This Workshop & Workbook developed by

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The focus of this workshop is to provide a detailed example of Superpave *volumetric* asphalt mixture design.
Superpave Overview

- The final product of the SHRP asphalt program area is Superpave. Superpave is an acronym which stands for:

Superior Performing Asphalt Pavements
Major Steps in Superpave

- Selection of Materials,
- Selection of a Design Aggregate Structure,
- Selection of the Design Binder Content, and
- Evaluation of Moisture Sensitivity of the Design Mixture.
Criteria

- Environment,
- Traffic level & speed, and
- Pavement structure.
SIMULATION BACKGROUND

- Location: Hot Mix, USA
- Estimated, 20-year, design traffic is 6,300,000 ESAL’s
- Posted traffic speed is 80 kph (50 mph)
  - Estimated, ave speed is 72 kph (45 mph)
- 19.0 mm Surface Course
  - Such that the top of the pavement layer from the surface is less than 100 mm.
Update:

- All Superpave mixes are designed volumetrically.

- Currently under NCHRP study 9-19, “Superpave Models Development,” being conducted under the direction of Dr. Matt Witczak, a simple performance test is being identified/developed.
A simple performance test

- Superpave mix design is volumetrically based.
  - Does not include a “strength test”

  - Dr. Matt Witczak (Arizona State University)
  - Dr. Ed Harrigan (NCHRP)
  - http://www2.nas.edu/trbcrp/
A simple performance test

- **Objective:**
- To evaluate and recommend a fundamentally based, but simple, performance test(s) in support of the Superpave volumetric mix design procedure.

Spring 2000
A simple performance test

- Flow Time
- E*, G*
Selection of Materials

Performance Grade Binder
Mineral Aggregate
Modifiers / Additives
Selection of Materials

- The PG binder required for the project is based on environmental data, traffic level, and traffic speed.

- The SHRP researchers developed algorithms to convert high and low air temperatures to pavement temperatures.
SHRP Temperature Models

- $T_{(pav)} = (T_{(air)} - 0.00618 \text{ Lat}^2 + 0.2289 \text{ Lat} + 42.4) \times 0.9545 - 17.78$
  - where $T_{(pav)}$ is the high pavement temp at 20 mm below the surface, °C

- $T_{(d)} = T_{(air)} + 0.051 \ d -0.000063 \ d^2$
  - where $T_{(d)}$ is low pavement temp at a depth, d, in mm, °C
The original SHRP low temp algorithm do not correctly determine the low-pavement-temperature. The FHWA LTPP program has developed a new algorithm based on over 30 weather stations from across North America.

The Binder ETG feels the new LTPP algorithm is far more accurate and should be used in all AASHTO documents.
LTPP Temperature Models

- High, $T_{(pav)} = 54.32 + 0.78 \ T_{(air)} - 0.0025 \text{Lat}^2$
  - $-15.14 \log_{10}(H+25) + z(9 + 0.61 \sigma_{air}^2)^{1/2}$

- Low, $T_{(pav)} = -1.56 + 0.72 \ T_{(air)} - 0.004$ \text{Lat}^2
  - $+6.26 \log_{10}(H+25)$
  - $-z (4.4 + 0.52 \sigma_{air}^2)^{1/2}$

- with Reliability
Reliability

- A factor of safety can be incorporated into the performance grading system based on temperature reliability. The 50 % reliability temperatures represent the straight average of the weather data. The 98 % reliability temperatures are determined based on the standard deviations of the low ($\sigma_{\text{Low Temp}}$) and high ($\sigma_{\text{High Temp}}$) temperature data.
Reliability

Hot Mix, USA
High Temp, $\sigma = 2^\circ C$

$50\% \ 84 \ 97.5 \ 99.9$

$52^\circ C \ 54^\circ \ 56^\circ \ 58^\circ$

Average
Reliability

- \( T_{\text{max at 98%}} = T_{\text{max at 50%}} + 2 \times \sigma_{\text{High Temp}} \)
- \( T_{\text{min at 98%}} = T_{\text{min at 50%}} - 2 \times \sigma_{\text{Low Temp}} \)
PG “Grade Bumping”

- Traffic level and speed are also considered in selecting the project PG binder either through reliability or “grade bumping.” A table is provided in AASHTO MP-2 to provide guidance on grade selection.

- This table was developed by the Superpave Lead States.
## Grade Bumping

<table>
<thead>
<tr>
<th>Traffic ESAL’s</th>
<th>Adjustment to Binder PG Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standing</td>
</tr>
<tr>
<td>&lt; 0.3</td>
<td>-</td>
</tr>
<tr>
<td>0.3 to &lt; 3</td>
<td>2</td>
</tr>
<tr>
<td>3 to &lt; 10</td>
<td>2</td>
</tr>
<tr>
<td>10 to &lt; 30</td>
<td>2</td>
</tr>
<tr>
<td>≥ 30</td>
<td>2</td>
</tr>
</tbody>
</table>
Author’s Note

- Use either reliability or the table to address high traffic levels and slower speeds. Both methods can effectively “bump” the PG grade such that the appropriate binder is used.

- However, using them together will result in an unnecessarily stiff binder, which may cause problems during production and lay down.
### PG grade Increments

<table>
<thead>
<tr>
<th>Average 7-day Maximum Pavement Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average 1-day Minimum Pavement Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2</td>
</tr>
</tbody>
</table>
Hot Mix, USA
Project Location & Historical Temperature Data

A. Latitude is 41.1 degrees,
B. 7-day ave. max. air temp. is 33.0°C with a σ of 2°C, and
C. 1-day ave. min. air temp. is -21.0°C with a σ of 3°C.

