Rapid Technologies to Enhance Quality Control on Asphalt Pavements Ground Penetrating Radar (GPR) Rolling Density Meter (RDM)

FHWA/AASHTO Hosted Webinar

March 8, 2018
Purpose of Today’s Webinar

- Provide an overview of SHRP R06C RDM technology project.
- Discuss the value added by using RDM technology (what it is, why should you care, how it affects your bottom line, and how you get there).
- Illustrate RDM use in day-to-day practice.
- Present a summary of the results from the field demonstration projects in terms of its day-to-day application.
- Discuss the benefits from the RDM technology as related to improvement of uniformity of compaction density.
A Few Housekeeping Details

• **Tell us what you think.** We want to hear from all of you on the call during the discussion segments.

• **Please add your comments and questions throughout the webinar to the chat box provided.**
Agenda

• Welcome and Introduction
• SHRP2 Overview – AASHTO
• SHRP2 R06C GPR Product Overview – FHWA
• GPR and RDM Technology – GSSI
• Results of R06C Implementation – Lev Khazanovich
• Application and Benefits from RDM Users
  – Minnesota DOT
  – TTI
  – Alaska DOT&PF
• Questions and Discussion
Welcome

Presenters
• Roger Roberts, GSSI
• Curt Turgeon, Kyle Hoegh and Shongtao Dai, Minnesota DOT
• Stephen Sebesta and Bryan Wilson, TTI
• Rich Giessel, Alaska DOT&PF

Moderators
• Kate Kurgan, Moderator/ R06C Product Lead, AASHTO
• Steve Cooper/ R06C Product Lead, FHWA
• Lev Khazanovich, Subject Matter Expert

Recorded presentation will be posted on the AASHTO SHRP2 website: http://shrp2.transportation.org/Pages/R06C_RapidTechnologiesToEnhanceQualityControl.aspx
SHRP2 Implementation:
INNOVATE – IMPLEMENT - IMPROVE

$155 million
FUNDING ASSISTANCE
63
SHRP2 SOLUTIONS
430+
PROJECTS IMPLEMENTED

- DOT: 52 Recipients
- MPO/LOCAL: 30 Recipients
- UNIVERSITY: 12 Recipients
- FEDERAL/TRIBAL: 7 Recipients

- RENEWAL: 230+
- CAPACITY: 100+
- RELIABILITY: 90+
- SAFETY: 11
SHRP2 Implementation:
INNOVATE – IMPLEMENT - IMPROVE

304,406
PARTICIPANTS ENGAGED

12,378
OUTREACH ACTIVITIES

16,629
HOURS TECHNICAL ASSISTANCE

RESULTS
Save lives, money, and time
- Bridges being built more quickly
- Smoother traffic flows and less congestion
- Reduced construction costs
- Safer roadways
- Smarter environmental reviews
R06C Technologies to Enhance QC on Asphalt Pavements

THE CHALLENGE: Develop solutions to measure and quantify non-uniformity of asphalt mixture construction

Localized non-uniform areas fail prematurely. Random testing seldom catches problem

Increased use of night paving makes inspection more difficult
R06C - Technologies to Enhance QC on Asphalt Pavements

Thermal Profile during Placement: Pave-IR

Density uniformity and compaction: GPR Rolling Density Meter
PaveScan RDM

SHRP2 Implementation Task Force Meeting

March 8, 2018
PaveScan RDM – What is it?

It is a complete GPR system providing:

• **Real-time** dielectric values of compacted asphalt
• **Full Coverage** (lane width and length)
• Automatically located core locations
• **Compaction information on-site** (after core calibration)
• Export to CSV and Google Earth KML files
PaveScan RDM – Configurations

1-Channel Configuration

3-Channel Configuration
PaveScan RDM – Field Setup

1. Attach antennas and cabling
2. 10 Minute warm-up
3. System Calibration (3 minutes)
   a. Airwave
   b. Metal Plate
PaveScan RDM – Data Collection Strategies

Data is collected at walking speed (4-5 ft/second)

Single Pass – Wheel Paths and in between

Two Pass – Down and back
PaveScan RDM – Data Collection

The image shows a tablet display with various options and settings for data collection, including heatmap, histogram, linechart, and dielectric values. The display interface is user-friendly, allowing for collect, core, and save options.
PaveScan RDM – Data Collection Con’t

