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UNIVERSITY OF MICHIGAN

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ARCHITECTURE 324

STRUCTURES II

Lecture Topics :

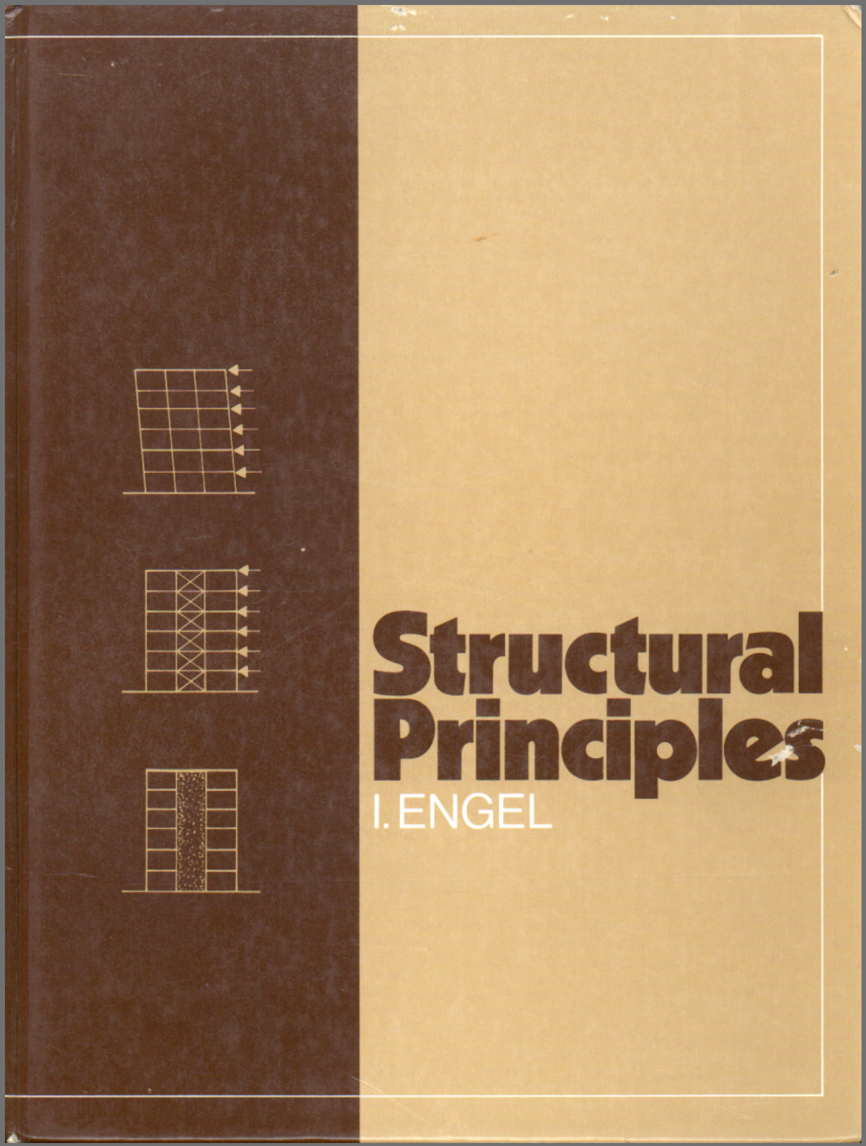
Course Syllabus

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.
Englewood Cliffs, N.J. : Prentice-Hall, 1984

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 flexure and in shear, and torsion 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 demonstrations. 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. Facility and equipment for structural model testing is also available.

EVALUATION
Evaluation is based upon three tests (39%), a series of home work problems (48%), and a construction/testing project (13%). All work will be set on a 100 point scale with a full range of letter grades assigned.

		A	100. – 93.0	A-	92.9 – 90.0
B+	89.9 – 87.0	B	86.9 – 83.0	B-	82.9 – 80.0
C+	79.9 – 77.0	C	76.9 – 73.0	C-	72.9 – 70.0
D+	69.9 – 67.0	D	66.9 – 63.0	D-	62.9 – 60.0
		E	59.9 – 0.0		

By University policy the minimum passing grade is a D (63.0).

