ARCH 324 - Structures 2, Winter 2009

von Buelow, Peter

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University of Michigan
Lecture Topics:

Course Syllabus
Chapter 11 – Wood Beams

Teaching Staff:

Prof.
Peter von Buelow

GSI's:
Donaghy, Ryan
Drew, Thomas
Ducharme-Smith, Matt
Lindstrom, Michael
Ozor, Chigozie Amara

Source: I. Engel. Structural principles.
Course Syllabus

Organization

• Lecture – Monday & Friday
• Recitation – Wednesday
• Exercises – from textbook
• Problems – on web

Evaluation

• Tests  39%
• Problems 48%
• Project 13%

Text

• Structural Principles by I. Engel
• Course Pack at Copy Center
• Web site
  https://www.umich.edu/~arch324

CATALOG DESCRIPTION
This course covers the basic principles of elastic behavior for different materials such as wood, steel, concrete, and composite materials, and compares the properties and applications of materials generally. It investigates cross sectional stress and strain behavior in tension and in shear, and bending as well as the stability of beams and columns. The qualitative behavior of combined stresses and fracture in materials is also covered. Prerequisite: ARCH 314

OBJECTIVES
Students are introduced to the fundamentals of analysis and design of simple structural members in steel, wood and concrete. Basic code requirements strength, stability and serviceability are discussed. Principles of composite materials design, structural continuity, and combined stresses are covered.

ORGANIZATION
A series of lectures are regularly given on each Monday and Friday. The lectures cover concepts and procedures, including discussions. Each Wednesday the class is broken into smaller sections for recitation in which problems can be solved with more student/instructor interaction. Solutions to homework problems are entered online through the course website. Three tests are used to measure student comprehension of the material. In addition, a construction/testing project is used to allow students an opportunity to apply concepts to a physical design. Computer facilities, including software, are available for supporting computations. Faculty and equipment for structural model testing is also available.

EVALUATION
Evaluation is based upon three tests (35%), a series of homework problems (45%), and a construction/testing project (15%). All work will be set on a 100 point scale with a full range of letter grades assigned.

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<th>Grade</th>
<th>Percentage</th>
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<td>0.0 – 49.9</td>
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By University policy the minimum passing grade is a D (60.0).

LECTURES AND EXERCISES
Solutions to exercises (example problems from the text) are provided in the course pack. These as well as lecture slides are also available on the course web site. In addition, the lectures will be recorded and posted to the web site. Students are expected to review any lectures which they miss. The exercises will not be collected or scored, but solutions can be discussed in the Wednesday recitation sessions or by appointment with GS's.

PROBLEMS
A set of homework problems covering the primary aspects of the course will be given to each student. Each student will have a unique set of problems to solve. Students submit solutions online for scoring. Each problem may be worked up to 3 times (3 different data sets) for credit. The best score from one of the 3 trials will be recorded. Late problems will be penalized at -6% per day up to a maximum of -30%. Problems are accessed through the course web site. A FAQ which explains the policy concerning the problems is also posted.

PROJECT
A group project to design, construct and test a compression structure will be assigned during the course. It will be documented with both a preliminary and a report which together count 12% of the final grade.

TEXT
The required text is Structural Principles, by I. Engel. (Prentice Hall, 1984). A course pack is available at the TCAUP Media Center. Additional material will be posted to the course web site: http://www.umich.edu/~arch324.
Course Schedule

Lectures
Monday & Friday
video recorded and posted

Homework
web format

Tests
three total
closed book
closed notes

Project
tower
Weight, height and load
Design with Wood

Code in the USA: NDS

It is ASD and LRFD

Source: American Forest & Paper Association,
NDS: national design specification for wood
Allowable Flexure Stress $F'_b$

$F'_b$ from tables determined by species and grade

$F'_b = F_b$ (usage factors)

usage factors for flexure:
- $C_D$ Load Duration Factor
- $C_M$ Moisture Factor
- $C_L$ Beam Stability Factor
- $C_F$ Size Factor
- $C_{fu}$ Flat Use
- $C_r$ Repetitive Member Factor

