TAUBMAN COLLEGE
ARCHITECTURE & URBAN PLANNING
UNIVERSITY OF MICHIGAN

Arch324
STRUCTURES II

Winter 2024
Recitation

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GSI: Mohsen Vatandoost

Welcome to Recitation session 02/02

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Office: Room 3104
hours:
Fri: 11:30 – 14:30
Mon, Wed: 11:00 - 12:00
walk-ins welcome!

Please feel free to ask questions.

Welcome to Recitation session 02/02

Outline:

- Quick **Recap** of the week
- Provide the solution for the assignment **(Homework 3)**
- Answering student's questions
- Lab: **Wood Columns**
- **Tower Project:** how to start

Please feel free to ask questions.

Contact: Mohsenv@umich.edu

Recap of the week

Wood column Analysis / Design

Failure Mode - Strength

Short Columns – fail by crushing

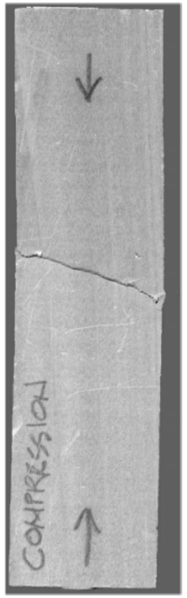
Analysis

$$f_c = \frac{P}{A} \leq F'_c$$

Design

$$A = \frac{P}{F'_c}$$

- f_c = Actual compressive stress
- A = Cross-sectional area of column (in^2)
- P = Load on the column
- F'_c = Allowable compressive stress per codes



Failure Modes – Stability

Long Columns – fail by buckling

Traditional Euler

$$f_{cr} = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$$

- E = Modulus of elasticity of the column material (psi)
- K = Stiffness (curvature mode) factor
- L = Column length between ends (inches)
- r = radius of gyration = $\sqrt{I/A}$ (inches)

$$r = d/\sqrt{12}$$

NDS Equation

$$F_{cE} = \frac{0.822E'_{min}}{\left(\frac{l_e}{d}\right)^2}$$

- E'min = reduced E modulus (psi)
- le = Ke l_u (inches)
- d (inches)
- $0.822 = \pi^2/12$

Recap of the week

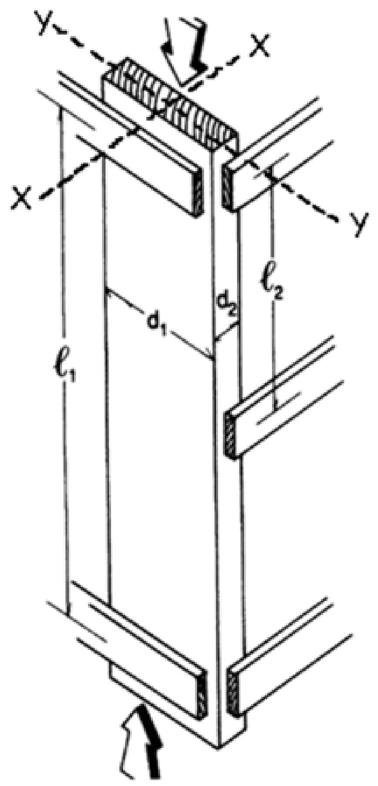
Capacity Analysis of Columns

Data:

- Column – <u>size</u>, length
- Support conditions
- Material properties – F_c , E

Required:

- Maximum Load Capacity, Pmax



1. Calculate slenderness ratio l_e/d
   largest ratio governs. Must be < 50
2. Find adjustment factors
   C_D C_M C_t C_F C_i
3. Calculate C_P
4. Determine F'c by multiplying the tabulated Fc by all the above factors
5. Set actual stress = allowable, fc = F'c
6. Find the maximum allowable load
   Pmax = F'c A

