Enhanced Durability Through Increased In-Place Pavement Density

Mark D. Blow, P.E.
Sr. Regional Engineer
Understanding the Importance of Density
Evolution of Traffic

- Interstate highways - 1956
- AASHO Road Test - 1958-62
  - still widely used for pavement design
  - legal truck load - 73,280 lbs.
- Legal load limit to 80,000 lbs. - 1982
  - 10% load increase
  - 40-50% greater stress to pavement
- Radial tires, higher contact pressure
- FAST Act raising load limit to 120,000 lbs. (in select locations)
Led to Rutting in 1980s

Courtesy of pavementinteractive.org
Which led to...Superpave

- Fixed the rutting problem
- Gyratory compaction lowered binder contents
- Add in higher and higher recycled materials?
Linking Density to Pavement Durability
Improved Compaction = Improved Performance

A BAD mix with GOOD density out-performed a GOOD mix with POOR density for ride and rutting.

WesTrack Experiment
For both thicker and thinner, reduced in-place density at the time of construction results in significant loss of Service Life!
Effect of Percentage of Air Voids on Fatigue Life
20C, 500 microstrain

Nf = -1361.88*AV² + 15723.35*AV + 88162
R² = 0.98

UK-AI Study
1.5% increase in density leads to 10% increase in fatigue life.
Performance Tests @ 7% Air Voids

Tensile Strength & Moisture Susceptibility vs. Air Voids
AASHTO T 283

Dry Strength
Wet Strength
TSR

Tensile Strengths, kPa

Sample Air Voids

4% 6% 8% 10%

TSR (Ratio)
0 0.68 0.73 0.78 0.83 0.88 0.93

Asphalt Institute Research
5 studies cited for fatigue life
7 studies cited for rutting
“A 1% decrease in air voids was estimated to improve the fatigue performance of asphalt pavements between 8.2 and 43.8%, to improve the rutting resistance by 7.3 to 66.3%, and to extend the service life by conservatively 10%.”
Research from New Jersey

\[ Y(\text{time}) = -1.1 \times (\text{Air Voids}) + 16.6 \]

\[ R^2 = 0.32 \]
Permeability can be Catastrophic
Finer NMAS mixes generally less permeable at equivalent air void levels!

From NCAT Report 03-02
Mix Design Properties that Affect Compactibility and Durability
Mixture Factors Affecting Compaction

- Mix Properties
  - Aggregate
    - Gradation
    - Angularity
  - Asphalt Cement
    - Grade
    - Quantity
- Volumetrics
  - Air Voids
  - VMA
  - VFA
- Balancing a Mix
Choosing a Gradation

12.5 mm Nominal Sieve Size

Sieve Size (mm)

Percent Passing

Blend 2
Blend 3
Blend 4

Choosing a Gradation

Courtesy of NCAT
Coarse, intermediate, and fine gradations. *No differences in rutting performance!*

<table>
<thead>
<tr>
<th>Limestone</th>
<th>Gravel</th>
<th>Slag &amp; Lms</th>
<th>Granite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine</td>
<td>Fine</td>
<td>Fine</td>
<td>Coarse</td>
</tr>
<tr>
<td>Intermed.</td>
<td></td>
<td></td>
<td>Intermed.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Limestone</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Fine</td>
<td>Coarse</td>
<td>Coarse</td>
<td>Intermed.</td>
</tr>
<tr>
<td>Coarse</td>
<td></td>
<td></td>
<td>Fine</td>
</tr>
</tbody>
</table>
Choosing a Gradation

Finer Gradations

More Compactable

More Workable

Less Permeable

Courtesy of NCAT
Effect of Aggregate on Compaction

- **GRADATION**
  - continuously-graded, gap-graded, etc.

