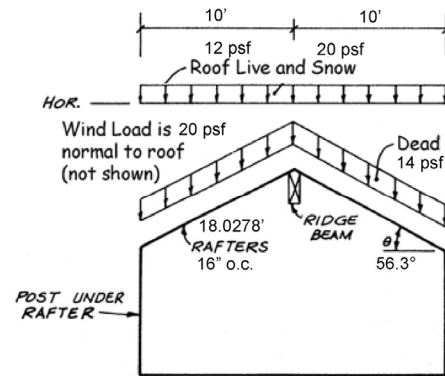
$$\text{MOMENTS: } \frac{wl^2}{8}$$

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

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

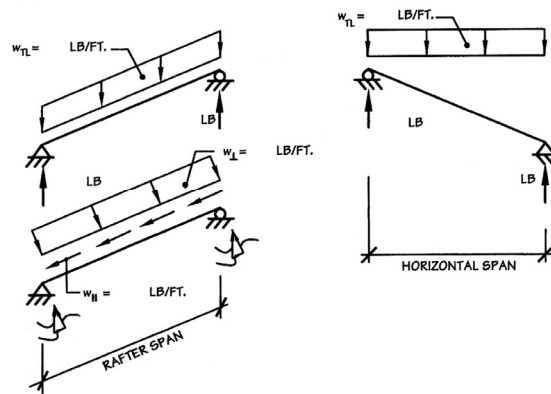
$$S: \frac{26.67(10)^2}{8} = 333.3 \text{ FT-LBS}$$

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



Analysis Example 3

Add this example
but first get numbers that match drawing



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. $0.6D + 0.6W$

To find the controlling case :

Sum moments / C_D

the largest controls

LOAD CASES :

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

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

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

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

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

$$D + .75(.6W) + .75 S : \frac{420.6 + .75(.6(1083.5)) + .75(333.3)}{1.4} = 723.8$$

LARGEST CONTROLS

∴ LOAD CASE 15

$$D + .75(.6W) + .75 S$$

$$M_E = \underline{\underline{1158 \text{ FT-LBS}}}$$

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		F_t	F_c
		Thickness (breadth)			
		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
Stud	14" & wider	0.9	1.0	0.9	0.9
	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
Construction, Standard	8" & wider	Use No.3 Grade tabulated design values and size factors			
	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:

$$F_b = 700 \text{ psi}$$

USE WITH TABLE 4A ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Design values in pounds per square inch (psi)							Specific Gravity ⁴
		Bending 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}	
WESTERN CEDARS									
Select Structural		1,000	600	155	425	1,000	1,100,000	400,000	0.36
No. 1	2" & wider	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:

$$F_b = 700 \text{ psi}$$

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

$$F'_b = 700 \text{ psi} (1.6 \ 1.1 \ 1.15) = 1416.8 \text{ psi}$$

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:

$$f_b = M / S_x$$

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

$$f_b = 649.7 \text{ psi}$$

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

try 24" o.c. ?

check shear

Analysis Example

Given: loading, member size, material and span.

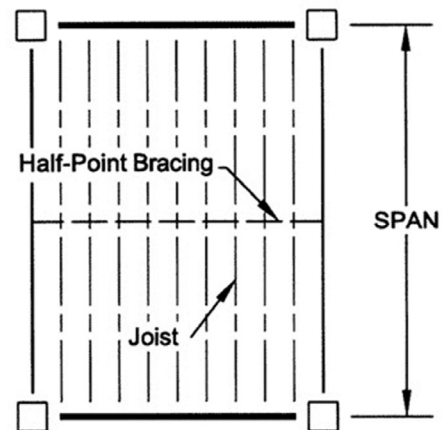
Req'd: LL capacity in psf

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 F_b , F_v and E_{min} for Douglas Fir – South No2.

