ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN

ARCH 331

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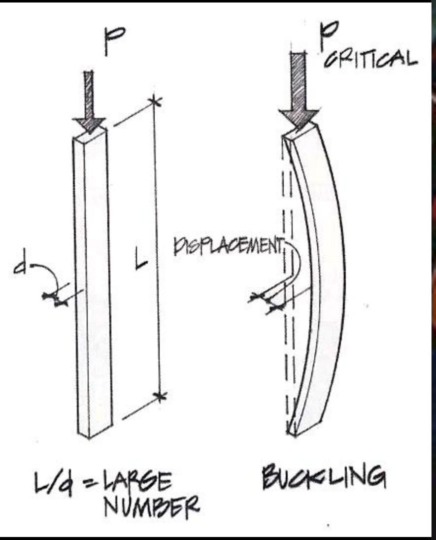
FALL 2013

lecture
sixteen

wood construction: column design

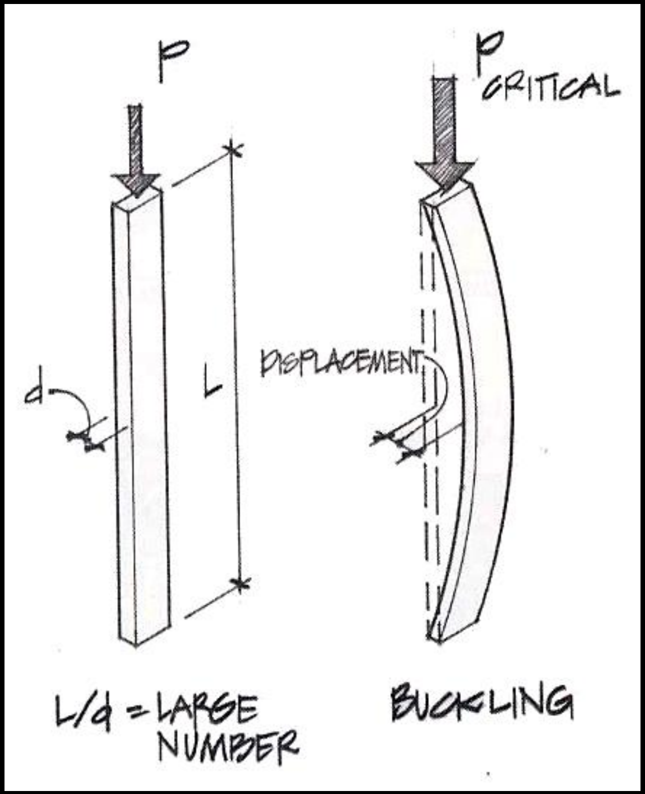
Compression Members (revisited)

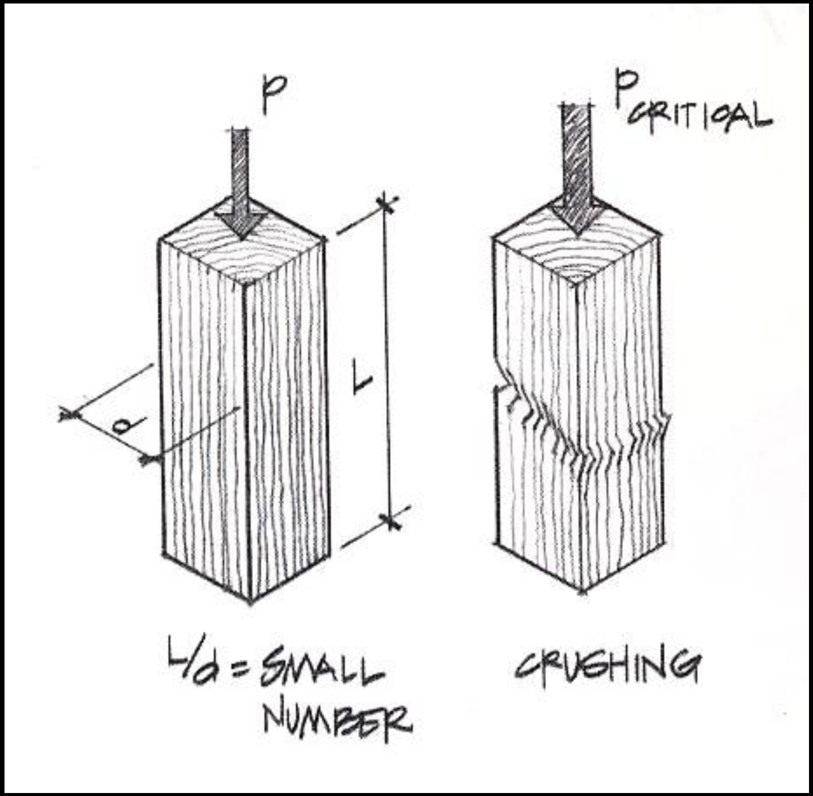
- *designed for strength & stresses*
- *designed for serviceability & deflection*
- *need to design for <u>stability</u>*
  - *ability to support a specified load without sudden or unacceptable deformations*



