

**ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN**

ARCH 331

DR. ANNE NICHOLS

SUMMER 2014

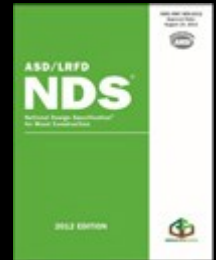
lecture
twelve

**wood construction:
materials & beams**



Wood Beam Design

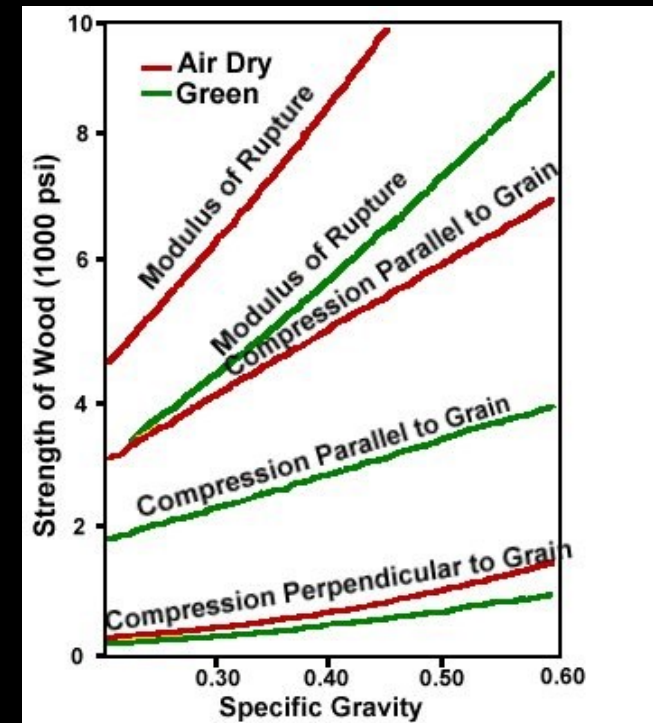
- *National Design Specification*
 - *National Forest Products Association*
 - *ASD & LRFD (combined 2005)*
 - *adjustment factors x tabulated stress = allowable stress*
 - *adjustment factors terms, C with subscript*
 - *i.e, bending:*



