ME 302 Materials Mechanics

Introduction and Overview

This is a fundamental course in all Civil and Mechanical Engineering Programs.

Sometimes it is called:

“Strength of Materials” or “Mechanics of Materials”
CEE 370 Engineering Mechanics of Deformable Bodies

The Civil Engineering Department is offering their own Mechanics of Materials Course.

All Civil Engineering majors or pre-CEE majors should drop ME 302 and sign up for CEE 370.

CEE 370 meets in CBC C-120
11:30 AM – 12:45 PM
Instructor: Prof. Aly Said
Course Material

- Lectures & Notes
- Text Book
- Website
- Email
<table>
<thead>
<tr>
<th>Instructor: Dr. Brendan J. O’Toole, Ph.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Professor:</strong> Brendan J. O'Toole, Ph.D.</td>
</tr>
<tr>
<td><strong>Office:</strong> TBE B122</td>
</tr>
<tr>
<td><strong>Phone:</strong> 895-3885</td>
</tr>
<tr>
<td><strong>E-Mail:</strong> <a href="mailto:bj@me.unlv.edu">bj@me.unlv.edu</a></td>
</tr>
<tr>
<td><strong>Days/Time/Room:</strong> TR / 11:30 AM – 12:45 PM / MPE 232</td>
</tr>
<tr>
<td><strong>Text:</strong> “Mechanics of Materials”, 4th Edition</td>
</tr>
<tr>
<td>Beer, Johnston, &amp; DeWolf</td>
</tr>
<tr>
<td>McGraw Hill, 2006</td>
</tr>
<tr>
<td><strong>O’Toole Website:</strong> <a href="http://www.egr.unlv.edu/~bj/">http://www.egr.unlv.edu/~bj/</a></td>
</tr>
<tr>
<td><strong>Prerequisites:</strong></td>
</tr>
<tr>
<td>EGG 206 Engineering Mechanics I (Statics)</td>
</tr>
<tr>
<td>MAT 182 Calculus II</td>
</tr>
<tr>
<td>PHY 180 Physics I</td>
</tr>
<tr>
<td>EGG (MEG) 100 Intro. to Engineering Design</td>
</tr>
</tbody>
</table>
Instructor: Dr. Brendan J. O’Toole

• **Education**
  
  – B.S. in Mechanical and Aerospace Engineering, University of Delaware, 1986.

• **Employment**
  
  – **Associate Professor** - Mechanical Engineering, UNLV (8/92 - present)
    
    • Areas of interest:
      
      – Experimental and computational solid mechanics
      – Structural Dynamics, Finite Element Analysis, and Design
      – Fabrication of components and structures (emphasis on composites)
      – Mechanics of solid cellular foams: dynamic & static properties
  
  – **Director** – Center for Materials and Structures (CMS)
    University of Nevada Las Vegas (12/05 - present)
  
  – **Program Manager** – Soldiers Future Force Electronics Reliability and Survivability Technology Program, UNLV/U.S. Army Research Laboratory Cooperative Agreement
  
  – **Director of Engineering** – High Pressure Science and Engineering Center
    University of Nevada Las Vegas (1/03 - present)
  
  – **Visiting Research Associate** - Composites and Lightweight Structures Branch
    U.S. Army Research Laboratory, Aberdeen MD (10/01 - 4/02)
    
    • Computational simulation of composite armor systems under ballistic impact loading.
Active Projects for Dr. Brendan J. O’Toole

- Development of a Reconfigurable Tooling System, 2Phase Technologies, Inc.
- Development of Nano-Fiber Reinforced Polyurethane Foams, Department of Energy Stockpile Stewardship Program
- Soldier FERST - Soldier’s Objective Force Electronics Reliability and Survivability Technology Program, US Army
  - Ballistic Shock Propagation Through Structural Joints
  - High Frequency Shock Mitigation in Air Gun Experiments
- Design/Education Oriented Projects
  - Human Powered Vehicle Design, ASME Competition
  - Developing a Balloon Satellite Program, NASA Space Grant/EPSCoR Program
  - High School First Robotics Competition, NASA Space Grant/EPSCoR Program
- Composite Blast Containment Vessels, Sandia National Laboratories
- Blast Loading on Vehicle Structures, DOD EPSCoR and UNLV
MEG 302 Course Objectives

