Wood

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Wood construction
Wood construction

Advantages of wood

- Availability
- Relatively low cost
- Durability
- Light weight
Wood uses in Civil Engineering

- Buildings
- Bridges
- Utility poles
- Floors
- Roofs
- Trusses
- Piles

Wood types and trees

- Natural
- Engineered
  - Laminates
  - Plywood
  - Standard board
- All trees used for wood production are exogenous
  - Deciduous produce hardwoods - furniture
  - Conifers produce softwoods - construction
Wood design and US agencies

- **United states agency’s regulating wood products**
  - Forest Service of the Department of Agriculture

- **Wood design requires knowledge of**
  - Properties of wood
  - Design of joints and connections

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### Sources of wood

**Table 10.1** Major Sources of Hardwood and Softwood Species by Region

<table>
<thead>
<tr>
<th>Hardwoods</th>
<th>Softwoods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Western</strong></td>
<td><strong>Northern and</strong></td>
</tr>
<tr>
<td>Ash</td>
<td>Red alder</td>
</tr>
<tr>
<td>Beech</td>
<td>Aspen</td>
</tr>
<tr>
<td>Black locust</td>
<td>Black locust</td>
</tr>
<tr>
<td>Black walnut</td>
<td>Black walnut</td>
</tr>
<tr>
<td>Blue spruce</td>
<td>Big bud maple</td>
</tr>
<tr>
<td>Bur oak</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Douglas fir</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Eastern hemlock</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Red oak</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Red maple</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Redwood</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Redwood</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Redwood</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Redwood</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Southern balsam fir</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Southern ponderosa pine</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Southern sugar pine</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Southern western white pine</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Southern western red cedar</td>
<td>Paper birch</td>
</tr>
<tr>
<td>Southern redwood</td>
<td>Paper birch</td>
</tr>
</tbody>
</table>

* Change to large hardwood, but harder from same timber varieties.
Structure of wood

- **Growth rings - annual rings**
  - Early wood (rapid growth) - spring
  - Latewood (dense, dark, thick-walled cells) - summer

Structural features of wood
Structural features of wood

- **Anisotropic properties**
  - Affect stiffness, strength, and shrinkage
  - Tubular geometry of wood cells

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Chemical composition

- **The components of wood are:**
  - Cellulose, lignin, hemicellulose, extractives, and minerals.

- **Cellulose makes 50% by weight**
  - Cellulose is a linear polymer with glucose as the main component
  - Linear cellulose molecules arrange themselves into strands called fibrils as the tree grows
  - Fibrils form cell walls

- **Extractives**
  - 5 to 30% of the wood substance
  - Tannins, coloring matters, oils, fats, resins, waxes, gums, starches, etc.
Chemical composition

- **Lignin**
  - 23 to 33% of softwood by weight
  - 16 to 25% of hardwood by weight
  - Is the glue that holds the tubular cells together
  - Responsible for longitudinal shear strength of wood

- **Hemicellulose**
  - 15 to 20% of softwood by weight
  - 20 to 30% of hardwood by weight
  - Polymeric units made from sugar molecules

- **Minerals**
  - 0.1 to 3% of the wood matter
  - Calcium, potassium, phosphate, and silica

Moisture content

- **Weight of water over oven dry weight**
- **Shrinkage, weight, and strength depend on the moisture content of wood**
- **Moisture**
  - Bound - Adsorbed within cell wall
  - Free water - Condensed water or water vapor in cell cavities
- **Cell walls saturated but no water in the cell cavities is called fiber saturation point (FSP) - 21 to 32%**
  - Changes in moisture below FSP has great effect on physical and mechanical properties
  - Physical and mechanical properties are independent of changes in moisture above FSP
Wood production

- **Dimensional lumber**
  - 2 to 5 in. thick sawn on all four sides

- **Heavy timber**
  - Sawn on all four sides (4x6, 6x8, 8x8)

- **Round stock**
  - Posts and poles – marine piling, utility

- **Engineered wood**
  - Bonding wood strands, veneer, lumber
    - Plywood, glued laminated timber
Common sawing patterns

- (a) Flat sawn, 45° or less – tend to distort
- (b) Rift sawn, 45° to 80°
- (c) Vertical sawn, 80° to 90° - structurally the best

Quality of bards is related to the angle the growth rings make with the face of the board

- (a) Flat sawn, 45° or less – tend to distort
- (b) Rift sawn, 45° to 80°
- (c) Vertical sawn, 80° to 90° - structurally the best
Seasoning

