Optimized Mix Design Approach

Asphalt Mixture and Construction Expert Task Group (ETG) Meeting, April 8, 2015
Fall River, MA

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Oldcastle Materials
Discussion Topics

- Why the need for an Optimized Mix Design (OMD) Approach?
- What is currently being done in response to observed performance issues?
- What is the proposed framework for OMD?
- What are the next steps?
Why the Need for a New Mix Design Approach?

- Continuing to increase binder replacement without addressing mix performance is not sustainable
  - Recognize performance issues related to dry mixes exist in some areas and start working toward a solution
  - Issues are concerning to Oldcastle and the Industry
  - NAPA recently created the Pavement Performance Task Group in response to concerns
- Increase our understanding of the factors which drive mix performance to help us optimize our mixes
- Start thinking outside of long held “rules and constraints” and utilize more creativity and innovation
- Better apply the knowledge and resources that exists within the asphalt industry
- Take the lead and be a quality leader, good partner, and innovator
Steps Must be Taken *Now* Towards Solutions

- Long term research is certainly needed, but we must take steps *now* towards a solution
- **Each day**, approximately 1.4 Million tons of HMA are produced in the U.S. (M-F production basis)
  - *Equivalent to ~2500 lane miles @ 12’ wide and 1.5” thick*
  - *Distance from New York to Las Vegas*
Superpave system is quickly becoming unrecognizable

Specifications are changing rapidly as agencies search for ways to improve durability
- Lowering gyrations
- Increasing VMA
- Lowering air voids
- Lowering gyrations + Increasing VMA + Lowering air voids
- Minimum film thickness
- Minimum binder content by mass (non-aggregate gravity adjusted)
- Limiting recycle
- Softer PG binders
- Establishing “cause and effect” is difficult to impossible

Focus Needs to be on Obtaining the Appropriate Effective Binder Volume (Vbe) for the Given Mix and Application
Gyration levels vary widely

Levels are being reduced with the intent of gaining more binder content in mixes

**Problem:** Mixes are designed to meet specifications while minimizing cost with lower gyrations not always equating to more binder

<table>
<thead>
<tr>
<th>State</th>
<th>Gyration Level¹</th>
<th>Notes</th>
<th>State</th>
<th>Gyration Level¹</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>60</td>
<td>All Mixes</td>
<td>New Mexico</td>
<td>75, 100, 125</td>
<td>75 low volume, 125 urban interstates, 100 res</td>
</tr>
<tr>
<td>Arkansas</td>
<td>50, 75, 100, 125</td>
<td></td>
<td>New York</td>
<td>50, 75, 100</td>
<td>50 and 100 rarely used</td>
</tr>
<tr>
<td>Colorado</td>
<td>75, 100</td>
<td>100 mm diameter specimens</td>
<td>North Carolina</td>
<td>50, 65, 75, 100</td>
<td>50 for low volume fine 9.5 mix</td>
</tr>
<tr>
<td>Connecticut</td>
<td>75, 100</td>
<td>Towns/municipalities use 50</td>
<td>Ohio</td>
<td>65</td>
<td>All Mixes</td>
</tr>
<tr>
<td>Florida</td>
<td>50, 65, 75, 100</td>
<td>Most are 75 level C and 100 level D/E</td>
<td>Oklahoma</td>
<td>64-22 (50), 70-28 (60), and 76-28 (80)</td>
<td>Vary based on PG binder</td>
</tr>
<tr>
<td>Idaho</td>
<td>50, 75, 100, 125</td>
<td></td>
<td>Oregon</td>
<td>65, 80, 100</td>
<td></td>
</tr>
<tr>
<td>Iowa</td>
<td>50, 60, 65, 68, 76, 86, 96, 109, 126</td>
<td>Original Nd levels + 3 low volume mixes levels</td>
<td>Pennsylvania</td>
<td>50, 75, 100</td>
<td></td>
</tr>
<tr>
<td>Kansas</td>
<td>75, 100</td>
<td>Researching going to 60 or 3% air voids at 75</td>
<td>Rhode Island</td>
<td>50</td>
<td>DOT guides producer into gradings with higher AC; will specify H, V, L binders to combat rutting</td>
</tr>
<tr>
<td>Kentucky</td>
<td>50, 75, 100</td>
<td></td>
<td>Tennessee</td>
<td>65 or 75 Marshall</td>
<td></td>
</tr>
<tr>
<td>Maine</td>
<td>50, 75</td>
<td>50 used more within last 3 to 5 years</td>
<td>Texas</td>
<td>50</td>
<td>Engineer can reduce gyrations to between 35 and 50.</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>50, 75, 100</td>
<td>75 and 100 most common</td>
<td>Utah</td>
<td>50, 75, 100, 125</td>
<td>Mostly 75 Ndesign, 12.5 mm w/ 3.5% air voids</td>
</tr>
<tr>
<td>Michigan</td>
<td>45, 50, 76, 86, 96, 109, 126</td>
<td>Original Nd levels + 2 low volume mixes levels</td>
<td>Vermont</td>
<td>50, 65, 80</td>
<td>50 and 80 rarely used</td>
</tr>
<tr>
<td>Minnesota</td>
<td>40, 60, 90, 100</td>
<td>For &lt;1, 1-3, 3-10, &gt;10M ESAL</td>
<td>Virginia</td>
<td>65</td>
<td>All Mixes. Researching 50 gyrations for some mixes based on Marshall C mixes w/ desire to have additional 0.2% binder.</td>
</tr>
<tr>
<td>Mississippi</td>
<td>50, 65, 85</td>
<td></td>
<td>Washington</td>
<td>50, 75, 100, 125</td>
<td></td>
</tr>
<tr>
<td>Missouri</td>
<td>50, 75, 80, 100, 125</td>
<td>Ni and Nm still specified for 125 HV mix</td>
<td>West Virginia</td>
<td>50, 65, 80, 100</td>
<td>80 and 100 drop to 65 and 80, respectively if PG 76 is used or mix placed below top two lifts</td>
</tr>
<tr>
<td>Montana</td>
<td>75</td>
<td>Went to 75 from 100 in lieu of 100 and min. film thickness</td>
<td>Ne aid</td>
<td>40, 65, 95</td>
<td>40 shoulder, 65 low volume, 95 high volume</td>
</tr>
<tr>
<td>Nebraska</td>
<td>40, 65, 95</td>
<td></td>
<td>Nevada</td>
<td>Use Hveem</td>
<td></td>
</tr>
<tr>
<td>Nevada</td>
<td>Use Hveem</td>
<td></td>
<td>New Hampshire</td>
<td>50, 75</td>
<td>3 to 3.5 air voids on 9.5 mm 75 gyr</td>
</tr>
<tr>
<td>New Jersey</td>
<td>50, 75</td>
<td>50 rarely used</td>
<td>New Jersey</td>
<td>50, 75</td>
<td>3 to 3.5 air voids on 9.5 mm 75 gyr</td>
</tr>
</tbody>
</table>