- (from NDS Supplement)

Table 4A 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 G	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}			
DOUGLAS FIR-SOUTH											
Select Structural		1,350	900	180	520	1,600	1,400,000	510,000			
No. 1	2" & wider	925	600	180	520	1,450	1,300,000	470,000	0.46	WWPA	
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		975	600	180	520	1,650	1,200,000	440,000			
Standard	2" - 4" wide	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 in²

$S_x = 21.39$ in³

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in. ²	X-X AXIS		Y-Y AXIS	
			Section Modulus S_{xx} in. ³	Moment of Inertia I_{xx} in. ⁴	Section Modulus S_{yy} in. ³	Moment of Inertia I_{yy} in. ⁴
Boards¹						
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_c	$F_{t\perp}$	F_e	E and E_{min}
0.85*	1.0	0.97	0.67	0.8**	0.9

* when $(F_b/C_r) \leq 1,150$ psi, $C_M = 1.0$
 ** when $(F_b/C_r) \leq 750$ psi, $C_M = 1.0$

Flat Use Factor, C_u

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_u		
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

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		F_t	F_c
		Thickness (breadth)			
		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
Stud	14" & wider	0.9	1.0	0.9	0.9
	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
Construction, Standard, Utility	8" & wider	Use No.3 Grade tabulated design values and size factors			
	2", 3", & 4"	1.0	1.0	1.0	1.0
	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	—	0.4	0.6

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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.

$$\ell_u = 5' = 60"$$

$$d = 9.25"$$

$$\ell_u / d = 6.48 < 7$$

$$\ell_e = 2.06 \ell_u = 123.6$$

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:

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

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:

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

where:

F_b^{*} = reference bending design value multiplied by all applicable adjustment factors except C_{tu}, C_v (when C_v ≤ 1.0), and C_L (see 2.3), psi

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

$$l_e = 123.6$$

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

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

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

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

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

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

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

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

$$C_L = 1.0349 - 0.23198 = 0.8029$$

Analysis Example

Determine the Factored Allowable Stress

F'_b = F_b (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

$$F'_b = 850(1.15 \times 1.1 \times 0.8029) = 863.3 \text{ psi}$$

$$F'_v = 180(C_D C_M C_t C_i) = 180 \text{ psi}$$

Analysis Example

Allowable Stresses

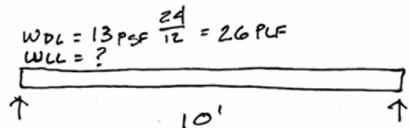
$$F'b = 863.3 \text{ psi}$$

$$F'v = 180 \text{ psi}$$

Determine LL capacity

$$M = F'b S_x$$

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in. ²	X-X AXIS		Y-Y AXIS	
			Section Modulus S _x in. ³	Moment of Inertia I _{xx} in. ⁴	Section Modulus S _y in. ³	Moment of Inertia I _{yy} in. ⁴
Boards¹						
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



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

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

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

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

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

$$\Delta \text{ACTUAL } V_{\text{max}} = \frac{V}{2} = \frac{(26 + 97.11) 10}{2} = 615.5 \text{ LB}$$

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

Analysis Example

Given: loading, member size, material and span.

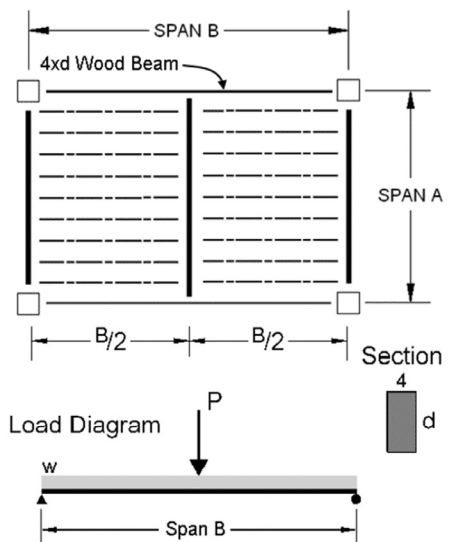
Req'd: Safe or Unsafe

3. Wood Beam Analysis

Analyze the given 4x dimensioned lumber beam to determine if it passes or fails the NDS code criteria. The beam carries both dead and live floor load plus its own selfweight (CD = 1.0). Check the actual shear and bending stresses against the factored allowable stresses including all applicable factors from the NDS. Load duration is based on the live load. Assume normal temperature, and no incising (Ct = Ci = 1.0). Find the beam selfweight including the given moisture content. The beam is braced at the ends and the C.L. (meets criteria in 4.4.1) so CL = 1.0.

