ARCHITECTURE 324
Structures II

Recitation 02

Sections 04&05

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Office Hours

→ Office Hours

→ Day: Fridays, 12:00 PM - 1:00 PM

→ Location Options:

- In-person meetings: [2223B]
- Virtual meetings via Zoom

Please make sure to sign up at least 24 hours in advance to allow for proper scheduling via this link:

https://docs.google.com/forms/d/e/1FAIpQLSdOb4gAc6SoCdsMAZP4zKrn3ecPyGt6dwVahVcOD3EqXGG-oA/viewform?usp=dialog

If the slots are fully booked or if you have a time conflict, please email me directly to find an alternative time (arfazel@umich.edu)

Contents

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*

Design Procedure

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

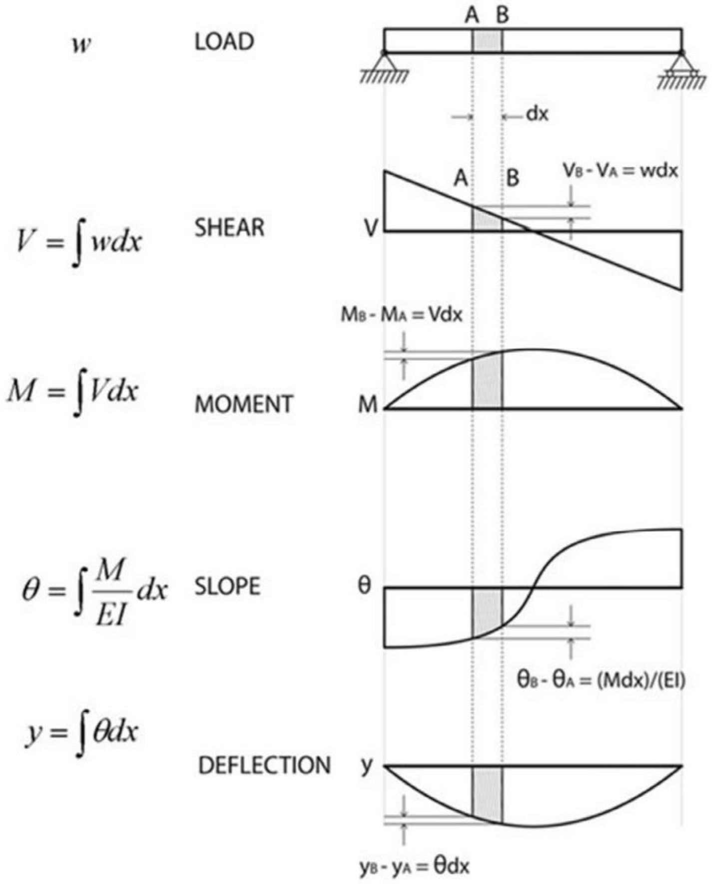
1. **Find Max Shear & Moment**
   - Simple case – equations
   - Complex case - diagrams
2. **Determine allowable stresses, F_b**
   - Apply usage factors to get F'_b
3. **Solve $S = M/F_b'$**
4. **Choose a section from Table 1B**
   - Revise DL and F_b'
   - Check step 3 and revise.
5. **Check shear 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

