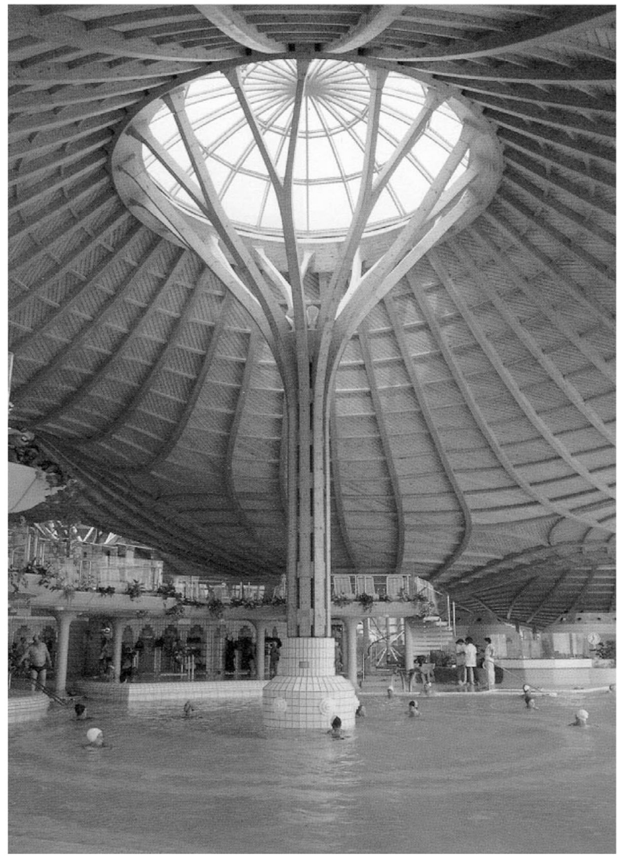
Architecture 324
Structures II

Wood Column Analysis

- Failure Modes
- Euler Equation
- End Conditions and Lateral Bracing
- Analysis of Wood Columns



Solemar, Bad Dürrheim
Klaus Linkwitz, 1987

Failure Modes

FLEXURE

BEAM

AXIAL

COLUMNS

Strength

$$f_b = \frac{Mc}{I} \qquad f_v = \frac{VQ}{Ib}$$

$$f_c = \frac{P}{A}$$

Stability

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

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

Serviceability

Deflection (or Bearing)

Bearing (crushing limit)

Leonhard Euler (1707 – 1783)

Euler Buckling (elastic buckling)

$$P_{cr} = \frac{\pi^2 AE}{\left(\frac{KL}{r}\right)^2} = \frac{\pi^2 IE}{(KL)^2}$$

SLENDERNESS

$$r = \sqrt{\frac{I}{A}}$$

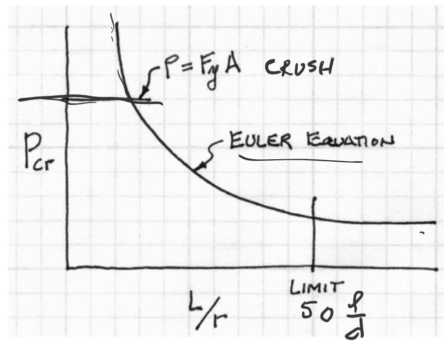
$$I = Ar^2$$

portrait by Emanuel Handmann,1753

- A = Cross sectional area (in^2)
- E = Modulus of elasticity of the material (lb/in^2)
- K = Stiffness (curvature mode) factor
- L = Column length between pinned ends (in.)
- r = radius of gyration (in.)

$$\frac{P}{A} = f_{cr} = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} = F_{cE} = \frac{0.822\ E'_{min}}{\left(\frac{le}{d}\right)^2}$$