DATASET: 1	-2	-3
Wood Species	HEM-FIR	
Wood Grade	Select Structural	
Span A	16 FT	
Span B	12 FT	
Nominal Depth of Beam, d	12 IN	
Moisture Content, m.c.	15 %	
Floor DL	7 PSF	
Floor LL	35 PSF	

Logged in as: psVB



Analysis Example

Determine Loading

- Find Tributary area, A_T
 $6' \times 8' = 48 \text{ SF}$
- Determine member selfweight (w)

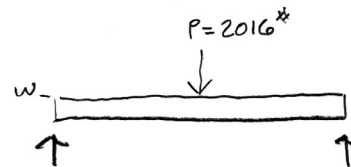
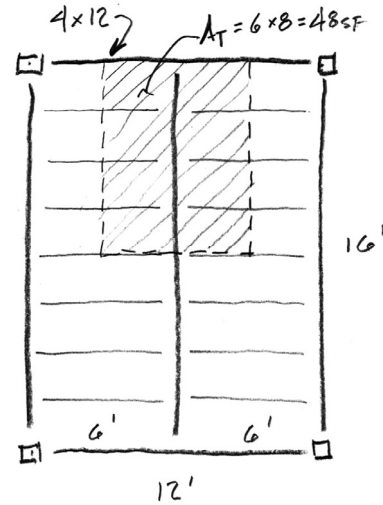
$$DL = 7 \text{ PSF}$$

$$LL = 35 \text{ PSF}$$

$$\text{TOTAL} = 42 \text{ PSF}$$

$$P = A_T \times \text{PSF}$$

$$= 48 \times 42 = 2016^*$$



Analysis Example

Section Properties:

4 x 12 (3.5" x 11.25")

Area = 39.38 in²

$S_x = 73.83 \text{ in}^3$

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in. ²	X-X AXIS		Y-Y AXIS	
			Section Modulus S_{xx} in. ³	Moment of Inertia I_{xx} in. ⁴	Section Modulus S_{yy} in. ³	Moment of Inertia I_{yy} in. ⁴
Boards¹						
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

Analysis Example

Selfweight of member:

Density at 0 M.C. = $62.4 \times G$ (dry)
 $62.4 \times 0.43 = 26.8$ PCF

The following formula shall be used to determine the density in lbs/ft³ of wood:

$$\text{density} = 62.4 \left[\frac{G}{1 + G(0.009)(\text{m.c.})} \right] \left[1 + \frac{\text{m.c.}}{100} \right]$$

where:

G = specific gravity of wood

m.c. = moisture content of wood, %

To include M.C. use NDS formula.

$$D = 62.4 \left[\frac{0.43}{1 + 0.43(0.009)(15)} \right] \left[1 + \frac{15}{100} \right]$$

$$25.35 \times 1.15 = 29.16 \text{ PCF}$$

w (PLF) = D (PCF) x Area (IN²)/144

$$W = \text{PLF} = D \frac{\text{AREA}}{144} = 29.16 \frac{39.38}{144}$$

$$w = 7.975 \text{ PLF}$$

Analysis Example

Determine Beam Forces
 by superposition equations

1. SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD

Total Equiv. Uniform Load	= wl
$R = V$	= $\frac{wl}{2}$
V_x	= $w\left(\frac{l}{2} - x\right)$
M_{max} (at center)	= $\frac{wl^2}{8}$
M_x	= $\frac{wx}{2}(l - x)$
Δ_{max} (at center)	= $\frac{5wl^4}{384EI}$
Δ_x	= $\frac{wx}{24EI}(l^3 - 2lx^2 + x^3)$