Actual Flexure Stress $f_b$

$f_b = M c / I = M / S$

$S = I / c = b d^2 / 6$

$F'_b \geq f_b$

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<tr>
<th>Load Duration</th>
<th>$C_D$</th>
<th>Typical Design Loads</th>
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<td>Permanent</td>
<td>0.9</td>
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<td>Ten years</td>
<td>1.0</td>
<td>Occupancy Live Load</td>
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<td>Two months</td>
<td>1.15</td>
<td>Snow Load</td>
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<td>Seven days</td>
<td>1.25</td>
<td>Construction Load</td>
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<tr>
<td>Ten minutes</td>
<td>1.6</td>
<td>Wind/Earthquake Load</td>
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<tr>
<td>Impact$^2$</td>
<td>2.0</td>
<td>Impact Load</td>
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</table>

Source: NDS 2005
Allowable Shear Stress $F'_{V}$

$F_{V}$ from tables determined by species and grade

$F'_{V} = F_{V}$ (usage factors)

usage factors for shear:
- $C_D$ Load Duration Factor
- $C_M$ Moisture Factor

Actual Shear Stress $f_v$

$f_v = VQ / I b = 1.5 V/A$

Can use $V$ at $d$ from support as maximum

$F'_{V} \geq f_v$

Source: NDS 2005
Analysis Procedure

Given: loading, member size, material and span.
Req’d: Safe or Unsafe

1. Find Max Shear & Moment
   • Simple case – equations
   • Complex case - diagrams

2. Determine actual stresses
   • $f_b = M/S$
   • $f_v = 1.5 \, V/A$

3. Determine allowable stresses
   • $F_b'$ and $F_v'$ (from NDS)

4. Check that actual < allowable
   • $f_b < F_b'$
   • $f_v < F_v'$

5. Check deflection

6. Check bearing ($F_b = R/A_b$)

<table>
<thead>
<tr>
<th>Nominal Size b x d</th>
<th>Actual Size b x d</th>
<th>Area in.$^2$</th>
<th>$I_y$ in.$^4$</th>
<th>$S_y$ in.$^3$</th>
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Source: Structural Principles
Analysis Procedure

Given: loading, member size, material and span.

Req’d: Safe or Unsafe

1. Find Max Shear & Moment
   - Simple case – equations
   - Complex case - diagrams

```
GIVEN: LOAD = 145*
SPAN = 6'
SECTION = 2x4 (1.5x3.5)
F' 6 = 1800  F'V = 180 psi

REQ'D: PASS or FAIL
```

```
\[
M_x = \frac{PL}{4} = \frac{145 \times (6')}{4}
\]

\[
M_x = 217.5'\times = 2610'' - \#
\]

\[
V = \frac{P}{2} = 145/2 = 72.5''
\]
```
Analysis Procedure

2. Determine actual stresses
   • \( f_b = \frac{M}{S} \)
   • \( f_v = 1.5 \frac{V}{A} \)

3. Determine allowable stresses
   • \( F'_b \) and \( F'_v \) (from NDS)

4. Check that actual < allowable
   • \( f_b < F'_b \)
   • \( f_v < F'_v \)

5. Check deflection

6. Check bearing \((F_b = \frac{R}{A_b})\)
Analysis Procedure

Given: member size, material and span.  
Req’d: Max. Safe Load (capacity)

1. Assume $f = F$  
   • Maximum actual = allowable stress

2. Solve stress equations for force  
   • $M = F_b S$  
   • $V = 0.66 F_v A$

3. Use maximum forces to find loads  
   • Back calculate a load from forces  
   • Assume moment controls  
   • Check shear

4. Check deflection  
5. Check bearing

### Properties of Sawn Lumber Sections

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<th>Actual Size</th>
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Source: Structural Principles
Analysis Procedure

Given: member size, material and span.
Req’d: Max. Safe Load (capacity)

1. Assume $f = F$
   - Maximum actual = allowable stress

2. Solve stress equations for force
   - $M = F_b S$
   - $V = 0.66 F_v A$

3. Use maximum forces to find loads
   - Back calculate a load from forces

---

Given: $\text{SPAN} = 6', \text{SECTION} = 2 \times 4 (1.5 \times 3.5)$
$F_b' = 1800 \text{ psi, } F_v' = 180$

Req’d: Maximum Load $P$

- $f_b = F_b' = 1800 \text{ psi} = \frac{M}{S_x}$
  - $S_x = 3.063 \text{ in}^2$
  - $M_t = F_b' S_x = 1800 (3.063) = 5508 \text{ in} - \text{lb}$
  - $P = 459 \text{ lb}$

$M_t = \frac{PL}{4}$
$P = \frac{M_t}{4/L}$
$P = 459 \times \frac{4}{L}$
$P = 3060 \text{ lb}$
Analysis Procedure (cont.)