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



Failure Mode - Strength

Short Columns – fail by crushing

Analysis

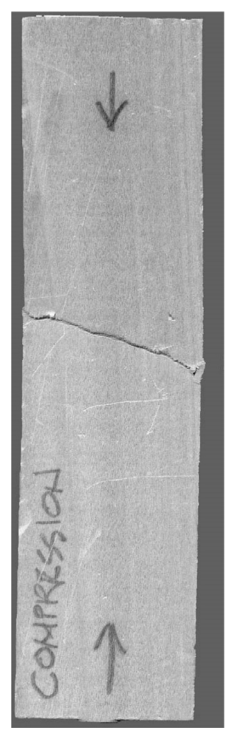
$$f_c = \frac{P}{A} \leq F'_c$$

Cp (BUCKLING)

Design

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

LOAD



- 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

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

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

Slenderness Ratio le/d

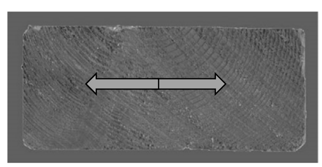
Slenderness Ratios:

The larger ratio will fail first.

Try to balance for efficiency.

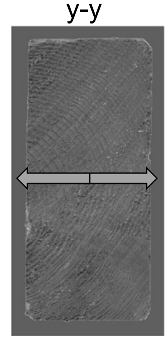
Slenderness Limited to < 50

x-x



d = 3.5

y-y



b = 1.5

X-X

$K_e = 1.0$

$l_e = 1.0(96)$

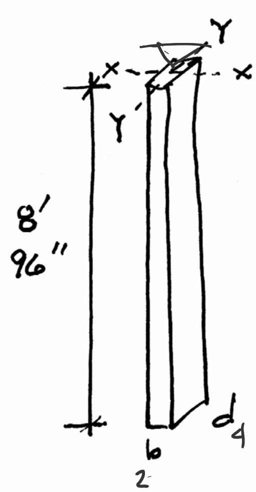
$\frac{l_e}{d} = \frac{96}{3.5} = 27.4$ (4")

Y-Y

$K_e = 1.0$

$l_e = 1.0(96)$

$\frac{l_e}{b} = \frac{96}{1.5} = 64$ (2") X



End Support Conditions, K_e

K_e is a constant based on the end conditions

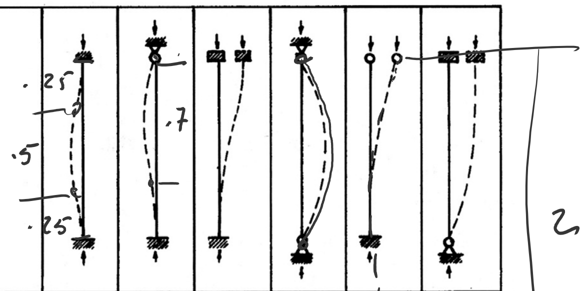
ℓ is the actual length

ℓ_e is the effective length (curved part)

$\ell_e = K_e \ell$

Table G1 Buckling Length Coefficients, K_e

Buckling modes:



Theoretical K_e value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design K_e when ideal conditions approximated	0.65	0.80	1.2	1.0	2.10	2.4

End condition code:
- Rotation fixed, translation fixed
- Rotation free, translation fixed
- Rotation fixed, translation free
- Rotation free, translation free

use these →

Allowable Flexure Stress F_c'

F_c from tables determined by species and grade

$F_c' = F_c$ (adjustment factors)

Actual Flexure Stress f_b

$f_c = P/A$

ALLOW > ACTUAL

$$F_c' \geq f_c$$

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

(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 (COLUMNS)	Modulus of Elasticity E	Grading Rules Agency
EASTERN HEMLOCK-BALSAM FIR								
Select Structural		1250	575	140	335	1200	1,200,000	NELMA NSLB
No.1		775	350	140	335	1000	1,100,000	
No.2	2" & wider	575	275	140	335	825	1,100,000	
No.3		350	150	140	335	475	900,000	
Stud	2" & wider	450	200	140	335	525	900,000	
Construction		675	300	140	335	1050	1,000,000	
Standard	2"-4" wide	375	175	140	335	850	900,000	
Utility		175	75	140	335	550	800,000	