- **SHRP Algorithms**
  - High Pvmt 53.2°C
  - Low Pvmt -21.0°C
  - PG 58-22 at 50%
  - PG 58-28 at 98%

- **LTPP Algorithms**
  - High Pvmt 50.8°C
  - Low Pvmt -14.7°C
  - PG 52-16 at 50%
  - PG 58-22 at 98%
PG Selection

- For Hot Mix, USA, the 50 % reliability LTPP performance grade is a PG 52-16.
- The project traffic level and speed do not require grade bumping.
- However, the traffic speed is just above the threshold for grade bumping, and
- Historically in this area pavements have shown susceptibility to low-temperature cracking.
PG Selection

- Such that, the agency shall require a

- PG 58-22.
Performance Grade (PG) Binders
AASHTO MP-1

- Construct-ability check
  - Pump-ability
- Rutting check
- Fatigue cracking check
- Low-temp cracking check
## Binder Selection, PG 58-22

<table>
<thead>
<tr>
<th>Test</th>
<th>Temperature</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unaged</strong></td>
<td>Original</td>
<td></td>
</tr>
<tr>
<td>Flash Point</td>
<td>230°C min</td>
<td>Safety</td>
</tr>
<tr>
<td>Rotational Viscosity</td>
<td>135°C</td>
<td>Pump-ability</td>
</tr>
<tr>
<td>Dynamic Shear</td>
<td>PG High Temp</td>
<td>Rutting</td>
</tr>
<tr>
<td><strong>Aged</strong></td>
<td>R.T.F.O.</td>
<td>After Construction</td>
</tr>
<tr>
<td>Mass Loss</td>
<td>PG High Temp</td>
<td>Age Susceptibility</td>
</tr>
<tr>
<td>Dynamic Shear</td>
<td></td>
<td>Rutting</td>
</tr>
<tr>
<td><strong>Aged</strong></td>
<td>P.A.V</td>
<td>5 to 7 years</td>
</tr>
<tr>
<td>Dynamic Shear</td>
<td>Intermediate Temp</td>
<td>Fatigue Cracking</td>
</tr>
<tr>
<td>Creep Stiffness, BBR</td>
<td>PG Low Temp + 10</td>
<td>Low Temp Cracking</td>
</tr>
</tbody>
</table>
Q. Will a modified binder be required to satisfy this PG grade?
Typically, if the difference between the high and low temperatures is less than 90°C, modification is not required!
The Superpave low temp binder spec has been revised using a new scheme to determine the critical thermal cracking temperature.

The new scheme unites the rheological properties obtained using the BBR and the failure properties acquired the DTT.
PG Binders, AASHTO MP1(*)

- Low-temp cracking check
- Bending Beam Rheometer
- Direct Tension Test
Role of DTT and BBR

Thermal stress curve (dotted line) is computed from BBR data. Failure strength is measured using the DTT. Where they meet, determines critical cracking temperature, \( T_c \).
Reserve Strength for Low and High m-value

Role of S and m-value......

Binder with low m-value has less reserve strength than high m-value binder and thus has less resistance to thermal fatigue.
Binder tests required for design

- Rotational Viscosity
  - SHRP adopted the Asphalt Institutes guidelines based on the temperature-viscosity relationship
  - Mixing Temperature: 150 to 190 centiStokes, cSt
  - Compaction Temperature: 250 to 310 cSt
Question?

What is a centiStoke?
centi - metric prefix for 1/100
Stoke - great physicist from the 18 century, so...

A centiStoke is square centimeter per second or one hundredth of a great dead dude.
centiStoke is the unit of measurement for kinematic viscosity. Gravity induces the flow in this viscosity measurement and the density of the material effects the rate of flow. centiPoise is the unit of absolute viscosity measure. A partial vacuum or rotational viscometer is used where gravity effects are negligible.
Project Binder, PG 58-22

- $G_b = 1.030$
- Viscosity at 135°C = 364 cP = 0.364 Pa-s
- Viscosity at 160°C = 100 cP = 0.100 Pa-s
Question?

What are the mixing and compaction temperatures?
Answer.

First the temperature correction factors for $G_b$ are calculated at the test temperatures:

- $CF_{135^\circ C} = -.0006(135^\circ C) + 1.0135 = 0.933$
- $CF_{160^\circ C} = -.0006(160^\circ C) + 1.0135 = 0.918$

Then the test results are then converted from Pascal-seconds to centiStokes.
Temperature-Viscosity Chart

Log-Log of Viscosity in centiStokes

Log of Absolute Temperature, shown in °K (273 + °C)

- Blue: Compaction
- Green: Mixing
- Green: Range
- Red Diamond: PG 58-22

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Summary of Binder Mix Testing

- **Mixing Temperature Range**
  - 148°C to 152°C

- **Compaction Temperature Range**
  - 138°C to 142°C
Notes on Equiviscous Temperatures

- This relationship **does not** work for all modified asphalt binders.

- The conversion from centipoise to centiStokes is important, however it is not required. Determining mixing and compaction temperatures using centipoise will only effect the results by 1 to 2°C.
Selection of Materials

Performance Grade Binder
Mineral Aggregate
Modifiers / Additives
Superpave utilizes a completely new system for testing, specifying, and selecting asphalt binders. While no new aggregate tests were developed, current methods of selecting and specifying aggregates were refined and incorporated.
Aggregate Selection

- The $G_{sb}$ (bulk) and $G_{sa}$ (apparent) are determined for each aggregate. The specific gravities are used in trial binder content and VMA calculations.

<table>
<thead>
<tr>
<th>Stockpiles</th>
<th>Gsb</th>
<th>Gsa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>2.567</td>
<td>2.680</td>
</tr>
<tr>
<td>Intermediate</td>
<td>2.587</td>
<td>2.724</td>
</tr>
<tr>
<td>Man. Fines</td>
<td>2.501</td>
<td>2.650</td>
</tr>
<tr>
<td>Natural Fines</td>
<td>2.598</td>
<td>2.673</td>
</tr>
</tbody>
</table>
Specific Gravity Tests for Aggregates

- Two tests are needed
  - Coarse aggregate
    (retained on the 4.75 mm sieve)
  - Fine aggregate
    (passing the 4.75 mm sieve)
Coarse Aggregate Specific Gravity

- ASTM C127
  - Dry aggregate
  - Soak in water for 24 hours
  - Decant water
  - Use pre-dampened towel to get SSD
  - Determine mass of SSD agg in bucket
  - Determine mass under water
  - Dry to constant mass
  - Determine oven dry mass
Coarse Aggregate Specific Gravity
Coarse Aggregate Specific Gravity
Coarse Aggregate Specific Gravity Calculations

- $G_{sb} = \frac{A}{(B - C)}$
  - $A =$ mass oven dry
  - $B =$ mass SSD
  - $C =$ mass under water