Note: 1) Gyration level highlighted in "Bold" indicates main level used.
Agencies are Searching for Solutions: Example 1

- Alabama DOT
- Nd = 60 gyrations for all mixes
- Increased VMA + minimum total binder content for non-RAS and RAS mixes (0.2% higher) + 3.5% design voids for RAS mixes
Agencies are Searching for Solutions: Example 2

- Virginia DOT
- Nd = 65 for all mixes

**TABLE II-14**

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>VTM (%) Production (Note 1)</th>
<th>VFA (%) Design</th>
<th>VFA (%) Production (Note 2)</th>
<th>Min. VMA (%)</th>
<th>Fines/Asphalt Ratio (Note 3)</th>
<th>No. of Gyrrations N Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM-9.0A</td>
<td>2.0-5.0</td>
<td>75-80</td>
<td>70-85</td>
<td>16</td>
<td>0.6-1.3</td>
<td>65</td>
</tr>
<tr>
<td>SM-9.0D</td>
<td>2.0-5.0</td>
<td>75-80</td>
<td>70-85</td>
<td>16</td>
<td>0.6-1.3</td>
<td>65</td>
</tr>
<tr>
<td>SM-9.0E</td>
<td>2.0-5.0</td>
<td>75-80</td>
<td>70-85</td>
<td>16</td>
<td>0.6-1.3</td>
<td>65</td>
</tr>
<tr>
<td>SM-9.5A</td>
<td>2.0-5.0</td>
<td>73-79</td>
<td>68-84</td>
<td>15</td>
<td>0.6-1.2</td>
<td>65</td>
</tr>
<tr>
<td>SM-9.5D</td>
<td>2.0-5.0</td>
<td>73-79</td>
<td>68-84</td>
<td>15</td>
<td>0.6-1.2</td>
<td>65</td>
</tr>
<tr>
<td>SM-9.5E</td>
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<td>73-79</td>
<td>68-84</td>
<td>15</td>
<td>0.6-1.2</td>
<td>65</td>
</tr>
<tr>
<td>SM-12.5A</td>
<td>2.0-5.0</td>
<td>70-78</td>
<td>65-83</td>
<td>14</td>
<td>0.6-1.2</td>
<td>65</td>
</tr>
<tr>
<td>SM-12.5D</td>
<td>2.0-5.0</td>
<td>70-78</td>
<td>65-83</td>
<td>14</td>
<td>0.6-1.2</td>
<td>65</td>
</tr>
<tr>
<td>SM-12.5E</td>
<td>2.0-5.0</td>
<td>70-78</td>
<td>65-83</td>
<td>14</td>
<td>0.6-1.2</td>
<td>65</td>
</tr>
<tr>
<td>IM-19.0A</td>
<td>2.0-5.0</td>
<td>69-76</td>
<td>64-81</td>
<td>13</td>
<td>0.6-1.2</td>
<td>65</td>
</tr>
<tr>
<td>IM-19.0D</td>
<td>2.0-5.0</td>
<td>69-76</td>
<td>64-81</td>
<td>13</td>
<td>0.6-1.2</td>
<td>65</td>
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<tr>
<td>IM-19.0E</td>
<td>2.0-5.0</td>
<td>69-76</td>
<td>64-81</td>
<td>13</td>
<td>0.6-1.2</td>
<td>65</td>
</tr>
<tr>
<td>BM-25.0A</td>
<td>1.0-4.0</td>
<td>67-87</td>
<td>67-92</td>
<td>12</td>
<td>0.6-1.3</td>
<td>65</td>
</tr>
<tr>
<td>BM-25.0D</td>
<td>1.0-4.0</td>
<td>67-87</td>
<td>67-92</td>
<td>12</td>
<td>0.6-1.3</td>
<td>65</td>
</tr>
</tbody>
</table>

