Section 2-0 Principles of Timber Design

US&R Structures Specialist Training – StS-1

Section StS1-2-0:

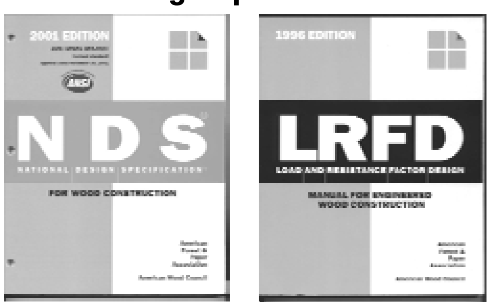
Principles of Timber Design

Jun09

Introduction

- **Wood is the primary material for providing temporary shoring during US&R operations.**
- **Timber design not always part of the structural engineering curriculum.**
- **Module introduces the principles of timber design and how they relate to US&R shoring.**

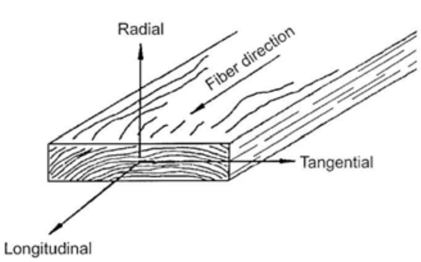
Timber Design Specifications



Wood

- *Non-Homogeneous* – primary component comprised of bonded elongated glucose monomers that form the cell walls of wood.
- *Orthotropic* – wood has unique and independent mechanical properties in the directions of three mutually perpendicular axis.
- *Anisotropic* – wood exhibits different mechanical properties when measured along different axes.

Wood - Anisotropic



USDA Forest Service *Wood Handbook*, 1999

Trees

Given all the different varieties, trees can still be dividing into two broad classes:

- **Hardwoods**
- **Softwoods**

Hardwoods – Deciduous trees. Seeds are enclosed in the a flower. Broad leaves.

Softwoods – Coniferous trees. Cone-bearing (seeds are exposed) with needle-like or scale-like evergreen leaves.

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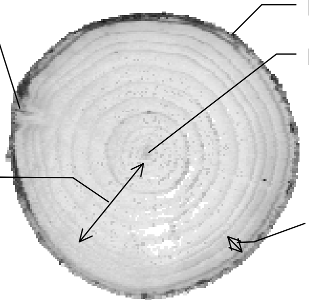
Typical Tree Cross Section



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Sapwood

- Mechanism for water and sap transport.
- Contains both living and dead cells.
- Greater portion of the wood in second-growth trees.

Heartwood

- Consists of inactive cells.
- Does not assist in water and sap transport.
- May be darker in color than softwood due to extractive content.

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Growth Rings

- A familiar characteristic of a tree or log cross section.
- Also referred to as *Annual Rings*.
- Found in trees that grow in temperate climates so that distinct yearly growing seasons occur.
- Inner portion of the growth ring forms first in the growing season and is called *Earlywood*.
- Outer portion of the growth ring forms later in the growing season and is called *Latewood*.

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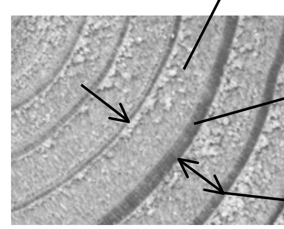
Growth Rings



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Earlywood

- Fast growing (also referred to Springwood).
- Cells with relatively large cavities & thin walls.
- Less dense and weaker than Latewood.

Latewood

- Slow growing (also referred to Summerwood).
- Cells with relatively small cavities and thick walls.
- More dense and stronger than Earlywood.