- $G_{s,SSD} = \frac{B}{(B - C)}$

- $G_{sa} = \frac{A}{(A - C)}$

- Water absorption capacity, %
  - Absorption % = \left[\frac{(B - A)}{A}\right] \times 100
Fine Aggregate Specific Gravity

- ASTM C128
  - Dry aggregate
  - Soak in water for 24 hours
  - Spread out and dry to SSD
  - Add 500 g of SSD agg to pyc of known volume
    - Pre-filled with some water
  - Add more water, agitate until air bubble are removed
  - Fill to line, determine the mass of the pycnometer, aggregate and water
  - Empty aggregate into pan and dry to constant mass
  - Determine oven dry mass
Fine Aggregate Specific Gravity
Fine Aggregate Specific Gravity
Fine Aggregate Specific Gravity
Fine Aggregate Specific Gravity Calculations

- \( G_{sb} = \frac{A}{(B + S - C)} \)
  - \( A \) = mass oven dry
  - \( B \) = mass of pycnometer filled with water
  - \( C \) = mass pycnometer, SSD agg and water
  - \( S \) = mass SSD aggregate

- \( G_{s,SSD} = \frac{S}{(B + S - C)} \)

- \( G_{sa} = \frac{A}{(B + A - C)} \)

- Water absorption capacity, %
  - Absorption % = \( \frac{[(S - A) / A] \times 100}{1} \)
Consensus Property Standards

- Coarse Aggregate Angularity
  - ASTM D 5821

- Fine Aggregate Angularity
  - AASHTO T 304-96

- Flat & Elongated Particles
  - ASTM D 4791

- Sand Equivalent
  - AASTHO T 176
Source Property Standards

Set by Specifying Agency (DOT)

- LA Abrasion
  - AASHTO T 96
- Soundness
  - AASHTO T 104
- Clay Lumps & Friable Particles
  - AASHTO T 112
Author’s Note

- An aggregate which does not individually comply with the criteria is not eliminated from the aggregate blend.

- However, its percentage of use in the total aggregate blend is limited.
Coarse Aggregate Angularity, CAA

- What is a fractured face?
- ASTM D5821, Percentage of Fractured Particles in Coarse Aggregates

- FRACTURED FACES - “A face will be considered a ‘fractured face’ only if it has a projected area at least as large as one quarter of the maximum projected area (maximum cross-sectional area) of the particle and the face has sharp and well defined edges.”
Coarse Aggregate Angularity, CAA

...and the face has sharp and well defined edges.”
Coarse Aggregate Angularity, CAA

0% Crushed 100% with 2 or More Crushed Faces
Coarse Aggregate Angularity, CAA

<table>
<thead>
<tr>
<th>Traffic ESALs</th>
<th>Depth from Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 to &lt; 10</td>
<td>&lt; 100 mm</td>
</tr>
<tr>
<td></td>
<td>&gt; 100 mm</td>
</tr>
<tr>
<td></td>
<td>85/80</td>
</tr>
<tr>
<td></td>
<td>60/ -</td>
</tr>
<tr>
<td>85% one fractured face</td>
<td>Minimum</td>
</tr>
<tr>
<td>80% two+ fractured faces</td>
<td></td>
</tr>
</tbody>
</table>
Coarse Aggregate Angularity

- Increase Resistance to:
  - Rutting
  - Fatigue Cracking
  - Low-temperature Cracking

- Effect:
  - Production
  - Lay-down
Fine Aggregate

Angularity

Natural sands: typically < 45
Manufactured sands: typically > 42
Fine Aggregate Angularity, FAA

uncompacted voids = \( \frac{V - \frac{M}{G_{sb}}}{V} \times 100\% \)
Fine Aggregate Angularity, FAA

Uncompacted Voids, \( U = \left( \frac{V - W}{G_{sb}} \right) \times 100 \)}
Fine Aggregate Angularity, FAA

- Increase Resistance to:
  - Rutting
  - Fatigue Cracking
  - Low-temperature Cracking

- Effect:
  - Production
  - Lay-down
Flat & Elongated Particles, F&E

- Superpave uses a single measurement be made for flat/elongated particles.

- The 5:1 ratio refers simply to the maximum to minimum dimension.
Flat & Elongated Particles, F&E
Flat & Elongated Particles, F&E

- Increase Resistance to:
  - Rutting
  - Fatigue Cracking
  - Low-temperature Cracking

- Effect:
  - Production
  - Lay-down
Sand Equivalent, SE

- Clay content is the percentage of clay material contained in the aggregate fraction that is finer than a 4.75 mm sieve.

- \[ SE = 100 \times \frac{SR}{CR} \]
Bottle of Solution on Shelf Above Top of Cylinder

Hose and Irrigation Tube

Measurement Rod
Sand Equivalent, SE

- Increase Resistance to:
  - Rutting
  - Fatigue Cracking
  - Low-temperature Cracking

- Effect:
  - Production
  - Lay-down
Lead States

- A consolidated table has been developed for the consensus property standards criteria.

- This new table has 5 traffic levels; to correspond to the new SGC compaction criteria.
### 1999 Consensus Criteria

<table>
<thead>
<tr>
<th>ESAL</th>
<th>CAA</th>
<th>FAA</th>
<th>SE</th>
<th>F&amp;E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\leq 100)</td>
<td>(&gt; 100)</td>
<td>(\leq 100)</td>
<td>(&gt; 100)</td>
</tr>
<tr>
<td>(&lt; 0.3)</td>
<td>55/-</td>
<td>-/-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.3 to &lt; 3</td>
<td>75/-</td>
<td>50/-</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>3 to &lt; 10</td>
<td>85/80</td>
<td>60/-</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>10 to &lt; 30</td>
<td>95/90</td>
<td>80/75</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>(\geq 30)</td>
<td>100</td>
<td>100</td>
<td>45</td>
<td>45</td>
</tr>
</tbody>
</table>
Hot Mix, USA: CAA

<table>
<thead>
<tr>
<th>Stockpile</th>
<th>Results</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>99 / 97</td>
<td>85 / 80</td>
</tr>
<tr>
<td>Intermediate</td>
<td>80 / 60</td>
<td>85 / 80</td>
</tr>
</tbody>
</table>

