Continuous Asphalt Density Measurement with GPR-based Rolling Density Meter

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Why MnDOT is interested?

- MnDOT uses cores to determine density
  - Random locations: Need coverage of the surface
  - Longitudinal Joint deterioration
  - Fill gap in IC and IR
    - MnDOT is planning to fully implement IC&IR 2018
    - IC&IR is QC tool
    - RDM (GPR) can be QA tool

- GSSI Horn Antenna System in 2014

- RDM in 2015
Equipment Calibration and Questions

- Measurement difference among the antenna pairs?
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?

\[
h_1 = \frac{v^* \Delta t}{2}
\]

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

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

\[ F_r \sim 0.5 \nu \left( \frac{t}{f_c} \right)^{1/2} \]

at \( D=18'' \), \( F_r \) (Radius) \( \sim 6'' \) (for 1.5Ghz)

\( D=12'' \), \( F_r \) (Radius) \( \sim 3.8'' \) (for 2.5Ghz-RDM)
MnDOT’s Plan

- **2016 Field Testing:**
  - TH52 and TH14: Surveyed about 18 miles.

- **2017 Field Testing**
  - 2 to 3 construction projects in 2017 will be selected for data collection. A consultant will be hired for part of the data collection. The focus will be placed on:
    1) Educating consultant and contractors on this new technology
    2) Further verifying the developed statistical method.
    3) Testing application feasibility of vehicle mounted RDM system on construction projects.

- **2018 Field Testing**
  - IC, IR&RDM on CIR&FDR projects. A consultant will be hired for more data collection/field inspection.
  - Further improve the system if needed.
  - Develop a pilot RDM specification.
Issues To Be Addressed

- **Sensitivity Study:**

  How does each component in a mixture affect dielectric constant, such as aggregate type, gradation, binder type and content?

  Develop a guideline on when contractor should notify agency if there is mixture change during construction.
Software Improvements
- Distance from antenna to pavement surface
- RDM data directly into VETA
- GPS Accuracy
- Etc.

Equipment Precision and Accuracy
- Method for check/verify precision
- Calibration Procedure
  - Current: High-density polyethylene (HDPE)

Local Support for RDM from GSSI in Future?
- If fully implemented in construction projects
- AASHTO Protocol
  - Survey Set Up
  - Survey Data Collection
  - Data Processing
  - Data Analysis & Applications

- Quality Acceptance Criteria
  - Compaction Uniformity
  - Density: Mainline and Longitudinal Joint

- Use of data in PM system for evaluating Long-term Performance?
Results

- On-Site Identification of high and low levels of compaction
- Mainline Survey: multiple passes
- Joint Survey: one antenna close to joint
Relating Dielectric Measurements to Air Void Content

Mix Model

\[ G_{mb}, G_{mn} \]

Air
\[ \varepsilon_0 \]

Asphalt binder
\[ G_b, P_b(\%o) \]
\[ \varepsilon_b \]

Absorbed Asphalt binder

Aggregate
\[ G_{ab}, G_{ae} \]
\[ \varepsilon_a \]

HMA volume and mass composition

\[ V_T = 1 \]
\[ V_{gb}, V_{ae} \]

\[ M_B = \text{mass of binder} \]
\[ M_T = \text{total mass} \]
\[ M_a = \text{mass of aggregate} \]
\[ M_{ab} = \text{bulk specific gravity of aggregate} \]
\[ G_{ab} = \text{specific gravity of binder} \]
\[ G_{mb} = \text{bulk specific gravity of HMA} \]
\[ G_{mn} = \text{maximum specific gravity of HMA} \]
\[ V_T = \text{total volume} \]
\[ V_a = \text{volume of air} \]
\[ V_b = \text{total volume of binder} \]
\[ V_{gb} = \text{bulk volume of aggregate} \]
\[ V_{ae} = \text{effective volume of aggregate} \]

\[ \varepsilon_a = \text{dielectric constant of air} = 1.0 \]
\[ \varepsilon_b = \text{dielectric constant of binder} \]
\[ \varepsilon_e = \text{dielectric constant of aggregate} \]
\[ P_b = \text{binder content} \]

\[ y = 218.23e^{-0.706x} \]
\[ R^2 = 0.7654 \]

Figure 3.50. Calibrating GPR to predict in-place air voids from Region 2 data.
Relating Dielectric Measurements to Air Void Content

Mix Model Slope (AV%/e) ~ Double Field Observed
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%
TH 52 – Mainline

- Number of Roller Effects
  - Section with added binder + 5 rollers has highest density

- Median Density:
  - Blue: 93.4%
  - Yellow: 93.1%
  - Green: 93%
  - Red: 94%
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 52: Comparison with other Factors

Import RDM data into Veta for comparison with IR and other data

Local decreases (blue) at unconfined edges

Local Increase after Added Roller

Dielectric

Stationing [ft]

Dielectric [ft]

Local decreases (blue) at unconfined edges

Speed (ft/min)

Temperature (°F)

[A] [B] [C]
Comparison of Test Sections

- Mix B (3/4-) to A(1/2-): no 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%
TH 14 – Longitudinal Joint

- Evotherm helped on the joint compaction density

### Highway 014W Project

- **Median Density:**
  - Red: 93.1% (ML)
  - Blue: 93.1% (ML)
  - Yellow: 92.9% (CJ+E)
  - Green: 91.5% (CJ)
  - \((CJ+E)/ML = 99.7\%\)

- **Core:**
  - 93.8% (ML)
  - 93.5% (CJ+E) - only 2 cores
  - \(CJ/ML = 99.6\%\)
Percent within limits (PWL) implications

- Good measure if enough data: takes into account magnitude and spread in data
- < 10 data points for each QA Core assessment:
  - Core PWL st.dev > 10 percent
- >150,000 data points for each RDM assessment
Example Simple Use of Technology: TH14 roller pattern #1 vs Roller Pattern #2

On-Site

After Core Calibration
Example On-Site Analysis:
I35 Echelon Paving “Smush” Technique:

Core Measured % Density: 89.6%
Example On-Site Analysis:
I35 Echelon Paving Overlapping Technique:

Core Measured % Density: 93.0%

Switch to Overlap improved density
~ by 3% air void content
Recommendation #1 - Mainline:

Require dielectric distribution readings from RDM per 500ft.

Ex: Require E of 5.31 ≥ 92% density?

E of 5.31 includes > 95% data

Take cores at E=5.31, Then measure density
Recommendation #2 – Longitudinal Joint:

Require RDM readings at the longitudinal Joint and X distance away from the Joint, use ratio of dielectrics between LJ and ML.

Ex: Ratio of $E \geq 95\%$
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.
  - 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.
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