Architectural Structures: Form, Behavior, and Design

Arch 331 Dr. Anne Nichols Summer 2013

thirteen

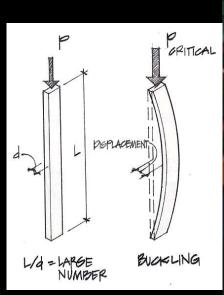
wood construction: column design



Wood Columns 1 Lecture 13

Compression Members (revisited)

- designed for strength & stresses
- designed for serviceability & deflection
- need to design for <u>stability</u>
 - ability to support a specified load without sudden or unacceptable deformations

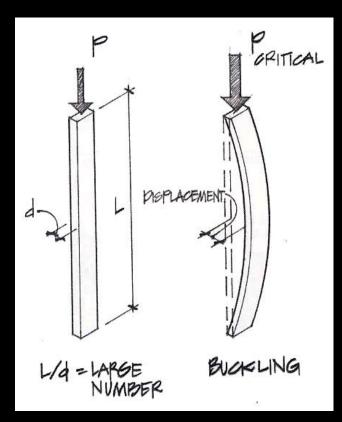


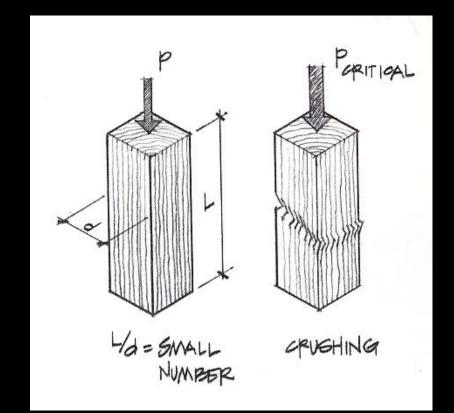


Effect of Length (revisited)

long & slender

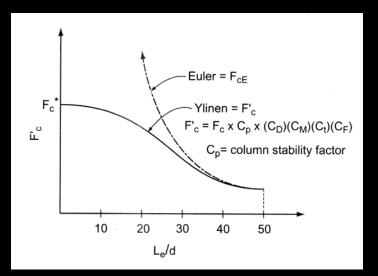
short & stubby





Critical Stresses (revisited)

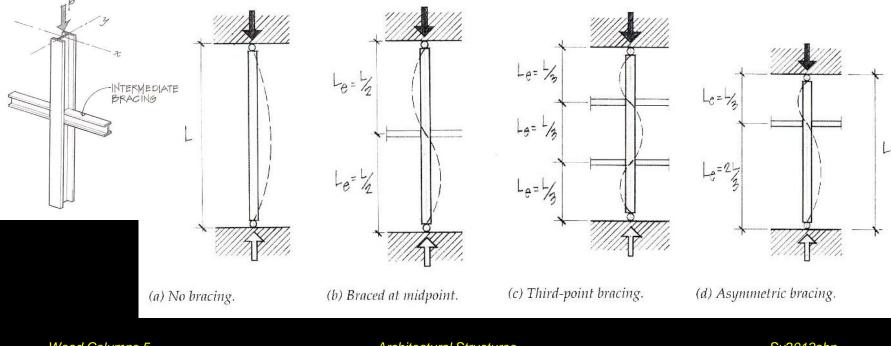
- when a column gets stubby, crushing will limit the load
- real world has loads with eccentricity



Bracing (revisited)

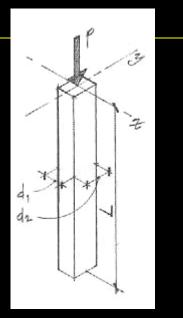
• bracing affects shape of buckle in one direction

both should be checked!



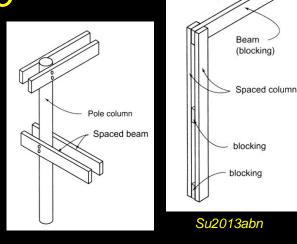
Wood Columns

- slenderness ratio = L/d_{min}
 - $-d_{1} = smallest dimension$ $-l_{e}/d \leq 50 \quad (max)$ $f = -f \leq F$



- where F'_c is the allowable compressive strength parallel to the grain
- bracing common
- posts, round, built-up

