1. **Introduction**

Pavement design inputs covered in previous topics:
- Predicted stresses and strains –
- Traffic –

What material properties have we used up to now?

- Most paving materials are not elastic,
- If the load is small compared to the strength of the material and is repeated for a large number of times, the
Resilient Modulus ($M_R$)

Type and duration of loading is supposed to simulate that occurring in the field.

### Typical Flexible Pavement Structure

1. **Surface Course**
   - Layer that comes to contact with traffic;

2. **Base**
   - Provides additional load distribution and contributes to

3. **Subbase (optional)**
   - Functions primarily as structural support but it can also help with drainage and frost action

4. **Subgrade**
   - Native soil – the only
Topic 5 – Material Characterization

Subgrade performance generally depends on:
1. Load bearing capacity;
2. Moisture content;
3. Shrinkage and/or swelling;

Remedies for poor subgrade conditions:
1. Remove and replace;
2. Stabilization;
3. Additional base layers;

Subgrade Seasonal Variations

![Graph showing seasonal variations in subgrade performance with time.]
2. Design Resilient Modulus (Base & Subgrade)

2.1 Correlations

Maybe there is information already available

Also:
- \( M_R = 1500 \text{(CBR)} \)
- \( M_R = 1155 + 555 \text{(R)} \)

2.1.1 California Bearing Ratio (CBR)

- Basically a
- Piston
- Pressure is recorded
- Take the ratio to the bearing capacity of a standard rock
- Range:

\[
\text{CBR} = \frac{\text{Pressure to cause 0.1" penetration for standard rock}}{...}
\]
### California Bearing Ratio (CBR)

**Coarse-grained soils**
- GW: 40 - 80
- GP: 30 - 60
- GM: 20 - 60
- GC: 20 - 40
- SW: 20 - 40
- SP: 10 - 40
- SM: 10 - 40
- SC: 5 - 20

**Fine-grained soils**
- ML: 15 or less
- CL LL < 50%: 15 or less
- OL: 5 or less
- MH: 10 or less
- CH LL > 50%: 15 or less
- OH: 5 or less
Topic 5 – Material Characterization

2.1.2 Stabilometer (R-value)

- Resistance value of a soil determined by stabilometer
- Apply vertical pressure
- Measure

\[
R = 100 - \frac{100}{\left(\frac{2.5}{D^2}\right) \times \left(\frac{p_v}{p_h} - 1\right) + 1}
\]

\[p_v \, \& \, p_h = \text{Vertical and horizontal pressure respectively}\]
\[D^2 = \text{displacement of stabilometer fluid to increase } p_h \text{ from 5 to 100 psi, measured in revolutions of a calibrated pump handle}\]
2.2 In-situ Testing (Plate Loading Test)

- Circular plate 30 in Ø; series of plates used to minimize bending
- Apply load at constant rate
- Pressure held constant until the deflection increases no more than 0.001 in/min for three consecutive minutes
- Use average

\[ k = \frac{p}{\Delta} \]

\( k = \) \( p = \) \( \Delta = \)

Figure 7.36 – Correlation of \( k \) with \( M_R \)
Topic 5 – Material Characterization

2.3 Laboratory Testing (Triaxial Test)

Sample = \sigma_1 = \sigma_2 = \sigma_3

Deviator Stress: Axial stress in

What can affect the results?

State of confinement defined by the first invariant
2.3.1 Triaxial Test – Granular Material

- For Granular subgrade:
  - $M_r = \text{function}$
  - $k_1 \& k_2$

Run Triaxial test at certain levels of confining pressure and vary the deviator stress. (Example 7.2 Huang)

![Graph showing log $M_r$ vs log $\theta$](image)

---

2.3.1 Triaxial Test – Granular Material

**Sample Conditioning**

1. Set the confining pressure to 5 psi, and apply a deviator stress of 5 psi, and then 10 psi, each for 200 repetitions
2. Set the confining pressure to 10 psi, and apply a deviator stress of 10 psi, and then 15 psi, each for 200 repetitions
3. Set the confining pressure to 15 psi, and apply a deviator stress of 15 psi, and then 20 psi, each for 200 repetitions

**Resilient Modulus Test**

After sample conditioning the resilient modulus test follows a constant confining pressure-increasing deviator sequence, and the results are recorded at the 200$^{th}$ repetition of each deviator stress.
2.3.1 Triaxial Test – Granular Material

