SUPERPAVE MIX DESIGN
Superpave Gyratory Compaction and Mixture Requirements

• Section objectives
  – Describe the Superpave gyratory compactor
  – Review the Superpave mixture requirements
  – Summarize the moisture sensitivity test

Final Result
Participant will know the principles of the SGC and what mix criteria are included in the Superpave system
Goals of Compaction Method

• Simulate field densification
  – traffic
  – climate
• Accommodate large aggregates
• Measure of compactability
• Conducive to QC
Superpave Gyratory Compactor

• Basis
  – Texas equipment
  – French operational characteristics
• 150 mm diameter
  – Up to 37.5 mm nominal size
• Height recordation
Superpave Mix Design

- Reaction frame
- Tilt bar
- Rotating base
- Height measurement
- Loading ram
- Mold
- Control and data acquisition panel
Superpave Mix Design

ram pressure
600 kPa

150 mm diameter mold

30 gyrations per minute

1.25 degrees (external)
Common SGC Types

- **Troxler**
  - 4140
  - 4141

- **Pine**
  - AFGC125X
  - AFG1A

- **Brovold**
  - HM-293

- **Interlaken**
  - GYR-001

- **Rainhart**
  - 144

Superpave Mix Design
The increase in density (%Gmm) with each gyration is used to graph this compaction curve.
Gyratory Compaction

• We will evaluate the density of the HMA at two points:
  – $N_{\text{initial}}$
  – $N_{\text{design}}$

• These N’s represent numbers of gyrations.
### Current AASHTO $N_{design}$ Table

<table>
<thead>
<tr>
<th>Traffic Level</th>
<th>Compaction Level</th>
<th>$N_{initial}$</th>
<th>$N_{design}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 0.3$</td>
<td></td>
<td>6</td>
<td>50</td>
</tr>
<tr>
<td>$0.3$ to $&lt; 3.0$</td>
<td></td>
<td>7</td>
<td>75</td>
</tr>
<tr>
<td>$3.0$ to $&lt; 30.0$</td>
<td></td>
<td>8</td>
<td>100</td>
</tr>
<tr>
<td>$&gt; 30.0$</td>
<td></td>
<td>9</td>
<td>125</td>
</tr>
</tbody>
</table>

Some States use different $N_{design}$ Tables
Gyratory Compaction

• The density \((G_{mb})@N_{design}\) is the most important. This is where we will calculate the volumetric properties.

• \(N_{initial} \) and \(N_{design}\) are points at which we use to check the compactability and densification of the HMA.
Four Steps for Superpave Mix Design

1. Materials Selection
2. Design Aggregate Structure
3. Design Binder Content
4. Moisture Sensitivity
Example Project Data-

- Project on I-43
- Milwaukee, Wisconsin
- 18,000,000 ESAL Design
- Asphalt Overlay - 88 mm total thickness
  - 38 mm - wearing course (12.5 mm NMAS)
  - 50 mm - intermediate course (19 mm NMAS)
4 Steps of Superpave Mix Design

1. Materials Selection
2. Design Aggregate Structure
3. Design Binder Content
4. Moisture Sensitivity

Superpave Mix Design
Step 1. Materials Selection

• Binder Selection
  – Binder grade is specified in nearly all cases
  – Selecting the supplier of the binder is most often based on cost.

• Aggregates Selection
  – Choice of aggregates is usually limited to locally available materials
Project Weather Conditions

Pavement Temperature (°C), Milwaukee, Wisc.

