Verification of Gyration
Levels in the Superpave $N_{\text{design}}$ Table

The compaction effort used in a volumetric mix design should produce laboratory samples which approximate the ultimate density of the pavement.

The goal of this project is to verify the laboratory compaction efforts established in 1999 for the Superpave gyratory compactor.

Original SGC Compaction Effort

<table>
<thead>
<tr>
<th>Design</th>
<th>Average Design High Air Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESAL's (millions)</td>
<td>&lt;39 °C</td>
</tr>
<tr>
<td>N Nini N Ndes N Nmax</td>
<td>N Nini N Ndes N Nmax</td>
</tr>
<tr>
<td>&lt;0.3</td>
<td>7</td>
</tr>
<tr>
<td>0.3 - 1</td>
<td>7.5</td>
</tr>
<tr>
<td>1 - 3</td>
<td>7.5</td>
</tr>
<tr>
<td>3 - 10</td>
<td>8</td>
</tr>
<tr>
<td>10 - 30</td>
<td>8</td>
</tr>
<tr>
<td>30 - 100</td>
<td>9</td>
</tr>
<tr>
<td>&gt;100</td>
<td>9</td>
</tr>
</tbody>
</table>

SGC Compaction Effort 1999

<table>
<thead>
<tr>
<th>ESAL's</th>
<th>N Nini</th>
<th>N Ndes</th>
<th>N Nmax</th>
<th>App</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.3</td>
<td>6</td>
<td>50</td>
<td>75</td>
<td>Light</td>
</tr>
<tr>
<td>0.3 to &lt; 3</td>
<td>7</td>
<td>75</td>
<td>115</td>
<td>Medium</td>
</tr>
<tr>
<td>3 to &lt; 30</td>
<td>8</td>
<td>100</td>
<td>160</td>
<td>High</td>
</tr>
<tr>
<td>10 to &lt;30</td>
<td>8</td>
<td>100</td>
<td>160</td>
<td>High</td>
</tr>
<tr>
<td>≥ 30</td>
<td>9</td>
<td>125</td>
<td>205</td>
<td>Heavy</td>
</tr>
</tbody>
</table>

Thoughts on $N_{\text{design}}$

- Laboratory compaction effort should produce sample density approximately equal to ultimate pavement density.
- Ultimate pavement density believed to be reached after 2-3 years of traffic.
- Typically, select laboratory density of 96% of Theoretical maximum density or 4% air voids.
  - Too little air voids (<2%) results in rutting.
  - Too many air voids tend to cause durability problems.

Acknowledgement

This work was sponsored by NCHRP 9-9 (1) and would not be possible without the cooperation of all of the state agencies which participated.

Base mix (< 100 mm) option to drop one level, unless the mix will be exposed to traffic during construction.
**NCHRP 9-9(1) Field Projects**

Verification of $N_{\text{design}}$ Table

**Experimental Plan**

- Sample 40 pavements at the time of construction with a range of:
  - Lift Thickness to NMAS (2-4)
  - Design Gyration Level (50-125)
  - Binder Grade (Normal to +2 bumps)
  - Gradation (Fine or Coarse)

- Roadway cores taken at construction, 3 months, 6 months, 1 year, and 2 years after construction from right wheel path
- Project extended to monitor projects 4 years after construction
- Goal: predict gyrations to match field density

**Pavement Densification**

![Cumulative Frequency of Construction Densities](chart.png)

- Cumulative Frequency, %
- Percent Maximum Density, %

![Map of Field Project Locations](map.png)

Legend:
- Project Site
Factor Affecting As-Constructed Density

VTRC

Pavement Densification

Factors Affecting 3-Month Densification

Affect of Month of Construction on 2-Year Density

Ultimate Density

Summary of Performance of NCHRP 9-9(1) Projects

- 4-year density less than 2-year density in 15 of 35 cases
- Paired t-test significantly different in 8 cases, 4-year density higher in 6 of 8 cases
- Population t-test significantly different in one case, density lower
- Ultimate density reached after 2-years

- Average rut depth 1.7 mm, one project with 6.4 mm (high traffic unmodified)
- Raveling common
- Overlays over PCC evidence reflective cracking, even when total (new) overlay 3.5 inches or more, most after 2-years
- Joints vary from fair to very good
- Some permeability evidenced by wet spots
Estimation of Density at a Given Gyration Level

\[ \text{Density at Gyration } X = \frac{\text{Density at NDesign} \times \text{Height at NDesign}}{\text{Height at Gyration } X} \]

Dynamic Angle Verification Kit

\[ y = 0.9752x + 2.6026 \quad R^2 = 0.84 \]

\[ y = 1.1005x + 10.837 \quad R^2 = 0.75 \]
**CO Density Study Conclusions**

Aschenbrener and Harmelink, 2002

- Mixes have not reached their design level of compaction after six years.
- Six-year trend indicates they never will.
- Majority of the densification occurred in the first three years.
- Based on data from these 25 sections, the optimal number of gyrations is too high – mixes too stiff for climate and traffic.

