APPLIED ARCHITECTURAL STRUCTURES:
STRUCTURAL ANALYSIS AND SYSTEMS
ARCH 631
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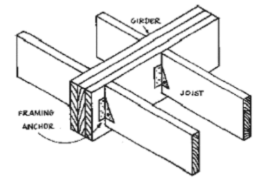
FALL 2013

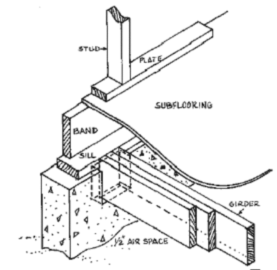
lecture
nineteen

wood construction and design

Timber Construction

- all-wood framing systems
  - studs, beams, floor diaphragms, shearwalls
  - glulam arches & frames
  - post & beams
  - trusses
- composite construction
  - masonry shear walls
  - concrete
  - steel



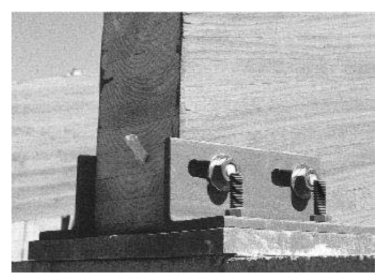


Timber Construction

- studs, beams
- floor diaphragms & shear walls

Timber Construction

- glulam arches & frames
  - manufactured or custom shapes
  - glue laminated
  - bigger members



Timber Construction

- *post & beam*

- *trusses*

Timber Construction

- *composite construction*

Timber Construction by Code

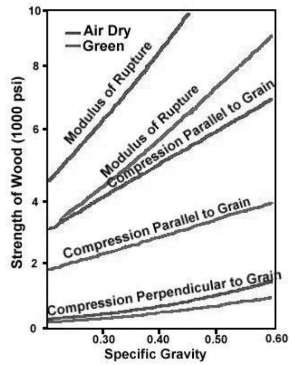
- *light-frame*
  - *light loads*
  - *2x's*
  - *floor joists – 2x6, 2x8, 2x10, 2x12 typical at spacings of 12", 16", 24"*
  - *normal spans of 20-25 ft or 6-7.5 m*
  - *plywood spans between joists*
  - *stud or load-bearing masonry walls*
  - *limited to around 3 stories –<u>fire safety</u>*

Timber Construction by Code

- *heavy timber*
  - *member size rated for fire resistance*
  - *solid or built-up sections*
  - *beams spaced 4', 6' or 8' apart or 1, 2 or 2.5 m*
  - *normal spans of 10-20 ft or 3-6 m*
  - *timber columns or load-bearing masonry walls*
  - *knee-bracing common*

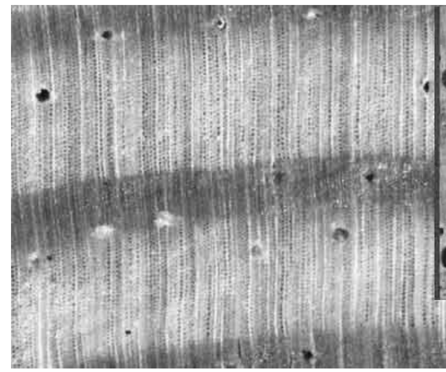
Timber

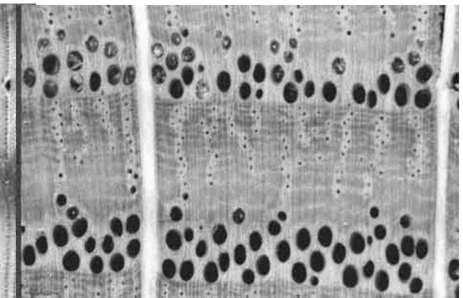
- *lightweight : strength ~ like steel*
- *strengths vary*
  - *by wood type*
  - *by direction*
  - *by "flaws"*
- *size varies by tree growth*
- *manufactured wood*
  - *assembles pieces*
  - *adhesives*