$$R = \frac{wl}{2} + \frac{P}{2}$$

$$\frac{7.975(12)}{2} + \frac{2016}{2}$$

$$47.85 + 1008 = 1055.8 \#$$

$$V_{\text{max}} = R$$

7. SIMPLE BEAM—CONCENTRATED LOAD AT CENTER

Total Equiv. Uniform Load	= $2P$
$R = V$	= $\frac{P}{2}$
M_{max} (at point of load)	= $\frac{Pl}{4}$
M_x (when $x < \frac{l}{2}$)	= $\frac{Px}{2}$
Δ_{max} (at point of load)	= $\frac{Pl^3}{48EI}$
Δ_x (when $x < \frac{l}{2}$)	= $\frac{Px}{48EI}(3l^2 - 4x^2)$

$$M_d = \frac{wl^2}{8} + \frac{Pl}{4}$$

$$\frac{7.975(12)^2}{8} + \frac{2016(12)}{4}$$

$$143.5 + 6048 = 6191.5 \#$$

Analysis Example

Determine actual stresses

- $f_b = M/S$
- $f_v = 1.5 V/A$

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in. ²	X-X AXIS		Y-Y AXIS	
			Section Modulus S _{xx} in. ³	Moment of Inertia I _{xx} in. ⁴	Section Modulus S _{yy} in. ³	Moment of Inertia I _{yy} in. ⁴
Boards¹						
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	0.880	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

ACTUAL STRESS:

$$f_b = \frac{M}{S_x} = \frac{6191.5(12)}{73.83} = 1006.3 \text{ psi}$$

$$f_v = \frac{3}{2} \frac{V}{A} = 1.5 \frac{1055.8}{39.38} = 40.22 \text{ psi}$$

Analysis Example

Determine allowable stresses

- F_b and F_v (from NDS)

DESIGN VALUES FOR WOOD CONSTRUCTION – NDS SUPPLEMENT

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⊥}	F _c	E			E _{min}
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

3. Determine allowable stresses

- $F_b = 1400$ psi
- $F_v = 150$ psi

Determine factors:

- CD = 1.0 (LL)
- CM = 1.0 (15%)
- Ct = 1.0
- CL = 1.0 (4.4.1)
- CF =
- Cfu = 1.0
- Ci = 1.0
- Cr = 1.0

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD and LRFD											LRFD only		
		ASD 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
$F_b' = F_b$	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

Adjustment Factors

Allowable Flexure Stress F_b'

F_b from tables determined by species and grade

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

$$b/d = 3.5 / 11.25 = 3.11 \quad (\text{case b})$$

Assuming ends are braced, $C_L = 1.0$

3.3.3 Beam Stability Factor, C_L

3.3.3.1 When the depth of a bending member does not exceed its breadth, $d \leq b$, 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, $C_L = 1.0$.

2012 NDS

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.

Analysis Example

Determine allowable stresses

4 x 12

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in. ²	X-X AXIS		Y-Y AXIS	
			Section Modulus S _{xx} in. ³	Moment of Inertia I _{xx} in. ⁴	Section Modulus S _{yy} in. ³	Moment of Inertia I _{yy} in. ⁴
Boards¹						
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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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	18.96	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
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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

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 _{cL}	F _c	E and E _{min}
0.85*	1.0	0.97	0.67	0.8**	0.9

* when (F_b)(C_F) ≤ 1,150 psi, C_M = 1.0

** when (F_b)(C_F) ≤ 750 psi, C_M = 1.0

Size Factors, C _F			
Grades	Width (depth)	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
Stud	12"	1.0	1.1
	14" & wider	0.9	1.0
	2", 3", & 4"	1.1	1.1
Construction, Standard	5" & 6"	1.0	1.0
	8" & wider	Use No.3 Grade tabulated design v	
Utility	2", 3", & 4"	1.0	1.0
	4"	1.0	1.0
	2" & 3"	0.4	—