• Learn the Vocabulary
• Improve Your Skill at Drawing Free Body Diagrams
• Learn About Material Behavior
• Learn How To Solve Mechanics Problems. This is the largest part of the class. The solution procedure for most mechanics problems involves one or more of the following tasks:
  – A statics analysis of a component to find the internal reactions (forces & moments)
  – Determine stresses and strains in a component based on internal reactions
  – Find the deformation of the component
  – Compare calculated values of stress & deformation with known acceptable values
• Improve Your Engineering Design Skills
This is a sampling of terms that are defined in the text. We will discuss them throughout the semester. You are expected to understand the meaning of these terms. You are also expected to know the correct units for material properties and other variables.
Free Body Diagrams

• Free Body Diagrams were first introduced in Physics and Statics courses.
• They are a powerful tool that help define the important loads, reactions, geometry, and coordinate system in a problem so that the correct equilibrium equations are defined and solved.
Material Response to Loading

Assume rod $BC$ has a length $L$ and a uniform cross-sectional area $A$. The rod is suspended from point $B$ and a load $P$ is applied to end $C$. When the load is applied, the rod elongates an amount $\delta$. Plotting the magnitude $P$ of the load against the deformation, we obtain a certain load-deformation diagram.

If the cross-sectional area is $2A$, a load of $2P$ is required to produce the same deformation. In both cases the normal stress is the same: $\sigma = P/A$.

If a load $P$ is applied to a rod with a cross-sectional area $A$ and length $2L$, the deformation is $2\delta$. In either case the ratio of the deformation to the rod length is the same; it is equal to $\delta/L$.

This observation leads to the concept of normal strain.

$$\varepsilon = \delta / L$$
Tensile Test of EP-823 Maraging Steel

Stress vs Strain

0.000 0.050 0.100 0.150 0.200 0.250
Strain

0.000 0.050 0.100 0.150 0.200 0.250
Stress (ksi)
Axial Loading

Example from Software CD included with textbook.

Determine the displacement of end D of the rod shown, knowing that it is made from a steel with \( E = 200 \text{ MPa} \).

The rod can be divided into three sections as shown. For each section, we know:

\[
L_1 = 0.4 \text{ m} \quad A_1 = 200 \times 10^{-6} \text{ m}^2 \\
L_2 = L_3 = 0.3 \text{ m} \quad A_2 = A_3 = 600 \times 10^{-6} \text{ m}^2
\]

The internal force in each section is determined from a free-body diagram of the portion of the rod located to the right of the section. For each section we have:

**Section 1**

\[
\sum F_x = 0: \quad 400 - P_1 = 0 \\
P_1 = 400 \times 10^3 \text{ N}
\]

**Section 2**

\[
\sum F_x = 0: \quad 400 - 450 - P_2 = 0 \\
P_2 = -50 \times 10^3 \text{ N}
\]

**Section 3**

\[
\sum F_x = 0: \quad 400 - 450 + 850 - P_3 = 0 \\
P_3 = 800 \times 10^3 \text{ N}
\]

The displacement at D is determined from:

\[
\delta_D = \sum_{i=1}^{3} \frac{P_i L_i}{A_i E} \\
= \frac{1}{E} \left[ \frac{P_1 L_1}{A_1} + \frac{P_2 L_2}{A_2} + \frac{P_3 L_3}{A_3} \right] \\
= \frac{1}{200 \times 10^9} \left[ \frac{(400 \times 10^3)(0.4)}{200 \times 10^{-6}} - \frac{(50 \times 10^3)(0.3)}{600 \times 10^{-6}} + \frac{(800 \times 10^3)(0.3)}{600 \times 10^{-6}} \right]
\]

\[
\delta_D = (4 - 0.125 + 2) \times 10^{-3} \text{ m} \quad \delta_D = 5.875 \text{ mm}
\]
For a uniform shaft of radius \( r \) and length \( L \), it has been shown that the maximum shearing strain \( \gamma_{\max} \) is related to the angle of twist \( \phi \) by

\[
\gamma_{\max} = \frac{cr}{L}
\]

In addition, the maximum shearing stress is related to the applied torque \( T \) by

\[
\tau_{\max} = \frac{Tr}{J}
\]

If the applied torque is not large enough to cause the shearing stress to exceed the yield stress anywhere in the shaft, Hooke’s law applies, and \( \gamma_{\max} = \frac{\tau_{\max}}{G} \), so

\[
\gamma_{\max} = \frac{cr}{L} = \frac{\tau_{\max}}{G} = \frac{Tr}{GJ}
\]

Solving for \( \phi \),

\[
\phi = \frac{T\ell}{GJ}
\]

where \( \phi \) is expressed in radians. This relation shows that the angle of twist is proportional to the applied torque \( (T) \), shaft length \( (L) \), material \( (G) \), and geometry \( (J) \).
Beams and Bending

Mechanics of Materials

File: Beam Bending Analysis

At $x = 4$ ft: 
\[ \sigma_{\text{top}} = 2.918 \text{ ksi} \]
\[ \sigma_{\text{bot}} = -6.16 \text{ ksi} \]

At $x = 8$ ft the moment is positive, so the top of the beam is in compression and the bottom is in tension.

