The Bailey Method

- Originally developed by Robert D. Bailey
  - The Bailey Method was developed by Bob Bailey in the early 1980’s.
  - He retired as a civil engineer, who worked with the Illinois DOT, District 5 Materials Bureau for over 35 years
  - Research and Development of the Method has been continued by the Heritage Research Group of Indianapolis

What is the Bailey Method?

- The Bailey Method will
  - Evaluate individual aggregates
  - Determine what is “Coarse” and “Fine”
  - Evaluate aggregate packing characteristics
  - Combined blend by VOLUME and by weight
  - Estimate Air void and VMA changes due to gradation.

Aggregate Blending

- Trial and Error?
  - Specification Bands
    - Coarse
    - Medium
    - Fine
  - Which blend is best?
  - How will a gradation change affect Volumetric Properties
- Is there a more systematical way to calculate changes?
**What is VMA?**

VMA
- Volume of the voids in a compacted aggregate sample
- to accommodate asphalt and air.

**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

**VMA Characteristics**

![VMA Relationship Graph]

![Aggregate Packing Image]
**Aggregate Packing**

**What Influences the Results?**

- **Gradation**
  - continuously-graded, gap-graded, etc.
- **Shape**
  - flat & elongated, cubical, round
- **Surface Texture** (micro-texture)
  - smooth, rough
- **Type & Amount of Compactive Effort**
  - static pressure, impact or shearing
- **Strength**

**What Happens to Void Size & Space?**

**Principle #1 - P.C.S.**

- **All Round particles**
  
  $$\text{Void size} = 0.15 \times d$$

- **2 Round & 1 Flat**
  
  $$\text{Void size} = 0.20 \times d$$
**Principle #1 - P.C.S.**

**Diameter (d) = NMPS**

1 Round & 2 Flat

Void size = 0.24 x d

**All Flat particles**

Void size = 0.29 x d

Average Void size = 0.22 x d for all four conditions

**Primary Control Sieve = 0.22 x NMAS**
### Primary Control Sieve

<table>
<thead>
<tr>
<th>Mixture NMAS</th>
<th>NMAS x 0.22</th>
<th>Primary Control Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5mm (1-1/2”)</td>
<td>8.250mm</td>
<td>9.5mm (3/8”)</td>
</tr>
<tr>
<td>25.0mm (1”)</td>
<td>5.500mm</td>
<td>4.75mm (#4)</td>
</tr>
<tr>
<td>19.0mm (3/4”)</td>
<td>4.180mm</td>
<td>4.75mm (#4)</td>
</tr>
<tr>
<td>12.5mm (1/2”)</td>
<td>2.750mm</td>
<td>2.36mm (#8)</td>
</tr>
<tr>
<td>9.5mm (3/8”)</td>
<td>2.090mm</td>
<td>2.36mm (#8)</td>
</tr>
<tr>
<td>4.75mm (#4)</td>
<td>1.045mm</td>
<td>1.18mm (#16)</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.

### The Main Principles

- **Coarse Aggregate (CA)** – The largest particles that create voids in the mix.
  - and
- **Fine Aggregate (FA)** – The smaller particles that fill the voids created by the Coarse Aggregate.

### Bailey Method Mix Types

- The Bailey Method defines the mix type by volume of CA in the mix.
  - Laboratory Unit weight Tests are conducted to determine the volume of Coarse and Fine Aggregate Stockpiles.
**Loose Unit Weight - CA & FA**

- **NO** compactive effort
  - Std Unit Weight Bucket
- **Start** of particle-to-particle contact
- Determine **LUW**
  - Kg/m³ or lbs./ft³
- Determine **volume** of voids

**AASHTO T19**

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**Rodded Unit Weight - CA & FA**

- **With** compactive effort
  - 3 layers in Unit Wt Bucket
  - Rodded 25 times each
- **Increased** particle-to-particle contact
- Determine **RUW**
  - Kg/m³ or lbs./ft³
- Determine **volume** of voids

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**Fine-Graded Mixes**

- **CA Volume** < LUW
- **Little to No** particle-to-particle contact of CA
- **Fine** fraction carries most of the load

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**Coarse-Graded Mixes**

- **CA Volume** ≈ LUW
- **Some** particle-to-particle contact of CA
- **Coarse and Fine** fractions carry load
Stone Matrix Asphalt Mixes

- **CA Volume > RUW**
- **Coarse** fraction carries the load
- Remaining voids filled with **mastic**
  - FA, mineral filler, fibers & asphalt cement

Coarse vs. Fine aggregate

- The individual aggregates stockpiles must be categorized as Coarse or Fine.
- Stockpile passing the PCS of the Mix has:
  - more than 50% of the mix = Fine Aggregate.
  - less than 50% of the mix = Coarse Aggregate.

