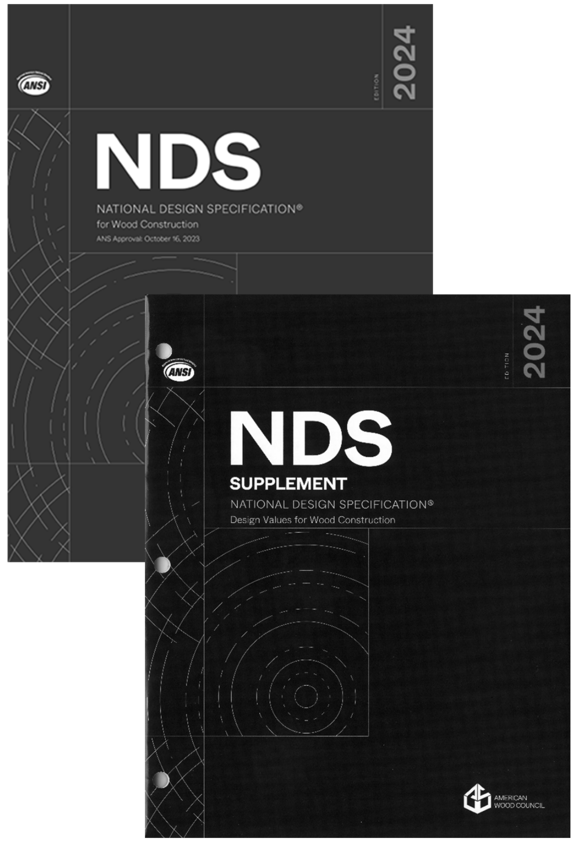
Architecture 544
Wood Structures

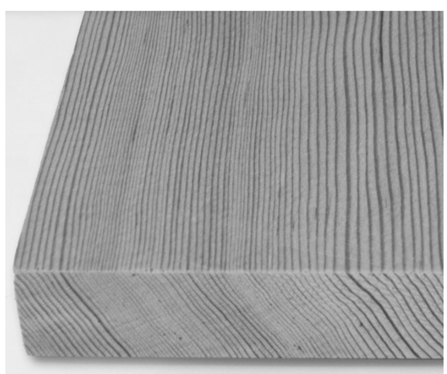


Wood Beam Design

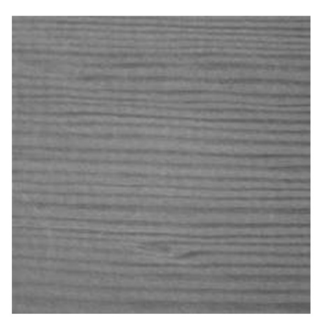
- ASD approach
- NDS criteria
- Wood Beam Design

Wood of the Day

Douglas Fir



DOUGLAS FIR-LARCH										
Select Structural	2" & wider	1,500	1,000	180	625	1,700	1,900,000	690,000	0.50	WCLIB WWPA
No. 1 & Btr		1,200	800	180	625	1,550	1,800,000	660,000		
No. 1		1,000	675	180	625	1,500	1,700,000	620,000		
No. 2		900	575	180	625	1,350	1,600,000	580,000		
No. 3		525	325	180	625	775	1,400,000	510,000		
Stud	2" & wider	700	450	180	625	850	1,400,000	510,000		
Construction	2" - 4" wide	1,000	650	180	625	1,650	1,500,000	550,000		
Standard		575	375	180	625	1,400	1,400,000	510,000		
Utility		275	175	180	625	900	1,300,000	470,000		
DOUGLAS FIR-LARCH (NORTH)										
Select Structural	2" & wider	1,350	825	180	625	1,900	1,900,000	690,000	0.49	NLGA
No. 1 & Btr		1,150	750	180	625	1,800	1,800,000	660,000		
No. 1/ No. 2		850	500	180	625	1,400	1,600,000	580,000		
No. 3		475	300	180	625	825	1,400,000	510,000		
Stud	2" & wider	650	400	180	625	900	1,400,000	510,000		
Construction	2" - 4" wide	950	575	180	625	1,800	1,500,000	550,000		
Standard		525	325	180	625	1,450	1,400,000	510,000		
Utility		250	150	180	625	950	1,300,000	470,000		
DOUGLAS FIR-SOUTH										
Select Structural	2" & wider	1,350	900	180	520	1,600	1,400,000	510,000	0.46	WWPA
No. 1		925	600	180	520	1,450	1,300,000	470,000		
No. 2		850	525	180	520	1,350	1,200,000	440,000		
No. 3		500	300	180	520	775	1,100,000	400,000		
Stud	2" & wider	675	425	180	520	850	1,100,000	400,000		
Construction	2" - 4" wide	975	600	180	520	1,650	1,200,000	440,000		
Standard		550	350	180	520	1,400	1,100,000	400,000		
Utility		250	150	180	520	900	1,000,000	370,000		