Wood Columns 6 Lecture 13

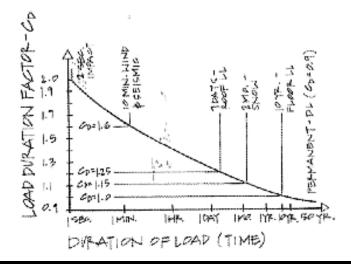


Allowable Wood Stress

$$F'_{c} = F_{c}(C_{D})(C_{M})(C_{t})(C_{F})(C_{p})$$

ere:

 $F_c = compressive strength$ parallel to grain $C_{D} = load duration factor$ C_{M} = wet service factor (1.0 dry) C_t = temperature factor C_{F} = size factor $C_{p} = column$ stability factor



(Table 10.3)

W/

Strength Factors

wood properties and load duration, C_D
 short duration
 higher loads
 normal duration
 > 10 years

• stability, C_{ρ}

- combination curve - tables

http://www.swst.org/teach/set2/struct1.html

 $F_c' = F_c^* C_p = (F_c C_D) C_p$

C_p Charts – Appendix A

Table 14 Column Stability Factor C_p.

Tuble 14 Column Stubility Factor C _p .													
			$"C_p"$	$F_c' =$	$C_p \cdot F_c^* F_{CI}$	= -	$\frac{.30 E}{(l/d)^2} \text{ for}$	or sawed	posts F _C	E =	$\frac{.418 E}{(l/d)^2}$	for glu-	lam posts
F_{CE} F_{C}^{*}	Sawed (Glu-Lam	F_{CE}	Sawed	Glu-Lam		F_{CE} F_{C}^{*}	Sawed	Glu-Lam			Sawed	Glu-Lam
	C_p	C_p		C_p	C_p			C_p	C_p			C_p	C_p
0.00	0.000	0.000	0.4	0 0.360	0.377	1	0.80	0.610	0.667		1.20	0.750	0.822
0.01	0.010	0.010	0.4	1 0.367	0.386		0.81	0.614	0.672		1.22	0.755	0.826
0.02	0.020	0.020	0.42	2 0.375	0.394		0.82	0.619	0.678		1.24	0.760	0.831
0.03	0.030	0.030	0.43	3 0.383	0.403		0.83	0.623	0.683		1.26	0.764	0.836
0.04	0.040	0.040	0.44	4 0.390	0.411		0.84	0.628	0.688		1.28	0.769	0.840
0.05	0.049	0.050	0.4	5 0.398	0.420		0.85	0.632	0.693		1.30	0.773	0.844
0.06	0.059	0.060	0.4	6 0.405	0.428		0.86	0.637	0.698		1.32	0.777	0.848
0.07	0.069	0.069	0.42	7 0.412	0.436		0.87	0.641	0.703		1.34	0.781	0.852
0.08	0.079	0.079	0.48	8 0.419	0.444		0.88	0.645	0.708		1.36	0.785	0.855
0.09	0.088	0.089	0.49	9 0.427	0.453		0.89	0.649	0.713		1.38	0.789	0.859
0.10	0.098	0.099	0.50	0 0.434	0.461		0.90	0.653	0.718		1.40	0.793	0.862
0.11	0.107	0.109	0.5	1 0.441	0.469		0.91	0.658	0.722		1.42	0.796	0.865
0.12	0.117	0.118	0.52	2 0.448	0.477		0.92	0.661	0.727		1.44	0.800	0.868
0.13	0.126	0.128	0.53	3 0.454	0.484		0.93	0.665	0.731		1.46	0.803	0.871
0.14	0.136	0.138	0.54	4 0.461	0.492		0.94	0.669	0.735		1.48	0.807	0.874
0.15	0.145	0.147	0.55	5 0.468	0.500		0.95	0.673	0.740		1.50	0.810	0.877
0.16	0.154	0.157	0.56	6 0.474	0.508		0.96	0.677	0.744		1.52	0.813	0.879
0.17	0.164	0.167	0.52	7 0.481	0.515		0.97	0.680	0.748		1.54	0.816	0.882
0.18	0.173	0.176	0.58	8 0.487	0.523		0.98	0.684	0.752		1.56	0.819	0.884
0.19	0.182	0.186	0.59	9 0.494	0.530		0.99	0.688	0.756		1.58	0.822	0.887