Superpave Mix Design
Asphalt Binder Grades
Milwaukee, Wisc.
Climate Based Selection

Pavement Temperature (°C), Milwaukee, Wisc
Binder Selection
Milwaukee, Wisc

PG 52-28  PG 58-34

Reliability(%)  50  74.5  99.9  99.6

Selected PG 58-34
Temp-Vis Relationship

PG 58-34 Binder

Mix Temp Range: 165-172°C
Comp Temp Range: 151-157°C

Viscosity, Pa-s vs Temperature, C

Mixing Range
Compaction Range
Select Aggregates

Available Stockpiles

• #1 stone
• 12.5 mm chip
• 9.5 mm chip
• Manufactured sand
• Screen sand
Aggregate Properties
## Coarse Aggregate Angularity

### Test Results

<table>
<thead>
<tr>
<th>Aggr.</th>
<th>1+ Frac Faces</th>
<th>Crit.</th>
<th>2+ Frac Faces</th>
<th>Crit.</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Stone</td>
<td>92%</td>
<td></td>
<td>88%</td>
<td></td>
</tr>
<tr>
<td>12.5 mm Chip</td>
<td>97%</td>
<td>95% min</td>
<td>94%</td>
<td>90% min</td>
</tr>
<tr>
<td>9.5 mm Chip</td>
<td>99%</td>
<td></td>
<td>95%</td>
<td></td>
</tr>
</tbody>
</table>
## Fine Aggregate Angularity

### Test Results

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>% Air Voids</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufactured Sand</td>
<td>52%</td>
<td>45% min</td>
</tr>
<tr>
<td>Screen Sand</td>
<td>40%</td>
<td></td>
</tr>
</tbody>
</table>
# Flat & Elongated Particles

## Test Results

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>% Flat &amp; Elongated</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Stone</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>12.5mm Chip</td>
<td>0%</td>
<td>10% max.</td>
</tr>
<tr>
<td>9.5mm Chip</td>
<td>0%</td>
<td></td>
</tr>
</tbody>
</table>
# Sand Equivalent

## Test Results

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Sand Equivalent</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufactured Sand</td>
<td>47</td>
<td>45 min</td>
</tr>
<tr>
<td>Screen Sand</td>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>

Superpave Mix Design
4 Steps of Superpave Mix Design

1. Materials Selection

2. Design Aggregate Structure

3. Design Binder Content

4. Moisture Sensitivity

TSR
Selection of Design Aggregate Structure

- Establish trial blends
- Check aggregate consensus properties
- Compact specimens
- Evaluate trial blends
- Select design aggregate structure
Gradation

Percent Passing

max density line

control point

nom max size

max size

0.075 0.3 2.36 4.75 9.5 12.5 19.0

Sieve Size, mm (raised to 0.45 power)

Superpave Mix Design 28
IH-43 Trial Gradations
19.0 mm Nominal Mixture

Sieve Size (mm) raised to 0.45 power

% PASSING

0.075 2.36 19.0

Trial Blend 1

Trial Blend 2

Trial Blend 3

Sieve Size (mm) raised to 0.45 power
# Example Trial Blends

<table>
<thead>
<tr>
<th></th>
<th>Trail Blend 1</th>
<th>Trail Blend 2</th>
<th>Trail Blend 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Stone</td>
<td>25</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>½” Chip</td>
<td>15</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>3/8” Chip</td>
<td>22</td>
<td>13</td>
<td>30</td>
</tr>
<tr>
<td>Mfg Sand</td>
<td>18</td>
<td>17</td>
<td>31</td>
</tr>
<tr>
<td>Scr. Sand</td>
<td>20</td>
<td>15</td>
<td>14</td>
</tr>
</tbody>
</table>
• Blended aggregate properties are determined

<table>
<thead>
<tr>
<th>Property</th>
<th>Criteria</th>
<th>Blend 1</th>
<th>Blend 2</th>
<th>Blend 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Ang.</td>
<td>95%/90% min.</td>
<td>96%/92%</td>
<td>95%/92%</td>
<td>97%/93%</td>
</tr>
<tr>
<td>Fine Ang.</td>
<td>45% min.</td>
<td>46%</td>
<td>46%</td>
<td>48%</td>
</tr>
<tr>
<td>Flat/Elongated</td>
<td>10% max.</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Sand Equiv.</td>
<td>45 min.</td>
<td>59</td>
<td>58</td>
<td>54</td>
</tr>
<tr>
<td>Combined $G_{sb}$</td>
<td>n/a</td>
<td>2.699</td>
<td>2.697</td>
<td>2.701</td>
</tr>
<tr>
<td>Combined $G_{sa}$</td>
<td>n/a</td>
<td>2.768</td>
<td>2.769</td>
<td>2.767</td>
</tr>
</tbody>
</table>
Compact Specimens (Trial Blends)