1SM = Surface Mixture; IM = Intermediate Mixture; BM = Base Mixture.

Note 1: Asphalt content should be selected at 4.0 % Air Void.

Note 2: During production of an approved job mix, the VFA shall be controlled within these limits.

Note 3: Fines/asphalt ratio is based on effective asphalt content.

Note 4: Base mix shall be designed at 2.5% air voids. BM-25.0A shall have a minimum asphalt content of 4.4% unless otherwise approved by the Engineer. BM-25.0D shall have a minimum asphalt content of 4.6% unless otherwise approved by the Engineer.
Enhancing the Durability of Asphalt Pavements

Impact of Mix Design on Asphalt Pavement Durability

Ramon Bonaquist
Advanced Asphalt Technologies, LLC

- "VBE is the primary mixture design factor affecting both durability and fatigue cracking resistance. Durability and fatigue resistance improve with increasing VBE."

- "Stone matrix asphalt (SMA) mixtures, which are considered to be extremely durable and crack resistant, have the highest minimum design VBE."

- "The mix design manual developed in NCHRP Project 9-33 recommends that agencies should consider increasing the design VMA by 1.0% “to obtain mixtures with increased asphalt binder content, which can improve field compaction, fatigue resistance, and general durability”

- "A number of state highway agencies have decreased the design gyration levels in an attempt to increase effective binder contents. However, decreasing the design gyrations may not always produce mixtures with higher VBE. If a producer is able to change gradation or the source of some of the aggregates in the mixture, it may be possible to remain near the minimum design VBE at the lower gyration level.”
Balanced Mix Design Approaches are Currently Utilized by Some Agencies

- Texas (Hamburg + OT)
- Louisiana (Hamburg + SCB)
- New Jersey (APA + OT)

Questions

- While the utilized balanced approach design may be an improvement, is it appropriate for all mixes?
  - For example,
    - 1) Are universal volumetrics (e.g., VMA and air voids) controlling without regard to traffic?
    - 2) Are the utilized performance tests appropriate for the probable mode of distress?
Mix Design Approaches

- **Indiana**: Matching design and field compaction (5-5)
  - Key points....
    - Target 5% air voids for lab and field compaction
    - Ndesign of 50
    - M323 Vbe used (VMA – Va @ 4%)
      - Drive up liquid and adjust aggregate structure accordingly.
  - Improved stiffness compared to M323 designs @ Nd = 100 and 7% field air voids.
Optimized Mix Design Overview
1890
- Barber Asphalt Paving Company
  - Asphalt cement 12 to 15% / Sand 70 to 83% / Pulverized carbonite of lime 5 to 15%

1905
- Clifford Richardson, New York Testing Company
  - Surface sand mix: 100% passing No. 10, 15% passing No. 200, 9 to 14% asphalt
  - Asphaltic concrete for lower layers, VMA terminology used, 2.2% more VMA than current day mixes or ~0.9% higher binder content

1920s
- Hubbard Field Method (Charles Hubbard and Frederick Field)
  - Sand asphalt design
  - 30 blow, 6” diameter with compression test (performance) asphaltic concrete design (Modified HF Method)

1927
- Francis Hveem (Caltrans)
  - Surface area factors used to determine binder content; Hveem stabilometer and cohesionmeter used
  - Air voids not used initially, mixes generally drier relative to others, fatigue cracking an issue

1943
- Bruce Marshall, Mississippi Highway Department
  - Refined Hubbard Field method, standard compaction energy with drop hammer
  - Initially, only used air voids and VFA, VMA added in 1962; stability and flow utilized

1993
- Superpave
  - Level 1 (volumetric)
  - Level 2 and 3 (performance based, but never implemented)

Conventional Mix Design Thoughts

- Largely **recipe driven** based on what we think works
  - Items specified
    - Aggregates (via spec. property requirements)
    - Blend grading
    - Volumetrics
      - Air voids, VMA, VFA, Dust/Aceff, film thickness, etc.
    - PG binder type and minimum amount in some cases
    - RAP and/or RAS content
    - Other additives use and amount

- **Problem**....
  - Recipe specifications have become convoluted and confounded over time with *specified items competing against each other to achieve the desired goals*
    - New requirements get added and nothing gets removed
    - Innovation has become stifled with our knowledge outpacing specifications
Let’s stop using a recipe to “bake the cake”. Define what you want in the cake and open up the recipe to meet the end result.