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**The Whole Truth – Predicted Gyrations**
Summary of Pavement Densification at 2000 Track

- After initial consolidation/aggregate reorientation, densification only occurred when temperature above 28° C (82 °F)
- Mixes containing modified (PG 76-22) binders densified significantly less than unmodified (PG 67-22) binders (2%)
- Unmodified lower lift shows less densification (0.8%) – future trend unclear

Would NCHRP 9-9(1) relationships improve without PG 76-22?

Proposed Ndesign Levels for an SGC DIA of 1.16 ± 0.02 Degrees

- 20-Year Design Traffic, ESALs
- 2-Year Design Traffic, ESALs
- Ndesign

<table>
<thead>
<tr>
<th>20-Year Design Traffic, ESALs</th>
<th>2-Year Design Traffic, ESALs</th>
<th>Ndesign</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 300,000</td>
<td>&lt; 20,000</td>
<td>50</td>
</tr>
<tr>
<td>300,000 to 3,000,000</td>
<td>20,000 to 200,000</td>
<td>65</td>
</tr>
<tr>
<td>3,000,000 to 10,000,000</td>
<td>200,000 to 675,000</td>
<td>65</td>
</tr>
<tr>
<td>10,000,000 to 30,000,000</td>
<td>675,000 to 2,000,000</td>
<td>80</td>
</tr>
<tr>
<td>&gt; 30,000,000</td>
<td>&gt; 2,000,000</td>
<td>100</td>
</tr>
</tbody>
</table>

Locking Point
**Locking Point**

- Concept developed by Illinois DOT (Bill Pine)
- Plot of Log gyrations vs. density non-linear beyond locking point
- Point where aggregate locks together – additional gyrations degrade aggregate
- Point after which change rule: 25 gyrations = 1% VMA = 0.4 AC% generally true

**Definition of Locking Point**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<tbody>
<tr>
<td></td>
<td>60</td>
<td>111.9</td>
<td>111.9</td>
<td>111.8</td>
<td>111.8</td>
<td>111.7</td>
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<td>111.6</td>
<td>111.6</td>
<td>111.5</td>
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<tr>
<td></td>
<td>70</td>
<td>111.4</td>
<td>111.4</td>
<td>111.3</td>
<td>111.3</td>
<td>111.2</td>
<td>111.2</td>
<td>111.1</td>
<td>111.1</td>
<td>111.0</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>111.0</td>
<td>110.9</td>
<td>110.9</td>
<td>110.8</td>
<td>110.8</td>
<td>110.7</td>
<td>110.7</td>
<td>110.7</td>
<td>110.6</td>
</tr>
</tbody>
</table>

**Pine Locking Point**

110.6

**Troxler Locking Point**

110.7

**y = 0.7201x + 23.883**

**R² = 0.2637**

**y = 0.6905x + 27.214**

**R² = 0.2474**

**Locking Point at 2-1 Density, %**

**As-Constructed Density, %**

<table>
<thead>
<tr>
<th>Pine</th>
<th>Troxler</th>
<th>Linear (Pine)</th>
<th>Linear (Troxler)</th>
</tr>
</thead>
<tbody>
<tr>
<td>93.0</td>
<td>93.0</td>
<td>92.5</td>
<td>92.0</td>
</tr>
<tr>
<td>94.0</td>
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<td>93.0</td>
</tr>
<tr>
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<td>96.0</td>
<td>96.0</td>
<td>95.5</td>
<td>95.0</td>
</tr>
<tr>
<td>97.0</td>
<td>97.0</td>
<td>96.5</td>
<td>96.0</td>
</tr>
</tbody>
</table>

**y = 0.9748x + 3.1728**

**R² = 0.98**

**Troxler Density at 3-2-2 Locking Point**

88.0

**Trove Density at 3-2-2 Locking Point**

93.0

**y = 0.743x + 25.343**

**R² = 0.77**

**Line of Equality**

**y = 0.9748x + 3.1728**

**R² = 0.98**

**y = 0.743x + 25.343**

**R² = 0.77**
Mix Design requires a balance between Rut Resistance and Durability

Typically, we design for Rut Resistance

VMA Comparison

Other Thoughts on Increasing AC%

- In-place density has a large effect on performance
- Lower design air voids
  - If design VMA above minimum VMA contractor may add more dust
- Raise minimum VMA
  - Increase in minimum VMA will increase AC%
  - If minimum VMA increased without changing gyration levels, then mix may be harder to compact
- It’s a system

What Does This Mean for Mix Design?

- Test Track Data Indicates:
  - Modified binders densify less than unmodified binders
  - This may mean that mixes containing modified binders may be designed at lower gyrations or higher asphalt contents to enhance durability

This may be a way to balance rut resistance and durability!

What Effect Would Lower Gyrations Have?

- Increase design asphalt content?
  - Not necessarily
  - Contractors tend to design mixes with lower laboratory compaction efforts with more of a “cushion” between design and minimum VMA
  - Could raise minimum VMA by 0.5%
- Should allow more compactable mixes (in field) and increase AC% slightly

Other Thoughts on Increasing AC%

- In-place density has a large effect on performance
- Lower design air voids
  - If design VMA above minimum VMA contractor may add more dust
- Raise minimum VMA
  - Increase in minimum VMA will increase AC%
  - If minimum VMA increased without changing gyration levels, then mix may be harder to compact
- It’s a system