Wood Columns 9 Lecture 13

Column Charts – Appendix A, 12 & 13

Table 12 Allowable Column Loads—Selected Species/Sizes. (Continued)														
									8×8	A = 56.25	8×10	A = 71.25	8×12	A = 86.25
l/d	(<i>l/d</i>)sq	Fce	Fce/Fc		Ср		F'c(psi)		Pa (k)		Pa (k)		Pa	
			Norm	Snow	Norm	Snow	Norm	Snow	Norm	Snow	Norm	Snow	Norm	Snow
19.2	368.64	1302.08	1.30	1.13	.7731	.7315	773	841	43.5	47.3	55.1	59.9	66.7	72.6
20.8	432.64	1109.47	1.11	0.96	.7258	.6767	726	778	40.8	43.8	51.7	55.4	62.6	67.1
22.4	501.76	956.63	0.96	0.83	.6767	.6235	677	717	38.1	40.3	48.2	51.1	58.4	61.8
24.00	576.00	833.33	0.83	0.72	.6235	.5694	624	655	35.1	36.8	44.4	46.7	53.8	56.5
25.60	655.36	732.42	0.73	0.64	.5747	.5244	575	603	32.3	33.9	40.9	43.0	49.6	52.0
27.20	739.84	648.79	0.65	0.56	.5303	.4744	530	546	29.8	30.7	37.8	38.9	45.7	47.1
28.80	829.44	578.70	0.58	0.50	.4873	.4336	487	499	27.4	28.0	34.7	35.5	42.0	43.0
30.40	924.16	519.39	0.52	0.45	.4475	.3975	448	457	25.2	25.7	31.9	32.6	38.6	39.4
32.00	1024.00	468.75	0.47	0.41	.4122	.3673	412	422	23.2	23.8	29.4	30.1	35.6	36.4
33.60	1128.96	425.17	0.43	0.37	.3826	.3360	383	386	21.5	21.7	27.3	27.5	33.0	33.3
35.20	1239.04	387.40	0.39	0.34	.3518	.3118	352	359	19.8	20.2	25.1	25.5	30.3	30.9
36.80	1354.24	354.44	0.35	0.31	.3199	.2869	320	330	18.0	18.6	22.8	23.5	27.6	28.5
38.40	1474.56	325.52	0.33	0.28	.3035	.2615	304	301	17.1	16.9	21.6	21.4	26.2	25.9
40.00	1600.00	300.00	0.30	0.26	.2785	.2442	279	281	15.7	15.8	19.8	20.0	24.0	24.2
41.60	1730.56	277.37	0.28	0.24	.2615	.2267	262	261	14.7	14.7	18.6	18.6	22.6	22.5
43.20	1866.24	257.20	0.26	0.22	.2442	.2090	244	240	13.7	13.5	17.4	17.1	21.1	20.7
44.80	2007.04	239.16	0.24	0.21	.2267	.2000	227	230	12.8	12.9	16.2	16.4	19.6	19.8
46.40	2152.96	222.95	0.22	0.19	.2090	.1819	209	209	11.8	11.8	14.9	14.9	18.0	18.0
48.00	2304.00	208.33	0.21	0.18	.2000	.1728	200	199	11.3	11.2	14.3	14.2	17.3	17.1
DF-L No.1 (P			Fc = 1000			E=1.6								
DF-L No.1 & BtrDim.Lum			Fc = 1500			E=1.8								
	<i>IId</i> 19.2 20.8 22.4 24.00 25.60 27.20 28.80 30.40 32.00 33.60 35.20 36.80 38.40 40.00 41.60 43.20 44.80 44.80 46.40 48.00	I/d (I/d)sq 1/d (I/d)sq 19.2 368.64 20.8 432.64 22.4 501.76 24.00 576.00 25.60 655.36 27.20 739.84 28.80 829.44 30.40 924.16 32.00 1024.00 33.60 1128.96 35.20 1239.04 36.80 1354.24 38.40 1474.56 40.00 1600.00 41.60 1730.56 43.20 1866.24 44.80 2007.04 46.40 2152.96 48.00 2304.09 DF-L No.1 1	I/d (I/d)sq Fce I/d (I/d)sq Fce 19.2 368.64 1302.08 20.8 