- Green wood - 30 to 200% moisture
- Seasoning removes excess moisture
- Structural wood
  - Recommended moisture 7% (dry states) to 14% (coastal regions)
- **Seasoning = air or kiln drying**
  - Air drying - can take up to 4 months
  - Kiln drying – 20 to 50°C, 4 to 10 days

Lumber grades

- **Typically graded according to # of flaws, that affect**
  - Strength, durability, or workability
- **Also stress graded**
- **Common defects**
  - Knots, checks, pitch pockets, shakes, and stains
- **Agencies certified by the American Lumber Standards Committee Board of Review**
  - Northeastern Timber Manufacturer Association
  - Northern Hardwood and pine Man. Asstn.
  - Redwood Inspection Service
  - Southern Pine Inspection Bureau
### Lumber grades

#### TABLE 10.3 Sample of Stress Grading of Softwood for Structural Applications

<table>
<thead>
<tr>
<th>Grade Designation</th>
<th>Bending</th>
<th>Tension Parallel to Grain</th>
<th>Compression Parallel to Grain</th>
<th>Modulus of Elasticity</th>
<th>Minimum Modulus of Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>900F-1.0E</td>
<td>900</td>
<td>350</td>
<td>1,050</td>
<td>1,000,000</td>
<td>510,000</td>
</tr>
<tr>
<td>1600F-1.3E</td>
<td>1,650</td>
<td>1,020</td>
<td>1,700</td>
<td>1,300,000</td>
<td>660,000</td>
</tr>
<tr>
<td>1900F-1.5E</td>
<td>1,950</td>
<td>1,375</td>
<td>1,800</td>
<td>1,500,000</td>
<td>750,000</td>
</tr>
<tr>
<td>2250F-1.7E</td>
<td>2,250</td>
<td>1,750</td>
<td>1,925</td>
<td>1,700,000</td>
<td>860,000</td>
</tr>
<tr>
<td>2400F-2.0E</td>
<td>2,400</td>
<td>1,925</td>
<td>1,975</td>
<td>2,000,000</td>
<td>1,020,000</td>
</tr>
<tr>
<td>2850F-2.3E</td>
<td>2,850</td>
<td>2,300</td>
<td>2,150</td>
<td>2,300,000</td>
<td>1,170,000</td>
</tr>
<tr>
<td>3000F-2.4E</td>
<td>3,000</td>
<td>2,400</td>
<td>2,200</td>
<td>2,400,000</td>
<td>1,220,000</td>
</tr>
</tbody>
</table>

2. Stresses apply to lumber used at 19 percent maximum moisture content. When lumber is designed for use where the moisture content will exceed 19 percent for an extended period of time, the values shown herein shall be multiplied by certain wet service factors.
3. Bending values are applicable to lumber loaded on edge. When loaded flatwise, these values may be increased by multiplying by certain flatwise factors.
4. For a complete list of grade designations and more detailed design values see reference (American Forest & Paper Association, 2005).

#### TABLE 10.4 Example of Design Values of Eastern White Pine

<table>
<thead>
<tr>
<th>Grade Designation</th>
<th>Size Classification</th>
<th>Bending</th>
<th>Tension Parallel to Grain</th>
<th>Shear Parallel to Grain</th>
<th>Compression Perpendicular to Grain</th>
<th>Modulus of Elasticity</th>
<th>Minimum Modulus of Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select</td>
<td>Structural</td>
<td>1,250</td>
<td>575</td>
<td>135</td>
<td>350</td>
<td>1,500</td>
<td>1,200,000</td>
</tr>
<tr>
<td>No. 1</td>
<td>775</td>
<td>350</td>
<td>135</td>
<td>340</td>
<td>1,000</td>
<td>1,100,000</td>
<td>440,000</td>
</tr>
<tr>
<td>No. 2</td>
<td>2&quot; wide</td>
<td>575</td>
<td>275</td>
<td>135</td>
<td>350</td>
<td>825</td>
<td>1,100,000</td>
</tr>
<tr>
<td>No. 3</td>
<td>300</td>
<td>150</td>
<td>135</td>
<td>350</td>
<td>1,000</td>
<td>900,000</td>
<td>320,000</td>
</tr>
<tr>
<td>Std.</td>
<td>2&quot; wide</td>
<td>450</td>
<td>200</td>
<td>135</td>
<td>350</td>
<td>525</td>
<td>900,000</td>
</tr>
<tr>
<td>Construction</td>
<td>675</td>
<td>200</td>
<td>135</td>
<td>350</td>
<td>1,050</td>
<td>1,000,000</td>
<td>370,000</td>
</tr>
<tr>
<td>Standard</td>
<td>2&quot;-4&quot; wide</td>
<td>375</td>
<td>175</td>
<td>135</td>
<td>350</td>
<td>850</td>
<td>900,000</td>
</tr>
<tr>
<td>Utility</td>
<td>175</td>
<td>75</td>
<td>135</td>
<td>350</td>
<td>550</td>
<td>800,000</td>
<td>240,000</td>
</tr>
</tbody>
</table>