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 – **HW3**

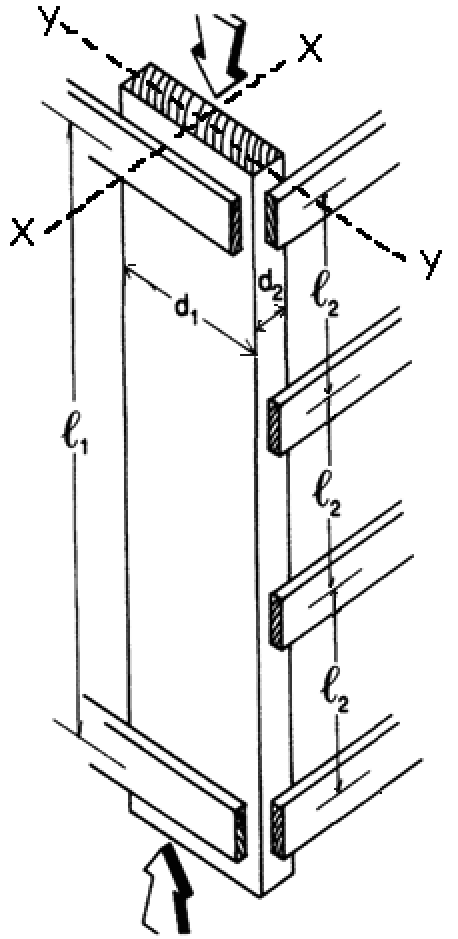
3. Wood Column Analysis

For the given dimensioned lumber column with 1/3 point weak axis bracing, determine the maximum load capacity of the given load type. Moisture Content = 15%. Ct = Ci = 1.0. Assume pinned end conditions (K=1).

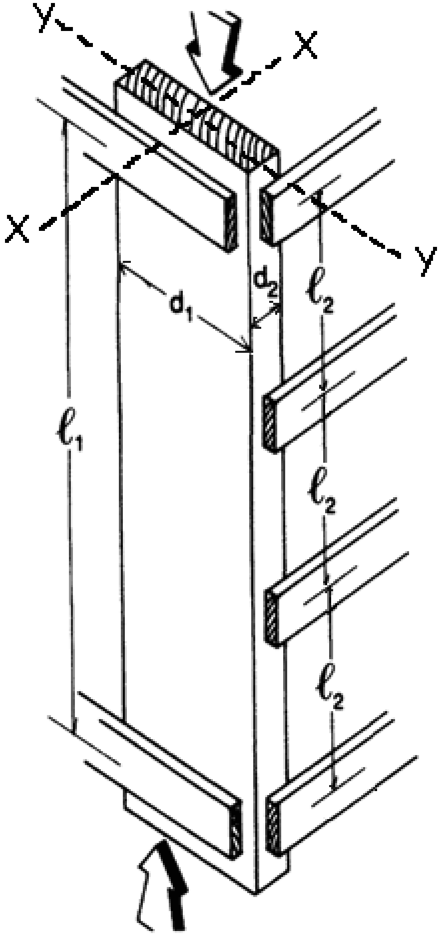
DATASET: 1 -2- -3-

Wood Species	HEM-FIR
Wood Grade	Select Structural
Strong Axis Length, L1	15 FT
Weak Axis Length, L2	5 FT
Narrow Width, d2	4 IN
Wide Width, d1	10 IN
LoadType	Live Load

- Problem:



Provide the solution for the assignment – **HW3**



#	Question	Your Response	
1	Tabulated Allow. Compressive Stress, Fc		PSI
2	Tabulated Minimum Modulus of Elasticity, Emin		PSI
3	Load Duration Factor, CD		
4	Size Factor, CF		
5	Factored Allow. Modulus of Elasticity, E'min		PSI
6	Strong Axis (x-x) Slenderness Ratio, lex/d1		
7	Weak Axis (y-y) Slenderness Ratio, ley/d2		
8	Controling Slenderness Ratio, le/d		
9	Critical Buckling Design Value for Compression, FcE		PSI
10	Reference Comression Design Value, Fc*		PSI
11	Constant for Sawn Lumber, c		
12	Column Stability Factor, CP		
13	Factored Allow. Compressive Stress, F'c		PSI
14	Column Area, A		IN2
15	Maximum Allowable Axial Load Capacity, Pmax		LBS

Provide the solution for the assignment – **HW3**

NDS Supplement

Wood Species → HEM-FIR
Wood Grade → SELECT Structural

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	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		

Provide the solution for the assignment – **HW3**

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 – **HW3**

Table 2.3.3 Temperature Factor, C_t

Reference Design Values	In-Service Moisture Conditions[1]	C_t		
		$T \le 100°F$	$100°F < T \le 125°F$	$125°F < T \le 150°F$
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 – **HW3**

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

Size Factors, C_F = 1.0

Provide the solution for the assignment – **HW3**

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:

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, $C_M = 1.0$

m.c. = 15% → $C_M = 1.0$

Wet Service Factors, C_M

Provide the solution for the assignment – **HW3**

C_T **Buckling stiffness factor**

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 plywood 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:

$$C_T = 1 + \frac{K_M \ell_e}{K_T E}$$

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

Provide the solution for the assignment – **HW3**

$$E'_{min} = C_M \cdot C_t \cdot C_i \cdot C_T \cdot E_{min}$$

- $C_M \rightarrow 1$
- $C_t \rightarrow 1$
- $C_i \rightarrow 1$
- $C_T \rightarrow$ Buckling Stiffness Factor
- $E_{min} \rightarrow$ 580000 psi