4. Use maximum forces to find loads
   - Back calculate a load from forces
   - Use P from moment to find $V_{\text{max}}$

$$V_{\text{max}} = \frac{P}{2} = \frac{306}{2} = 153 \text{ * }$$

$$f_v = \frac{3}{2} \frac{V}{A} = 1.5 \left( \frac{153}{5.25} \right) = 43.7 \text{ psi}$$

$$43.7 \text{ psi} < 180 \text{ OK}$$

5. Check deflection
6. Check bearing
Design Procedure

Given: load, wood, span
Req’d: member size

1. Find Max Shear & Moment
   - Simple case – equations
   - Complex case - diagrams

2. Determine allowable stresses

3. Solve $S = M / F_b$

4. Choose a section from S table
   - Revise DL and $F_b$

5. Check shear stress
   - First for $V_{max}$ (easier)
   - If that fails try $V$ at $d$ distance from support
   - If the section still fails, choose a new section with $A = 1.5V / F_v$

6. Check deflection

7. Check bearing

### Properties of Sawn Lumber Sections

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<td>6 \times 8</td>
<td>&quot; \times 7\frac{1}{4}</td>
<td>41.25</td>
<td>193.36</td>
<td>51.56</td>
</tr>
<tr>
<td>6 \times 10</td>
<td>&quot; \times 9\frac{1}{2}</td>
<td>52.25</td>
<td>392.96</td>
<td>82.73</td>
</tr>
<tr>
<td>6 \times 12</td>
<td>&quot; \times 11\frac{1}{4}</td>
<td>63.25</td>
<td>697.07</td>
<td>121.23</td>
</tr>
<tr>
<td>6 \times 14</td>
<td>&quot; \times 13\frac{1}{4}</td>
<td>74.25</td>
<td>1127.67</td>
<td>167.06</td>
</tr>
<tr>
<td>6 \times 16</td>
<td>&quot; \times 15\frac{1}{4}</td>
<td>85.25</td>
<td>1706.78</td>
<td>220.23</td>
</tr>
</tbody>
</table>

Source: Structural Principles
Design Procedure

**Given:** load, wood, span  
**Req’d:** member size

1. **Find Max Shear & Moment**  
   - Simple case – equations  
   - Complex case - diagrams
Design Procedure

2. Determine allowable stresses (given)

3. Solve $S = \frac{M}{F_b'}$

4. Choose a section from S table
   - Revise DL and $F_b'$

8. Check shear stress
   - First for $V_{max}$ (easier)
   - If that fails try $V$ at $d$ distance (remove load $d$ from support)
   - If the section still fails, choose a new section with $A = 1.5V/F_v'$

9. Check deflection
10. Check bearing
GRADING

Visual Grading
Each member is assessed for visual defects. (splits, knots, density, etc.)

Machine Evaluated Lumber (MEL)
Each member is assessed for density using x-ray technology.

Machine Stress Rated (MSR)
Each member is stressed by running it through rollers which measure the deflection and stiffness. The E modulus in bending can be calculated from the deflection.
SIZE CATEGORIES

<table>
<thead>
<tr>
<th>Category</th>
<th>Size Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boards</td>
<td>1 to 1½ in. thick</td>
</tr>
<tr>
<td></td>
<td>2 in. and wider</td>
</tr>
<tr>
<td>Dimension lumber</td>
<td>2 to 4 in. thick</td>
</tr>
<tr>
<td></td>
<td>2 in. and wider</td>
</tr>
<tr>
<td>Timbers</td>
<td>5 in. and thicker</td>
</tr>
<tr>
<td></td>
<td>5 in. and wider</td>
</tr>
</tbody>
</table>