- Establish trial asphalt binder content
- Establish trial aggregate weight
- Batch, mix, and compact specimens
- Determine $N_{ini}$ and $N_{des}$
- Determine mixture properties
Specimen Preparation

- Specimen height
  - Mix design - 115 mm (4700 g)
  - Moisture sensitivity - 95 mm (3500 g)
- Loose specimen for $G_{mm}$ (Rice)
  - Sample size varies with NMAS
    - 19 mm (2000 g)
    - 12.5 mm (1500 g)
Batching Samples of Trial Blends
Superpave Mix Design
Short Term Aging

Two hours at the compaction temperature

Superpave Mix Design
Superpave Mix Design
Superpave Mix Design
Measure $G_{mb}$, $G_{mm}$ and calculate volumetric properties.
Superpave Mixture Requirements

- Specimen height
- Mixture volumetrics
  - Air voids
  - Voids in the mineral aggregate (VMA)
  - Voids filled with asphalt (VFA)
- Dust proportion
- %Gmm @ N_{ini}
# Trial Blend Results

<table>
<thead>
<tr>
<th>Property</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial Binder Content</td>
<td>4.4%</td>
<td>4.4%</td>
<td>4.4%</td>
</tr>
<tr>
<td>%G_{mm} @ N_{des}</td>
<td>96.2%</td>
<td>95.7%</td>
<td>95.2%</td>
</tr>
<tr>
<td>%G_{mm} @ N_{ini}</td>
<td>87.1%</td>
<td>85.6%</td>
<td>86.3%</td>
</tr>
<tr>
<td>%Air Voids</td>
<td>3.8%</td>
<td>4.3%</td>
<td>4.8%</td>
</tr>
<tr>
<td>%VMA</td>
<td>12.7%</td>
<td>13.0%</td>
<td>13.5%</td>
</tr>
<tr>
<td>%VFA</td>
<td>68.5%</td>
<td>69.2%</td>
<td>70.1%</td>
</tr>
<tr>
<td>Dust Proportion</td>
<td>0.9</td>
<td>0.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Estimated Volumetric at 4% AV

\[ P_{be} = P_{bi} - 0.4 \times (4-V_a) \]

- \( P_{be} \): estimated design asphalt content
- \( P_{bi} \): asphalt content used in trial blends

\[ VMA_e = VMA_i + C \times (4-V_a) \]

- \( VMA_e \): estimated VMA at design asphalt content
- \( VMA_i \): initial VMA of trial blend
- \( C \): constant: 0.1 when air voids < 4% and 0.2 when air voids > 4%
### Volumetric Design Criteria

<table>
<thead>
<tr>
<th>Traffic ESAL</th>
<th>SGC Criteria</th>
<th>VMA</th>
<th>VFA</th>
<th>Dust Binder</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.3</td>
<td>N&lt;sub&gt;ini&lt;/sub&gt; ≤ 91.5</td>
<td>N&lt;sub&gt;des&lt;/sub&gt; = 96.0</td>
<td>see slide 53</td>
<td>70-80</td>
</tr>
<tr>
<td>&lt; 3</td>
<td>≤ 90.5</td>
<td>= 96.0</td>
<td>65-78</td>
<td>65-75</td>
</tr>
<tr>
<td>&gt; 3</td>
<td>≤ 89.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Compare Trial Blends to Mixture Criteria