- **SHAPE**
  - flat & elongated, cubical, round

- **SURFACE TEXTURE**
  - smooth, rough

- **STRENGTH**
  - resistance to breaking, abrasion, etc.
“Asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure.”
Balanced Mix Design Approach

• **General Procedure**
  - Design and test mix for **Rutting**
  - Test mix for **Cracking** and/or **Durability**
  - **Performance Testing**

• **States that are using this approach**
  - Texas
  - Louisiana
  - New Jersey
  - Illinois
  - California
  - Wisconsin
New Jersey Balanced Design

![Graph showing APA Rutting (mm), Overlay Tester Fatigue (cycles), and Optimum AC% (JMF) vs. Asphalt Content (%)]

Area of Balanced Performance: 5.2 - 5.9%

Courtesy of Tom Bennert
<table>
<thead>
<tr>
<th></th>
<th>Fatigue Cracking</th>
<th>Rutting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Air Voids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For every 1% increase</td>
<td>40% increase</td>
<td>22% decrease</td>
</tr>
<tr>
<td><strong>Design VMA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For every 1% increase</td>
<td>73% decrease</td>
<td>32% increase</td>
</tr>
<tr>
<td><strong>Compaction Density</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For every 1% lower in-place Air Voids</td>
<td>19% decrease</td>
<td>10% decrease</td>
</tr>
</tbody>
</table>

*Increasing Density Improved Both!*

Courtesy of Nelson Gibson
Why are the target values for lab-molded air voids and roadway air voids different? Lab-molded air voids simulate the in-place density of HMA after it has endured several years of traffic in the roadway.

<table>
<thead>
<tr>
<th>In-place Density</th>
<th>Air Voids</th>
</tr>
</thead>
<tbody>
<tr>
<td>≈15-25% Before Rolling</td>
<td>6 - 8 % After Rolling</td>
</tr>
</tbody>
</table>

Future Traffic

Lab-Molded Density

Air Voids

4% Superpave
Superpave 5 – Purdue Research

• Design at 5% air voids and compact to 5% voids in field (95% $G_{mm}$)
• Lower design gyration to increase in-place density
  • No change in rutting resistance
  • No change in stiffness
  • Improve pavement life
    • Reduced aging
• Maintained Volume of Eff. Binder ($V_{be}$)
  • Increased VMA by 1%

Courtesy of Gerald Huber
Factors Affecting Compaction
Lift Thickness Effect on Compaction

• Aggregates need room to densify
• Too thin vs. NMAS leads to:
  • Roller bridging
  • Aggregate lockup
  • Aggregate breakage
• Compaction Difficulties
## Superpave Size Designations

<table>
<thead>
<tr>
<th>Superpave Designation</th>
<th>Nom Max Size, mm</th>
<th>Max Size, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5 mm</td>
<td>37.5</td>
<td>50.0</td>
</tr>
<tr>
<td>25.0 mm</td>
<td>25.0</td>
<td>37.5</td>
</tr>
<tr>
<td>19.0 mm</td>
<td>19.0</td>
<td>25.0</td>
</tr>
<tr>
<td>12.5 mm</td>
<td>12.5</td>
<td>19.0</td>
</tr>
<tr>
<td>9.5 mm</td>
<td>9.5</td>
<td>12.5</td>
</tr>
</tbody>
</table>
NMAS grading is different than older “Topsize” Grading

Old Rule of Thumb - Minimum lift thickness = 2x Topsize

  • Thicker lifts are easier to compact
  • Cool slower, providing longer compaction time
  • Reduce paver speed

NMAS - Minimum compacted thickness

✓ 4 times nominal aggregate size
✓ 3 times nominal aggregate size for fine graded mixtures

Minimum - NOT MAXIMUM!
Design Problems

• The job mix formula (JMF) typically requires a gradation be developed that meets the specifications.

• Field production gradation tolerances are then applied to the JMF to account for variations during production.

• Lift thickness that meet the minimum guidelines for the specified mixture NMAS are often selected during project design.

