Material Properties

Outline

• Modes of deformation
  – Ductile vs. Brittle behavior
• Stress-Strain Relationships
  – Elasticity
  – Viscosity
  – Plasticity
• Role of
  – Temperature
  – Pressure
  – Strain Rate

Causes and Consequences

• Differential Stress – Cause of deformation
• Strain – The consequence of differential Stress
• Quantitative relationship?
• Example: Mohr-Coulomb failure

Mechanical Behavior depends on Material Properties

• Solid?
• Liquid?
• Plastic?
• …

What is a Solid? What is a Liquid?

<table>
<thead>
<tr>
<th>Solid</th>
<th>Liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Strong</td>
<td>• Weak</td>
</tr>
<tr>
<td>• Hard</td>
<td>• Soft (?)</td>
</tr>
<tr>
<td>• Maintains shape</td>
<td>• Takes shape of vessel</td>
</tr>
<tr>
<td>• Deforms proportionally to load</td>
<td>• Deforms under any load</td>
</tr>
</tbody>
</table>

What about Play-Do?

• Shares some properties with both solids and liquids
• Plastic material
Elastic Solids

- Example 1: Ruler
- Example 2: Rock and Hammer

Stress-Strain Relationship

- “Ut tensio sic uis” (Robert Hooke, 1676)
- “Change in length is proportional to the applied force”
  - $F = K \Delta x$

Linear Elastic Behavior

$$F = K \Delta x$$
$$\sigma = E \cdot \varepsilon$$

Young’s Modulus

- Elastic constant
- Like the spring constant
- Units of Stress
  - Plexiglass $E = 3$ Gpa
  - Shale $E = 10$-30 Gpa
  - Granite $E = 40$-70 Gpa
  - Basalt $E = 60$-80 Gpa
  - Steel $E = 200$ Gpa

Calculating Elastic Strain (1 D)

- Example:
  - $\sigma_n = 100$ MPa (lithostatic stress at 3.8 km depth)
  - $E = 10$ GPa $= 10,000$ MPa (shale)
  - $\varepsilon = -\frac{\sigma_n}{E}$
  - $\varepsilon = -100/10,000 = -0.01 = -1%$

What happens when you pull on a rubber band?

- It gets longer …. And skinnier!
- Poisson’s Ratio $\nu = \left| \frac{-\varepsilon_{xx}}{\varepsilon_{yy}} \right|$
- $\nu = 0.5$ incompressible material (no volume loss)
- Rocks $\nu = 0.1$ to 0.3

Examples
Stress-Strain in 3D

- We need to consider the contribution of the perpendicular stresses

\[ \varepsilon_{xx} = -\frac{1}{E} (\sigma_{xx} - \nu (\sigma_{yy} + \sigma_{zz})) \]

Fluids

- Viscous behavior
- Non-recoverable deformation
- Continue to deform regardless of how small the stress
- Resistance is proportional to strain rate
- Strain is time-dependent

How do rocks behave?

- Mixed behavior
- Non-linear
- Elastic at low strain
- Plastic at high strain

Limestone Deformation

- Variable Confining Pressure
- Plastic
- Elastic
- Yield Point
- Creep curve
Deformation Experiments

Effect of Confining Pressure

Effect of Temperature
Solnhofen Limestone

Effect of Strain Rate
Yule Marble

Crustal Strength Curve