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 GSI'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 -5% per day up to a maximum of -35%. 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 13% 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

Architecture 324 — Winter 2009

ARCHITECTURAL STRUCTURES II (3)

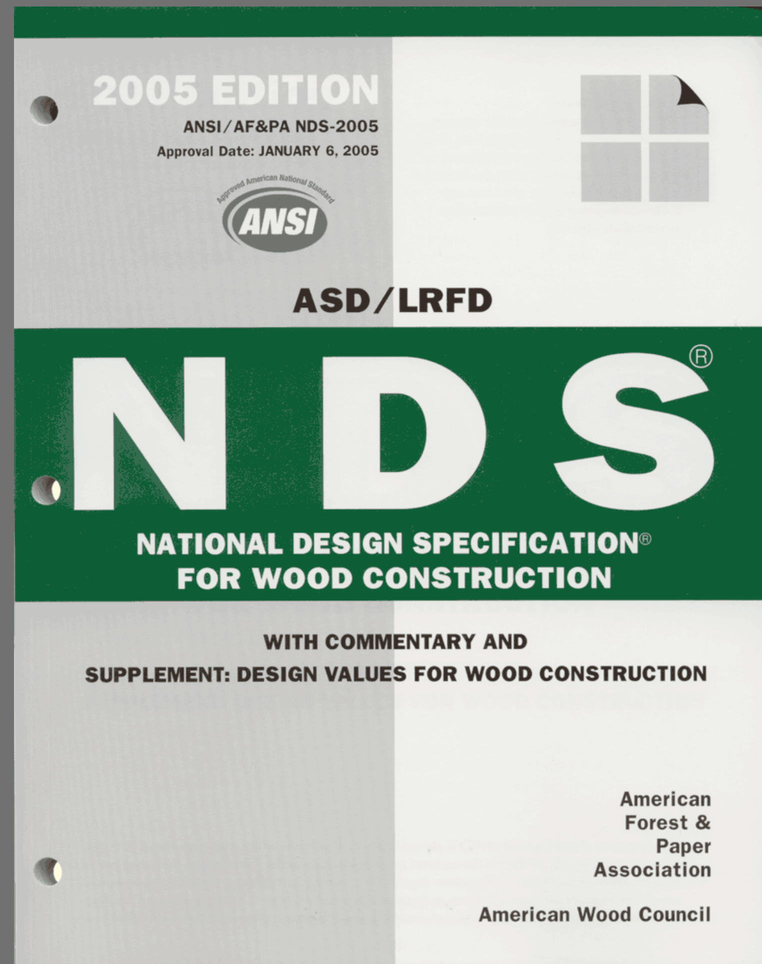
Lecture and Exercise Schedule

DATE	TOPIC	PROBLEMS (due dates online)
JAN 7	11 – Design of Wood Beams	
JAN 9	11 – Design of Wood Beams	
JAN 12	11 – Design of Wood Beams	1. Wood Beam Analysis
JAN 14	Recitation	
JAN 16	18 – Columns	2. Wood Beam Design
JAN 19	**MLK - NO CLASS**	
JAN 21	Recitation	3. Wood Column Analysis
JAN 23	18 – Columns	
JAN 26	12 - Combined Materials	4.Steel Column Design
JAN 28	Recitation	
JAN 30	12 - Combined Materials – Flitched Beams	5. Transformed Sections
FEB 2	12 - Combined Materials – Flitched Beams	
FEB 4	Recitation	<Preliminary Project Report>
FEB 6	13 – Reinforced Concrete WSD	6. Flitched Beams
FEB 9	**Test 1 – Chapters 11, 18 & 12**	
FEB 11	Recitation	
FEB 13	13 – Reinforced Concrete WSD	7. Reinforced Concrete WSD
FEB 16	14 – ASD Steel Beams	
FEB 18	Recitation	
FEB 20	14 – Composite Sections	8. Steel Beam Design
FEB 23	**VACATION – NO CLASS**	
FEB 25	**VACATION – NO CLASS**	
FEB 27	**VACATION – NO CLASS**	
MAR 2	Video – "The Tower Without Ends"	NA 6234.F72 P37 T69
MAR 4	Recitation	
MAR 6	**Tower Testing**	9. Composite Sections
MAR 9	15 - Concrete – Ultimate Strength	
MAR 11	Recitation	<Final Project Report>
MAR 13	15 - Concrete – Ultimate Strength	10. Ult. Strength Concrete Analysis
MAR 16	15 - Concrete – Ultimate Strength	
MAR 18	Recitation	
MAR 20	16 – Deflection of Beams	11. Ult. .Strength Concrete Design
MAR 23	**Test 2 – Chapters 12, 13, 14 & 15**	
MAR 25	Recitation	
MAR 27	16 – Deflection of Beams	12. Beam Deflections
MAR 30	16 – Deflection of Beams	
APR 1	Recitation	
APR 3	17. Structural Continuity	13. Beam Deflections
APR 6	17. Structural Continuity	
APR 8	Recitation	
APR 10	Video – "To Engineer is Human"	14. Three Moment Theorem
APR 13	19 – Combined Stress	
APR 15	Recitation	
APR 17	19 – Prestressing	15. Combined Stress
APR 20	**Test 3 – Chapters 16, 17, & 19**	

