UNSATURATED SOIL MECHANICS IMPLEMENTATION DURING PAVEMENT CONSTRUCTION QUALITY ASSURANCE

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Office of Materials and Road Research
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- University of Minnesota
- University of Missouri
- University of Wisconsin
Topics

- M-E Pavement Design Framework
- Performance Based Construction QA
- Unsaturated Soil Mechanics
- What We’ve Learned
- Next Steps
Mechanistic Empirical Design

- Provides the Framework for Performance Based Material Property Inputs
- Sponsor: MN Local Road Research Board
- Contact: Bruce.Tanquist@state.mn.us
Performance Based Testing

- Achieve agreement between construction quality assurance, pavement design and performance
- Quantify the performance of alternative materials and construction practices
- Show the economic benefit of improved materials and construction practices
- Reward good construction and greater uniformity
- Implement tools that will strengthen the decisions made by construction inspection personnel
General QC/QA Procedure

- **Quality Control by the Contractor**
  - Prepares Quality Control Plan
  - Includes moisture testing
  - Includes roller compaction value
  - Includes corrective actions to be taken

- **Quality Assurance by Agency Owner**
  - Review and approval of the Contractor’s QC plan
  - QA testing using the light weight deflectometer (LWD) dynamic cone penetrometer (DCP) and moisture tests
  - Approval of the Contractor’s QC report
  - Archive of electronic QC and QA data
# DCP and LWD Granular Target Values

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<th>Grading Number</th>
<th>Moisture Content</th>
<th>Target DPI</th>
<th>Target LWD Deflection Zorn</th>
<th>Inverse DPI</th>
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Unsaturated Soil Mechanics

- Strength and Modulus Greatly Affected by Suction
- Suction Depends on Solids, Voids and Water
  - Quantity of Gravel, Sand, Silt, and Clay Particles
  - Distribution of Particles and Voids
  - Particle Shape and Void Shape
  - Packing Density (measure of void space)
  - Moisture Content (measure of water in voids)
Fundamentals of Soil Physics, Hillel 1980
Soil Water Characteristic Curves Minnesota Fine Grained Soils
Fredlund and Xing, 1994, Estimated Using Functions of the Plastic Limit
100 Percent of Standard Proctor Density

Plastic Limit = 15%
Plastic Limit = 20%
Plastic Limit = 25%
Plastic Limit = 30%
Soil Water Characteristic Curves Minnesota Fine Grained Soils
Fredlund and Xing, 1994, Estimated Using Functions of the Plastic Limit
100 Percent of Standard Proctor Density

Field Moisture as a Percent of Optimum Moisture (Plastic Limit - 5%) (percent)

Suction ‘capillary tension’ (kPa)
Deflection Target Value vs Gravimetric Moisture Content
100 Percent of Standard Proctor Density

- Plastic Limit=15
- Plastic Limit=20
- Plastic Limit=25
- Plastic Limit=30
Zorn Deflection Target Value vs Field Moisture
MnDOT Mr k-values estimated using suction and volumetric water at saturation
\[ \sigma_1 = 100 \text{ kPa} \quad \sigma_3 = 40 \text{ kPa} \]
100 Percent of Standard Proctor Density
Standard Proctor Optimum Moisture vs Maximum Relative Density
Mn/DOT Textural "all soils" Classification

\[ y = 348.42e^{-0.03x} \]
\[ R^2 = 0.94 \]
Zorn Deflection Target Value vs Field Moisture
MnDOT Mr k-values estimated using suction and volumetric water at saturation
\( \sigma_1 = 100 \text{ kPa} \) \( \sigma_3 = 40 \text{ kPa} \)
100 Percent of Standard Proctor Density
Why Deflection Target Values?

- Design engineer can determine allowable deflection for each layer of the pavement foundation using pavement design software. This includes the moisture content range allowed during construction and the expected deflections.
- Construction engineer and inspection personnel measure deflection and moisture to verify that the design parameters have been achieved.
LWD Deflection Target and Data vs Percent of Standard Proctor Optimum
MnROAD08 PL=19% Optimum Moisture=14% T99Density=115 lbs/ft3

Zorn LWD data  Target Value  Power(Target Value)
LWD Deflection Target and Data vs Percent of Standard Proctor Optimum
US94 2009 Plastic Limit=26% Optimum Moisture=21% T99Den=101 lbs/ft³

- Zorn LWD data
- Target Value
- Power(Target Value)
Zorn Deflection Target Value vs Suction
MnDOT Mr k-values estimated using suction and volumetric water at saturation
sigma1=100 kPa sigma3=40 kPa
100 Percent of Standard Proctor Density
Conclusions

- Compaction equipment and field tests are now available that can measure the properties used to design pavements and predict performance.
- LWDs and DCPs can be used during construction quality assurance to efficiently verify design target values.
- Several options exist to quantify moisture and more field measurement devices are coming.
- The time is now to accelerate implementation of performance based quality assurance so that our investments are well spent.
Roadmap: What’s Next

- Purchase more LWDs for performance based QA testing
- Specification to include design-based minimum targets
- Specification to include design-based uniformity targets
- Industry/Agency inspector certification training
- Educate designers, opportunity to refine/validate design
- MnPAVE enhancements to predict construction QA targets
- MnPAVE enhancements to include unsaturated mechanics
- Continued participation with national projects
- Implementation of new moisture/suction QA test
Thank You.

Questions?

http://www.dot.state.mn.us/materials/research_lwd.html
Zorn Deflection Target Value vs Exudation Pressure

MnDOT Mr k-values estimated using suction and volumetric water at saturation

$\sigma_1 = 100 \text{kPa}$ $\sigma_3 = 40 \text{kPa}$

100 Percent of Standard Proctor Density
Modulus Estimated Using Unsaturated Mechanics vs Measured Plate Load Modulus
Plate load data from Mn/DOT Inv. 183, 1968
Plastic limit greater than 10
\[ \sigma_1 = 100 \text{ kPa} \quad \sigma_3 = 40 \text{ kPa} \]