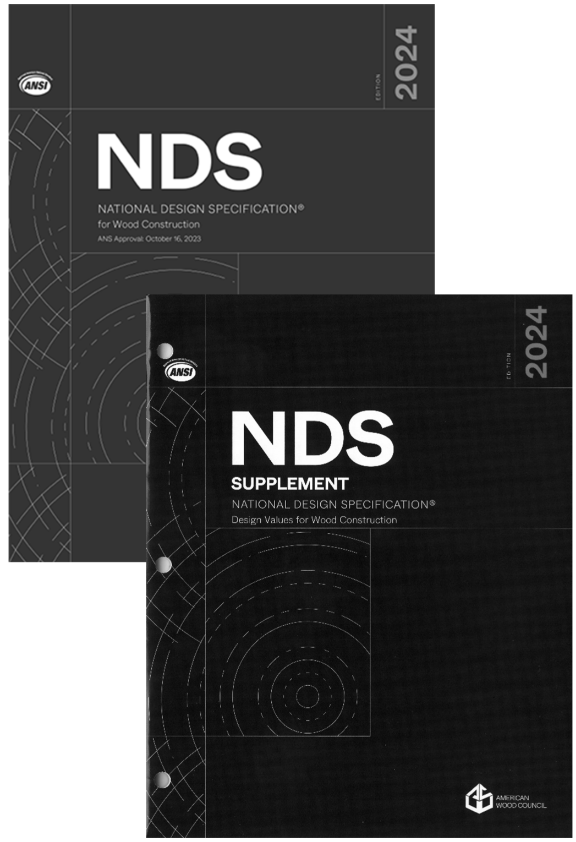
Architecture 324
Structures II



Wood Beam Design

- Wood Beam Capacity Analysis
- Wood Beam Design

Analysis Procedure (capacity)

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

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

Table 4A (Cont.) **Reference Design Values for Visual** **(2" - 4" thick)[1,2,3]**
(All species except Southern Pine—see duration and dry service conditions. See NDS adjustment factors.)

USE WITH TABLE 4A AD

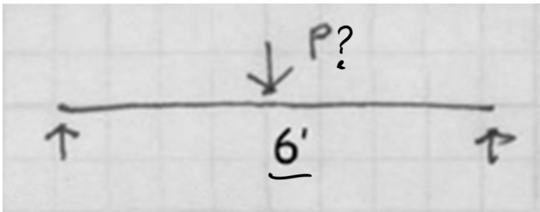
Species and commercial grade	Size classification	Design val Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v
SPRUCE-PINE-FIR				
Select Structural	2" & wider	1,250	700	135
No. 1/ No. 2	2" & wider	875	450	135
No. 3	2" & wider	500	250	135
Stud	2" & wider	675	350	135
Construction	2"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

from *NDS 2012*

Analysis Example (capacity)

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

GIVEN : SPAN = 6' P @ ¢
SECTION = 2x4 (1.5 x 3.5)
NDS Table 4A F_b = 875 psi F_v = 135 psi
REQ'D : MAXIMUM LOAD P



using SPF No.2 and 10 min load

1. Determine F_b and F'_b
2. Assume $f_b = F'_b$
   - Maximum actual = allowable stress
3. Solve stress equations for force
   - $M = f_b S$ (i.e. moment capacity)

$$f_b = \overset{ALLOW}{F'_b} = \overset{F_b}{875}\,\overset{C_D}{(1.6)}\,\overset{2\times4\ C_F}{(1.5)}$$

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

NDS Sup. Table 1B

$$S_x = 3.063 \text{ in}^3 \quad 2\times4$$

$$\overset{ALLOW}{M_{¢}} = F'_b S_x = 2100(3.063)$$

$$= 6432.3 \text{ "-\#}$$

$$= 536 \text{ '-\#}$$

Analysis Example (capacity)