The moment is in kip-ft, and must be converted to kip-in., so $M = 64(12) = 768$ kip-in.

At the top of the beam
\[ \sigma = -\frac{My}{I} = -\frac{(768 \text{ kip-in.})(3.94 \text{ in.})}{518.18 \text{ in.}^4} \]
\[ \sigma_{\text{top}} = -5.836 \text{ ksi} \]

At the bottom of the beam
\[ \sigma = -\frac{My}{I} = -\frac{(768 \text{ kip-in.})(-8.31 \text{ in.})}{518.18 \text{ in.}^4} \]
\[ \sigma_{\text{bot}} = 12.32 \text{ ksi} \]

The maximum tensile stress is at $x = 8$ ft and is at the bottom of the beam, and the maximum compressive stress is at $x = 4$ ft, and is also on the bottom of the beam.
Pressure Vessels & Design
Buckling

\[ P_{cr} = \frac{\pi^2 EI}{L^2} \]
<table>
<thead>
<tr>
<th>Dates</th>
<th>Ch</th>
<th>Sec</th>
<th>Topics</th>
<th>Homework Due Dates</th>
<th>Proposed Lab Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>T 8/29</td>
<td>1</td>
<td>1-6</td>
<td>Concept of Stress, Normal Stress Components of Stress, Safety Factors</td>
<td>Send an e-mail to Dr. O'Toole so he can create a class list.</td>
<td>No Lab</td>
</tr>
<tr>
<td>R 8/31</td>
<td>1</td>
<td>7-13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 9/5</td>
<td>2</td>
<td>1-8</td>
<td>Stress-Strain curves, Axial Loading Static Indeterminacy</td>
<td></td>
<td>1: Safety &amp; Statistics</td>
</tr>
<tr>
<td>R 9/7</td>
<td>2</td>
<td>9-10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 9/12</td>
<td>2</td>
<td>11-15</td>
<td>Poisson’s Ratio, Shearing Strain Torsion: Stresses, Angle of Twist</td>
<td></td>
<td>2: Strain Gage Bonding</td>
</tr>
<tr>
<td>R 9/14</td>
<td>3</td>
<td>1-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 9/19</td>
<td>3</td>
<td>5-8</td>
<td>Statically Ind. Torsion, Power Bending: Stress &amp; Deformation</td>
<td></td>
<td>2: Strain Gage Bonding</td>
</tr>
<tr>
<td>R 9/21</td>
<td>4</td>
<td>1-5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 9/26</td>
<td>4</td>
<td>6-12</td>
<td>EXAM 1: Chapters 1.3 Bending: Eccentric Axial Loading</td>
<td>Project Title</td>
<td>3: Tensile Testing</td>
</tr>
<tr>
<td>R 9/28</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 10/3</td>
<td>5</td>
<td>1-2</td>
<td>Shear &amp; Bending Moment Diagrams Load, Shear, &amp; Moments</td>
<td>Ch 4: 7, 12, 18, 35, 46, 51, 103, 105</td>
<td>3: Tensile Testing</td>
</tr>
<tr>
<td>R 10/5</td>
<td>5</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 10/10</td>
<td>5</td>
<td>4</td>
<td>Design of Beams for Bending Shear Stresses in Beams</td>
<td></td>
<td>4: Torsion</td>
</tr>
<tr>
<td>R 10/12</td>
<td>6</td>
<td>1-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 10/17</td>
<td>6</td>
<td>4-6</td>
<td>Shear in Narrow Rectangular Beams Thin Walled Members</td>
<td>Ch 5: 10, 20, 25, 27, 45, 46, 60, 68, 73</td>
<td>5: Beam Bending</td>
</tr>
<tr>
<td>R 10/19</td>
<td>6</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Homework Policies

HOMEWORK ASSIGNMENT GUIDELINES:

Homework is due at the beginning of class on the dates highlighted in bold on the outline. For example, homework #1 is due on Thursday, September 7. Homework assignments and due dates may change and will be announced in class. Sloppy or unprofessional work will be returned ungraded. Late Homework Will Not Be Accepted because solutions will be posted soon after the due date. Solutions will be posted on the MEG 302 Course Website. A password will be provided in class to allow access to the HW solutions.