Quick refresher

Relationships of Forces and Deformations

Sequential Integrals



$$\text{load} = \frac{d^4y}{dx^4} = \frac{dV}{dx}\frac{1}{EI} = \frac{w}{EI}$$

$$\text{shear} = \frac{d^3y}{dx^3} = \frac{dM}{dx}\frac{1}{EI} = \frac{V}{EI}$$

$$\text{moment} = \frac{d^2y}{dx^2} = \frac{M}{EI}$$

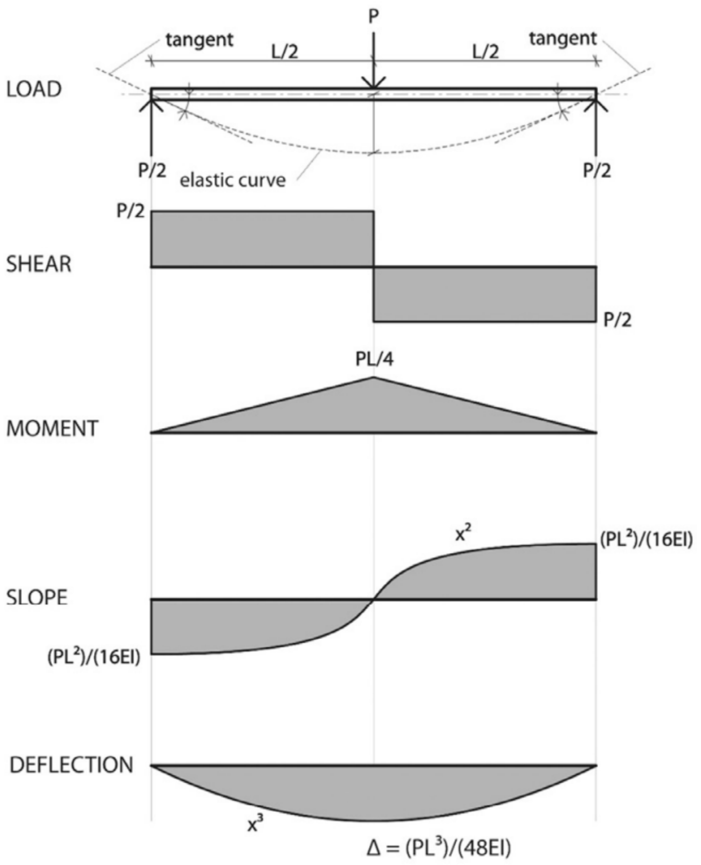
$$\text{slope} = \frac{dy}{dx}$$

$$\text{deflection} = y$$

Quick refresher

Symmetrically Loaded Beams

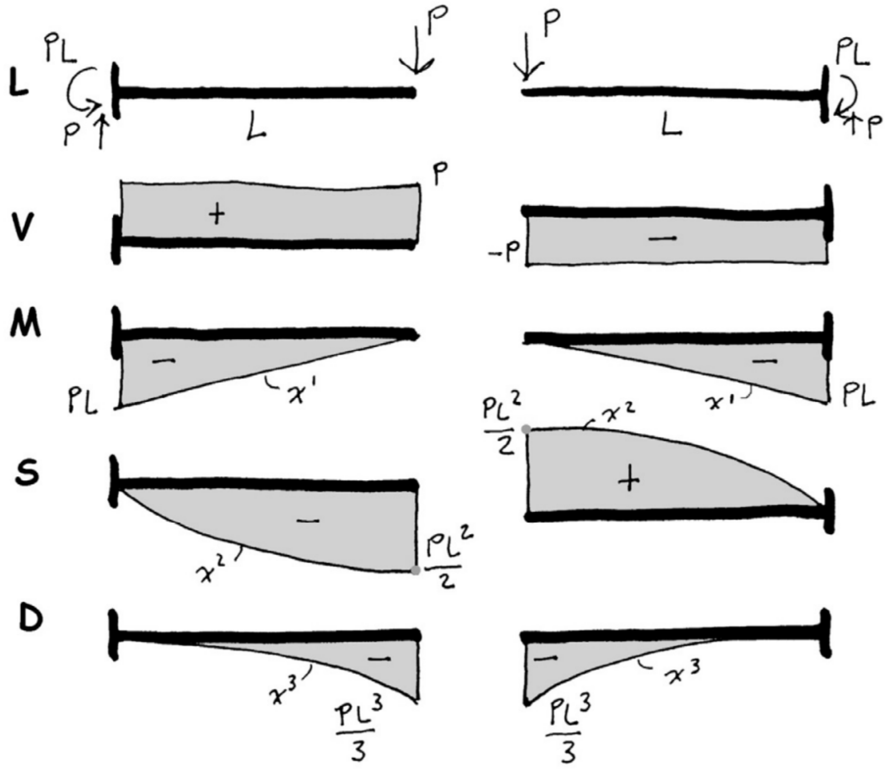
- **Maximum slope** occurs at the ends of the beam
- A point of zero slope occurs at the center line. This is the point of **maximum deflection**.
- **Moment is positive** for gravity loads.
- Shear and slope have **balanced** + and - areas.
- **Deflection is negative** for gravity loads.



Quick refresher

Cantilever Beams

- One end fixed. One end free
- Fixed end has maximum moment, but zero slope and deflection.
- Free end has maximum slope and deflection, but zero moment.
- Slope is either downward (-) or upward (+) depending on which end is fixed.
- Shear sign also depends of which end is fixed.
- Moment is always negative for gravity loads.



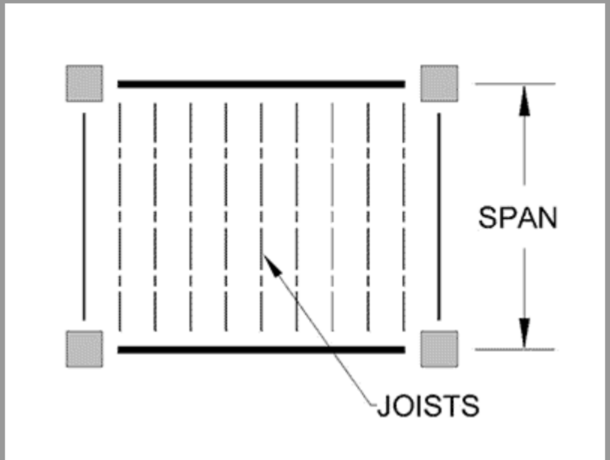
Problem Set 02

2. Wood Beam Design

Design a 2x dimensioned lumber floor joist to carry the given dead + live floor load (neglect joist selfweight). 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	SPRUCE-PINE-FIR
Wood Grade	No.1/No.2
Span	15 FT
Joist Spacing, o.c.	12 IN
Moisture Content, m.c.	15 %
Floor DL	7 PSF
Floor LL	35 PSF



#	Question	Your Response	Correct Answer	Score
1	Tabulated Allow. Bending Stress, Fb	PSI	SUBMIT	
2	Tabulated Allow. Shear Stress, Fv	PSI	SUBMIT	
3	Tabulated Modulus of Elasticity, E	PSI	SUBMIT	
4	Total Applied Floor Load, (DL+LL)	PSF	SUBMIT	
5	Load on Joist, w	PLF	SUBMIT	
6	Actual Beam Bending Moment, M	FT-LB	SUBMIT	