Analysis Example

3. Determine allowable stresses

- F_b' = F_b (usage factors)

$$\begin{aligned}
 \underline{F_b} & C_D = 1.0 \text{ (LIVE LOAD)} \\
 C_{Tb} & = 1.0 \quad 15\% < 19\% \text{ (NDS SUP. P. 32)} \\
 C_t & = 1.0 \quad T_{EMP} < 100^\circ \\
 C_L & = 1.0 \quad \text{BRACED PER NDS 4.4.1} \\
 C_F & = 1.1 \quad \text{FOR 4x12 (NDS SUP. P 32)} \\
 C_{Fu} & = 1.0 \quad \text{(NOT) (NDS SUP P 32)} \\
 C_i & = 1.0 \quad \text{(NOT) (NDS P 29-30)} \\
 C_r & = 1.0 \quad \text{(NOT) (NDS SUP P 32)}
 \end{aligned}$$

$$F'_b = 1400(1.1) = \underline{1540 \text{ PSI}}$$

Analysis Example

3. Determine allowable stresses

- $F'_v = F_v$ (usage factors)

$$\begin{aligned} \underline{F_v} \quad C_D &= 1.0 \\ C_{M_v} &= 1.0 \\ C_t &= 1.0 \\ C_i &= 1.0 \end{aligned}$$

$$F'_v = 150(1.0) = \underline{\underline{150 \text{ PSI}}}$$

Analysis Example

Check that actual \leq allowable

- $f_b \leq F'_b$
- $f_v \leq F'_v$

$$\begin{aligned} f_b &< F'_b \\ 1006.3 \text{ psi} &< 1540 \therefore \checkmark \text{OK} \end{aligned}$$

$$\begin{aligned} f_v &< F'_v \\ 40.22 \text{ psi} &< 150 \therefore \checkmark \text{OK} \end{aligned}$$

Check deflection

Check bearing ($F_{C\perp} = \text{Reaction}/A_{\text{bearing}}$)

Design Procedure

Given: load, wood, span

Req'd: member size

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		Y-Y AXIS	
			Section Modulus S_{xx} in. ³	Moment of Inertia I_{xx} in. ⁴	Section Modulus S_{yy} in. ³	Moment of Inertia I_{yy} in. ⁴
Boards¹						
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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2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266
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Design Example (joist)

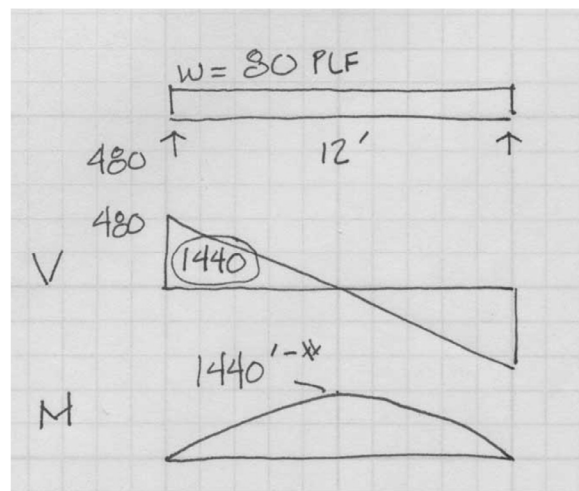
Given: total load, wood, span

Req'd: member size

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

GIVEN: $F_b' = 1000$ PSI
 $F_v' = 100$ PSI
 SPAN = 12'
 DL + LL = 80 PLF

REQ'D: SECTION SIZE



Design Example

2. Estimate allowable stresses

(given in this example)

$$F'_b = 1000 \text{ psi}$$

$$F'_v = 100 \text{ psi}$$

3. Solve $S = M/F'_b$

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

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

4. Choose a section from S table

- Revise DL and F'_b

$$2 \times 10 \quad S_x = 21.39 > 17.28 \quad \checkmark$$

$$A = 13.88 \text{ in}^2$$

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in. ²	X-X AXIS		Y-Y AXIS	
			Section Modulus S_{xx} in. ³	Moment of Inertia I_{xx} in. ⁴	Section Modulus S_{yy} in. ³	Moment of Inertia I_{yy} in. ⁴
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2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547
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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