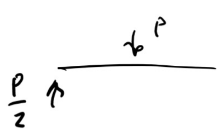
3. **Use maximum forces to find loads**
   - Back calculate a maximum load from moment capacity

$$M_{¢} = PL/4$$

$$P = M_{¢}\,4/L$$

$$P = 536\text{ '-\#}(4)/6'$$

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



4. **Check shear**
   - Check shear for load capacity from step 3.
   - Use P from moment to find Vmax
   - Check that $f_v < F_v'$ = 135 x 1.6 = 216psi

$$V_{max} = P/2 = 357/2 = 178.5\text{\#}$$

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

$$51 \text{ psi} < \underset{1.6 \times 135\ (C_D\ F_v)}{\overset{F'_v}{216 \text{ psi}}} \ \checkmark \text{ok}$$

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

Design Procedure

Given: load, wood and grade, span, other usage conditions
Req'd: member size

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

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

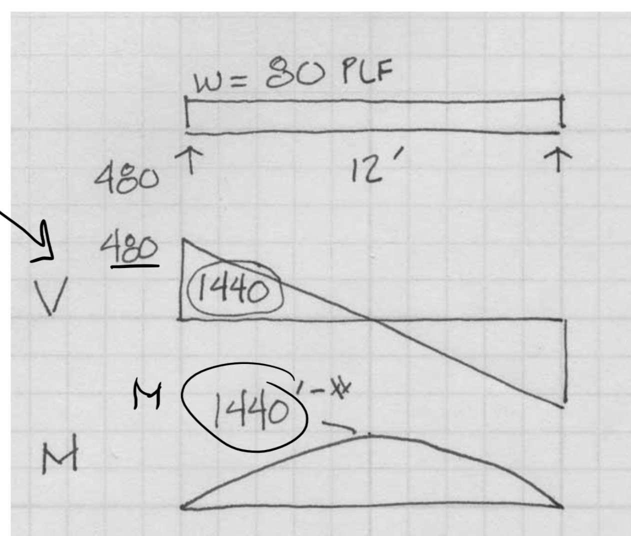
Design Example

Given: load, wood and grade, span, other usage conditions (F'_b)
Req'd: member size

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

REQ'D: SECTION SIZE

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



Design Example

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

3. **Solve $S=M/F_b'$**

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

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 $A=1.5V/F_v'$

6. **Check deflection**
7. **Check bearing**

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

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

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A $in.^2$	X-X AXIS Section Modulus S_{xx} $in.^3$	X-X AXIS Moment of Inertia I_{xx} $in.^4$	Y-Y AXIS Section Modulus S_{yy} $in.^3$	Y-Y AXIS Moment of Inertia I_{yy} $in.^4$
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	$\boxed{21.39}$	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

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

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

51.87 psi < 100 psi ✓ OK

Timber Beam Design

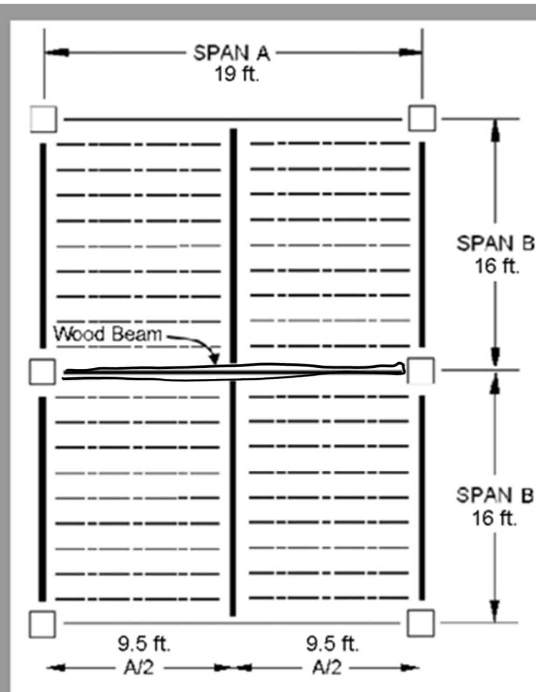
Given: load, wood and grade, span, other usage conditions (F'_b)
Req'd: member size (in this example both b and d)

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).