Problem Set 02

#Q1: Tabulated Allow. Bending Stress, Fb

#Q2: Tabulated Allow. Shear Stress, Fv

#Q3: Tabulated Modulus of Elasticity, E

DATASET: 1 -2- -3-

Wood Species	SPRUCE-PINE-FIR
Wood Grade	No.1/No.2
Span	15 FT
Joist Spacing, o.c.	12 IN
Moisture Content, m.c.	15 %
Floor DL	7 PSF
Floor LL	35 PSF

According to the table, for "Spruce-Pine_Fir grade, No. 1 and No. 2, we have the following:

$$\boldsymbol{F_b} = 875\ PSI$$

$$\boldsymbol{F_V} = 135\ PSI$$

$$\boldsymbol{E} = 1{,}400{,}000\ PSI$$

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

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

USE WITH TABLE 4A ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Design values in pounds per square inch (psi): Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v	Compression perpendicular to grain $F_{c\perp}$	Compression parallel to grain F_c	Modulus of Elasticity E	E_{min}	Specific Gravity[4] G	Grading Rules Agency
RED OAK										
Select Structural	2" & wider	1,150	675	170	820	1,000	1,400,000	510,000	0.67	NELMA
No. 1		825	500	170	820	825	1,300,000	470,000		
No. 2		800	475	170	820	625	1,200,000	440,000		
No. 3		475	275	170	820	375	1,100,000	400,000		
Stud	2" & wider	625	375	170	820	400	1,100,000	400,000		
Construction	2" - 4" wide	925	550	170	820	850	1,200,000	440,000		
Standard		525	300	170	820	650	1,100,000	400,000		
Utility		250	150	170	820	425	1,000,000	370,000		
REDWOOD										
Select Structural	2" & wider	1,100	625	160	425	1,100	1,100,000	400,000	0.37	RIS
No. 1		775	450	160	425	900	1,100,000	400,000		
No. 2		725	425	160	425	700	1,000,000	370,000		
No. 3		425	250	160	425	400	900,000	330,000		
Stud	2" & wider	575	325	160	425	450	900,000	330,000		
Construction	2" - 4" wide	825	475	160	425	925	900,000	330,000		
Standard		450	275	160	425	725	900,000	330,000		
Utility		225	125	160	425	475	800,000	290,000		
SPRUCE-PINE-FIR										
Select Structural	2" & wider	1,250	700	135	425	1,400	1,500,000	550,000	0.42	NLGA
No. 1/ No. 2		875	450	135	425	1,150	1,400,000	510,000		
No. 3		500	250	135	425	650	1,200,000	440,000		
Stud	2" & wider	675	350	135	425	725	1,200,000	440,000		
Construction	2" - 4" wide	1,000	500	135	425	1,400	1,300,000	470,000		
Standard		550	275	135	425	1,150	1,200,000	440,000		
Utility		275	125	135	425	750	1,100,000	400,000		

4

REFERENCE DESIGN VALUES

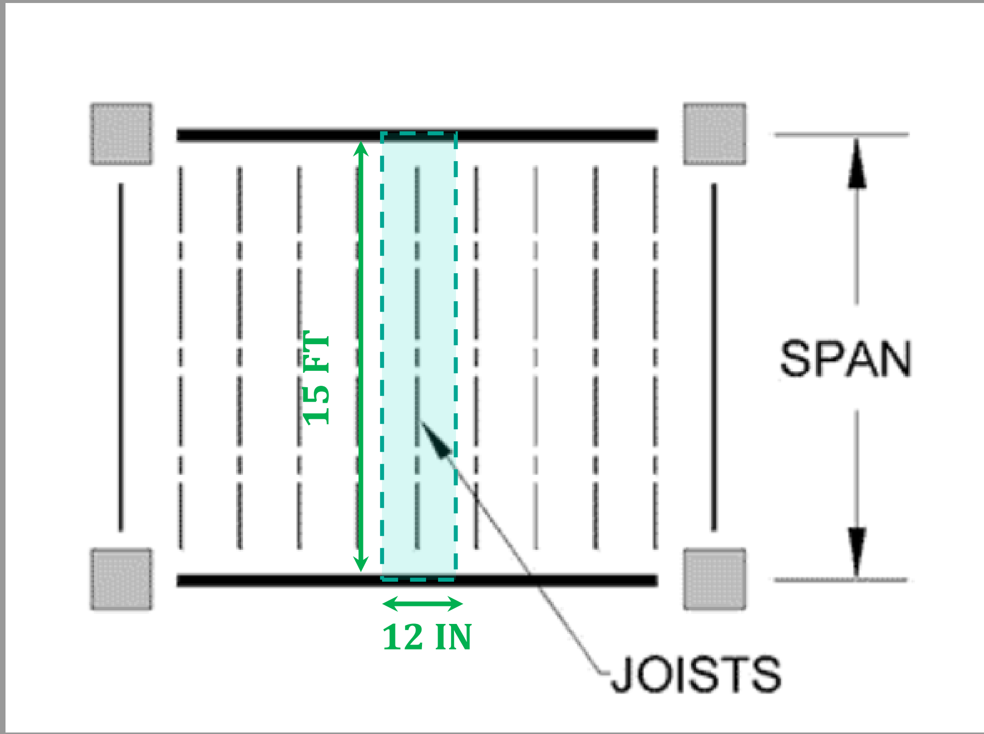
Problem Set 02

#Q4: Total Applied Floor Load, (DL+LL)

