Architecture 324
Structures II

Wood Column Design

- Design of Wood Columns
- Stud Wall Design

Timber Column Design

Given:

- Lumber species, grade
- Conditions of use
- Load

Required:

- column size

1. Find adjustment factors (all except C_P)
   C_D C_M C_t C_F C_i
2. Guess C_P
3. Estimate Area and d (based on bracing)
4. Calculate slenderness ratio l_e/d
   largest ratio governs. Must be < 50
5. Calculate C_P
6. Determine F'_c by multiplying the tabulated Fc by all the above factors
7. Revise Area: $A = P/F'_c$
8. Revise C_P
9. Repeat until $F'_c > P/A$

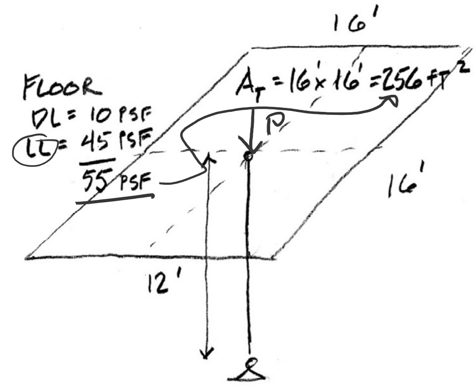
Timber Column Design

Given:

- White Oak, No.1 Fc = 825 psi
- dry use, normal temp., not incised
- Load: D+L=55 psf

Required:

- column size



1. Find adjustment factors (all except C_P)
   1.0
   C_D ~~C_M~~ ~~C_t~~ C_F ~~C_i~~
2. Guess C_P → try 0.5

Table 4D (Cont.) **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	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	
WHITE OAK										
Select Structural	Beams and Stringers	1,400	825	205	800	900	1,000,000	370,000	0.73	NELMA
No.1		1,200	575	205	800	775	1,000,000	370,000		
No.2		750	375	205	800	475	800,000	290,000		
Select Structural	Posts and Timbers	1,300	875	205	800	950	1,000,000	370,000		
No.1		1,050	700	205	800	825	1,000,000	370,000		
No.2		600	400	205	800	400	800,000	290,000		

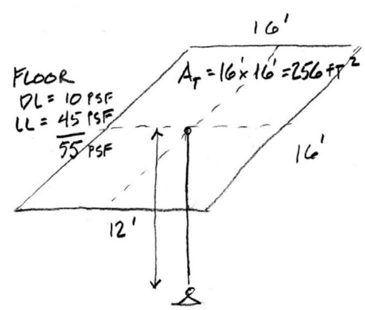
Timber Column Design

Given:

- White Oak, No. 1 Fc = 825 psi
- dry use, normal temp., not incised
- Load: D+L=55 psf, P = 14080 lbs

Required:

- column size



1. Find adjustment factors (all except C_P)
   C_D C_M C_t C_F C_i = 1.0 ✓
2. Guess C_P → try 0.5
3. Estimate Area and d (based on bracing)
4. Calculate slenderness ratio l_e/d
   largest ratio governs. Must be < 50

Size Factor, C_F TIMBER

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

ESTIMATE SIZE:

GUESS $C_P = 0.5$ ✓

$$A = \frac{P}{F'_c} = \frac{14080\#}{825(.5)} = 34 \text{ in}^2$$

(F_c, C_p)

TRY:

$$\sqrt{A} = d \qquad \sqrt{34} = 5.8''$$

SAY 5.5" × 5.5"
6×6

TRY 6×6

$$\frac{l_e}{d} = \frac{(1)144''}{5.5} = 26.18$$

(K_e)

Timber Column Design

Given:

- White Oak, No.1
- dry use, normal temp., not incised
- Load: D+L=55 psf

Required:

- column size

5. Calculate C_P

CHECK C_p ON GRAPH – ADJUST IF NEEDED

$$F_{cE} = \frac{0.822\,(370\,000)}{26.18^2} = 443.7 \text{ psi}$$

(E_{min} ; l_e/d)

$$F_c^* = F_c\,(C_D\, C_M\, C_F\, C_t\, C_i) = 825 \text{ psi}$$

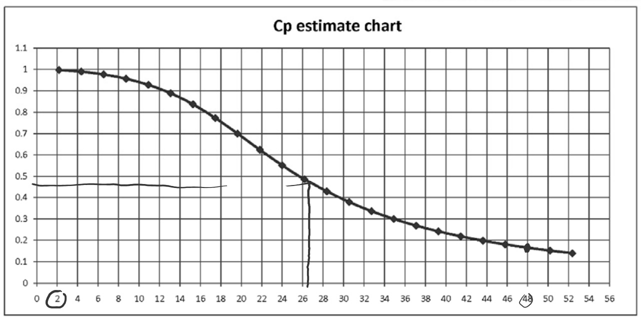
(C_t = 1.0)

$$F_{cE}/F_c^* = \frac{443.7}{825} = 0.5378$$

$$C_p = \frac{1+0.5378}{2(0.8)} - \sqrt{\left[\frac{1+0.5378}{2(0.8)}\right]^2 - \frac{0.5378}{0.8}}$$

$$C_p = 0.46$$

C_P



ℓ/d

Timber Column Design

Given:

- White Oak, No. 1 Fc = 825 psi
- dry use, normal temp., not incised
- Load: D+L=55 psf

Required:

- column size

6. Determine F'_c by multiplying the tabulated F_c by all the above factors
7. Revise Area: $A = P/F'_c$
8. Revise C_P
9. Repeat until $F'_c > P/A$

Table 1B Section Properties of Standard Dressed

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}
Timbers (5" x 5" and larger)[2]						
Post and Timber (see NDS 4.1.3.4 and NDS 4.1.5.3)						
5 x 5	4-1/2 x 4-1/2	20.25	15.19	34.17	15.19	34.17
6 x 6	5-1/2 x 5-1/2	30.25	27.73	76.26	27.73	76.26
6 x 8	5-1/2 x 7-1/2	41.25	51.56	193.4	37.81	104.0
8 x 8	7-1/2 x 7-1/2	56.25	70.31	263.7	70.31	263.7
8 x 10	7-1/2 x 9-1/2	71.25	112.8	535.9	89.06	334.0

REVISED F'_c

$$F'_c = 825\,(0.46) = 379.5$$

(C_p = 0.46)

$$A = \frac{P}{F'_c} = \frac{14080^{\#}}{379.5^{\#}/in^2} = 37.1 \text{ in}^2$$

~~6x6~~: A = 30.25 < 37.1 ∴ FAILS

6x8 = 41.25 in² > 37.1

TRY 6x8

$$l_e/d = \frac{144''}{5.5''} = 26.18$$

(SAME AS 6x6)

C_p = 0.46 (NO CHANGE)

F'_c = 379.5 psi

$$P/A = \frac{14080^{\#}}{41.25 \text{ in}^2} = 341.3 \text{ psi}$$

379.5 > 341.3 ∴ OK

Timber Column Design

Design Aids

example of a column chart

P = 14080 lbs

from AWC Manual for Engineered Wood Construction – 2005

Table M4.5-2a ASD Column Capacity[1,2,3,4,5] (P', P'_x, P'_y), Timbers
6-inch nominal thickness (5.5 inch dry dressed size), $C_D = 1.0$.