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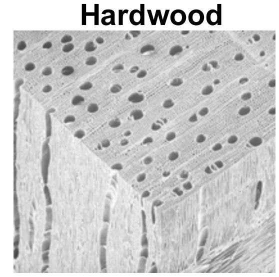
Cell Structure of Wood

Softwood

Hardwood



(*Society of Wood Science & Technology*)

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Water

- Water of a living tree can make up ⅔ of its total weight.
- Water is contained in wood as either bound water or free water.
- Bound water is held within cell walls by bonding forces between water and cellulose molecules.
- Free water is contained in the cell cavities and is not held by bonding forces (like water in a pipe.)

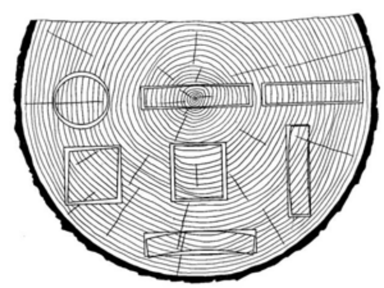
Drying of Wood

- Structural wood must be dried to reduce its moisture content to an acceptable level for the end user.
- Drying results in an increase in strength and stiffness.
- Drying results in a volume change as the cell wall shrink (shrinkage).
- General Drying processes: Air and Kiln.

Shrinkage

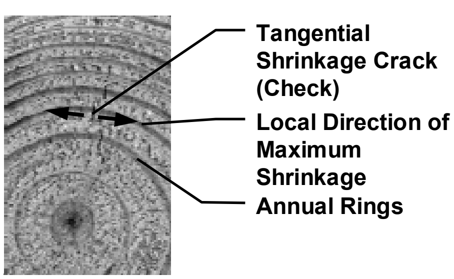
- Wood is dimensionally unstable when moisture content is reduced below its Fiber Saturation Point (*FSP*) or Green state (approx. 25%).
- Occurs as moisture is removed (seasoning).
- Degree dependent on orientation with grain: tangential, radial, and longitudinal.
  - Tangential = shrink abt 1/3% for each 1% moisture
  - Radial = shrink abt 1/5% for each 1% moisture
  - Longitudinal = Nil for D. Fir & So. Pine
- Results in defects due to grain separation.

Shrinkage



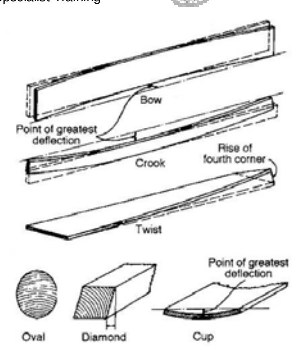
USDA Forest Service *Wood Handbook*, 1999

Tangential Shrinkage



Warping

Differential shrinkage caused by differences in radial, tangential, and longitudinal shrinkage is a major cause of warp.



USDA Forest Service *Wood Handbook*, 1999

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Factors Affecting Wood Strength and Behavior

- Wood Species
- Moisture Content
- Growing Defects such as Knots and Checks
- Shrinkage Cracks
- Wood Grain Orientation (slope of grain)
- Growth Rate (rings per inch)

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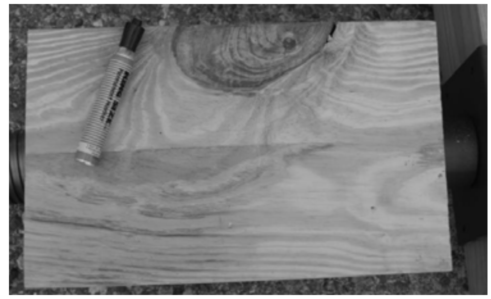
Knots



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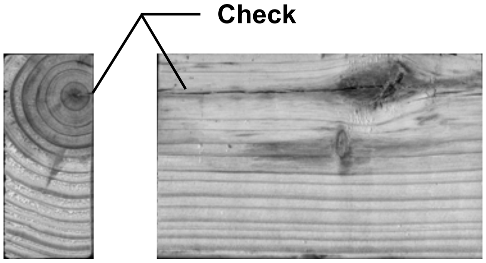
Checks