Design Example

$$2 \times 10 \quad S_x = 21.39 > 17.28 \quad \checkmark$$

$$A = 13.88 \text{ in}^2$$

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 $A = 1.5V/F'_v$

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

$$51.87 \text{ psi} < 100 \text{ psi} \quad \checkmark \text{ OK}$$

6. Check deflection

7. Check bearing

Design Example (joist)

Given: load, wood, span

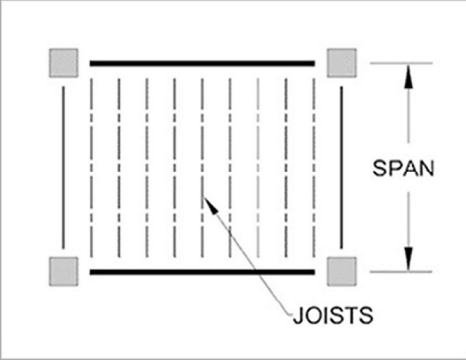
Req'd: member size

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 C_t , C_{fu} , and $C_i = 1.0$. 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	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}		
HEM-FIR										
Select Structural		1,400	925	150	405	1,500	1,600,000	580,000		
No. 1 & Btr		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	0.43	WCLIB WWPA
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		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		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		Y-Y AXIS	
			Section Modulus S _{xx} in. ³	Moment of Inertia I _{xx} in. ⁴	Section Modulus S _{yy} in. ³	Moment of Inertia I _{yy} in. ⁴
Boards¹						
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	18.96	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

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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, $C_r = \frac{1}{1.5}$, 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 _v	F _c	F _t	E and E _{min}	
0.85*	1.0	0.97	0.67	0.8**	0.9

* when (F_b/C_M) ≤ 1,150 psi, C_M = 1.0
** when (F_b/C_M) ≤ 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"	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		F _t	F _c
		Thickness (breadth)			
		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
Stud	12"	1.0	1.1	1.0	1.0
	14" & wider	0.9	1.0	0.9	0.9
	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, Utility	2", 3", & 4"	1.0	1.0	1.0	1.0
	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	—	0.4	0.6

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Design Example

Determine allowable stresses.

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

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

$$= 975 \left(\underset{C_D}{1.0} \times \underset{C_M}{1.15} \times \underset{C_t}{1.0} \times C_F \right) \approx 1121 \text{ psi}$$

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

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

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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.

$$M = \frac{w l^2}{8} = \frac{42 (20')^2}{8} = 2100 \text{ ft}\cdot\text{ft}$$

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 S_x to the actual S_x 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

2x10 21.39 (CF=1.1) MIGHT WORK

2x12 31.64 (CF=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		Y-Y AXIS	
			Section Modulus S_{xx} in. ³	Moment of Inertia I_{xx} in. ⁴	Section Modulus S_{yy} in. ³	Moment of Inertia I_{yy} in. ⁴
Boards¹						
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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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 5	2-1/2 x 4-1/2	11.25	8.44	18.96	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

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TRY 2x10 $C_F = 1.1$

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

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

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

\therefore USE 2x10

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 K_{cr}

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	//360	//360	//240
Supporting nonplaster ceiling	//240	//240	//180
Not supporting ceiling	//180	//180	//120
Floor members	//360	—	//240
Exterior walls:			
With plaster or stucco finishes	—	//360	—
With other brittle finishes	—	//240	—
With flexible finishes	—	//120	—
Interior partitions: ^b			
With plaster or stucco finishes	//360	—	—
With other brittle finishes	//240	—	—
With flexible finishes	//120	—	—
Farm buildings	—	—	//180
Greenhouses	—	—	//120

