Pavement Foundation Quality Assurance Opportunities

Arizona Pavements and Materials Conference
Phoenix, Arizona
November 15-16, 2017
John Siekmeier P.E. M.ASCE
Acknowledgements

- Minnesota DOT Districts and Local Agencies
- Other State DOTs, FHWA and NCHRP
- Contractors and Manufacturers
- Universities and Consulting Engineers
- U.S. Congress “MAP-21” and “FAST”
Presentation Outline

- Pavement Foundations are Important
- Pavement Design Framework
- Performance Based Specifications
- Quantifying Moisture and Geogrid
- Lessons Learned and Next Steps
Pavement Foundations are Important

STATEWIDE 2016 PAVEMENT CONDITION
Pavement Quality Index (PQI)
- Poor (0.0 - 1.8)
- Fair (1.9 - 2.7)
- Good (2.8 - 4.6)

Surface Condition

STATEWIDE 2016 PAVEMENT CONDITION
Remaining Service Life (RSL)
- Low (0 - 3 years)
- Moderate (4 - 11 years)
- High (12 or more years)

Remaining Service Life
Pavement Management Van
If RQI is estimated to be 2.5 in 2022.

If reference year is 2016.

Then the remaining service life = 6 years.

Annual condition of each section is measured.

Future performance of each section is estimated.
Mechanistic Pavement Design is Part 1 of the Solution

- Provides the framework for using performance based material properties

- Free pavement design software available
  www.dot.state.mn.us/app/mnpave/index.html

- Just Google “MnPAVE”
Memo

TO:       PCMG, CMG, MnDOT Districts, Materials Engineers, Soils Engineers, State Aid

FROM:    Glenn M. Engstrom, Director
              Office of Materials & Road Research

DATE:    October 31, 2014

SUBJECT: Pavement Design Manual Publication

I am pleased to announce the publication of the MnDOT Pavement Design Manual.

This publication represents a significant effort to update pavement design procedures and codify existing documents into a single point of reference. As of November 1, 2014, all MnDOT pavement designs shall follow the pavement design, pavement-type selection, LCCA, and alternate bidding as laid out in the Pavement Design Manual. To view the manual, please follow http://www.dot.state.mn.us/materials/pvmtdesign/newmanual.html
Design Requires Performance Inputs

Structure

Confidence Level (50 to 99%) 85 Default

View
- Thickness Values
- Coefficient of Variation
- Adjusted Thickness

Mill and Overlay
Edit Structure

Layers | Material | Thickness (in.)
--- | --- | ---
1 | HMA | 4
2 | Old HMA | 4
3 | AggBase | 12
4 | EngSoil | 24
5 | UndSoil | 4

Old HMA Modulus
- Default Values
- FWD Deflections

Agg. Test Type
- Lab Mr., ksi
- R-Value
- DCP, mm/blow

Soil Test Type
- Lab Mr., ksi
- R-Value
- DCP, mm/blow
- Silt % Clay %

Other
- Design Modulus, ksi
- Poisson's Ratio

View
- Test Results
- Resistance Factors
- Coefficient of Variation

Check box to enter test data. Uncheck to use Basic defaults.

FWD Data

Cl.5

CL
Performance Based Construction Testing is Part 2 of the Solution

- Draft specifications produced by NCHRP 10-84 and Transportation Pooled Fund TPF 5(285)

- Modified version is available at NRRA Pooled Fund website (Geotechnical Team)
  [http://www.dot.state.mn.us/mnroad/nrra/index.html](http://www.dot.state.mn.us/mnroad/nrra/index.html)

- Just Google “NRRA”
Change is Underway

- From Traditional Construction Testing
  - Specify Relative Density
  - Specify Gravimetric Moisture
  - Observation and Test Rolling

- To Performance Based Construction Testing
  - Specify Modulus and/or Strength
  - Specify Volumetric and/or Gravimetric Moisture
  - Observation, Test Rolling, and/or Intelligent Compaction
## DCPs and LWDs in Indiana

<table>
<thead>
<tr>
<th></th>
<th>DCPs</th>
<th>LWDs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indiana DOT</td>
<td>130+</td>
<td>60+</td>
</tr>
<tr>
<td>Private Sector</td>
<td>30+</td>
<td>10+</td>
</tr>
</tbody>
</table>

DCP Indiana DOT Test Method No. 509-15P
LWD Indiana DOT Test Method No. 508-12T
Back to the Future: Ralph Proctor reminds us.

- Strength is not achieved by density alone.
- Optimum moisture is for compaction.
- Need to avoid rutting during construction.

photo courtesy of Dr. J. David Rogers
University of Missouri-Rolla
“Methods for hand compaction, such as dropping various weight tampers from different heights and mechanical tampers, were tried and discarded.”

“No use is made of the actual peak dry weight.”

“The measure of soil compaction used is the indicated saturation penetration resistance.”
Proctor Penetrometer

Photo courtesy of Humboldt
Dynamic Cone Penetrometer

ASTM D 6951-03
Light Weight Deflectometer

ASTM E 2583 07
(includes load measurement)

ASTM E 2835 11
(no load measurement)

AASHTO TP 123-01 draft
(determining lab target values)

AASHTO TP 456-01 draft
(field quality assurance)

Benefits of Performance Tests

- Empowers inspector with useful measures
- Verifies pavement design inputs
- Creates as-built record of construction
- Optimizes future pavement designs
Construction Testing Summary

- LWDs and DCPs are being used to measure properties that significantly affect performance (this includes moisture measurement).