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Slope of Grain

Slope of Grain	% of Retained Strength
0	100%
1 in 20	93%
1 in 10	81%
1 in 5	55%

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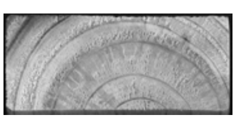
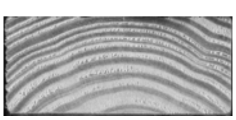
Growth Rings Per Inch



Fast Growing

Lower Strength



Slow Growing

Higher Strength

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Additional Factors Affecting Strength

- Decay
- Heartwood and Sapwood
- Shakes
- Wane
  - (see FOG Sect 4 Glossary)
- Reaction Wood

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Grading

Appearance Grading

Based on size & distribution of defect

Stress Grading

Based on measured relationship between load and deflection

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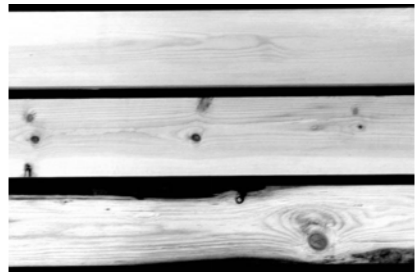
Visual Grading (Southern Pine)



No. 1

No. 2

No. 3

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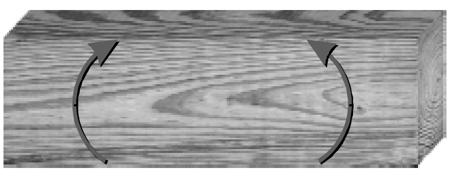
Extreme Fiber in Bending, F_b

F_b (Compression)



F_b (Tension, Controls)

Strength base on Modulus of Rupture.

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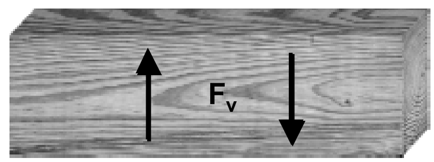
Flexural Shear, F_v



NDS-2001 increased the allowable shear values for all species by approx. 100%.

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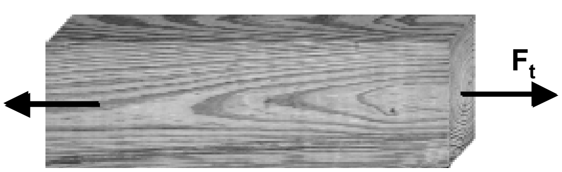
Tension, F_t



Not much test data. Usually F_b is modified.

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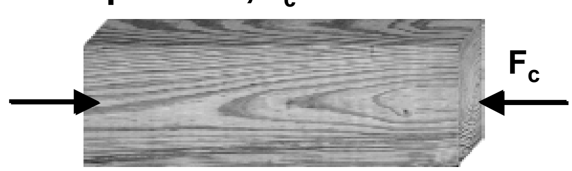
Compression, F_c



Length to least cross sectional dimension of less than 11. Otherwise, stability issues.

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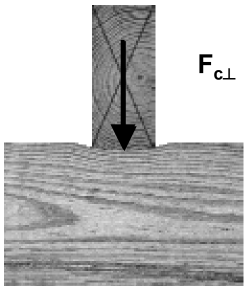
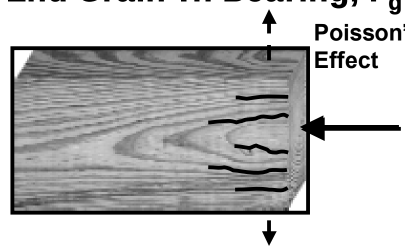
Compression Perpendicular to Grain, $F_{c\perp}$



$F_{c\perp}$

- Weak stress orientation but very ductile
- 650 psi for post bearing
- 500 psi for cribbing (due to exaggerated deflections)

End Grain In Bearing, F_g



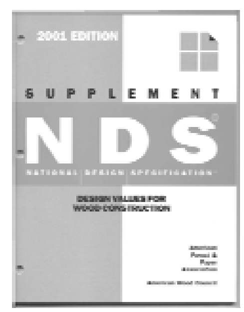
Replaced by F_c NDS-2001.

