TAUBMAN COLLEGE
ARCHITECTURE & URBAN PLANNING
UNIVERSITY OF MICHIGAN

Arch324
STRUCTURES II

Winter 2025
Recitation

FACULTY: Prof. Peter von Bülow
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Welcome to Recitation session 01/17

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Office: Room 3122
hours:
Fri: 11:30 – 12:30
Mon, Wed: 11:00 - 12:00
Click here to Schedule -------------walk-ins welcome!

Please feel free to ask questions.

Welcome to Recitation session 01/17

Outline:

- Quick **Recap** of the week
- Provide the solution for the assignment **(Homework 1)**
- Answering student's questions
- Lab: **Beam Deflection**

Please feel free to ask questions.

Recap of the week

Allowable Stress Design by NDS

Flexure

$F_b' \geq f_b$

Allowable Flexure Stress F_b'

F_b from NDS Supplement tables determined by species and grade

$F_b' = F_b$ (usage factors)

usage factors for flexure:

- C_D Load Duration Factor
- C_M Moisture Factor
- C_t Temperature Factor
- C_L Beam Stability Factor
- C_F Size Factor
- C_{fu} Flat Use
- C_i Incising Factor
- C_r Repetitive Member Factor

$\geq$

Actual Flexure Stress f_b

$f_b = Mc/I = M/S$

$S = I/c = bd^2/6$

Check/ Design

Recap of the week

Allowable Stress Design by NDS

Shear

$F_v' \geq f_v$

Allowable Shear Stress Fv'

F_v from tables determined by species and grade

$F_v' = F_v$ (usage factors)

usage factors for shear:

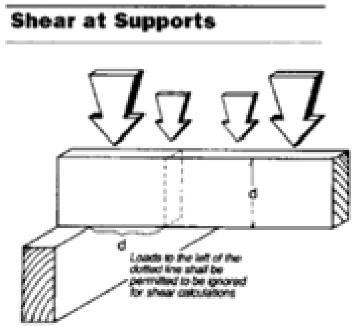
- C_D Load Duration Factor
- C_M Moisture Factor
- C_t Temperature Factor
- C_i Incising Factor

$\geq$

Actual Shear Stress fv

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

Can use V at d from support as maximum



Check/ Design

Recap of the week

Adjustment Factors

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD only	ASD and LRFD										LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Incising Factor	Repetitive Member Factor	Column Stability Factor	Buckling Stiffness Factor	Bearing Area Factor	Format Conversion Factor	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
$F_{c\perp}' = F_{c\perp}$	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	-

Provide the solution for the assignment – **HW1**

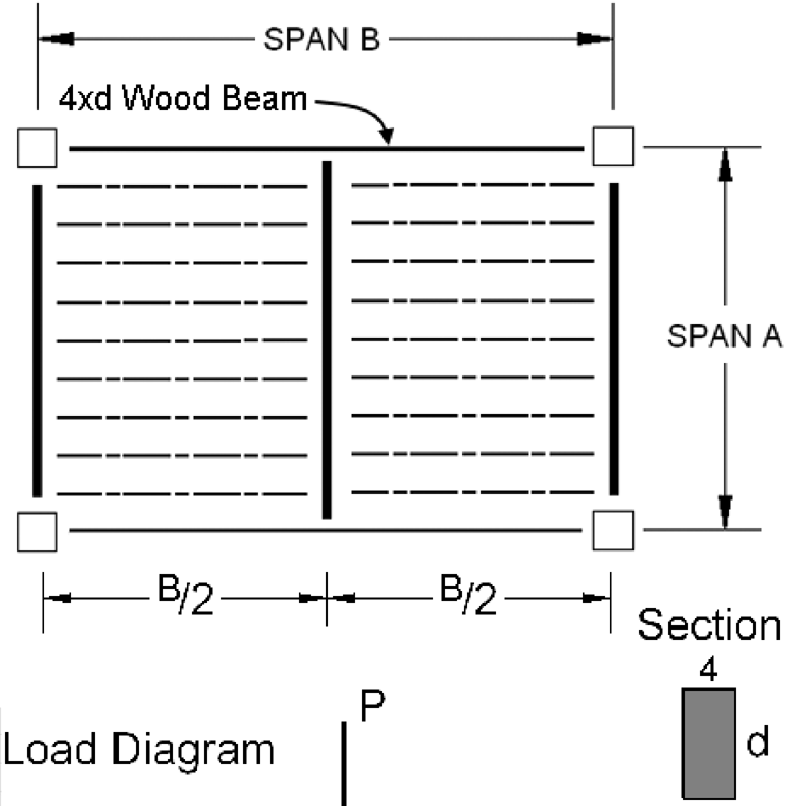
1. Wood Beam Analysis

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

DATASET: 1 -2- -3-

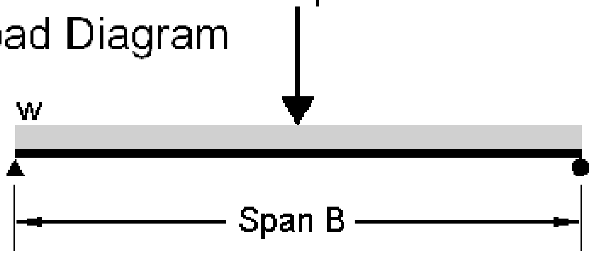
Wood Species	NORTHERN WHITE CEDAR
Wood Grade	No.1
Span A	16 FT
Span B	14 FT
Nominal Depth of Beam, d	16 IN
Moisture Content, m.c.	20 %
Floor DL	9 PSF
Floor LL	45 PSF