Submit your assignments on 8.5” x 11” paper. Be sure to include your name at the top of the first page. Include the following information for each problem:
- Most of the problems will require a sketch of the problem along with one or more Free Body Diagrams showing the applied loads along with the external and internal reactions.
- Show all of your work. Make reference to equations in the book if you do not want to repeat them.
- Draw a box around your final answer or answers. You will not receive credit for a correct answer if you have not shown the work.

Each problem will be graded on a scale from 0-10. The homework counts as a significant percentage of your final grade so do not blow it off. Some of the problems may take several hours so manage your time accordingly. You are encouraged to help each other figure out the problems but do not copy each other’s work.

The homework is assigned for three main reasons:
- To elaborate on material discussed in class and in the text
- To provide practice in solving mechanics problems
- To assess your understanding of the material
Office Hours and Grading

O’Toole Office Hours Fall 2006:

Monday: 10-2
Tuesday: 2-4
Wednesday: 10-2
Thursday: 1:30 – 2:30
Friday: 2-4

The best way to meet with me is to send e-mail to set up an appointment. I check my e-mail throughout the day and should respond quickly. I can be reached at:

Office Phone: 895 - 3885
E-mail: bj@me.unlv.edu

GRADING

Your grade for the course will be based on weekly homework assignments, three in-class exams, a group design project and a comprehensive final exam which are weighted as shown below:

<table>
<thead>
<tr>
<th>In-Class Exams (3)</th>
<th>Homework</th>
<th>Design Project</th>
<th>Final Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 % (15 % each)</td>
<td>15 %</td>
<td>10 %</td>
<td>30 %</td>
</tr>
</tbody>
</table>

The letter grade cut-offs vary slightly from semester to semester. The table below shows an approximate correlation between final percentage grade and final letter grade.

<table>
<thead>
<tr>
<th>88 - 100%</th>
<th>78 - 87%</th>
<th>73 - 77%</th>
<th>68 - 72%</th>
<th>58 - 67%</th>
<th>50 - 57%</th>
<th>&lt; 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A- to B+</td>
<td>B</td>
<td>B- to C+</td>
<td>C</td>
<td>D</td>
<td>F</td>
</tr>
</tbody>
</table>
Additional Course Policies

CHEATING
Copying each other's homework assignments is considered cheating. Any form of cheating on homework or an exam will result in a failing grade for the course. All of the assigned homework problems have answers in the back of the book. Use this information to check your work. DO NOT PUT THE ANSWER FROM THE BACK OF THE BOOK AT THE END OF YOUR PROBLEM IF YOUR WORK DOES NOT SUPPORT THIS ANSWER OR YOU WILL GET ZERO POINTS FOR THE ENTIRE ASSIGNMENT.

Time Management
This will be a difficult class.
Plan to spend 6-10 hours per week on homework assignments.
Plan to be completely stumped on some of the problems.
Plan your work periods at least 2 days before the due date.
Plan to have questions after your first attempt at solving the homework problems.
Write your questions down when you think of them, Ask for help until you understand the problem.

DISABILITY RESOURCE CENTER
If you have a documented disability that may require assistance, you will need to contact the Disability Resource Center (DRC) for coordination in your academic accommodations. The DRC is located in the Reynolds Student Services Complex room 137. Their phone number is 895-0866.
Additional Resources

Engineers Edge
http://www.engineersedge.com/mechanics_material_menu.shtml

What is eFunda?
eFunda stands for engineering Fundamentals. Its mission is to create an online destination for the engineering community, where working professionals can quickly find concise and reliable information to meet the majority of their daily reference needs.

http://www.efunda.com/formulae/formula_index.cfm

Material Properties (MATWEB)
http://www.matweb.com/index.asp?ckck=1

Source of Materials
http://www.mcmaster.com/

Unit Conversion
http://www.digitaldutch.com/unitconverter/
Scope of Project: The design project provides you with an opportunity to apply the topics learned in class to any mechanics oriented design problem of interest to you and your teammates. You and your team will be responsible for:

- Identifying a design problem (A list of examples is available on the course website)
  - (e.g. wall mounted bookshelf for home)
- Defining a specific set of objectives and constraints for the problem (ex. Below)
  - The bookshelf must support 20 textbooks and 20 large 3-ring binders
  - The bookshelf must not sag in the middle by more than 0.125 inches
  - The bookshelf must be less than 14 inches deep
- Use a standard design procedure for defining a list of design criteria, alternative designs to be considered, design variables, scheduling, analysis, etc. You should have completed a project like this as part of your Introduction to Engineering Design Course. An outline of this procedure is posted on the class website.
- You will not be building or testing anything for this project. Your project must specify a recommended design with specific dimensions, materials, and costs outlined. You must also make it clear how you arrived at this final design and show why it is better than other alternatives under consideration.