Effect of Length (revisited)

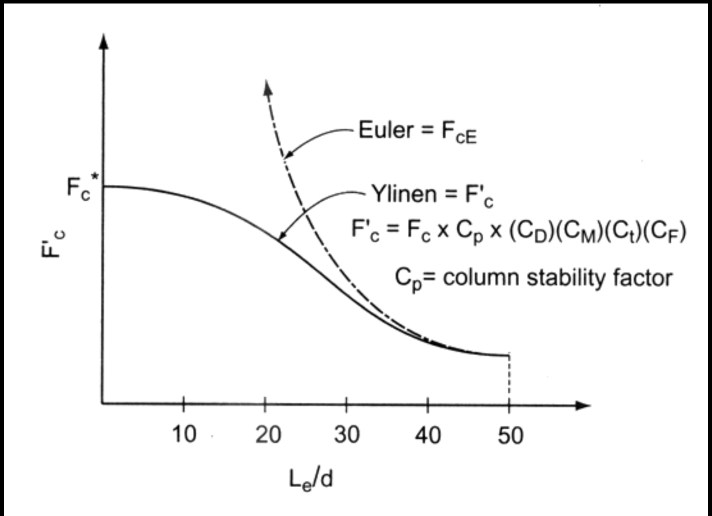
- *long & slender*
- *short & stubby*





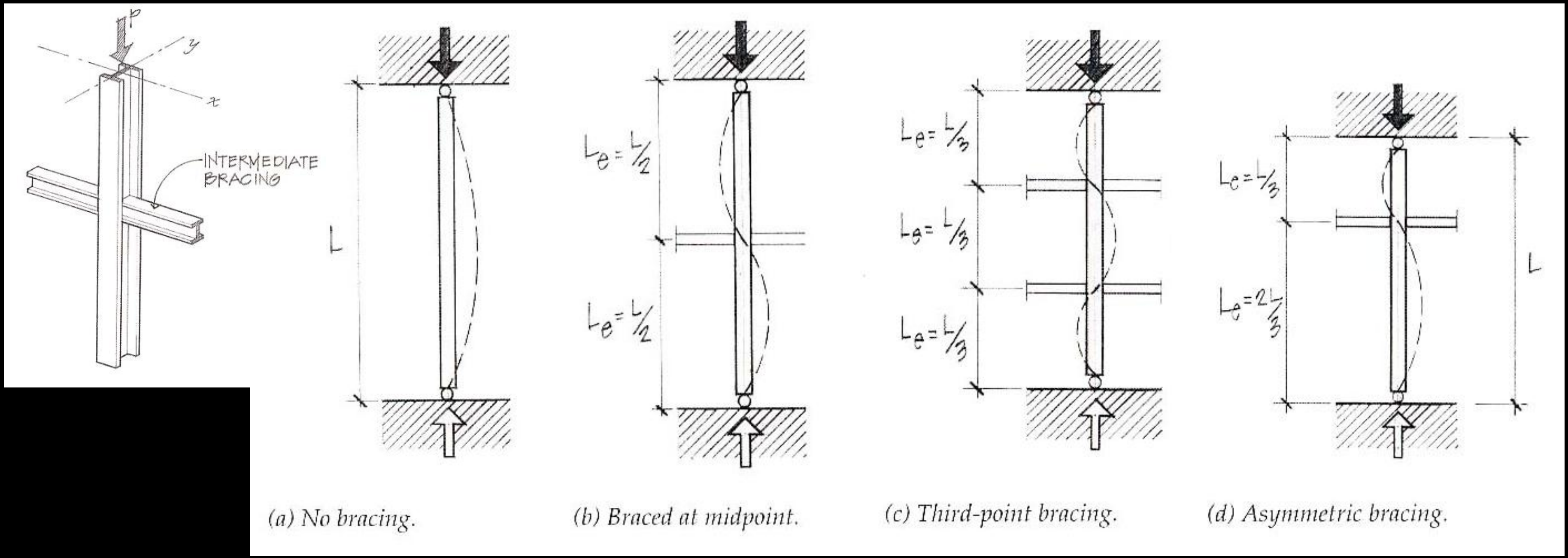
Critical Stresses (revisited)