Design Procedure

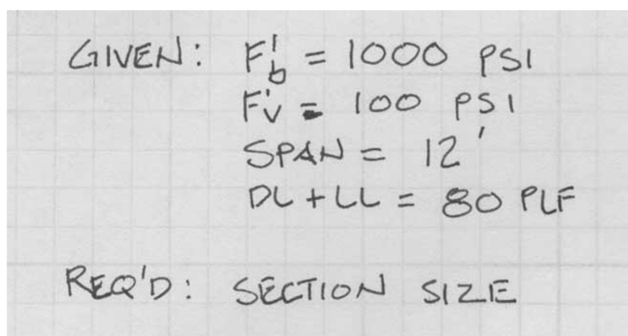
Given: load, wood, span
Req'd: member size

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

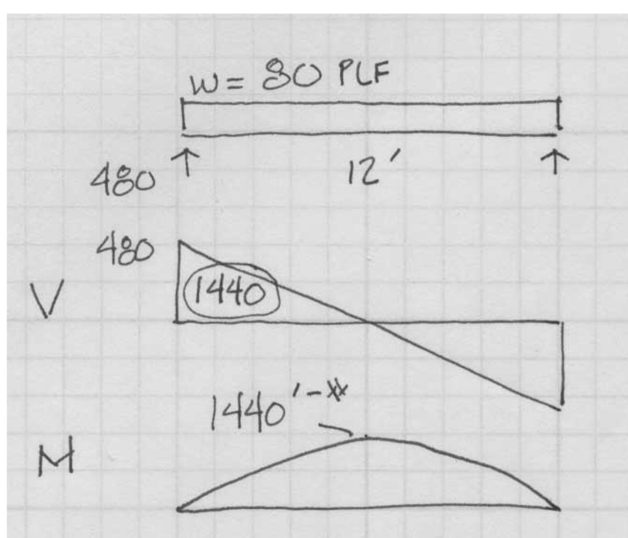
Nominal Size	Standard Dressed Size (S4S)	Area of Section	X-X AXIS Section Modulus	X-X AXIS Moment of Inertia	Y-Y AXIS Section Modulus	Y-Y AXIS Moment of Inertia
b x d	b x d	A	S_{xx}	I_{xx}	S_{yy}	I_{yy}
	in. x in.	in.^{2}	in.^{3}	in.^{4}	in.^{3}	in.^{4}
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977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

Given: total load, wood, span
Req'd: member size



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



Design Example

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

3. Solve $S=M/F_b'$

$$F_b' = M/S_x \qquad S_x = M/F_b'$$

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

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

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

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.²	X-X AXIS Section Modulus S_{xx} in.³	X-X AXIS Moment of Inertia I_{xx} in.⁴	Y-Y AXIS Section Modulus S_{yy} in.³	Y-Y AXIS Moment of Inertia I_{yy} in.⁴
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
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2 x 3	1-1/2 x 2-1/2	3.750	1.56	1.953	0.938	0.703
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3 x 5	2-1/2 x 4-1/2	11.25	8.44	18.98	4.688	5.859
3 x 6	2-1/2 x 5-1/2	13.75	12.60	34.66	5.729	7.161
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Design Example