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 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	-

Allowable Flexure Stress F_c’

F_c from tables determined by species and grade

$F_c' = F_c \, (C_D \, C_M \, C_t \, C_F \, C_i \, C_P)$

Adjustment factors for compression:

- C_D Load Duration Factor
- C_t Temperature Factor

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) Actual stress due to (DL) ≤ (0.9) (Design value)
(2) Actual stress due to (DL+LL) ≤ (1.0) (Design value)
(3) Actual stress due to (DL+WL) ≤ (1.6) (Design value)
(4) Actual stress due to (DL+LL+SL) ≤ (1.15) (Design value)
(5) Actual stress due to (DL+LL+WL) ≤ (1.6) (Design value)
(6) Actual stress due to (DL+SL+WL) ≤ (1.6) (Design value)
(7) Actual stress due to (DL+LL+SL+WL) ≤ (1.6) (Design value)

Table 2.3.3 Temperature Factor, C_t

Reference Design Values	In-Service Moisture Conditions[1]	C_t T≤100°F	C_t 100°F<T≤125°F	C_t 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.

Allowable Flexure Stress F_c'
(For **Dimensioned Lumber**)

F_c from tables determined by species and grade

$F_c' = F_c (C_D\ C_M\ C_t\ C_F\ C_i\ C_P)$

Adjustment factors for compression:
- C_M Moisture Factor
- C_F Size Factor

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, $C_M = 1.0$

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

Allowable Flexure Stress F_c'
(For **Timbers**)

F_c from tables determined by species and grade

$F_c' = F_c (C_D\ C_M\ C_t\ C_F\ C_i\ C_P)$

Adjustment factors for compression:
- C_M Moisture Factor
- C_F Size Factor

Size Factor, C_F

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

Wet Service Factor, C_M

When timbers are 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 (for Southern Pine and Mixed Southern Pine, use tabulated design values without further adjustment):

Wet Service Factors, C_M

F_b	F_t	F_v	$F_{c\perp}$	F_c	E and E_{min}
1.00	1.00	1.00	0.67	0.91	1.00

Allowable Flexure Stress F_c'

F_c from tables determined by species and grade

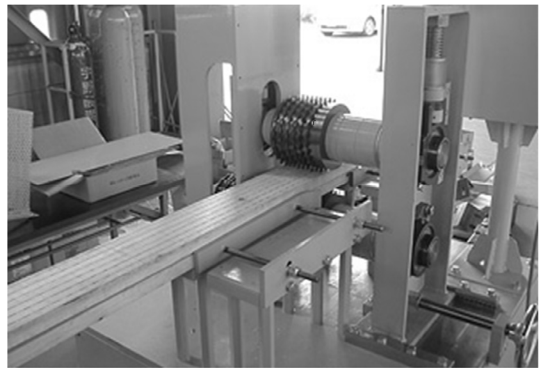
$F_c' = F_c\,(C_D\,C_M\,C_t\,C_F\,C_i\,C_P)$

Adjustment factors for compression :

C_i Incising Factor

Table 4.3.8 Incising Factors, C_i

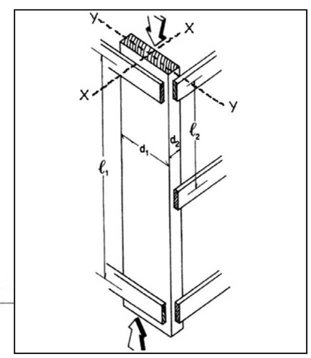
Design Value	C_i
E, E_{min}	0.95
F_b, F_t, F_c, F_v	0.80
$F_{c\perp}$	1.00



Allowable Compression Stress F_c'

F_c from tables determined by species and grade

$F_c' = F_c\,(C_D\,C_M\,C_t\,C_F\,C_i\,C_P)$



3.7 Solid Columns

3.7.1 Column Stability Factor, C_P

3.7.1.1 When a compression member is supported throughout its length to prevent lateral displacement in all directions, $C_P = 1.0$.