LL = 35 PSF = 35 PLF

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

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

0.849 > 0.667 \therefore FAILS

International Building Code (IBC)

Timber Beam Design

Given: load, wood, span

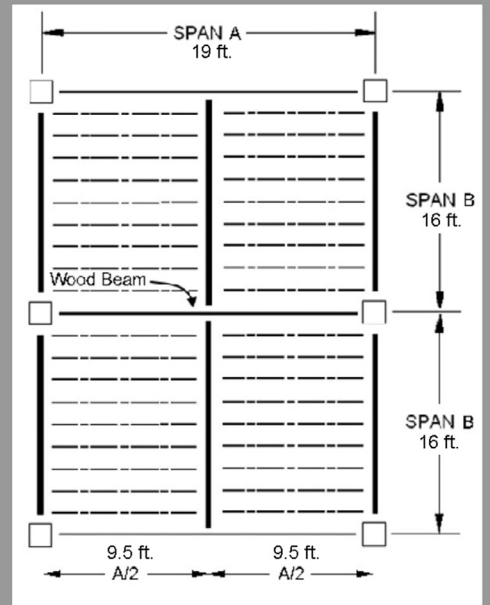
Req'd: member size (in this example both b and d)

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).

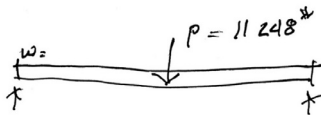
DATASET: 1 -2-

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



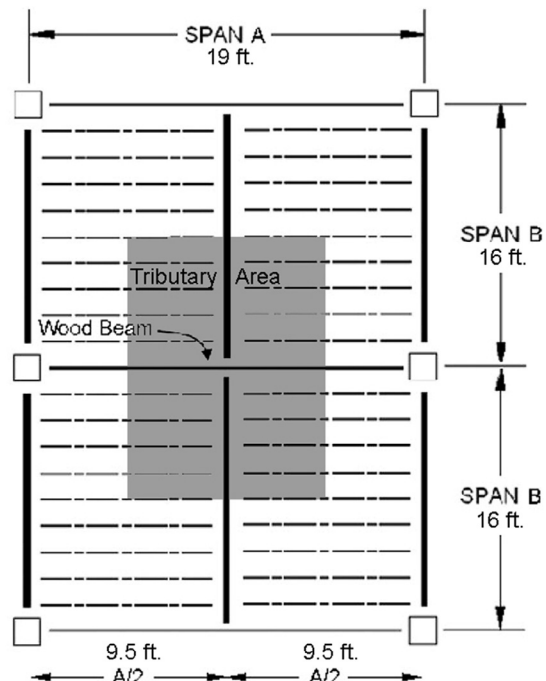
COAST SITKA SPRUCE
No.2
DENSITY 30 PCF
M.C. 15%
DL 19 PSF
LL 55 PSF

$$P_{D+L} = (19+55)(19 \times 16) = 11248 \text{ LBS}$$

$$w = \text{BEAM SELFWEIGHT}$$

$$M_P = \frac{P \ell}{4} = \frac{11248(19)}{4} = 53428 \text{ ft-lb}$$

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



Timber Beam Design

Find allowable stress

$$F_b = 625 \text{ psi}$$

$$F_v = 115 \text{ psi}$$

$$E = 1200000 \text{ psi}$$

$$E_{min} = 440000 \text{ psi}$$

From NDS Supplement:
Coast Sitka Spruce No2

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)							Modulus of Elasticity	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⊥}	F _c	E	E _{min}			
COAST SITKA SPRUCE											
Select Structural	Beams and Stringers	1,150	675	115	455	775	1,500,000	550,000	0.43	NLGA	
No.1		950	475	115	455	650	1,500,000	550,000			
No.2		625	325	115	455	425	1,200,000	440,000			
Select Structural	Posts and Timbers	1,100	725	115	455	825	1,500,000	550,000	0.43	NLGA	
No.1		875	575	115	455	725	1,500,000	550,000			
No.2		525	350	115	455	500	1,200,000	440,000			