#Q5: Load on Joist, w

DATASET: 1 -2- -3-

Wood Species	SPRUCE-PINE-FIR
Wood Grade	No.1/No.2
Span	15 FT
Joist Spacing, o.c.	12 IN
Moisture Content, m.c.	15 %
Floor DL	7 PSF
Floor LL	35 PSF



$$\textbf{Tributary Area} = Span \times Joist\ spacing$$

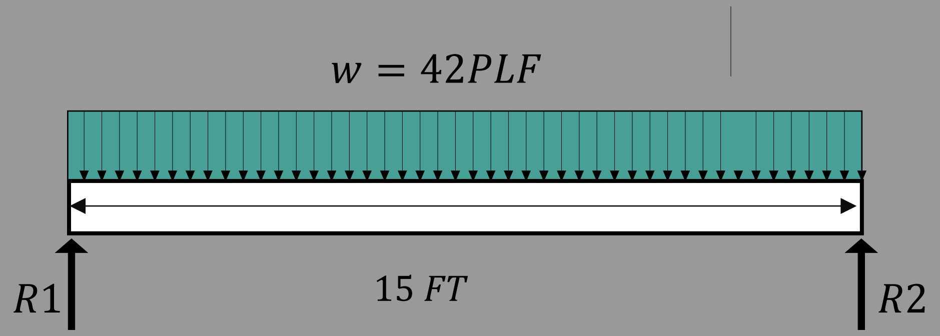
$$= 15 \times \frac{12}{12} = 15\ FT^2$$

$$\textbf{Total load on floor} = (DL + LL) = (7 + 35) = 42 \text{ PSF}$$

$$\textbf{Load on joist} = \frac{Area(DL + LL)}{span} = \frac{15(42)}{15} = 42 \text{ PLF}$$

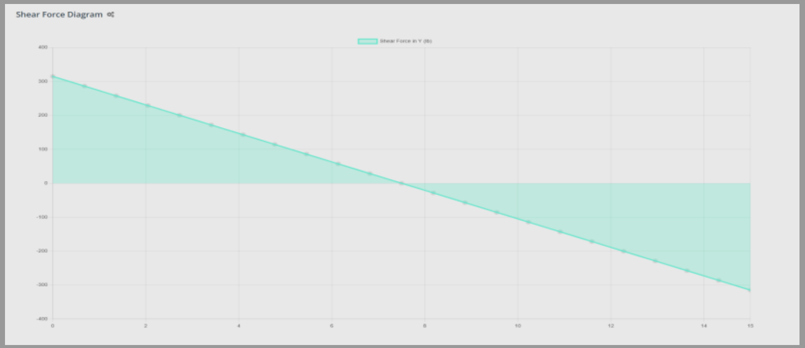
Problem Set 02

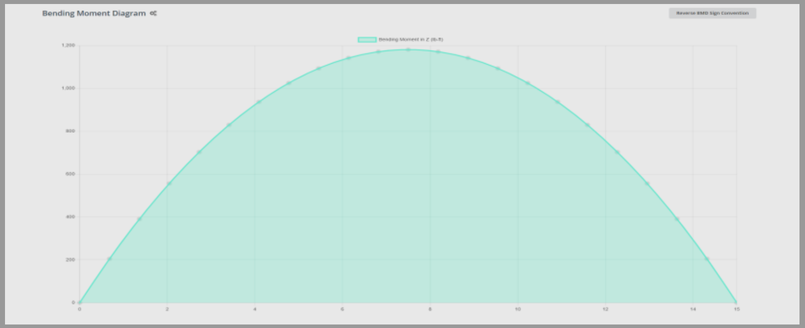
#Q6: Actual Beam Bending Moment, M
#Q7: Actual Maximum Shear Force (at reaction) , V



$$\boldsymbol{M}_{max} = \frac{w.L^2}{8} = \frac{42 \times 15^2}{8} = 1181.25\ FT - LB$$

$$\boldsymbol{V}_{max} = \frac{w.L}{2} = \frac{42 \times 15}{2} = 315\ LBS$$





Hint: Some online sources for drawing the beam diagrams and check your calculations

https://skyciv.com/free-beam-calculator/
https://optimalbeam.com/beam-calculator.php

Problem Set 02

#Q8 - 16

8 Nominal Depth of the Final Joist Used
9 Size Factor, CF
10 Repetetive Member Factor, Cr
11 Wet Service Factor for Fb, CM_b
12 Wet Service Factor for Fv, CM_v
13 Factored Allow. Bending Stress, F'b
14 Factored Allow. Shear Stress, F'v
15 Actual Bending Stress, fb_actual
16 Actual Shear Stress, fv_actual