Q. Do the stockpiles meet the criteria, Y/N? If the answer is “no,” what does this mean?

(a) Stockpile can not be used, or
(b) Percentage of stockpile in blend is limited.
# Hot Mix, USA: FAA

<table>
<thead>
<tr>
<th>Stockpile</th>
<th>Results</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man. Fines</td>
<td>48</td>
<td>45</td>
</tr>
<tr>
<td>Natural Fines</td>
<td>42</td>
<td>45</td>
</tr>
</tbody>
</table>

**Q.** Do the stockpiles meet the criteria, Y/N? If the answer is “no,” what does this mean?

(a) Stockpile can not be used, or  
(b) Percentage of stockpile in blend is limited.
Author’s Note

- Fine aggregates with higher fine aggregate angularity may aid in the development of higher voids in mineral aggregate (VMA).
### Hot Mix, USA: F&E

<table>
<thead>
<tr>
<th>Stockpile</th>
<th>Results</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>9</td>
<td>?</td>
</tr>
<tr>
<td>Intermediate</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

**Q.** Do the stockpiles meet the criteria, Y/N? If the answer is “no,” what does this mean?

(a) Stockpile can not be used, or  
(b) Percentage of stockpile in blend is limited.
#### Hot Mix, USA: SE

<table>
<thead>
<tr>
<th>Stockpile</th>
<th>Results</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermed Agg</td>
<td>45</td>
<td>?</td>
</tr>
<tr>
<td>Man. Fines</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>Natural Fines</td>
<td>39</td>
<td></td>
</tr>
</tbody>
</table>

**Q.** Do the stockpiles meet the criteria, Y/N? If the answer is “no,” what does this mean?

(a) Stockpile can not be used, or

(b) Percentage of stockpile in blend is limited.
Q. For this project, did any of the criteria change from using the original tables versus the new standards in AASHTO MP-2?

<table>
<thead>
<tr>
<th>Consensus</th>
<th>Original</th>
<th>Current ‘99</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAA</td>
<td>85 /80</td>
<td>85 /80</td>
</tr>
<tr>
<td>FAA</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>F&amp;E</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>SE</td>
<td>45</td>
<td>45</td>
</tr>
</tbody>
</table>
Mixture ETG Discussion

- Stockpile data collected as part of DP90 was offered for discussion of the use of the 3:1 ratio.

- 27 Stockpiles from 12 different projects sites located in:
  - California, Nevada, Alabama, Maine, Louisiana, Missouri, Illinois, South Carolina, Connecticut, Texas, Wisconsin, Minnesota, and Oklahoma.
F&E, 5:1 versus 3:1
F&E, 5:1 versus 3:1

Percent of Data within Criteria

Criteria (maximum)

30
It is recommended each specifying agency should perform a market analysis to access the impact of specifying a 3:1 source property standard.
Source Property Standards

- LA Abrasion
  - Max loss approximately 35% to 40%
- Soundness
  - Max loss approximately 10% to 20%
- Clay Lumps & Friable Particles
  - Max range from 0.2% to 10%
Selection of a Design Aggregate Structure

FHWA 0.45 Power Chart
Control Points / Restricted Zone
Superpave Gyratory Compactor
The FHWA 0.45 Power chart is used to define permissible gradations.

- **Nominal Maximum Sieve Size:** One standard sieve size larger than the first sieve to retain more than 10 percent.

- **Maximum Sieve Size:** One standard sieve size larger than the nominal maximum size.
Question?

What is a "standard" sieve?
**“Standard Sieves”**

<table>
<thead>
<tr>
<th>Standard Sieves, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.0</td>
</tr>
<tr>
<td>37.5</td>
</tr>
<tr>
<td>25.0</td>
</tr>
<tr>
<td>19.0</td>
</tr>
<tr>
<td>12.5</td>
</tr>
<tr>
<td>9.5</td>
</tr>
<tr>
<td>4.75</td>
</tr>
</tbody>
</table>
What if I decide not to use the "standard" sieves?
You'll design asphalt mix, but it will NOT be Superpave!
The Match Game - Round 1

Ms. Metric meets Mr. English

No. 200 Sieve

(A) 0.15 mm
(B) 0.075 mm
(C) 19.0 mm
The Match Game - Round 1

Ms. Metric meets Mr. English

No. 200 Sieve

(A) 0.15 mm
(B) 0.075 mm
(C) 19.0 mm
The Match Game - Round 2

Ms. Metric meets Mr. English

1/2” Sieve

(A) 9.5 mm
(B) 19.0 mm
(C) 12.5 mm
The Match Game - Round 2

Ms. Metric meets Mr. English

1/2” Sieve

(A) 9.5 mm
(B) 19.0 mm
(C) 12.5 mm
The Match Game - Round 3

Ms. Metric meets Mr. English

1/4” Sieve

(A) 4.75 mm
(B) 9.5 mm
(C) 2.36 mm
Ms. Metric meets Mr. English

(A) 4.75 mm
(B) 9.5 mm
(C) 2.36 mm
(D) None of the above!

1/4” Sieve
Gradation Criteria

- Control Points
  - Maximum Size
  - Nominal Maximum Size
  - Key Sieves: 0.075 and 2.36 mm

- Recommended Restricted Zone
  - Starting from 0.30 to 2.36 or 4.75 mm
## Gradation Criteria - 19 mm Mix

<table>
<thead>
<tr>
<th>Sieve, mm</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>19.0</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>2.36</td>
<td>23</td>
<td>49</td>
</tr>
<tr>
<td>0.075</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td><strong>Recommended Restricted Zone</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.36</td>
<td>34.6</td>
<td>34.6</td>
</tr>
<tr>
<td>1.18</td>
<td>28.3</td>
<td>22.3</td>
</tr>
<tr>
<td>0.60</td>
<td>20.7</td>
<td>16.7</td>
</tr>
<tr>
<td>0.30</td>
<td>13.7</td>
<td>13.7</td>
</tr>
</tbody>
</table>
FHWA 0.45 Power Chart

Sieve Size raised to the 0.45 Power

Percent Passing

Control
Points
Restricted Zone
Max Density
FHWA 0.45 Power Chart

Sieve Size raised to the 0.45 Power vs. Percent Passing

Control
Points
Restricted Zone
Max Density
Trial No. 1

37
FHWA 0.45 Power Chart

Percent Passing vs. Sieve Size raised to the 0.45 Power

- Control
- Points
- Restricted Zone
- Max Density
- Trial No. 1
- Trial No. 2
- Trial No. 3

Values:
- 0
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3
- 3.5
- 4
- 4.5

Trial No. 1: 37
Estimated Trial Blend Properties
Huber’s Method

- Determine what portion of the stockpiles apply to consensus property standard for each trial blend.