- 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!*

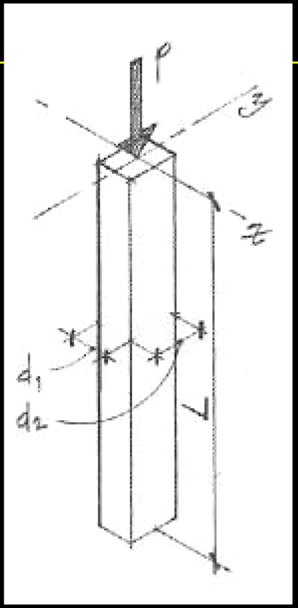


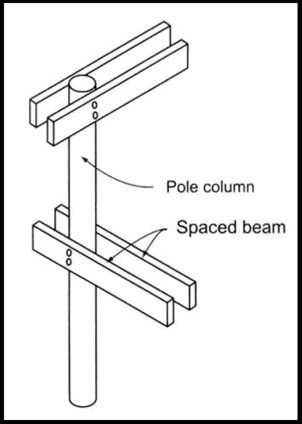
Wood Columns

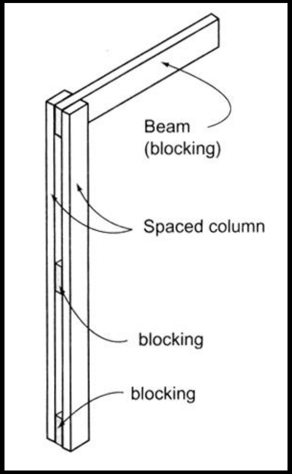
- *slenderness ratio = L/d_{min}*
  - *d_1 = smallest dimension*
  - *$\ell_e/d \le 50$ (max)*

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

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







Allowable Wood Stress

$$F_c' = F_c\left(C_D\right)\left(C_M\right)\left(C_t\right)\left(C_F\right)\left(C_p\right)$$

- *where:*

  F_c = compressive strength parallel to grain

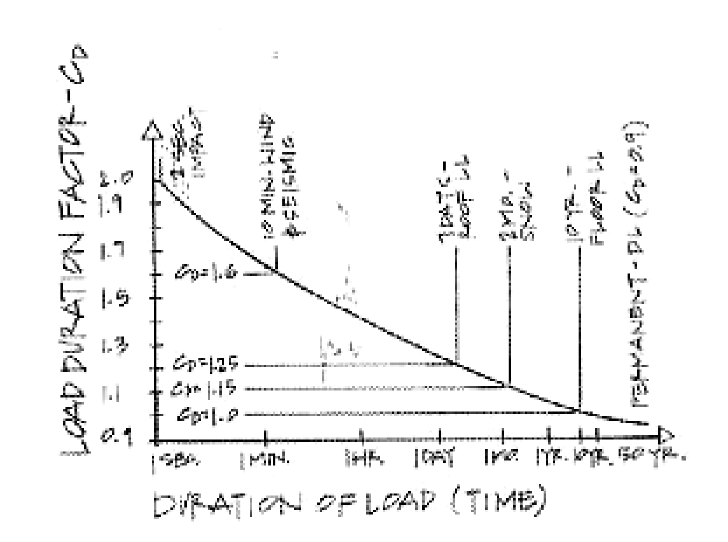
  C_D = load duration factor

  C_M = wet service factor (1.0 dry)

