**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 axes.
- Anisotropic – wood exhibits different mechanical properties when measured along different axes.

**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.
Typical Tree Cross Section

- **Bark**
- **Encased Branch (Knot)**
- **Pith**
- **Heartwood**
- **Sapwood**

**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.

**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.

**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.

**Cell Structure of Wood**
- **Softwood**
- **Hardwood**

(Society of Wood Science & Technology)
Section 2-0 Principles of Timber Design

Water

■ Water of a living tree can make up \( \frac{2}{3} \) 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.

Tangential Shrinkage

Tangential Shrinkage Crack (Check)
Local Direction of Maximum Shrinkage
Annual Rings

Warping

Differential shrinkage caused by differences in radial, tangential, and longitudinal shrinkage is a major cause of warp.
Section 2-0 Principles of Timber 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)

Knots

Checks

Slope of Grain

<table>
<thead>
<tr>
<th>Slope of Grain</th>
<th>% of Retained Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>1 in 20</td>
<td>93%</td>
</tr>
<tr>
<td>1 in 10</td>
<td>81%</td>
</tr>
<tr>
<td>1 in 5</td>
<td>55%</td>
</tr>
</tbody>
</table>

Growth Rings Per Inch

Fast Growing
Lower Strength

Slow Growing
Higher Strength

Additional Factors Affecting Strength
- Decay
- Heartwood and Sapwood
- Shakes
- Wane
  - (see FOG Sect 4 Glossary)
- Reaction Wood
Section 2-0  Principles of Timber Design

**Grading**
- Appearance Grading
  - Based on size & distribution of defect
- Stress Grading
  - Based on measured relationship between load and deflection

**Visual Grading (Southern Pine)**
- No. 1
- No. 2
- No. 3

**Extreme Fiber in Bending, F_b**
- \( F_b \) (Compression)
- \( F_b \) (Tension, Controls)
  - Strength base on Modulus of Rupture.

**Flexural Shear, F_v**
- NDS-2001 increased the allowable shear values for all species by approx. 100%.

**Tension, F_t**
- Not much test data. Usually \( F_b \) is modified.

**Compression, F_c**
- Length to least cross sectional dimension of less than 11. Otherwise, stability issues.
Section 2-0  Principles of Timber Design

**Compression Perpendicular to Grain, \( F_{cL} \)**

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

**End Grain In Bearing, \( F_g \)**

- Poisson's Effect
- 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.

**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, \( C_M \)
Section 2-0 Principles of Timber Design

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.

Wet Use Factor, \( C_M \)
Allowable stress values assume a moisture content not greater than 19%. If greater, must reduce allowable stresses as shown:

<table>
<thead>
<tr>
<th>Wet Service Factors, ( C_M )</th>
<th>( F_b )</th>
<th>( F_t )</th>
<th>( F_x )</th>
<th>( F_{\perp} )</th>
<th>( F_y )</th>
<th>( E )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0.85 )</td>
<td>( 1.0 )</td>
<td>( 0.97 )</td>
<td>( 0.67 )</td>
<td>( 0.8 )</td>
<td>( 0.9 )</td>
<td></td>
</tr>
</tbody>
</table>

\( * \) when \( (F_t)(C_d) \leq 1150 \) psi, \( C_y = 1.0 \)
\( ** \) when \( (F_x)(C_d) \leq 750 \) psi, \( C_y = 1.0 \)

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
\[ E = 1,400,000 \text{ to } 1,600,000 \text{ psi} \]
\[ F_b = 1,500 \text{ psi for } 4x \text{ and } 1,200 \text{ psi for } 6x \]
\[ F_v = 95 \text{ psi for } 4x \text{ and } 85 \text{ psi for } 6x \]
  (Increased by a factor of 2 in NDS-2001)
\[ F_b < \frac{M}{S} = \frac{(6M)}{(bh^2)} \quad F_v < \frac{(3V)}{(2bh)} \]

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 \( L/D = 25 \):
\[ F_a = 420,000 \text{ psi} / (25)^2 = 672 \text{ psi} \]
Therefore: \( F_a = 672 \text{ psi} > F_{c_L} = 625 \text{ psi} \)
Section 2-0 Principles of Timber Design

Bearing in Header & Wedges

\[ F_{cl} = 625 \text{ psi} \]

\[ F_{cl} \times A_{bearing} = 625 \times 3.5 \times 3.5 = 7,700 \text{ lbs per bearing area} \]

Use 8k (653 psi, round up)

672 psi > 653 psi

Cribbing Bearing Design

\[ F_{cl} = 500 \text{ psi} \]

\[ F_{cl} \times A_{bearing} = 500 \times 3.5 \times 3.5 = 6,125 \text{ lbs per bearing area} \]

Use 6k

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.

Raker Cleat

US&R Wire Nails – Lateral Resistance

<table>
<thead>
<tr>
<th>Size</th>
<th>Diameter</th>
<th>Length</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>8d common</td>
<td>0.128”</td>
<td>2-1/2”</td>
<td>90</td>
</tr>
<tr>
<td>16d vinyl coat</td>
<td>0.148”</td>
<td>3-1/4”</td>
<td>120</td>
</tr>
<tr>
<td>16d common</td>
<td>0.162”</td>
<td>3-1/2”</td>
<td>140</td>
</tr>
</tbody>
</table>

- 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)
Section 2-0 Principles of Timber Design

References