- Problem:

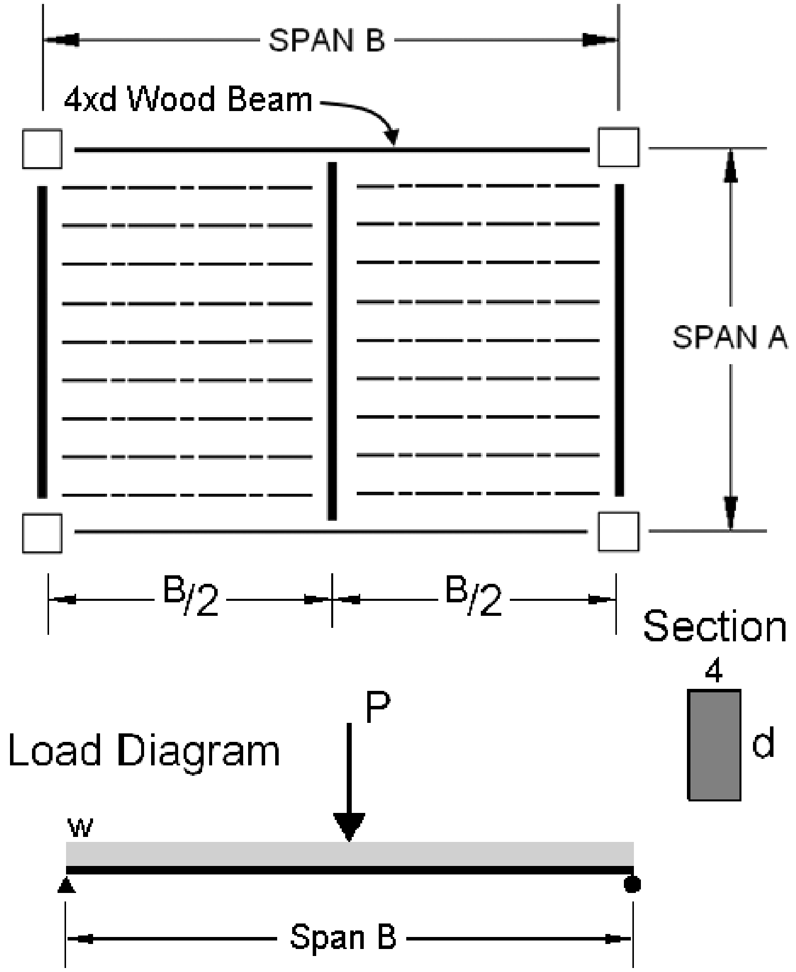


Northern white cedar → 4A, 4D, 4E → p46
Specific Gravity = 0.31
Moisture Content, m.c. 20%
Note: (19% or less considered dry condition)
Wood Density

16"
4"



Provide the solution for the assignment – **HW1**



#	Question	Your Response	
1	Tabulated Allow. Bending Stress, Fb		PSI
2	Tabulated Allow. Shear Stress, Fv		PSI
3	Tabulated Wood Dry Density (specific gravity)		
4	Total Actual Applied Point Load, P		LBS
5	Wood Density (Including M.C.)		PCF
6	Beam Selfweight (Including M.C.), w		PLF
7	Actual Beam Bending Moment, M		FT-LB
8	Actual Maximum Shear Force (at reaction) , V		LBS
9	Size Factor, CF		
10	Wet Service Factor for Fb, CM_b		
11	Wet Service Factor for Fv, CM_v		
12	Factored Allow. Bending Stress, F'b		PSI
13	Factored Allow. Shear Stress, F'v		PSI
14	Actual Bending Stress, fb_actual		PSI
15	Actual Shear Stress, fv_actual		PSI
16	Bending Stress Passing: enter "1" for pass or "0" for fail		(1 or 0)
17	Shear Stress Passing: enter "1" for pass or "0" for fail		(1 or 0)

Provide the solution for the assignment – **HW1**

Analysis Procedure

Given: loading, member size, material and span.