$$f_b \leq F'_b = F_b \times (\text{product of adjustment factors})$$

Timber

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

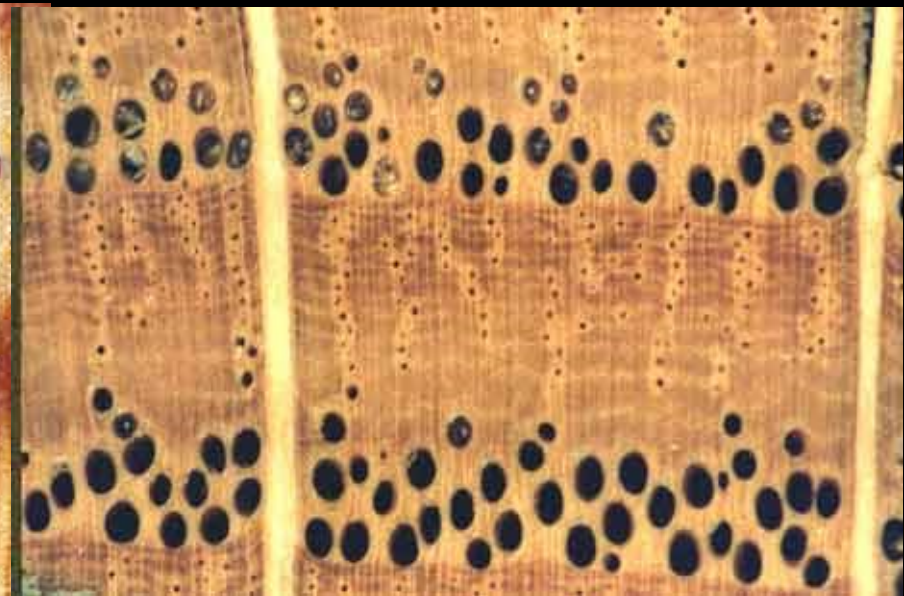


Wood Properties

- *cell structure and density*



softwood

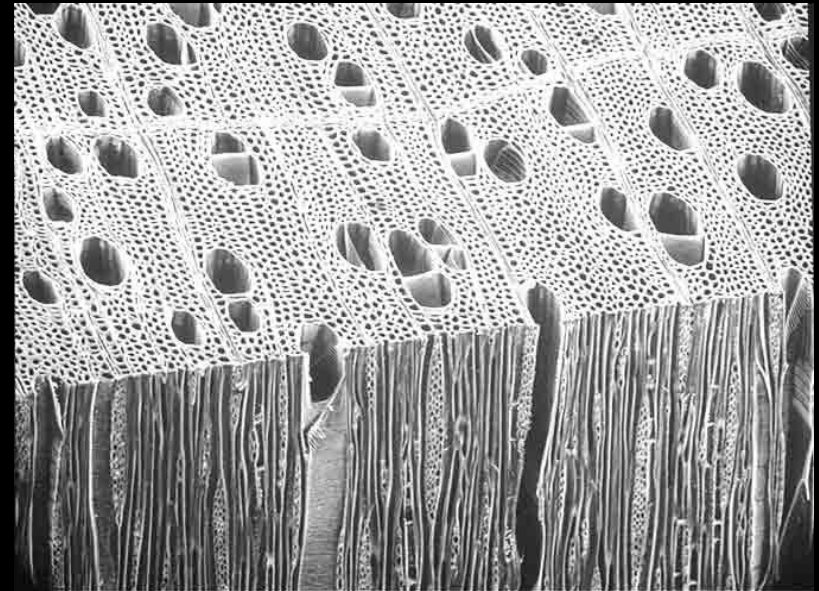


hardwood

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

Wood Properties

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



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

Wood Properties

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



Structural Lumber

- dimension – 2 x's (nominal)
- beams, posts, timber, planks
- grading
 - select structural
 - no. 1, 2, & 3
- tabular values by species
- glu-lam
- plywood



Species and commercial grade	Size classification	Design values in pounds per square inch				
		Extreme fiber in bending "F _b "		Tension parallel to grain "F _t "	Horizontal shear "F _v "	Compression perpendicular to grain "F _{cL} "
		Single-member uses	Repetitive-member uses			
SOUTHERN PINE (Surfaced dry. Used at 19% max. m.c.)						
Select Structural		2000	2300	1150	100	565
Dense Select Structural		2350	2700	1350	100	660
No. 1		1700	1950	1000	100	565
No. 1 Dense	2" to 4" thick 2" to 4" wide	2000	2300	1150	100	660
No. 2		1400	1650	825	90	565
No. 2 Dense		1650	1900	975	90	660
No. 3		775	900	450	90	565
No. 3 Dense		925	1050	525	90	660
Stud		775	900	450	90	565
Construction Standard	2" to 4" thick	1000	1150	600	100	565
Utility	4" wide	575	675	350	90	565
		275	300	150	90	565
Select Structural		1750	2000	1150	90	565

Adjustment Factors

- *terms*

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

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

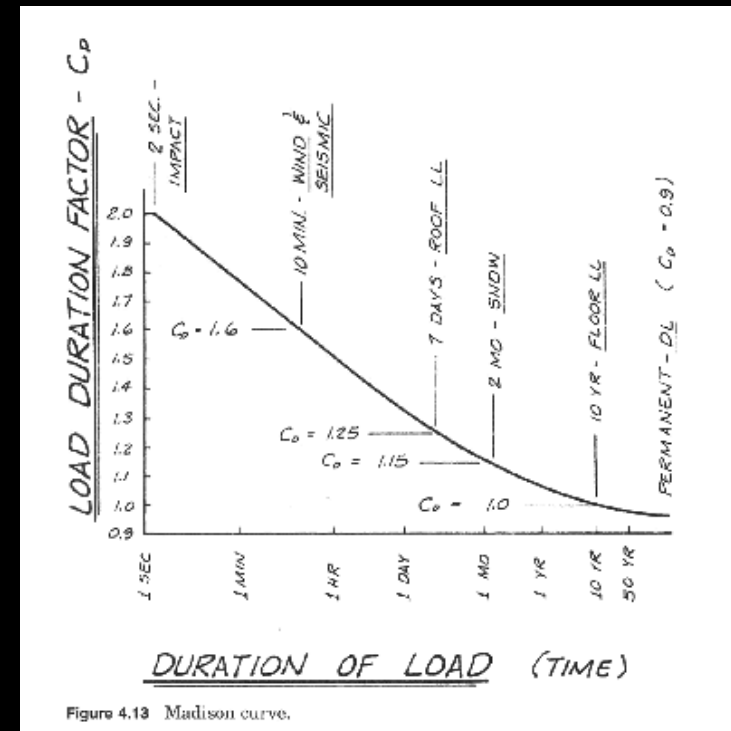


Table 10.3 (pg 376)

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*
 - C_H = *shear stress factor*
 - *splitting*
 - C_V = *volume factor*
 - *same as C_F for glue laminated timber*
 - C_L = *beam stability factor*
 - *beams without full lateral support*
 - C_C = *curvature factor for laminated arches*

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)

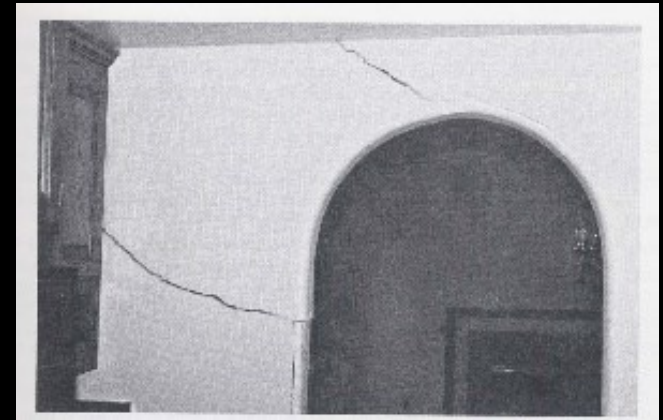
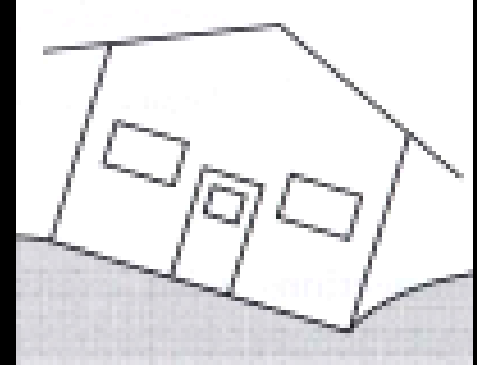