Step 1

$$\textit{Trial 1: estimation for joists}$$

$$d = \frac{L}{18\sim20} = \frac{15}{20} \times 12 = \; 9\sim10\ IN$$

Step 2

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

$$F'_b = F_b\,(C_D \cdot C_m \cdot 1 \cdot 1 \cdot C_F \cdot 1\,.\,1 \cdot C_r)$$

Starting with 2×10

$C_F = 1.1$ *Trial1*

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

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
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	0.651	0.781	0.911	1.042	1.172	1.302
2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984	0.911	1.094	1.276	1.458	1.641	1.823
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266	1.172	1.406	1.641	1.875	2.109	2.344
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547	1.432	1.719	2.005	2.292	2.578	2.865
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039	1.888	2.266	2.643	3.021	3.398	3.776
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602	2.409	2.891	3.372	3.854	4.336	4.818
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164	2.930	3.516	4.102	4.688	5.273	5.859
2 x 14	1-1/2 x 13-1/4	19.88	43.89	290.8	4.969	3.727	3.451	4.141	4.831	5.521	6.211	6.901

Table 4A Adjustment Factors

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

Problem Set 02

#Q8 - 16

8	Nominal Depth of the Final Joist Used
9	Size Factor, CF
10	Repetetive Member Factor, Cr
11	Wet Service Factor for Fb, CM_b
12	Wet Service Factor for Fv, CM_v
13	Factored Allow. Bending Stress, F'b
14	Factored Allow. Shear Stress, F'v
15	Actual Bending Stress, fb_actual
16	Actual Shear Stress, fv_actual

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

$m.c. = 15\% \Rightarrow$

$C_M = 1$

$C_r = 1.15$

Trial1

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 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

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

Problem Set 02

#Q8 - 16

8 Nominal Depth of the Final Joist Used
9 Size Factor, CF
10 Repetetive Member Factor, Cr
11 Wet Service Factor for Fb, CM_b
12 Wet Service Factor for Fv, CM_v
13 Factored Allow. Bending Stress, F'b
14 Factored Allow. Shear Stress, F'v
15 Actual Bending Stress, fb_actual
16 Actual Shear Stress, fv_actual

Selected joist: $2 \times 10\ IN$

$$\frac{d}{b} = \frac{10}{2} = 5 \Rightarrow$$

Trial1

The compression edge of the member shall be held in line for its entire length to prevent lateral displacement.

According to 3.3.3, $C_l = 1$

Trial1

3.2 Bending Members – General

3.2.1 Span of Bending Members

For simple, continuous and cantilevered bending members, the span shall be taken as the distance from face to face of supports, plus ½ the required bearing length at each end.

3.2.2 Lateral Distribution of Concentrated Load

Lateral distribution of concentrated loads from a critically loaded bending member to adjacent parallel bending members by flooring or other cross members shall be permitted to be calculated when determining design bending moment and vertical shear force (see 15.1).

3.2.3 Notches

3.2.3.1 Bending members shall not be notched except as permitted by 4.4.3, 5.4.5, 7.4.4, and 8.4.1. A gradual taper cut from the reduced depth of the member to the full depth of the member in lieu of a square-cornered notch reduces stress concentrations.

3.2.3.2 The stiffness of a bending member, as determined from its cross section, is practically unaffected by a notch with the following dimensions:

notch depth ≤ (1/6) (beam depth)
notch length ≤ (1/3) (beam depth)

3.2.3.3 See 3.4.3 for effect of notches on shear strength.

3

DESIGN PROVISIONS AND EQUATIONS

3.3 Bending Members – Flexure

3.3.1 Strength in Bending

The actual bending stress or moment shall not exceed the adjusted bending design value.

3.3.2 Flexural Design Equations

3.3.2.1 The actual bending stress induced by a bending moment, M, is calculated as follows:

$$f_b = \frac{Mc}{I} = \frac{M}{S} \qquad (3.3\text{-}1)$$

For a rectangular bending member of breadth, b, and depth, d, this becomes:

$$f_b = \frac{M}{S} = \frac{6M}{bd^2} \qquad (3.3\text{-}2)$$

3.3.2.2 For solid rectangular bending members with the neutral axis perpendicular to depth at center:

$$I = \frac{bd^3}{12} = \text{moment of inertia, in.}^4 \qquad (3.3\text{-}3)$$

$$S = \frac{I}{c} = \frac{bd^2}{6} = \text{section modulus, in.}^3 \qquad (3.3\text{-}4)$$

3.3.3 Beam Stability Factor, C_L

3.3.3.1 When the depth of a bending member does not exceed its breadth, $d \le b$, 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. When such lateral support is provided at points of bearing, but no additional lateral support is provided throughout the length of the bending member, the unsupported length, ℓ_u, is the distance between such points of end bearing, or the length of a cantilever. When a bending member is provided with lateral support to prevent rotation at intermediate points as well as at the ends, the unsupported length, ℓ_u, is the distance between such points of intermediate lateral support.

3.3.3.5 The effective span length, ℓ_e, for single span or cantilever bending members shall be determined in accordance with Table 3.3.3.