Modulus of Elasticity, E

- Differs with respect to orientation with grain.
- E_L – Longitudinal direction (bending stiffness, deflection), tabulated value.
- E_T – Tangential and E_R – Radial are between 0.01 and 0.10 of E_L.

NDS Supplement

In addition to other information, such as cross sectional properties, the NDS Supplement provides the tabulated allowable stress values for different species of wood and their grades.



NDS Supplement – Allowable Stresses

USE WITH TABLE 4A ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Design values in pounds per square inch (psi): Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v	Compression perpendicular to grain $F_{c\perp}$	Compression parallel to grain F_c	Modulus of Elasticity E	Grading Rules Agency
DOUGLAS FIR-LARCH								
Select Structural		1500	1000	95	625	1700	1,900,000	
No.1 & Btr	2"-4" thick	1200	800	95	625	1550	1,800,000	
No.1		1000	675	95	625	1500	1,700,000	
No.2	2"& wider	900	575	95	625	1350	1,600,000	WCLIB WWPA
No.3		525	325	95	625	775	1,400,000	
Stud		700	450	95	625	850	1,400,000	
Construction	2"-4" thick	1000	650	95	625	1650	1,500,000	
Standard		575	375	95	625	1400	1,400,000	
Utility	2"-4" wide	275	175	95	625	900	1,300,000	
DOUGLAS FIR-LARCH (NORTH)								
Select Structural	2"-4" thick	1350	825	95	625	1900	1,900,000	
No.1/No.2		850	500	95	625	1400	1,600,000	
No.3	2"& wider	475	300	95	625	825	1,400,000	NLGA
Stud		650	400	95	625	900	1,400,000	
Construction	[illegible]	950	575	95	625	1800	1,500,000	
Standard		525	325	95	625	1450	1,400,000	
Utility	[illegible]	250	150	95	625	950	1,300,000	

NDS-1997

Adjustment Factors

NDS requires modification of the tabulated allowable stress values based on specific usage conditions as well as to account for stability:

- Duration of Load, C_D
- Size Factor, C_F
- Column Stability, C_P
- Wet Use, C_M

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Load Duration Factor, C_D

- Wood can carrying greater maximum loads for shorter periods of time.
- Tabulated allowable stresses assume Live Load conditions (duration up to 10 years).
- Can use 60% increase for Wind and Earthquake loading.
  - Other codes use 1.33 increase
- 100% increase for impact loading
  - 2 sec or less.

Size Factor, C_F

Size Factor, C_F

Tabulated bending, tension, and compression parallel to grain design values for dimension lumber 2" to 4" thick shall be multiplied by the following size factors:

Size Factors, C_F

Grades	Width (depth)	F_b Thickness (breadth) 2" & 3"	F_b Thickness (breadth) 4"	F_t	F_c
Select Structural, No. 1 & Btr. No. 1, No. 2, No. 3	2", 3" & 4"	1.5	1.5	1.5	1.15
	5"	1.4	1.4	1.4	1.1
	6"	1.3	1.3	1.3	1.1
	8"	1.2	1.3	1.2	1.05
	10"	1.1	1.2	1.1	1.0
	12"	1.0	1.1	1.0	1.0
	14" & wider	0.9	1.0	0.9	0.9
Stud	2", 3" & 4"	1.1	1.1	1.1	1.05
	5" & 6"	1.0	1.0	1.0	1.0
	8" & wider	Use No. 3 Grade tabulated design values and size factors			
Construction & Standard	2", 3" & 4"	1.0	1.0	1.0	1.0
Utility	4"	1.0	1.0	1.0	1.0
	2" & 3"	0.4	—	0.4	0.6

Wet Use Factor, C_M

Allowable stress values assume a moisture content not greater than 19%. If greater, must reduce allowable stresses as shown:

Wet Service Factors, C_M

F_b	F_t	F_v	$F_{c\perp}$	F_c	E
0.85*	1.0	0.97	0.67	0.8**	0.9

* when $(F_b)(C_F) \leq 1150$ psi, $C_M = 1.0$
** when $(F_c)(C_F) \leq 750$ psi, $C_M = 1.0$

US&R Shoring

- Shoring capacity calculations based on Douglas Fir and Southern Pine.
  - See StS FOG & SOG, Sect 4 - FAQ for other species.
- Based on NDS-1991.
- Allowable stresses may be increased for emergency shoring
  - 1.25 for wood stresses (use 1.0 for posts)
  - 1.60 for nails (very short term raker load)

Bending Members

E = 1,400,000 to 1,600,000 psi

F_b = 1,500 psi for 4x and 1,200 psi for 6x

F_v = 95 psi for 4x and 85 psi for 6x
(Increased by a factor of 2 in NDS-2001)

$F_b < M/S = (6M)/(bh^2)$ $F_v < (3V)/(2bh)$

Compression Members

Members are proportioned to preclude buckling:

$F_a = 0.3\ E\ (L/D)^2$ (square posts)

For E = 1,400,000 psi and L/D = 25:

$F_a = 420{,}000\ \text{psi} / (25)^2 = 672$ psi

Therefore: $F_a = 672$ psi > $F_{c\perp} = 625$ psi

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Bearing in Header & Wedges

$F_{c\perp}$ = 625 psi

$F_{c\perp}$ x $A_{bearing}$ =

625 x 3.5 x 3.5 =

7,700 lbs per bearing area

<u>Use 8k</u> (653 psi, round up)

672 psi > 653 psi

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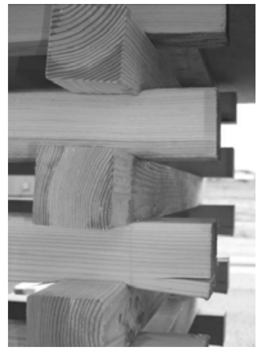
Cribbing Bearing Design



$F_{c\perp}$ = 500 psi

$F_{c\perp}$ x $A_{bearing}$ =

500 x 3.5 x 3.5 =

6,125 lbs per bearing area

<u>Use 6k</u>

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Connections

- **Usually steel fasteners that are subject to either:**
  - **Shear (lateral resistance) – Z**
  - **Withdrawal (tension) – W**
- **Design values for shear are based on mechanics approach while withdrawal values are empirical.**
- **Connection strength a function of wood (Specific Gravity) and fastener.**

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Connections

Four possible failure modes:

1. **Uniform bearing failure in wood.**
2. **Non-uniform bearing failure in wood (fastener rotation without bending).**
3. **Single plastic hinge in fastener with wood bearing failure.**
4. **Two plastic hinges in fastener with wood bearing failure.**

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Raker Cleat

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US&R Wire Nails – Lateral Resistance

Size	Diameter	Length	Z
8d common	0.128″	2-1/2″	90 lbs
16d vinyl coat	0.148″	3-1/4″	120 lbs
16d common	0.162″	3-1/2″	140 lbs

- **Penetrate at least 12x dia to use full value.**
- **May increase value for metal side plates & duration of load (also plywood gusset?)**
- ***For US&R: 8d = 140 lbs, 16d vc = 190 lbs, 16d = 220lb (1.6 x increase – No Splits)***

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References

1. ***National Design Specifications for Wood Construction and Supplement,*** **American Forest & Products Association, 1991, 1997, and 2001 (www.awc.org).**
2. ***Wood Handbook: Wood as an Engineering Material*****, General Technical Report 113, Forest Products Laboratory, U.S. Dept. of Agriculture,1999.**
3. ***Design of Wood Structures - ASD*** **(4th Edition), Breyer, D.E., Fridley, K.J., Cobeen, K.E., McGraw-Hill , 1999.**

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