Load Combinations

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

Beam Design Criteria

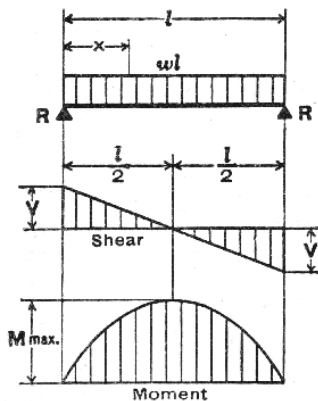
- *strength design*
 - *bending stresses predominate*
 - *shear stresses occur*
- *serviceability*
 - *limit deflection and cracking*
 - *control noise & vibration*
 - *no excessive settlement of foundations*
 - *durability*
 - *appearance*
 - *component damage*
 - *ponding*



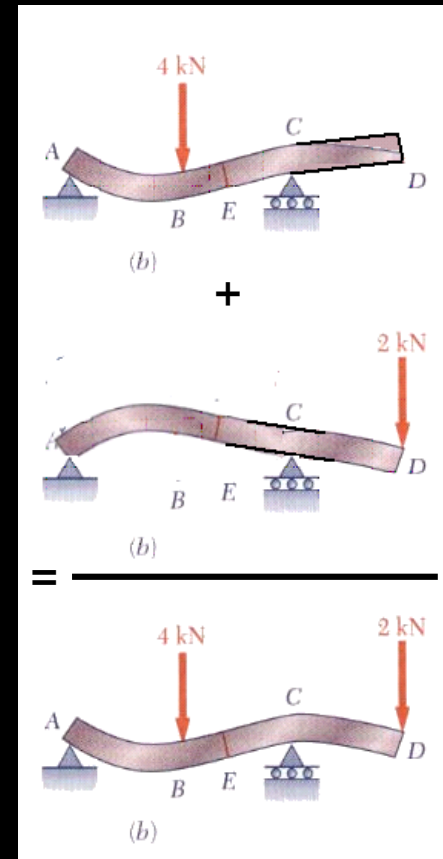
Beam Design Criteria

- *superpositioning*
 - use of beam charts
 - elastic range only!
 - “add” moment diagrams
 - “add” deflection **CURVES** (not maximums)

1. SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD



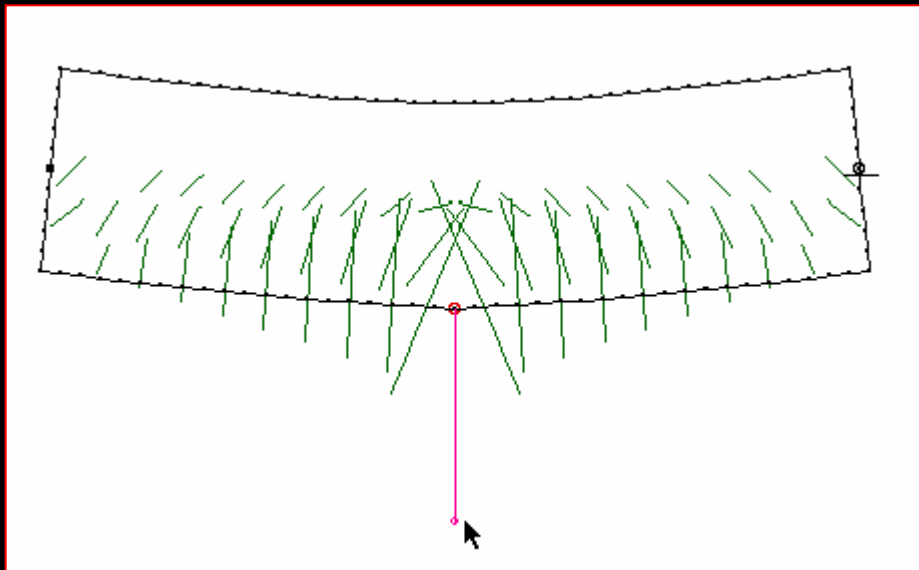
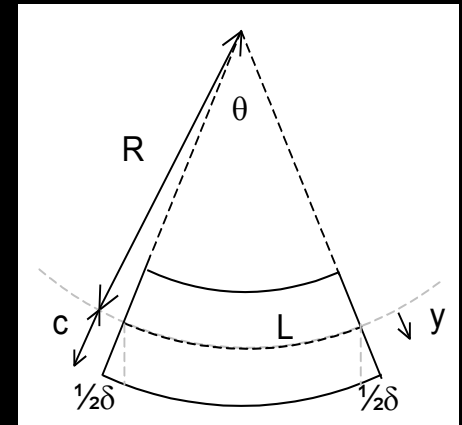
Total Equiv. Uniform Load	$= wl$
$R = V$	$= \frac{wl}{2}$
V_x	$= w \left(\frac{l}{2} - x \right)$
$M_{\text{max.}} \text{ (at center)}$	$= \frac{wl^2}{8}$
M_x	$= \frac{wx}{2} (l - x)$
$\Delta_{\text{max.}} \text{ (at center)}$	$= \frac{5wl^4}{384EI}$
Δ_x	$= \frac{wx}{24EI} (l^3 - 2lx^2 + x^3)$