- What defines a good cake? Good Taste
- What defines a good mix? Optimized Performance

Optimized Mix Design Approach Foundational Points

- “Use what works”
- “Eliminate what doesn’t”
- “Be simple and practical”

Build on our existing knowledge foundation.
- “Good doesn’t have to be complicated and complicated isn’t always good.”
What is a “Good” Mix Design?

- Depends on how we define “Good”.
- “Good” is not defined by any one of these factors alone
  - Cheap or Expensive
  - Simple or Complex
  - Empirical or Theoretical (Mechanistic)
  - Quick or Slow to design
  - Virgin or High Binder Replacement
  - Workable or Harsh
  - Consistent or Erratic properties
  - Zero penalties or Abundant penalties
- A “good” mix must be at least partially defined as one that meets the requirements of the job (specification compliance and/or customer expectations, and performance) while being designed using an optimized approach which considers cost.
An optimized design approach should yield a mix which meets the mix design and production goals.
A mix needs appropriate binder to have good stability (resist rutting) and durability (resist cracking) performance.

- A given mix may have many “design” binder contents, but only one “optimum”

- **Must move away from the philosophy of “putting as little binder in the mix as possible just to limit cracking”**

- Greatly limit the “rules” for the mix designer
  - Eliminate/reduce restrictions for
    - Recycle,
    - Aggregate blend grading,
    - Aggregate,
    - PG binder,
    - Volumetrics
  - Focus on the end result of **PERFORMANCE**
Optimized Mix Design Approach (OMEGA)

I. Material Evaluation and Selection

II. Mixture Stability Performance Evaluation

III. Mixture Durability Performance Evaluation

IV. Mixture Workability Evaluation
Material Evaluation and Selection

- Emphasis on using local materials, maximizing recycle, and engineering the binder for the given application while keeping performance in mind.
- Increased awareness and focus needed on importance of material properties (e.g., RAP aggregate gravity and recycled binder continuous grading).

Optimized Mix Design Approach – Framework

**MATERIAL SELECTION**

**AGGREGATE SELECTION**
- Utilize locally available materials provided fundamental property requirements are met.
- Focus on balancing quarry production (use what we make).
- Effective communication between aggregate/asphalt LOB.
- Utilize total cost of ownership in selecting aggregate products. Consider aggregate cost, drying energy, and specification compliance.

**BINDER SELECTION**
- Determine the true PG classification for the virgin binder and any recycled products considered for use.
- Utilize LTPP software to determine the needed PG binder for the given project location.
- Perform binder blending to evaluate the final composite PG grade required for the given project location or specification requirement.

**RECYCLE SELECTION**
- Maximize recycle based on mix performance, recycle availability and economics.
- Conduct binder grading analysis on all recycled products for binder blending efforts.
- Investigate asphalt rejuvenator use.

**OPTIMUM BINDER CONTENT SELECTION**
Optimized Mix Design Approach – Framework

• Optimum Binder Content Selection (Key Points)
  • Design based on volume w/ a single gyration level used (e.g., locking point), 60 to 75 gyrations is typical
  • Understand that gyration level does actually control binder content
  • Stop breaking aggregate during compaction and establishing unrealistic and unnecessary targets for field.
  • Volumetrics calculated for information purposes

OPTIMUM BINDER CONTENT SELECTION

OPTIMIZE BINDER VOLUME
• Design mixes based on optimizing asphalt binder volume for given aggregate blend
• Utilize one gyratory compaction level for all mixes
• Calculate Volumetric Properties for Information and Guidance

UTILIZE ONE GYRATION LEVEL (N_{design})
• Establish One N_{design} Level Based on Locking Point Type Concept (60 to 75 gyrations)
• Locking point = 1st of 3 consecutive gyrations with the same height
• Sufficient to lock aggregate structure together, but not to degrade aggregate.

CALCULATE TRADITIONAL VOLUMETRIC PROPERTIES FOR INFORMATION ONLY
• Design will be performance based and not strictly dependent on meeting volumetric property requirements.
Optimized Mix Design Approach – Framework

- Locking point or point where aggregate structure is “established” will obviously vary.
  - 1\textsuperscript{st} of 3 consecutive, 1\textsuperscript{st} of 2 consecutive, 3-2-2, etc.
- Agencies are typically using 60 to 75 gyrations for most of their designs, which is in the “range” of locking point determinations.
- Establish for a given mix in consideration
- Compact specimens at Pb based on Vbe for anticipated traffic.
Optimized Mix Design Approach – Framework

**Optimum Binder Content Selection**

- Estimate **target effective binder volume (Vbe)** based on NMAS and traffic level
  - Smaller NMAS and lower traffic mixes need more binder
  - Adjust virgin binder content as a function of RAP and RAS addition to compensate for lack of 100% recycled binder contribution
  - Conduct mix design compaction at four binder contents (Vbe min, Vbe min-0.50, Vbe min - 1.0, Vbe min + 0.50)