2. Stresses apply to lumber used at 19 percent maximum moisture content. When lumber is designed for use where the moisture content will exceed 19 percent for an extended period of time, the values shown herein shall be multiplied by certain wet service factors.
3. Bending values are applicable to lumber loaded on edge. When loaded flatwise, these values may be increased by multiplying by certain flatwise factors.
4. For a complete list of grade designations and more detailed design values see reference (American Forest & Paper Association, 2005).
Lumber defects

- Pitch
- Tight knot
- Check or split
- Blue stain
- Loose knot
- Cup

Lumber defects

- Crook
- Bow
- Cup
- Twist
Physical properties

- **Specific gravity and density**
  - Dry density 160 kg/m³ (10 pcf) to 1000 kg/m³ (65 pcf)
  - Specific gravity of cell walls = 1.5

- **Thermal properties**
  - Thermal conductivity – 0.34 to 1.16 Btu/h-ft- °F
  - Thermal conductivity Increases with moisture
  - Coefficient of thermal expansion = 0.009 to 0.0014 mm/m/°C
  - Expansion is proportional to density
    - Expansion = 5 to 10 times greater across the grain than parallel to grain

- **Electrical properties**
  - Good insulator

Mechanical properties

- **Modulus of elasticity**
  - Tangent to stress-strain curve = 1.3 to 2.1 Msi
  - Different in tension and compression

- **Strength (tension and compression)**
  - Compression perpendicular to grain = 315 to 510 psi
  - Compression parallel to grain = 1150 to 1650 psi
  - Tension parallel to grain = 1050 to 1150 psi
Mechanical properties

- **Creep**
  - Under constant load wood will creep
  - Creep is the permanent deformation left after a long-term load is removed

- **Damping**
  - Occurs mainly due to internal friction
  - Depends on temperature and moisture content
  - At normal temperature and moisture content wood has 10 times as much damping as metals

Mechanical testing

- **Compression**
  - Parallel and perpendicular to fiber (depends on moisture content)
- **Tension** - Parallel and perpendicular
- **Static bending**
- **Hardness**
- **Shear parallel to grain**
- **Moisture**
- **Specific gravity and shrinkage**
Mechanical testing

![Test specimens of wood: (a) tension parallel to grains, (b) tension perpendicular to grains, (c) compression parallel to grains, (d) compression perpendicular to grains, (e) hardness perpendicular to grains, (f) hardness parallel to grains, and (g) bending. (© Pearson Education, Inc. Used by permission.)](image)

Some failure modes

![Types of failure in the compression-parallel-to-grain test. (ASTM D143). Reprinted with permission of ASTM.](image)
Design considerations

- Correct design values for
  - Wet service
  - Temperature
  - Beam stability
  - Size
  - Volume
  - Fatigue
  - Curvature
  - Form
  - Column stability
  - Bearing area
  - Load duration

Wood decay

- Ingredients required for wood decay by fungi growth
  - Moisture
  - Food - cellulose
  - Oxygen
- Bacteria
- Insects
  - Beatles and termites
- Marine organisms
  - Shipworms, pholads
Wood preservation

- Petroleum-based solutions
  - Coal-tar creosote, petroleum creosote, pentachlorophenol
- Waterborne preservatives
  - Ammoniacal copper arsenate
  - Chromated copper arsenate
  - Ammoniacal copper zinc arsenate
  - Advantages over oil – cleanliness, ability to be painted
  - Disadvantages – dangerous to humans
  - No arsenic-based treatment allowed in residential construction

Engineered wood products

**FIGURE 10.14** Cutting of plies for plywood and glulam: (a) rotary cutting and (b) slicing (© Pearson Education, Inc. Used by permission.)
## Engineered wood products