• If the JMF falls at the lower limit of the gradation specified for the NMAS mix selected, and

• The field production goes coarse as allowed by the production tolerances,

• The actual NMAS placed is different than that specified in the plans

• This can result in poor placement, compaction and durability
# Wisconsin DOT Specified Mix Gradations

## Standard Superpave Gradation Recommendations

<table>
<thead>
<tr>
<th>SIEVE</th>
<th>No. 1 (37.5 mm)</th>
<th>No. 2 (25.0 mm)</th>
<th>No. 3 (19.0 mm)</th>
<th>No. 4 (12.5 mm)</th>
<th>No. 5 (9.5 mm)</th>
<th>SMA No. 4 (12.5 mm)</th>
<th>SMA No. 5 (9.5 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.0-mm</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37.5-mm</td>
<td>90 - 100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25.0-mm</td>
<td>90 max</td>
<td>90 - 100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19.0-mm</td>
<td>____</td>
<td>90 max</td>
<td>90 - 100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.5-mm</td>
<td>____</td>
<td>____</td>
<td>90 max</td>
<td>90 - 100</td>
<td>100</td>
<td>90 - 97</td>
<td>100</td>
</tr>
<tr>
<td>9.5-mm</td>
<td>____</td>
<td>____</td>
<td>____</td>
<td>90 max</td>
<td>90 - 100</td>
<td>58 - 72</td>
<td>90 - 100</td>
</tr>
<tr>
<td>4.75-mm</td>
<td>____</td>
<td>____</td>
<td>____</td>
<td>____</td>
<td>90 max</td>
<td>25 - 35</td>
<td>35 - 45</td>
</tr>
<tr>
<td>75-μm</td>
<td>0 - 6.0</td>
<td>1.0 - 7.0</td>
<td>2.0 - 8.0</td>
<td>2.0 - 10.0</td>
<td>2.0 - 10.0</td>
<td>8.0 - 12.0</td>
<td>10.0 - 14.0</td>
</tr>
<tr>
<td>% MINIMUM VMA</td>
<td>11.0</td>
<td>12.0</td>
<td>13.0</td>
<td>14.0[1]</td>
<td>15.0[2]</td>
<td>16.0</td>
<td>17.0</td>
</tr>
</tbody>
</table>

[2] 15.5 for LT and MT mixes.
## NYSDOT - Marshall Mix Gradations

**TABLE 403-1 COMPOSITION OF HOT MIX ASPHALT MIXTURES**

<table>
<thead>
<tr>
<th>Screen Sizes</th>
<th>Mixture Requirements&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Base</th>
<th>Binder</th>
<th>Shim</th>
<th>Top&lt;sup&gt;3,4&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 1</td>
<td>Type 2</td>
<td>Type 3</td>
<td>Type 5</td>
<td>Type 6, 6F2, 6F3</td>
</tr>
<tr>
<td>50.0 mm</td>
<td>General Job Mix limits %</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Mix Tol. %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37.5 mm</td>
<td>General Job Mix limits %</td>
<td>90 - 100</td>
<td>75 - 100</td>
<td>7</td>
<td>95 - 100</td>
</tr>
<tr>
<td></td>
<td>Mix Tol. %</td>
<td></td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25.0 mm</td>
<td>General Job Mix limits %</td>
<td>78 - 95</td>
<td>55 - 80</td>
<td>8</td>
<td>70 - 90</td>
</tr>
<tr>
<td></td>
<td>Mix Tol. %</td>
<td>5</td>
<td>8</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>12.5 mm</td>
<td>General Job Mix limits %</td>
<td>57 - 84</td>
<td>23 - 42</td>
<td>7</td>
<td>48 - 74</td>
</tr>
<tr>
<td></td>
<td>Mix Tol. %</td>
<td>6</td>
<td>7</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>6.3 mm</td>
<td>General Job Mix limits %</td>
<td>40 - 72</td>
<td>5 - 20</td>
<td>6</td>
<td>48 - 74</td>
</tr>
<tr>
<td></td>
<td>Mix Tol. %</td>
<td>7</td>
<td>6</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>3.2 mm</td>
<td>General Job Mix limits %</td>
<td>26 - 57</td>
<td>2 - 15</td>
<td>4</td>
<td>32 - 62</td>
</tr>
<tr>
<td></td>
<td>Mix Tol. %</td>
<td>7</td>
<td>4</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>850 μm</td>
<td>General Job Mix limits %</td>
<td>12 - 36</td>
<td>-</td>
<td>7</td>
<td>15 - 39</td>
</tr>
<tr>
<td></td>
<td>Mix Tol. %</td>
<td>7</td>
<td>-</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>425 μm</td>
<td>General Job Mix limits %</td>
<td>8 - 25</td>
<td>-</td>
<td>7</td>
<td>8 - 27</td>
</tr>
<tr>
<td></td>
<td>Mix Tol. %</td>
<td>7</td>
<td>-</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>180 μm</td>
<td>General Job Mix limits %</td>
<td>4 - 16</td>
<td>-</td>
<td>4</td>
<td>4 - 16</td>
</tr>
<tr>
<td></td>
<td>Mix Tol. %</td>
<td>4</td>
<td>-</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>75 μm</td>
<td>General Job Mix limits %</td>
<td>2 - 8</td>
<td>-</td>
<td>2</td>
<td>2 - 8</td>
</tr>
<tr>
<td></td>
<td>Mix Tol. %</td>
<td>2</td>
<td>-</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>PGB Content</td>
<td>4.0 - 6.0</td>
<td>2.5 - 4.5</td>
<td>4.5 - 6.5</td>
<td>4.5</td>
<td>7.0-9.5</td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<sup>1</sup> General Job Mix limits and Mix Tolerance (%)