Species	Column Length (ft)	Select Structural 6 x 6, 6" width (=5.5") P'	Select Structural 6 x 8, 8" width (=7.5") P'x	Select Structural 6 x 8, 8" width (=7.5") P'y	No. 1 6 x 6, 6" width (=5.5") P'	No. 1 6 x 8, 8" width (=7.5") P'x	No. 1 6 x 8, 8" width (=7.5") P'y	No. 2 6 x 6, 6" width (=5.5") P'	No. 2 6 x 8, 8" width (=7.5") P'x	No. 2 6 x 8, 8" width (=7.5") P'y
	2	34,500	47,200	47,000	30,000	41,100	40,900	21,000	28,800	28,700
	4	33,400	46,400	45,500	29,200	40,500	39,800	20,500	28,400	28,000
	6	31,100	45,000	42,500	27,600	39,500	37,600	19,600	27,800	26,700
Douglas Fir-Larch	8	27,300	42,700	37,300	24,800	37,800	33,800	18,000	26,800	24,500
	10	22,300	39,200	30,400	20,900	35,300	28,500	15,700	25,400	21,400
	12	17,500	34,600	23,900	16,800	31,800	22,900	13,000	23,400	17,700
	14	13,700	29,500	18,700	13,300	27,800	18,200	10,500	20,900	14,300
	16	10,900	24,700	14,800	10,700	23,700	14,600	8,500	18,200	11,500
	2	29,200	40,000	39,800	25,500	34,900	34,800	17,300	23,600	23,600
	4	28,200	39,300	38,500	24,800	34,400	33,800	16,900	23,400	23,000
	6	26,200	38,100	35,800	23,300	33,500	31,800	16,100	22,900	22,000
	8	22,800	36,000	31,100	20,800	31,900	28,400	14,900	22,100	20,300
Hem-Fir	10	18,400	32,900	25,100	17,400	29,700	23,700	13,100	21,000	17,800
	12	14,300	28,800	19,600	13,800	26,600	18,900	10,900	19,400	14,800
	14	11,200	24,300	15,200	10,900	23,000	14,900	8,800	17,400	12,000
	16	8,800	20,200	12,000	8,700	19,500	11,900	7,200	15,200	9,800
	2	28,500	39,000	38,900	24,800	33,900	33,800	15,800	21,600	21,500
	4	27,700	38,500	37,800	24,200	33,500	33,000	15,500	21,400	21,100
	6	26,200	37,500	35,700	23,100	32,800	31,500	15,000	21,000	20,400
	8	23,500	35,900	32,100	21,200	31,600	28,900	14,100	20,500	19,200
Southern Pine	10	19,900	33,500	27,100	18,400	29,900	25,100	12,700	19,700	17,400
	12	16,000	30,200	21,800	15,200	27,500	20,700	11,000	18,500	15,000
	14	12,700	26,400	17,300	12,300	24,500	16,700	9,200	17,100	12,500
	16	10,100	22,400	13,800	9,900	21,300	13,500	7,600	15,300	10,300
	2	24,000	32,900	32,700	21,000	28,800	28,700	15,000	20,600	20,500
	4	23,400	32,400	31,900	20,500	28,400	28,000	14,700	20,300	20,100
	6	22,100	31,600	30,100	19,600	27,800	26,700	14,100	19,900	19,300
	8	19,900	30,300	27,100	18,000	26,800	24,500	13,100	19,300	17,900
Spruce-Pine-Fir	10	16,800	28,300	23,000	15,700	25,400	21,400	11,600	18,400	15,800
	12	13,600	25,600	18,500	13,000	23,400	17,700	9,800	17,100	13,400
	14	10,800	22,400	14,700	10,500	20,900	14,300	8,000	15,500	11,000
	16	8,600	19,100	11,800	8,500	18,200	11,500	6,500	13,700	8,900

1. P'_x values are based on a column continuously braced against weak axis buckling.
2. P'_y values are based on a column continuously braced against strong axis buckling.
3. To obtain LRFD capacity, see *NDS* Appendix N.
4. Tabulated values apply to members in a dry service condition, $C_M = 1.0$; normal temperature range, $C_t = 1.0$; and unincised members, $C_i = 1.0$.
5. Column capacities are based on concentric axial loads only and pin-pin end conditions ($K_e = 1.0$ per *NDS* Appendix Table G1).

4

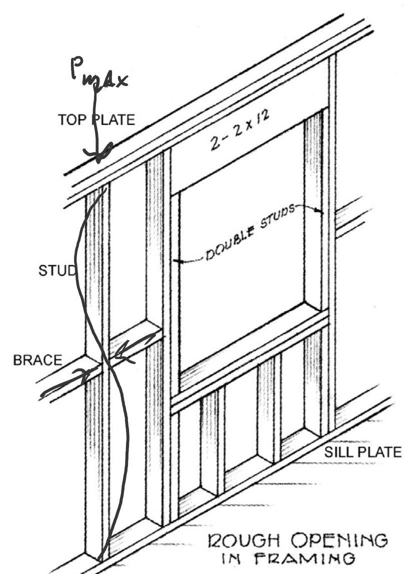
M4: SAWN LUMBER

Stud Wall Design

Given:
- Lumber species, grade and size
- Conditions of use
- Load — size 2x4 or 2x6

Required:
- **Stud spacing**

1. Calculate slenderness ratio l_e/d
   largest ratio governs. Must be < 50
2. Find adjustment factors (all except C_P)
   C_D C_M C_t C_F C_i
3. Calculate C_P
4. Determine F'_c by multiplying the tabulated F_c by all the above factors
5. Set actual stress = allowable: $f_c = F'_c$
6. Find the capacity of one stud: $Pmax = F'_c\ A$
7. Find allowable spacing (12", 16" or 24" o.c.)
8. Check bearing.



