ELEMENTS OF ARCHITECTURAL STRUCTURES: FORM, BEHAVIOR, AND DESIGN

ARCH 614

DR. ANNE NICHOLS

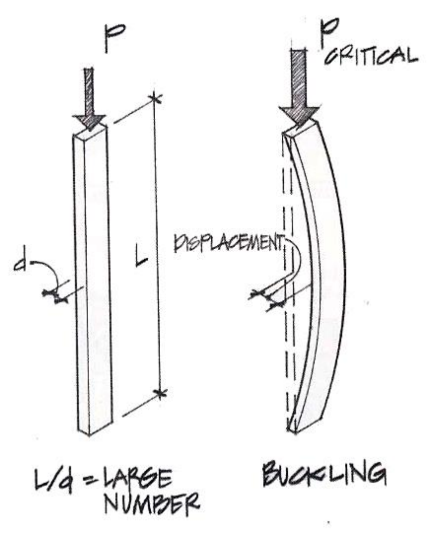
SPRING 2014

lecture
fourteen

wood construction: column design

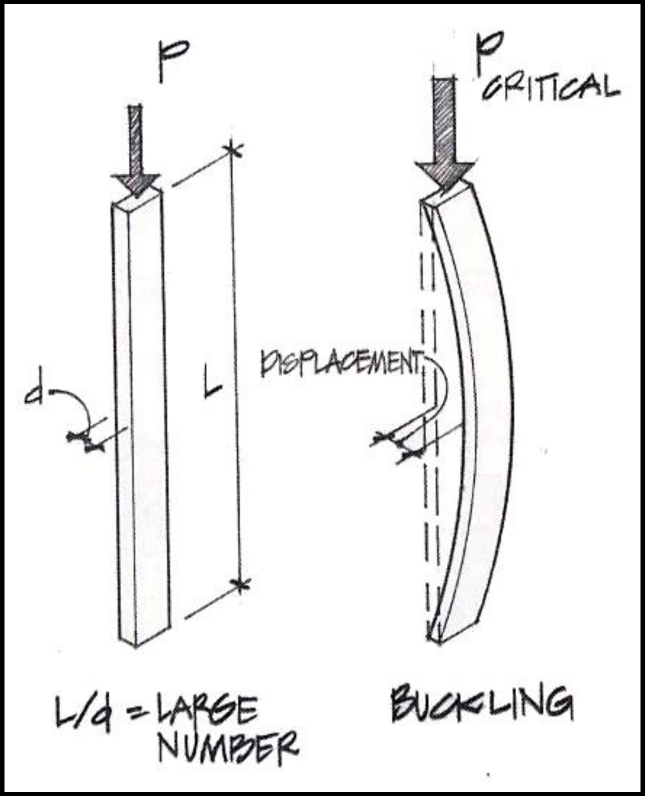
Compression Members (revisited)

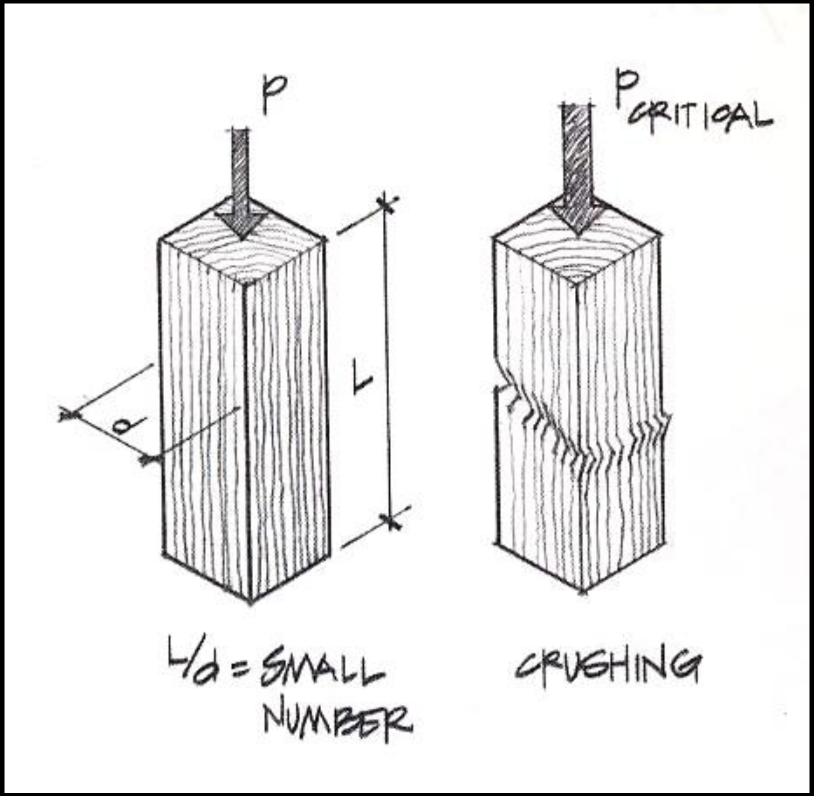
- *designed for strength & stresses*
- *designed for serviceability & deflection*
- *need to design for <u>stability</u>*
  - *ability to support a specified load without sudden or unacceptable deformations*