<sup>3</sup> General Job Mix limits and Mix Tolerance (%)

<sup>4</sup> General Job Mix limits and Mix Tolerance (%)

Note: NA indicates Not Applicable.
<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percentage by Weight Passing Sieves</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-1/4&quot; max</td>
<td>1&quot; max</td>
<td>3/4&quot; max</td>
<td>1/2&quot; max</td>
</tr>
<tr>
<td>1-1/4 in. (30.0 mm)</td>
<td>100</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>1 in. (24.0 mm)</td>
<td>86-98</td>
<td>100</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>3/4 in. (19.0 mm)</td>
<td>68-93</td>
<td>76-98</td>
<td>100</td>
<td>--</td>
</tr>
<tr>
<td>1/2 in. (12.5 mm)</td>
<td>57-81</td>
<td>66-86</td>
<td>79-99</td>
<td>100</td>
</tr>
<tr>
<td>3/8 in. (9.5 mm)</td>
<td>49-69</td>
<td>57-77</td>
<td>68-88</td>
<td>79-99</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>34-54</td>
<td>40-60</td>
<td>48-68</td>
<td>58-78</td>
</tr>
<tr>
<td>No. 8 (2.36 mm)</td>
<td>22-42</td>
<td>26-46</td>
<td>33-53</td>
<td>39-59</td>
</tr>
<tr>
<td>No. 16 (1.18 mm)</td>
<td>13-33</td>
<td>17-37</td>
<td>20-40</td>
<td>26-46</td>
</tr>
<tr>
<td>No. 30 (0.600 mm)</td>
<td>8-24</td>
<td>11-27</td>
<td>14-30</td>
<td>19-35</td>
</tr>
<tr>
<td>No. 50 (0.300 mm)</td>
<td>6-18</td>
<td>7-19</td>
<td>9-21</td>
<td>12-24</td>
</tr>
<tr>
<td>No. 100 (0.150 mm)</td>
<td>4-12</td>
<td>6-16</td>
<td>6-16</td>
<td>7-17</td>
</tr>
<tr>
<td>No. 200 (0.075 mm)</td>
<td>3-6</td>
<td>3-6</td>
<td>3-6</td>
<td>3-6</td>
</tr>
</tbody>
</table>