Design with Wood

Code in the USA: **NDS**

It is ASD and LRFD



Source: American Forest & Paper Association, NDS: national design specification for wood construction : Washington, D.C. 2005 edition

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

Table 2.3.2 Frequently Used Load Duration Factors, C_D[1]

Load Duration	C_D	Typical Design Loads
Permanent	0.9	Dead Load
Ten years	1.0	Occupancy Live Load
Two months	1.15	Snow Load
Seven days	1.25	Construction Load
Ten minutes	1.6	Wind/Earthquake Load
Impact[2]	2.0	Impact Load

Source: NDS 2005

Actual Flexure Stress f_b

$f_b = Mc/I = M/S$

$S = I/c = bd^2/6$

$F_b' >= f_b$

(1) Actual stress due to (DL)	≤ (0.9) (Design value)
(2) Actual stress due to (DL+LL)	≤ (1.0) (Design value)
(3) Actual stress due to (DL+WL)	≤ (1.6) (Design value)
(4) Actual stress due to (DL+LL+SL)	≤ (1.15) (Design value)
(5) Actual stress due to (DL+LL+WL)	≤ (1.6) (Design value)
(6) Actual stress due to (DL+SL+WL)	≤ (1.6) (Design value)
(7) Actual stress due to (DL+LL+SL+WL)	≤ (1.6) (Design value)

Source: NDS 2005

Allowable Shear Stress Fv'

F_v from tables determined by species and grade

$F_v' = F_v$ (usage factors)

usage factors for shear:

C_D Load Duration Factor

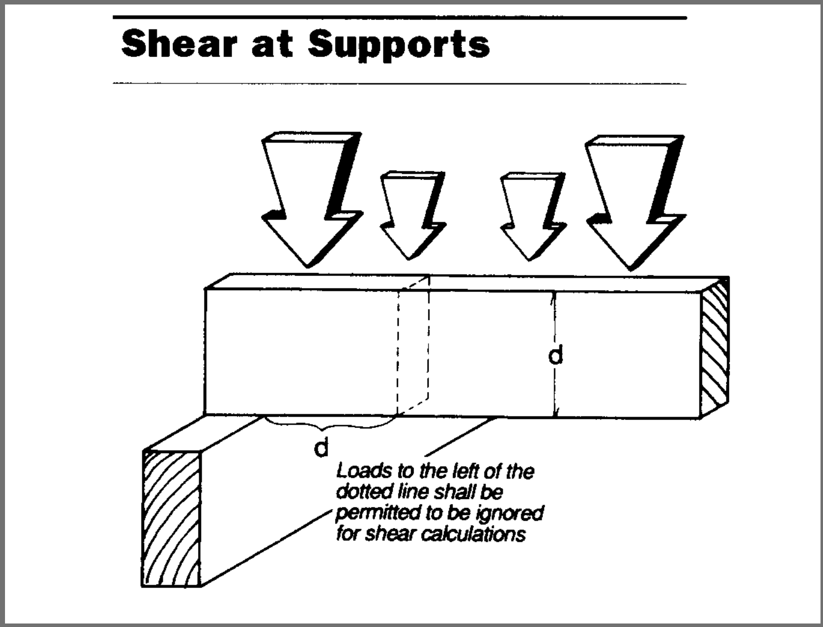
C_M Moisture Factor

Actual Shear Stress fv

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

Can use V at d from support as maximum

$F_v' >= f_v$



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)