Adjustable Scrollbars
PaveScan RDM – Playback

Over 6000 Measurements Shown
PaveScan RDM – Playback

Histogram
Distribution of Values
PaveScan RDM – Playback Statistics

Per-Profile Average, Min, Median, Max, Standard Dev, and Histogram Statistics
PaveScan RDM – Playback
## PaveScan RDM – Locate Cores

<table>
<thead>
<tr>
<th>Relative Dielectric</th>
<th>Lateral Offset</th>
<th>Sensor Position</th>
<th>Serial #</th>
<th>Distance</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Dielectric</th>
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</thead>
<tbody>
<tr>
<td>High</td>
<td>7</td>
<td>Right</td>
<td>63</td>
<td>850-85.30</td>
<td>61.36875906</td>
<td>-149.53209829</td>
<td>5.71</td>
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<td>63</td>
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<tr>
<td>High</td>
<td>11</td>
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<td>60</td>
<td>850+11.60</td>
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<td>9</td>
<td>Center</td>
<td>61</td>
<td>859+43.70</td>
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<td>Center</td>
<td>61</td>
<td>857+16.80</td>
<td>61.37045089</td>
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<tr>
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<td>61</td>
<td>856+48.10</td>
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<td>5.19</td>
</tr>
</tbody>
</table>

Showing 1 to 9 of 9 entries

[Back to File]
PaveScan RDM – Core Calibration

User-Entered Core Dielectrics

User-Entered Core % Voids

Equation: 

\[ \%\text{Voids} = Ae^{Bd} \]

where \( d \) = dielectric
PaveScan RDM – Percent Compaction

Playback File: GHHE-HMA-L1-SH-12R_047

Percent Compaction
Distance: 858+40.00 ft
Channel: L#60
Value: 92.91
PaveScan RDM – Export

- .CSV files, import to 3\textsuperscript{rd} party software
- Statistics
- KML files for Google Earth
PaveScan RDM – Google Earth

Example of a Google Earth display

Bridge

Data provided by Rich Giessel, Alaska DOT
PaveScan RDM – AND!!!

- No more certifications!!!
- No more security regulations!!!
- No more nuclear technology!!!
PaveScan RDM is a complete GPR system providing:

• **Real-time** dielectric values of compacted asphalt
• **Full Coverage** (lane width and length)
• Automatically located core locations
• **Compaction information on-site** (after core calibration)
• Export to CSV and Google Earth KML files

And

• **No certifications, security issues, factory calibrations**
Nondestructive Evaluation of Bituminous Compaction Uniformity Using Rolling Density Meter

Summary of SHRP2 R06C Implementation Project

Lev Khazanovich, Ph.D.
University of Pittsburgh
• Objectives:
  – Evaluate RDM equipment
  – Provide support to states in implementing RDM
• Partnership
  – FHWA, AASHTO, CH2M Hill, and ARA
  – University of Minnesota
  – MnDOT, Maine DOT, and Nebraska DOT
• Field Trails
  – Maine
  – Nebraska
  – Minnesota
Field Testing

• Objectives
  – DOT personnel training
  – RDM technology evaluation/refinement
  – Test protocols and specifications development

• Projects
  – US-52 near Zumbrota, Minnesota
  – HWY 2 in Lincoln, Nebraska
  – US-1 near Cherryfield, Maine
  – State Rte 9 near Clifton, Maine
  – I-95 near Pittsfield, Maine
  – US-14 near Eyota, Minnesota
Field Testing – Lessons Learned

• RDM is an implementation-ready device
  – Easy to operate
  – Provides reparative measurements
  – Can operate continuously for 6-8 hours

• Day and night testing was conducted without interfering paving or delaying moving closure

• RDM is capable of providing real time assessment of in-place compaction uniformity

• Good dielectric – air void correlations were obtained for the majority of the projects

• Good core data collection protocol is a key
Minnesota DOT Vision

Curt Turgeon, P.E.
Not to scale

Elephant = 6 tons

Hedgehog < 1 pound

For every 100 elephants of mix, we sample and test two hedgehogs (cores)

THAT’S IT?
TH 52: Comparison with Other Factors
Interstate 35 – Passing Lane Offset Comparison

- First ½ mile stretch
  - Most of the increase occurs in the first 500 ft when 4 ft. away from the joint
- Gradual increase over 2500 ft occurs at 2 ft. from the joint
Interstate 35 – Local Variation Offset Comparison