<table>
<thead>
<tr>
<th>Blend</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder Content</td>
<td>4.3%</td>
<td>4.5%</td>
<td>4.7%</td>
<td></td>
</tr>
<tr>
<td>%G_{mm} \text{ at } N_{ini}</td>
<td>86.9%</td>
<td>85.9%</td>
<td>87.1%</td>
<td>&lt; 89%</td>
</tr>
<tr>
<td>%Air Voids</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>%VMA</td>
<td>12.7%</td>
<td>13.0%</td>
<td>13.3%</td>
<td>≥ 13.0%</td>
</tr>
<tr>
<td>%VFA</td>
<td>68.5%</td>
<td>69.2%</td>
<td>70.1%</td>
<td>65-75%</td>
</tr>
<tr>
<td>Dust Proportion</td>
<td>0.9</td>
<td>0.8</td>
<td>0.9</td>
<td>0.6-1.2</td>
</tr>
</tbody>
</table>
Select Design Aggregate Structure

What to do if none of the 3 trial blends are acceptable?

- Recombine aggregates to form further trial blends (i.e., Blend 4, Blend 5, etc.)

- Obtain new materials (aggregates, asphalt binder, modifiers)
4 Steps of Superpave Mix Design

1. Materials Selection
2. Design Aggregate Structure
3. Design Binder Content
4. Moisture Sensitivity

Superpave Mix Design
Determining the Design Asphalt Content

• The selected trial blend becomes the design aggregate structure.

• Batch, mix, and compact more samples with this gradation with four asphalt contents.

• Determine volumetric properties

• Select $P_b$ at 4.0% air voids and check other volumetric properties.
Superpave Mix Design
### Design Binder Content Samples

<table>
<thead>
<tr>
<th>Binder Content</th>
<th>4.2%</th>
<th>4.7%</th>
<th>5.2%</th>
<th>5.7%</th>
</tr>
</thead>
<tbody>
<tr>
<td>%G_{mm} @ N_{ini}</td>
<td>85.7%</td>
<td>87.1%</td>
<td>87.4%</td>
<td>88.6%</td>
</tr>
<tr>
<td>%G_{mm} @ N_{des}</td>
<td>94.6%</td>
<td>96.1%</td>
<td>97.1%</td>
<td>98.2%</td>
</tr>
<tr>
<td>%Air Voids</td>
<td>5.4%</td>
<td>3.9%</td>
<td>2.9%</td>
<td>1.8%</td>
</tr>
<tr>
<td>%VMA</td>
<td>13.3%</td>
<td>13.1%</td>
<td>13.3%</td>
<td>13.5%</td>
</tr>
<tr>
<td>%VFA</td>
<td>59.4%</td>
<td>70.2%</td>
<td>78.2%</td>
<td>86.7%</td>
</tr>
<tr>
<td>Dust Proportion</td>
<td>1.0</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Densification Curves

I-43, 19.0 mm NMAS, Blend 3

% MAX THEORETICAL DENSITY

NUMBER OF GYRATIONS

4.2% AC
4.7% AC
5.2% AC
5.7% AC
Mix Air Voids Requirement

4% at $N_{des}$ Regardless of the Traffic Level
Air Voids - Example Mix Design

I-43 Binder Course, Blend 3

Air Voids = 4%
Mix VMA Requirements
Voids in the Mineral Aggregate

<table>
<thead>
<tr>
<th>NMAS, mm</th>
<th>Minimum VMA, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>15.0</td>
</tr>
<tr>
<td>12.5</td>
<td>14.0</td>
</tr>
<tr>
<td>19.0</td>
<td>13.0</td>
</tr>
<tr>
<td>25.0</td>
<td>12.0</td>
</tr>
<tr>
<td>37.5</td>
<td>11.0</td>
</tr>
</tbody>
</table>
VMA – Example Mix Design

