Importance of Resilient Modulus (MR) and its Interpretation
Subgrade Design Inputs

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2015 Purdue Road School
J PCP cross section

- 9” – 13” J PCP
- 3” Open graded stone
- 6” Dense graded stone
- Subgrade treatment
- Soil Subgrade/natural
HMA pavement cross section

1.5” Surface
2.5” Intermediate
3”+ Dense graded base
3” Open graded base
3” Dense graded base
Subgrade treatment
Soil subgrade/natural
Pavement Design Considerations:
- Pavement performance
- Traffic
- Roadbed soil
- Material for construction
- Environment
- Drainage
- Reliability
- Life Cycle cost
- Shoulder design
Subgrade Design Inputs (1993)

- Mr = Resilient Modulus (Psi) used for flexible pavement
- Elastic property of soil (non-linear)
- Represents compacted layer of subgrade
- K value = Modulus of subgrade reaction used for Rigid pavement
- Mr = 1500 X CBR
- Mr from FWD used for Rehab
MEPDG(2009)

- Mechanisti Empirical Pavement Design Guide
  - State-of-art tool for design and analysis of new and rehabilitated pavement structure
  - Based on M-E principles
  - Calculates pavement responses (stresses, strains & deflection)
  - Uses responses to calculate damage over time
  - MEPDG predicts multiple performance indicators
MEPDG is an iterative process

- Outputs are pavement distresses and not traffic
- Trial design based on performance criteria
- Level 1, 2, 3

Performance criteria for flexible pavement:
- Roughness (IRI)
- Rutting
- Transverse cracking
- Fatigue cracking
Performance criteria for Rigid Pavement

- Roughness (IRI)
- Faulting
- Cracking

Ref: Chapter 304 IDM
MEPDG design Considerations

- Foundation/Subgarde
- Existing pavement condition
- Paving material
- Construction factors
- Environmental factors
- Traffic loading
- Subdrainage
- Shoulder design
- Rehabilitation treatment & strategies
Cont.

- New pavement & rehab options
- Pavement performance
- Design reliability
- LCC
Subgrade/ Foundation Inputs

- Characterization of the pavement foundation
- Subsurface characterization
- Laboratory testing of subgrade soils
- Condition of Mr lab test specimens
- Identification and treatment of special subsurface condition
- Foundation improvement & strengthening
AASHTOWare Pavement ME....

- **Subgrade**
  - General
  
  Layer thickness (in): The thickness of the selected layer

- Poisson's ratio: ME Design provides a default value of 0.35.

- Coefficient of lateral earth pressure ($k_0$): ME Design provides a default value of 0.5.
Modulus

Resilient Modulus (psi): ME Design displays the default value (Level 3) for the selected material class.

Input Level: 2 & 3

Level 2: directly or using its correlations with soil index and strength properties.

Level 3: override the default resilient modulus value (Level 3) of the subgrade material.

ME Design does not provide Level 1 input option for resilient modulus of subgrade materials.
Analysis Types

- Seasonal variations (freezing, thawing and moisture)
- Values by temperature/moisture:
- Monthly representative values:
- Annual representative values:
Method

- Resilient modulus (psi)
- California Bearing Ratio (CBR) (percent)
- R-value
- Layer Coefficient-ai
- Dynamic Cone Penetrometer (DCP) Penetration (in./blow)
- Plasticity Index (PI) and Gradation (i.e., Percent Passing No. 200 sieve)
Gradation & other Eng prop.

