Structure II Recitation 1/26

Wood Beam Design

Before We Start..

1. Homework (Due Sunday)
2. Weekly quiz (Due Sunday)
3. Lab sheet (Due Friday during recitation)
4. Notes will be uploaded on the structure website on Friday (Check the “Recitation” tab)
5. Remember to do the on topic quiz on canvas if you miss the lectures
6. My email: tyling@umich.edu

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

Design Procedure

Given: load, wood and grade, span, other usage conditions

Req'd: member size

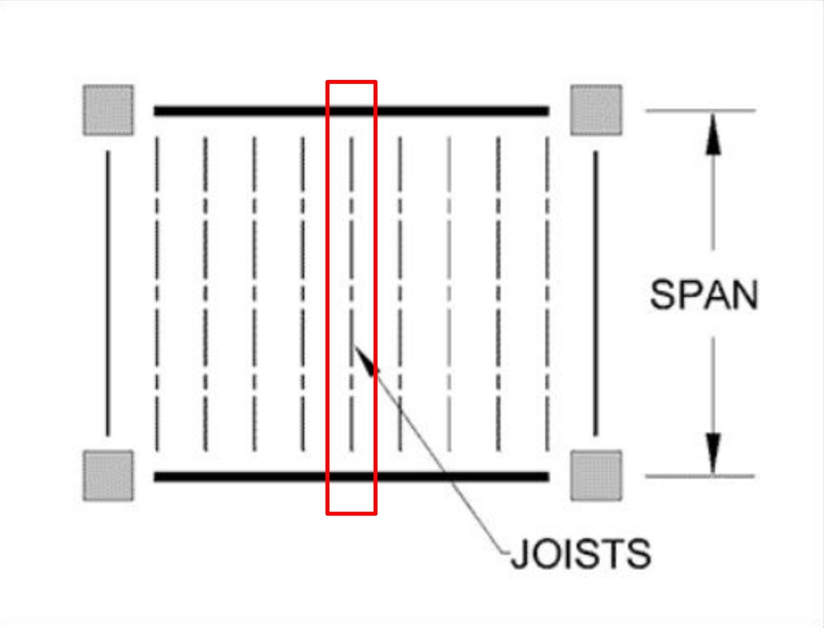
1. **Find Max Shear & Moment**
   - Simple case – equations
   - Complex case - diagrams
2. **Determine allowable stresses, F_b**
   - Apply usage factors to get F'_b
3. **Solve $S = M/F_b'$**
4. **Choose a section from Table 1B**
   - Revise DL and F_b'
   - Check step 3 and revise.
5. **Check shear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

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	EASTERN HEMLOCK-TAMARACK
Wood Grade	Select Structural
Span	16 FT
Joist Spacing, o.c.	19.2 IN
Moisture Content, m.c.	25 %
Floor DL	6 PSF
Floor LL	40 PSF



Q1: Tabulated Allowable Bending Stress (Fb)
Q2: Tabulated Allowable Shear Stress (Fv)
Q3: Tabulated Modulus of Elasticity (E)

Given from Question

Wood Species	EASTERN HEMLOCK-TAMARACK
Wood Grade	Select Structural

Check Table 4A:

Fb = **1250 psi**, Fv = **170 psi**, E = **12000000 psi**

NDS Supplement, Table 4A, P.41~(PDF)

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	
EASTERN HEMLOCK-TAMARACK										
Select Structural	2" & wider	1,250	575	170	555	1,200	1,200,000	440,000	0.41	NELMA NSLB
No. 1		775	350	170	555	1,000	1,100,000	400,000		
No. 2		575	275	170	555	825	1,100,000	400,000		
No. 3		350	150	170	555	475	900,000	330,000		
Stud	2" & wider	450	200	170	555	525	900,000	330,000		
Construction	2" - 4" wide	675	300	170	555	1,050	1,000,000	370,000		
Standard		375	175	170	555	850	900,000	330,000		
Utility		175	75	170	555	550	800,000	290,000		
EASTERN SOFTWOODS										

Q4: Total Applied Floor Load (DL+LL)

Calculation:

(DL + LL) = 40 + 6 = **<u>46 PSF</u>**

Given from Question

Floor DL	6 PSF
Floor LL	40 PSF
Span	16 FT
Joist Spacing, o.c.	19.2 IN

Q5: Load on Joist (w)

