Introduction to Properties of Wood
Material Properties

- Microstructure & macrostructure
- Softwoods & hardwoods
- Defects & stress grading
- Moisture & load duration effects
- Stress grading
Wood Chemical Composition

- Cellulose (40-50%)
- Lignin (18-25%)
- Hemicellulose (20-30%)
- Extractives
- Ash-forming minerals (2-30%)
Wood Chemical Composition

Cellulose – Carbohydrate of long chain polymers organized into microfibrils

\[
(C_6H_{10}O_5)_n
\]

(Note: Cotton is pure cellulose)

Lignin – Organic compound that binds the microfibrils together in the secondary walls and middle lamella
Wood Chemical Composition

- **Hemicellulose** – A cellulose-like material in the wood cell wall that is easily decomposed by dilute acid to yield simple sugars
- **Extractives** – Organic material deposited during heartwood formation (gums, resins, oils, alkaloids)
Micrograph – Red Pine

ew = early wood
lw = late wood
rc = resin canal
r = ray
Macrostructure - Red Oak

A = cambium layer
B = inner bark
C = outer bark
D = sap wood
E = heart wood
F = pith
G = rays
Macrostructure - Douglas Fir

ob = outer bark
ib = inner bark
cz = cambium zone
gi = growth increment
p = pith
x = wood
Softwoods

- Naked seeds in cones
- Needle-like leaves
- Usually evergreen
- Simple cell structure

- Some are very high strength
  - Douglas fir
  - Southern Pine
Hardwoods

- Seeds are enclosed in shells
- Broad leaves
- Deciduous
- Complex cell structure
- Some are very low strength
  - Aspen
  - Cottonwood
Defects

- Knots
- Checks, shakes, splits
- Reaction wood
- Wane, skip
- Slope of grain
- Warp
Knots

- **Intergrown**
  - Tree trunk grows around and with a living branch

- **Encased**
  - Tree trunk grows around a dead branch
Checks, shakes, splits

- Checks – radial cracks due to differential shrinkage ($S_T > S_R$)
- Shakes – tangential cracks due to shock loading or growth defect
- Split – any thru-thickness crack
Reaction Wood

- Growth defect
- Abnormal cell growth while under bending stress
- Softwoods – Compression wood
- Hardwoods – Tension wood
- Bigger problem for lumber than for timber
Reaction Wood

Compression Wood

Tension Wood
Compression Wood in Lumber

Compression wood

Longitudinal shrinkage cracking

Warp from differential shrinkage
Wane & Skip

- Cutting defects
- Wane – Incomplete rectangular cross section due to cutting too close to the bark
- Skip – Saw gouge, chip, or other recessed area not removed by planing at the mill.
Slope of Grain

- Growth or cutting defect
- Wood cell fibers not parallel to member axis
- Common around knots
- Causes failure by shear and tension perp.
Warp

- **Bow** – Curvature about minor axis
- **Crook** – Curvature about major axis
- **Twist** – board does not lie flat
- **Kink** – Sharp bend at a knot
- **Cup** – Curvature about longitudinal axis
Warp

- Bow
- Point of greatest deflection
- Crook
- Rise of fourth corner
- Twist
- Point of greatest deflection
- Kink
- Point of greatest deflection
- Cup
Moisture Content

- \( MC = \frac{\text{Weight of } H_2O}{\text{Weight of Solids}} \)
- \( MC > 100\% \) in a living tree
- \( \text{at } 70^\circ F \& 65\% \text{ RH}, \ MC \approx 12\% \)
- \( MC > 19\% \) defined as “wet service”
Shrinkage

Decrease in dimension due to loss of moisture

- $S_t \sim 2xS_r$

Softwoods – Doug Fir: $S_t = 7-8\%$

Hardwoods – Red Oak: $S_t = 9-13\%$
Shrinkage Deformation
Moisture Affects

- Stiffness
- Strength

![Graph showing the relationship between moisture content and increase in modulus of elasticity due to drying.](image-url)
Duration of Load Effects

- Madison Curve

Impact

- Wind
- Roof live
- Snow
- Live
- Dead
Stress Grading

Method of classifying lumber to identify its structural qualities

Visual or Machine methods

Agencies that write grading rules

- WWPA - Western Wood Products Assn.
- NELMA - Northeast Lumber Manufacturers Assn.
- NLGA - National Lumber Grades Authority (Canada)
- ... several others
Stress Grading

- Visual grading
  - Visual examination of each piece
  - Identification of defect types and effects
  - High variability in result
  - For dimension lumber and timbers
TIMBERS

70.00  BEAMS and STRINGERS

All Species
5" and Thicker

Width More Than 2" Greater Than Thickness

Grades of Beams and Stringers are designed for construction uses where material larger than Joists and Planks is required. The various grades are used in all types of building – home, industrial, farm and in special engineered construction such as bridges, auditoriums, stadiums and the like. Some grades are selected for appearance and strength. Other grades are designed for serviceability with strength and appearance qualities available in graduated increments to provide reliable and economical construction.

There are four grade choices: SELECT STRUCTURAL, NO. 1, NO. 2 and NO. 3. The Select Structural, No. 1 and No. 2 grades are assigned design values as shown in Table 2.

STANDARD SIZES for BEAMS and STRINGERS

<table>
<thead>
<tr>
<th>Thicknesses and Widths</th>
<th>Surfaces</th>
<th>Inch</th>
<th>mm(1)</th>
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<td>13 off</td>
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(1) See Section 723.00.
Standard lengths are 6’ and longer in multiples of 1’.