Beam Deformations

- *curvature relates to*
 - *bending moment*
 - *modulus of elasticity*
 - *moment of inertia*

$$\frac{1}{R} = \frac{M}{EI}$$



$$\text{curvature} = \frac{M(x)}{EI}$$

$$\theta = \text{slope} = \int \frac{M(x)}{EI} dx$$

$$\Delta = \text{deflection} = \iint \frac{M(x)}{EI} dx$$

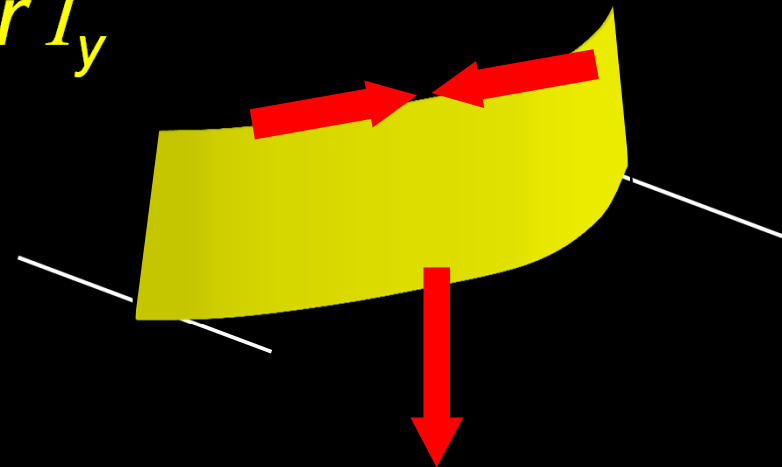
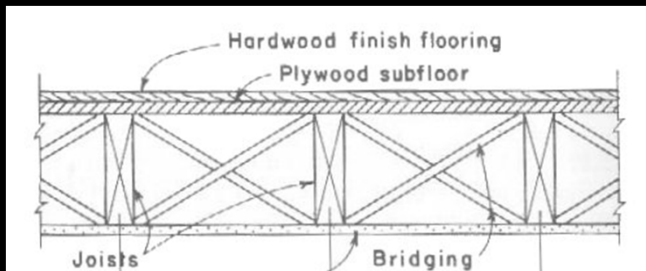
Deflection Limits

- *based on service condition, severity*

<i>Use</i>	<i>LL only</i>	<i>DL+LL</i>
<i>Roof beams:</i>		
<i>Industrial</i>	<i>L/180</i>	<i>L/120</i>
<i>Commercial</i>		
<i>plaster ceiling</i>	<i>L/240</i>	<i>L/180</i>
<i>no plaster</i>	<i>L/360</i>	<i>L/240</i>
<i>Floor beams:</i>		
<i>Ordinary Usage</i>	<i>L/360</i>	<i>L/240</i>
<i>Roof or floor (damageable elements)</i>		<i>L/480</i>

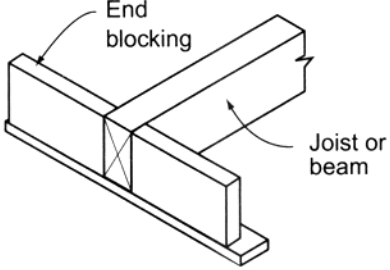
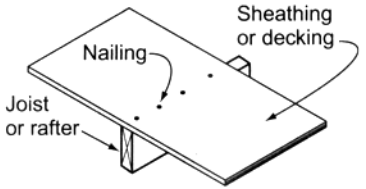
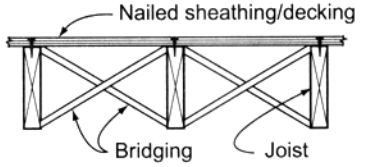
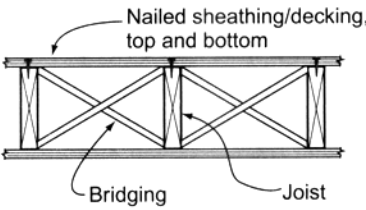
Lateral Buckling

- *lateral buckling caused by compressive forces at top coupled with insufficient rigidity*
- *can occur at low stress levels*
- *stiffen, brace or bigger I_y*



Timber Beam Bracing

Table 9.3 Lateral bracing requirements for timber beams.

Beam Depth/Width Ratio	Type of Lateral Bracing Required	Example
2 to 1	None	
3 to 1	The ends of the beam should be held in position	 <p>End blocking Joist or beam</p>
5 to 1	Hold the compression edge in line (continuously)	 <p>Nailing Sheathing or decking Joist or rafter</p>
6 to 1	Diagonal bracing should be used	 <p>Nailed sheathing/decking Bridging Joist</p>
7 to 1	Both edges of the beam should be held in line	 <p>Nailed sheathing/decking, top and bottom Bridging Joist</p>

Design Procedure

1. Know F_{all} for the material or F_U for LRFD

2. Draw V & M , finding M_{max}



3. Calculate $S_{req'd}$ ($f_b \leq F_b$)

b

4. Determine section size

$$S = \frac{bh^2}{6}$$

Beam Design

4*. *Include self weight for M_{max}*
– *and repeat 3 & 4 if necessary*

5. *Consider lateral stability*

Unbraced roof trusses were blown down in 1999 at this project in Moscow, Idaho.