- First 500 ft local comparison
  - Can observe cyclical variation in the mat at different compaction levels
- Both offsets show similar variations in compaction
Interstate 35 – Passing Lane Offset Comparison

- 1000 ft comparison after increase in compaction
  - Can observe cyclical variation in the mat at similar compaction levels
  - Variability within offsets are lower
Minnesota DOT – RDM Experience

- Dr. Kyle Hoegh, MnDOT
- Dr. Shongtao Dai, MnDOT
- Dr. Lev Khazanovich, U. of Pittsburgh
Acknowledgements

- FHWA/AASHTO for providing RDM
- MnDOT district materials and constructions
- UMN students
Equipment Calibration

- Obtained RDM in 2015
- Measurement difference among the antenna
- High Density Polyethylene (HDPE)
  - Reported dielectric: 2.3-2.35

\[ E_{HMA} = \left(1 + \frac{A_0}{A_p}\right)^2 \]
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?

Surface layer

Underlying layer

\[
h_1 = v^* \Delta t_1 / 2
\]

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

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

\[ Fr \sim 0.5 \times (\frac{tr}{fc})^{1/2} \]

D=12”, Fr (Radius) ~ 3.6” (for 2.7Ghz-RDM)
MnDOT’s Plan

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

2017 Field Testing
- 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 Plan
- “Ghost” specification for contractor to use.
- Further improve the system based on feedback.
Field Equipment Validation

Green-MnDOT with Vehicle Mounted RDM

Red – Consultant with Walking Cart RDM
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)
GPR Asphalt Compaction Evaluation: 2016
TH 14 Field Testing

- 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.

<table>
<thead>
<tr>
<th>Color</th>
<th>Mix</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>Red</td>
<td>¾” mix + 4 rollers</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>½” mix + 4 rollers</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>½” mix + 3 rollers</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>¾” mix + 3 rollers</td>
<td>control (4'-8')</td>
</tr>
</tbody>
</table>

- Median Density:
  - Red: 94.2%
  - Blue: 94.1%
  - Yellow: 93.5%
  - Green: 93.3%

Cores vs RDM Medians
Evotherm helped joint compaction density

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

- Core:
  - 93.8% (ML)
  - 93.5% (CJ+Ev)- only 2 cores
  - CJ/ML= 99.6%
2017 TH52 N Standard Paving

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Stationing range, ft.</th>
<th>Offset range, ft.</th>
<th>Color</th>
<th>Samples</th>
<th>10th Percentile Air Void Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving Mat</td>
<td>223+50 to 1012+13</td>
<td>2 to 10</td>
<td>Blue</td>
<td>257,817</td>
<td>7.5%</td>
</tr>
<tr>
<td>Driving Joint</td>
<td></td>
<td>0.3 to 0.7</td>
<td>Brown</td>
<td>95,706</td>
<td>11.8%</td>
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</table>
### 2017 I-35 Echelon Paving

<table>
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<th>Group Name</th>
<th>Stationing range, ft.</th>
<th>Offset range, ft.</th>
<th>Color</th>
<th>Samples</th>
<th>10th Percentile Air Void Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passing Mat</td>
<td>507+24 to 1012+13</td>
<td>-10 to -2</td>
<td>Red</td>
<td>137,309</td>
<td>6.5%</td>
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<tr>
<td>Passing Joint</td>
<td></td>
<td>-0.7 to -0.3</td>
<td>Green</td>
<td>37,864</td>
<td>7.4%</td>
</tr>
</tbody>
</table>

Relative Frequency (Bin Count/Group Samples)

- Relative Frequency: 0 to 0.8
- Air Void Content: 4.0% to 8.0%

![Relative Frequency Graph](image)
IC and PMTP Technology

- Reduced Paver Speeds
- Steps to Reduce Number of Paver Stops
- Additional Rollers
- Modification to Rolling Patterns
- Delivery Method Changes
- Equipment Considerations
- Increased Fleet Management
- Monitor Stockpiles
- Requesting Paving Crew Summaries
- Caring and taking Pride

Process Changes
GPR Asphalt Compaction: Roller Technique Evaluation

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Stationing range, ft.</th>
<th>Offset range, ft.</th>
<th>Color</th>
<th>Samples</th>
<th>Core Taken at 10th %, Air Void Content</th>
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<tbody>
<tr>
<td>Roller Technique #1</td>
<td>920+00 to 925+00</td>
<td>Centered on Joint</td>
<td>Red</td>
<td>1000</td>
<td>9.6%</td>
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<tr>
<td>Roller Technique #2</td>
<td>935+00 to 940+00</td>
<td>Centered on Joint</td>
<td>Green</td>
<td>1000</td>
<td>7.7%</td>
</tr>
</tbody>
</table>

• Example 500 ft section where 2 different echelon breakdown roller techniques were used on the joint:
  • On-site RDM dielectric indicated greater compaction using technique 2
  • Core taken at 10th percentile indicated greater compaction in technique 2
• On-site dielectric can be used to give feedback as to what techniques are more effective for compaction
Future Improvements for Implementation

- **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.