3.7.1.2 The effective column length, ℓ_e, for a solid column shall be determined in accordance with principles of engineering mechanics. One method for determining effective column length, when end-fixity conditions are known, is to multiply actual column length by the appropriate effective length factor specified in Appendix G, $\ell_e = (K_e)(\ell)$.

3.7.1.3 For solid columns with rectangular cross section, the slenderness ratio, ℓ_e/d, shall be taken as the larger of the ratios ℓ_{e1}/d_1 or ℓ_{e2}/d_2 (see Figure 3F) where each ratio has been adjusted by the appropriate buckling length coefficient, K_e, from Appendix G.

3.7.1.4 The slenderness ratio for solid columns, ℓ_e/d, shall not exceed 50, except that during construction ℓ_e/d shall not exceed 75.

3.7.1.5 The column stability factor shall be calculated as follows:

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

where:

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

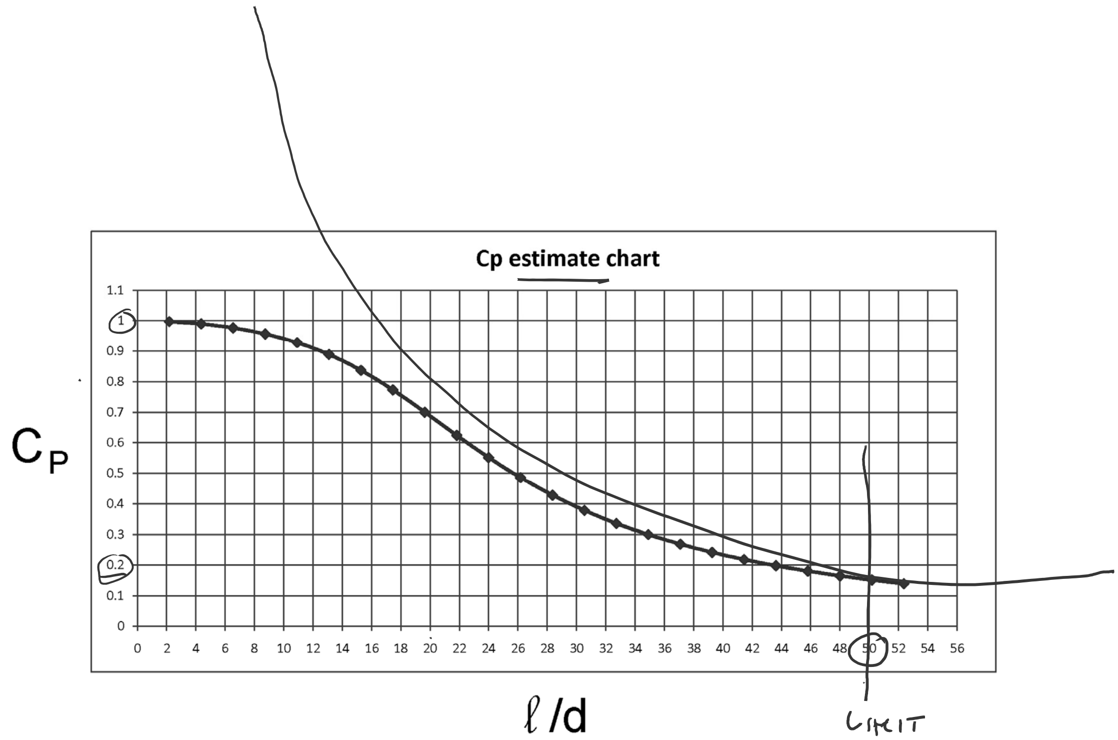
EULER $$F_{cE} = \frac{0.822\,E_{min}'}{(\ell_e/d)^2}$$

c = 0.8 for sawn lumber

c = 0.85 for round timber poles and piles

c = 0.9 for structural glued laminated timber or structural composite lumber

C_P



This is an estimate – not the exact value

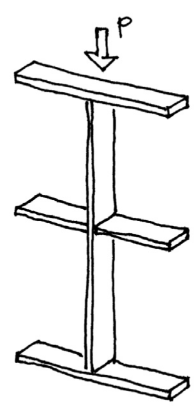
Analysis of Wood Columns

Data:

- Column – size, length
- Support conditions
- Material properties – F_c , E
- Load

Required:

- Pass/Fail or margin of safety

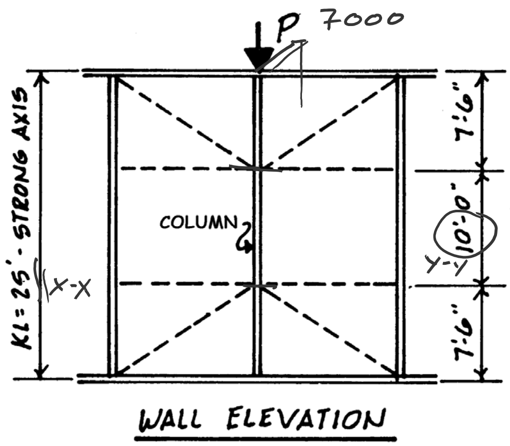


1. Calculate slenderness ratio l_e/d largest ratio governs. Must be < 50
2. Find adjustment factors C_D C_M C_t C_F C_i — TABLES
3. Calculate C_P
4. Determine allowable F'c by multiplying the tabulated Fc by all the above factors
5. Calculate the actual stress: fc = P/A
6. Compare Allowable and Actual stress.
   F'c > fc passes

Analysis Example: Pass/Fail

Data: section 4x8 (nominal)
Douglas Fir-Larch No1
M.C. 15%
P = 7000 LBS (Snow Load)

Find: Pass/Fail



From NDS Supplement Table 4A
Fc = 1500 psi
Emin = 620000 psi

C_D = 1.15 (snow)
C_M = 1.0
C_t = 1.0
C_F = 1.05 (4x8)
C_i = 1.0
C_P = ?

Species and commercial grade	Size classification	Compression perpendicular to grain $F_{c\perp}$	Compression parallel to grain F_c	Modulus of Elasticity E	E_{min}
DOUGLAS FIR-LARCH					
Select Structural		625	1,700	1,900,000	690,000
No. 1 & Btr		625	1,550	1,800,000	660,000
No. 1	2" & wider	625	1,500	1,700,000	620,000
No. 2		625	1,350	1,600,000	580,000
No. 3		625	775	1,400,000	510,000
Stud	2" & wider	625	850	1,400,000	510,000
Construction	2" - 4" wide	625	1,650	1,500,000	550,000
Standard		625	1,400	1,400,000	510,000
Utility		625	900	1,300,000	470,000

Analysis Example: Pass/Fail

Determine Allowable Flexure Stress F_c'

Fc = 1500 psi

$F_c' = F_c (C_D C_M C_t C_F C_i C_P)$

Adjustment factors for compression:

C_M Moisture Factor = 1.0 (dry)

C_F Size Factor = 1.05

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, $C_M = 1.0$

Size Factors, C_F

Grades	Width (depth)	F_b Thickness (breadth) 2" & 3"	F_b 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

Analysis Example: Pass/Fail

Calculate 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:

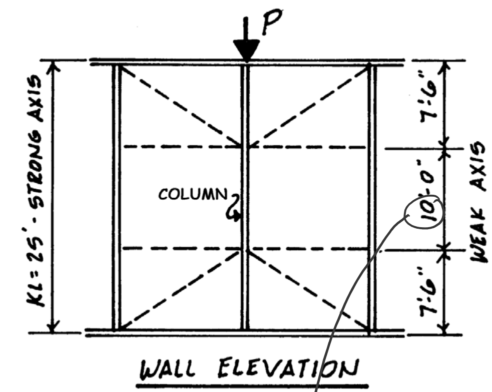
F_c^* = reference compression design value parallel to grain multiplied by all applicable adjustment factors except C_p (see 2.3), psi