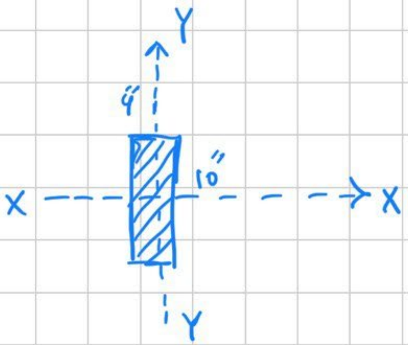
Wood Trusses

$$C_T = 1 + \frac{K_M l_e}{K_T E} \qquad (l_e < 96'')$$

NDS 4.4.2 (3.7 Appendix H)

Note: when $l_e > 96''$ (8 FT) $\longrightarrow$ $l_e = 96''$ and calculate C_T

Provide the solution for the assignment – **HW3**



x–x

$$l_{ex} = 15' \times 12 = 180''$$

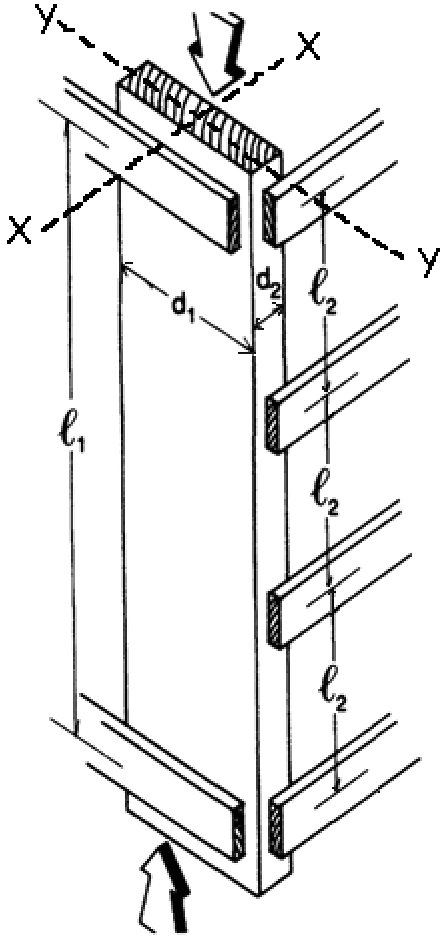
$$\frac{l_{ex}}{d_1} = \frac{180}{9.25} = 19.4594 < 50 \checkmark$$

Max

y–y

$$l_{ey} = 5' \times 12 = 60''$$

$$\frac{l_{ey}}{d_2} = \frac{60}{3.5} = 17.1428 < 50 \checkmark$$



Provide the solution for the assignment – **HW3**

3.7.1 Column Stability Factor, C_P

$$C_P = \frac{1+(F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1+(F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}} \quad (3.7\text{-}1)$$

where:

F_c^* = reference compression design value parallel to grain multiplied by all applicable adjustment factors except C_P (see 2.3), psi

$$F_{cE} = \frac{0.822\ E_{min}'}{(\ell_e/d)^2}$$

c = 0.8 for sawn lumber

c = 0.85 for round timber poles and piles

c = 0.9 for structural glued laminated timber, structural composite lumber, and cross-laminated timber

$$F_{CE} = \frac{0.822\ E_{min}'}{(\ell_e/d)^2} = \frac{0.822\ (580000)}{(19.4594)^2} = 1259.0442 \text{ psi}$$

$$F_c^* = C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_i \cdot F_c$$

$$F_c^* = 1 \times 1 \times 1 \times 1 \times 1 \times 1500 = 1500 \text{ psi}$$

$$C_p = \frac{1 + \left(\frac{1259.0442}{1500}\right)}{2(0.8)} - \sqrt{\left[\frac{1+\left(\frac{1259.0442}{1500}\right)}{2(0.8)}\right]^2 - \frac{\left(\frac{1259.0442}{1500}\right)}{0.8}}$$

$\frac{1259.0442}{1500} \rightarrow 0.8393$

$$C_p = 0.627672$$

Provide the solution for the assignment – **HW3**

$$F_c' = C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_i \cdot C_P \cdot F_c$$

$$C_D = 1,\quad C_M = 1,\quad C_t = 1,\quad C_F = 1,\quad C_i = 1,\quad C_P = 0.627672,\quad F_c = 1500 \text{ psi}$$

$$F_c' = 941.5082 \text{ PSI}$$

Column Area → From Table 1B → $A = 32.38 \text{ in}^2$

$$P_{max} = F_c' \cdot A = (941.5082 \text{ PSI})(32.38 \text{ in}^2) = 30486.03 \text{ LBS}$$