Timber Beam Design

Trial 1:
choose S_x and size

$$S_x = M / F_b$$

TRY 1

$$F_b \approx F_b = 625 \text{ psi}$$

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

$$12 \times 24$$

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

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

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		Y-Y AXIS		Approximate weight in pounds per linear foot (lbs/ft) of piece when density of wood equals:					
			Section Modulus S _{xx} in. ³	Moment of Inertia I _{xx} in. ⁴	Section Modulus S _{yy} in. ³	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
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
$d \leq 12"$	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"

$le = 1.11 lu$

$$C_L: \quad lu = 9.5' \quad lu/d = 4.851 \\ = 114''$$

$$le = 1.11(lu) \\ = 1.11(114) = 126.5$$

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

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

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

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

$$C_L = 0.999$$

Timber Beam Design

Trial 1: 12 x 24 $S_x = 1058 \text{ in}^3$ $A = 270 \text{ in}^2$

TRY 1 CONT.

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

$$F'_b = F_b (C_D C_F C_L) = 625 (1.0 \cdot 0.928 \cdot 0.999) = 579.3 \text{ psi}$$

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

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

$$M_{\text{TOTAL}} = M_p + M_w = 53428 + 2538 = 55969 \text{ FT-LB}$$

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

1159.4 > 1058 so 12 x 24 is too small

Timber Beam Design

Trial 2: $S_x \text{ req'd} = 1159 \text{ in}^3$

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

Nominal Size b x d in. x in.	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in. ²	X-X AXIS		Y-Y AXIS		Approximate weight in pounds per linear foot (lbs/ft) of piece when density of wood equals:					
			Section Modulus S_{xx} in. ³	Moment of Inertia I_{xx} in. ⁴	Section Modulus S_{yy} in. ³	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
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
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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
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 $S_x = 1243 \text{ in}^3$

Timber Beam Design

Trial 2: 14 x 24 (13 1/2 x 23 1/2) $S_x = 1243 \text{ in}^3$

revise adjustment factors:

$$C_F = \left(\frac{12}{23.5}\right)^{1/4} = 0.928$$

$$C_L \quad l_e = 126.5''$$

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

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

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

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

$$C_L = 0.999$$

Timber Beam Design

Trial 2: 14 x 24 $A = 317.3 \text{ in}^2$ $S_x = 1243 \text{ in}^3$

check stresses:

$w = 66.1 \text{ PLF}$

TRY 2

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

$$F_b' = 625(1.0 \cdot 0.928 \cdot 0.999) = 579.5 \text{ psi}$$

$$\text{CHECK } f_b = \frac{M}{S_x} = \frac{56410}{1242.6} = 544.8 \text{ psi} < 579.5 = F_b'$$

← REVISE $M_w = 944.8 \text{ FT-LB}$

$$\text{CHECK SHEAR: } V_{\max} = \frac{wl}{2} + \frac{P}{2} = \frac{66.1(19)}{2} + \frac{11248}{2} = 6251.9 \text{ LB}$$

$$f_v = \frac{3}{2} \frac{V}{A} = \frac{3}{2} \frac{6251.9}{317.3} = 29.56 \text{ psi} < 115 = F_v' \quad \checkmark$$

∴ USE 14 x 24

Timber Beam Design

Trial 2: 14 x 24 $I_x = 14600 \text{ in}^4$

check deflection:

assume 30% of LL is sustained

see NDS 3.5

$K_{cr} = 1.5$ "seasoned lumber"

DEFLECTION

LONG-TERM: w_D P_D 30% P_L

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

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

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

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

TABLE 1604.3 DEFLECTION LIMITS^{a, b, c, h, i}

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

SHORT-TERM: 70% P_L

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

TOTAL DEFLECTION:

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

$$= 1.5(0.0867) + 0.0825 = \underline{\underline{0.213''}}$$

$$L/240 = 19(12)/240 = 0.95''$$