The unit of our answer is PLF

Calculation:

from Q4

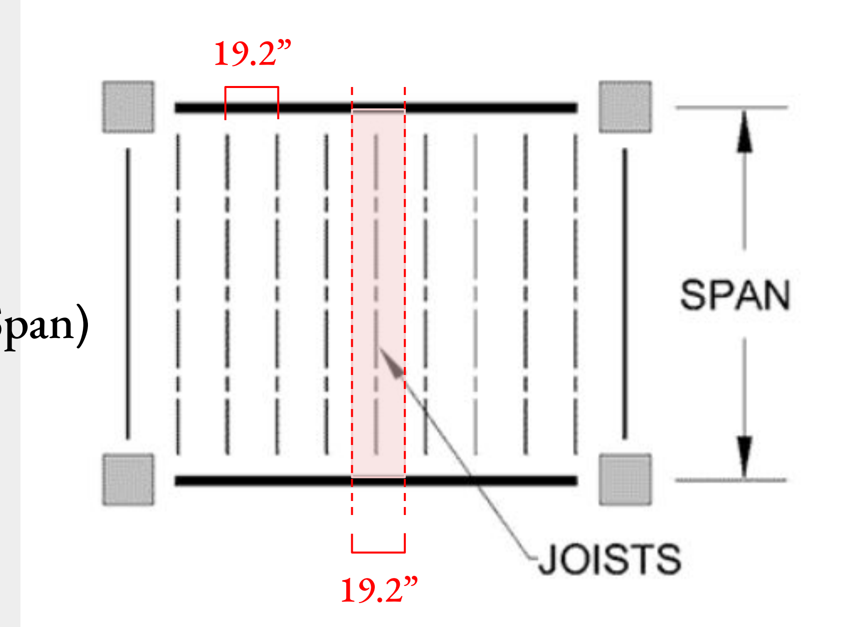
w

= (Total Applied Floor Load) x (Tributary Area) / (Span)

= 46 x (19.2 x 16) / 16 x $\boxed{(1/12)}$ → Convert Unit

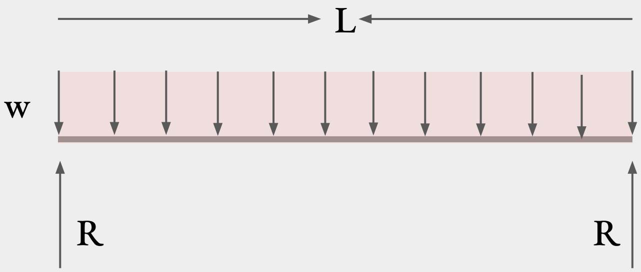
= 46 x 19.2 /12

= **<u>73.6 PLF</u>**



Q6: Actual Beam Bending Moment (M)

Look for the maximum moment, use the equation method:
For uniformly distributed load on a simple beam,
the maximum moment $M = w \times L^2/8$



$M = w \times L^2/8 = 73.6 \times 16^2/8 =$ **2355.2 FT*LB**

from Q5

Q7: Actual Maximum Shear Force (At Reaction) (V)

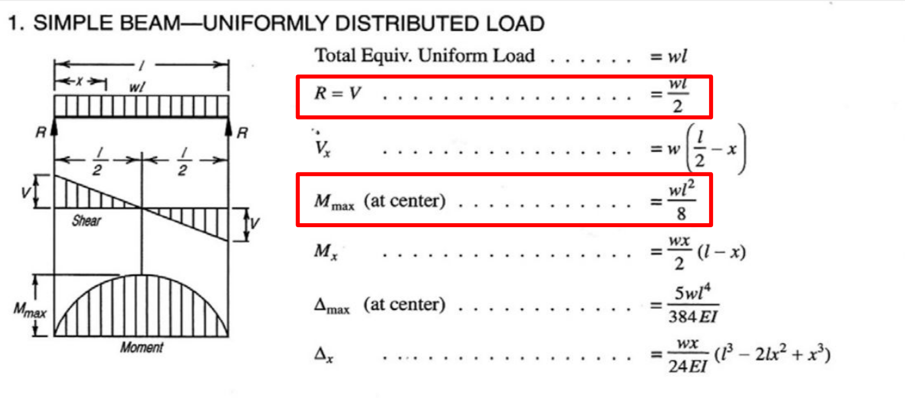
Since the system is symmetrical, the two reaction forces are the same
For uniformly distributed load on a simple beam,
the maximum shear force $V = R$

$\Sigma Fy = 0$:

$w \times L = R + R$

$R = w \times L / 2 = 588.8$

$V = R =$ **588.8 LBS**



Q8: Nominal Depth of the Final Joist Use (2 x ?)