Req'd: Safe or Unsafe (Pass/Fail)

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

2. Determine actual stresses
   - $f_b = M/S$
   - $f_v = 1.5\ V/A$

3. Determine allowable stresses
   - F_b and F_v (from NDS)
   - $F_b' = F_b$ (usage factors)
   - $F_v' = F_v$ (usage factors)

4. Check that actual ≤ factored allowable
   - $f_b \leq F'_b$
   - $f_v \leq F'_v$

5. Check deflection < building code max.
6. Check bearing ($F_{c\perp} \geq \text{Reaction}/A_{bearing}$)

Provide the solution for the assignment – **HW1**

NDS Supplement

Wood Species → Northern White Cedar
Wood Grade → No.1

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

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

USE WITH TABLE 4A ADJUSTMENT FACTORS

Species and commercial grade	Size classification	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
NORTHERN WHITE CEDAR										
Select Structural	2" & wider	775	450	120	370	750	800,000	290,000	0.31	NELMA
No. 1	2" & wider	575	325	120	370	600	700,000	260,000	0.31	NELMA
No. 2	2" & wider	550	325	120	370	475	700,000	260,000	0.31	NELMA
No. 3	2" & wider	325	175	120	370	275	600,000	220,000	0.31	NELMA
Stud	2" & wider	425	250	120	370	300	600,000	220,000	0.31	NELMA
Construction	2" - 4" wide	625	375	120	370	625	700,000	260,000	0.31	NELMA
Standard	2" - 4" wide	350	200	120	370	475	600,000	220,000	0.31	NELMA
Utility	2" - 4" wide	175	100	120	370	325	600,000	220,000	0.31	NELMA

Q1 (No. 1, Bending 575)

Q2 (No. 1, Shear 120)

Q3 (Specific Gravity 0.31)

Provide the solution for the assignment – **HW1**

[NDS- Supplement- p 12]

The following formula shall be used to determine the density in lbs/ft^3 of wood:

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

where:

G = specific gravity of wood

m.c. = moisture content of wood, %

$$\text{density} = 62.4\left[\frac{0.31}{1+0.31(0.009)(20)}\right]\left[1+\frac{20}{100}\right]$$

$$= 21.98 \ pcF \ \left(\frac{lb}{ft^3}\right)$$

Q5

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
4 x 4	3-1/2 x 3-1/2	12.25	7.15	12.51	7.146	12.51	2.127	2.552	2.977	3.403	3.828	4.253
4 x 5	3-1/2 x 4-1/2	15.75	11.81	26.58	9.188	16.08	2.734	3.281	3.828	4.375	4.922	5.469
4 x 6	3-1/2 x 5-1/2	19.25	17.65	48.53	11.23	19.65	3.342	4.010	4.679	5.347	6.016	6.684
4 x 8	3-1/2 x 7-1/4	25.38	30.66	111.1	14.80	25.90	4.405	5.286	6.168	7.049	7.930	8.811
4 x 10	3-1/2 x 9-1/4	32.38	49.91	230.8	18.89	33.05	5.621	6.745	7.869	8.993	10.12	11.24
4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20	6.836	8.203	9.570	10.94	12.30	13.67
4 x 14	3-1/2 x 13-1/4	46.38	102.41	678.5	27.05	47.34	8.051	9.661	11.27	12.88	14.49	16.10
4 x 16	3-1/2 x 15-1/4	53.38	135.66	1034	31.14	54.49	9.266	11.12	12.97	14.83	16.68	18.53

Provide the solution for the assignment – **HW1**

DL: 9 PSF

LL: 45 PSF

load case: DL+LL

Calculation of Point load:

14'   16'

$\left(\frac{B}{2} \times A\right) \times 9 + \left(\frac{B}{2} \times A\right) \times 45 = \frac{6048}{2}$ LBS $= 3024$ (lb)

lb/ft²

Q4

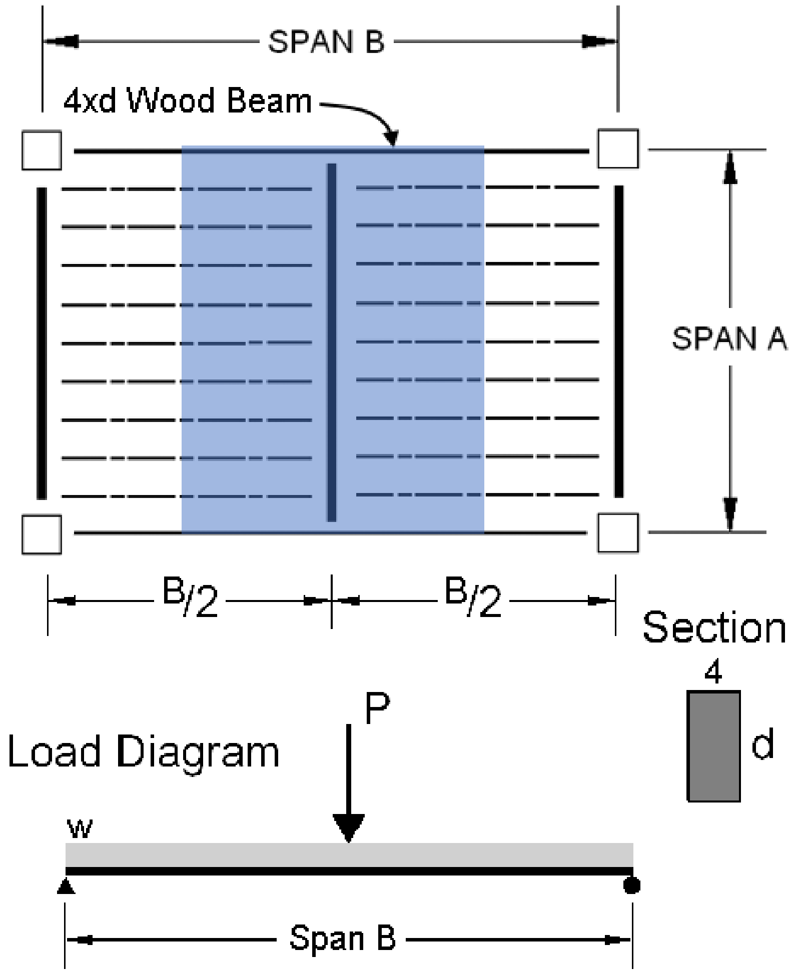
Beam self weight:

Table 1B →

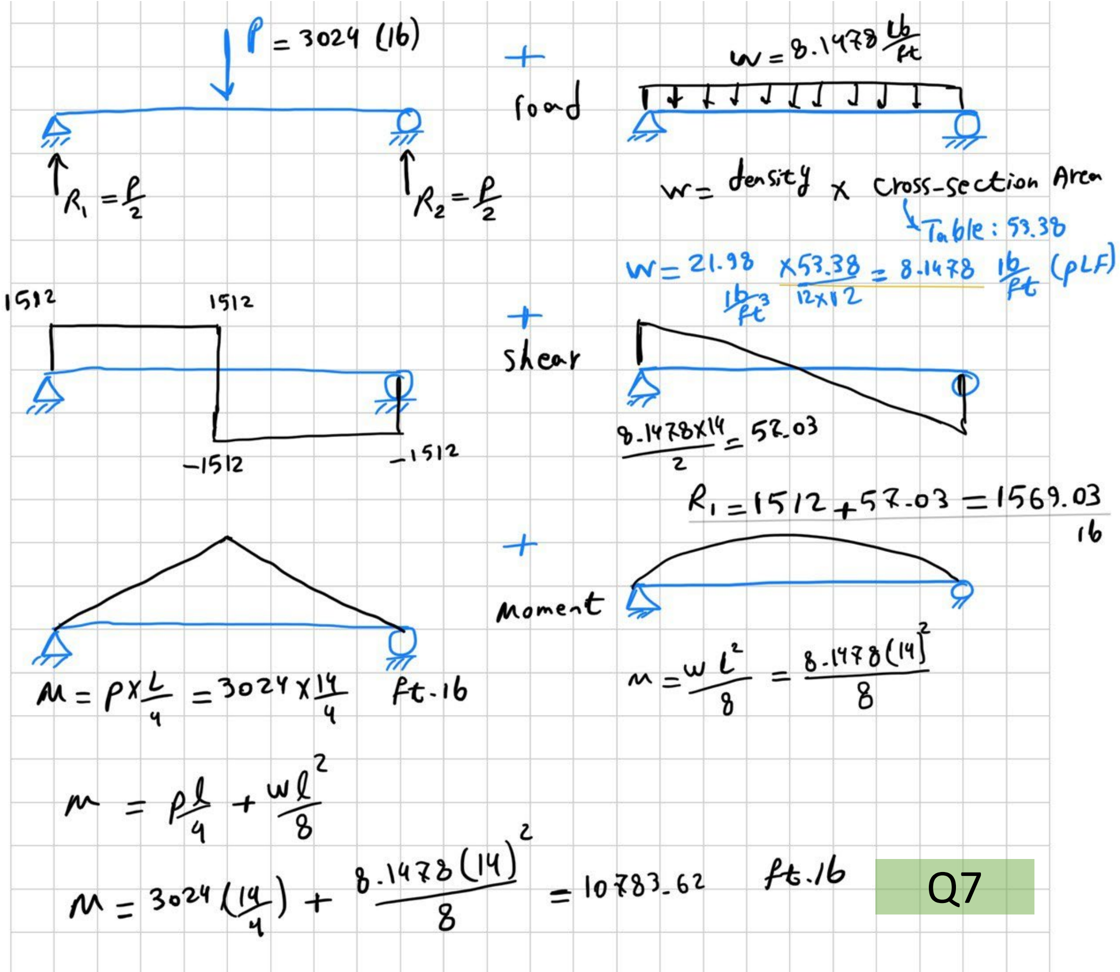
25 lb/ft³   9.266 PLF

21.98   ? → 8.1467 lb/ft

Q6

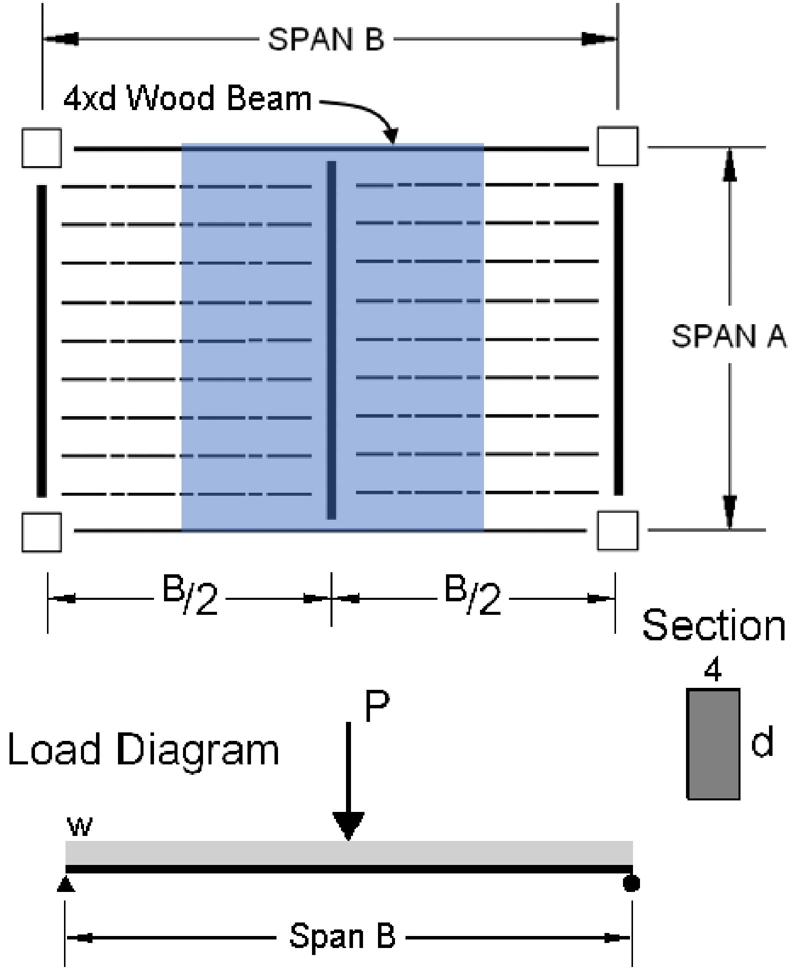


Provide the solution for the assignment – **HW1**



Q8

Q7



Provide the solution for the assignment – **HW1**

Actual stress:

$$f_b = \frac{M}{S}, \quad S \rightarrow 135.66\ in^3 \quad \longrightarrow \quad f_b = \frac{10783.62 \times 12\ (ft.lb)}{135.66\ (in^3)} = 953.88 \left(\frac{lb}{in^2}\right)\ PSI$$

Q14

$$f_v = 1.5\frac{V}{A}, \quad A \rightarrow 53.38\ in^2 \quad \longrightarrow \quad f_v = 1.5 \times \frac{1569.03\ (lb)}{53.38\ (in^2)} = 44.09 \left(\frac{lb}{in^2}\right)\ PSI$$

Q15

Provide the solution for the assignment – **HW1**

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

Load duration is based on the live load (C_D = 1.0)

Provide the solution for the assignment – **HW1**

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.

normal temperature, C_t = 1.0

Provide the solution for the assignment – **HW1**

Q9

Size Factors, C_F

		F_b		F_t	F_c
		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

Size Factors, C_F = 1.0

Provide the solution for the assignment – **HW1**

Table 4.3.8	**Incising Factors, C_i**
Design Value	C_i
E, E_{min}	0.95
F_b, F_t, F_c, F_v	0.80
$F_{c\perp}$	1.00

no incising, $C_i = 1.0$

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:

Q11

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, $C_M = 1.0$