- Gradation
- Liquid Limit
- Plasticity Index
- Is Layer Compacted?
- Maximum dry unit weight
- Saturated hydraulic conductivity (ft/hr)
- Specific gravity of solids
- Optimum gravimetric water content (%)
- User-defined Soil Water Characteristic Curve (SWCC)
Importance of Resilient Modulus (MR) and it’s Interpretation

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Geotech Construction & Tech Support Engineer, INDOT
2015 Purdue Road School
March 2015
MR Research Under J TRP


- FHWA/JTRP 2010 SPR-3008, Evaluation of In-situ Stiffness of Subgrade by Resilient Modulus and FWD.
Base Stresses

\[ \sigma_v \text{ Vertical Stress} \]

\[ \sigma_h \text{ Horizontal Stress} \]
Deformation Under Load

New

Old

Deformation
Total Deformation consists of Two Components:

Elastic Recoverable
Plastic Permanent
Resilient Modulus:
Dynamic Deviator Stress/ Resilient Strain

![Graph showing stress vs. strain with terms 'Permanent strain' and 'Resilient strain'.]
As the confining stress on the base material increases, the stiffness on the Mr increases.
Resilient Modulus, $M_R$

$$M_R = \frac{\text{Stress}}{\text{Recoverable Strain}}$$

Units of Stress – psi, ksi, kPa, etc.
# AASHTO Classifications

Classification of Soil and Soil-Aggregate Mixtures from AASHTO M-145

<table>
<thead>
<tr>
<th>General Class.</th>
<th>A-1</th>
<th>A-2</th>
<th>A-3</th>
<th>A-4</th>
<th>A-5</th>
<th>A-6</th>
<th>A-7</th>
</tr>
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<tbody>
<tr>
<td>Sieve Analysis, % Passing No. 10 No. 40 No. 200</td>
<td>50 max.</td>
<td>50 max.</td>
<td>51 min.</td>
<td>51 min.</td>
<td>51 min.</td>
<td>51 min.</td>
<td>51 min.</td>
</tr>
<tr>
<td>Charac.'s of Fraction passing No. 40 Liquid Limit Plasticity Index</td>
<td>6 max.</td>
<td>N.P.</td>
<td>40 max.</td>
<td>40 max.</td>
<td>40 max.</td>
<td>35 max.</td>
<td>35 max.</td>
</tr>
<tr>
<td>Usual types of Significant Constituent Materials</td>
<td>Stone Fragments, Gravel and Sand</td>
<td>Fine Sand</td>
<td>Silty or Clayey Gravel and Sand</td>
<td>Silty Soils</td>
<td>Clayey Soils</td>
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<td></td>
</tr>
<tr>
<td>General Rating as Subgrade</td>
<td>Excellent to Good</td>
<td></td>
<td></td>
<td>Fair to Poor</td>
<td></td>
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</table>
How is the Resilient Modulus performed?
The Laboratory Model

- The pavement stresses are modelled in the laboratory in a triaxial cell.
  - Cylindrical soil specimen separated from cell pressure by rubber membrane.
  - Cell is pressurized to provide confining stress (normal stress).
  - Hydraulic actuator ram provides cyclic shear and normal stresses.
  - Digitally controlled.
AASHTO T-307

Resilient Modulus Test Sequence

- Conditioning sequence – 1000 cycles
  (6 psi conf. , 4 psi deviator stress)
- 15 test sequences – 100 cycles each
  - 3 different confining stress levels (6,4,2 psi)
  - 5 different (increasing) deviator stress 
    (2,4,6,8,10 psi) per confining stress
- Modulus is calculated from last 5 cycles of each sequence
Resilient Modulus Machine
Resilient Modulus Machine
Preparing the Sample

- A specimen shall be molded at 95% compaction at OMC.
- A Shelby sample for MR
- Data sheet of a resilient modulus test showing the stress sequence shall be provided.