- **Establish Calibration Curve in Lab**
  - Potentially no field core needed
  - Currently use field cores for calibration
  - Location accuracy?

- **Calibration Procedure**
  - Current: High-density polyethylene (HDPE) and Garolite
  - Swerving on field: max difference of 0.08?
Texas Experience with the RDM

Stephen Sebesta, TTI
Bryan Wilson, PE, TTI
March 8, 2018
How to Improve Acceptance Testing

More

Bigger

Smarter
## Deployment of RDM on Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Mix Type</th>
<th>NMAS (in.)</th>
<th>Binder Type</th>
<th>Optimum AC (%)</th>
<th>Aggregate Type</th>
<th>Theo. Max SG</th>
<th>Thickness (in.)</th>
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<tr>
<td>Gen 1 &amp; 2</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>FM 1887</td>
<td>TOM-C</td>
<td>3/8</td>
<td>70-22</td>
<td>6.7</td>
<td>Limestone</td>
<td>2.474</td>
<td>1.0</td>
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<tr>
<td>RM 12</td>
<td>TOM-F</td>
<td>1/4</td>
<td>76-22</td>
<td>7.3</td>
<td>Sandstone</td>
<td>2.348</td>
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<td>Riverside</td>
<td>DG Ty-C</td>
<td>1/2</td>
<td>76-22</td>
<td>4.8</td>
<td>Limestone</td>
<td>2.447</td>
<td>2.0</td>
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<tr>
<td>US 183</td>
<td>TOM-F</td>
<td>1/4</td>
<td>76-22</td>
<td>7.2</td>
<td>Sandstone</td>
<td>2.376</td>
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<td>US 90</td>
<td>SP Ty-D</td>
<td>3/8</td>
<td>70-22</td>
<td>5.2</td>
<td>Quartzite</td>
<td>2.443</td>
<td>1.5</td>
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<td>IH 10</td>
<td>SP Ty-C</td>
<td>1/2</td>
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<td>FM 31</td>
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<td>3/8</td>
<td>64-22</td>
<td>5.4</td>
<td>...</td>
<td>2.481</td>
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<td>DG Ty-D</td>
<td>3/8</td>
<td>64-22</td>
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<td>76-22</td>
<td>6.0</td>
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Antenna impact on Calibration

<table>
<thead>
<tr>
<th>Predictor Variable</th>
<th>Model p-value</th>
<th>Model R²</th>
<th>Variable p-value</th>
<th>Significant</th>
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<tbody>
<tr>
<td>Dielectric</td>
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<td>0.895</td>
<td>&lt;0.0001</td>
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<td>0.3111</td>
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<td>Project_Day</td>
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<td>&lt;0.0001</td>
<td>Yes</td>
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<tr>
<td>Project_Day*Dielectric</td>
<td>&lt;0.0001</td>
<td></td>
<td>&lt;0.0001</td>
<td>Yes</td>
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</table>
# Production Day impact on Calibration

<table>
<thead>
<tr>
<th>Predictor Variable</th>
<th>Model p-value</th>
<th>Model R²</th>
<th>Variable p-value</th>
<th>Significant</th>
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</thead>
<tbody>
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<td>Dielectric</td>
<td>&lt;0.0001</td>
<td>0.845</td>
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<td>Project</td>
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<tr>
<td>Day</td>
<td>&lt;0.0001</td>
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<td>0.0696</td>
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<tr>
<td>Project*Dielectric</td>
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<td>&lt;0.0001</td>
<td>Yes</td>
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<tr>
<td>Day*Dielectric</td>
<td>0.0145</td>
<td></td>
<td></td>
<td>Yes</td>
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</tbody>
</table>
Example influence of Paving Day

No clear explanation for this shift. Records show no major change in mix design or construction processes.
Example iteration of one possible air void prediction scenario