**ASPHALT BINDER % DETERMINATION**

1. Estimate target binder content (by mass) based on achieving target minimum volume of effective binder (Vbe) for various NMAS as below:

<table>
<thead>
<tr>
<th>NMS</th>
<th>Target Minimum Binder Volume at Traffic Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>4.75</td>
<td>13.0</td>
</tr>
<tr>
<td>9.5</td>
<td>12.0</td>
</tr>
<tr>
<td>12.5</td>
<td>11.0</td>
</tr>
<tr>
<td>19</td>
<td>10.0</td>
</tr>
<tr>
<td>25</td>
<td>9.0</td>
</tr>
<tr>
<td>37.5</td>
<td>8.0</td>
</tr>
</tbody>
</table>

2. Conduct mix design compaction at four binder contents (Vbe min, Vbe min-0.50, Vbe min - 1.0, Vbe min + 0.50).

**Vbe Adjustment for Recycle**

Recycle mixes will likely require additional considerations to help ensure sufficient Vbe is present. Options include adding additional virgin binder or rejuvenators to gain more effective binder from the recycle. Economics of both approaches should be evaluated along with the subsequent performance testing.

1. Make virgin binder addition adjustment to compensate for lack of 100% binder contribution from recycle products

**Initial Rule of Thumb**

**Additional Virgin Binder % = 0.005 (RAP%) + 0.055 (RAS%)**

Based on assumption that 90 and 70% of RAP and RAS binder contributes, respectively.

2. Utilize rejuvenators to increase the effective binder content from the recycle products.
Initial Vbe Estimation

- As starting point, utilize the M323 VMA requirement to drive the required Vbe for high volume mixes.
- Increase the Vbe by 0.5 and 1.0% for medium and low volume traffic respectively.
- **0.2% Vbe ~ 0.1% Pbe**
- Calculate the Pbe (mass) based on the aggregate blend Gsb value
  - **CRITICAL** to have accurate Gsb on blend.

<table>
<thead>
<tr>
<th>NMS</th>
<th>M323 VMA</th>
<th>Air Voids</th>
<th>VMA Target at Traffic Level</th>
<th>Target Minimum Binder Volume at Traffic Level</th>
<th>Estimated Effective Binder Content (Pbe) @ Gsb = 2.65</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>4.75</td>
<td>16</td>
<td>4</td>
<td>17</td>
<td>16.5</td>
<td>16</td>
</tr>
<tr>
<td>9.5</td>
<td>15</td>
<td>4</td>
<td>16</td>
<td>15.5</td>
<td>15</td>
</tr>
<tr>
<td>12.5</td>
<td>14</td>
<td>4</td>
<td>15</td>
<td>14.5</td>
<td>14</td>
</tr>
<tr>
<td>19</td>
<td>13</td>
<td>4</td>
<td>14</td>
<td>13.5</td>
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<tr>
<td>25</td>
<td>12</td>
<td>4</td>
<td>13</td>
<td>12.5</td>
<td>12</td>
</tr>
<tr>
<td>37.5</td>
<td>11</td>
<td>4</td>
<td>12</td>
<td>11.5</td>
<td>11</td>
</tr>
</tbody>
</table>
Total Binder Estimation from Vbe

- Total binder content (Pb) can then be estimated using basic volumetrics.

<table>
<thead>
<tr>
<th>Property/Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate Blend Bulk Specific Gravity, Gsb</td>
<td>2.650</td>
</tr>
<tr>
<td>Aggregate Blend Effective Specific Gravity, Gse</td>
<td>2.675</td>
</tr>
<tr>
<td>Target Minimum Volume of Effective Binder (Vbe min), %</td>
<td>11.0</td>
</tr>
<tr>
<td>Effective Binder Content (Pbe @ Vbe min), %</td>
<td>4.75</td>
</tr>
<tr>
<td>Absorbed Binder Content (Pba @ Vbe min), %</td>
<td>0.36</td>
</tr>
<tr>
<td>Total Binder Content @ Vbe min, %</td>
<td>5.09</td>
</tr>
</tbody>
</table>
**Recycle Binder Adjustment**

- **Assumption:** 90 and 70%, respectively of the RAP and RAS binder effectively contributes to the total mix binder.
  - Is this correct? No one knows, but common sense says not all binder is contributing.
- What is the impact from this adjustment?
  - At the surface, there is an obvious increase in virgin liquid cost
  - However, optimized mix design approach could open the door for more creativity and innovation which would offset cost and potentially yield more savings.

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**Vbe Adjustment for Recycle**

Recycle mixes will likely require additional considerations to help ensure sufficient Vbe is present. Options include adding additional virgin binder or rejuvenators to gain more effective binder from the recycle. Economics of both approaches should be evaluated along with the subsequent performance testing.

1. Make virgin binder addition adjustment to compensate for lack of 100% binder contribution from recycle products

**Initial Rule of Thumb**

\[ \text{Additional Virgin Binder} \% = 0.005 \times \text{(RAP\%)} + 0.055 \times \text{(RAS\%)} \]

Based on assumption that 90 and 70% of RAP and RAS binder contributes, respectively.