Asphalt percent:
- **Stone or gravel**: 4.5-7.0, 4.5-7.0, 5.0-7.5, 5.5-8.0
- **Slag**: 5.0-7.5, 5.0-7.5, 6.5-9.5, 7.0-10.5
NMAS in SGC Experiment

Effect of Lift Thickness On Achieving Density

12.5 mm Limestone mix @ 75 gyrations
SGC Density vs. Lift Thickness

Effect of Lift Thickness On Achieving Density

- Suit-Kote-NY-75 gyration/600kPa - 9.5mm mixture

9.5 mm crushed gravel @ 75 gyrations
Lift Thickness
Lift Thickness

Thin lift overlays require finer mixture types!!
# Superpave Mix Designations

<table>
<thead>
<tr>
<th>Superpave Mix Designations</th>
<th>Maximum Size</th>
<th>Minimum Compacted Lift Thickness (Fine)</th>
<th>Minimum Compacted Lift Thickness (Coarse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5 mm (1-1/2 inch)</td>
<td>50.0 mm (2 inch)</td>
<td>112.5 mm (4-1/2 inch)</td>
<td>150 mm (6 inch)</td>
</tr>
<tr>
<td>25.0 mm (1 inch)</td>
<td>37.5 mm (1-1/2 inch)</td>
<td>75 mm (3 inch)</td>
<td>100 mm (4 inch)</td>
</tr>
<tr>
<td>19.0 mm (3/4 inch)</td>
<td>25.0 mm (1 inch)</td>
<td>57 mm (2-1/4 inch)</td>
<td>76 mm (3 inch)</td>
</tr>
<tr>
<td>12.5 mm (1/2 inch)</td>
<td>19.0 mm (3/4 inch)</td>
<td>37.5 mm (1-1/2 inch)</td>
<td>50 mm (2 inch)</td>
</tr>
<tr>
<td>9.5 mm (3/8 inch)</td>
<td>12.5 mm (1/2 inch)</td>
<td>28.5 mm (1-1/8 inch)</td>
<td>38 mm (1-1/2 inch)</td>
</tr>
<tr>
<td>4.75 mm (3/16 inch)</td>
<td>9.5 mm (3/8 inch)</td>
<td>14.25 mm (9/16 inch)</td>
<td>19 mm (3/4 inch)</td>
</tr>
</tbody>
</table>
Thicker lifts are easier to compact !!
Effect of Temperature on Compaction

Temperature Control is Critical
Material Cooling

• Thicker = More Time for Compaction
• Free tools for estimating compaction time
  • PaveCool—single lift (generation 1)
    • PC
    • iOs App
    • Google App
  • MultiCool—multiple lifts (generation 2)
    • PC
    • Google App
    • Mobile Web
PaveCool Example

• Key Inputs
  • Temperature
  • Air
  • Base
  • Mix Delivery
  • Wind Speed
  • Lift Thickness

• Output
  • Cooling Curve
  • Estimated Compaction Time
PaveCool Example

2 Inch Lift
50°F Air, Surface Temp
Mix Delivery temp - 300°F
28 minutes to complete compaction operations

2.5 Inch Lift
50°F Air, Surface Temp
Mix Delivery temp - 300°F
39 minutes to complete compaction operations
Paving Goals

• Continuous Operations
  • Hot plant running nonstop
  • Paver running at constant speed nonstop

• Production = Hauling = Paver Processing = Compaction Speed
Achieving Density on HMA Joints
Longitudinal Joints
We Know Unsupported Edge Will Have Lower Density

Proper Overlap

Sufficient Material for Roll-Down

Cold (unconfined) side

Hot (confined) side

Low Density Area

Please note Cold side and Hot side, as they are terms used throughout this Workshop.
Joint vs. Mat Density

2006-2007, with 6" cores taken over joint
Air void & Permeability research says 6-7% $P_a$ needed

Past standard joint construction practices reach 9-10%

Dilemma at the Joint
The Pennsylvania Example
Joint Issues
In PA
PA Joint Density Spec Highlights

• Both type of LJs allowed (butt or notch wedge)
• Joint Lot = 12,500’. Core every 2,500’. 5 cores per lot.
• Core location
  • For Butt: directly over visible joint
  • For Notch Wedge: middle of wedge
• Percent Within Limits (PWL)
  • Incentive starts at 80% PWL
  • Disincentive at <50% PWL
• Lower Specification Limit
  • 2010-2013: 89% TMD
  • 2014-2015: 90% TMD
• Corrective action for < 88% TMD
## PA: How Did it Work?