$F_b * C_f = 575 < 1150$ then $C_M = 1$ Q10

Wet Service Factors, C_M

Provide the solution for the assignment – **HW1**

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:

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

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	ℓ_e=1.33 ℓ_u		ℓ_e=0.90 ℓ_u + 3d
Concentrated load at unsupported end	ℓ_e=1.87 ℓ_u		ℓ_e=1.44 ℓ_u + 3d
Single Span Beam[1,2]	where $\ell_u/d < 7$		where $\ell_u/d \geq 7$
Uniformly distributed load	ℓ_e=2.06 ℓ_u		ℓ_e=1.63 ℓ_u + 3d
Concentrated load at center with no intermediate lateral support	ℓ_e=1.80 ℓ_u		ℓ_e=1.37 ℓ_u + 3d
Concentrated load at center with lateral support at center		ℓ_e=1.11 ℓ_u	
Two equal concentrated loads at 1/3 points with lateral support at 1/3 points		ℓ_e=1.68 ℓ_u	
Three equal concentrated loads at 1/4 points with lateral support at 1/4 points		ℓ_e=1.54 ℓ_u	
Four equal concentrated loads at 1/5 points with lateral support at 1/5 points		ℓ_e=1.68 ℓ_u	
Five equal concentrated loads at 1/6 points with lateral support at 1/6 points		ℓ_e=1.73 ℓ_u	
Six equal concentrated loads at 1/7 points with lateral support at 1/7 points		ℓ_e=1.78 ℓ_u	
Seven or more equal concentrated loads, evenly spaced, with lateral support at points of load application		ℓ_e=1.84 ℓ_u	
Equal end moments		ℓ_e=1.84 ℓ_u	

Beam stability factor, C_L

The beam is braced at the ends and the C.L. (meets criteria in 4.4.1) so C_L = 1.0.

