HMA COMPACCTION ASSESSMENT USING GPR ROLLING DENSITY METER

Rick Bradbury, MaineDOT
Shongtao Dai, MnDOT

NEAUPG
Atlantic City, NJ
October 17, 2018
The Importance of Density

• Optimum density provides:
  – Reduced oxidation
  – Reduced moisture damage
  – Decreased rutting potential
  – Improved fatigue life
  – Increased load bearing capacity

• Past studies relating density to pavement life
  – Rule of thumb: 1 % decrease below minimum results in 10% loss of life

Uniform density throughout the pavement layer is critical
Enemy of Density: Segregation

- Two main types of segregation
  - Mechanical (aka physical or gradation)
  - Thermal
- Often identified visually; subjective
- May not be apparent at time of construction
- Difficult to quantify
- Very difficult to enforce contractually
- Major cause of premature pavement failures
Rapid Technologies to Enhance Quality Control on Asphalt Pavements (R06C)

Two non-destructive techniques for evaluating asphalt pavements during construction

– Infrared thermal scanning
– Ground Penetrating Radar

• Measures uniformity and potential defect areas in asphalt pavements during construction.
• Offers real-time testing of potentially 100 percent of the pavement area.
Current Density Tests

Density gauge
(Nuclear or electrical)

Core samples

Typical random sampling measures ≈ 0.003 % of pavement area
Ground penetrating radar

- Widely used for many applications
  - Utility location
  - Pavement thickness
  - Bridge deck deterioration
- Uses electromagnetic wave reflection to “see” through materials
- Research for decades to use for pavement density
  - Accuracy never achieved
Theory of operation for density

- Measures dielectric properties of asphalt surface
- Dielectric constant - ability of a substance to store electrical energy in an electric field
  - Air dielectric: 1.00059
  - Asphalt, aggregate ≈ 3 to 6
  - Water: 80
  - New pavement: mixture is uniform; dielectric variation primarily caused by % air voids – directly relates to density
- Based on ratio of reflection from asphalt surface to reflection from metal plate
  - Approximately 1” -1.5” into layer – not reading entire layer thickness
GSSI PaveScan RDM

- Three – 2GHz antenna
- Portable push cart
- Capable of scanning 6’ width
- Onboard computer
  - Captures dielectric values
  - Can be correlated to core densities
Metal plate calibration
Correlation procedure

- Scan a pavement section
- Device identifies high, low, median density locations
- Take static reading directly over each location
- Obtain cores at each location
- Test cores; enter results in software

Correlation accuracy depends on obtaining core densities over entire range of measured dielectric values
Density Profiles

Typical density profile
Density varies with depth

Limitations

Affected by:
- Surface moisture
- Temps below 40 F
- Mix constituents (change in aggregate source, etc.)

Layers < 1”: accuracy affected by underlying layer

Layers > 2.5” – 3”: affected by density gradients within layer
Further enhancements

- Some users are adapting with vehicle mounts
- Minnesota DOT – leaders in data analysis
- Single antenna cart units - lower price
- Being investigated for longitudinal joint use
- Incorporation into VETA software
  - Data analysis of Intelligent compaction, thermal profile, and (soon) GPR density
Minnesota Experience on RDM

• Shongtao Dai, MnDOT
• Kyle Hoegh, MnDOT
Acknowledgements

- FHWA/AASHTO
- GSSI
- MnDOT district materials and constructions
Why MnDOT is interested in?

- MnDOT Uses Cores Density for Acceptance
  - Need a tool for continuous assessment: RDM

- Longitudinal Joint deterioration

- IC and IR Implementation
  - IC&IR are QC tools
  - RDM (GPR) can be a QA tool

- RDM in 2015
MnDOT Equipment

- Push Cart Type RDM
- Vehicle Mounted RDM
Mainline Survey: multiple passes

Joint Survey: one antenna close to joint
Equipment Calibration

- High Density Polyethylene (HDPE)
- Reported dielectric: 2.3-2.35

$$\varepsilon_{HMA} = \left( 1 + \frac{A_0}{A_P} \right)^2 \left( 1 - \frac{A_0}{A_P} \right)$$

Graphs showing dielectric variations and antenna measurements.
Underlying layer effect on surface measurement?

- How thick does the HMA layer need to be so that the underlying layer (agg. base) has no effects?

\[ h_1 = v \frac{\Delta t_1}{2} \]

\[ v = \frac{c}{\sqrt{\varepsilon_1}} \]

\( dT \sim 0.439 \text{us} \)
Footprint area of an antenna (Fresnel Zone)?

\[ Fr \approx 0.5 \sqrt{\frac{v}{\sqrt{fr}}} \]

\[ D=12", \ Fr \text{ (Radius) } \approx 3.6" \text{ (for 2.7Ghz-RDM)} \]
Use histogram to assess uniformity and quality.