- Example: CAA for 1 fractured face for Trial Blend No. 1
Estimated Trial Blend Properties
Huber’s Method

<table>
<thead>
<tr>
<th>Stockpile</th>
<th>CAA</th>
<th>(A) Trial Blend #1</th>
<th>(B) % of +4.75mm</th>
<th>(AxB) % App to CAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>99/97</td>
<td>46 %</td>
<td>97 %</td>
<td>44.6 %</td>
</tr>
<tr>
<td>Inter.</td>
<td>80/60</td>
<td>24 %</td>
<td>75 %</td>
<td>18 %</td>
</tr>
<tr>
<td>Man. Fines</td>
<td>/</td>
<td>15 %</td>
<td>0 %</td>
<td>0</td>
</tr>
<tr>
<td>Natural Fines</td>
<td>/</td>
<td>15 %</td>
<td>0 %</td>
<td>0</td>
</tr>
</tbody>
</table>

Portion of the stockpiles that apply to consensus property.
Huber’s Method

- C = Test result, and
- D = Portion of the stockpile that applies to consensus property standard,
- n = Stockpile number.

\[
\text{Est. Property} = \frac{[(C \times D)_1 + (C \times D)_2 \ldots n]}{[(D)_1 + (D)_2 \ldots n]}
\]
## Estimated Trial Blend Properties

### Huber’s Method

<table>
<thead>
<tr>
<th>Stockpile</th>
<th>(C) CAA +1</th>
<th>(D) % App to CAA</th>
<th>(CxD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>99</td>
<td>44.6 %</td>
<td>44.2 %</td>
</tr>
<tr>
<td>Inter.</td>
<td>80</td>
<td>18 %</td>
<td>14.4 %</td>
</tr>
</tbody>
</table>

- Est. Property = \[\frac{n}{\sum (CxD)_i + \sum (D)_i \ldots n}\]
## Estimated Trial Blend Properties

### Huber’s Method

<table>
<thead>
<tr>
<th>Stockpile</th>
<th>(C) CAA +1</th>
<th>(D) % App to CAA</th>
<th>(Cx*D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>99</td>
<td>44.6 %</td>
<td>44.2 %</td>
</tr>
<tr>
<td>Inter.</td>
<td>80</td>
<td>18 %</td>
<td>14.4 %</td>
</tr>
</tbody>
</table>

\[
\text{CAA}_{+1} = \frac{(99 \times 44.2) + (80 \times 14.4)}{(44.2) + (14.4)}
\]
# Estimated Trial Blend Properties

**Huber’s Method**

<table>
<thead>
<tr>
<th>Stockpile</th>
<th>(C) CAA +1</th>
<th>(D) % App to CAA</th>
<th>(CxD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>99</td>
<td>44.6 %</td>
<td>44.2 %</td>
</tr>
<tr>
<td>Inter.</td>
<td>80</td>
<td>18 %</td>
<td>14.4 %</td>
</tr>
</tbody>
</table>

\[ \text{CAA}_+1 = \left[ \frac{4375.8}{(58.6)} + (1152) \right] = 94 \% \]
Estimating Trial Blend Properties

Q. What is CAA 2+ and SE for Trial Blend No.3?
Answers.

- CAA 2+ = 81
- SE = 44.47 = 44
What’s Next?

- Based upon project environment and traffic we have selected a PG binder, PG 58-22.
- Based upon traffic and layer location we have set consensus criteria and accessed our stockpiles.
- Using the FHWA 0.45 power chart we have developed trial blends. . .
Next we need to . . .

- Estimated asphalt binder contents for the trial blends,
- Mix and compact the trial blends in the Superpave gyratory compactor (SGC),
- Evaluate the trial blends volumetrically, and
- Select the Design Aggregate Structure.
Goals of Compaction

- Simulate field densification
  - traffic
  - climate
- Accommodate large aggregates
- Measure compact-ability
- 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 Gyratory Compactor

- Ram pressure: 600 kPa
- 150 mm diameter mold
- 30 gyrations per minute
- 1.25 degrees
FHWA Pooled Fund Purchase
Superpave Gyratory Compactor
Estimating Trial Binder Contents

- Based on experience for a 19.0 mm nominal, surface mix, the asphalt binder content should be...?
The Calculations

- Step 1: Estimate Gse
- Step 2: Estimate Vba
- Step 3: Estimate Vbe
- Step 4: Estimate Pbi, (binder - initial)

"by hand"
"by computer"
Step 1: Estimate Gse

- Gse = Gsb + 0.8 (Gsa - Gsb)
  - 0.8 factor accounts for absorption, for high absorption aggregates use 0.6 or 0.5

- Trial Blend No. 1, TB#1

- Gse = 2.566 +0.6(2.685 -2.566) = 2.637
Step 2: Estimate Vba

- $V_{ba} = f(V_a, P_b, P_s, G_b, G_{sb}, G_{se})$

  - $V_a = 0.04$, 4% voids
  - $P_b = 0.05$, (approximately 5% binder)
  - $P_s = 1 - P_b = 0.95$

- TB#1: $V_{ba} = 0.0233$
Step 3: Estimate $V_{be}$

- $V_{be} = 0.176 - 0.0675 \ln (Sn)$
  - $Sn =$ Nominal maximum size in mm

- $V_{be} = 0.176 - 0.0675 \ln(19) = 0.090$
  - This value is true for all blends.
Step 4: Estimate $P_{bi}$

- $P_{bi} = f(Va, Gb, Gse, Vbe, Vba)$

- TB#1: $P_{bi} = 4.95\%$

- Author’s Note: The equations can not replace experience.
## Summary of Estimated Pbi

<table>
<thead>
<tr>
<th>Trial Blend</th>
<th>$P_{bi}$</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.95</td>
<td>5.0</td>
</tr>
<tr>
<td>2</td>
<td>4.98</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>4.95</td>
<td>5.0</td>
</tr>
</tbody>
</table>
Required Testing

<table>
<thead>
<tr>
<th>Trial Blend</th>
<th>SGC</th>
<th>Rice, Gmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 (4800 g/ea)</td>
<td>2 (2000 g/ea)</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>43.2 kg</strong></td>
<td><strong>12.0 kg</strong></td>
</tr>
</tbody>
</table>

"the lab"
Required Aging

- Original Specification:
  - Aging of both gyratory and $G_{mm}$ samples,
  - 4 hours at 135°C in a forced-draft oven,
  - Mixing samples every hour.
Specimens are mixed at the equiviscous mixing temperature.