Selection of Project: You may choose any project provided it is:

- acceptable to the instructor
- utilizes (at least) the principles covered in Chapters 1 through 8
- Includes a group of 2-5 students
- You may not select a project that is a copy of a problem in the textbook.
Submit list of group members and project title: September 28, 2006
Send to bj@me.unlv.edu, include all student e-mail addresses along with the title of the project.

Final written report due by: Friday December 8, 2006

Report: The written report will be graded on its mathematical correctness, grammar, spelling, style of writing, clarity, and brevity, as well as other criteria usually applied to a written report. Send final report to bj@me.unlv.edu, as an attached MS WORD file. If you are not using MS WORD, see instructor. Hard copies of reports will NOT be accepted. All figures, drawings, equations, etc. must be imported into the report document. You can scan handwritten equations or use Equation Editor, MathType, MathCad, or a similar tool for equations.
The following outline is a brief overview of the design process. You should be familiar with the design process from the required “Introduction to Engineering Design” course. The presentation and report for your project should include

- **Identify Need**
  - A customer usually approaches an engineer or engineering team with a problem. Your group must act as the customer initially by selecting a problem (approved by the instructor).

- **Problem Definition**
  - Try to come up with a specific definition of the problem
  - Consult with the customer before proceeding, make sure your definition matches the need

- **Search for Information**
  - Gather information from as many sources as possible
    - Library books
    - Library technical journals
  - Also examine existing products

- **Criteria and Constraints** (All projects will have different design criteria and constraints. The following is a partial list of possible criteria and constraints.)
  - Cost
  - Reliability
  - Weight
  - Ease of operation
  - Ease of Maintenance
  - Appearance
  - Strength
  - Compatibility
  - Safety Features
  - Noise Level
  - Effectiveness
  - Durability
  - Feasibility
  - Acceptance
Design Process (Part 2)

- **Alternative Solutions** (You must consider a minimum of 3 different solutions to your design problem.)
  - Initial brainstorming session should be very informal
  - Write down every idea mentioned
  - Everyone must feel comfortable stating their ideas
  - There will be many bad ideas that can be eliminated later
- **Analysis** (You must include some analysis covered in this class: axial loading, torsion, bending, combined loads, buckling, beam deflections, ...)
  - Use your engineering knowledge to evaluate the alternatives based on your design criteria
- **Decision Making**
  - Use the results of your analysis to compare all the alternatives using a systematic process
- **Specifications**
  - Write a thorough description of your design
  - Include detailed drawings if needed
- **Communication**
  - Selling your idea
  - Written reports
  - Oral presentations
  - Visual aids
<table>
<thead>
<tr>
<th>Design Project Ideas (Page 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staircase Design</td>
</tr>
<tr>
<td>Pull Trailer (for a car)</td>
</tr>
<tr>
<td>Closet Shelving System</td>
</tr>
<tr>
<td>3 Leg Table</td>
</tr>
<tr>
<td>Book Shelf</td>
</tr>
<tr>
<td>Bike Rack</td>
</tr>
<tr>
<td>Gazebo</td>
</tr>
<tr>
<td>Trebuchet</td>
</tr>
<tr>
<td>TV Tray</td>
</tr>
<tr>
<td>Children's Playhouse</td>
</tr>
<tr>
<td>Foot Bridge</td>
</tr>
<tr>
<td>Work Bench</td>
</tr>
<tr>
<td>House Patio Cover</td>
</tr>
<tr>
<td>Space Saving Hammock</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Residential Piping System</td>
</tr>
<tr>
<td>PVC Sprinkler System</td>
</tr>
<tr>
<td>Roll Cage for a Dune Buggy</td>
</tr>
<tr>
<td>Compact Folding Stadium Seat</td>
</tr>
<tr>
<td>Weight Lifting Bar</td>
</tr>
<tr>
<td>Rope Bridge</td>
</tr>
<tr>
<td>Trampoline</td>
</tr>
<tr>
<td>Slide</td>
</tr>
<tr>
<td>Traffic Signal</td>
</tr>
<tr>
<td>Interstate Median</td>
</tr>
</tbody>
</table>
Good Luck This Semester !!