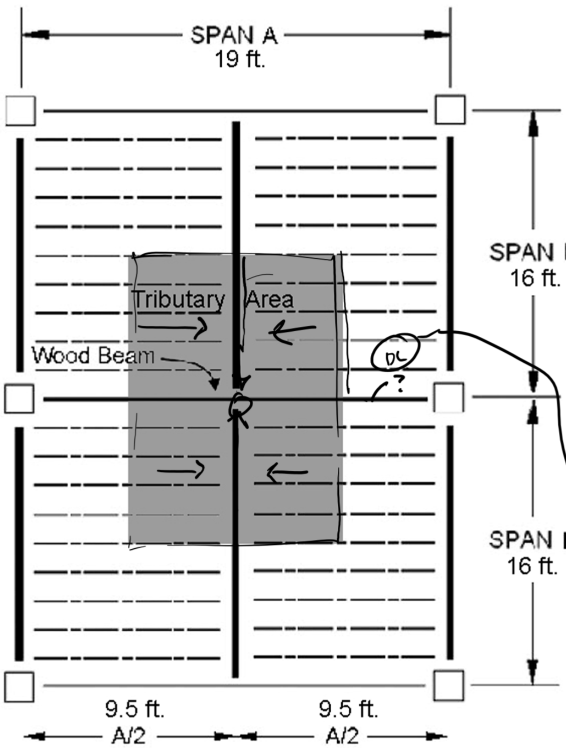
DATASET: 1 -2-

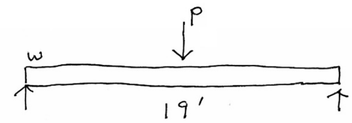
Wood Species	COAST SITKA SPRUCE
Wood Grade	No.2
Span A	19 FT
Span B	16 FT
Dead Load	19 PSF
Live Load	55 PSF
Wood density, D	30 PCF



Timber Beam Design

Find applied load and force





GIVEN:
COAST SITKA SPRUCE No 2 15% M.C.
G = 0.43 DENSITY ≈ 30 PCF

Trial 1:

ESTIMATE SIZE (RULE OF THUMB)

$d'' \approx L/15 \approx 19/15 = 1.3' = 15.6'' \approx 16''$

$b:d = 1:2 \quad b = 8''$

∴ ESTIMATE 8×16

DL = 19 PSF LL = 55 PSF

$P_{D+L} = (19+55)(\text{TRIBUTARY AREA})$
$= 74(152) = 11248$ LBS

$w = 24.22$ PLF (TAB 1B)

$M_P = \frac{P\ell}{4} = \frac{11248(19)}{4} = 53\,428$ '-#

$M_w = \frac{w\ell^2}{8} = \frac{24.22(19)^2}{8} = 1093$ '-#

+ 54 521 '-#

Timber Beam Design

Find allowable stress

$F_b = 625$ psi

$F_v = 115$ psi

$E = 1200000$ psi

$E_{min} = 440000$ psi

From NDS Supplement:
Coast Sitka Spruce No2

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, %

m.c = 15% G = 0.43
density = 29.2 pcf use 30

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	Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v	Compression perpendicular to grain $F_{c\perp}$	Compression parallel to grain F_c	Modulus of Elasticity E	Modulus of Elasticity E_{min}	Specific Gravity[4] G	Grading Rules Agency
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		
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

TRY 1

$F'_b \approx F_b = 625$ PSI

$S_x = M / F'_b = \dfrac{54521 \text{ '-\#} (12)}{625 \text{ \#/in}^2}$

$S_x = 1047 \text{ in}^3$ (REQUIRED)