Data sheet shall include: confining stress, deviator stress, resilient strain, permanent strain, resilient modulus etc.
## Typical Confining and Deviatoric Stress Values

<table>
<thead>
<tr>
<th>Confining Stress (psi) ($\delta_c$ or $\delta_3$)</th>
<th>Deviatoric Stress (psi) ($\delta_d$ or $\delta_{\text{cyclic}}$)</th>
<th>References</th>
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<tr>
<td>2</td>
<td>5.4</td>
<td>Rahim (2005)</td>
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<td>2</td>
<td>7.5</td>
<td>George (2004)</td>
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<td>Ping et al. (2001)</td>
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<td>Asphalt Institute (as cited by Ping et al. 2001)</td>
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<td>Daleiden et al. (as cited by Ping et al. 2001)</td>
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<td>Lee et al. (1997)</td>
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<td>2</td>
<td>6</td>
<td>Jones and Witczak (1977)</td>
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</table>
### Resilient Modulus Test Data

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<thead>
<tr>
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<td>1.914</td>
<td>0.0698</td>
<td>8.128</td>
<td>0.02</td>
<td>0.00</td>
<td>10480</td>
<td>1122.6</td>
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<td>3.847</td>
<td>0.048</td>
<td>10.05</td>
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<td>0.00</td>
<td>7175.6</td>
<td>91.964</td>
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<td>5.771</td>
<td>0.0811</td>
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<td>0.00</td>
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<td>7.68</td>
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<td>0.00</td>
<td>5104.4</td>
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## RESILIENT MODULUS TEST DATA

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<td>0.19</td>
<td>0.00</td>
<td>4506</td>
<td>51.894</td>
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</table>
Deviator Stress = 6 psi

Confining Stress = 2 psi

Based on limited Testing for A-6, A-7, A-4 (Indiana Soils)

\[ M_R = 695.4 \text{ (Su 1\% )} - 5.93 \text{ (Su 1\% )}^2 \]

Su at 1\% Strain rate

\[ R^2 = .97 \]
MR and CBR Relations

- \( M_r (\text{ksi}) = 1.42 \times CBR \) (Heukelom and Klomp)
- \( M_r (\text{ksi}) = 5.409 \times CBR^{0.711} \) (Green and Hall)
- \( M_r (\text{ksi}) = 2.554 \times CBR^{0.64} \) (Powell et al.)
- \( M_r (\text{ksi}) = 1.2 \times CBR \) (Ohio DOT)
- \( M_r (\text{psi}) = 1500 \times CBR \) (INDOT)
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Sample Description</th>
<th>Compaction AASHTO T-99 (Method A)</th>
<th>Dry Density &amp; Moisture Content (Before &amp; After Test)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Max. Dry Density (pcf)</td>
<td>OMC %</td>
</tr>
<tr>
<td>1</td>
<td>Sample passing (# 4 Sieve) and mix with (5 % Cement)</td>
<td>125.5</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Sample passing (# 4 Sieve) and mix with (5 % Cement)</td>
<td>125.5</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Sample passing (# 4 Sieve) and mix with (5 % Cement)</td>
<td>125.5</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Sample passing (# 4 Sieve) and mix with (5 % Cement)</td>
<td>124.5</td>
<td>6.4</td>
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<tr>
<td>6</td>
<td>Sample passing (# 4 Sieve) and mix with (5 % Cement)</td>
<td>124.5</td>
<td>6.4</td>
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</tbody>
</table>

Note: Sample 2 was crumbled during the test.
Resilient Modulus ($M_R$) of FDR Samples

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Confining Stress (psi)</th>
<th>Deviator Stress (psi)</th>
<th>Avg. $M_R$ (psi)</th>
<th>$R^2$</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>2 thru 10</td>
<td>15660</td>
<td>0.8628</td>
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<tr>
<td></td>
<td>4</td>
<td>2 thru 10</td>
<td>16246</td>
<td></td>
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<tr>
<td></td>
<td>2</td>
<td>2 thru 10</td>
<td>13086</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>2 thru 10</td>
<td>18613</td>
<td>0.8147</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2 thru 10</td>
<td>14085</td>
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<td>5</td>
<td>6</td>
<td>2 thru 10</td>
<td>33491</td>
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<td>2 thru 10</td>
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<td>2</td>
<td>2 thru 10</td>
<td>13909</td>
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</table>

Passing No. 4 sieve material

Note: 59% Material passing # 4 sieve.