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

c = 0.8 for sawn lumber

c = 0.85 for round timber poles and piles

c = 0.9 for structural glued laminated timber or structural composite lumber



4x8 3.5”x7.25”

X-X

$\ell_{ex} = 25' = 300"$

$\ell_{ex}/d_1 = \frac{300"}{7.25"} = 41.4$ LARGER

Y-Y

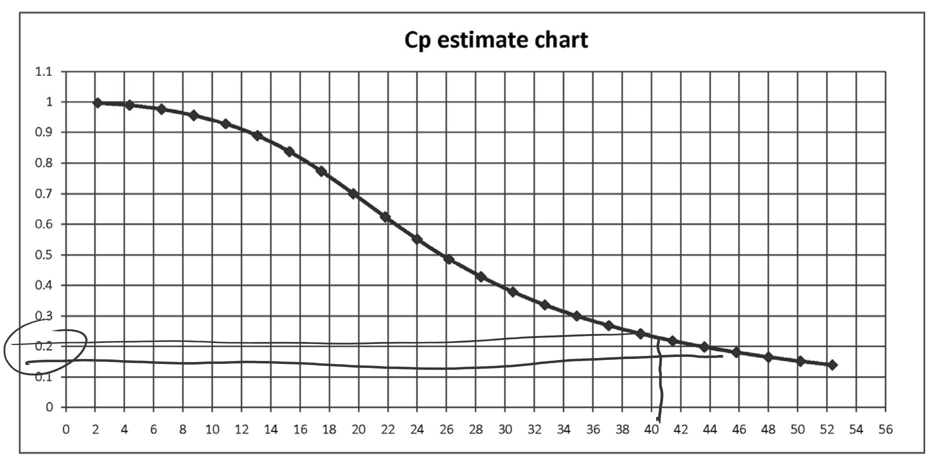
$\ell_{ey} = 10' = 120"$

$\ell_{ey}/d_2 = \frac{120"}{3.5"} = 34.3$

$\ell_e/d = 41.4 < 50$ ✓

C_P

C_P



ℓ/d

This is an estimate – not the exact value

Analysis Example: Pass/Fail

Calculate 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 or structural composite lumber

$F_{cE} = \frac{0.822\ E'_{min}}{(\ell_e/d)^2} = \frac{0.822(620000)}{(41.4)^2} = 297.6$ psi

$F_c^* = 1500(1.15 \cdot 1.05)$ (C_D, C_F) $= 1811.25$ psi

$F_{cE}/F_c^* = \frac{297.6}{1811.25} = 0.164$

$c = 0.8$

$C_P = \frac{1+0.164}{2(0.8)} - \sqrt{\left[\frac{1+0.164}{2(0.8)}\right]^2 - \frac{0.164}{.8}}$

$C_P = 0.1584$

Analysis Example: Pass/Fail

Determine Allowable stress

$F'_c = 1500(1.15 \cdot 1.05 \cdot 0.1584)$ (C_D, C_F, C_P)

$= 286.9$ psi

Compare Allowable and Actual stress

F'c > fc passes

$f_c = \frac{P}{A} = \frac{7000\#}{25.38\ in^2} = 275.8$ psi

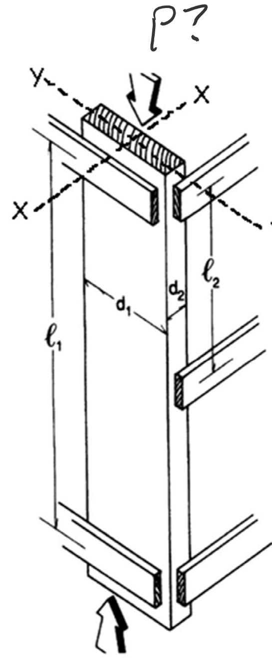
$F'_c > f_c$ ✓ OK

$286 > 275$

Capacity Analysis of Columns

Data:
- Column – size, length
- Support conditions
- Material properties – F_c, E