4.4 Special Design Considerations

4.4.1 Stability of Bending Members

4.4.1.1 Sawn lumber bending members shall be designed in accordance with the lateral stability calculations in 3.3.3 or shall meet the lateral support requirements in 4.4.1.2 and 4.4.1.3.

4.4.1.2 As an alternative to 4.4.1.1, rectangular sawn lumber beams, rafters, joists, or other bending members, shall be designed in accordance with the following provisions to provide restraint against rotation or lateral displacement. If the depth to breadth, d/b, based on nominal dimensions is:

(a) $d/b \le 2$; no lateral support shall be required.
(b) $2 < d/b \le 4$; 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.
(c) $4 < d/b \le 5$; 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.
(d) $5 < d/b \le 6$; 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.
(e) $6 < d/b \le 7$; 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.

4.4.1.3 If a bending member is subjected to both flexure and axial compression, the depth to breadth ratio shall be no more than 5 to 1 if one edge is firmly held in line. If under all combinations of load, the unbraced edge of the member is in tension, the depth to breadth ratio shall be no more than 6 to 1.

4.4.2 Wood Trusses

4.4.2.1 Increased chord stiffness relative to axial loads where a 2" x 4" or smaller sawn lumber truss compression chord is subjected to combined flexure and axial compression under dry service condition and has 3/8" or thicker wood structural panel sheathing nailed to the narrow face of the chord in accordance with code required roof sheathing fastener schedules (see References 32, 33, and 34), shall be permitted to be accounted for by multiplying the reference modulus of elasticity design value for beam and column stability, E_{min}, by the buckling stiffness factor, C_T, in column stability calculations (see 3.7 and Appendix H). When $\ell_e < 96"$, C_T shall be calculated as follows:

$$C_T = 1 + \frac{K_M \ell_e}{K_T E} \qquad (4.4\text{-}1)$$

where:

ℓ_e = effective column length of truss compression chord (see 3.7), in.

K_M = 2300 for wood seasoned to 19% moisture content or less at the time of wood structural panel sheathing attachment.

= 1200 for unseasoned or partially seasoned wood at the time of wood structural panel sheathing attachment.

K_T = 1 – 1.645(COV_E)

= 0.59 for visually graded lumber

= 0.75 for machine evaluated lumber (MEL)

= 0.82 for products with $COV_E \le 0.11$ (see Appendix F.2)

When $\ell_e > 96"$, C_T shall be calculated based on ℓ_e = 96".

4.4.2.2 For additional information concerning metal plate connected wood trusses see Reference 9.

4

SAWN LUMBER

Problem Set 02

#Q8 - 16

8 Nominal Depth of the Final Joist Used
9 Size Factor, CF
10 Repetetive Member Factor, Cr
11 Wet Service Factor for Fb, CM_b
12 Wet Service Factor for Fv, CM_v
13 Factored Allow. Bending Stress, F'b
14 Factored Allow. Shear Stress, F'v
15 Actual Bending Stress, fb_actual
16 Actual Shear Stress, fv_actual

Shortest duration load

Live load < dead load ⇒

$C_D = 1$ **Trial1**

2.1 General

2.1.1 General Requirement

Each wood structural member or connection shall be of sufficient size and capacity to carry the applied loads without exceeding the adjusted design values specified herein.

2.1.1.1 For ASD, calculation of adjusted design values shall be determined using applicable ASD adjustment factors specified herein.

2.1.1.2 For LRFD, calculation of adjusted design values shall be determined using applicable LRFD adjustment factors specified herein.

2.1.2 Responsibility of Designer to Adjust for Conditions of Use

Adjusted design values for wood members and connections in particular end uses, shall be appropriate for the conditions under which the wood products are used, taking into account conditions such as the differences in wood strength properties with different moisture contents, load durations, and types of treatment. Common end use conditions are addressed in this Specification. It shall be the final responsibility of the designer to relate design assumptions with design values, and to make design value adjustments appropriate to the end use conditions.

2.2 Reference Design Values

Reference design values and design value adjustments for wood products in 1.1.1.1 are based on methods specified in each of the wood product chapters. Chapters 4 through 10 contain design provisions for sawn lumber, glued laminated timber, poles and piles, prefabricated wood I-joists, structural composite lumber, wood structural panels, and cross-laminated timber, respectively. Chapters 11 through 14 contain design provisions for connections. Reference design values are for normal load duration under the moisture service conditions specified.

2.3 Adjustment of Reference Design Values

2.3.1 Applicability of Adjustment Factors

Reference design values shall be multiplied by all applicable adjustment factors to determine adjusted design values. The applicability of adjustment factors to sawn lumber, structural glued laminated timber, poles and piles, prefabricated wood I-joists, structural composite lumber, wood structural panels, cross-laminated timber, and connection design values is defined in 4.3, 5.3, 6.3, 7.3, 8.3, 9.3, 10.3, and 11.3, respectively.