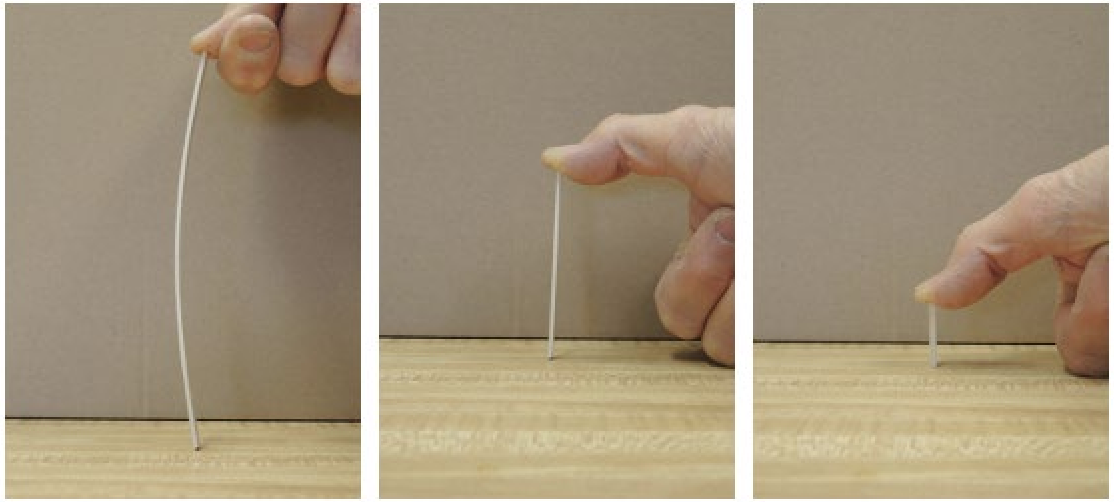
Provide the solution for the assignment – **HW3**

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

[NDS- Supplement]

Lab: Wood Columns



Description

This project uses observation and calculation to understand the effect of slenderness on column capacity.

Goals

To observe the buckling behavior of columns through physical modeling.
To find the controlling slenderness ratio.
To calculate the critical buckling and crushing loads.

Lab: Wood Columns

Procedure

1. For the 1/16"x1/4" basswood column provided, with L=6" calculate the controlling (weak axis) slenderness ratio and Pcr using the Euler equation. Use K=1.0.
2. Find the actual critical buckling load approximating the load with your finger.
3. Repeat the procedure for L=3" and L=1".
4. Calculate the slenderness and Pcr for both of these lengths.
5. Calculate the ultimate crushing load based on the max compressive stress, F_c.
6. Approximately locate P for each length on the load vs. slenderness curve shown below

Basswood Properties

Emin = 1,650,000. psi

Fc = 4745 psi
Area = 0.015625 in^2
d_1 = 0.25 in
d_2 = 0.0625 in

L = 6" L/d =

P =

L = 3" L/d =

P =

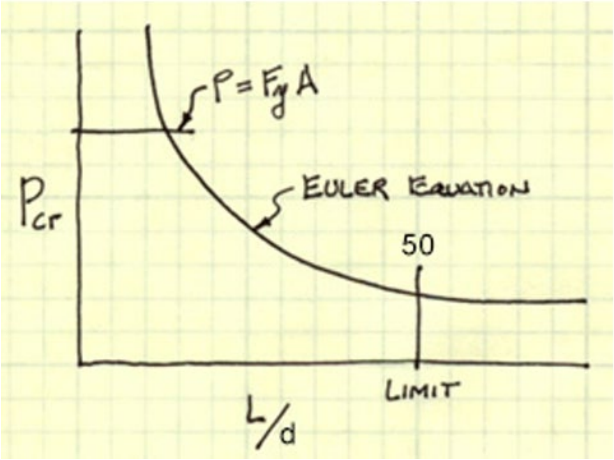
L = 1" L/d =

P =

Equations:

$$FcE = \frac{0.822\ E'min}{(le/d)2}$$

$$P_{max} = F_c \times A$$



Tower Project: How to start

- ✓ Team up!
- ✓ Look at great examples: similar towers and high-rise buildings
- ✓ Look at student’s work in the last semester in the course website
- ✓ Familiar yourself with DRFRAME
- ✓ Test material

Thank you.

Any question?

Please feel free to ask questions.

Contact: Mohsenv@umich.edu