  C_t = temperature factor

  C_F = size factor

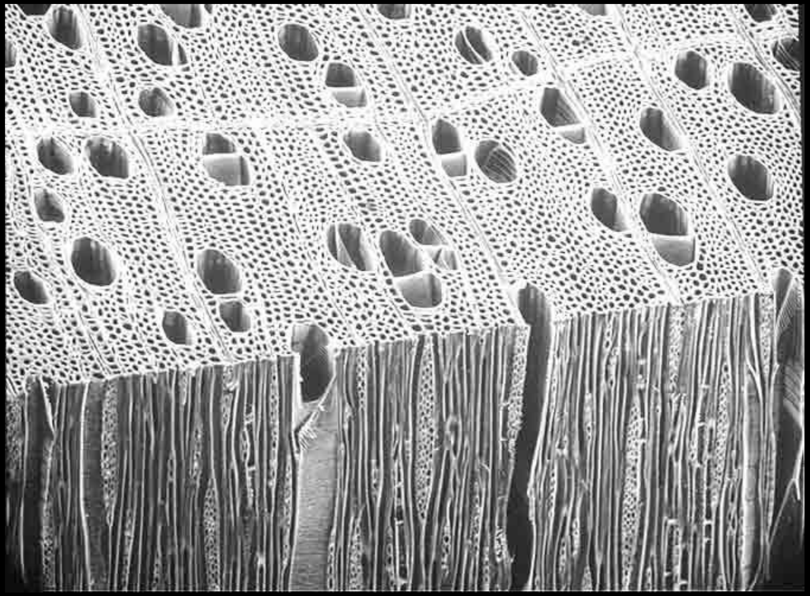
  C_p = column stability factor



(Table 10.3)

Strength Factors

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



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

- stability, C_p
  - combination curve - tables

$$F_c' = F_c^* C_p = \left(F_c C_D\right) C_p$$

C_p Charts – Appendix A

Table 14 Column Stability Factor C_p.

"C_p" $F_c' = C_p \cdot F_c^*$ $F_{CE} = \frac{.30\,E}{(l/d)^2}$ for sawed posts $F_{CE} = \frac{.418\,E}{(l/d)^2}$ for glu-lam posts

F_{CE}/F_c^*	Sawed C_p	Glu-Lam C_p	F_{CE}/F_c^*	Sawed C_p	Glu-Lam C_p	F_{CE}/F_c^*	Sawed C_p	Glu-Lam C_p	F_{CE}/F_c^*	Sawed C_p	Glu-Lam C_p
0.00	0.000	0.000	0.40	0.360	0.377	0.80	0.610	0.667	1.20	0.750	0.822
0.01	0.010	0.010	0.41	0.367	0.386	0.81	0.614	0.672	1.22	0.755	0.826
0.02	0.020	0.020	0.42	0.375	0.394	0.82	0.619	0.678	1.24	0.760	0.831
0.03	0.030	0.030	0.43	0.383	0.403	0.83	0.623	0.683	1.26	0.764	0.836
0.04	0.040	0.040	0.44	0.390	0.411	0.84	0.628	0.688	1.28	0.769	0.840
0.05	0.049	0.050	0.45	0.398	0.420	0.85	0.632	0.693	1.30	0.773	0.844
0.06	0.059	0.060	0.46	0.405	0.428	0.86	0.637	0.698	1.32	0.777	0.848
0.07	0.069	0.069	0.47	0.412	0.436	0.87	0.641	0.703	1.34	0.781	0.852
0.08	0.079	0.079	0.48	0.419	0.444	0.88	0.645	0.708	1.36	0.785	0.855
0.09	0.088	0.089	0.49	0.427	0.453	0.89	0.649	0.713	1.38	0.789	0.859
0.10	0.098	0.099	0.50	0.434	0.461	0.90	0.653	0.718	1.40	0.793	0.862
0.11	0.107	0.109	0.51	0.441	0.469	0.91	0.658	0.722	1.42	0.796	0.865
0.12	0.117	0.118	0.52	0.448	0.477	0.92	0.661	0.727	1.44	0.800	0.868
0.13	0.126	0.128	0.53	0.454	0.484	0.93	0.665	0.731	1.46	0.803	0.871
0.14	0.136	0.138	0.54	0.461	0.492	0.94	0.669	0.735	1.48	0.807	0.874
0.15	0.145	0.147	0.55	0.468	0.500	0.95	0.673	0.740	1.50	0.810	0.877
0.16	0.154	0.157	0.56	0.474	0.508	0.96	0.677	0.744	1.52	0.813	0.879
0.17	0.164	0.167	0.57	0.481	0.515	0.97	0.680	0.748	1.54	0.816	0.882
0.18	0.173	0.176	0.58	0.487	0.523	0.98	0.684	0.752	1.56	0.819	0.884
0.19	0.182	0.186	0.59	0.494	0.530	0.99	0.688	0.756	1.58	0.822	0.887

Column Charts – Appendix A, 12 & 13

Table 12 Allowable Column Loads—Selected Species/Sizes. (Continued)