Wood Properties

- *cell structure and density*



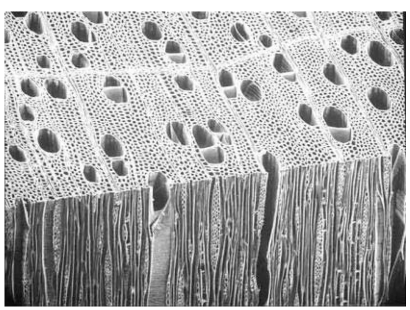


hardwood

softwood

Wood Properties

- *moisture*
  - *exchanges with air easily*
  - *excessive drying causes warping and shrinkage*
  - *strength varies some*
- *temperature*
  - *steam*
  - *volatile products*
  - *combustion*

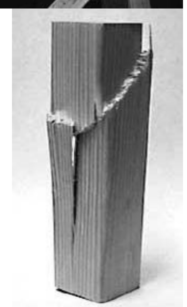


Wood Properties

- *load duration*
  - *short duration*
    - *higher loads*
  - *normal duration*
    - *> 10 years*
- *creep*
  - *additional deformation with no additional load*

Wood Properties

- strength
  - allowable design loads are given with respect to direction of loading
  - wood is weakest in shear parallel to the grain
  - wood is strongest in compression and tension parallel to grain



Lumber Grading

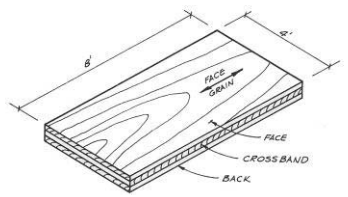
- light-framing
  - construction
  - standard
  - utility
  - economy
- structural light-framing
  - select structural
  - no. 1, 2, & 3

visual

mechanical

Engineered Wood

- plywood
  - veneers at different orientations
  - glued together
  - split resistant
  - higher and uniform strength
  - limited shrinkage and swelling
  - used for sheathing, shear walls, diaphragms

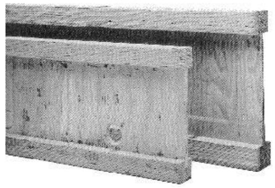


Engineered Wood

- glued-laminated timber
  - glulam
  - short pieces glued together
  - straight or curved
  - grain direction parallel
  - higher strength
  - more expensive than sawn timber
  - large members (up to 100 feet!)
  - flexible forms

Engineered Wood

- I sections
  - beams
- other products
  - pressed veneer strip panels (Parallam)

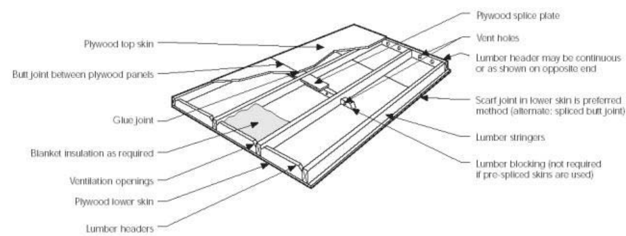


- wood fibers
  - Hardieboard: cement & wood

Timber Elements

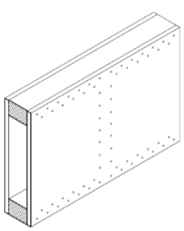
- stressed-skin elements
  - modular built-up “plates”
  - typically used for floors or roofs

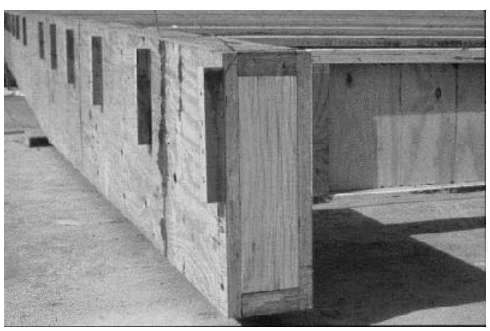
Figure 1. Typical Two-Sided Stressed-Skin Panel



Timber Elements

- built-up box sections
  - built-up beams
  - usually site-fabricated
  - bigger spans