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

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

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

51.87 psi < 100 psi ✓ OK

6. Check deflection
7. Check bearing

Design Example (joist)

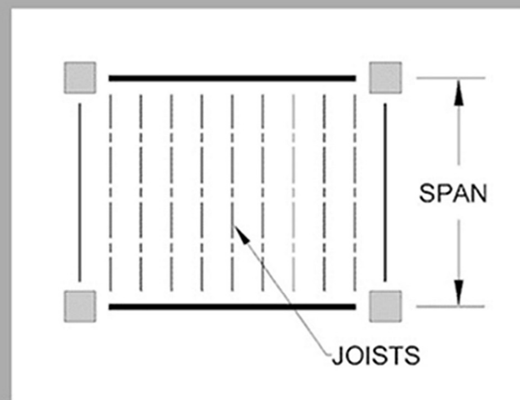
Given: load, wood, span
Req'd: member size

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 Ct, Cfu, and Ci = 1.0. Find the short term deflection of your chosen beam under live load only (100% LL is short term). Compare your LL deflection with the code limit of L/360.

DATASET: 1 -2- -3-

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



Design Example

Determine allowable stresses

- F_b and F_v (from NDS)

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

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

USE WITH TABLE 4A ADJUSTMENT FACTORS

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

Design Example

Determine allowable stresses

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.^{2}	X-X AXIS Section Modulus S_{xx} in.^{3}	X-X AXIS Moment of Inertia I_{xx} in.^{4}	Y-Y AXIS Section Modulus S_{yy} in.^{3}	Y-Y AXIS Moment of Inertia I_{yy} in.^{4}
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
1 x 4	3/4 x 3-1/2	2.625	1.531	2.680	0.328	0.123
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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
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4 x 8	3-1/2 x 7-1/4	25.38	30.66	111.1	14.80	25.90
4 x 10	3-1/2 x 9-1/4	32.38	49.91	230.8	18.89	33.05
4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20
4 x 14	3-1/2 x 13-1/4	46.38	102.41	678.5	27.05	47.34
4 x 16	3-1/2 x 15-1/4	53.38	135.66	1034	31.14	54.49

Table 4A Adjustment Factors

Repetitive Member Factor, C_r

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

Wet Service Factor, C_M

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

Wet Service Factors, C_M

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

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

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

Flat Use Factor, C_{fu}

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

Flat Use Factors, C_{fu}

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

NOTE

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

Size Factor, C_F

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

Size Factors, C_F

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

Design Example

Determine allowable stresses.

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

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

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

C_D C_r C_M

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

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

Design Example

Determine moment from loading.

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

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

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

With the beam loading, calculate the maximum moment.

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

Design Example

Estimate the Required Section Modulus.

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

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

FROM TABLE 1B (NDS)

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

Design Example

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

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

TRY 2×10 $C_F = 1.1$

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

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

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

∴ USE 2×10

Design Example

Check Deflection

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

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

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

International Building Code (IBC)