In-place Density Summary, Reported by PA DOT

<table>
<thead>
<tr>
<th>Year</th>
<th># Lots</th>
<th>Avg. Roadway Density, %TMD</th>
<th>Avg. Joint Density, %TMD</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>18</td>
<td>93.9</td>
<td>87.8</td>
<td>begin measuring at Jt.</td>
</tr>
<tr>
<td>2008</td>
<td>43</td>
<td>94.1</td>
<td>88.9</td>
<td>method spec</td>
</tr>
<tr>
<td>2009</td>
<td>29</td>
<td>94.1</td>
<td>89.2</td>
<td>method spec</td>
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<tr>
<td>2010</td>
<td>No data</td>
<td>transition to PWL spec</td>
<td></td>
<td></td>
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<tr>
<td>2011</td>
<td>137</td>
<td>94.1</td>
<td>91.0</td>
<td>PWL, LSL 89%</td>
</tr>
<tr>
<td>2012</td>
<td>162</td>
<td>94.0</td>
<td>91.6</td>
<td>PWL, LSL 89%</td>
</tr>
<tr>
<td>2013</td>
<td>167</td>
<td>93.9</td>
<td>91.4</td>
<td>PWL, LSL 89%</td>
</tr>
<tr>
<td>2014</td>
<td>316</td>
<td>94.1</td>
<td>92.3</td>
<td>PWL, LSL 90%</td>
</tr>
<tr>
<td>2015</td>
<td>493</td>
<td>92.6</td>
<td></td>
<td>PWL, LSL 90%</td>
</tr>
</tbody>
</table>
PA: Increased Projected Life of Joints Due to Improved Joint Density
<table>
<thead>
<tr>
<th>Year</th>
<th>Incentive Payments</th>
<th>Disincentive Payments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>$268K</td>
<td>$99K</td>
</tr>
<tr>
<td>2012</td>
<td>$489K</td>
<td>$63K</td>
</tr>
<tr>
<td>2013</td>
<td>$588K</td>
<td>$25K</td>
</tr>
<tr>
<td>2014</td>
<td>$1,002K</td>
<td>$127K</td>
</tr>
</tbody>
</table>

Note: MI and CT have averaged over 91.5%, and AK over 92.0% density at the joint over recent construction seasons.
Constructing a Quality Longitudinal Joint

- Types of LJs
- Planning for the Joint
- Placement and Rolling

Use best practices for paving previously discussed!
The Best Longitudinal Joint: Echelon Paving

New Jersey
But, the need to maintain traffic limits the opportunities to pave in echelon.

Consequently, most longitudinal joints are built with a cold joint.
Preferred Joint Type? Experts Evenly Divided.

Notched Wedge

Butt
### Average Joint Densities from PA DOT for Entire Paving Season

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Notched Wedge</strong></td>
<td>91.7%</td>
<td>91.7%</td>
<td>“mostly notched wedge joints”</td>
</tr>
<tr>
<td><strong>Butt (vertical)</strong></td>
<td>90.3%</td>
<td>90.7%</td>
<td></td>
</tr>
</tbody>
</table>
Plan for Longitudinal Joints...
(i.e. Discuss During Pre-Con Meeting)

- Joint Type
- Layout Plan of Final Lift showing joints (DelDOT)
  - Recognize need to offset joints between layers
  - Avoid wheel paths, RPMs, striping (if possible)
- Testing of Joint
  - Type, location, schedule, by whom
- Joint Construction Practices
  - Paving, rolling, materials
- Pave low to high when possible for *shingle effect*
  - Avoids holding rain water at joint by hot side being slightly higher (recommendation later)
Poor planning – joint in wheelpath
First Pass Must Be Straight!