Eff. Col. Len(ft)	*l/d*	(*l/d*)sq	*Fce*	*Fce/Fc** Norm	Snow	*Cp* Norm	Snow	*F'c*(psi) Norm	Snow	8×8 *Pa* (k) Norm	*A* = 56.25 Snow	8×10 *Pa* (k) Norm	*A* = 71.25 Snow	8×12 *Pa* Norm	*A* = 86.25 Snow
12	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
13	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
14	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
15	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
16	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
17	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
18	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
19	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
20	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
21	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
22	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
23	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
24	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
25	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
26	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
27	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
28	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
29	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
30	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&T)		*Fc* = 1000		*E* = 1.6								
	DF-L No.1 & Btr		Dim.Lum		*Fc* = 1500		*E* = 1.8								

Procedure for Analysis

1. calculate L_e/d_{min}
   - KL/d each axis, choose largest
2. obtain F'_c
   - compute $$F_{cE} = \frac{K_{cE}E}{\left(\frac{L_e}{d}\right)^2}$$
     - K_{cE} =0.3 sawn
     - K_{cE} = 0.418 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 $F_c' = F_c^* C_p$

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* $F_{cE} = \dfrac{K_{cE}E}{\left(\frac{L_e}{d}\right)^2}$
     - K_{cE} *=0.3 sawn*
     - K_{cE} *= 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)

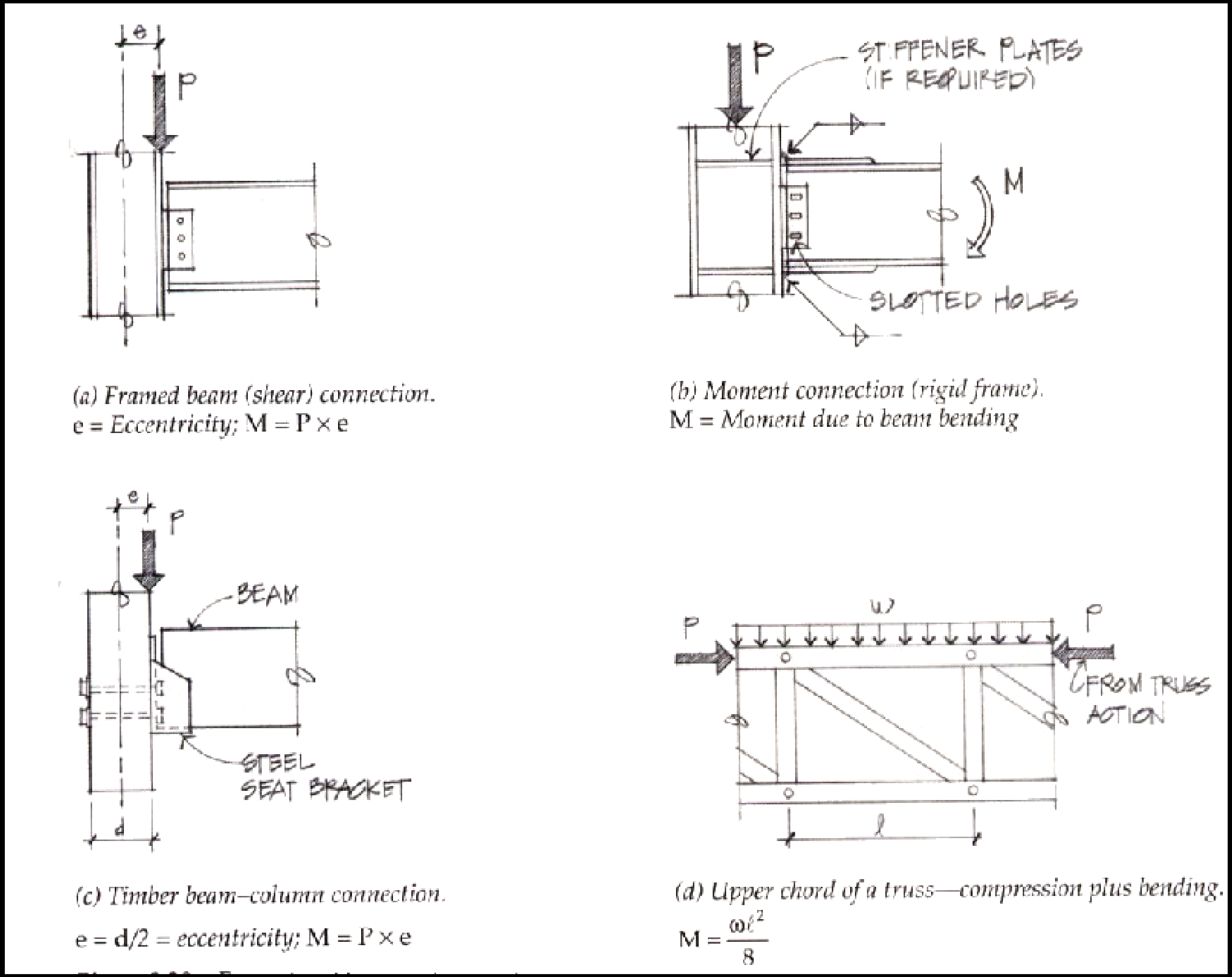
6. *compute* $F_c' = F_c^* C_p$
7. *compute* $P_{allowable} = F'_c \cdot A$
   - *or find* $f_{actual} = P/A$
8. *is* $P \le P_{allowable}$*?* *(or* $f_{actual} \le F'_c$*?)*
   - *yes: OK*
   - *no: pick a bigger section and* ***go back to step 2****.*