Effect of Length (revisited)

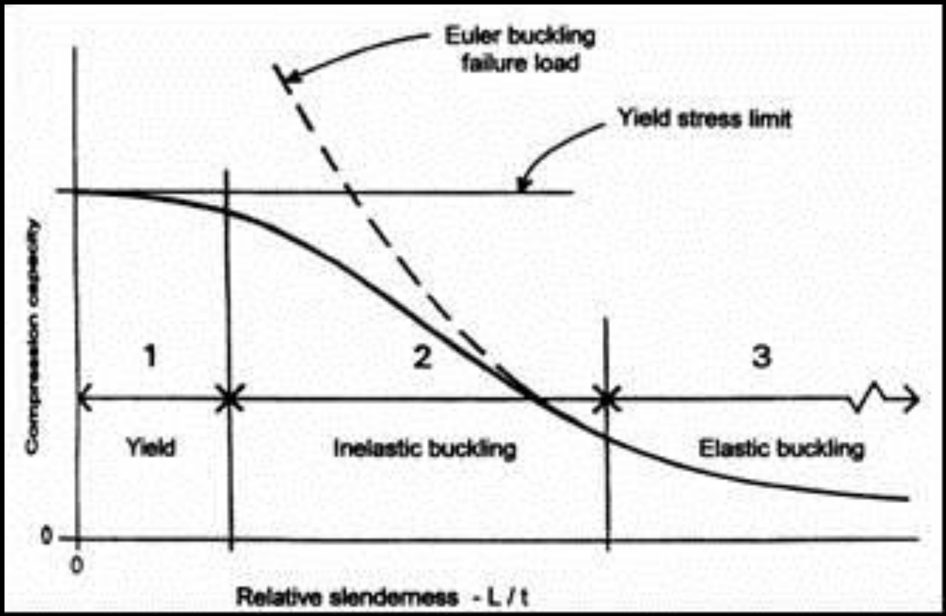
- *long & slender*
- *short & stubby*





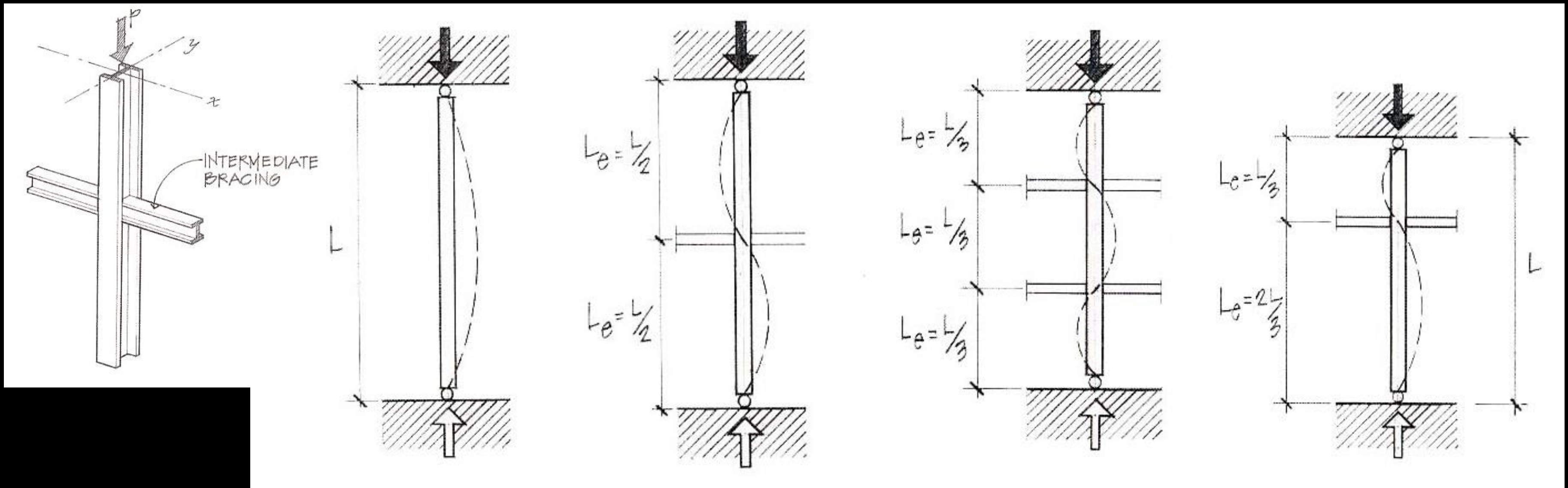
Critical Stresses (revisited)