Photo: Ken Carper



Beam Design

6. Evaluate shear stresses - horizontal

- $(f_v \leq F_v)$

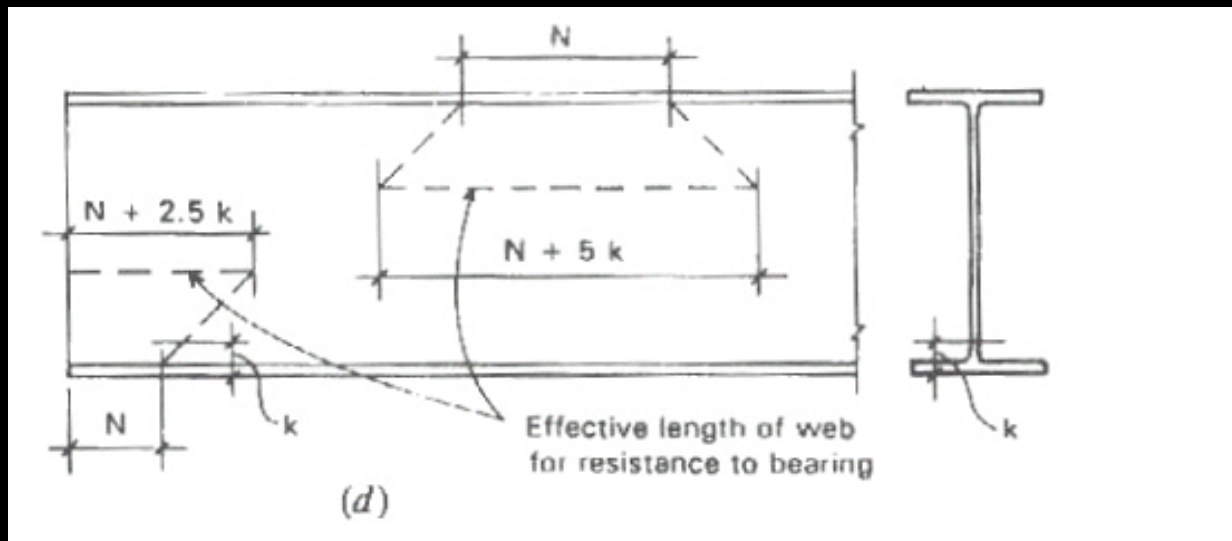
- rectangles and W's $f_{v-\max} = \frac{3V}{2A} \approx \frac{V}{A_{web}}$