### Table 10.6 Classification of Engineered Wood Products

<table>
<thead>
<tr>
<th>Wood stock</th>
<th>Structural Panels/Sheets (sheathing, flooring)</th>
<th>Structural Shapes (beams, columns, headers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Veneer</td>
<td>Plywood</td>
<td>Laminated veneer lumber</td>
</tr>
<tr>
<td>Strands</td>
<td>Flakeboard</td>
<td>Oriented strand lumber</td>
</tr>
<tr>
<td>Waferboard - random orientation of strands</td>
<td></td>
<td>Laminated strand lumber</td>
</tr>
<tr>
<td>Oriented Strand Board - strands oriented, panels made in plys</td>
<td>Parallel strand lumber (Parallam)</td>
<td></td>
</tr>
<tr>
<td>Composite</td>
<td>COM-PLY - Wood fiber core with veneer exterior</td>
<td>N/A</td>
</tr>
<tr>
<td>Dried lumber</td>
<td>N/A</td>
<td>Glued laminated lumber (Glulam)</td>
</tr>
</tbody>
</table>

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Design properties of laminated veneer lumber

Table 10.8: Design Properties for APA-LVS Performance Rated LVL (APA-EWS, 2009)

<table>
<thead>
<tr>
<th>APA-EWS Stress Class</th>
<th>Bending module (10^6 psi)</th>
<th>Allowable tensile stress parallel to grain (psi)</th>
<th>Compressive stress parallel to grain (psi)</th>
<th>Edgewise shear stress (psi)</th>
<th>Stress perpendicular to grain (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0E-2000°F</td>
<td>1.5</td>
<td>2550</td>
<td>1500</td>
<td>130</td>
<td>875</td>
</tr>
<tr>
<td>1.0E-2000°F</td>
<td>1.5</td>
<td>2550</td>
<td>1500</td>
<td>130</td>
<td>875</td>
</tr>
<tr>
<td>1.0E-2000°F</td>
<td>1.0</td>
<td>2500</td>
<td>1750</td>
<td>130</td>
<td>700</td>
</tr>
<tr>
<td>2.0E-2000°F</td>
<td>2.0</td>
<td>2000</td>
<td>1400</td>
<td>1750</td>
<td>750</td>
</tr>
<tr>
<td>2.1E-2000°F</td>
<td>2.1</td>
<td>1100</td>
<td>2800</td>
<td>285</td>
<td>750</td>
</tr>
</tbody>
</table>

Arrangement of laminated glulam

Figure 10.20: Lay up arrangement for balanced and unbalanced glulams.
### Stress Classes of Glulams (APA-EWS, 2004)

<table>
<thead>
<tr>
<th>Stress Class</th>
<th>Tension Zone Stressed in Tension (psi)</th>
<th>Compression Zone Stressed in Tension¹ (psi)</th>
<th>Compression Perpendicular to Grain (psi)</th>
<th>Shear Parallel to Grain (psi)</th>
<th>Modulus of Elasticity (10⁶ psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16F-1.3E</td>
<td>1600</td>
<td>925</td>
<td>315</td>
<td>195</td>
<td>1.3</td>
</tr>
<tr>
<td>20F-1.5E</td>
<td>2000</td>
<td>1100</td>
<td>425</td>
<td>210</td>
<td>1.5⁵</td>
</tr>
<tr>
<td>24F-1.7E</td>
<td>2400</td>
<td>1450</td>
<td>500</td>
<td>210</td>
<td>1.7</td>
</tr>
<tr>
<td>24F-1.8E</td>
<td>2400</td>
<td>1450²</td>
<td>650</td>
<td>265⁴</td>
<td>1.8</td>
</tr>
<tr>
<td>26F-1.8E</td>
<td>2600</td>
<td>1950</td>
<td>650</td>
<td>265⁴</td>
<td>1.9</td>
</tr>
<tr>
<td>28F-1.8E</td>
<td>2800</td>
<td>2300</td>
<td>740</td>
<td>300</td>
<td>2.1⁶</td>
</tr>
<tr>
<td>30F-2.1E SP²</td>
<td>3000</td>
<td>2400</td>
<td>740</td>
<td>300</td>
<td>2.1⁶</td>
</tr>
<tr>
<td>30F-2.1E LVL³</td>
<td>3000</td>
<td>3000</td>
<td>510⁹</td>
<td>300</td>
<td>2.1</td>
</tr>
</tbody>
</table>

¹ Stress in compression zone is not usually used in fiber bending.

² 24F-1.7E SP² = 24F-1.8E

³ 24F-1.7E LVL³ = 24F-1.8E LVL