BEAMS and STRINGERS

70.10  SELECT STRUCTURAL

Select Structural Beams and Stringers are graded primarily for strength properties, but most pieces of this grade are suitable for exposed uses where both strength and good appearance are desired.
Lumber and Timber

- **Lumber:** $2 \text{ in} < b < 4 \text{ in}$

- **Timber:** $b \geq 5$, $d \geq 5$

  - Posts and Timbers: $d \leq b + 2 \text{ in}$
  - Beams and Stringers: $d > b + 2 \text{ in}$
In-Grade Test Program

- For dimension lumber only
- Test each stress grade individually
- Account for statistical variation
- Use “lower 5% exclusion limit”
  - 5% of all pieces will be below the limit
- Reduce by factor of 2.1
  - Factor of safety
  - Time effect factor
Test Data Variation

Mean = 5000 psi
COV = 0.3
Test Statistics

Mean of all tests: $F$

Standard deviation: $\sigma$

Coefficient of variation: $COV = \frac{\sigma}{\bar{F}}$

5% exclusion limit: $F_{5\%} = \bar{F} - 1.64\sigma$
Sample Design Value, Fb

\[ F = 5000 \text{psi} \]
\[ COV = 0.3 \]
\[ \sigma = 1500 \text{psi} \]
\[ \bar{F}_{5\%} = \bar{F} - 1.64\sigma \]
\[ \bar{F}_{5\%} = 2540 \text{psi} \]
\[ FS = 2.1 \]
\[ F_b = 1210 \text{psi} \]
Timber Design Values

- For timbers only
- Small, clear specimens tested
- Use “lower 5% exclusion limit”
- Adjust for knots, size effect, etc.
- Reduce by factor of 2.1
Stress Grading

- Machine grading
  - Nondestructive evaluation of each piece
  - Measurement of stiffness or density
  - Statistical correlation to strength
  - For dimension lumber only (currently)
  - Most machine graded lumber goes into nail-plate trusses
E vs Fb Correlation, Eqn. Form

[Diagram showing the relationship between Modulus of Rupture (PSI) and Modulus of Elasticity ($10^6$ PSI). Key points and annotations are indicated, such as predictor model (lower confidence line), minimum E (estimator value), and grades.]
E vs Fb Correlation, Real Data
Grade Stamps

- **Visual Grade**: 12 SEL STR S-GRN DOUG FIR-L
- **Machine Grade**: MACHINE RATED 12 S-DRY D FIR 2400 Fb 1925 Ft 2.0 E
Design Methods

- **Allowable stress design**
  - ANSI/AF&PA NDS-1997 (NDS-2001)

- **Load and resistance factor design**
  - AF&PA/ASCE Standard 16-95

- Both are recognized by building codes
Allowable stress design (ASD)

- aka: Working stress design
- Uses service level loads
- Assumes elastic behavior
- Unknown reliability (probability of failure)
Allowable Stress Design

Design inequality:

\[ \sum Q_i \leq \frac{R_n}{FS} \]

... is usually written in terms of stress:

\[ f_b \leq F'_b, \quad f_b = \frac{M_x}{S_x}, \quad F'_b = \frac{MOR}{FS} \]

(in psi)
Load and Resistance Factor Design (LRFD)

- aka: Limit states design
- aka: Ultimate strength design (like concrete)
- Uses factored loads
- Recognizes inelastic behavior (if any)
- Well defined reliability (probability of failure)
Load and Resistance Factor Design

- Design inequality:
  \[ \sum \gamma_i Q_i \leq \phi R_n \]

- ... is usually written in terms of force or moment:

\[
M_u \leq \lambda \phi_b M' \quad \left\{ \begin{array}{l}
M_u = 1.2M_D + 1.6M_L \\
\text{Factor up the moments}
\end{array} \right.
\]

- time effect factor (only used in wood)
A structure does not care which design method was used
Behavior is independent of design rules
ASD has worked fine for years
For inelastic (ductile) materials, LRFD more closely expresses behavior
ASD vs LRFD

**ASD advantages**
- Comfort and familiarity - not trivial considerations!

**LRFD advantages**
- More consistent reliability, esp. w.r.t. loads
- Adapts more easily to new developments:
  - Engineered wood products
  - Connection systems
  - Mixed material systems
NDS Overview

- Specification
- Allowable stress tables
- Commentary
- Other supplements
Specification

Chapter 1 - Boiler plate & notation

- \( f_i \rightarrow \) Actual stress, an analysis quantity
- \( F_i \rightarrow \) Allowable stress or material strength
- \( C_i \rightarrow \) Adjustment factor
- \( F_i' \rightarrow \) Adjusted allowable stress
Chapter 2 - Equation format for allowable stresses

\[ F'_b = F_b \left[ C_D C_M C_t C_L C_F C_V C_{fu} C_i C_r C_c C_f \right] \]

adjustment factors

tabulated design value (allowable stress)
Design Values for Wood Construction (DVWC)

Materials covered

- Dimension lumber
  - Visually graded
    - Western woods
    - Southern pine
  - Machine graded
- Timbers – softwood and hardwood
  - Visually graded
Design Values for Wood Construction (DVWC)

Properties listed
- \( F_b \rightarrow \text{Bending} \)
- \( F_t \rightarrow \text{Tension} \)
- \( F_v \rightarrow \text{Shear} \)
- \( F_{c\perp} \rightarrow \text{Compression perpendicular} \)
- \( F_c \rightarrow \text{Compression parallel} \)
- \( E \rightarrow \text{Modulus of Elasticity (MOE)} \)
<table>
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<tr>
<th>SPECIES AND COMMERCIAL GRADE</th>
<th>SIZE CLASSIFICATION</th>
<th>EXTREME FIBER IN BENDING $F_b$</th>
<th>Tension Parallel to Grain $F_P$</th>
<th>Compression Parallel to Grain $F_C$</th>
<th>Compression Perpendicular to Grain $F_C\perp$</th>
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