* Deviator Stress: 2,4,6,8,10

Sample No. 5 tested 3% above the OMC
Sample # 2 was crumbled during test.
Typical Pavement Subgrade Recommendations

- Subgrade Type in accordance with 207.04
- Resilient Modulus of prepared subgrade xxxx psi
- Resilient Modulus of undisturbed subgrade xxxx psi
- Predominant Soil encountered in Subgrade INDOT Textural Classification AASHTO
- Presence of Groundwater Table…(based on boring information)
- Subsurface drains if Geotechnical problems exist
- Filter fabric if soils are silty (> 50% or soils are erodible)
INDOT Policy For MR test

INDOT has been performing the MR test for Geotechnical consultants on state projects.

On Local agency projects the Mr test is required to go to an Approved Geotechnical Laboratory.
Resilient Modulus Procedure

Geotechnical consultants will provide the following:

- Shelby Tube Sample (≥ 50% recovery)
- A 10 lb. sample bag (Passing #4 sieve)
- Specific Gravity test
- Atterberg Limits Testing
- Moisture Density Curve (Standard Proctor)
- Optimum Moisture, Maximum Wet & Dry Densities

- Natural Moisture Test (as received)

- Sample bag must contain following information:
  - Date, Geotechnical Consultant, Des # and/or Contract #, Road, County, Boring #, Sample Depth, Station, and Location.
## Summary of all Tests

<table>
<thead>
<tr>
<th>Resilient Modulus Sample Info</th>
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<tbody>
<tr>
<td>Sample ID</td>
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<tr>
<td>Soils Classification</td>
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<tr>
<td>AASHTO Class. &amp; Group Index</td>
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<tr>
<td>Passing #10</td>
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<tr>
<td>Passing #40</td>
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<tr>
<td>Passing #200</td>
</tr>
<tr>
<td>% Gravel</td>
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<tr>
<td>% Sand</td>
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<tr>
<td>% Silt</td>
</tr>
<tr>
<td>% Clay</td>
</tr>
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<td>PL</td>
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<td>PI</td>
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<td>Sulfate Content ppm</td>
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<tr>
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<tr>
<td>LOI</td>
</tr>
<tr>
<td>Ca/ mg</td>
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<tr>
<td>Max Wet Density</td>
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<td>Max Dry Density</td>
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<tr>
<td>Optimum Moisture</td>
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</tbody>
</table>
Pavement, Subgrade & It’s Foundation Section

- Aggregate No. 53
- Drainage Layer & Separation Layer
- PCCP
- Subgrade Foundation
- Subgrade varies 6 to 24 inches
Following procedure should be used for Resilient Modulus sampling for cohesive soils:

**Re-Construction/ New Construction**

- A continuous flight auger shall be used to penetrate the existing pavement and pavement sub-base material to a depth approximately 4-6 inches blow the top of the subgrade.

- A 24 inch long and 3 inches in diameter Shelby Tube sample shall be collected from the borehole. The sample shall have minimum of 50% recovery.
Upon completion of the Shelby tube sampling the flight auger shall be reintroduced to the borehole and advanced to a depth of approximately 4-5 feet.

Approximately 25 lbs. of auger cuttings shall be collected for the bag sample.

Soils from bag sample and Shelby Tube sample should be the same.

Rubbllization / Full depths Reclamation etc.

Shelby Tube Sample / Soil samples to be remolded for MR.
Resilient Modulus Test Requirements

- New Construction / Re-Construction / Lane Widening etc.
  - One Resilient Modulus test on remolded / mile of roadway or 10 roadway or subgrade borings.
  - One Resilient Modulus test on Shelby Tube / mile of roadway or 10 roadway or subgrade borings.
  - When soils are consistent, MR test may be reduced.
- For FDR projects: A resilient modulus on Shelby Tube or remolded to natural density / mile of roadway or 10 roadway borings.
- Roadway <800 Lft. MR can be estimated from unconfined test of 1% strain rate. (Woojin & Lee eq.)
Questions?