Section 2.0 Principles of Wood Design

FEMA US&R Response Sys/U.S. Army Corps of Engineers
US&R Structure Specialist Training – StS1

SECTION 2.0

Principles of Timber Design

Oct08

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.

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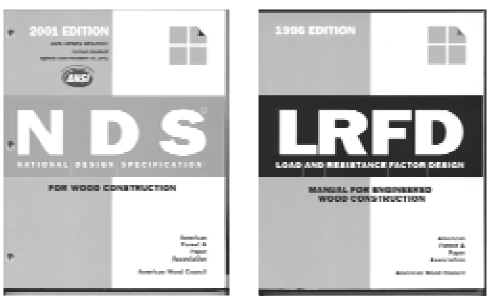
Timber Design Specifications



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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.**

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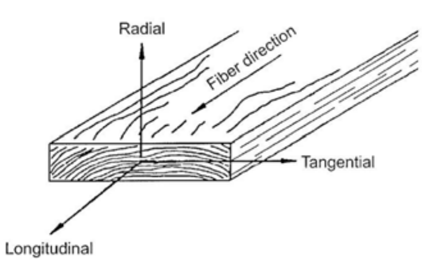
Wood - Anisotropic



USDA Forest Service *Wood Handbook*, 1999

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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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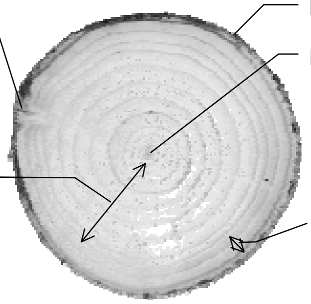
Typical Tree Cross Section



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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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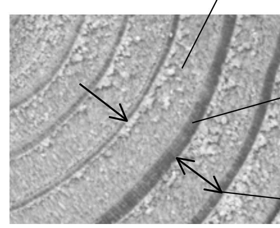
Growth Rings



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Earlywood

- Fast growing (also referred to Springwood).
- Cells with relatively large cavities and 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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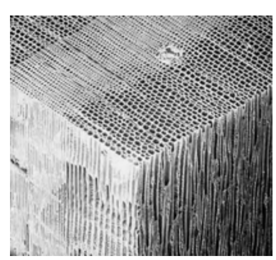
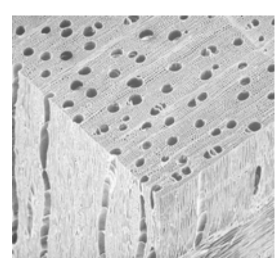
Cell Structure of Wood

Softwood



Hardwood



(Society of Wood Science And Technology)

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Section 2.0 Principles of Wood Design

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.)

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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.

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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.

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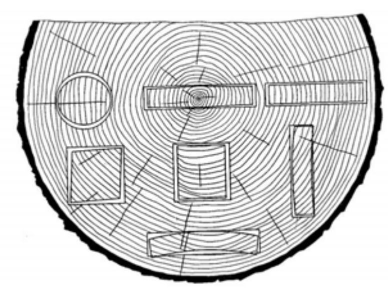
Shrinkage



USDA Forest Service *Wood Handbook*, 1999

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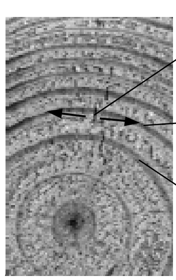
Tangential Shrinkage



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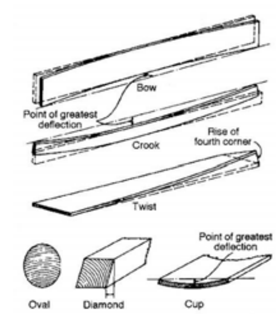
Warping

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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Section 2.0 Principles of Wood Design

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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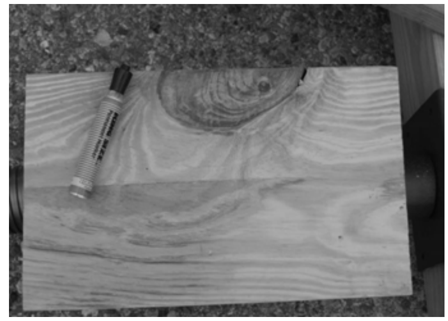
Knots



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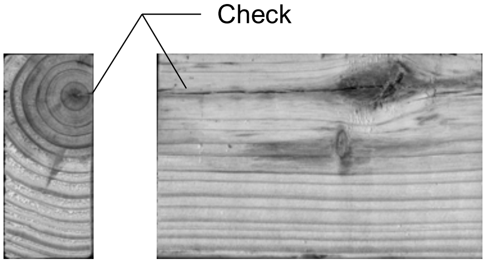
Checks



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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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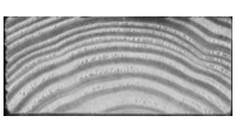
Growth Rings Per Inch