2.3.2 Load Duration Factor, C_D (ASD Only)

2.3.2.1 Wood has the property of carrying substantially greater maximum loads for short durations than for long durations of loading. Reference design values apply to normal load duration. Normal load duration represents a load that fully stresses a member to its allowable design value by the application of the full design load for a cumulative duration of approximately ten years. When the cumulative duration of the full maximum load does not exceed the specified time period, all reference design values except modulus of elasticity, E, modulus of elasticity for beam and column stability, E_{min}, and compression perpendicular to grain, $F_{c\perp}$, based on a deformation limit (see 4.2.6) shall be multiplied by the appropriate load duration factor, C_D, from Table 2.3.2 or Figure B1 (see Appendix B) to take into account the change in strength of wood with changes in load duration.

2.3.2.2 The load duration factor, C_D, for the shortest duration load in a combination of loads shall apply for that load combination. All applicable load combinations shall be evaluated to determine the critical load combination. Design of structural members and connections shall be based on the critical load combination (see Appendix B.2).

2.3.2.3 The load duration factors, C_D, in Table 2.3.2 and Appendix B are independent of load combination factors, and both shall be permitted to be used in design calculations (see 1.4.4 and Appendix B.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

1. Load duration factors shall not apply to reference modulus of elasticity, E, reference modulus of elasticity for beam and column stability, E_{min}, nor to reference compression perpendicular to grain design values, $F_{c\perp}$, based on a deformation limit.
2. Load duration factors greater than 1.6 shall not be used in the design of structural members pressure-treated with water-borne preservatives (see Reference 30), or fire retardant chemicals. Load duration factors greater than 1.6 shall not be used in the design of connections or wood structural panels.

2.3.3 Temperature Factor, C_t

Reference design values shall be multiplied by the temperature factors, C_t, in Table 2.3.3 for structural members that will experience sustained exposure to elevated temperatures up to 150°F (see Appendix C).

2.3.4 Fire Retardant Treatment

The effects of fire retardant chemical treatment on strength shall be accounted for in the design. Adjusted design values, including adjusted connection design values, for lumber and structural glued laminated timber pressure-treated with fire retardant chemicals shall be obtained from the company providing the treatment and redrying service. Load duration factors greater than 1.6 shall not apply to structural members pressure-treated with fire retardant chemicals (see Table 2.3.2).

2.3.5 Format Conversion Factor, K_F (LRFD Only)

For LRFD, reference design values shall be multiplied by the format conversion factor, K_F, specified in Table 2.3.5. The format conversion factor, K_F, shall not apply for designs in accordance with ASD methods specified herein.

2.3.6 Resistance Factor, ϕ (LRFD Only)

For LRFD, reference design values shall be multiplied by the resistance factor, ϕ, specified in Table 2.3.6. The resistance factor, ϕ, shall not apply for designs in accordance with ASD methods specified herein.

2.3.7 Time Effect Factor, λ (LRFD Only)

For LRFD, reference design values shall be multiplied by the time effect factor, λ, specified in Appendix N.3.3. The time effect factor, λ, shall not apply for designs in accordance with ASD methods specified herein.

Table 2.3.3 Temperature Factor, C_t

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

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

Problem Set 02

#Q8 - 16

8 Nominal Depth of the Final Joist Used
9 Size Factor, CF
10 Repetetive Member Factor, Cr
11 Wet Service Factor for Fb, CM_b
12 Wet Service Factor for Fv, CM_v
13 Factored Allow. Bending Stress, F'b
14 Factored Allow. Shear Stress, F'v
15 Actual Bending Stress, fb_actual
16 Actual Shear Stress, fv_actual

$$F'_b = F_b\,(C_D \cdot C_m \cdot C_t \cdot C_L \cdot C_F \cdot C_{fu} . C_i \cdot C_r)$$
$$= 875(1 \times 1 \times 1 \times 1 \times 1.1 \times 1 \times 1 \times 1.15)$$
$$= \boxed{\mathbf{1,106.87\ PSI}}$$

Trial1

$$F'_v = F_v\,(C_D \cdot C_m \cdot C_t \cdot C_i)$$
$$= 135(1 \times 1 \times 1 \times 1)$$
$$= \boxed{\mathbf{135\ PSI}}$$

Trial1

Problem Set 02

#Q8 - 16

8	Nominal Depth of the Final Joist Used
9	Size Factor, CF
10	Repetetive Member Factor, Cr
11	Wet Service Factor for Fb, CM_b
12	Wet Service Factor for Fv, CM_v
13	Factored Allow. Bending Stress, F'b
14	Factored Allow. Shear Stress, F'v
15	Actual Bending Stress, fb_actual
16	Actual Shear Stress, fv_actual

$$S_x = \frac{M_{max}}{F'_b} = \frac{1181.25\ FT - LB \times \frac{12\ IN}{1FT}}{1,106.87} = 12.8\ IN^3$$

Tial 2

Tial 1

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

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
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	0.651	0.781	0.911	1.042	1.172	1.302
2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984	0.911	1.094	1.276	1.458	1.641	1.823
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266	1.172	1.406	1.641	1.875	2.109	2.344
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547	1.432	1.719	2.005	2.292	2.578	2.865
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039	1.888	2.266	2.643	3.021	3.398	3.776
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602	2.409	2.891	3.372	3.854	4.336	4.818
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164	2.930	3.516	4.102	4.688	5.273	5.859
2 x 14	1-1/2 x 13-1/4	19.88	43.89	290.8	4.969	3.727	3.451	4.141	4.831	5.521	6.211	6.901