Comparison of Different CA's

- ACBF Slag
- Limestone
- Steel Slag

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Gsb</th>
<th>Gsb</th>
<th>Gsb</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACBF Slag</td>
<td>2.30</td>
<td>Limestone</td>
<td>2.63</td>
</tr>
<tr>
<td>Steel Slag</td>
<td>3.14</td>
<td>Steel Slag</td>
<td>2.30</td>
</tr>
</tbody>
</table>

All 3 at **their** corresponding **LUW**

- ACBF Slag: 1176.7 kg/m³, Voids = 48.8%
- Limestone: 1378.1 kg/m³, Voids = 47.6%
- Steel Slag: 1683.0 kg/m³, Voids = 46.4%

Chosen Unit Weight - CA(s)

- **< LUW**
- **LUW**
- **RUW**

- Fine-Graded: 60-85%
- Coarse-Graded: 95-105%
- SMA: 110-125%

**INCREASING CA CUW**
Why is mix type Important?

The Bailey Method will
– Estimate both due to gradation movement
  • Direction of VMA change and
  • Rate of VMA change.

The rate and direction of change is different for each type of mix!!!

VMA vs. CA Volume

Avoid these areas if possible

Bailey Method Perspective

• **Fine-graded mix**
  – Dense-graded mix
  – CA volume less than the CA LUW condition,
  – Coarse fraction is spread apart and floating in the fine fraction.

• **Coarse-graded mix**
  – Dense-graded mix
  – CA volume equal to or greater than the CA LUW condition
  – Represents the beginning of CA interlock.

• **Stone Matrix Asphalt (SMA)**
  – Gap-graded mix
  – CA volume greater than the CA RUW condition
  – Coarse fraction skeleton to carry the load.
Moral of the last slide

To design a mix with rock on rock contact,
• Determine the volume of coarse aggregate
• Then calculate the volume of fine aggregate necessary to fill the voids!

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. FAc ratio (Control with FA Volume blend)
   - As it increases, VMA decreases

4. FAf ratio (Control with % minus 0.075mm)
   - As it increases, VMA decreases

The Main Principles

- Coarse Aggregate Ratio (CA)
  - Relates to the coarse & intermediate fractions.
- Fine Agg Fine Ratio (FAf)
  - Relates to the amount of fine sand in the mix
- Fine Agg. Coarse Ratio (FAc)
  - Relates to the amount of large sand in the mix.
- Primary Control sieve (PCS)
  - Defines what is coarse and fine

Coarse-Graded & Fine Graded Mixes

Rules-of-thumb or ratios

Amount and Direction for each 1% Change in VMA

1. %PCS \( \pm \Delta \% = \pm 1\% \text{ VMA} \)
2. CA Ratio \( \pm \Delta = \pm 1\% \text{ VMA} \)
3. FAc Ratio \( \pm \Delta = \pm 1\% \text{ VMA} \)
4. FAf Ratio \( \pm \Delta = \pm 1\% \text{ VMA} \)
**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
  - For PROPOSED blend changes

- **Saves Time and Reduces Risk!**

**Does the Method Work?**

**AI Blend 4 & 6**
### The Bailey Method

#### Regularly Scheduled Courses

- **Introductory Course**
  - 1 – Day
  - 18 Hosted to date by SAPA

- **Main Course**
  - 3 – Days Early February & January
  - Lexington
  - Over 350 graduates

- **Advance Course**
  - 2 – Days
  - Lexington
  - Graduates with one year experience

Bill Pine – Heritage Research

- Advance Mix Design
- TRB Circular

#### Worldwide

- Canada
- Caribbean
- China
- France
- Russia
- South Africa

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**AI Blend 4 & 6**

<table>
<thead>
<tr>
<th></th>
<th>Blend 4</th>
<th>Blend 6</th>
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</thead>
<tbody>
<tr>
<td>25-mm</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>19-mm</td>
<td>98.7%</td>
<td>98.2%</td>
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<td>12.5-mm</td>
<td>89.9%</td>
<td>86.4%</td>
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<td>9.5-mm</td>
<td>74.4%</td>
<td>71.0%</td>
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<td>4.75-mm</td>
<td>38.4%</td>
<td>38.8%</td>
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<tr>
<td>2.36-mm</td>
<td>23.0%</td>
<td>25.1%</td>
</tr>
<tr>
<td>1.18-mm</td>
<td>15.7%</td>
<td>17.7%</td>
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<tr>
<td>0.6-mm</td>
<td>11.2%</td>
<td>12.6%</td>
</tr>
<tr>
<td>0.3-mm</td>
<td>7.8%</td>
<td>7.8%</td>
</tr>
<tr>
<td>0.15-mm</td>
<td>5.9%</td>
<td>5.3%</td>
</tr>
<tr>
<td>0.075-mm</td>
<td>5.2%</td>
<td>4.6%</td>
</tr>
</tbody>
</table>

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“I got to the lab the day after attending the class and we had a mix design problem.

I plugged the gradations into the Bailey spreadsheet and it told me to take the mix in a direction I would never taken

When we got the results back the volumetrics were right down the middle”

- Graduate of the 3-day Bailey Course
The Bailey Method

• “This class answered 95% of the questions I’ve had over the last 30 years of doing mix designs
• And showed me how to find the answers on the remaining 5%”
  • Graduate of the 3-day Bailey Course

The Bailey Method

• “To sum it all up in numbers, last year we lost around $250,000 in deducts for Voids, VMA, and Compaction.
• This year, using the Bailey Method, we are up $300,000 in incentives.
• To make this an even greater accomplishment, we achieved this on half of the incentive jobs we had last year.”
  • Graduate of the 3-day Bailey Course

Thanks!

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