432.64 1109.47 22.4 501.76 956.63 24.00 576.00 833.33 25.60 655.36 732.42 27.20 739.84 648.79 28.80 829.44 578.70 30.40 924.16 519.39 32.00 1024.00 468.75 33.60 1128.96 425.17 35.20 1239.04 387.40 36.80 1354.24 354.44 38.40 1474.56 325.52 40.00 1600.00 300.00 41.60 1730.56 277.37 43.20 1866.24 257.20 44.80 2007.04 239.16 46.40 2152.96 222.95 48.00 2304.09 208.33 DF-L No.1 (P&T)	I/d (I/d)sq Fce Fce/Fc' I/d (I/d)sq Fce Fce/Fc' 19.2 368.64 1302.08 1.30 20.8 432.64 1109.47 1.11 22.4 501.76 956.63 0.96 24.00 576.00 833.33 0.83 25.60 655.36 732.42 0.73 27.20 739.84 648.79 0.65 28.80 829.44 578.70 0.58 30.40 924.16 519.39 0.52 32.00 1024.00 468.75 0.47 33.60 1128.96 425.17 0.43 35.20 1239.04 387.40 0.39 36.80 1354.24 354.44 0.35 38.40 1474.56 325.52 0.33 40.00 1600.00 300.00 0.30 41.60 1730.56 277.37 0.28 43.20 1866.24 257.20 0.26 4	I/d (I/d)sq Fce Fce/Fc' I/d (I/d)sq Fce Fce/Fc' I Morm Snow 19.2 368.64 1302.08 1.30 1.13 20.8 432.64 1109.47 1.11 0.96 22.4 501.76 956.63 0.96 0.83 24.00 576.00 833.33 0.83 0.72 25.60 655.36 732.42 0.73 0.64 27.20 739.84 648.79 0.65 0.56 28.80 829.44 578.70 0.58 0.50 30.40 924.16 519.39 0.52 0.45 32.00 1024.00 468.75 0.47 0.41 33.60 1128.96 425.17 0.43 0.37 35.20 1239.04 387.40 0.39 0.34 36.80 1354.24 354.44 0.35 0.31 38.40 1474.56 325.52 0.33 0.26	I/d (I/d)sq Fce Fce/Fc' Cp I/d (I/d)sq Fce Fce/Fc' Cp 19.2 368.64 1302.08 1.30 1.13 .7731 20.8 432.64 1109.47 1.11 0.96 .7258 22.4 501.76 956.63 0.96 0.83 .6767 24.00 576.00 833.33 0.83 0.72 .6235 25.60 655.36 732.42 0.73 0.64 .5747 27.20 739.84 648.79 0.65 0.56 .5303 28.80 829.44 578.70 0.58 0.50 .4873 30.40 924.16 519.39 0.52 0.45 .4475 32.00 1024.00 468.75 0.47 0.41 .4122 33.60 1128.96 425.17 0.43 0.37 .3826 35.20 1239.04 387.40 0.39 0.34 .3199 36.80 1354.24<	IddI	Idd Idd Idd Idd Idd Idd Idd Fce Fce/Fc Cp Fc(psi) 19.2 368.64 1302.08 1.30 1.13 .7731 .7315 773 20.8 432.64 1109.47 1.11 0.96 .7258 .6767 726 22.4 501.76 956.63 0.96 0.83 .6767 .6235 .6777 24.00 576.00 833.33 0.83 0.72 .6235 .5694 624 25.60 655.36 732.42 0.73 0.64 .5747 .5244 575 27.20 739.84 648.79 0.65 0.56 .5303 .4744 530 28.80 829.44 578.70 0.58 0.50 .4873 .4336 487 30.40 924.16 519.39 0.52 0.45 .4475 .3975 448 32.00 1024.00 468.75 0.47 0.41 .4122 .3663	Image: constraint of the state of the st	Image: series of the	Image: constraint of the state of	Image: constraint of the state of	Image: constraint of the second se	Image: constraint of the state in