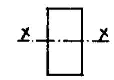
4. Check that actual < allowable

- $f_b < F'_b$
- $f_v < F'_v$

5. Check deflection

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

PROPERTIES OF SAWN LUMBER SECTIONS

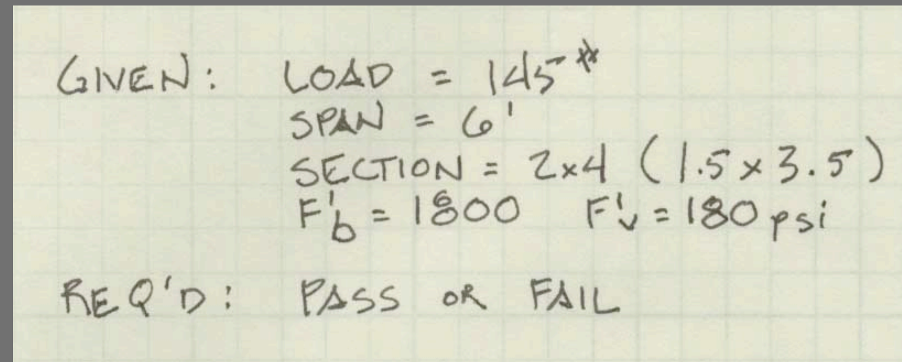


Nominal Size b × d	Actual Size b × d	Area in.^{2}	I_x in.^{4}	S_x in.^{3}
2 × 4	1½ × 3½	5.25	5.36	3.06
2 × 6	″ × 5½	8.25	20.80	7.56
2 × 8	″ × 7¼	10.88	47.64	13.14
2 × 10	″ × 9¼	13.88	98.93	21.39
2 × 12	″ × 11¼	16.88	177.98	31.64
3 × 4	2½ × 3½	8.75	8.93	5.10
3 × 6	″ × 5½	13.75	34.66	12.60
3 × 8	″ × 7¼	18.13	79.39	21.90
3 × 10	″ × 9¼	23.13	164.89	35.65
3 × 12	″ × 11¼	28.13	296.63	52.73
4 × 4	3½ × 3½	12.25	12.50	7.15
4 × 6	″ × 5½	19.25	48.53	17.65
4 × 8	″ × 7¼	25.38	111.15	30.66
4 × 10	″ × 9¼	32.38	230.84	49.91
4 × 12	″ × 11¼	39.38	415.28	73.83
6 × 6	5½ × 5½	30.25	76.26	27.73
6 × 8	″ × 7½	41.25	193.36	51.56
6 × 10	″ × 9½	52.25	392.96	82.73
6 × 12	″ × 11½	63.25	697.07	121.23
6 × 14	″ × 13½	74.25	1127.67	167.06
6 × 16	″ × 15½	85.25	1706.78	220.23