Specimens are short term aged for 2-hours at the equiviscous compaction temperature in a forced-draft oven.

This is only for volumetric design.
Aging
History Lesson on Compaction

- SHRP researcher evaluated 9 GPS sites to develop the original SGC compaction table.
- Mixture ETG conducted the “N-design II” study using data for State projects, TFHRC, and WesTrack.
- NCHRP 9-9 investigated the sensitivity of the original compaction table
History continued. . .

- September 23, 1998, a date which changed SGC compaction forever.
  – Mixture ETG, Baltimore, Maryland
Compaction
SGC Criteria

- N ini - “Tenderness Check” represents the mix during construction. Mixes that compact too quickly in the SGC may have tenderness problems during construction.

- N des - . . .

- N max - . . .
SGC Criteria

- \( N_{\text{ini}} \)
- \( N_{\text{des}} - \) “Volumetric Check”
  Represents the mix after construction and initial trafficking. Mix volumetrics, \((V_a, V_{MA}, \text{and} V_{FA})\), are compared to empirically based criteria.
- \( N_{\text{max}} \) - . . .
SGC Criteria

- $N_{ini}$
- $N_{des}$
- $N_{max}$ - Optional “Rutting Check”

Mixes that commonly rut have been compacted below 2% air voids under traffic. Mixes compacting below 2% air voids in the SGC may have rutting problems.
Why Volumetrics?

Colorado Study

![Graph showing relationship between in-place air voids and rutting. Projects are sorted by air voids, with a line indicating 3% Va.]
### Original SGC Compaction Effort

#### 7 Day Average Design High Air Temperature

<table>
<thead>
<tr>
<th>Estimated Traffic</th>
<th>&lt; 39°C</th>
<th>39°-40°C</th>
<th>41°-42°C</th>
<th>43°-44°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.3</td>
<td>68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 100</td>
<td></td>
<td></td>
<td></td>
<td>172</td>
</tr>
</tbody>
</table>

- **28 Compaction Levels**
### SGC Compaction Effort ‘99

<table>
<thead>
<tr>
<th>ESAL’s</th>
<th>$N_{ini}$</th>
<th>$N_{des}$</th>
<th>$N_{max}$</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>

Base mix (< 100 mm) option to drop one level, unless the mix will be exposed to traffic during construction.
Q. What should VMA criteria be a function of?
Voids in Mineral Aggregate, VMA

Minimum VMA

Nominal Maximum Sieve Size, mm
## Volumetric Design Criteria ‘99

<table>
<thead>
<tr>
<th>Traffic ESAL</th>
<th>SGC Criteria</th>
<th>VMA</th>
<th>VFA</th>
<th>Fines $P_{be}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$N_{ini}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 0.3</td>
<td>$\leq 91.5$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 3</td>
<td>$\leq 90.5$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 10</td>
<td>$\leq 89.0$</td>
<td>=96.0</td>
<td>$\leq 98.0$</td>
<td>n/a</td>
</tr>
<tr>
<td>&lt; 30</td>
<td>$\leq 89.0$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 30</td>
<td>$\leq 89.0$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values in the table:
- VMA: 70-80
- VFA: 65-78
- Fines $P_{be}$: 0.6-to-1.2

Note: N_{des} and N_{max} are not explicitly shown in the table but are implied in the criteria.
Hot Mix, USA

Est. 20-year design traffic is 6.3M ESAL’s

<table>
<thead>
<tr>
<th>Property</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{ini} / %G_{mm}$</td>
<td></td>
</tr>
<tr>
<td>$N_{des} / %G_{mm}$</td>
<td></td>
</tr>
<tr>
<td>$N_{max} / %G_{mm}$</td>
<td></td>
</tr>
<tr>
<td>VMA</td>
<td></td>
</tr>
<tr>
<td>VFA</td>
<td></td>
</tr>
<tr>
<td>Dust-to-Binder</td>
<td></td>
</tr>
</tbody>
</table>
Est. 20-year design traffic is 6.3M ESAL’s

<table>
<thead>
<tr>
<th>Property</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{ini} / %G_{mm}$</td>
<td>8 gyr $\leq$ 89%</td>
</tr>
<tr>
<td>$N_{des} / %G_{mm}$</td>
<td>100 gyr = 96%</td>
</tr>
<tr>
<td>$N_{max} / %G_{mm}$</td>
<td>160 gyr $\leq$ 98%</td>
</tr>
<tr>
<td>VMA</td>
<td>13.0 min</td>
</tr>
<tr>
<td>VFA</td>
<td>65 to 75</td>
</tr>
<tr>
<td>Dust-to-Binder</td>
<td>0.6 to 1.2</td>
</tr>
</tbody>
</table>
SGC Compaction Curve

- % $G_{mm}$ vs Log (No. of Gyrations)
  - Height is monitored during compaction and is used to calculate the densification of the specimen, expressed as % $G_{mm}$.

$$\%G_{mm\,des} = \frac{G_{mb}}{G_{mm}} \times 100$$
SGC Compaction Curve

- % G\text{mm} vs Log (No. of Gyrations)
  - Height data, h \text{ini}, h \text{des}

\[ \% \text{Gmm ini} = \% \text{Gmm des} \times \frac{h \text{ des}}{h \text{ ini}} \]
SGC Compaction Calculations

- Trail Blend No. 1

- $G_{mm} = 2.475$
  - Specimen 1, $G_{mb} = 2.351$
  - Specimen 1, $G_{mb} = 2.348$
  - Specimen 1, $G_{mb} = 2.353$
SGC Calc’s for Trial Blend No. 1