I-43 Binder Course, Blend 3

VMA = 13.2%

% ASPHALT BINDER

Superpave Mix Design
Mix VFA Requirements
Voids Filled with Asphalt

<table>
<thead>
<tr>
<th>Traffic 10^6 ESALs</th>
<th>Range of VFA, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.3</td>
<td>70 - 80</td>
</tr>
<tr>
<td>&lt; 1</td>
<td>65 - 78</td>
</tr>
<tr>
<td>&lt; 3</td>
<td>65 - 75</td>
</tr>
<tr>
<td>&gt; 3</td>
<td>65 - 75</td>
</tr>
</tbody>
</table>

Superpave Mix Design
VFA – Example Mix Design

I-43 Binder Course, Blend 3

VFA = 70%
Mix Requirement for Dust Proportion

\[
0.6 \leq \frac{\% \text{ weight of } -0.075 \text{ material}}{\% \text{ weight of effective asphalt}} \leq 1.2
\]

Unabsorbed binder in mix
Dust Proportion – Example Mix Design

I-43 Binder Course, Blend 3

DP = 0.9

% ASPHALT BINDER

Superpave Mix Design
\%G_{mm} @ N_{ini}

I-43 Binder Course, Blend 3

\%G_{mm} @ N_{ini} = 87.1\%
**Select Design Asphalt Binder Content**

Summary of Mixture Properties @ 4.7% AC

<table>
<thead>
<tr>
<th>Property</th>
<th>Result</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Air Voids</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>%VMA</td>
<td>13.2%</td>
<td>&gt;13.0%</td>
</tr>
<tr>
<td>%VFA</td>
<td>70%</td>
<td>65-75%</td>
</tr>
<tr>
<td>D/A Ratio</td>
<td>0.9</td>
<td>0.6-1.2</td>
</tr>
<tr>
<td>$%G_{mm} @ N_{ini}$</td>
<td>87.1%</td>
<td>&lt;89%</td>
</tr>
</tbody>
</table>
4 Steps of Superpave Mix Design

1. Materials Selection
2. Design Aggregate Structure
3. Design Binder Content
4. Moisture Sensitivity

Superpave Mix Design
Moisture Sensitivity
AASHTO T 283

- Measured on proposed aggregate blend and asphalt content

![Diagram showing 3 conditioned specimens and 3 dry specimens with a tensile strength ratio of 80% minimum.]

Superpave Mix Design
AASHTO T 283 Conditioning

• Short term aging
  – Loose mix 16 hrs @ 60°C
  – Comp mix 72-96 hrs @ 25°C

• Two subsets with equal voids
  – One “dry”
  – One saturated
AASHTO T 283 Conditioning

• Optional freeze cycle

• Hot water soak
AASHTO T 283 Test Procedure

51 mm/min @ 25 °C

Avg **Dry** Tensile Strength  Avg **Wet** Tensile Strength

\[
\text{Wet} \quad \text{TSR} = \frac{\text{Wet}}{\text{Dry}} \quad \geq 80 \% 
\]
Calculate %TSR

\[
\%TSR = 100 \times \frac{\text{Wet Strength}}{\text{Dry Strength}}
\]

\[
= 100 \times \frac{721 \text{ kPa}}{872 \text{ kPa}} = 82.6\%
\]

Criterion is 80% minimum. Design asphalt mixture exceeds the minimum requirement.
Design Asphalt Mixture

- **Aggregate:**
  - 10% #1 Stone
  - 15% 12.5mm Chip
  - 30% 9.5mm Chip
  - 31% Manuf. Sand
  - 14% Screen Sand

- **Asphalt Binder:**
  - 4.7% PG 58-34

- **Aggregate Gradation:**
  - 25 mm 100%
  - 19.0 mm 97%
  - 12.5 mm 89%
  - 9.5 mm 77%
  - 4.75 mm 44%
  - 2.36 mm 32%
  - 1.18 mm 22%
  - 0.6 mm 15%
  - 0.3 mm 8%
  - 0.15 mm 4%
  - 0.075 mm 3.5%
Questions – does it all make sense?