2. Utilize rejuvenators to increase the effective binder content from the recycle products.
20% RAP Comparison (100% and 90% Binder Contribution)

<table>
<thead>
<tr>
<th>Materials and Mix Characteristics</th>
<th>100% RAP</th>
<th>90% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP Binder Content, %</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>RAS Binder Content, %</td>
<td>20.0</td>
<td></td>
</tr>
<tr>
<td>Effective RAP Binder Contribution, %</td>
<td>100.0</td>
<td>90.0</td>
</tr>
<tr>
<td>Effective RAS Binder Contribution, %</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Total Mix Asphalt Binder Content, %</td>
<td>5.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material Costs</th>
<th>100% RAP</th>
<th>90% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin Asphalt Binder Cost / Ton, $</td>
<td>500.00</td>
<td></td>
</tr>
<tr>
<td>Virgin Aggregate Blend Cost, $</td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>RAP Cost / RAP Ton, $</td>
<td>8.00</td>
<td></td>
</tr>
<tr>
<td>RAS Cost / RAS Ton, $</td>
<td>20.00</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material Costs (As Used in Mix)</th>
<th>100% RAP</th>
<th>90% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP Cost / Mix Ton, $</td>
<td>1.60</td>
<td></td>
</tr>
<tr>
<td>RAS Cost / Mix Ton, $</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>RAP + RAS Cost / Mix Ton, $</td>
<td>1.60</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Binder Replacement</th>
<th>100% RAP</th>
<th>90% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP Binder Provided, %</td>
<td>1.00</td>
<td>0.90</td>
</tr>
<tr>
<td>RAS Binder Provided, %</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Total Recycle Binder Provided, %</td>
<td>1.00</td>
<td>0.90</td>
</tr>
<tr>
<td>Binder Replacement from Recycled, %</td>
<td>18.18</td>
<td>16.36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Savings</th>
<th>100% RAP</th>
<th>90% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP Net Savings / Mix Ton, $</td>
<td>5.30</td>
<td>4.80</td>
</tr>
<tr>
<td>RAS Net Savings / Mix Ton, $</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>RAP + RAS Net Savings / Mix Ton, $</td>
<td>5.30</td>
<td>4.80</td>
</tr>
</tbody>
</table>
RAP Savings Impact

- Lost savings ($0.50/ton) from using 90% effective RAP binder contribution can be recovered by using a relatively small amount more RAP.
- 23% vs 20% in this example.
- 23% @ 90% contribution = $5.52 compared to $5.30 (20% at 100% contribution)

### RAP Savings (Binder + Aggregate) "What If" Table - RAP Eff. Binder Cont.

<table>
<thead>
<tr>
<th>Net Savings</th>
<th>Effective Binder Contribution From RAP, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>15</td>
<td>2.10 2.29 2.48 2.66 2.85 3.04 3.23 3.41 3.60 3.79</td>
</tr>
<tr>
<td>16</td>
<td>2.24 2.44 2.64 2.84 3.04 3.24 3.44 3.64 3.84 4.04</td>
</tr>
<tr>
<td>17</td>
<td>2.38 2.59 2.81 3.02 3.23 3.44 3.66 3.87 4.08 4.29</td>
</tr>
<tr>
<td>18</td>
<td>2.52 2.75 2.97 3.20 3.42 3.65 3.87 4.10 4.32 4.55</td>
</tr>
<tr>
<td>19</td>
<td>2.66 2.90 3.14 3.37 3.61 3.85 4.09 4.32 4.56 4.80</td>
</tr>
<tr>
<td>20</td>
<td>2.80 3.05 3.30 3.55 3.80 4.05 4.30 4.55 4.80 5.05</td>
</tr>
<tr>
<td>21</td>
<td>2.94 3.20 3.47 3.73 3.99 4.25 4.52 4.78 5.04 5.30</td>
</tr>
<tr>
<td>22</td>
<td>3.08 3.36 3.63 3.91 4.18 4.46 4.73 5.01 5.28 5.56</td>
</tr>
<tr>
<td>23</td>
<td>3.22 3.51 3.80 4.08 4.37 4.66 4.95 5.23 5.52 5.81</td>
</tr>
<tr>
<td>24</td>
<td>3.36 3.66 3.96 4.26 4.56 4.86 5.16 5.46 5.76 6.06</td>
</tr>
<tr>
<td>25</td>
<td>3.50 3.81 4.13 4.44 4.75 5.06 5.38 5.69 6.00 6.31</td>
</tr>
<tr>
<td>26</td>
<td>3.64 3.97 4.29 4.62 4.94 5.27 5.59 5.92 6.24 6.57</td>
</tr>
<tr>
<td>27</td>
<td>3.78 4.12 4.46 4.79 5.13 5.47 5.81 6.14 6.48 6.82</td>
</tr>
<tr>
<td>28</td>
<td>3.92 4.27 4.62 4.97 5.32 5.67 6.02 6.37 6.72 7.07</td>
</tr>
<tr>
<td>29</td>
<td>4.06 4.42 4.79 5.15 5.51 5.87 6.24 6.60 6.96 7.32</td>
</tr>
<tr>
<td>30</td>
<td>4.20 4.58 4.95 5.33 5.70 6.08 6.45 6.83 7.20 7.58</td>
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<tr>
<td>31</td>
<td>4.34 4.73 5.12 5.50 5.89 6.28 6.67 7.05 7.44 7.83</td>
</tr>
<tr>
<td>32</td>
<td>4.48 4.88 5.28 5.68 6.08 6.48 6.88 7.28 7.68 8.08</td>
</tr>
<tr>
<td>33</td>
<td>4.62 5.03 5.45 5.86 6.27 6.68 7.10 7.51 7.92 8.33</td>
</tr>
<tr>
<td>34</td>
<td>4.76 5.19 5.61 6.04 6.46 6.89 7.31 7.74 8.16 8.59</td>
</tr>
<tr>
<td>35</td>
<td>4.90 5.34 5.78 6.21 6.65 7.09 7.53 7.96 8.40 8.84</td>
</tr>
<tr>
<td>36</td>
<td>5.04 5.49 5.94 6.39 6.84 7.29 7.74 8.19 8.64 9.09</td>
</tr>
<tr>
<td>37</td>
<td>5.18 5.64 6.11 6.57 7.03 7.49 7.96 8.42 8.88 9.34</td>
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<tr>
<td>38</td>
<td>5.32 5.80 6.27 6.75 7.22 7.70 8.17 8.65 9.12 9.60</td>
</tr>
<tr>
<td>39</td>
<td>5.46 5.95 6.44 6.92 7.41 7.90 8.39 8.87 9.36 9.84</td>
</tr>
<tr>
<td>40</td>
<td>5.60 6.10 6.60 7.10 7.60 8.10 8.60 9.10 9.60 10.10</td>
</tr>
</tbody>
</table>
A performance based system greatly enhances the mix designer’s ability to utilize creative thinking and innovative concepts and creative thinking.