- Minnesota DOT policy encourages compaction equipment be used to fully map the as-built pavement layers.

- AASHTO draft specifications are available for performance based construction management.
Quantifying the Importance of Moisture
Lessons Learned from Case Studies

- Modulus and strength are greatly affected by the moisture between the particles, which causes a suction or tensile stress between the particles.

- Tensile stress between particles depends on:
  - Quantity of sand, silt, and clay particles (gradation)
  - Particle shape (roughness)
  - Porosity (total void space “openness”)
  - Moisture content (how much water is in the voids)
Fundamentals of Soil Physics, Hillel

air void

sand grain

moisture bridges
**Need Moisture Content Inputs**

- **Structure**
  - **Confidence Level (50-99)**: 70
  - **Use Mean Values**: 
    - **Overburden Calculation**
  - **View**:
    - Thickness Values
    - Coefficient of Variation
    - Adjusted Thickness
  - **Edit Structure**
    - **Layers**
      - 1: HMA
      - 2: AggBase
      - 3: Subbase
      - 4: EngSoil
      - 5: UndSoil
      - **Thickness (in.)**: 5, 9, 12, 36
    - **Design Mode**: Basic
    - **Units**: English
  - **Finished Structure**
    - Go to Control Panel
  - **Parameter Shown Below**:
    - Design Modulus, ksi
    - Poisson's Ratio
    - Seasonal Modulus Multipliers
    - Modulus Coefficient of Variation, %
  - **Structural Number**: 3.7

- **Parameter Table**
  - **Design Mode**: Basic
  - **Units**: English
  - **View**:
    - **Pavement Temperature Equation**
    - **Input Moisture Characteristics**
  - **Layers**
    - **Thickness (in.)**:
      - Fall: 1, Winter: 1, Early Spring: 1, Late Spring: 1, Summer: 1
  - **Simulate FWD**, **Simulate LWD**, **View Damage Equations**

- **moisture included here**
For typical moistures, suction range is 1 – 60 kPa.
Distinct Element Model with Suction
Laboratory Resilient Modulus
Increasing suction increases resilient modulus.
Seasonal Factors Compared

Structure

[Diagram showing seasonal factors comparison]

Original factors

DEM results from PFC

1 0.5 0.7 1.2
Quantifying the Benefit of Geogrid
Geogrid History and Widening

Photo courtesy of Jim Bittmann
Photos courtesy of Jim Bittmann
• Ideally geogrid would be the only difference between test sections.

• Reality is that other variables include soil, water, and temperature.
Field Testing and Numerical Modeling of In Situ Resilient Modulus
Automated Plate Load Test (Ingios)

Trunk Highway 72 September 2016

MnROAD

July August 2017
IC Map of Geogrid MnROAD 2017

Figure Courtesy of Ingios Geotechnics

Link to Research Pays Off Seminar, David White, October 2017
http://www.dot.state.mn.us/mnroad/researchpayoff/index.html
Numerical Modeling of Geogrid
Parameters Studied

Aggregate gradation
Friction between particles (roughness)
Moisture content (suction/tensile stress)
Confining stress
Geogrid depth within aggregate base layer
Geogrid with Red Showing Tension
Triaxial Grid Deformed by Aggregate
Triaxial Grid Deformed by Aggregate
Modulus of 8 Inch Aggregate Base Layer
Confinement = 150 kPa  Particle Friction = .8  Moisture Tension = 1 kPa (gap 3 mm)

No Grid

\[ M_1 = 61 \text{ MPa (8.8 ksi)} \]
\[ M_2 = 63 \text{ MPa (9.1 ksi)} \]
\[ M_3 = 74 \text{ MPa (10.7 ksi)} \]
\[ M_4 = 79 \text{ MPa (11.5 ksi)} \]
\[ M_5 = 79 \text{ MPa (11.5 ksi)} \]
\[ M_6 = 84 \text{ MPa (12.2 ksi)} \]
Modulus of 8 Inch Aggregate Base Layer

Confinement = 150 kPa  Particle Friction = .8  Moisture Tension = 1 kPa (gap 3 mm)

With Grid

\[ M = 149 \text{ MPa} \quad (21.6 \text{ ksi}) \]
\[ M = 166 \text{ MPa} \quad (24.1 \text{ ksi}) \]
\[ M = 169 \text{ MPa} \quad (24.5 \text{ ksi}) \]
Modulus of 8 Inch Aggregate Base Layer
Confinement = 150 kPa  Particle Friction = .8  Moisture Tension = 1 kPa (gap 3 mm)

Geogrid Gain Factors
\( \left( \frac{M_2}{M_1} \right) \) at axial strain

\begin{align*}
\text{(0.02\%)} & \quad \text{(0.05\%)} & \quad \text{(0.1\%)} \\
2.4 & \quad 2.2 & \quad 2.1 \\
2.4 & \quad 2.1 & \quad 2.0 \\
\end{align*}

No Grid
Slope = \( M_{\text{ng}} \)

With Grid
Slope = \( M_{\text{grid}} \)
Rutting vs Geogrid Gain Factor

Damage must be less than 1.0 to achieve a 20 year design life.
Lessons Learned and Next Steps

- Modulus increases as moisture suction increases.
- Geogrid provides a quantifiable benefit that enhances pavement performance.
- Implementation continues so that the people’s investments are used more effectively.
Thanks for Listening.
Please ask questions and keep pulling together.