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



Bracing (revisited)

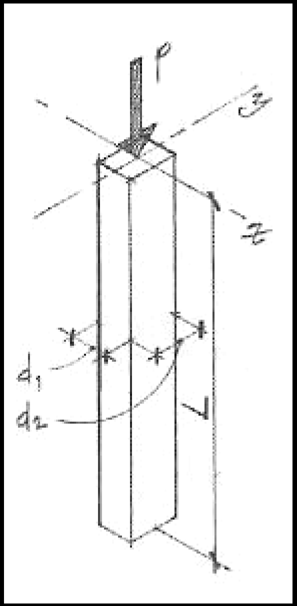
- *bracing affects shape of buckle in one direction*
- *both should be checked!*



(a) No bracing. (b) Braced at midpoint. (c) Third-point bracing. (d) Asymmetric bracing.

Wood Columns

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



$$f_c = \frac{P}{A} \leq F_c'$$

  - *where F_c' is the allowable compressive strength parallel to the grain*
  - *bracing common*

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

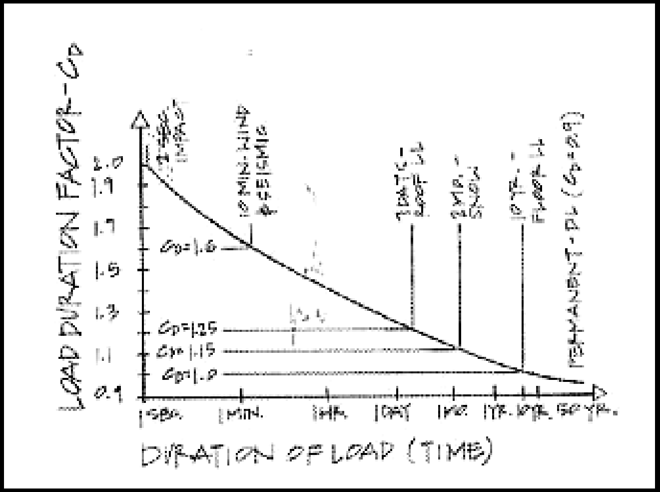
  C_D = load duration factor

  C_M = wet service factor (1.0 dry)

  C_t = temperature factor

  C_F = size factor

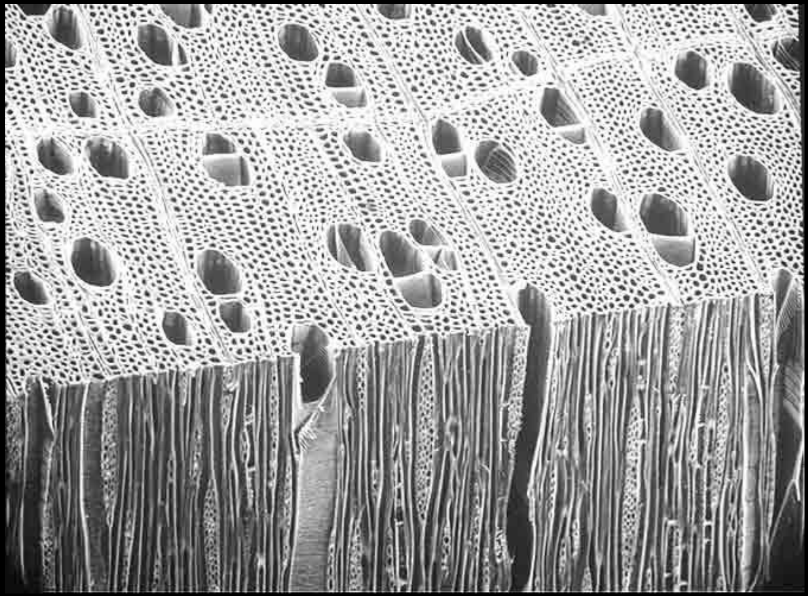
  C_p = column stability factor $= f\left(F_{cE} / F_c^*\right)$