Source: Structural Principles

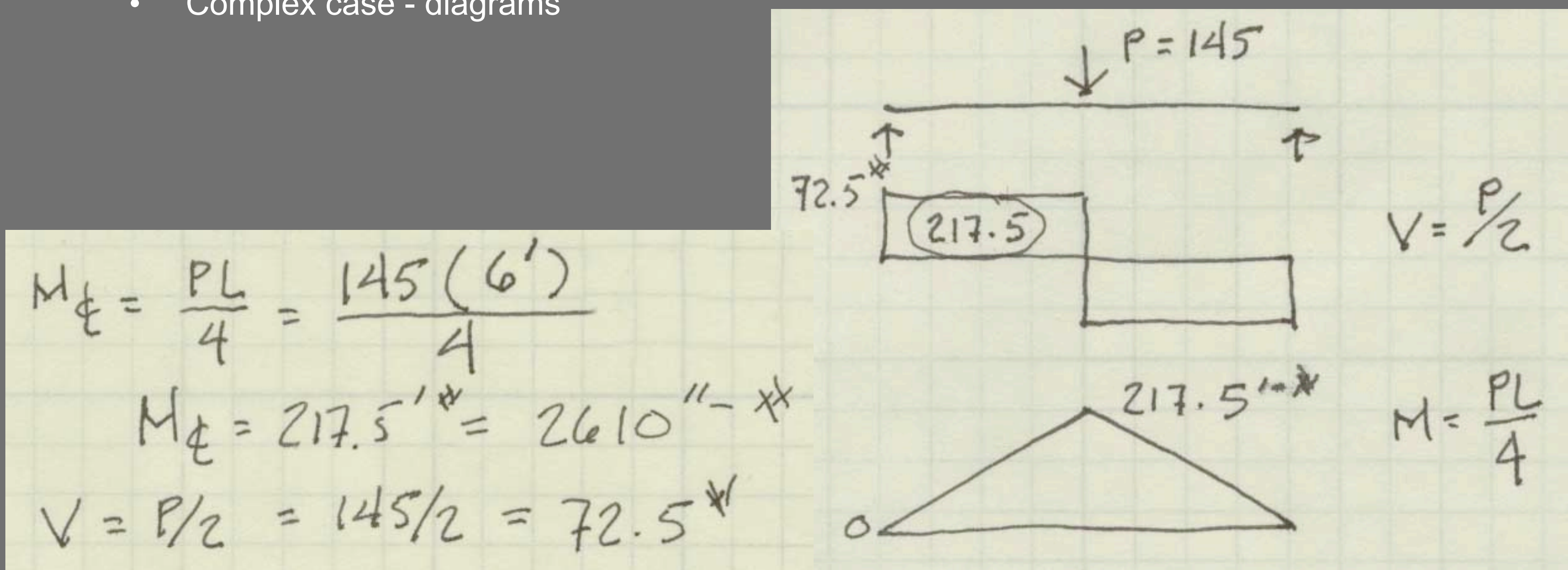
Analysis Procedure

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



1. Find Max Shear & Moment

- Simple case – equations
- Complex case - diagrams



Analysis Procedure

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

$$f_b = M/S_x$$

$$S_x = \frac{bd^2}{6} = \frac{1.5(3.5)^2}{6} = 3.063\ in^3$$

$$f_b = \frac{2610''\text{-}\#}{3.063\ in^3} = 852\ psi$$

$$f_v = \frac{3}{2}\frac{V}{A} = 1.5(72.5^{\#}/5.25\ in^2)$$

$$f_v = 20.71\ psi$$

3. **Determine allowable stresses**
   - F_b' and F_v' (from NDS)

$F'_b = 1800$ PSI $\quad F'_v = 180$ PSI

(FROM NDS)

4. **Check that actual < allowable**
   - $f_b < F'_b$
   - $f_v < F'_v$
5. **Check deflection**
6. **Check bearing** ($F_b = R/A_b$)

852 psi < 1800 psi ✓ OK

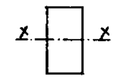
20.71 psi < 180 psi ✓ OK

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



Nominal Size b × d	Actual Size b × d	Area in.^{2}	I_x in.^{4}	S_x in.^{3}
2 × 4	1½ × 3½	5.25	5.36	3.06
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2 × 10	″ × 9¼	13.88	98.93	21.39
2 × 12	″ × 11¼	16.88	177.98	31.64
3 × 4	2½ × 3½	8.75	8.93	5.10
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6 × 14	″ × 13½	74.25	1127.67	167.06
6 × 16	″ × 15½	85.25	1706.78	220.23

Source: Structural Principles

Analysis Procedure

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

GIVEN : SPAN = 6' P @ ℄
SECTION = 2x4 (1.5 x 3.5)
$F'_b = 1800$ psi $F'_v = 180$

REQ'D : MAXIMUM LOAD P

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

$f_b = F'_b = 1800 \text{ psi} = M/S_x$

$S_x = 3.063 \text{ in}^3$

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

$M_{℄} = F'_b S_x = 1800(3.063)$
$= 5508$ "-#
$= 459$ '-#

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

$M_{℄} = \frac{PL}{4}$ $P = M_{℄} 4/L$

$P = 459(4)/6$

$P = 306$ #

Analysis Procedure (cont.)

4. **Use maximum forces to find loads**
   - Back calculate a load from forces
   - Use P from moment to find Vmax

$$V_{max} = P/2 = \frac{306}{2} = 153^{\#}$$

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

$$43.7\,psi < 180 \quad \checkmark\ ok$$

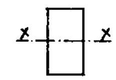
5. **Check deflection**
6. **Check bearing**