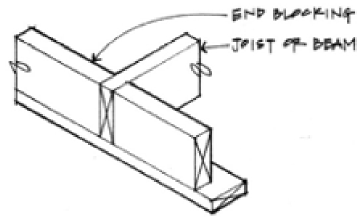
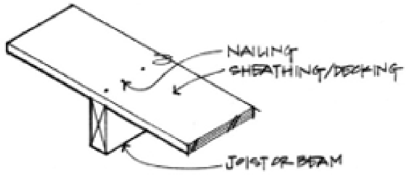
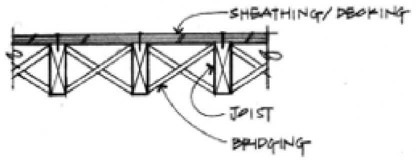
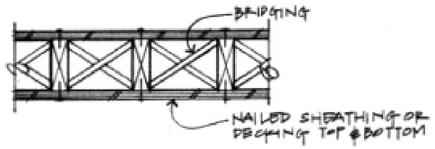
Provide the solution for the assignment – **HW1**

C_L

$C_L = 1.0$
when bracing meets 4.4.1
for the depth/width ratio

Otherwise

$C_L < 1.0$
calculate factor using
section 3.3.3

Beam Depth/ Width Ratio	Type of Lateral Bracing Required	Example
2 to 1	None	
3 to 1 2x6 2x8	The ends of the beam should be held in position	
5 to 1 2x10	Hold compression edge in line (continuously)	
6 to 1 2x12	Diagonal bridging should be used	
7 to 1 2x14	Both edges of the beam should be held in line	

Provide the solution for the assignment – **HW1**

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.

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

Provide the solution for the assignment – **HW1**

$$F_b' = C_D \cdot C_M \cdot C_t \cdot C_L \cdot C_F \cdot C_{fu} \cdot C_i \cdot C_r \cdot F_b = 575 \text{ psi}$$

$C_D = 1$, C_M: if $F_b C_F \le 1150 \rightarrow C_M = 1$, $C_t = 1$, $C_L = 1$, $C_F = 1$, $C_{fu} = 1$, $C_i = 1$, $C_r = 1$, $F_b = 575$

Q12

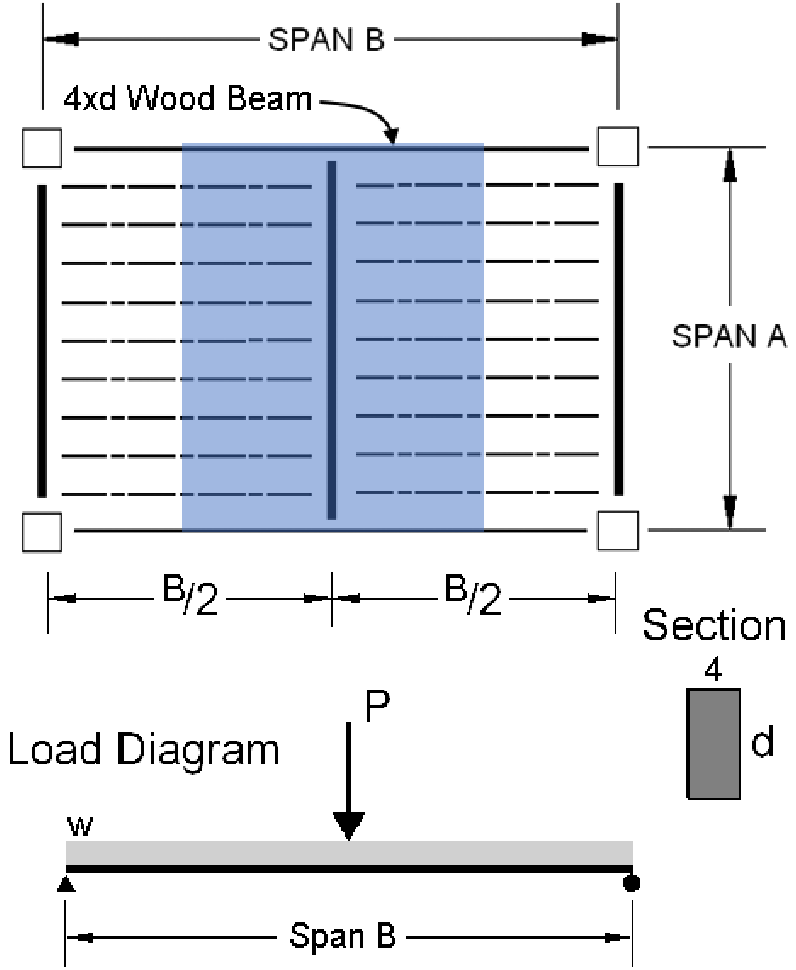
$$F_v' = C_D \cdot C_M \cdot C_t \cdot C_i \cdot F_v = 116.4 \text{ psi}$$