LL = 35 PSF = 35 PLF

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

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

0.849 > 0.667 ∴ FAILS

Timber Beam Design

Given: load, wood, span

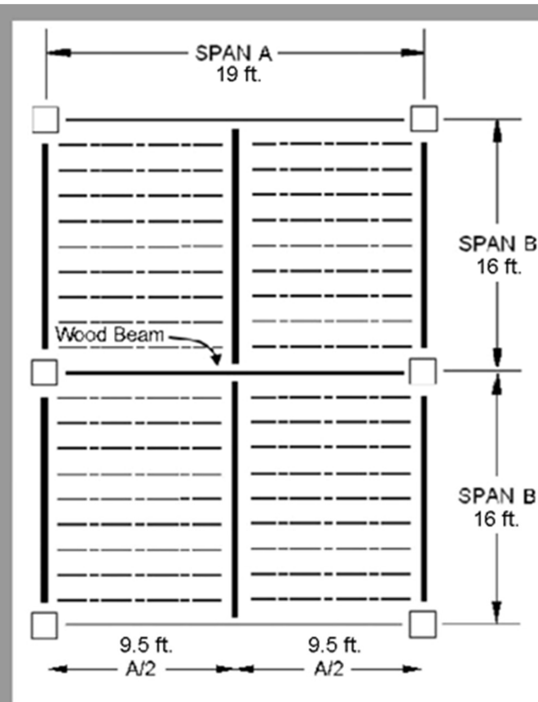
Req'd: <u>member size</u> (in this example both b and d)

5. Sawn Lumber - Beams

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

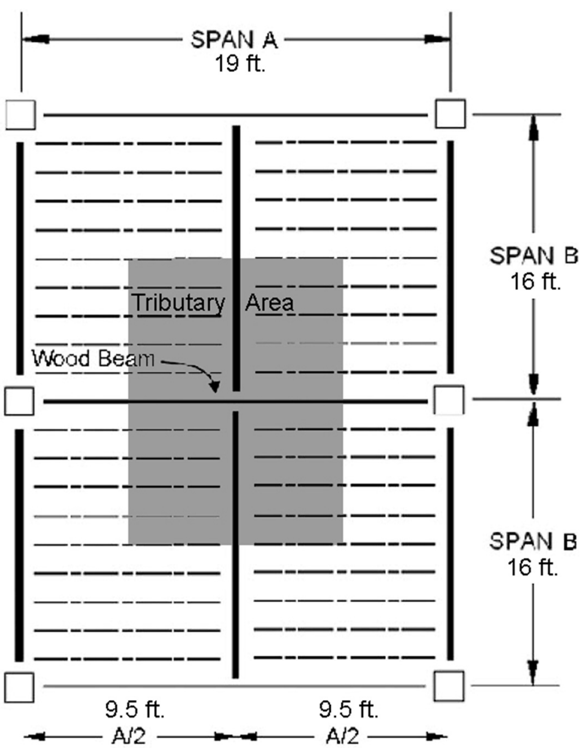
DATASET: 1 -2-

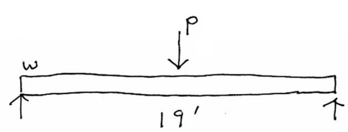
Wood Species	COAST SITKA SPRUCE
Wood Grade	No.2
Span A	19 FT
Span B	16 FT
Dead Load	19 PSF
Live Load	55 PSF
Wood density, D	30 PCF



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)

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

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

$\therefore$ ESTIMATE 8 x 16

DL = 19 PSF LL = 55 PSF

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

$= 74(152) = 11\,248$ LBS

$w = 24.22$ PLF (TAB 1B)

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

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

$+ \quad 54\,521$ '-#

Timber Beam Design

try 8 x 16

30 PCF

24.22 PLF

∴ ESTIMATE 8 x 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)

