About Midterm Exam 3

• When and where
  – Thurs April 21st, 5:45-7:00 pm
  – Rooms: Same as Exam I and II, See course webpage.
  – Your TA will give a brief review during the discussion session.
• Coverage: Chapts 9 – 12 (4 chapters)
• Format
  – Closed book, 20 multiple-choices questions (format as in practice exams)
  – 1 page 8x11 formula sheet allowed, must be self prepared, no photo copying/download-printing of solutions, lecture slides, etc.
  – Bring a calculator (but no lap-top computer), Only basic calculation functionality can be used. Bring a 2B pencil for Scantron.
  – Fill in your ID and section #
• Special requests:
  – If different from Exam II, email me at than@hep.wisc.edu
  – One alternative exam: 3:30pm – 4:45pm, Thurs Mar. 24, Cham 5280 (as before).

Chapter 12 – Static equilibrium and Elasticity

Lecture 2

• Stable and unstable equilibrium
• Stress and Strain
  – Young’s Modulus
  – Shear Modulus
  – Bulk Modulus

Condition for static equilibrium

• Conditions for a rigid body to be in a static equilibrium:
A) Net external force must be 0: no linear acceleration
\[ \sum \vec{F}_{ext} = 0 \]
B) Net external torque must be 0: no angular acceleration
\[ \sum \vec{\tau}_{ext} = 0 \]

Stability

An object is in equilibrium:

Imagine a small shift (displacement)
Force-generated torque restores equilibrium \(\rightarrow\) Stable
Stability of equilibrium

- The static equilibrium condition can be
  - Stable
  - Unstable
- In order to understand the stability condition we look at the potential energy situation
The configuration that is in neutral equilibrium is

A. 1  B. 2  C. 3  D. 4  E. 5
The configuration that is in neutral equilibrium is

A. 1    B. 2     C. 3  D. 4  E. 5

Solids – microscopic view

- Have definite volume
- Have definite shape
- Molecules are held in specific locations
  - by electrical forces
  - vibrate about equilibrium positions
  - Can be modeled as springs connecting molecules

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Stress and Strain

- All objects are deformable by external forces
- An object may be stretched by a tensile force. The relative change in length due to F is called strain:
  \[ \text{Strain} = \frac{\Delta L}{L} \]
- Stress is the ratio of the force F to the cross-sectional area A:
  \[ \text{Stress} = \frac{F}{A} \]

Stress and Strain

- Young’s modulus

\[ Y = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{\Delta L/L} \]
The ultimate strength of a material is the maximum stress the material can withstand before it breaks or fractures.

Some materials are stronger in compression than in tension.

Linear to the Elastic Limit.

Shear stress and shear strain
- Shear modulus

- The ratio of the shear force to the horizontal area that it is applied to is called

\[ \text{Shear stress} = \frac{F_s}{A} \]

- We define shear strain

\[ \text{Shear strain} = \frac{\Delta X}{L} \]

the shear modulus

\[ M_s = \frac{\text{Shear stress}}{\text{Shear strain}} = \frac{F_s/A}{\Delta X/L} = \frac{F_s}{A \tan \theta} \]

Table 12-1 Young's Modulus Y and Strengths of Various Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Y, GPa</th>
<th>Tensile strength, MPa</th>
<th>Compressive strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>70</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Brass</td>
<td>16</td>
<td>250</td>
<td>270</td>
</tr>
<tr>
<td>Tensile</td>
<td>9</td>
<td>370</td>
<td>17</td>
</tr>
<tr>
<td>Concrete</td>
<td>110</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Iron (wrought)</td>
<td>190</td>
<td>280</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>16</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>200</td>
<td>520</td>
<td>520</td>
</tr>
</tbody>
</table>

Note: These values are approximate. Actual values for particular samples may differ.

Note: 1 GPa = 10^9 MPa = 10^9 Pa
Shear stress and shear strain

Table 12-2: Approximate Values of the Shear Modulus M^s of Various Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>M^s (GN/m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>30</td>
</tr>
<tr>
<td>Brass</td>
<td>36</td>
</tr>
<tr>
<td>Copper</td>
<td>42</td>
</tr>
<tr>
<td>Iron</td>
<td>70</td>
</tr>
<tr>
<td>Lead</td>
<td>5.4</td>
</tr>
<tr>
<td>Steel</td>
<td>104</td>
</tr>
<tr>
<td>Tungsten</td>
<td>150</td>
</tr>
</tbody>
</table>

Block of jello

Bulk Modulus: Volume Elasticity

- Bulk modulus characterizes the response of an object to uniform squeezing
  - Suppose the forces are perpendicular to, and acts on, all the surfaces — as when an object is immersed in a fluid
  - The object undergoes a change in volume without a change in shape

- Volume stress, \( \Delta P \), is the ratio of the force to the surface area
  - This is also the Pressure
- The volume strain is equal to the ratio of the change in volume to the original volume

Notes on Moduli

- Solids have Young’s, Shear, and Bulk moduli
- Liquids (or gases) have only bulk moduli

Moduli Values

<table>
<thead>
<tr>
<th>Substance</th>
<th>Young’s Modulus (N/m^2)</th>
<th>Shear Modulus (N/m^2)</th>
<th>Bulk Modulus (N/m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tungsten</td>
<td>35 \times 10^{11}</td>
<td>14 \times 10^{10}</td>
<td>20 \times 10^{10}</td>
</tr>
<tr>
<td>Steel</td>
<td>20 \times 10^{10}</td>
<td>8.4 \times 10^{10}</td>
<td>6 \times 10^{10}</td>
</tr>
<tr>
<td>Copper</td>
<td>11 \times 10^{10}</td>
<td>4.2 \times 10^{10}</td>
<td>14 \times 10^{10}</td>
</tr>
<tr>
<td>Brass</td>
<td>9.1 \times 10^{10}</td>
<td>5.5 \times 10^{10}</td>
<td>6.1 \times 10^{10}</td>
</tr>
<tr>
<td>Aluminum</td>
<td>7.0 \times 10^{10}</td>
<td>2.5 \times 10^{10}</td>
<td>7.0 \times 10^{10}</td>
</tr>
<tr>
<td>Glass</td>
<td>6.5-7.8 \times 10^{10}</td>
<td>2.6-3.2 \times 10^{10}</td>
<td>5.6-5.5 \times 10^{10}</td>
</tr>
<tr>
<td>Quartz</td>
<td>5.6 \times 10^{10}</td>
<td>2.6 \times 10^{10}</td>
<td>2.7 \times 10^{10}</td>
</tr>
<tr>
<td>Water</td>
<td>—</td>
<td>—</td>
<td>0.21 \times 10^{10}</td>
</tr>
<tr>
<td>Mercury</td>
<td>—</td>
<td>—</td>
<td>2.8 \times 10^{10}</td>
</tr>
</tbody>
</table>