$C_D = 1$, $C_M = 0.97$, $C_t = 1$, $C_i = 1$, $F_v = 120$

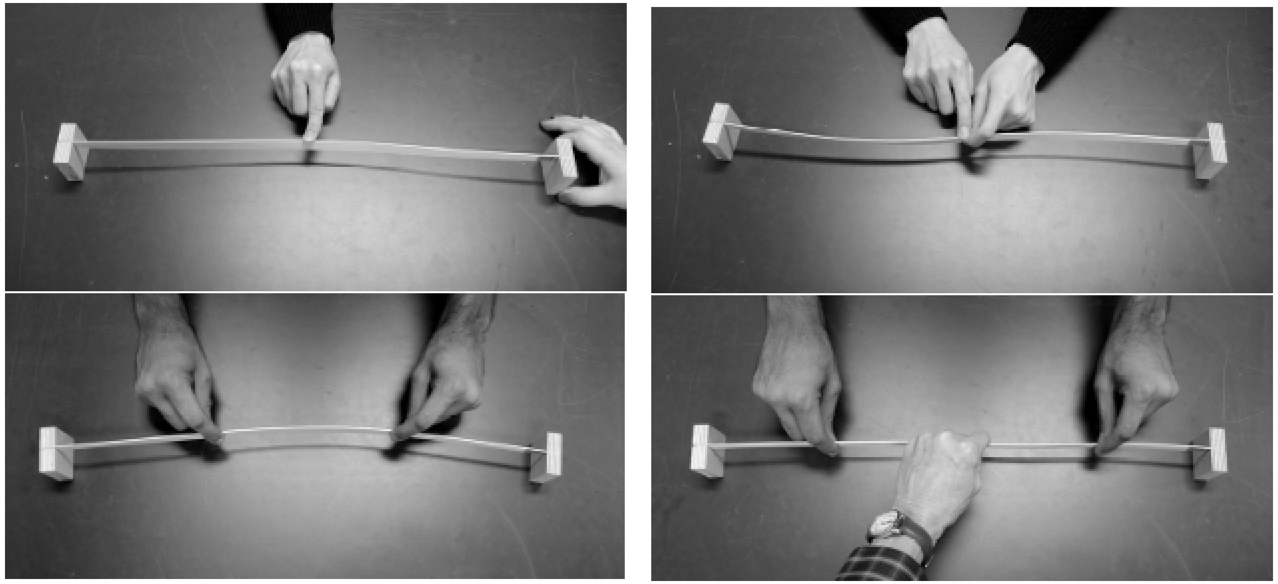
Q13

$f_b = 953.88 > F_b' = 575 \longrightarrow$ Fail (Actual / Allowable) Q16

$f_v = 44.09 < F_v' = 116.4 \longrightarrow$ pass Q17



Lab: Wood Beams Stability



Beam Properties

b = 1.5 IN
d = 11.25 IN
L = 45 FT

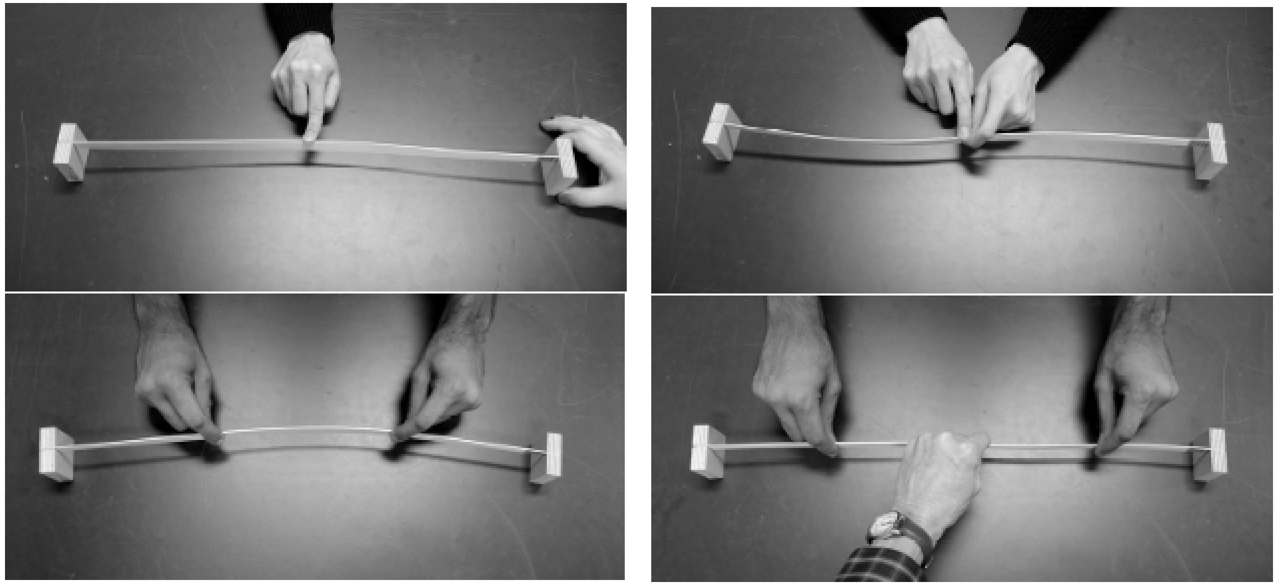
Description

This project uses observation and calculation to understand how bracing effects the stability and performance of a wooden beam.

Goals

To observe the bending behavior of a simple span beam through physical modeling.
To see the effects of unbraced length on lateral buckling.
To calculate the effective length for different bracing conditions.

Lab: Wood Beams Stability



Beam Properties

b = 1.5 IN
d = 11.25 IN
L = 45 FT

Procedure

1. Set the 1/16”x1/2” basswood stick in the support as shown. This approximately models a 2x12 (1.5” x1.25”) at 1:24 scale with a span of 45 FT.