- Knowledge and experience may be outpacing specifications in some areas

Asphalt demand for mixes may increase using an optimized mix design approach; however, the cost can potentially be offset by many items:

- Local aggregate materials
- Capped aggregate products
- Alternate blend gradings
- Alternate binders
- Optimized use of recycled products (RAP, RAS, GTR, etc.)
- Additives (WMA, rejuvenators, etc.) use
- “XYZ Technology of Tomorrow”

Performance must be achieved without question or exception.
Optimized Mix Design Approach – Framework

- **Check Stability**
  - Utilize one of several available “rutting” evaluation tools.
  - Failure criteria based on best available research (local, regional, or national)

### MIX PERFORMANCE EVALUATION

#### DETERMINE RESISTANCE TO RUTTING
- Conduct testing with the asphalt pavement analyzer, Hamburg wheel tracker, or other accepted permanent deformation test.
- Set pass/fail criteria based on desired performance and placement within the pavement system.

#### Asphalt Pavement Analyzer
- AASHTO T340
- Maximum rut depth = 7 mm @ 8,000 cycles.

#### Hamburg Wheel Tracker
- AASHTO T324
- Maximum rut depth of 12.5 mm @ 20,000 cycles

### Accelerated Mix Performance Test (AMPT)
- AASHTO TP79
- Test temperature at 50% high pavement temperature reliability
- 20 mm depth for surface courses and top of pavement layer for intermediate and base

<table>
<thead>
<tr>
<th>Design Traffic, Million ESAL</th>
<th>HMA¹</th>
<th>WMA¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>3 to &lt; 10</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>10 to &lt; 30</td>
<td>190</td>
<td>105</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>740</td>
<td>415</td>
</tr>
</tbody>
</table>

¹ HMA conditioned 4 hours at 135 °C, WMA conditioned 2 hours at field compaction temperature.
Optimized Mix Design Approach – Framework

- **Check Durability**
  - Utilize one of many available “cracking” evaluation tools based on distress of interest
  - Failure criteria based on best available research (local, regional, or national)

**DETERMINE RESISTANCE TO CRACKING**
- Conduct testing using the bending beam fatigue, semi circular bend, disk shaped compression, etc.
  - Set pass/fail criteria based on desired performance and placement within the pavement system

**Utilize Locally Established Test Procedures**
1. Bending Beam Fatigue
2. Semi Circular Bend (SCB)
3. Disk Shaped Comact Tension (DCT)
4. Indirect Tensile Fracture Energy

**Bending Beam Fatigue**
- AASHTO T321
  - Target strain test level based on depth of mix from final surface
  - Test at multiple strain levels to establish fatigue life curve
  - Minimum 100,000 fatigue cycles to failure

**Semi Circular Bend**
- Test at 25C and 0.5 mm/min vertical loading rate
  - Minimum fracture resistance (Jc), (no formal design criteria established)
Check Durability (cont.)

- Cracking prediction is a known “weak” link in performance testing
- No general consensus on what is the best test or the appropriate failure threshold.
What is the Appropriate Cracking Test?

- The search continues......