- All Data Collected
  - Sampling Rate = 0.4 in/scan.
  - > 26 million measurements
  - Analysis based on 4 in. moving average
  - Equivalent to >1 million cores

- Summary Stats
  - 93.2% median density
  - STD: 1.18
  - 97.5% locations density > 90.8%
Examples: TH 52 – Left and Right Mainline

- Median Density
  - Right: 93.4%
  - Left: 93.1%

- STD: 0.92(R) and 0.96(L)

- 97.5% locations:
  - > 91.6% (R)
  - > 91.2% (L)
TH 52 – Longitudinal Joint

- Top lift Mainline vs Confined and Unconfined Joints Summary:
  - 93.5% (ML), 92.6%(CJ) and 91.4%(UCJ)
  - SD: 0.94(ML); 1.22(CJ); 1.8(UCJ)
  - Density:
    - UCJ/ML=97.7%; CJ/ML=99%
    - Core data: UCJ/ML=95.1%
      CJ/ML = 99.1%
  - 97.5% locations:
    - > 91.6%(ML),
    - > 90.2% (CJ)
    - > 87.8% (UCJ)
TH 14 – Mainline

- Comparison of Test Sections
  - Mix B (3/4-) to A(1/2-): not much difference on compaction.
  - Adding a roller: density slightly increased on this project.

- Median Density:
  - Blue: 94.1%
  - Red: 94.2%
  - Yellow: 93.5%
  - Green: 93.3%
Automatic to identify core locations at the end of each paving day
- At low and high dielectric locations
- Ex: 10% and 90%
Generate core location text file and load to a GPS device to automatically guide field person to the core location for obtaining the core.

<table>
<thead>
<tr>
<th>Core Number</th>
<th>X Coordinate</th>
<th>Y Coordinate</th>
</tr>
</thead>
<tbody>
<tr>
<td>R293.1</td>
<td>298478.7227</td>
<td>519108.2862</td>
</tr>
<tr>
<td>R294.1</td>
<td>302565.1707</td>
<td>520114.0246</td>
</tr>
<tr>
<td>R295.1</td>
<td>299279.1239</td>
<td>519298.2314</td>
</tr>
<tr>
<td>R296.1</td>
<td>299599.5422</td>
<td>519377.6685</td>
</tr>
<tr>
<td>R297.1</td>
<td>300540.5022</td>
<td>519610.8459</td>
</tr>
<tr>
<td>R298.1</td>
<td>300331.6291</td>
<td>519559.0812</td>
</tr>
<tr>
<td>R299.1</td>
<td>301378.5352</td>
<td>519818.6575</td>
</tr>
<tr>
<td>R300.1</td>
<td>301907.3905</td>
<td>519951.4897</td>
</tr>
<tr>
<td>R301.1</td>
<td>303106.5117</td>
<td>520228.2346</td>
</tr>
<tr>
<td>R302.1</td>
<td>302670.5928</td>
<td>520139.8712</td>
</tr>
<tr>
<td>R303.1</td>
<td>304480.9524</td>
<td>520289.7976</td>
</tr>
<tr>
<td>R304.1</td>
<td>304360.0461</td>
<td>520297.9872</td>
</tr>
</tbody>
</table>
Measure dielectric constant on a gyratory specimen?

- Establish Calibration Curve in Lab & Sensitivity Study
  - Currently use field cores for calibration: ex: 10% and 90%
  - Hope to establish calibration curve at lab in future
  - How does each component in a mixture affect dielectric constant, such as aggregate type, gradation, binder type and content?
Core Locator Application

Delrin

d=6cm (2.36")

Gyratory Measured Air voids versus Surface Dielectric

\[ AV = \exp \left( -7.53 \left( 3.40 \frac{1}{4.97} - 1 \right) \right) \]

\[ R^2 = 0.97 \]
Activities

- Calibration of Equipment

- Field Testing:
  - 2016: TH52 and TH14: Surveyed about 18 miles.
  - 2017: I35; Th52; Th22; Th60; CR86; Th110; CSAH13 and MnROAD
    - Hired American Engineering Testing (AET) to collect data
      - Educating consultant and contractors on this new technology
      - Testing application feasibility of vehicle mounted RDM system on construction projects.
  - 2018: “Ghost” specification and core locator – 1 or 2 projects
    - TH47, TH14, TH109 and TH50 so far
    - Work with GSSI on software improvements

- Research on Laboratory Calibration
  - Gyratory Specimen
Summary

- RDM is a good tool for mapping a continuous coverage of the relative compaction levels (higher dielectric = higher compaction)

- Histograms and general statistics can be used to give a complete assessments of the in-place compaction

- Potential Uses:
  - Assess compaction density and uniformity for QC/QA.
  - Provide on-site feedback to contractor of high and low compaction locations that they can cross-check with differences in mix or paving strategies in those locations to determine optimal construction procedures
  - Identification of trends in the air void content maps that can be cross-checked with IC and other data to determine the most critical factors in achieving higher density
For more information on improving the quality of asphalt pavements through SHRP2 products:

• Steve Cooper (FHWA) stephen.j.cooper@dot.gov
• Kate Kurgan (AASHTO) kkurgan@aashto.org

For more information on Maine’s experience:

• Rick Bradbury (Maine DOT) richard.bradbury@maine.gov

For more information on Minnesota’s experience:

• Shongtao Dai (Minnesota DOT) shongtao.dai@state.mn.us