2. First load the unbraced stick (ℓ_u = 45’) at the center line with you finger. Observe the lateral buckling failure. Find ℓ_e and calculate R_B from the NDS formula 3.3-5

3. Next brace the stick at the center load point (ℓ_u = 22.5’). Again observe the lateral failure. Find ℓ_e and calculate R_B from the NDS formula 3.3-5

Lab: Wood Beams Stability

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	ℓ_e=1.33 ℓ_u		ℓ_e=0.90 ℓ_u + 3d
Concentrated load at unsupported end	ℓ_e=1.87 ℓ_u		ℓ_e=1.44 ℓ_u + 3d
Single Span Beam[1,2]	where $\ell_u/d < 7$		where $\ell_u/d \geq 7$
Uniformly distributed load	ℓ_e=2.06 ℓ_u		ℓ_e=1.63 ℓ_u + 3d
Concentrated load at center with no intermediate lateral support	ℓ_e=1.80 ℓ_u		ℓ_e=1.37 ℓ_u + 3d
Concentrated load at center with lateral support at center		ℓ_e=1.11 ℓ_u	
Two equal concentrated loads at 1/3 points with lateral support at 1/3 points		ℓ_e=1.68 ℓ_u	
Three equal concentrated loads at 1/4 points with lateral support at 1/4 points		ℓ_e=1.54 ℓ_u	
Four equal concentrated loads at 1/5 points with lateral support at 1/5 points		ℓ_e=1.68 ℓ_u	
Five equal concentrated loads at 1/6 points with lateral support at 1/6 points		ℓ_e=1.73 ℓ_u	
Six equal concentrated loads at 1/7 points with lateral support at 1/7 points		ℓ_e=1.78 ℓ_u	
Seven or more equal concentrated loads, evenly spaced, with lateral support at points of load application		ℓ_e=1.84 ℓ_u	
Equal end moments		ℓ_e=1.84 ℓ_u	

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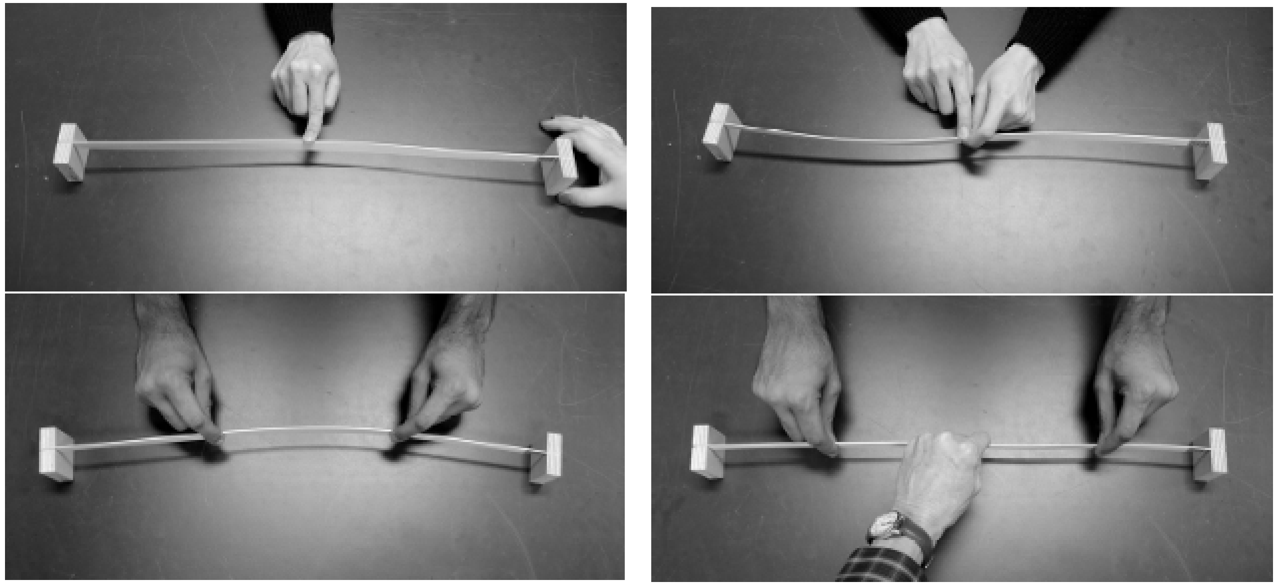
Beam Properties

b = 1.5 IN
d = 11.25 IN
L = 45 FT



4. Now brace and load the stick at the 1/3 points (ℓ_u = 15') and observer the lateral failure. Find ℓ_e and calculate R_B from the NDS formula 3.3-5
5. Finally, brace and load the stick at the 1/4 points (ℓ_u = 11.25') and again observer the failure. Find ℓ_e and calculate R_B from the NDS formula 3.3-5
6. Compare the R_B values found for the 4 bracing conditions and note how the bracing effects the slenderness. Note which case comes closest to 50 and which one is the smallest. As R_B decreases the beam gets more stable and stronger.

Thank you.

Any question?

Please feel free to ask questions.

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