$\therefore$ 8 x 16 $S_x = 300.3 \text{ in}^3$ FAILS

$\rightarrow$ TRY 12 x 24 $S_x = 1058 \text{ in}^3$

Trial 1:
choose S_x and size

$S_x = M / F'_b$

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

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

Timber Beam Design

Trial 2: 12 x 24 LL + DL m.c. < 19% not flat use

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

Timber Beam Design

Trial 2: 12 x 24 LL + DL m.c. < 19% not flat use

Table 4D Adjustment Factors

Size Factor, C_F

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

Size Factors, C_F

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

Flat Use Factor, C_{fu}

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

Flat Use Factor, C_{fu}

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

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

Wet Service Factor, C_M

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

Wet Service Factors, C_M

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

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

Timber Beam Design Trial 2: 12 x 24

C_L

Table 3.3.3

"Concentrated load at center with lateral support at center"

$l_e = 1.11\, l_u$

C_L:

$l_u = 9.5'$
$= 114"$

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

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

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

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

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

$C_L = 0.999$

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

$$R_B = \sqrt{\frac{l_e d}{b^2}} < 50 \quad (3.3\text{-}5)$$

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

3.3.3.8 The beam stability factor shall be calculated as follows:

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

40.5 40.5 40.5

where:

F_b^* = reference bending design value multiplied by all applicable adjustment factors except C_{fu}, C_V, and C_L (see 2.3) (C_F)

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

Timber Beam Design   Trial 2: 12 x 24

C_L Table 3.3.3

"Concentrated load at center with lateral support at center"

$l_e = 1.11\ l_u$

Table 3.3.3 Effective Length, ℓ_e, for Bending Members

Cantilever[1]	where $\ell_u/d < 7$		where $\ell_u/d \geq 7$
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]~~	where $\ell_u/d < 7$		where $\ell_u/d \geq 7$
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		$\boxed{\ell_e=1.11\ \ell_u}$	
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:
   $\ell_e = 2.06\ \ell_u$ where $\ell_u/d < 7$
   $\ell_e = 1.63\ \ell_u + 3d$ where $7 \leq \ell_u/d \leq 14.3$
   $\ell_e = 1.84\ \ell_u$ where $\ell_u/d > 14.3$
2. Multiple span applications shall be based on table values or engineering analysis.

Timber Beam Design

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

TRY 2 CONT.

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

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

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

CHANGES

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

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

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

1159.4 > 1058 so 12 x 24 is too small

Timber Beam Design

Trial 3: S_x req'd = 1159 in^3

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

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.^{2}	X-X AXIS Section Modulus S_{xx} in.^{3}	X-X AXIS Moment of Inertia I_{xx} in.^{4}	Y-Y AXIS Section Modulus S_{yy} in.^{3}	Y-Y AXIS Moment of Inertia I_{yy} in.^{4}	Approximate weight in pounds per linear foot (lbs/ft) of piece when density of wood equals: 25 lbs/ft^3	30 lbs/ft^3	35 lbs/ft^3	40 lbs/ft^3	45 lbs/ft^3	50 lbs/ft^3
Beams & Stringers (see NDS 4.1.3.3 and NDS 4.1.5.3)												
10 x 14	9-1/2 x 13-1/2	128.3	288.6	1948	203.1	964.5	22.27	26.72	31.17	35.63	40.08	44.53
10 x 16	9-1/2 x 15-1/2	147.3	380.4	2948	233.1	1107	25.56	30.68	35.79	40.90	46.02	51.13
10 x 18	9-1/2 x 17-1/2	166.3	484.9	4243	263.2	1250	28.86	34.64	40.41	46.18	51.95	57.73
10 x 20	9-1/2 x 19-1/2	185.3	602.1	5870	293.3	1393	32.16	38.59	45.03	51.46	57.89	64.32
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	$\boxed{1243}$	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	$\boxed{333.3}$	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 in^3

Timber Beam Design

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

revise adjustment factors:

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

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 3: 14 x 24 A = 317.3 in^2 S_x = 1243 in^3 w_{DL} = 66.1 PLF

check stresses:

TRY 3

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

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

REVISE $M_w = 444.8$ FT-LB

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

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

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

∴ USE 14x24

Timber Beam Design

Trial 3: 14 x 24 I_x = 14600 in^4

check deflection: assume 30% of LL is sustained

see NDS 3.5 K_{cr} = 1.5 “seasoned lumber”

3.5 Bending Members – Deflection

3.5.1 Deflection Calculations

If deflection is a factor in design, it shall be calculated by standard methods of engineering mechanics considering bending deflections and, when applicable, shear deflections. Consideration for shear deflection is required when the reference modulus of elasticity has not been adjusted to include the effects of shear deflection (see Appendix F).