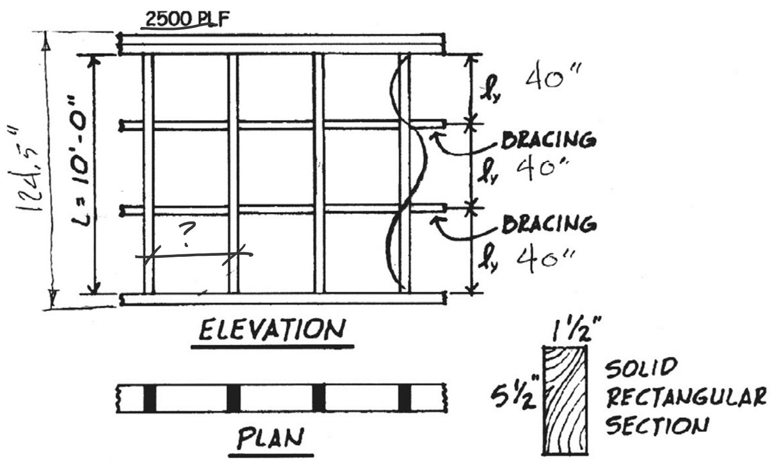
Stud Wall Example - design

Data:

- 2x6
- S-P-F, Stud   M.C. = 12%
- D+L Load = 2500 PLF
- Braced as shown K_e=1.0

Required:

- o.c. spacing



From NDS Supplement Table 4A

F_c = 725 psi

E_{min} = 440000 psi

C_D = 1.0 (LL)

C_{Mc} = 1.0 C_{ME} = 1.0

C_t = 1.0

C_F = 1.0 (stud)

C_i = 1.0

C_P = ?

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	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
SPRUCE-PINE-FIR										
Select Structural		1,250	700	135	425	1,400	1,500,000	550,000		
No. 1/ No. 2	2" & wider	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	0.42	NLGA
Construction		1,000	500	135	425	1,400	1,300,000	470,000		
Standard	2" - 4" wide	550	275	135	425	1,150	1,200,000	440,000		
Utility		275	125	135	425	750	1,100,000	400,000		

Stud Wall Example - design

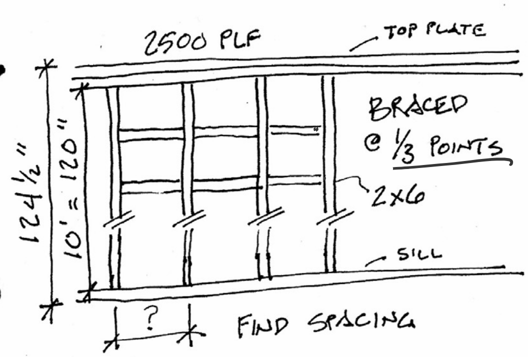
STUD WALL

S-P-F STUD GRADE

F_c = 725 psi

E_{min} = 440,000 psi

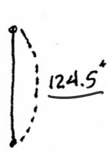
C_D = 1 C_M = 1 C_F = 1.0



X - X

l_{e_x} = 124.5"

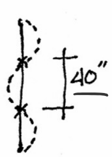
$l_e/d = \frac{124.5}{5.5} = 22.6$



Y - Y

l_{e_y} = 40"

$l_e/d = \frac{40}{1.5"} = 26.7$



CONTROLLING l_e/d = 26.7

Stud Wall Example - design

C_p

X – X

$\ell_{e_x} = 124.5''$

$\ell_e/d = \dfrac{124.5}{5.5} = 22.6$ (124.5")

Y – Y

$\ell_{e_y} = 40''$

$\ell_e/d = \dfrac{40}{1.5} = 26.7$ (40")

CONTROLLING $\ell_e/d = 26.7$

$$F_{cE} = \frac{0.822\, E_{min}'}{(\ell_e/d)^2} = \frac{0.822(440\,000)}{26.7^2} = 508.6$$