- general $f_{v-\max} = \frac{VQ}{Ib}$

Beam Design

7. Provide adequate bearing area at supports

$$f_p = \frac{P}{A} \leq F_p$$



Beam Design

8. Evaluate torsion

$$(f_v \leq F_v)$$

- circular cross section

$$f_v = \frac{T\rho}{J}$$

- rectangular

$$f_v = \frac{T}{c_1 ab^2}$$

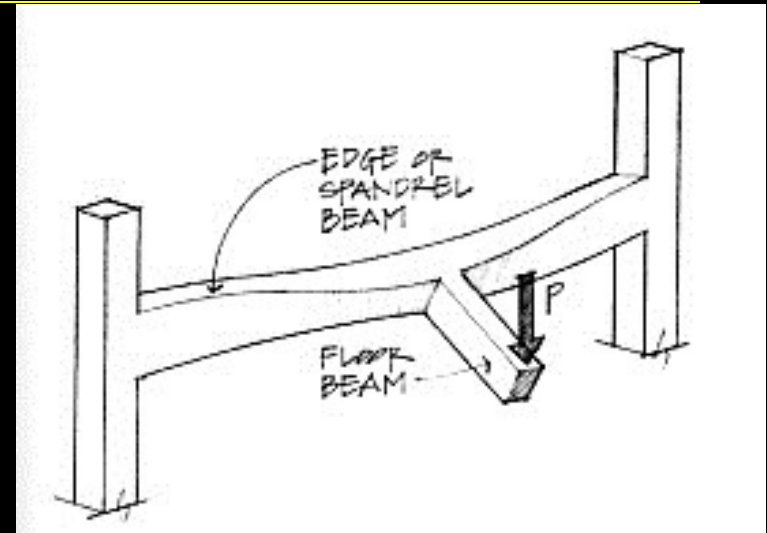
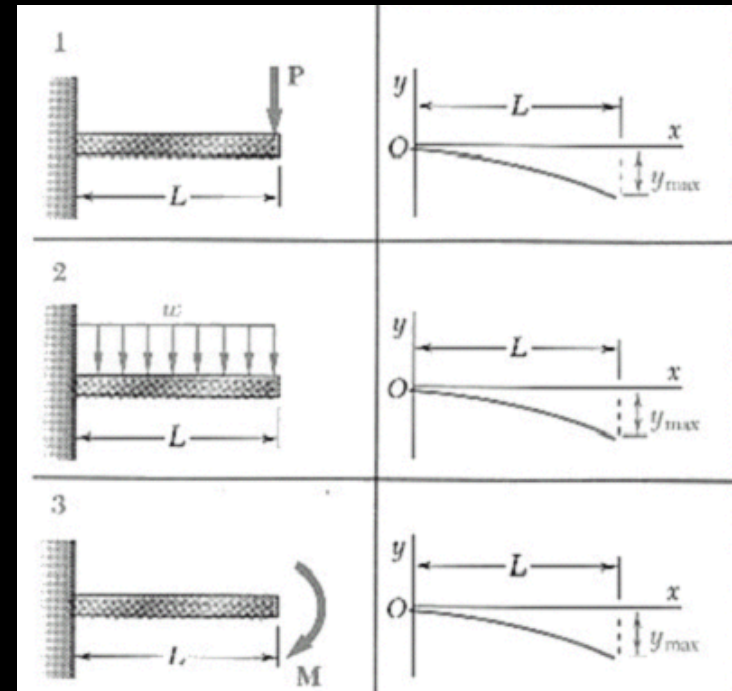
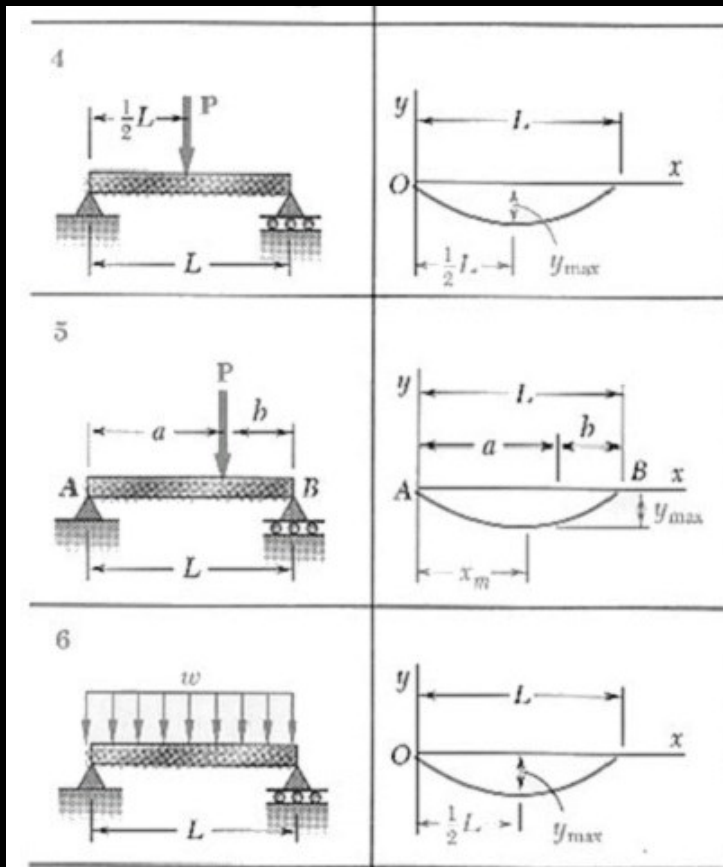


TABLE 3.1. Coefficients for Rectangular Bars in Torsion

a/b	c_1	c_2
1.0	0.208	0.1406
1.2	0.219	0.1661
1.5	0.231	0.1958
2.0	0.246	0.229
2.5	0.258	0.249
3.0	0.267	0.263
4.0	0.282	0.281
5.0	0.291	0.291
10.0	0.312	0.312
∞	0.333	0.333

Beam Design

9. Evaluate deflections



$$y_{\max}(x) = \Delta_{\text{actual}} \leq \Delta_{\text{allowable}}$$

Decking

- *across beams or joists*
- *floors: 16 in. span common*
 - *$\frac{3}{4}$ in. tongue-in-groove plywood*
 - *$\frac{5}{8}$ in. particle board over $\frac{1}{2}$ in. plywood*
 - *hardwood surfacing*
- *roofs: 24 in. span common*
 - *$\frac{1}{2}$ in. plywood*



Joists & Rafters

- allowable load tables (w)
- allowable length tables for common live & dead loads
- lateral bracing needed
- common spacings