Step 1: Estimate Allowable Stresses:

Given from Question:

$C_L = C_{fu} = C_t = C_i = 1$

C_r: Look at slide 12 (Q10)

C_M: Look at slide 13 (Q11&12)

C_D: Look at Table 2.3.2, $C_D = 1$ (for Occupancy Live Load)

Since we are not able know C_F yet, we estimate $C_F = 1$

$$
\begin{aligned}
F'b &= Fb \times (C_D \times C_M \times C_t \times C_L \times C_F \times C_{fu} \times C_i \times C_r) \\
&= Fb \times (C_D \times C_M \times C_F \times C_r) \\
&= 1250 \times (1 \times 0.85 \times 1 \times 1.15) \\
&= 1221.875 \text{ psi}
\end{aligned}
$$

$$
\begin{aligned}
F'v &= Fv \times (C_D \times C_M \times C_t \times C_i) \\
&= 170 \times (1 \times 0.97 \times 1 \times 1) \\
&= 164.9 \text{ psi}
\end{aligned}
$$

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.

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

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

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

Step 2: Search for the possible answers with Sx

Assume the estimated F'b (allowable) = fb (actual)
Use F'b = M/Sx to find Sx

$$f_b = M/S$$

For my situation:
Sx = M/F'b = 2355.2 / 1221.875 x $\boxed{12}$ = 23.136

from Q6 Convert Unit

Look at Table 1B, find the sizes that have the Sx closest to 23.126, for me will be 2 x 10 and 2 x 12

NDS Supplement, Table 1B, P.22 (PDF)

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
Boards[1]												
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396	1.465	1.758	2.051	2.344	2.637	2.930
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
3 x 4	2-1/2 x 3-1/2	8.75	5.10	8.932	3.646	4.557	1.519	1.823	2.127	2.431	2.734	3.038

Step 3: Check if allowable stresses are bigger than actual stresses for the chosen sizes:
First Test 2 x 10 (the smaller one):

<u>Bending Stress:</u> Check Slide 11

$F'b = Fb \times (C_D \times C_M \times \boxed{C_F} \times C_r) = 1250 \times (1 \times 0.85 \times 1.1 \times 1.15) = \boxed{\underline{\mathbf{1344.063\ psi}}}$ Q13

$fb = \boxed{M}/S = 2355.2 / 21.39 \times \boxed{12} = \boxed{\underline{\mathbf{1321.29\ psi}}}$ Q15

from Q6 Convert Unit

F'b (allowable) > fb (actual), It's a pass!

<u>Shear Stress:</u>

$F'v = Fv \times (C_D \times C_M \times C_t \times C_i) = 170 \times (1 \times 0.97 \times 1 \times 1) = \boxed{\underline{\mathbf{164.9\ psi}}}$ Q14

$fv = 1.5\boxed{V}/A = 1.5 \times 588.8/13.88 = \boxed{\underline{\mathbf{63.6\ psi}}}$ Q16

from Q7

F'v (allowable) > fv (actual), It's another pass!

Nominal Depth = **<u>10in</u>**

NDS Supplement, Table 1B, P.22 (PDF)

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
Boards[1]												
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396	1.465	1.758	2.051	2.344	2.637	2.930
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
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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
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3 x 4	2-1/2 x 3-1/2	8.75	5.10	8.932	3.646	4.557	1.519	1.823	2.127	2.431	2.734	3.038
3 x 5	2-1/2 x 4-1/2	11.25	8.44	18.98	4.688	5.859	1.953	2.344	2.734	3.125	3.516	3.906

Q9: Size Factor (C_F)

Look at Table 4A

C_F= **1.1**

Given from Question

Wood Species	EASTERN HEMLOCK-TAMARACK
Wood Grade	Select Structural

NDS Supplement, Table 4A, P.40 (PDF)

Size Factors, C_F

		F_b		F_t	F_c
	from Q8	Thickness (breadth)			
Grades	Width (depth)	2" & 3"	4"		
Select Structural, No.1 & Btr, No.1, No.2, No.3	2", 3", & 4"	1.5	1.5	1.5	1.15
	5"	1.4	1.4	1.4	1.1
	6"	1.3	1.3	1.3	1.1
	8"	1.2	1.3	1.2	1.05
	10"	1.1	1.2	1.1	1.0
	12"	1.0	1.1	1.0	1.0
	14" & wider	0.9	1.0	0.9	0.9
Stud	2", 3", & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
	8" & wider	Use No.3 Grade tabulated design values and size factors			
Construction, Standard	2", 3", & 4"	1.0	1.0	1.0	1.0
Utility	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	—	0.4	0.6

Q10: Repetitive Factor (C_r)

Check if your spacing bigger than 24 in
If bigger, $C_r = 1$
If smaller or equal, $C_r = 1.15$

Since my spacing $= 19.2\text{in} < 24$ in
$C_r = 1.15$

Given from Question

Joist Spacing, o.c.	19.2 IN

NDS Supplement, Table 4A, P.41~(PDF)

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.