Problem Set 02

#Q8 - 16

$\textit{Trial 2}: \textit{assumming } 2 \times 8$

$$F'_b = F_b \left(C_D \cdot C_m \cdot C_t \cdot C_L \cdot C_F \cdot C_{fu} \cdot C_i \cdot C_r\right)$$
$$= 875(1 \times 1 \times 1 \times 1 \times 1.2 \times 1 \times 1 \times 1.15)$$
$$= \mathbf{1,207.5\ PSI}$$

$$F'_v = F_v \left(C_D \cdot C_m \cdot C_t \cdot C_i\right)$$
$$= 135(1 \times 1 \times 1 \times 1)$$
$$= \mathbf{135\ PSI}$$

$$S_x = \frac{M_{max}}{F'_b} = \frac{1181.25\ FT-LB \times \frac{12\ IN}{1FT}}{1{,}207.5} = 11.73\ IN^3 < \mathbf{13.14} \Rightarrow \textit{pass}$$

$$F_v = 1.5\frac{V}{A} = 1.5\frac{315}{10.88} = \mathbf{43.42\ PSI} < \mathbf{135\ PSI} \Rightarrow \text{pass}$$

$$F_b = \frac{M}{S} = \frac{1181.25\ FT-LB \times \frac{12\ IN}{1FT}}{13.14} = \mathbf{1078.76\ PSI}$$

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

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
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	0.651	0.781	0.911	1.042	1.172	1.302
2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984	0.911	1.094	1.276	1.458	1.641	1.823
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266	1.172	1.406	1.641	1.875	2.109	2.344
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547	1.432	1.719	2.005	2.292	2.578	2.865
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039	1.888	2.266	2.643	3.021	3.398	3.776
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602	2.409	2.891	3.372	3.854	4.336	4.818
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164	2.930	3.516	4.102	4.688	5.273	5.859
2 x 14	1-1/2 x 13-1/4	19.88	43.89	290.8	4.969	3.727	3.451	4.141	4.831	5.521	6.211	6.901

Problem Set 02

#Q17: Factored Allow. Modulus of Elasticity, E'

$$E' = E\,(C_M \times C_t \times C_i) \Rightarrow$$

$$= 1{,}400{,}000(1 \times 1 \times 1)$$

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 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	-

4.3.5 Beam Stability Factor, C_L

Reference bending design values, F_b, shall be multiplied by the beam stability factor, C_L, specified in 3.3.3.

4.3.6 Size Factor, C_F

4.3.6.1 Reference bending, tension, and compression parallel to grain design values for visually graded dimension lumber 2" to 4" thick shall be multiplied by the size factors specified in Tables 4A and 4B.

4.3.6.2 Where the depth of a rectangular sawn lumber bending member 5" or thicker exceeds 12", the reference bending design values, F_b, in Table 4D shall be multiplied by the following size factor:

$$C_F = (12 / d)^{1/9} \leq 1.0 \qquad (4.3\text{-}1)$$

4.3.6.3 For beams of circular cross section with a diameter greater than 13.5", or for 12" or larger square beams loaded in the plane of the diagonal, the size factor shall be determined in accordance with 4.3.6.2 on the basis of an equivalent conventionally loaded square beam of the same cross-sectional area.

4.3.6.4 Reference bending design values for all species of 2" thick or 3" thick Decking, except Redwood, shall be multiplied by the size factors specified in Table 4E.

4.3.7 Flat Use Factor, C_{fu}

4.3.7.1 When sawn lumber 2" to 4" thick is loaded on the wide face, multiplying the reference bending design value, F_b, by the flat use factors, C_{fu}, specified in Tables 4A, 4B, 4C, and 4F, shall be permitted.

4.3.7.2 When members classified as Beams and Stringers are loaded on the wide face, the reference bending design value, F_b, and the reference modulus of elasticity, (E or E_{min}), shall be multiplied by the flat use factors, C_{fu}, specified in Table 4D.

Problem Set 02

#Q18: Short Term Deflection for 100% LL

#Q19: Short Term Deflection Limit for L/360

#Q20: Deflection Passing

2. Wood Beam Design

Design a 2x dimensioned lumber floor joist to carry the given dead + live floor load (neglect joist selfweight). 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	SPRUCE-PINE-FIR
Wood Grade	No.1/No.2
Span	15 FT
Joist Spacing, o.c.	12 IN
Moisture Content, m.c.	15 %
Floor DL	7 PSF
Floor LL	35 PSF

$$\textit{Live Load on joist} = \frac{15(DL+LL)}{span} = \frac{15(35)}{15} = 35\ \text{PLF} \times \frac{1FT}{12\ IN} = 2.916\ \ LB - inch$$

$$\Delta_{wL} = \frac{5w_l\,L^4}{384\,E'\,I} = \frac{5(2.916)(15\times 12)^4}{384\,(1400000)47.63} = 0.597\ IN$$

$$\textit{Short Term Deflection Limit} = \frac{\text{L}}{360} = \frac{15\ FT \times \frac{12\ IN}{1FT}}{360} = 0.5\ IN \Rightarrow \textit{Fails}$$

Lab

No Lab for this session ;)