(Table 5.2)

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

Column Stability Factor C_p

"C_p"

$F_c' = C_p \cdot F_c^*$ $F_{cE} = \frac{.30\,E}{(l_e/d)^2}$ for sawn posts $F_{cE} = \frac{.418\,E}{(l_e/d)^2}$ for Glu-Lam posts

F_{cE}/F_c^*	Sawn C_p	Glu-Lam C_p	F_{cE}/F_c^*	Sawn C_p	Glu-Lam C_p	F_{cE}/F_c^*	Sawn C_p	Glu-Lam C_p	F_{cE}/F_c^*	Sawn C_p	Glu-Lam C_p
0.00	0.000	0.000	0.60	0.500	0.538	1.20	0.750	0.822	2.40	0.894	0.940
0.01	0.010	0.010	0.61	0.506	0.545	1.22	0.755	0.826	2.45	0.897	0.941
0.02	0.020	0.020	0.62	0.512	0.552	1.24	0.760	0.831	2.50	0.899	0.943
0.03	0.030	0.030	0.63	0.518	0.559	1.26	0.764	0.836	2.55	0.901	0.944
0.04	0.040	0.040	0.64	0.524	0.566	1.28	0.769	0.840	2.60	0.904	0.946
0.05	0.049	0.050	0.65	0.530	0.573	1.30	0.773	0.844	2.65	0.906	0.947
0.06	0.059	0.060	0.66	0.536	0.580	1.32	0.777	0.848	2.70	0.908	0.949
0.07	0.069	0.069	0.67	0.542	0.587	1.34	0.781	0.852	2.75	0.910	0.950
0.08	0.079	0.079	0.68	0.548	0.593	1.36	0.785	0.855	2.80	0.912	0.951
0.09	0.088	0.089	0.69	0.553	0.600	1.38	0.789	0.859	2.85	0.914	0.952
0.10	0.098	0.099	0.70	0.559	0.607	1.40	0.793	0.862	2.90	0.916	0.953
0.11	0.107	0.109	0.71	0.564	0.613	1.42	0.796	0.865	2.95	0.917	0.954
0.12	0.117	0.118	0.72	0.569	0.619	1.44	0.800	0.868	3.00	0.919	0.955
0.13	0.126	0.128	0.73	0.575	0.626	1.46	0.803	0.871	3.05	0.920	0.956
0.14	0.136	0.138	0.74	0.580	0.632	1.48	0.807	0.874	3.10	0.922	0.957
0.15	0.145	0.147	0.75	0.585	0.638	1.50	0.810	0.877	3.15	0.923	0.958
0.16	0.154	0.157	0.76	0.590	0.644	1.52	0.813	0.879	3.20	0.925	0.959
0.17	0.164	0.167	0.77	0.595	0.650	1.54	0.816	0.882	3.25	0.926	0.960
0.18	0.173	0.176	0.78	0.600	0.655	1.56	0.819	0.884	3.30	0.927	0.961
0.19	0.182	0.186	0.79	0.605	0.661	1.58	0.822	0.887	3.35	0.929	0.961

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 (chart)
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 $$F_{cE} = \frac{K_{cE}E}{\left(\frac{L_e}{d}\right)^2}$$
      • 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 (chart)

Procedure for Design (cont'd)

6. calculate $F_c' = F_c^* C_p$
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**.