Q11. Wet Service Factor for Fb (C_{M_b}):

1. Check if Moisture Content < 19%

If bigger, go to next step

If smaller, $C_{M\_b} = 1$

2. Check if Fb x C_F < 1150

If bigger, $C_{M\_b} = 0.85$

If smaller, $C_{M\_b} = 1$

(We don't know C_F yet, but in my case Fb is bigger than 1150, so we estimate $C_{M\_b} = 0.85$)

After knowing my $C_F = 1.1$, $C_{M\_b} = \mathbf{0.85}$

Q12. Wet Service Factor for Fv (C_{M_v}):

1. Check if Moisture Content < 19%

If bigger, $C_{M\_v} = 0.97$

If smaller, $C_{M\_v} = 1$

For my case 25%>19%, $C_{M\_v} = \mathbf{0.97}$

Given from Question

Moisture Content, m.c.	25 %

NDS Supplement, Table 4A, P.40 (PDF)

Wet Service Factor, C_M

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

Wet Service Factors, C_M

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

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

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

Q17. Factored Allowable Modulus of Elasticity (E')

Formula:

$E' = E \times (C_M \times C_t \times C_i)$ (E from Q3)

Given from Question:

$C_t = C_i = 1$

For C_M, Check if M.C. > 19%

If yes, $C_M = 0.9$

If not, $C_M = 1$

Since my M.C. = 25% > 19%, $C_{M\_E} = 0.9$

Calculation:

$E' = E \times C_{M\_E} = 1200000 \times 0.9 =$ **<u>1080000 psi</u>**

Given from Question

Moisture Content, m.c.	25 %

$F_{c\perp}' = F_{c\perp}$	x	-	C_M	C_t	-	-	-	C_i	-	-	-	C_b	K_F	ϕ_c	λ
$F_c' = F_c$	x	C_D	C_M	C_t	-	C_F	-	C_i	-	C_P	-	-	K_F	ϕ_c	λ
$E' = E$	x	-	C_M	C_t	-	-	-	C_i	-	-	-	-	-	-	-
$E_{min}' = E_{min}$	x	-	C_M	C_t	-	-	-	C_i	-	-	C_T	-	K_F	ϕ_s	-

NDS Supplement, Table 4A, P.40 (PDF)

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:

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

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

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

Q18. Short Term Deflection for 100% LL

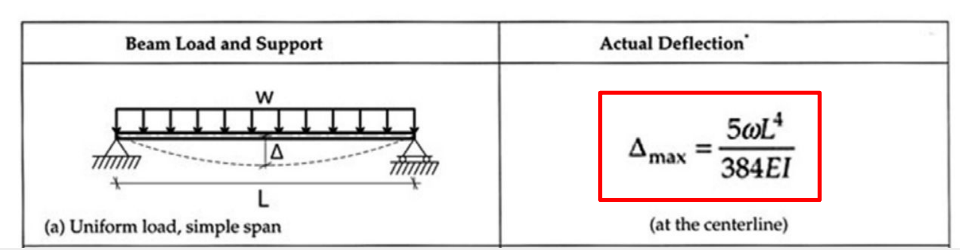
Formula:

Deflection = (5 x w x L^4) / (384 x E x I)

(E: Use E' from Q17)

(I: Look at Table 1B)

(L: Given from question)



Since we are looking at 100% LL,

We need to recalculate w with only LL

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Boards[1]												
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396	1.465	1.758	2.051	2.344	2.637	2.930
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
3 x 4	2-1/2 x 3-1/2	8.75	5.10	8.932	3.646	4.557	1.519	1.823	2.127	2.431	2.734	3.038

w = 40 x 19.2 / 12 = 64 PLF

NDS Supplement, Table 1B, P.22 (PDF)

Calculation:

Deflection

= (5 x 64 x16^4) / (384 x 1080000 x 98.93) x $\boxed{(12)^3}$

Convert Unit

= **<u>0.883 in</u>**

Q19. Short Term Deflection Limit for L/360

Span	16 FT

Calculation:

L / 360 = 16 / 360 x $\boxed{12}$ = **<u>0.533 in</u>**

Convert Unit

Q20. Deflection Passing

Check if Deflection (Q18) < Deflection Limit (Q19)
If bigger, the answer is “Fail”
If smaller, the answer is “Pass”

For my situation:
Since 0.883 > 0.533, the answer is **<u>Fail</u>**


ITS OVER
ITS FINALLY OVER
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