Wood Columns 10 Lecture 13

Procedure for Analysis

- 1. calculate L_e/d_{min}
 - KL/d each axis, choose largest
- 2. obtain F'_{c}

 - compute $F_{cE} = \frac{K_{cE}E}{(L_e/d)^2}$ $K_{cE} = 0.3$ sawn
 - $K_{cF} = 0.418 \, \text{glu-lam}$
- 3. compute $F_c^* \approx F_c C_D$
- 4. calculate F_{cE}/F_c^* and get C_p (Table 14)

5. calculate $F'_{c} = F^{*}_{c}C_{r}$

Procedure for Analysis (cont'd)

- 6. compute $P_{allowable} = F'_c \cdot A$
 - or find $f_{actual} = P/A$

7. is $P \leq P_{allowable}$? (or $f_{actual} \leq F'_c$?)

- yes: OK
- no: overstressed & no good

Procedure for Design

- 1. guess a size (pick a section)
- 2. calculate L_e/d_{min}
 - KL/d each axis, choose largest
- 3. obtain F'_c

 - compute $F_{cE} = \frac{K_{cE}E}{\left(\frac{L_e}{d}\right)^2}$ $K_{cE} = 0.3$ sawn
 - $K_{cF} = 0.418 \, glu$ -lam
- 4. compute $F_c^* \approx F_c C_D$
- 5. calculate F_{cE}/F_c^* and get C_p (Table 14)

Procedure for Design (cont'd)

- 6. compute $F_c' = F_c^* C_p$
- 7. compute $P_{allowable} = F'_c \cdot A$
 - or find $f_{actual} = P/A$
- 8. is $P \leq P_{allowable}$? (or $f_{actual} \leq F'_c$?)
 - yes: OK
 - no: pick a bigger section and **go back to step 2**.

Timber Construction by Code

- light-frame
 - light loads
 - 2x's
 - floor joists 2x6, 2x8, 2x10, 2x12 typical at spacings of 12", 16", 24"



- normal spans of 20-25 ft or 6-7.5 m
- plywood spans between joists
- <u>stud</u> or load-bearing masonry walls
- limited to around 3 stories fire safety

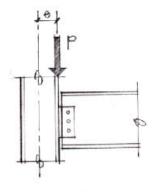
Design of Columns with Bending

satisfy

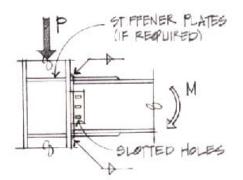
 strength
 stability

 pick

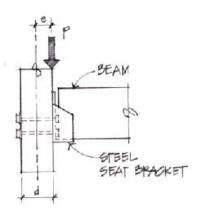
 section



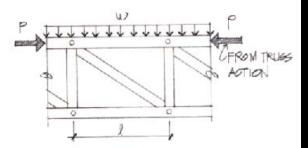
(a) Framed beam (shear) connection. $e = Eccentricity; M = P \times e$



(b) Moment connection (rigid frame). M = Moment due to beam bending



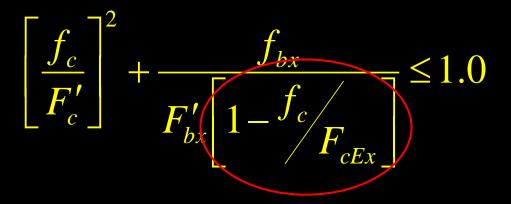
(c) Timber beam-column connection. $e = d/2 = eccentricity; M = P \times e$



(d) Upper chord of a truss—compression plus bending. $M = \frac{\omega \ell^2}{8}$

Design

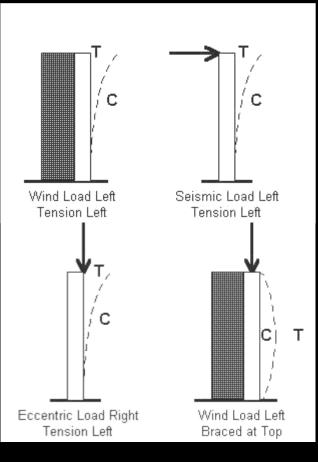
• Wood



[] term – magnification factor for P- Δ F'_{bx} – allowable bending strength

Design Steps Knowing Loads

- 1. assume limiting stress
 - buckling, axial stress, combined stress
- 2. solve for r, A or S
- 3. pick trial section
- 4. analyze stresses
- 5. section ok?
- 6. stop when section is ok



Laminated Timber Arches

- two & three hinged arches
- bent to wide range of curves
- bending and compression
- residual stress from laminating, C_c





Laminated Arch Design

- radius of curvature, R, limited by lam thickness, t
 - -R = 100t southern pine & hardwoods
 - -R = 125t softwood
- r = radius to inside face of laminations, 2
- $C_{c} = 1 2000 \left(\frac{t}{r} \right)$
- $F_b' = F_b(C_F C_c)$