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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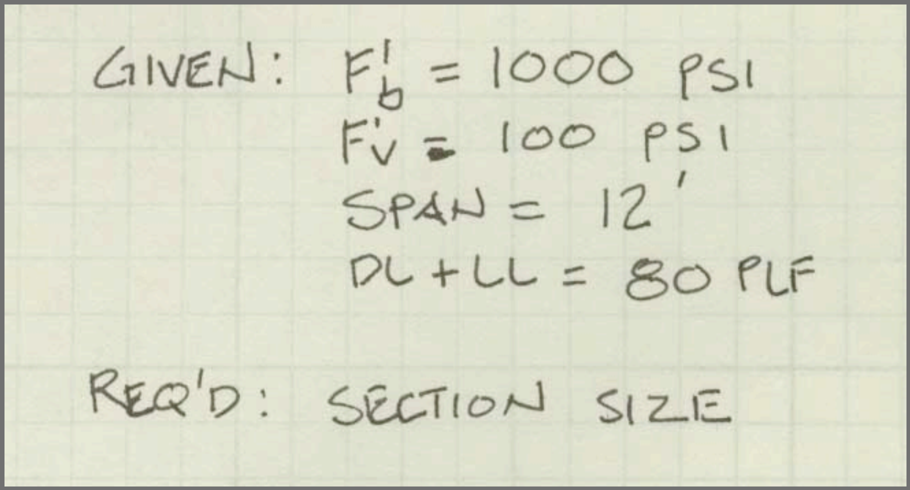
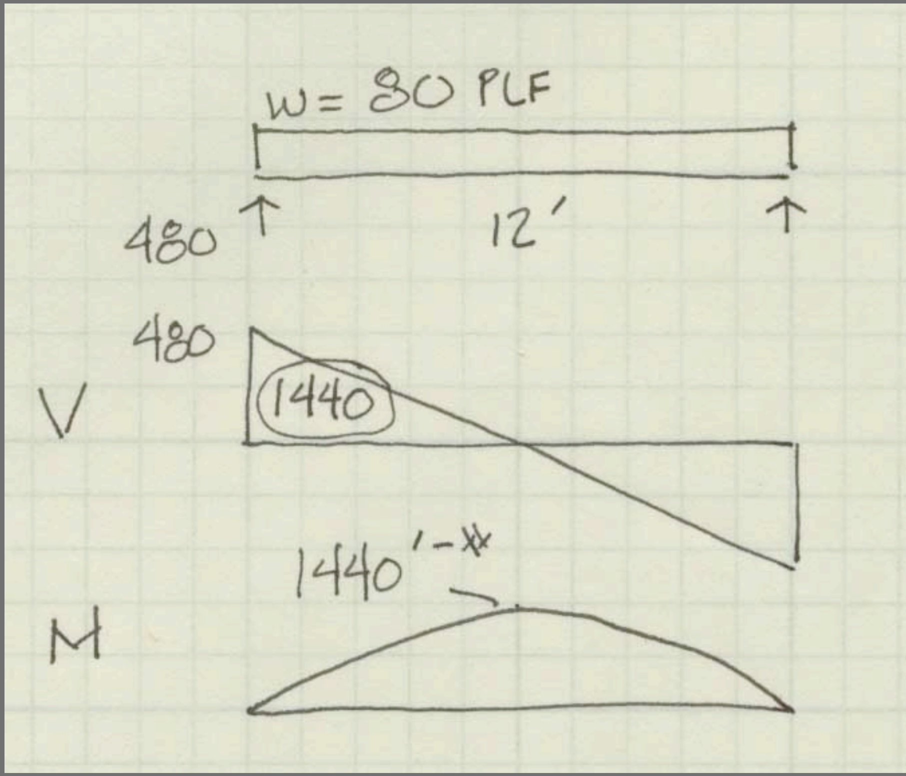
Source: Structural Principles

Design Procedure

Given: load, wood, span
Req'd: <u>member size</u>



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



Design Procedure

2. Determine allowable stresses
(given)

$$F_b' = M/S_x \qquad S_x = M/F_b'$$

3. Solve $S=M/F_b'$

$$S_x = \frac{1440(12)}{1000} = 17.28\ in^3$$

4. Choose a section from S table

- Revise DL and F_b'

