The Bailey Method

Achieving Volumetrics and HMA Compactability
Aggregate Blending

Where do you start?

- Trial and *Error*?
  - Specification Bands
    - Coarse
    - Medium
    - Fine
  - Which blend is *best*?
  - How will it work in the field during placement?
  - How will it perform?

- Is there a more *systematical* way to find a starting point?
Aggregate Blending

The Bailey Method

- Originally developed by Robert D. Bailey (Illinois Department of Transportation)

- Focus is Aggregate **packing**!

- Determine “**Coarse**” and “**Fine**”

- Evaluate individual agg’s **and** combined blend by **VOLUME** as well as by **weight**
Aggregate Packing

What Influences the Results?

- Gradation
  - continuously-graded, gap-graded, etc.

- Type & Amount of Compactive Effort
  - static pressure, impact or shearing

- Shape
  - flat & elongated, cubical, round

- Surface Texture (micro-texture)
  - smooth, rough

- Strength
  - degradation or lack thereof
Defining “Coarse” and “Fine”

- "Coarse" fraction
  - Larger particles that create voids

- "Fine" fraction
  - Smaller particles that fill voids

- Estimate void size using Nominal Maximum Particle Size (NMPS)
  - Break between “Coarse” and “Fine”
  - Primary Control Sieve (PCS)
Diameter \((d)\) = NMPS

Flat face of aggregate particle

Round face of aggregate particle

Average Void size = 0.22\(\times d\) for all four conditions

Primary Control Sieve = 0.22 \(\times\) NMPS
## Primary Control Sieve

<table>
<thead>
<tr>
<th>Mixture NMPS</th>
<th>NMPS x 0.22</th>
<th>Primary Control Sieve</th>
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<tbody>
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<tr>
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</table>

PCS determines the break between **Coarse** and **Fine** in the combined blend **and** if a given aggregate is a **CA** or **FA**
Evaluating Aggregates by Volume

- Why?
  - Better understand aggregate packing
  - Control VOLUME of Coarse and Fine for Mix “Type”

- How?
  - Test the individual Coarse and Fine aggregates
Loose Unit Weight - CA

- **NO** compactive effort applied
- **Start** of particle-to-particle contact
- Use **shoveling** procedure
- Strike off ~ level
  - Careful **not** to compact
- Determine **LUW**
  - Kg/m³ or lbs./ft³
- Determine **volume** of **voids**
Rodded Unit Weight - CA

- **With** compactive effort applied
- **Increased** particle-to-particle contact
- **Three** equal lifts using **shoveling** procedure
- Rod **25** times per lift
- **Strike off ~ level**
  - Careful **not** to compact
- **Determine RUW**
  - Kg/m³ or lbs./ft³
- **Determine volume of voids**

AASHTO T19
Chosen Unit Weight - CA(s)

- **< LUW**: Fine-Graded (< 90%)
- **LUW**: Coarse-Graded (95-105%)
- **RUW**: SMA (110-125%)
**Chosen Unit Weight - FA(s)**

- **100% LUW**
  - SMA

- **100% RUW**
  - Dense-graded

FA CUW “SET” According To Mix Type
Developing the Combined Blend

1. Determine Mix **Type** & NMPS
2. Choose the **VOLUME** of **CA**
3. Blend the **CA’s** by **VOLUME**
4. Blend the **FA’s** by **VOLUME**
5. Choose the **desired** % Minus 0.075mm

Convert the Individual aggregate %’s from **VOLUME** to **weight**
Combined Blend Evaluation

- Evaluation method depends on which fraction (Coarse or Fine) is in control:
  - Coarse-graded, SMA
  - Fine-graded
Combined Blend Evaluation

Coarse-Graded Mixes

1. **CA CUW (\% PCS)**
   - \( PCS = 0.22 \times NMPS \)

2. **CA Ratio**
   - \( \frac{\% \text{ Half Sieve} - \% \text{ PCS}}{100 - \% \text{ Half Sieve}} \)

3. **FA_r Ratio**
   - \( \frac{\% \text{ TCS}}{\% \text{ SCS}} \)

4. **FA_c Ratio**
   - \( \frac{\% \text{ SCS}}{\% \text{ PCS}} \)
Combined Blend Evaluation

Coarse-Graded Mixes

1. **CA CUW increase** = VMA increase
   - 4% change in PCS ≅ 1% change in VMA or Voids

2. **CA Ratio increase** = VMA increase
   - 0.20 change ≅ 1% change in VMA or Voids

3. **FAc Ratio increase** = VMA decrease
   - 0.05 change ≅ 1% change in VMA or Voids

4. **FAf Ratio increase** = VMA decrease
   - 0.05 change ≅ 1% change in VMA or Voids