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*
  - *stud 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*

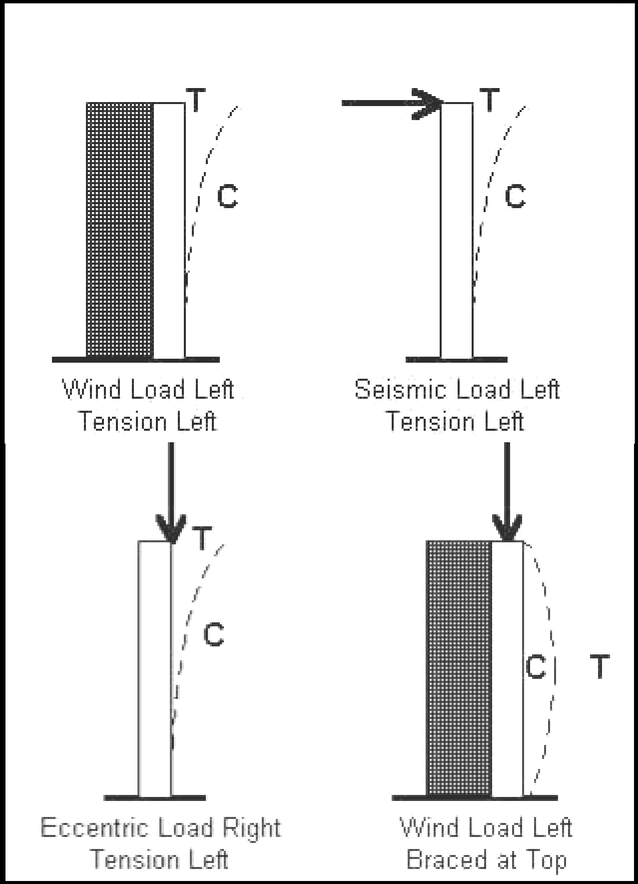
$$\left[\frac{f_c}{F'_c}\right]^2 + \frac{f_{bx}}{F'_{bx}\left[1 - \frac{f_c}{F_{cEx}}\right]} \leq 1.0$$

[] 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
- $C_C = 1 - 2000\left(\frac{t}{r}\right)^2$
- $F_b' = F_b(C_F C_c)$

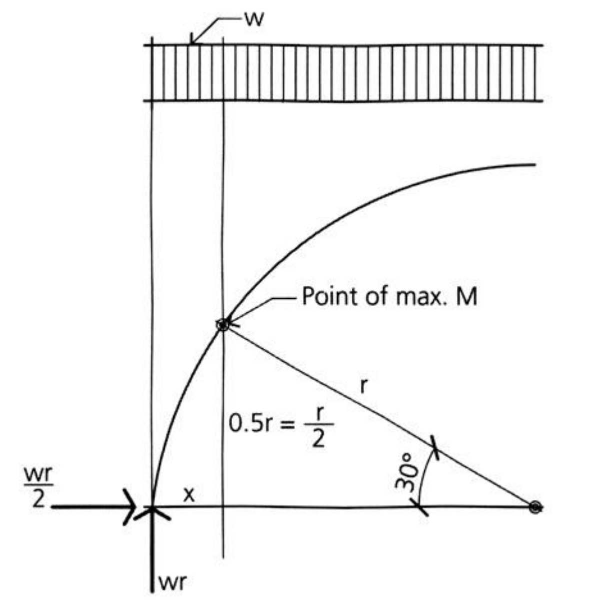


Fig. 24.6 Circular arch moment analysis