NCHRP 09-57 [Active]

**Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures**

<table>
<thead>
<tr>
<th>Project Data</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Funds:</td>
<td>$250,000</td>
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<tr>
<td>Staff Responsibility:</td>
<td>Edward T. Harrigan</td>
</tr>
<tr>
<td>Research Agency:</td>
<td>Texas A&amp;M Transportation Institute</td>
</tr>
<tr>
<td>Principal Investigator:</td>
<td>Fujie Zhou</td>
</tr>
<tr>
<td>Effective Date:</td>
<td>9/1/2014</td>
</tr>
<tr>
<td>Completion Date:</td>
<td>3/1/2016</td>
</tr>
</tbody>
</table>

2015 Track Research Cycle
- ~ 3 yr. cycle length
Optimized Mix Design Approach – Framework

- Alternate Check Durability
  - Cantabro test can provide a very quick, low cost durability measure

Diagram:

Cantabro Abrasion
- Utilize Cantabro abrasion test as a surrogate durability test.
- Test on compacted mix design specimens.
- LA drum @ 77F, 300 revolutions w/ no spheres
- Measure mass loss
- Tentative max mass loss of 10% (adjust limit based on local experience)

From: Issac Howard, SEAUPG 2014
• Evaluate Total Performance
  • Make necessary adjustments to improve stability and/or durability
  • If acceptable, proceed to economic analysis
Design Performance Curves - Example

Is there potential to set binder based on rutting alone. For example, select binder at ~80% of threshold for example (7 * 0.80 = 5.6 mm)

APA Criterion = 7 mm max

Cantabro Criterion = 10% max

Benefit is understanding performance at range of binder contents.
Other Possible Mix Evaluation Methods

- Desired attributes (Design + QC)
  - Minimal time + effort, expense, specimen preparation
  - Maximum use, understanding, performance correlation

- Marshall Stability and Flow
  - Min stability and Min flow

- Marshall Quotient or Stiffness (Stability/flow):
  - High values = stiff mixes

- Indirect Tensile
  - Strength (dry): High values = generally stiffer mixes
  - Failure strain: Low strains @ failure = generally stiffer mixes

Could the Old Become New Again?
Optimized Mix Design Approach – Framework

- Evaluate Mix Economics and Opportunity for Further Innovation
  - Evaluate performance curves to make sure meaningful optimization opportunity is not lost.
  - Utilize obtained knowledge of the mix to maximize performance while minimizing cost

![Diagram of mix design approach]
Optimized Mix Design Approach – Framework

- **Evaluate Mix Workability/Constructability**
  - Determine the relative compactability of the mix being designed and compare to a known standard.
  - Utilize Marshall hammer to simulate field rolling (i.e., constant applied stress similar to roller).

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**WORKABILITY EVALUATION**

- Evaluate the relative compactability of mixes using one of two approaches.

  - **Marshall Compactability Index**
  - Compact mixes in Marshall mold at varying blows per one side
    - Three compaction levels to define the stiffness/blow curve
      - For example, 20, 50, and 80 blows
    - Measure heights of compacted specimens, calculate Gmb (based on mass/volume), calculate air voids
    - Develop compaction vs voids curve (workability curve)
      - Fit regression line to data
      - Conduct for standard or “control” type mixes as reference
      - Perform similar evaluation for mix(es) in question
    - Determine from the workability curve, the blows corresponding to the desired in-place density of the mix(es). For example, if the specification requirement was 94% of Gmm, use 6% air voids.
    - Compare the Bd values for the control and the mixes in question
      - Divide the Bd for the mix being designed by the Bd value of the control to get an index value (BdM/BdC).
Workability - Example

- Compared to the control mix, Mix A and B would both be expected to be more difficult to compact with all factors being equal. Mix B would be the most difficult.
- Knowing the field compatibility of the control, guidance can be delivered to field personnel regarding the need for potential changes to the laydown operation.

<table>
<thead>
<tr>
<th>Blows</th>
<th>Control</th>
<th>Mix A</th>
<th>Mix B</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>10.0</td>
<td>10.3</td>
<td>10.5</td>
</tr>
<tr>
<td>50</td>
<td>6.0</td>
<td>7.0</td>
<td>7.5</td>
</tr>
<tr>
<td>80</td>
<td>4.0</td>
<td>4.8</td>
<td>6.0</td>
</tr>
<tr>
<td>Blows @ 7%</td>
<td>41</td>
<td>50</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>1.22</td>
<td>1.41</td>
<td>1.41</td>
</tr>
</tbody>
</table>
The Path Forward

- Proof of concept testing is being conducted with selected Oldcastle companies
- Other evaluation/testing is welcomed
- Review results and adjust procedure accordingly
  - Continually adjust based on experience
- Must continue with theoretical research/modeling efforts, but not be afraid (or too proud) to utilize practical approaches to find solutions.
- This is a long term effort with ups/downs, but we must start now.
Thoughts and Questions?

Shane Buchanan  
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Oldcastle Materials Company  
shane.buchanan@oldcastlematerials.com  
205-873-3316