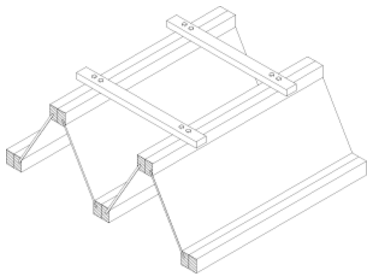


Timber Elements

- trusses
  - long spans
  - versatile
  - common in roofs

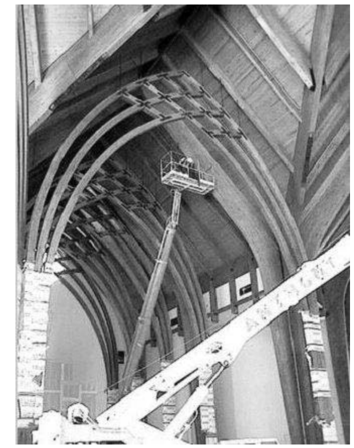
Timber Elements

- *folded plates and arch panels*
  - *usually of plywood*



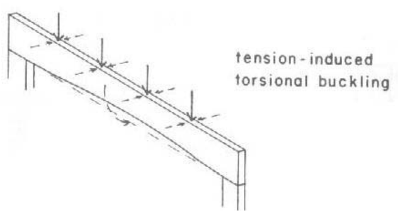
Timber Elements

- *arches and lamellas*
  - *arches commonly laminated timber*
  - *long spans*
  - *usually only for roofs*



Timber Elements

- *beams*
  - *joists*
  - *girders*
  - *lateral bracing*
  - *deflection*
    - *elastic*
    - *creep*



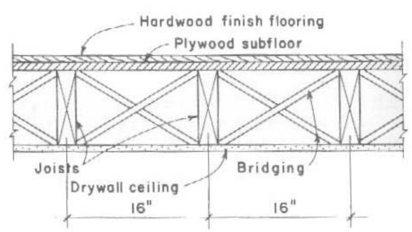


Figure 5.2 Typical joist floor construction.

Approximate Depths

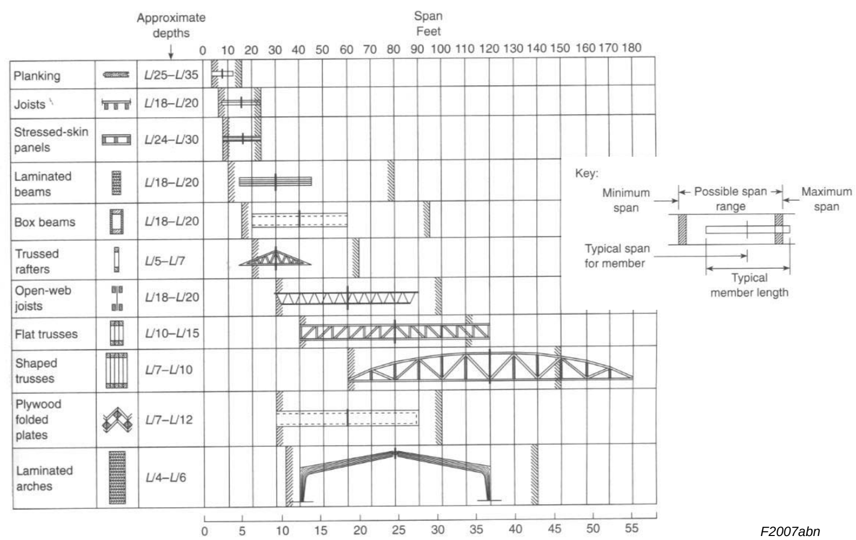


FIGURE 15–3 Approximate span ranges for timber systems.