Required:
- Maximum Load Capacity, Pmax

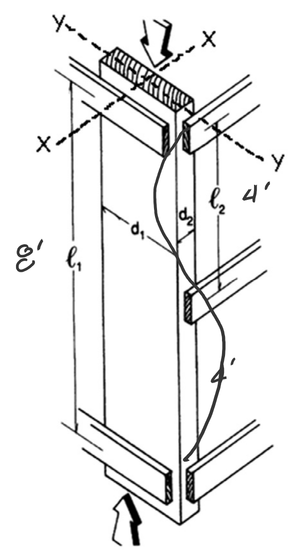


1. Calculate slenderness ratio l_e/d
   largest ratio governs. Must be < 50
2. Find adjustment factors
   C_D C_M C_t C_F C_i
3. Calculate C_P
4. Determine F'c by multiplying the tabulated Fc by all the above factors
5. Set actual stress = allowable, fc = F'c
6. Find the maximum allowable load
   Pmax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

Analysis Example: Capacity

Data:
- 4x10
- Hem – Fir, No. 2 M.C. = 20% > 19%
- Wind Load
- L_1 = 8' L_2 = 4' K_e=1.0

Required:
- Maximum Load Capacity, Pmax



From NDS Supplement Table 4A
Fc = 1300 psi
Emin = 470000 psi

C_D = 1.6 (Table 2.3.2.)
C_{Mc} = 0.8 C_{ME} = 0.9
C_t = 1.0
C_F = 1.0 (chart in Supplement)
C_i = 1.0
C_P = ?

x - x
$\ell_{ex} = 8' = 96''$
$\frac{\ell_{ex}}{d_1} = \frac{96}{9.25} = 10.4$

y - y
$\ell_{ey} = 4' = 48''$
$\frac{\ell_{ey}}{d_2} = \frac{48}{3.5} = 13.7$

$\ell_e/d = 13.7 < 50$ ✓

Allowable Flexure Stress F_c'

4 x 10   M.C. = 20%

F_c from tables determined by species and grade

$F_c' = F_c\,(C_D\ C_M\ C_t\ C_F\ C_i\ C_P)$

Adjustment factors for compression:

- C_M Moisture Factor $C_{Mc} = 0.8$ $C_{ME} = 0.9$
- C_F Size Factor = 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

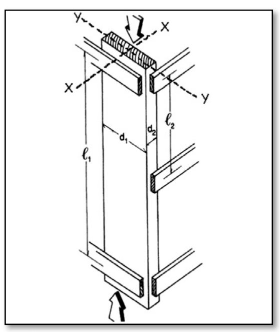
* when $(F_b)(C_F) \le 1{,}150$ psi, $C_M = 1.0$

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

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

Capacity Example



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

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 or structural composite lumber

Find C_P

$$F_{CE} = \frac{0.822\ E'_{min}}{(\ell_e/d)^2} = \frac{0.822(470000\,(0.9))}{13.7^2} = 1848.7\text{ psi}$$

$$F_C^* = 1300\,(1.6\ \ 0.8) = 1664.\text{ psi}$$

$$F_{CE}/F_C^* = \frac{1848.7}{1664} = 1.111$$

$$C_P = 0.7261$$

Find the maximum load, Pmax

$$F_C' = 1300\,(\overset{C_D}{1.6}\ \ \overset{C_M}{0.8}\ \ \overset{C_P}{0.7261}) = 1208\text{ psi}$$

$$P_{max} = F_C'\,A = 1208\,(32.38) = 39115\ \#$$

MAX LOAD