Image Sources: Donald E. Breyer. Design of wood structures
# SIZE CATEGORIES

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Nominal dimensions</th>
<th>Examples of sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF</td>
<td>Light Framing and</td>
<td>2 to 4 in.</td>
<td>2 × 2, 2 × 4, 4 × 4</td>
</tr>
<tr>
<td></td>
<td>Structural Light Framing</td>
<td>2 to 4 in.</td>
<td></td>
</tr>
<tr>
<td>SLF</td>
<td>Structural Joist and</td>
<td>2 to 4 in.</td>
<td>2 × 6, 2 × 14, 4 × 10</td>
</tr>
<tr>
<td></td>
<td>Plank</td>
<td>5 in. and wider</td>
<td></td>
</tr>
<tr>
<td>SJ&amp;P</td>
<td>Stud</td>
<td>2 to 4 in.</td>
<td>2 × 4, 2 × 6, 4 × 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 to 6 in.</td>
<td>(lengths limited to 10 ft and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>shorter)</td>
</tr>
<tr>
<td></td>
<td>Decking&quot;</td>
<td>2 to 4 in.</td>
<td>2 × 4, 2 × 8, 4 × 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 in. and wider</td>
<td></td>
</tr>
<tr>
<td>B&amp;S</td>
<td>Beams and Stringers</td>
<td>5 in. and</td>
<td>6 × 10, 6 × 14, 12 × 16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>thicker</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>More than 2 in. greater than</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>thickness</td>
</tr>
<tr>
<td>P&amp;T</td>
<td>Posts and Timbers</td>
<td>5 in. and</td>
<td>6 × 6, 6 × 8, 12 × 14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>thicker</td>
<td></td>
</tr>
</tbody>
</table>

*Decking is normally stressed about its minor axis. In this book, all other bending members are assumed to be stressed about the major axis of the cross section, unless otherwise noted.*
SIZE NOMINCLATURE

Full Sawn
• The size delivered is the full nominal size
• Not generally available

Rough Sawn
• Rough sawn condition with no surface planing
• Because no surfaces are planed, sizes are approximately 1/8” larger than S4S

Dressed
• The size after shrinkage from drying and surface planing
• Typically dressed on all 4 sides S4S

- Full Sawn  2 x 4
- Rough Sawn ~ 1 3/4 x 3 3/4
- Dressed S4S  1 1/5 x 3 1/5
GROWTH CHARACTERISTICS

Annual Rings

- Latewood is denser and stronger than earlywood.
- Sapwood is the actively living part of the tree. It is younger and transports water more readily than heartwood. The strength of the two is about the same.
- Density can be gauged visually by noting the % of latewood to earlywood

Knots

- Knots result from tree branches
- Knots weaken the member and effect the grading
Checks, Shakes and Splits

• All three are defects which weaken the wood
• Checks and splits are seasoning defects
• Shakes result from stress in the growing tree
Slope of Grain

• The slope of the grain is taken in relation to the long edge of the member

• It is measured as a ratio
e.g. 1” in 8”

• Increase in slope lowers the strength of the member
Moisture Content

- MC = %water to oven dry wood
- In a living tree, MC can be 200%
- “free water” is contained in cell cavity
- “bound water” is within the cell wall
- Fiber Saturation Point (FSP) is the MC at 0% free and 100% bound water
  FSP is about 30%
- Equilibrium Moisture Content (EMC) is reached in service

Shrinkage

- Shrinkage begins once MC<FSP
- Shrinkage is not the same in each direction
- Uncontrolled shrinkage results in splits
Engineered Wood Products

Glulam

- Glue laminated lumber
- Stress rated and graded
- Parallel grain
- Different finish grades
- Standard widths and lams
- Straight or curved
- Size limit by transportation
- Stock or custom dimensions

**Table 5.1.3 Net Finished Widths of Structural Glued Laminated Timbers**

<table>
<thead>
<tr>
<th>Nominal Width (in.)</th>
<th>3</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Net Finished Width (in.)</td>
<td>2-1/2</td>
<td>3-1/8</td>
<td>5-1/4</td>
<td>6-3/4</td>
<td>8-3/4</td>
<td>10-3/4</td>
<td>12-1/4</td>
<td>14-1/4</td>
</tr>
<tr>
<td>Western Species</td>
<td>3</td>
<td>5</td>
<td>6-3/4</td>
<td>8-1/2</td>
<td>10-1/2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Southern Pine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: NDS 2005
Engineered Wood Products

Prefabricated Wood I-Joists
- ASTM D 5055
- Standard dimensions
- Specifications per manufacturer
Engineered Wood Products

Structural Composite Lumber

- Laminated Veneer Lumber (LVL)
  - Veneer $\leq \frac{1}{4}''$

- Parallel Strand Lumber (PSL)
  - Strand thickness $\leq \frac{1}{4}''$

- Specifications per manufacturer
Engineered Wood Products

Wood Structural Panels

- **Plywood** – cross laminated wood veneer panels pressed and glued.

- **Oriented Strand Board (OSB)** – cross laminated layers of wood strands or wafers, compressed and glued

- **Composite Panel** – wood veneer and reconstituted wood based material