The Basics Of
The Bailey Method

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Aggregate Blending

The Bailey Method

- Originally developed by Robert D. Bailey
- Evaluate aggregate packing characteristics
- Determine what is “Coarse” and “Fine”
- Evaluate individual aggregates and the 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
  - Weak vs. Strong, Influence of particle shape?
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 = NMPS

Average Void Size = 0.22 \times NMPS

Primary Control Sieve \approx 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>
</tr>
</thead>
<tbody>
<tr>
<td>37.5mm</td>
<td>8.250mm</td>
<td>9.5mm</td>
</tr>
<tr>
<td>25.0mm</td>
<td>5.500mm</td>
<td>4.75mm</td>
</tr>
<tr>
<td>19.0mm</td>
<td>4.180mm</td>
<td>4.75mm</td>
</tr>
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<td>12.5mm</td>
<td>2.750mm</td>
<td>2.36mm</td>
</tr>
<tr>
<td>9.5mm</td>
<td>2.090mm</td>
<td>2.36mm</td>
</tr>
<tr>
<td>4.75mm</td>
<td>1.045mm</td>
<td>1.18mm</td>
</tr>
</tbody>
</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/m$^3$ or lbs./ft$^3$
- Determine volume of voids

AASHTO T19
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
**Chosen Unit Weight - CA(s)**

- **< LUW**
  - Fine-Graded
  - < 90%

- **LUW**
  - Coarse-Graded
  - 95-105%

- **RUW**
  - SMA
  - 110-125%

INCREASING CA CUW
**Chosen Unit Weight - FA(s)**

100% LUW

100% RUW

FA CUW

“SET”

According To Mix Type

SMA

Dense-graded
Developing the Combined Blend

1. Determine Mix Type & NMPS
2. Chose the VOLUME of CA
3. Blend the CA’s by VOLUME
4. Blend the FA’s by VOLUME
5. Chose 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 Gradation

<table>
<thead>
<tr>
<th>Sieve</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>97</td>
</tr>
<tr>
<td>C</td>
<td>76</td>
</tr>
<tr>
<td>D</td>
<td>63</td>
</tr>
<tr>
<td>E</td>
<td>39</td>
</tr>
<tr>
<td>F</td>
<td>25</td>
</tr>
<tr>
<td>G</td>
<td>17</td>
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<tr>
<td>H</td>
<td>11</td>
</tr>
<tr>
<td>I</td>
<td>7</td>
</tr>
<tr>
<td>J</td>
<td>5</td>
</tr>
<tr>
<td>K</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Sieve Size (mm) Raised to 0.45 Power

Coarse-graded

Fine

Coarse

% Passing

K J I H G F E D C B A
Combined Blend Evaluation

**Coarse-Graded Mixes**

- **Coarse Fraction**
  - Half Sieve = 0.5 x NMPS
  - PCS = 0.22 x NMPS

- **Fine Fraction**
  - SCS = 0.22 x PCS
  - TCS = 0.22 x SCS

**CA Ratio**

\[
\begin{align*}
\text{CA Ratio} &= \frac{\% \text{ Half Sieve} - \% \text{ PCS}}{100 - \% \text{ Half Sieve}} \\
\end{align*}
\]

**CA CUW (%) PCS**

**FA_c Ratio**

\[
\begin{align*}
\text{FA_c Ratio} &= \frac{\% \text{ SCS}}{\% \text{ PCS}} \\
\end{align*}
\]

**FA_t Ratio**

\[
\begin{align*}
\text{FA_t Ratio} &= \frac{\% \text{ TCS}}{\% \text{ SCS}} \\
\end{align*}
\]
Combined Blend Evaluation
Coarse-Graded Mixes

1. CA CUW increase = VMA increase
   – 4% change in PCS ≅ 1% change in VMA or Voids
   – Range 3 - 5%

2. CA Ratio increase = VMA increase
   – 0.20 change ≅ 1% change in VMA or Voids
   – Range 0.10 – 0.30

3. FA$_c$ Ratio increase = VMA decrease
   – 0.05 change ≅ 1% change in VMA or Voids
   – Range 0.025 – 0.075

4. FA$_f$ Ratio increase = VMA decrease
   – 0.05 change ≅ 1% change in VMA or Voids
   – Range 0.025 – 0.075

Has the most influence on VMA or Voids
Combined Blend Gradation

Sieve Size (mm) Raised to 0.45 Power

<table>
<thead>
<tr>
<th>Sieve</th>
<th>% Passing</th>
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<tbody>
<tr>
<td>A</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>92</td>
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<tr>
<td>C</td>
<td>60</td>
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<tr>
<td>D</td>
<td>32</td>
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<td>E</td>
<td>25</td>
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<td>F</td>
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<td>G</td>
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<td>H</td>
<td>15</td>
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<tr>
<td>I</td>
<td>13</td>
</tr>
<tr>
<td>J</td>
<td>11</td>
</tr>
<tr>
<td>K</td>
<td>9.5</td>
</tr>
</tbody>
</table>