string-line should be used to assure first pass is straight

Stringline for reference, and/or Skip Paint, Guide for following
Tough to get proper overlap (1”) with next pass
Best Way to Roll an Asphalt Joint
So Our Recommendation: Option 1
1st Roller Pass Hangs Over 4-6 inches
Compacting Notched Wedge

- Vibrating wedge
- Wheel compactor
Paint the Side of Joint (Butt or Wedge)

- Emulsion (Good),
- PG Asphalt (Better),
- Or Joint Adhesive (JA) (Best)
J-Band / VRAM
Hot Side Pass Placement
When Closing Joint, Set Paver Automation to Never Starve the Joint of Material

• Target final height difference of +0.1” on hot-side versus cold side
  • NH spec requires 1/8” higher
• Joint Matcher (versus Ski) is best option to ensure placing exact amount of material needed
• If hot-side is starved, roller drum will “bridge” onto cold mat and no further densification occurs at joint
Ski Best for Smoothness
(reference is average over length of ski)

Versus Joint Matcher, which is best for joint  (reference is exact location just in front of auger)
Destined for Failure

Likely that the hot side of joint was starved of material at these locations and bridging occurred.
Proper Overlap:

• 1.0 ± 0.5 inches

• Exception: Milled or sawed joint should be 0.5 inches
All Photos show Bottom of Lift 
(Note voids in top two from no overlap)
Lute the Longitudinal Joint

This lute person is doing a great job
Rolling the Supported Edge

Our Recommendation:

1\textsuperscript{st} pass all on hot mat with roller edge off joint approx 6-12 inches

2\textsuperscript{nd} pass overlaps on cold mat 3-6 inches
Other Options / New Products

- Mill & Pave One Lane at a Time
- Cut Back joint
- Joint Heaters
- Joint Adhesives (hot rubberized asphalt)
- Surface Sealers Over Joint
- Rubber Tire Rollers
- Warm Mix Asphalt
- Intelligent Compaction

Details provided in full workshop
GOAL
14 year old surface

- I-65 in IN: SR252 to US31
  - 12 inches HMA over Rubblized JCP
  - Warranty Project
Discuss the Importance of Tack Coats
Tack Coat’s Role in Compaction

Tack Coat Plays an Important Role in the Compaction Process
Good bond between underlying and the new layer being compacted is critical to “confine” the bottom of the new lift and keep it from sliding during rolling.
Successful Tack Coat

The Ultimate Goal:
Uniform, complete, and adequate coverage
Importance of Tack Coats

• To promote the bond between pavement layers.
  • To prevent slippage between pavement layers.
  • Vital for structural performance of the pavement. (Durability)
  • Resist rutting.
  • Achieve optimum density.
Loss of Fatigue Life Examples

- **May & King:**
  - 10% bond loss = 50% less fatigue life

- **Roffe & Chaignon**
  - No bond = 60% loss of life

- **Brown & Brunton**
  - No Bond = 75% loss of life
  - 30% bond loss = 70% loss of life

![Graph showing relationship between bond loss and loss of fatigue life](image-url)
Consequences of Debonding

Courtesy of NCAT
• **What is the Optimal Application Rate?**
  - Surface Type
  - Surface Condition

• **Recommended Ranges**

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>Residual Rate (gsy)</th>
<th>Appx. Bar Rate Undiluted* (gsy)</th>
<th>Appx. Bar Rate Diluted 1:1* (gsy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Asphalt</td>
<td>0.02 – 0.05</td>
<td>0.03 – 0.07</td>
<td>0.06 – 0.14</td>
</tr>
<tr>
<td>Existing Asphalt</td>
<td>0.04 – 0.07</td>
<td>0.06 – 0.11</td>
<td>0.12 – 0.22</td>
</tr>
<tr>
<td>Milled Surface</td>
<td>0.04 – 0.08</td>
<td>0.06 – 0.12</td>
<td>0.12 – 0.24</td>
</tr>
<tr>
<td>Portland Cement Concrete</td>
<td>0.03 – 0.05</td>
<td>0.05 – 0.08</td>
<td>0.10 – 0.16</td>
</tr>
</tbody>
</table>