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

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

$+$ 54521 '-#

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)												
6 x 10	5-1/2 x 9-1/2	52.25	82.73	393.0	47.90	131.7	9.071	10.89	12.70	14.51	16.33	18.14
6 x 12	5-1/2 x 11-1/2	63.25	121.2	697.1	57.98	159.4	10.98	13.18	15.37	17.57	19.77	21.96
6 x 14	5-1/2 x 13-1/2	74.25	167.1	1128	68.06	187.2	12.89	15.47	18.05	20.63	23.20	25.78
6 x 16	5-1/2 x 15-1/2	85.25	220.2	1707	78.15	214.9	14.80	17.76	20.72	23.68	26.64	29.60
6 x 18	5-1/2 x 17-1/2	96.25	280.7	2456	88.23	242.6	16.71	20.05	23.39	26.74	30.08	33.42
6 x 20	5-1/2 x 19-1/2	107.3	348.6	3398	98.31	270.4	18.62	22.34	26.07	29.79	33.52	37.24
6 x 22	5-1/2 x 21-1/2	118.3	423.7	4555	108.4	298.1	20.53	24.64	28.74	32.85	36.95	41.06
6 x 24	5-1/2 x 23-1/2	129.3	506.2	5948	118.5	325.8	22.44	26.93	31.41	35.90	40.39	44.88
8 x 12	7-1/2 x 11-1/2	86.3	165.3	950.5	107.8	404.3	14.97	17.97	20.96	23.96	26.95	29.95
8 x 14	7-1/2 x 13-1/2	101.3	227.8	1538	126.6	474.6	17.58	21.09	24.61	28.13	31.64	35.16
8 x 16	7-1/2 x 15-1/2	116.3	300.3	2327	145.3	544.9	20.18	24.22	28.26	32.29	36.33	40.36
8 x 18	7-1/2 x 17-1/2	131.3	382.8	3350	164.1	615.2	22.79	27.34	31.90	36.46	41.02	45.57
8 x 20	7-1/2 x 19-1/2	146.3	475.3	4634	182.8	685.5	25.39	30.47	35.55	40.63	45.70	50.78
8 x 22	7-1/2 x 21-1/2	161.3	577.8	6211	201.6	755.9	27.99	33.59	39.19	44.79	50.39	55.99
8 x 24	7-1/2 x 23-1/2	176.3	690.3	8111	220.3	826.2	30.60	36.72	42.84	48.96	55.08	61.20

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	Beams and Stringers	950	475	115	455	650	1,500,000	550,000	0.43	NLGA
No.2	Beams and Stringers	625	325	115	455	425	1,200,000	440,000	0.43	NLGA
Select Structural	Posts and Timbers	1,100	725	115	455	825	1,500,000	550,000	0.43	NLGA
No.1	Posts and Timbers	875	575	115	455	725	1,500,000	550,000	0.43	NLGA
No.2	Posts and Timbers	525	350	115	455	500	1,200,000	440,000	0.43	NLGA

Timber Beam Design

Trial 1:
choose S_x and size

$S_x = M / F'_b$

TRY 1

$F'_b \approx F_b = 625$ PSI

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

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

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

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

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	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"

$\ell_e = 1.11\ \ell_u$

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

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

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

3.3.3.8 The beam stability factor shall be calculated as follows:

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

where:

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

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

C_L:

$\ell_u = 9.5'$
$= 114''$

$\ell_e = 1.11(\ell_u)$
$= 1.11(114) = 126.5$

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

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

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

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

$C_L = 0.999$

Timber Beam Design

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

TRY 2 CONT.

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

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

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

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

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

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

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/ft³	30 lbs/ft³	35 lbs/ft³	40 lbs/ft³	45 lbs/ft³	50 lbs/ft³
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
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 $S_x = 1243\ in^3$

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 $\quad A = 317.3 \text{ in}^2 \quad S_x = 1242.6 \text{ in}^3$

$$F'_b = 625\,(1.0 \;\; 0.928 \;\; 0.999) = 579.5 \text{ psi}$$

CHECK $f_b = M/S_x = \frac{56410}{1242.6} = 544.8 \text{ psi} < 579.5 = F'_b$ (← REVISE $M_w = 944.8$ FT-LB)

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

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

∴ USE 14 x 24

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 2: 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

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

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

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

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

SHORT-TERM: 70% P_L

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

TOTAL DEFLECTION:

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

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

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:

$F_{c\perp} = 455$ PSI

$F'_{c\perp} = F_{c\perp}(C_M\, C_t\, C_i\, C_b)$

$= 455(1.0\ 1.0\ 1.0\ 1.0) = 455$ PSI

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

$F'_{c\perp} = f_{c\perp} = \frac{R}{A_b} = \frac{6251.9}{b\,\ell_b} = 455$ PSI

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