Fast Growing

Lower Strength



Slow Growing

Higher Strength

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Additional Factors Affecting Strength

- Decay
- Heartwood and Sapwood
- Shakes
- Wane
  - (see FOG5 Sect 5 Glossary)
- Reaction Wood

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Section 2.0 Principles of Wood Design

Grading

Appearance Grading

Based on size and distribution of defect

Stress Grading

Based on measured relationship between load and deflection

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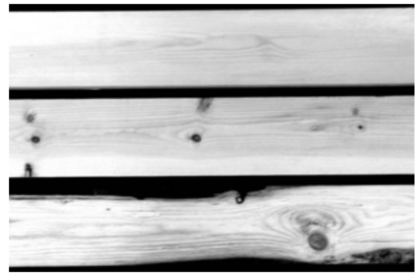
Visual Grading (Southern Pine)



No. 1

No. 2

No. 3

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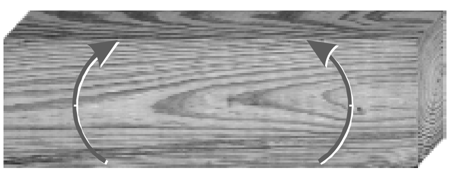
Extreme Fiber in Bending, F_b

F_b (Compression)



F_b (Tension, Controls)

Strength base on Modulus of Rupture.

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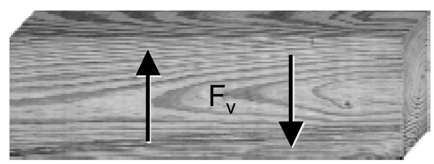
Flexural Shear, F_v



NDS-2001 increased the allowable shear values for all species by approximately 100 percent.

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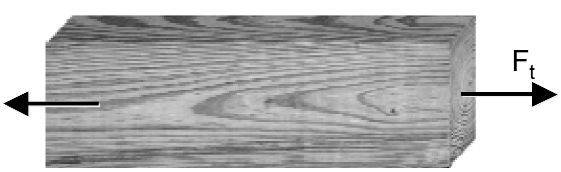
Tension, F_t



Not much test data. Usually F_b is modified.

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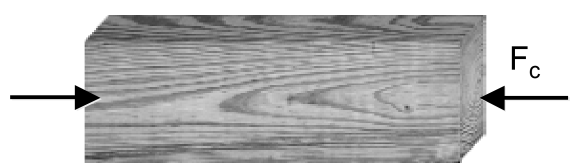
Compression, F_c



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

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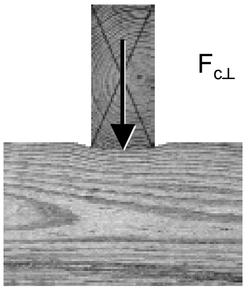
Compression Perpendicular to Grain, $F_{c\perp}$



$F_{c\perp}$

Weak stress orientation but very ductile

650 psi for post bearing

500 psi for cribbing (due to exaggerated deflections)

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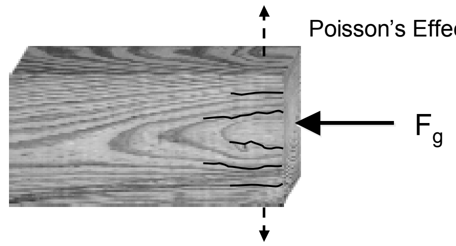
End Grain In Bearing, F_g



Replaced by F_c NDS-2001.

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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.

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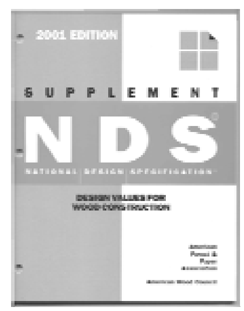
NDS Supplement

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.



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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	[illegible]	1000	650	95	625	1650	1,500,000	
Standard	[illegible]	575	375	95	625	1400	1,400,000	
Utility	[illegible]	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	[illegible]	525	325	95	625	1450	1,400,000	
Utility	[illegible]	250	150	95	625	950	1,300,000	

NDS-1997

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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.

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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

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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, $C_M = 1.0$

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US&R Shoring

- Shoring capacity calculations based on Douglas Fir and Southern Pine.
- See StS FOG5 & SOG, Sect 4 - FAQ for other species.
- Based on NDS-1991.
- Allowable stresses may be increased up to 60% for emergency shoring.

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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)

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

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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 Failure in 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

Use 8k (653 psi, round up)

672 psi > 653 psi

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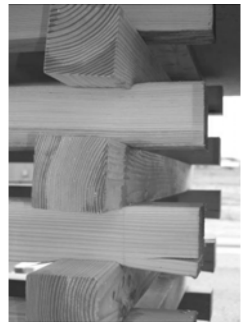
Cribbing Bearing Failure



$F_{c\perp}$ = 500 psi

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

500 x 3.5 x 3.5 =

6,125 lbs per bearing area

Use 6k

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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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