Test Procedure
1. Set the confining pressure to 20 psi, and apply a deviator stress of 1, 2, 5, 10, 15 and 20 psi
2. Reduce the confining pressure to 15 psi, and apply a deviator stress of 1, 2, 5, 10, 15 and 20 psi
3. Reduce the confining pressure to 10 psi, and apply a deviator stress of 1, 2, 5, 10, and 15 psi
4. Reduce the confining pressure to 5 psi, and apply a deviator stress of 1, 2, 5, 10, and 15 psi
5. Reduce the confining pressure to 1 psi, and apply a deviator stress of 1, 2, 5, 7.5, and 10 psi; stop the test after 200 repetitions of the last deviator stress level or when the specimen fails

<table>
<thead>
<tr>
<th>Confining Pressure, $\sigma_3$ (psi)</th>
<th>Deviator Stress, $\sigma_d$ (psi)</th>
<th>Recoverable Deformation, $\varepsilon_r$ (mils)</th>
<th>Resilient Stress Invariant, $\vartheta$ (psi)</th>
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</table>
Topic 5 – Material Characterization

2.3.1 Triaxial Test – Granular Material

\[ y = 3686x^{0.3511} \]

\[ M_R = 3686 \times \theta^{0.351} \]

Topic 5 – Material Characterization

2.3.2 Triaxial Test – Cohesive Material

- For Fine-grained (cohesive) subgrade:
  - \( M_R \) = function
  - \( k_1, k_2, k_3 \) & \( K_4 \)

Run Triaxial tests at certain values of deviator stress and vary the confining pressure. (Example 7.3 Huang)
2.3.3 Asphalt Institute Subgrade Characterization

- To determine subgrade MR, Asphalt Institute suggests:
  - Confining stress
  - Deviator stress
- For granular material:
  - For example use data from Fig 7.8
- For fine-grained material:
  - For example use data from Fig 7.9

2.3.4 Granular material example

![Graph showing relationship between stress invariant and resilient modulus](image)

Figure 7.8 Example 7.2 (1 psi = 6.9 kPa).
2.3.5 Fine-grained material example

![Graph showing resilient modulus vs. deviator stress](image)

*Figure 7.9 Example 7.3 (1 psi = 6.9 kPa).*

---

3. Hot-Mix Asphalt

3.1 Structural Layer Coefficient
- Used in AASHTO design procedure
- Describes the quality of the material
- Function of
  
  Why?

3.2 Marshall Test
- Used in the Marshall Mix Design procedure
- Performed on cylindrical specimens
- Apply load at controlled rate until failure

3.3 Cohesiometer Test
- Used to measure the
3. **Hot-Mix Asphalt (cont.)**

![Graph showing structural layer coefficient vs. load at 100 psi, and structural coefficient vs. load at 1400 psi.](image)

(a) Surface Course  
(b) Base Course

4. **Bases**

4.1 **Untreated Granular Base**

![Graph showing various properties such as CBR, E' value, and modulus-1000 psi.](image)
Topic 5 – Material Characterization

4.2 Stabilized Granular Base

![Graph showing structural coefficient vs. Marshall stability and modulus for Bituminous Treated and Cement Treated materials.]

Bituminous Treated

Cement Treated

Topic 5 – Material Characterization

5. Sub-Bases

![Graph showing structural coefficient vs. CBR, R-Value, Texas Tensile, and Modulus for Sub-Bases.]

Sub-Bases
6. Drainage
Important to keep water away from the pavement structure

6.1 Detrimental effects of water:
- Reduces
- Causes
- Pore-pressure increase $\rightarrow$ Pumping of fines $\rightarrow$ Loss of support
  - Load goes over saturated base & soil
  - Pore-pressure increases
  - Water is incompressible; moves up
- Causes
- 
- Frost action (in Northern climates)

6.2 Sources of water:
- i. Seepage
- ii. Raise of water table
- iii. Infiltration
- iv. From proximity of water table
  - Capillary moisture held in the pores from surface tension
- v. Vapor movement
  - Movement of water associated with fluctuating temperature and pressure
6.2 Sources of water:

![Diagram showing sources of water]

6.3 Protecting the Pavement Structure:

⚠️ Need to minimize availability of water
- Impervious surface/shoulders
- Drainage
- Drainage layer for subsurface water

Three drainage installations for subsurface water:
1. Drainage layer or blanket
2. Longitudinal drain
3. Transverse drain
6.4 Drainage Deficiencies for Pavements with Ditch

6.4.1 Typical Pavement with a Ditch

6.4.2 Water infiltrating from rutted shoulder

6.4.3 Water infiltrating due to debris caused ponding
6.4.4 Water infiltrating due to differential settlement

Opening along edge of pavement due to contraction and settlement

6.5 Subsurface Drainage

6.5.1 Drainage layer / Blanket

Pavement Surface  Base Course as drainage layer

Subbase as Filter
6.5.2 Longitudinal drainage

6.5.3 Transverse drainage

Same concept as longitudinal drainage, but in this case the drainage runs across the lanes.

Where would we use the transverse drain?