$$2 \times 10 \qquad S_x = 21.39 > 17.28 \ \checkmark$$
$$A = 13.88\ in^2$$

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 $A=1.5V/F_v'$

$$f_v = \frac{3}{2}\frac{V}{A} = \frac{1.5(480^{\#})}{13.88\ in^2} = 51.87$$

$$51.87\ psi < 100\ psi \ \checkmark\ OK$$

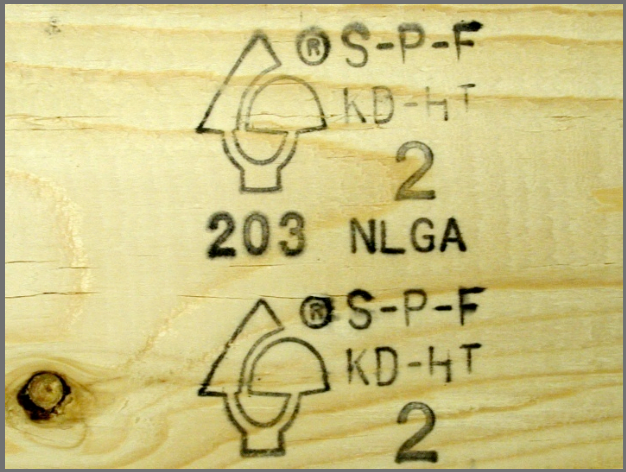
9. Check deflection

10. Check bearing

GRADING

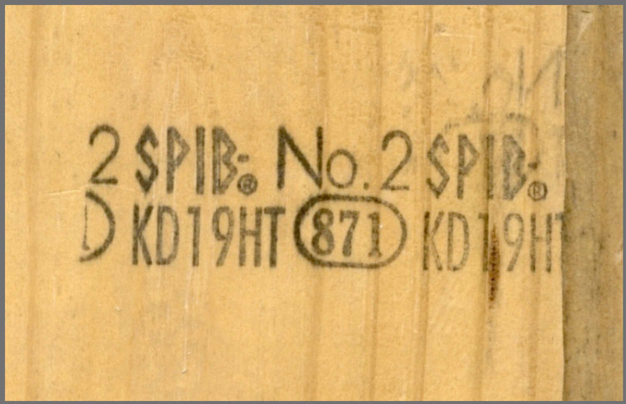
Visual Grading

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



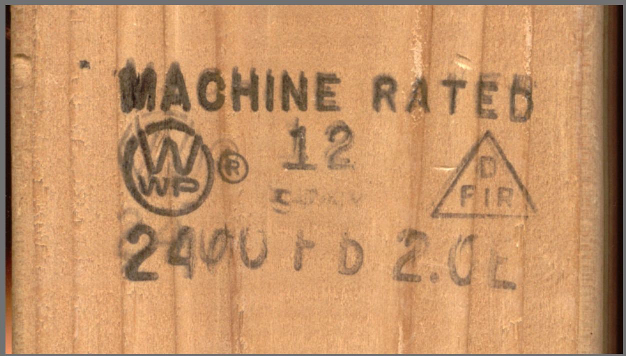
Machine Evaluated Lumber (MEL)

Each member is assessed for density using x-ray technology.



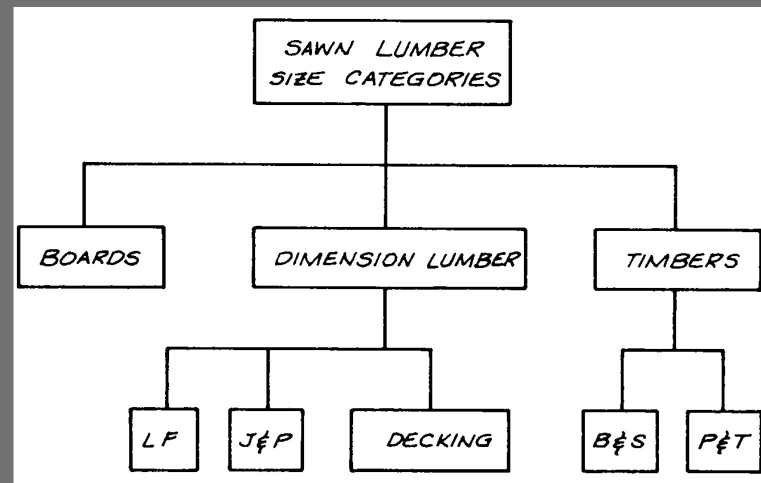
Machine Stress Rated (MSR)

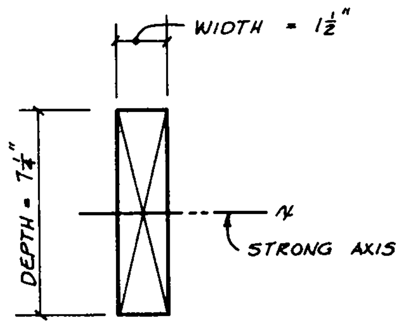
Each member is stressed by running it through rollers which measure the deflection and stiffness. The E modulus in bending can be calculated from the deflection.



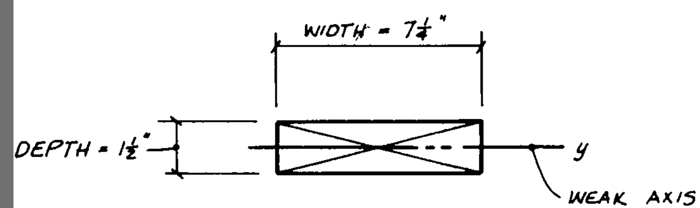
SIZE CATAGORIES

Boards	1 to 1½ in. thick 2 in. and wider
Dimension lumber	2 to 4 in. thick 2 in. and wider
Timbers	5 in. and thicker 5 in. and wider





2 x 8 SECTION



8 x 2 SECTION

Image Sources: Donald E. Breyer. Design of wood structures

SIZE CATAGORIES

Symbol	Name	Nominal dimensions: Thickness	Nominal dimensions: Width	Examples of sizes
LF SLF	Light Framing and Structural Light Framing	2 to 4 in.	2 to 4 in.	2 × 2, 2 × 4, 4 × 4
SJ&P	Structural Joist and Plank	2 to 4 in.	5 in. and wider	2 × 6, 2 × 14, 4 × 10
	Stud	2 to 4 in.	2 to 6 in.	2 × 4, 2 × 6, 4 × 6 (lengths limited to 10 ft and shorter)
	Decking*	2 to 4 in.	4 in. and wider	2 × 4, 2 × 8, 4 × 6
B&S	Beams and Stringers	5 in. and thicker	More than 2 in. greater than thickness	6 × 10, 6 × 14, 12 × 16
P&T	Posts and Timbers	5 in. and thicker	Not more than 2 in. greater than thickness	6 × 6, 6 × 8, 12 × 14

*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.