- Specimen 1

- \( \% \text{Gmm des} = \frac{\text{Gmb} \times 100}{\text{Gmm}} = \frac{2.351 \times 100}{2.475} \)

- \( \% \text{Gmm des} = 95.0 \% = 96.0\% \) Criterion
SGC Calc’s for Trial Blend No. 1

**Q.** What are they for specimens 2 & 3?

- \( \% \text{Gmm des} = \frac{\text{Gmb}}{\text{Gmm}} \times 100 = ? \)
SGC Calc’s for Trial Blend No. 1

- %Gmm max for specimens 2 & 3:
  - 2, %Gmm des = 94.9 %
  - 3, %Gmm des = 95.1 %
### SGC Height Data

#### Trail Blend No. 1

<table>
<thead>
<tr>
<th>Specimen</th>
<th>$H_{\text{ini}}$</th>
<th>$H_{\text{des}}$</th>
<th>$% G_{\text{mm}}$ at $N_{\text{des}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>129.6</td>
<td>117.4</td>
<td>95.0 %</td>
</tr>
<tr>
<td>2</td>
<td>129.8</td>
<td>117.4</td>
<td>94.9 %</td>
</tr>
<tr>
<td>3</td>
<td>129.9</td>
<td>117.8</td>
<td>95.1 %</td>
</tr>
</tbody>
</table>

$$% G_{\text{mm}} \text{ ini} = 95.0 \times \frac{117.4}{129.6} = 86.1\%$$
What is %Gmm ini for specimens 2 & 3?
%Gmm ini

- 2: %Gmm ini = 85.8 %
- 3: %Gmm ini = 86.2 %
SGC Compaction Chart

Log(Number of Gyrations)

Specimen 1
Specimen 2
Specimen 3
N initial
N design

57
Q. Is binder content high or low?

![Graph showing log of number of gyrations for different specimens.](image)

- Specimen 1
- Specimen 2
- Specimen 3

Log(Number of Gyrations)
Big Q. Should asphalt binder content be the main criteria for mixture design?
Trial Blends

Log(Number of Gyrations)

Trial Blend 1
Trial Blend 2
Trial Blend 3
N initial
N design

59
How do we choose?

We need to adjust the results to reflect 4.0\% voids at N_{des}?
Trial Blend No. 2

- Log(Number of Gyrations)

- Trial Blend 2
- N initial
- N design
Trial Blend No. 3

Log(Number of Gyrations)

% Gmm

Adjusted
Trial Blend 3
N initial
N design
Estimating the Properties at 4% Va

1) Estimate binder content
2) Estimate VMA
3) Estimate VFA
4) Estimate %Gmm ini
5) Estimate Dust-to-Binder ratio
Estimate Pb with 4% Va

- \[ Pb, \text{est} = Pbi - [0.4 \times (4 - \text{Va at N des})] \]

- Rule: 1 % Air Voids = 0.4 % Binder
Estimate VMA at $N_{des}$ w/ 4% $Va$

- $VMA, \text{ est} = VMA + C \left(4 - Va \text{ at } N_{des}\right)$
  
  - $C = \text{ constant (either 0.1 or 0.2)}$
  - $C = 0.1$, when $Va$ is less than 4.0%
  - $C = 0.2$, when $Va$ is 4.0% or greater
Estimate VFA at $N_{\text{des}}$ w/ 4% Va

\[ \text{VFA, est} = 100 \left( \frac{\text{VMA, est} - 4}{\text{VMA, est}} \right) \]
Estimate $\%G_{mm \text{ ini}}$ & $\%G_{mm \text{ max}}$

- $\%G_{mm \text{ ini, est}} = \%G_{mm \text{ ini}} - (4 - V_a \text{ at } N_{\text{des}})$
Estimate F/Pbe w/ 4% Va

- $P_{be, \text{est}} = f(G_b, G_{se}, G_{sb}, P_{b \text{ est}})$

- Author’s Note: The Dust-to-Binder ratio in Superpave is based upon the effective asphalt binder content, NOT the total.
**Compare Estimated Properties to Volumetric Criteria**

<table>
<thead>
<tr>
<th>Property</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{\text{ini}} / % G_{mm}$</td>
<td>$8 \text{ gyr} \leq 89%$</td>
</tr>
<tr>
<td>$N_{\text{des}} / % G_{mm}$</td>
<td>$100 \text{ gyr} = 96%$</td>
</tr>
<tr>
<td>VMA</td>
<td>$13.0 \text{ min}$</td>
</tr>
<tr>
<td>VFA</td>
<td>$65 \text{ to } 75$</td>
</tr>
<tr>
<td>Dust-to-Binder</td>
<td>$0.6 \text{ to } 1.2$</td>
</tr>
</tbody>
</table>
## Summary of Estimated Properties

<table>
<thead>
<tr>
<th>Trial Blends</th>
<th>( P_b )</th>
<th>VMA at ( N_{des} )</th>
<th>VFA at ( N_{des} )</th>
<th>Fines ( P_{be} )</th>
<th>( %G_{mm} ) at ( N_{ini} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.4</td>
<td>13.8</td>
<td>71</td>
<td>0.82</td>
<td>87.1</td>
</tr>
<tr>
<td>2</td>
<td>5.0</td>
<td>13.0</td>
<td>69</td>
<td>0.81</td>
<td>86.5</td>
</tr>
<tr>
<td>3</td>
<td>5.2</td>
<td>13.4</td>
<td>70</td>
<td>1.15</td>
<td>90.1</td>
</tr>
</tbody>
</table>

| Criteria      | 13 min   | 65-75           | 0.6-1.2         | 89 max        |

Is everything okay?
### Summary of Estimated Properties

<table>
<thead>
<tr>
<th>Trial Blends</th>
<th>( P_b )</th>
<th>VMA at ( N_{des} )</th>
<th>VFA at ( N_{des} )</th>
<th>Fines ( P_{be} )</th>
<th>( %G_{mm} ) at ( N_{ini} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.4</td>
<td>13.8</td>
<td>71</td>
<td>0.82</td>
<td>87.1</td>
</tr>
<tr>
<td>2</td>
<td>5.0</td>
<td>13.0</td>
<td>69</td>
<td>0.81</td>
<td>86.5</td>
</tr>
<tr>
<td>X</td>
<td>5.2</td>
<td>13.4</td>
<td>70</td>
<td>1.15</td>
<td>90.1</td>
</tr>
</tbody>
</table>

| Criteria     | 13 min  | 65-75        | 0.6-1.2       | 89 max         |

Is everything okay?
Design Aggregate Structure

Trial Blend No. 1
Q. What if all three Trial Blends meet the design requirement?
Selection of the Design Asphalt Binder Content