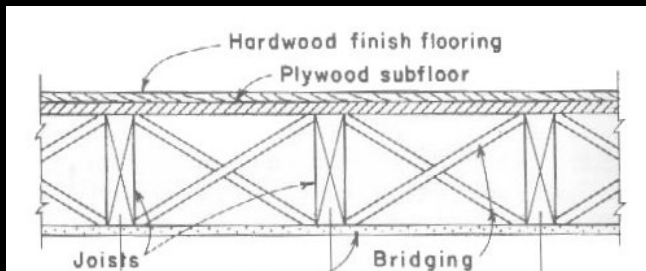


TABLE 5.5 Allowable Spans in Feet and Inches for Floor Joists

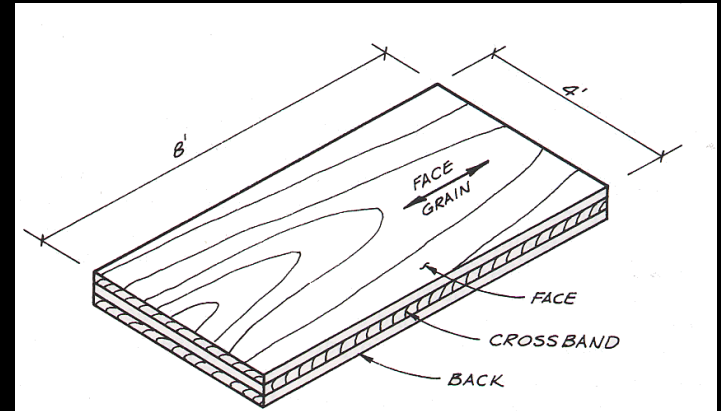
DESIGN CRITERIA:
 Deflection — For 40 psf (1.92 kN/m²) live load.
 Limited to span in inches (mm) divided by 360.
 Strength — Live load of 40 psf (1.92 kN/m²) plus dead load of 10 psf (0.48 kN/m²) determines the

Joist Size (in)	Spacing (in)	Modulus of Elasticity, E, in 1,000,000 psi		
		× 0.00689 for N/mm ²		
× 25.4 for mm		1.3	1.4	1.5
2 × 6	12.0	10-0	10-3	10-6
	16.0	9-1	9-4	9-6
	19.2	8-7	8-9	9-0
	24.0	7-11	8-2	8-4
2 × 8	12.0	13-2	13-6	13-10
	16.0	12-0	12-3	12-7
	19.2	11-3	11-7	11-10
	24.0	10-6	10-9	11-0
2 × 10	12.0	16-10	17-3	17-8
	16.0	15-3	15-8	16-0
	19.2	14-5	14-9	15-1
	24.0	13-4	13-8	14-0
2 × 12	12.0	20-6	21-0	21-6
	16.0	18-7	19-1	19-6
	19.2	17-6	17-11	18-4
	24.0	16-3	16-8	17-0
F _b	12.0	993	1,043	1,092
	16.0	1,093	1,148	1,202
	19.2	1,161	1,220	1,277
	24.0	1,251	1,314	1,376

Engineered Wood

- *plywood*

- *veneers at different orientations*
- *glued together*
- *split resistant*
- *higher and uniform strength*
- *limited shrinkage and swelling*
- *used for sheathing, decking, 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)*
 - *laminated veneer lumber (LVL)*
- *wood fibers*
 - *Hardieboard: cement & wood*