3.5.2 Long-Term Loading

Where total deflection under long-term loading must be limited, increasing member size is one way to provide extra stiffness to allow for this time dependent deformation (see Appendix F). Total deflection, Δ_T, shall be calculated as follows:

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

where:

K_{cr} = time dependent deformation (creep) factor

= 1.5 for seasoned lumber, structural glued laminated timber, prefabricated wood I-joists, or structural composite lumber used in dry service conditions as defined in 4.1.4, 5.1.4, 7.1.4, and 8.1.4, respectively.

Timber Beam Design

Trial 3: 14 x 24 I_x = 14600 in^4

check deflection:
assume 30% of LL is sustained

see NDS 3.5
K_{cr} = 1.5 “seasoned lumber”

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

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

L/240 = 19(12)/240 = 0.95”

DEFLECTION

LONG-TERM: w_D P_D 30% P_L

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

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

$$\Delta_{P_{L30\%}} = \frac{0.3(P_L)\ell^3}{48 EI} = \frac{0.3(8360)(19)^3(1728)}{48(1200000)(14600)} = 0.035''$$

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

SHORT-TERM: 70% P_L

$$\Delta_{P_{L70\%}} = \frac{0.7(P_L)\ell^3}{48 EI} = \frac{0.7(8360)(19)^3(1728)}{48(1200000)(14600)} = 0.0825''$$

TOTAL DEFLECTION:

$$\frac{\ell}{240} = \frac{19(12)}{240} = 0.95$$

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

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

PASS

Timber Beam Design

Bearing Stress

From NDS Supplement:
Coast Sitka Spruce No2

m.c = 15% G = 0.43
density = 29.2 pcf use 30

Table 4D Reference Design Values for Visually Graded Timbers (5" x 5" and larger)[1,3]
(Tabulated design values are for normal load duration and dry service conditions, unless specified otherwise. See NDS 4.3 for a comprehensive description of design value adjustment factors.)

USE WITH TABLE 4D ADJUSTMENT FACTORS

Species and commercial Grade	Size classification	Design values in pounds per square inch (psi)							Specific Gravity[4]	Grading Rules Agency
		Bending	Tension parallel to grain	Shear parallel to grain	Compression perpendicular to grain	Compression parallel to grain	Modulus of Elasticity			
		F_b	F_t	F_v	$F_{c\perp}$	F_c	E	E_{min}	G	
COAST SITKA SPRUCE										
Select Structural	Beams and Stringers	1,150	675	115	455	775	1,500,000	550,000	0.43	NLGA
No.1		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		
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 2: 14 x 24   b = 13.5"

check support bearing:

C_b = 1.0 (end support)

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:

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

where:

ℓ_b = bearing length measured parallel to grain, in.

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

Table 3.10.4 Bearing Area Factors, C_b

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

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

FIND MINIMUM ℓ_b:

$$F_{c\perp} = \underline{455} \text{ PSI}$$

$$F_{c\perp}' = \underline{F_{c\perp}} \left(C_M \, C_t \, C_i \, C_b \right)$$

$$= 455 (1.0 \; 1.0 \; 1.0 \; 1.0) = 455 \text{ PSI}$$

$$R = \text{END REACTION} = \frac{P}{2} + \frac{w\ell}{2} = 6251.9 \text{ LBS}$$

$$F_{c\perp}' = \underline{f_{c\perp}} = \frac{R}{A_b} = \frac{6251.9}{b \, \ell_b ?} = \underline{455} \text{ PSI}$$

$$\ell_b = \frac{6251.9 \text{ LB}}{13.5'' \; 455 \text{ PSI}} = \underline{1.02''} \text{ (MINIMUM)}$$