Optimum $P_b$
Design Asphalt Binder Content

- Specimens are compacted at varying asphalt binder contents:
  - Estimated asphalt binder content
  - ± 0.5 %
  - + 1.0 %
Lead States

- Based upon the recommendations of NCHRP 9-9,
- Optimization of the design aggregate blend is only compacted to $N_{\text{des}}$
- Check the design aggregate blend at the optimum asphalt compacted to $N_{\text{max}}$
## Required Tests

<table>
<thead>
<tr>
<th>Batched Pb</th>
<th>SGC Specimens</th>
<th>Gmm Rice</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9 (- ½ %)</td>
<td>3 (4800 g/ea)</td>
<td>2 (2000 g/ea)</td>
</tr>
<tr>
<td>5.4 (Target)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>5.9 (+ ½ %)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>6.4 (+ 1 %)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>57,600 g</strong></td>
<td><strong>16,000 g</strong></td>
</tr>
</tbody>
</table>
## Summary of Optimization

<table>
<thead>
<tr>
<th>Property</th>
<th>Results</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Va at $N_{des}$</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>VMA at $N_{des}$</td>
<td>13.5</td>
<td>13.0 min</td>
</tr>
<tr>
<td>VFA at $N_{des}$</td>
<td>70</td>
<td>65 to 75</td>
</tr>
<tr>
<td>$F/P_{be}$ ratio</td>
<td>0.87</td>
<td>0.6 to 1.2</td>
</tr>
<tr>
<td>$%G_{mm ini}$</td>
<td>86.9</td>
<td>$\leq 89$</td>
</tr>
<tr>
<td>$%G_{mm max}$</td>
<td>n/a</td>
<td>$\leq 98$</td>
</tr>
</tbody>
</table>
Summary of Optimization

**Va**

![Graph showing the relationship between Va and Asphalt Binder Content](image)

**VMA**

![Graph showing the relationship between VMA and Asphalt Binder Content](image)

**VFA**

![Graph showing the relationship between VFA and Asphalt Binder Content](image)

**F/P**

![Graph showing the relationship between F/P and Asphalt Binder Content](image)
Design Blend at Optimum Rutting Check

![Graph showing the relationship between % Gmm and Log(Number of Gyrations) for Optimum AC, N initial, N design, and N maximum.](image-url)
Author’s Note

- If you have limited experience with the trial gradations. It is recommended during the selection of the design aggregate structure that you compact at least one specimen to $N_{\text{max}}$ to assess the blends ability to resist rutting.
Evaluation of Moisture Sensitivity

AASHTO T-283
Evaluation of Moisture Sensitivity

Measured on Proposed Aggregate Blend and Asphalt Content

3 Conditioned Specimens

80% minimum

3 Dry Specimens

Tensile Strength Ratio
Evaluation of Moisture Sensitivity

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
Evaluation of Moisture Sensitivity

- optional freeze cycle
- hot water soak

16 hours @ -18 °C

24 hours @ 60 °C
Evaluation of Moisture Sensitivity

51 mm / min @ 25 °C

Avg Dry Tensile Strength

Avg Wet Tensile Strength

TSR = \frac{\text{Wet}}{\text{Dry}} \geq 80 \%
### Evaluation of Moisture Sensitivity

**AASHTO T-283**

<table>
<thead>
<tr>
<th>Samples</th>
<th>SGC</th>
<th>ITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconditioned Dry</td>
<td>3 Specimens 7 % Va</td>
<td>872 kPa</td>
</tr>
<tr>
<td>Conditioned Wet</td>
<td>3 Specimens 7 % Va</td>
<td>721 kPa</td>
</tr>
<tr>
<td>TSR</td>
<td>82.7 %</td>
<td></td>
</tr>
<tr>
<td>Superpave Criteria</td>
<td>80 % min</td>
<td></td>
</tr>
</tbody>
</table>
Question?

What if the TSR fails?
Author’s Note

- SHRP gave us the ECS
- Superpave calls for AASHTO T-283
  - 4” Marshall Specimens
- NCHRP 9-13 ties T-283 + gyratory
  - Jon Epps (University of Nevada at Reno)
Author’s Note

- In the interim agencies are...
  - Using Modified Lottman / Root-Tunnicliff
    - 150 & 100 mm SGC, 4” Marshall Specimens
    - 100% Saturation
  - Proof Tests
    - Asphalt Pavement Analyzer (Georgia LWT)
    - Hamburg Loaded Wheel Wheel Tester
  - Pull-off Test (Binder/Mastic only)
Better moisture sensitivity test

- July 28, 1999 -- NCHRP hosted “Moisture Sensitivity Focus Group”

- Outcome: NCHRP project to develop a new test for moisture sensitivity
Major Steps in Superpave

- Selection of Materials,
- Selections of a Design Aggregate Structure,
- Selection of the Design Binder Content, and
- Evaluation of Moisture Sensitivity.
  - Mixture/Aggregate & Binder ETG
  - Lead States
Guidelines for the use of RAP

- FHWA Mix ETG developed guidelines based upon consensus and limited testing (<15%, 15-25, 25%+).

- NCHRP 9-12, “Incorporation of RAP in the Superpave System”
  - Rebecca McDaniel (NC Superpave Center)
Superpave Field Management

DESIGN

QC

PRODUCTION

ACCEPTANCE

PERFORMANCE
Thank you.
FHWA 0.45 Power Chart

Sieve Size raised to the 0.45 Power vs. Percent Passing

- Control
- Points
- Restricted Zone
- Max Density
- Trial No. 1
- Trial No. 2
- Trial No. 3
Trial Blends

![Graph showing the relationship between log(n) and % Gnm for Trial Blends 1, 2, and 3, along with N initial and N design.](image-url)
Summary of Optimization

V_a

VMA

VFA

F/P_{be}