Has the most influence on VMA or Voids
Combined Blend Gradation

Sieve Size (mm) Raised to 0.45 Power

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<th>Sieve</th>
<th>% Passing</th>
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<td>A</td>
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<tr>
<td>B</td>
<td>92</td>
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<tr>
<td>C</td>
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<td>D</td>
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<td>I</td>
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</tr>
<tr>
<td>J</td>
<td>11</td>
</tr>
<tr>
<td>K</td>
<td>9.5</td>
</tr>
</tbody>
</table>

Coarse

Fine

0 10 20 30 40 50 60 70 80 90 100

% Passing

K J I H G F E D C B A

Sieve Size (mm) Raised to 0.45 Power
Combined Blend Evaluation

SMA Mixes

1. **CA CUW increase** = VMA increase
   - 2% change in PCS ≈ 1% change in VMA or Voids

2. **CA Ratio increase** = VMA increase
   - 0.20 change ≈ 1% change in VMA or Voids

3. **FAc Ratio increase** = VMA decrease
   - 0.10 change ≈ 1% change in VMA or Voids

4. **FAf Ratio increase** = VMA decrease
   - 0.10 change ≈ 1% change in VMA or Voids

Has the most influence on VMA or Voids

Has the 2nd most influence on VMA or Voids
Combined Blend Gradation

<table>
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<td>B</td>
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<td>C</td>
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<td>58</td>
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<td>F</td>
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<td>G</td>
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<td>H</td>
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<td>I</td>
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<td>J</td>
<td>7</td>
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<tr>
<td>K</td>
<td>4.4</td>
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</table>

Sieve Size (mm) Raised to 0.45 Power

Fine-graded

Fine

Coarse
Combined Blend Evaluation

**Fine-Graded Mixes**

- Original Coarse Fraction
- Original Half Sieve
- Original PCS

- New Coarse Fraction
- New Half Sieve
- New PCS

- New Fine Fraction
- New SCS
- New TCS

1. % CA LUW
2. New CA Ratio
3. New FA<sub>c</sub> Ratio
4. New FA<sub>f</sub> Ratio
Combined Blend Evaluation

Fine-Graded Mixes

1. **CA CUW decrease** = **VMA increase**
   - 6% change **original PCS** $\cong$ 1% change in **VMA or Voids**

2. **New CA Ratio increase** = **VMA increase**
   - 0.35 change $\cong$ 1% change in **VMA or Voids**

3. **New FA$_c$ Ratio increase** = **VMA decrease**
   - 0.05 change $\cong$ 1% change in **VMA or Voids**

4. **New FA$_f$ Ratio increase** = **VMA decrease**
   - 0.05 change $\cong$ 1% change in **VMA or Voids**

- **Old CA Ratio** still relates to **segregation susceptibility**

Has the most influence on **VMA or Voids**
## Estimating VMA or Voids

**Coarse-Graded Mix Example**

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>Trial #1 (%)</th>
<th>NMPS</th>
<th>Trial #2 (%)</th>
<th>HALF</th>
<th>PCS</th>
<th>SCS</th>
<th>TCS</th>
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<tr>
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<td>18.8</td>
<td></td>
<td>1.18</td>
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NMPS, HALF, PCS, TCS are the grading methods used for different size fractions.
Estimating VMA or Voids

Trial #2 vs. Trial #1

- **PCS**
  
  \[ 37.2\% - 38.2\% = -1.0\% \]

- **CA** ratio
  
  \[ 0.725 - 0.693 = +0.032 \]

- **FA_c** ratio
  
  \[ 0.444 - 0.492 = -0.048 \]

- **FA_f** ratio
  
  \[ 0.412 - 0.394 = +0.018 \]

- **Increases** VMA or Voids
  
  \[ 1.0/4.0 = +0.25\% \]

- **Increases** VMA or Voids
  
  \[ 0.032/0.2 = +0.16\% \]

- **Increases** VMA or Voids
  
  \[ 0.048/0.05 = +0.96\% \]

- **Decreases** VMA or Voids
  
  \[ 0.018/0.05 = -0.36\% \]

**Total Estimated Change:**

- **Plus ~ 1.0\% VMA**
<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>Mix Design</th>
<th>1</th>
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Predicting Performance

- We can relate to volumetric changes well.
- We can relate blend gradations and the four main principles to compactibility and segregation.
- But......performance includes much more!
So How Does the Method Help?

- In Developing **New** Blends:
  - Field Compactibility
  - Segregation Susceptibility

- In Evaluating **Existing** Blends:
  - What’s worked and what hasn’t?
  - More clearly define principle ranges

- In **Estimating** VMA/Void changes between:
  - Design trials
  - QC samples
  - **Saves Time and Reduces Risk!**
Questions or Comments?

Thank You!