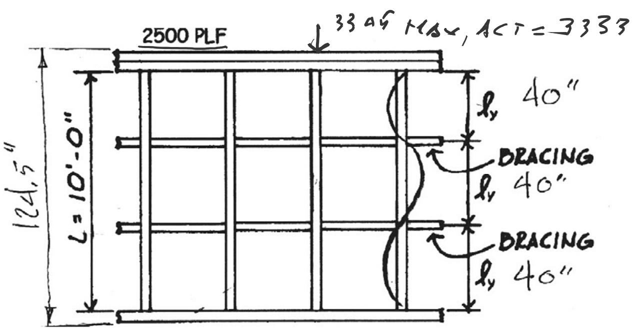
(E_{min}')

$$F_c^* = 725(1\times1\times1) = 725\text{ psi}$$

$$F_{cE}/F_c^* = \frac{508.6}{725} = 0.702$$

NDS eq. 3.7-1 → $C_p = 0.559$

Stud Wall Example - design



Find max allowable stress, F'_c

$$F'_c = 725\,(0.559) = \boxed{405.6\text{ psi}}$$

Calculate max load per stud

$$P_{STUD} = F'_c A = 405.6\text{ psi} \times 8.25\text{ in}^2 = 3345\ \#$$

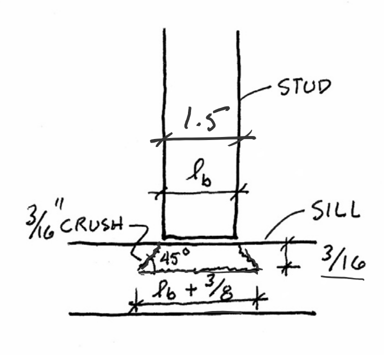
Determine max stud spacing

$$P_{STUD} = 2500\,\frac{16}{12} = 3333 < 3345$$

$\dfrac{2500\text{ PLF}}{3345\text{ LBS/STUD}} : \dfrac{12'}{S?}$; $S \le 16.06''$ → S = 16" O.C. (ROUND DOWN)

Stud Wall Example - design

Check bearing on sill plate
For 2x6 ℓ_b = 1.5”
C_b = 1.25



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:

$$C_b = \frac{\ell_b + 0.375}{\ell_b} \quad (3.10\text{-}2)$$

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:

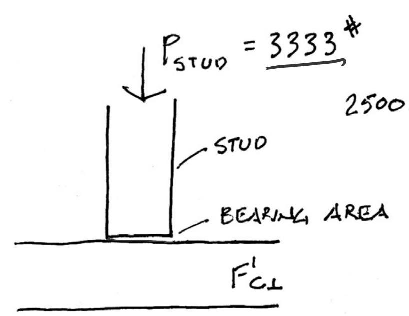
Table 3.10.4 Bearing Area Factors, C_b

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.

Stud Wall Example - design

Check bearing on sill plate
- determine C_b
- calculate $F'_{c\perp}$
- calculate $f_{c\perp}$
- check stress



$2500\text{PLF}\ \frac{16''}{12} = 3333\text{LB}$

b = 1.5”

C_b = 1.25

$F_{c\perp} = 425$ psi $\quad F'_{c\perp} = 425(1.25) = 531$ psi

$f_{c\perp} = \frac{P}{A} = \frac{3333\#}{8.25 \text{ in}^2} = 404$ psi (2 × 6)

$f_{c\perp} = 404 < 531 = F'_{c\perp}$ ✓ OK

Table 4A (Cont.) Reference Design Values for Visually Graded Di[mension lumber] (2" - 4" thick)[1,2,3]

(All species except Southern Pine—see Table 4B) (Tab[le] duration and dry service conditions. See NDS 4.3 for a compr[ehensive] adjustment factors.)

USE WITH TABLE 4A ADJUSTMENT FAC[TORS]

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 $F_{c\perp}$	Com[pression parallel to grain]				
SPRUCE-PINE-FIR										
Select Structural	2" & wider	1,250	700	135	425					
No. 1/ No. 2		875	450	135	425					
No. 3		500	250	135	425					
Stud	2" & wider	675	350	135	425	725	1,200,000	440,000	0.42	NLGA
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		