*Assume emulsion is 33% water and 67% asphalt.
Additional Resources

http://www.asphaltinstitute.org/tack-coat-information/


http://store.asphaltpavement.org/index.php?productID=786

## NYSDOT - 50 vs. 60 Series

<table>
<thead>
<tr>
<th></th>
<th>50 Series</th>
<th>60 Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specification Type</td>
<td>PWL</td>
<td>Average</td>
</tr>
<tr>
<td>Incentives</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Disincentives</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Acceptance Measurement</td>
<td>Cores</td>
<td>Gauge Readings</td>
</tr>
<tr>
<td>Use</td>
<td>Interstates/Parkways</td>
<td>Non-interstate routes</td>
</tr>
</tbody>
</table>
NYSDOT – 50 vs. 60 series

Average %G

Year

2012 2013 2014 2015

9.5mm - 50 series
9.5mm - 60 series
12.5mm - 50 series
12.5mm - 60 series

98
97
96
95
94
93
92
91
90
89

9.5mm - 50 series
9.5mm - 60 series
12.5mm - 50 series
12.5mm - 60 series
Newer Technologies to Enhance Compaction
Newer Technologies to Enhance Compaction

- Warm Mix Asphalt (WMA)
- SHRP2 Infrared (IR)
- Intelligent Compaction (IC)
Wrap Up
Maximizing Our R.O.I.

• Infrastructure loads continue to rise
• Budget availability continues to fall
• Increased pavement life can be economically achieved
• Research conservatively shows that a 10% increase in pavement life can be achieved by increasing compaction by 1%.

What would a 3% increase in compaction do for our industry?
Reduce Permeability

• Finer aggregate gradations are less permeable
  • May require higher level consensus properties
  • May require higher binder contents

• Design to a **minimum** lift thickness
  • $\geq 3 \times$ NMAS on fine graded mixtures
  • $\geq 4 \times$ NMAS on coarse graded mixtures

• Do not neglect future pavement preservation
Proper Tack Coat Application

- Specify and monitor adequate tack coat application
  - Allow the use of alternate materials
    - Low Tracking tack
    - Modified materials
    - Paving grade binders

A well compacted pavement section will not perform if it is not properly bonded!!
Improve Longitudinal Joints

Permeable Longitudinal Joints will:

• Cause safety concerns
• Necessitate premature maintenance
• Contribute to delamination
• Severely impact the life cycle performance
• Joint density no less than 2% mat density requirement
Specify Increased Compaction

• Shoot for 94% TMD
  • Regularly achieved on airfields throughout the country.

• Use Percent Within Limit specifications
  • A 92% LSL demands 93 – 94% compaction target
  • Use a one sided test – LSL only
  • Consider high side outlier testing

• Assure Density is achieved on the road
  • Consider Cores for acceptance
  • Require adequate gauge calibration
  • Regularly determine $G_{mm}$ on plant produced mix

• Pay for increased compaction – 5% Bonus
Use Best Construction Practices

Uniform Paving Train Operation

• Determine plant production rate
• Plan for sufficient, timed mix delivery
• Establish a constant paver speed
• Assure ample rollers are available
  • Keep water trucks up to the rollers
Use Best Construction Practices

Promote Innovation

- Encourage / require Intelligent Compaction
- Use WMA – compaction aid
- SHRP2 – IR
- Consider alternative rollers
  - Pneumatic
  - Vibratory Pneumatic
  - Oscillatory
  - ?
Bottom Line

Increased compaction = Increased Performance
And a Better R.O.I. for the taxpayers

Thank You for Your Time!!