Specific Column Charts

TABLE 6.1 Safe Loads for Wood Columns[a]

Column Section		Unbraced Length (ft)										
Nominal Size	Area (in.^{2})	6	8	10	12	14	16	18	20	22	24	26
4 × 4	12.25	11.1	7.28	4.94	3.50	2.63						
4 × 6	19.25	17.4	11.4	7.76	5.51	4.14						
4 × 8	25.375	22.9	15.1	10.2	7.26	6.46						
6 × 6	30.25	27.6	24.8	20.9	16.9	13.4	10.7	8.71	7.17	6.53		
6 × 8	41.25	37.6	33.9	28.5	23.1	18.3	14.6	11.9	9.78	8.91		
6 × 10	52.25	47.6	43.0	36.1	29.2	23.1	18.5	15.0	13.4	11.3		
8 × 8	56.25	54.0	51.5	48.1	43.5	38.0	32.3	27.4	23.1	19.7	16.9	14.6
8 × 10	71.25	68.4	65.3	61.0	55.1	48.1	41.0	34.7	29.3	24.9	21.4	18.4
8 × 12	86.25	82.8	79.0	73.8	66.7	58.2	49.6	42.0	35.4	30.2	26.0	22.3
10 × 10	90.25	88.4	85.9	83.0	79.0	73.6	67.0	60.0	52.9	46.4	40.4	35.5
10 × 12	109.25	107	104	100	95.6	89.1	81.2	72.6	64.0	56.1	48.9	42.9
10 × 14	128.25	126	122	118	112	105	95.3	85.3	75.1	65.9	57.5	50.4
12 × 12	132.25	130	128	125	122	117	111	104	95.6	86.9	78.3	70.2
14 × 14	182.25	180	178	176	172	168	163	156	148	139	129	119
16 × 16	240.25	238	236	234	230	226	222	216	208	200	190	179

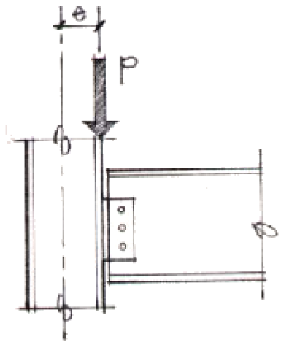
[a] Load capacity in kips for solid-sawn sections of No. 1 grade Douglas fir-larch with no adjustment for moisture or load duration conditions.

Timber Construction by Code

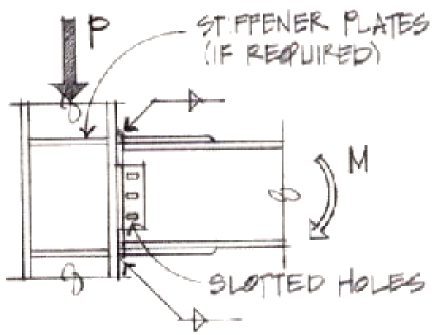
- *light-frame*
  - *light loads*
  - *2x's*
  - *floor joists – 2x6, 2x8, 2x10, 2x12 typical at spacings of 12", 16", 24"*
  - *normal spans of 20-25 ft or 6-7.5 m*
  - *plywood spans between joists*
  - *stud or load-bearing masonry walls*
  - *limited to around 3 stories – fire safety*

Design of Columns with Bending

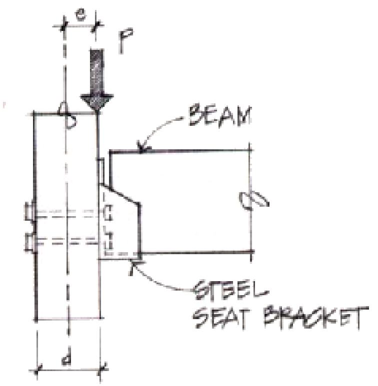
- *satisfy*
  - *strength*
  - *stability*
- *pick*
  - *section*



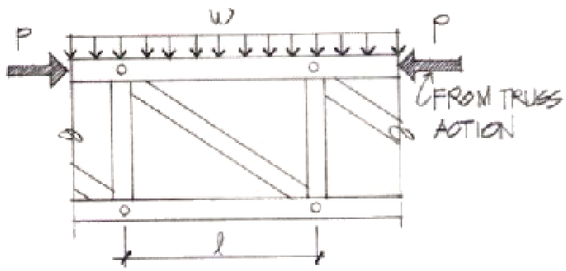
(a) Framed beam (shear) connection.
e = *Eccentricity;* M = P × e



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



(c) Timber beam–column connection.
e = d/2 = *eccentricity;* M = P × e



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

Design

- *Wood*

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

[] 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