Source: Donald E. Breyer. Design of wood structures. New York: McGraw-Hill, c1999. 4th edition

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

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

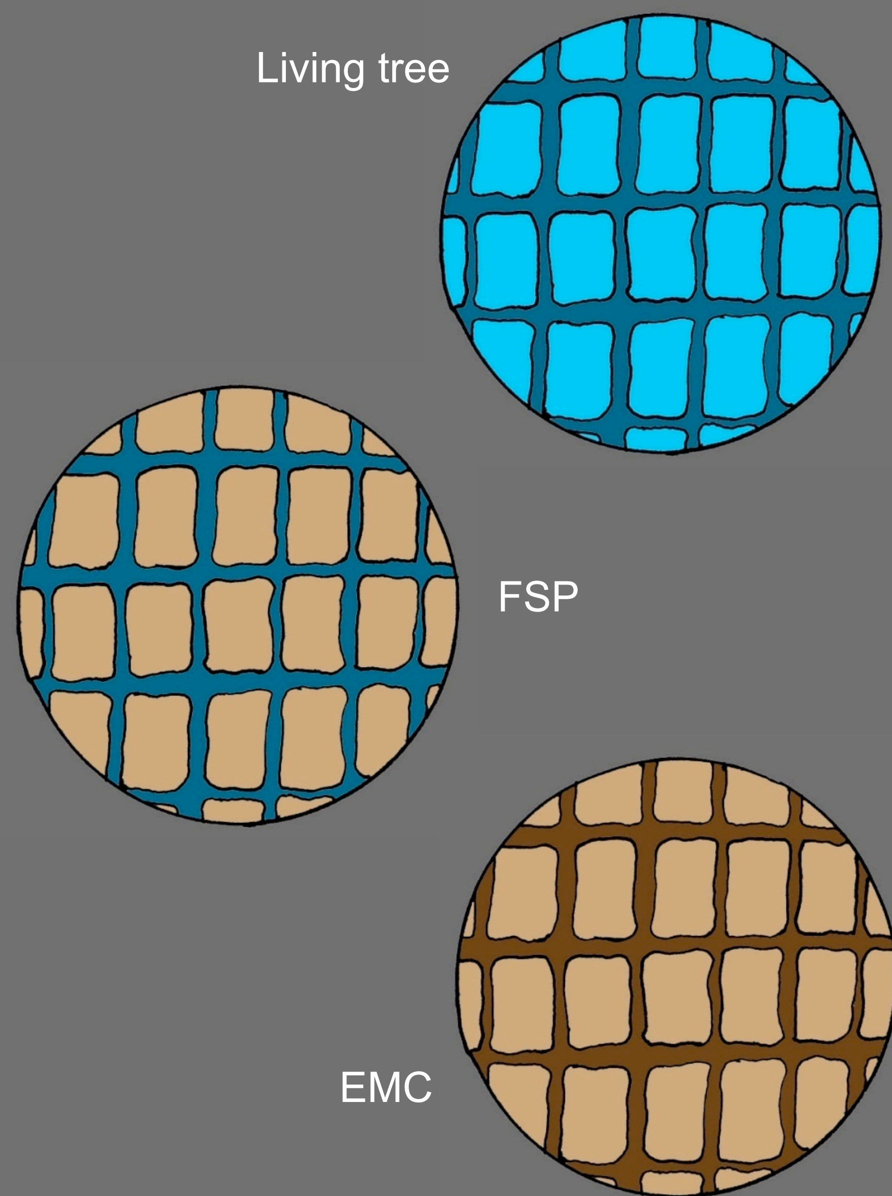
- The slope of the grain is taken in relation to the long edge of the member
- It is measured as a ratio
  e.g. 1" in 8"
- Increase in slope lowers the strength of the member

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

Nominal Width (in.)	3	4	6	8	10	12	14	16
Minimum Net Finished Width (in.) — **Western Species**	2-½	3-1/8	5-1/8	6-¾	8-¾	10-¾	12-¼	14-¼
Minimum Net Finished Width (in.) — **Southern Pine**	-	3	5	6-¾	8-½	10-½	-	-

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 ≤ ¼”

- **Parallel Strand Lumber** (PSL)
- Strand thickness ≤ ¼”

- 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