**Overall Accuracy and Bias Results (TxDOT Phase I Projects)**

<table>
<thead>
<tr>
<th>Prediction Method</th>
<th>Bias</th>
<th>Error Standard Deviation</th>
<th>Accuracy 95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg. Error (% voids)</td>
<td>p-value</td>
<td>(%) voids</td>
</tr>
<tr>
<td>GPR Dielectric (empirical)</td>
<td>0.02</td>
<td>0.463</td>
<td>0.99</td>
</tr>
</tbody>
</table>
Currently projects with ~20% not in target compaction region often receive bonus. As an industry, are we ok with this?
Next Steps

• TxDOT considering implementation effort using empirical calibration approach
• Deployment of RDM for information on projects in 2018 paving season
  – Test on subplot level
  – Void distributions
  – Hypothetical composite pay factor
  – Random placement sampling and testing still applicable
• Continued work on calibration approaches
Compaction Acceptance of Asphalt Paving using PaveScan RDM Continuous Full Coverage Data

SHRP2 R06C GPR RDM Implementation

Rich Giessel, P.E., State QA Engineer, Alaska DOT&PF
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March 8, 2018
• 50,000 Tons of Alaska Type VH Asphalt Paving (Superpave mix with Hard aggregate and Modified Oil)
• 15.2 Miles of 4 lane divided highway
• 2” Mill and fill to repair studded tire damage
• 65,000 ADT
• Alaska’s Glenn Highway-Hiland Rd to Eklutna
• May 22 to June 21, 2017
Low Density was Typical at Bridges
S. Birchwood Bridge,
Low Density (87%) at Longitudinal joint @ RDM
Resolution of 3 inch, but Core = 92.9%
Low Density Adjacent Rumble Strip
You get what you pay for!

On this project we offered a stepped bonus of up to $1.50/ft if average longitudinal joint compaction for the project achieved 94% of MSG

• >92.0% = $0.50 per lineal foot is added
• >93.0% = $1.00 per lineal foot is added
• >94.0% = $1.50 per lineal foot is added
Alaska’s goal is to compact asphalt pavements to our mix design value which is 96% for a mix designed with 4% Air Voids.

- Use the raw lot data to calculate % Conforming (PC) directly
- 5000 Ton lot with 2” lift thickness and 150 pcf density = 400,000 sf
- With PaveScan RDM readings every square foot, raw lot data will have 400,000 compaction values on about 6.3 lane miles
New Specification for Mat Compaction

Mat Compaction Bonus:

1. Set Lower Specification Limit for mat bulk density at 93.0% of Maximum Specific Gravity
2. For asphalt mat density pay factor calculate the Percentage of Conforming (PC) compaction values from the raw PaveScan RDM data for each lot.
3. Mat Density Pay Factor = 0.55 + PC/200
• Increase the longitudinal joint bonus linearly from the minimum value of 92.0% to 96.0% in 0.1% increments
• Alaska may offer a joint compaction bonus of $2.00/lineal foot when mix design compaction value is achieved.
• Joint compaction bonus may be based on average compaction and number of lineal feet of joint per lot or for the entire project.
Q: What happens when you don’t get what you paid for?

A: Require Repairs

Goal is “No Potholes Left Behind”
• Apply Sand Seal to the mat of an entire lane station that contains low (<92%) density areas that are small (less than 8 ft$^2$), discontinuous, and total more than 2% of a lane station area 

\[(2\%)(12' \times 100') = 24 \text{ ft}^2\]
• Apply Sand Seal to the mat of an entire lane station that contains a large (equal to or greater than 8 ft<sup>2</sup>) contiguous low density area. If a large, low-density area straddles a station line, is less than 50’ in length, and if it is the only low density area in both stations, then the 100’ lane length of sand seal shall be centered on the defect.
• Apply Joint Sealant to each station where the longitudinal joint within that station contains ≥5% joint density readings below 92.0%
• Receiving full joint bonus will not relieve Contractor from requirement to seal all defective segments of longitudinal joint
• Joint bonus is not paid until sealant has been successfully applied to all defective segments of the lot or project
Questions?
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Resources:
- AASHTO SHRP2 R06C Webpages:
  - http://shrp2.transportation.org/Pages/R06C_RapidTechnologiestoEnhanceQualityControl.aspx
- FHWA GoSHRP2 R06C Webpage:
  - https://www.fhwa.dot.gov/goshrp2/
Thank you!