Wood Design

- National Design Specification
  - National Forest Products Association
  - ASD & LRFD (combined 2005)
  - adjustment factors x tabulated stress = allowable stress
  - adjustment factors terms, C with subscript
  - i.e, bending:

$$f_b \le F_b' = F_b \times \left(product\ of\ adjustment\ factors \right)$$

Allowable Stresses

- design values
  - F_b: bending stress
  - F_t: tensile stress strong
  - F_v: horizontal shear stress weak
  - $F_{c\perp}$: compression stress (perpendicular to grain)
  - F_c: compression stress (parallel to grain) strong
  - E: modulus of elasticity
  - F_p: bearing stress (parallel to grain)

Adjustment Factors

- terms
  - C_D = load duration factor
  - C_M = wet service factor
    - 1.0 dry ≤16% MC
  - C_F = size factor
    - visually graded sawn lumber and round timber > 12" depth

$$C_F = (12/d)^{1/9} \le 1.0$$

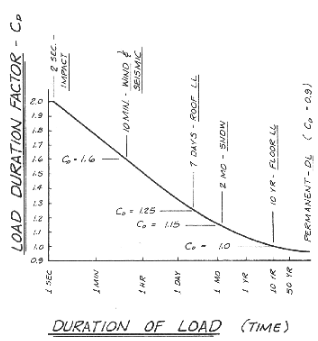
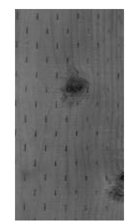


Figure 4.13 Madison curve.

Adjustment Factors

- terms
  - C_{fu} = flat use factor
    - not decking
  - C_i = incising factor
    - increase depth for pressure treatment
  - C_t = temperature factor
    - lose strength at high temperatures



Adjustment Factors

- terms
  - C_r = repetitive member factor
    - 1.15 for more than 3 joists, < 24" o.c., or connected by load-distributing element
  - C_H = shear stress factor
    - splitting
  - C_v = volume factor for glulam
    - replaces C_F for timber
  - C_L = beam stability factor
    - beams without full lateral support

Load Combinations

- design loads, take the bigger of
  - (dead loads)/0.9
  - (dead loads + any possible combination of live loads)/C_D
- deflection limits
  - <u>no load factors</u>
  - for stiffer members:
    - Δ_T max from LL + 0.5(DL)
    - for instantaneous deflection

Deflection Limits

- relies on Uniform Building Code specs

Use	LL only	DL+LL
Roof beams:		
Industrial	L/180	L/120
Commercial		
plaster ceiling	L/240	L/180
no plaster	L/360	L/240
Floor beams:		
Ordinary Usage	L/360	L/240

Wood Beam Design - Glulam

- find M
- determine allowable stress
  - Pinus Radiata (man.) basic working stress (MPa)

Timberbond Glulam

Moisture content	Bending parallel F'b	Compression parallel F'c	Tension parallel F'c	Shear in beam F's	Compression perpendicular F'p	Modular elasticity E(GPa)
F11						
16%	13.8	12.5	8.3	1.9	4.3	12.0
Engineering						
16%	12.1	11.7	7.3	1.8	4.0	11.0
No.1 Framing						
16%	10.6	10.9	6.4	1.8	4.0	9.0
No.2 Framing						
16%	8.2	10.0	4.9	1.8	4.0	8.0

Wood Beam Design - Glulam

- calculate $S_{required}$
- choose width and height so that $bh^2/6 > S_{req'd}$
- evaluate V, Δ, T
- consider bracing, connections

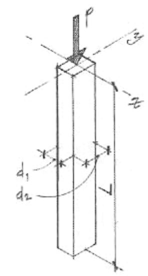
Technical Information

STANDARD SIZES OF STRAIGHT GLULAM MEMBERS

Beam Width (mm)			Beam Depth (mm)	
Nominal Dimension	Premium finish	Utility & Standard finish	No. of Laminations	Beam Depth
50	38	40	1	45
75	63	65	2	90
100	88	90	3	135
125	110	113	4	180
150	133	135	5	225
200	178	180	6	270
225	203	205	7	315
250	228	230	8	360
300	278	280	9	405
			10	450
			11	495
			12	540
			etc	etc

Wood Columns

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



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

  - where F'_c is the allowable compressive strength parallel to the grain

Allowable Wood Stress

$$F_c' = F_c(C_D)(C_M)(C_t)(C_F)(C_p)$$

- where:

  F_c = compressive strength parallel to grain

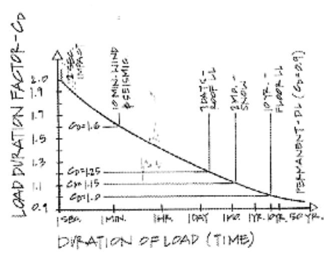
  C_D = load duration factor

  C_M = wet service factor (1.0 dry)

  C_t = temperature factor

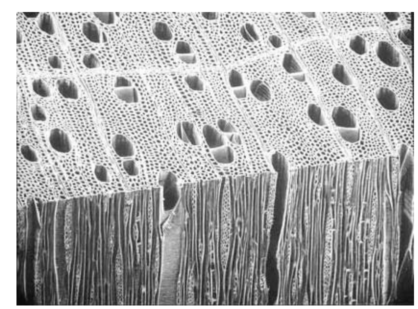
  C_F = size factor

  C_p = column stability factor



Strength Factors

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



- stability, C_p
  - combination curve - tables

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

C_p Charts

Table 14 Column Stability Factor C_p.

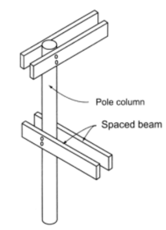
"C_p" $F_c' = C_p \cdot F_c^*$ $F_{CE} = \frac{.30\,E}{(l/d)^2}$ for sawed posts $F_{CE} = \frac{.418\,E}{(l/d)^2}$ for glu-lam posts

$\frac{F_{CE}}{F_C^*}$	Sawed C_p	Glu-Lam C_p	$\frac{F_{CE}}{F_C^*}$	Sawed C_p	Glu-Lam C_p	$\frac{F_{CE}}{F_C^*}$	Sawed C_p	Glu-Lam C_p	$\frac{F_{CE}}{F_C^*}$	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

Procedure

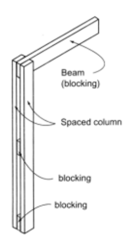
1. *obtain F'_c*
   - *find l_e/d or assume (l_e /d $\leq$ 50)*
   - *compute* $$F_{cE} = \frac{K_{cE}E}{\left(\frac{l_e}{d}\right)^2}$$
     - *K_{cE} =0.3 sawn*
     - *K_{cE} = 0.418 glu-lam*
   - *compute $F_c^* \approx F_c C_D$*
   - *find F_{cE}/F_c^* and get C_p*

$$F_c' = F_c^* C_p$$



Procedure

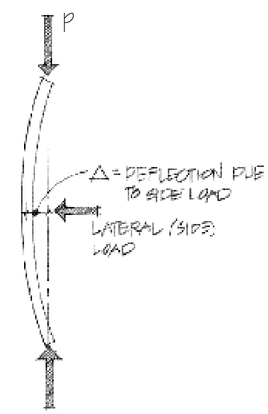
2. *select a section*
   - *if P & A known, set stress at limit*
     - *solve for l_e, L, or d_{min}*
   - *if P & l_e known,*
     - *find A, or d_{min}*
3. *continue from 2 until F'_c satisfied*



Eccentric Loading Stress Limit

- *in reality, as the column flexes, the moment increases*
- *<u>P-Δ effect</u>*

$$\frac{f_a}{F_a} + \frac{f_b \times (Magnification\ factor)}{F_{bx}} \leq 1.0$$



Column with Bending Design

- interaction equation

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

() term – magnification factor for P-Δ

F'_{bx} – allowable bending strength

Structural Supervision

- review changes in shop drawings!
- inspection of construction
  - verify compliance with plans
- some materials require more
  - variability of materials
  - sampling and testing

Construction Requirements - Wood

- if not treated
  - height above exposed ground
    - 18" joists, 12" girders
  - in masonry or concrete
    - provide ½" air space
- foundation sills must be treated
- structural members
  - must be protected from exposure to weather and water

Construction Requirements - Wood

- crawl space ventilation
- fire stops
  - walls
    - at ceiling and floor and every 10' along
  - interconnections
    - soffits and dropped ceilings
  - concealed spaces
    - access for passage of fire
    - stairways & between floors and roof