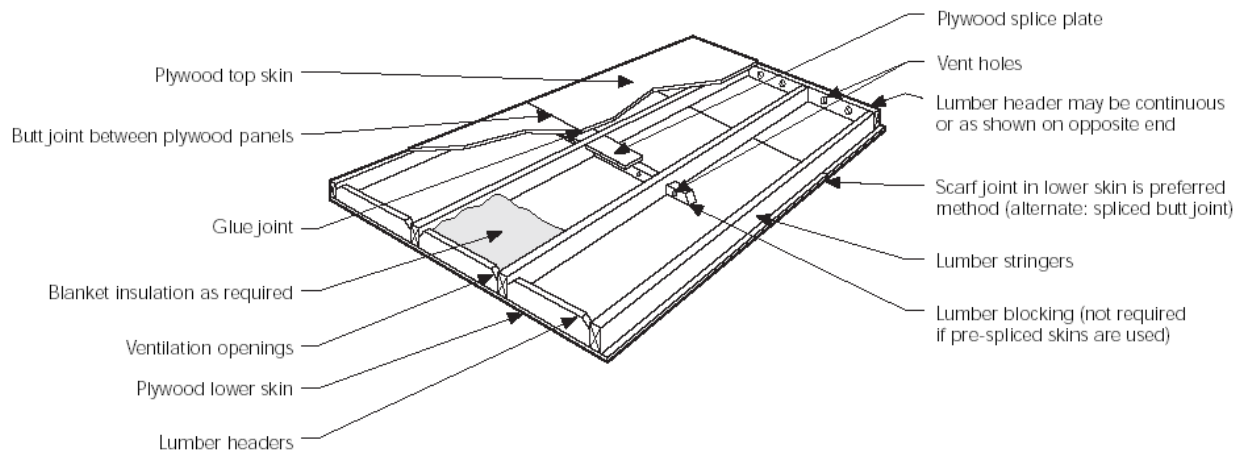


Timber Elements

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

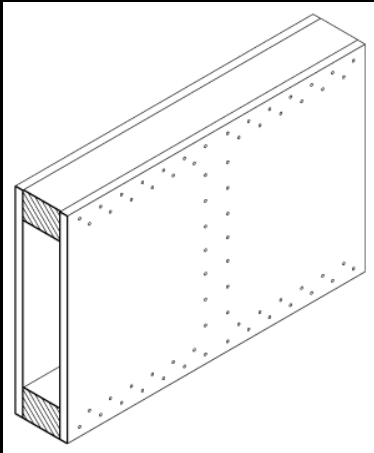


Figure 1. Typical Two-Sided Stressed-Skin Panel



Timber Elements

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



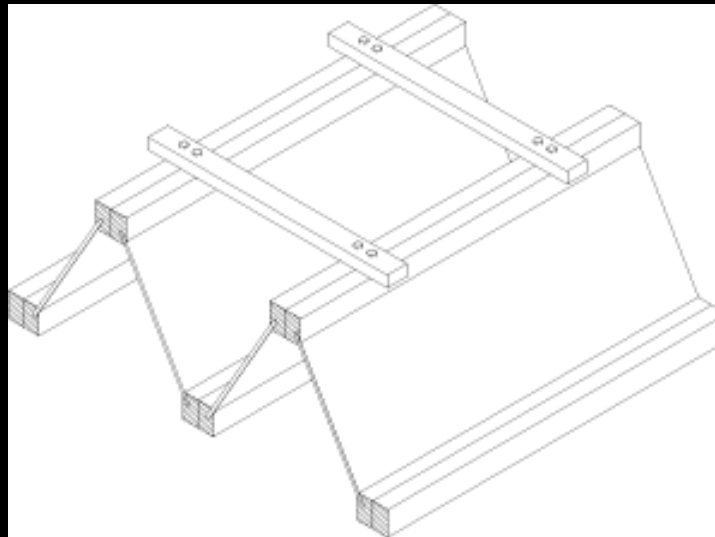
Timber Elements

- *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*



Approximate Depths

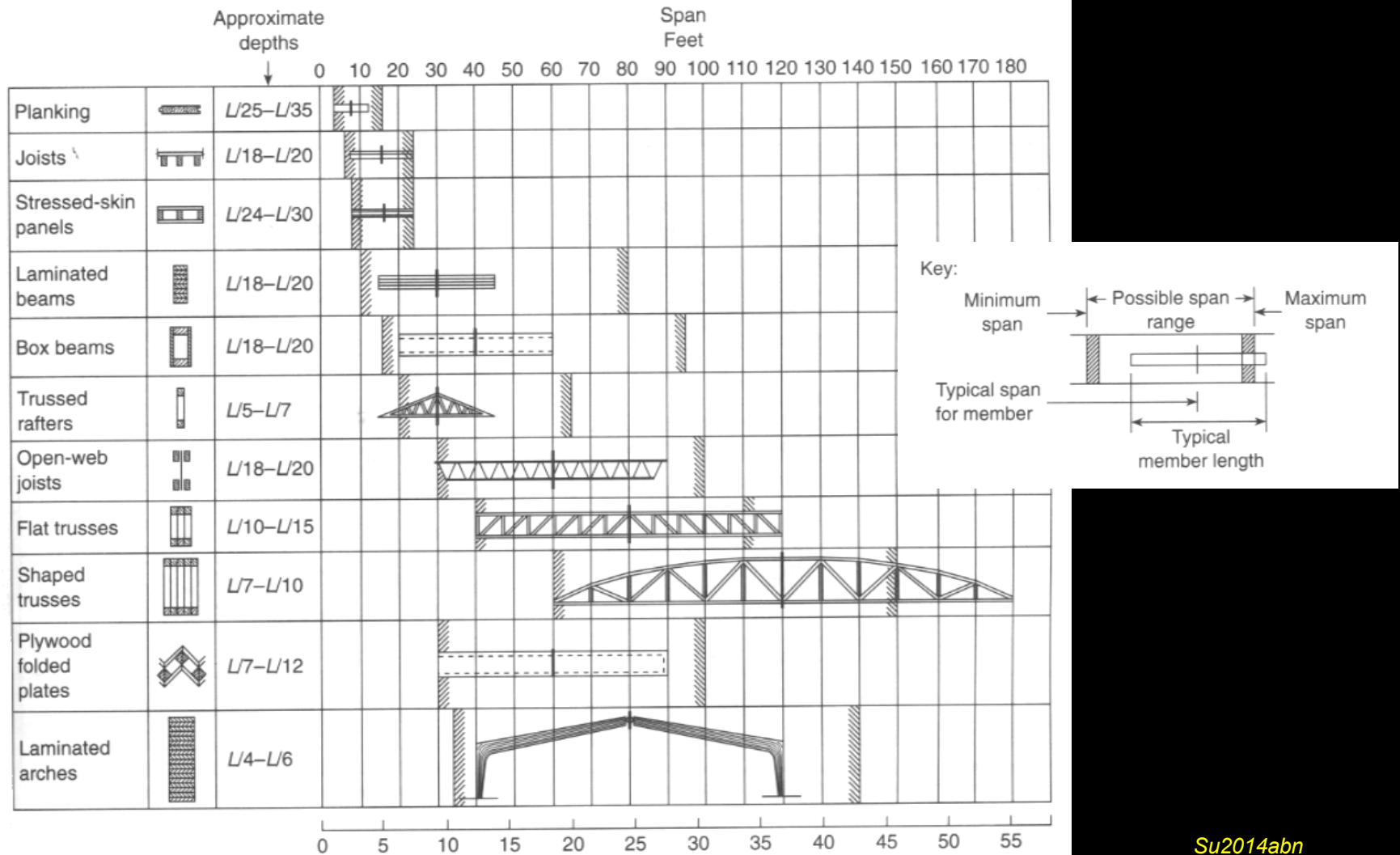


FIGURE 15-3 Approximate span ranges for timber systems. Meters