SMA

Fine

Coarse

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

SMA Mixes

1. **CA CUW increase** = **VMA increase**
   - 2% change in **PCS** \(\approx\) 1% change in VMA or Voids
   - Range 1 - 3%

2. **CA Ratio increase** = **VMA increase**
   - 0.20 change \(\approx\) 1% change in VMA or Voids
   - Range 0.10 – 0.30

3. **FA_c Ratio increase** = **VMA decrease**
   - 0.10 change \(\approx\) 1% change in VMA or Voids
   - Range 0.075 – 0.125

4. **FA_f Ratio increase** = **VMA decrease**
   - 0.10 change \(\approx\) 1% change in VMA or Voids
   - Range 0.075 – 0.125
<table>
<thead>
<tr>
<th>Sieve</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>98</td>
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<tr>
<td>C</td>
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<td>D</td>
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<td>E</td>
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<td>F</td>
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<td>G</td>
<td>32</td>
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<td>H</td>
<td>21</td>
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<tr>
<td>I</td>
<td>12</td>
</tr>
<tr>
<td>J</td>
<td>7</td>
</tr>
<tr>
<td>K</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Combined Blend Gradation

Sieve Size (mm) Raised to 0.45 Power
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** ≈ 1% change in VMA or Voids
   - Range 5 - 7%

2. **New CA Ratio increase** = VMA increase
   - 0.35 change ≈ 1% change in VMA or Voids
   - Range 0.25 – 0.45

3. **New FA\textsubscript{c} Ratio increase** = VMA decrease
   - 0.05 change ≈ 1% change in VMA or Voids
   - Range 0.025 – 0.075

4. **New FA\textsubscript{f} Ratio increase** = VMA decrease
   - 0.05 change ≈ 1% change in VMA or Voids
   - Range 0.025 – 0.075

- **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</th>
<th>Trial #1 (% Passing)</th>
<th>Trial #2 (% Passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0mm</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>19.0mm</td>
<td>97.4</td>
<td>98.0</td>
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<tr>
<td>12.5mm</td>
<td>76.2</td>
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<tr>
<td>9.5mm</td>
<td>63.5</td>
<td>63.6</td>
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<tr>
<td>4.75mm</td>
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<td>37.2</td>
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<td>2.36mm</td>
<td>23.6</td>
<td>22.1</td>
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<tr>
<td>1.18mm</td>
<td>18.8</td>
<td>16.5</td>
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<tr>
<td>0.60mm</td>
<td>13.1</td>
<td>11.8</td>
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<tr>
<td>0.30mm</td>
<td>7.4</td>
<td>6.8</td>
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<tr>
<td>0.15mm</td>
<td>5.7</td>
<td>5.2</td>
</tr>
<tr>
<td>0.075mm</td>
<td>4.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>

**NMPS**

**HALF**

**PCS**

**SCS**

**TCS**
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</th>
<th>Mix Design</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification</td>
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<td>19.0mm</td>
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<tr>
<td></td>
<td>Proposed</td>
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<td>98.8</td>
<td>95.9</td>
<td>40.1</td>
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<tr>
<td></td>
<td></td>
<td>100.0</td>
<td>95.9</td>
<td>95.7</td>
<td>39.4</td>
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<td></td>
<td>100.0</td>
<td>98.9</td>
<td>98.9</td>
<td>39.4</td>
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<tr>
<td></td>
<td></td>
<td>100.0</td>
<td>97.5</td>
<td>96.7</td>
<td>39.8</td>
</tr>
</tbody>
</table>

**Compares Each Sample to the Previous Sample**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mix Design</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proposed</td>
<td>100.0</td>
<td>97.5</td>
<td>96.7</td>
<td>39.8</td>
</tr>
</tbody>
</table>
The Four Main Principles

1. **% PCS (Volume of CA)**
   - Increase/decrease in VMA depends on mix type

2. **CA ratio** (Control with CA Volume blend)
   - Low values can be susceptible to segregation
   - High values can be difficult to compact
   - As it increases, VMA increases

3. **FA$_c$ ratio** (Control with FA Volume blend)
   - As it increases, VMA decreases

4. **FA$_f$ ratio** (Control with % minus 0.075mm)
   - As it increases, VMA decreases
So How Does the Method Help?

• In Developing **New** Blends:
  – Field Compactability
  – 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
  – Between QC and/or QA samples

• **Saves Time and Reduces Risk!**
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