Balanced Mix Design (BMD)

Dave Johnson, P.E.
Senior Regional Engineer, Asphalt Institute

Idaho Asphalt Conference
Moscow, Idaho
Discussion Items

• Need for Balanced Mix Design
• Performance Testing Discussion
• Balanced Mix Design Examples
• FHWA Balanced Mix Design Task Force Efforts
• Next Steps
Need for Balanced Mix Design
Balanced Mix Design Definition

• “Asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure.”

• Basically, it consists of designing the mix for an intended application and service requirement.
Why the Need for a New Mix Design Approach?

- **Problems:**
  - Relying on volumetrics along to provide performance
  - Dry mixes exist in some (not all) areas

- **Solutions:**
  - **Recognize performance issues** related to dry mixes in some areas. (Note: Many performance issues are caused factors outside the mix design)
  - **Increase understanding** of the factors which drive mix performance
  - **Design for performance** and not just to “the spec”.
  - **Start thinking** outside of long held “rules and constraints”
  - **Innovate!**
Mix Design Specifications

- Largely recipe driven
  - Aggregates and grading
  - Volumetrics (Va, VMA, VFA, D/A, etc.)
  - Binder grade and/or minimum %
  - RAP and/or RAS
  - WMA

- While this may work, there are problems
  - What happens when the recipe fails?
  - Specifications have become **convoluted and confounded**
    - Existing specified items compete against each other
    - New requirements get added and nothing gets removed
      - “Spec Book Creep”
  - Innovation has become stifled with our knowledge outpacing specifications
Steps Must be Taken Now Towards Solutions

- 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

Long term research is certainly needed, but we must take steps NOW towards a solution.
Design and optimum binder content are often used interchangeably

- However, they mean two different things

There can be many design binder contents for a mix, but only one truly optimum

- Optimum indicates the best binder content based on intended application, performance requirements/needs, and ultimately economics

- Goal is to get as close as possible to the true optimum for the mix
Oldcastle Survey Question: Within the past 5 years, what type of mix performance related distress has been most evident in your mixes?

~40 companies responding from ~30 states
Balance the Mix Design

Smooth Quiet Ride
Skid Resistance

Strength/Stability
Rut Resistance
Shoving
Flushing Resistant

Durability
Crack Resistance
Raveling
Permeability

DON’T ATTACK ONE HALF AT THE EXPENSE OF THE OTHER HALF!!
Superpave system is becoming unrecognizable with specifications changing rapidly as agencies search for ways to improve durability.

Establishing true “cause and effect” is impossible.

Survey Question: Which of the following specification changes has your DOT implemented in the last 5 years?
## Agencies are Searching for Solutions: Ndesign

- **Ndesign varies widely w/ levels being reduced with the intent of gaining more binder**

- **Problem:** Lower gyrations do not necessarily equate to more binder

### Gyration Level Table

<table>
<thead>
<tr>
<th>State</th>
<th>Gyration Level&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>60</td>
</tr>
<tr>
<td>Arkansas</td>
<td>50, 75, 100, 125</td>
</tr>
<tr>
<td>Colorado</td>
<td>75, 100</td>
</tr>
<tr>
<td>Connecticut</td>
<td>75, 100</td>
</tr>
<tr>
<td>Florida</td>
<td>50, 65, 75, 100</td>
</tr>
<tr>
<td>Idaho</td>
<td>50, 75, 100, 125</td>
</tr>
<tr>
<td>Iowa</td>
<td>50, 60, 65, 68, 76, 86, 96, 109, 126</td>
</tr>
<tr>
<td>Kansas</td>
<td>75, 100</td>
</tr>
<tr>
<td>Kentucky</td>
<td>50, 75, 100</td>
</tr>
<tr>
<td>Maine</td>
<td>50, 75</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>50, 75, 100</td>
</tr>
<tr>
<td>Michigan</td>
<td>45, 50, 76, 86, 96, 109, 126</td>
</tr>
<tr>
<td>Minnesota</td>
<td>40, 60, 90, 100</td>
</tr>
<tr>
<td>Mississippi</td>
<td>50, 65, 85</td>
</tr>
<tr>
<td>Missouri</td>
<td>50, 75, 80, 100, 125</td>
</tr>
<tr>
<td>Montana</td>
<td>75</td>
</tr>
<tr>
<td>Nebraska</td>
<td>40, 65, 95</td>
</tr>
<tr>
<td>Nevada</td>
<td>Use Hveem</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>50, 75</td>
</tr>
<tr>
<td>New Jersey</td>
<td>50, 75</td>
</tr>
<tr>
<td>New Mexico</td>
<td>75, 100, 125</td>
</tr>
<tr>
<td>New York</td>
<td>50, 75, 100</td>
</tr>
<tr>
<td>North Carolina</td>
<td>50, 65, 75, 100</td>
</tr>
<tr>
<td>Ohio</td>
<td>65</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>64-22 (50), 70-28 (60), and 76-28 (80)</td>
</tr>
<tr>
<td>Oregon</td>
<td>65, 80, 100</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>50, 75, 100</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>50</td>
</tr>
<tr>
<td>Tennessee</td>
<td>65 or 75 Marshall</td>
</tr>
<tr>
<td>Texas</td>
<td>50</td>
</tr>
<tr>
<td>Utah</td>
<td>50, 75, 100, 125</td>
</tr>
<tr>
<td>Vermont</td>
<td>50, 65, 80</td>
</tr>
<tr>
<td>Virginia</td>
<td>65</td>
</tr>
<tr>
<td>Washington</td>
<td>50, 75, 100, 125</td>
</tr>
<tr>
<td>West Virginia</td>
<td>50, 65, 80, 100</td>
</tr>
</tbody>
</table>

---

As of March 2015
Enhancing the Durability of Asphalt Pavements

- “Volume of Effective Binder (Vbe) is the primary mixture design factor affecting both durability and fatigue cracking resistance.”
  - $Vbe = VMA - Air\ Voids$

- “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.”
Enhanced Durability of Asphalt Pavements through Increased In-Place Pavement Density

Workshop Only (15)

Demonstration projects (10)
History of Mix Design

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)

Performance Testing of Asphalt Mixes
Stability Testing

Logging Trucks, Olympic Peninsula, 1947

Source: University of Washington Libraries
Stability Evaluation

- Evaluate mix stability with one of several available “rutting” tools.
  - Hamburg, APA, AMPT Flow Number, etc.
  - Failure criteria
    - Based on best available research (local, regional, or national)
    - Function of traffic (e.g., low, medium, high) and/or mix end use applications
Survey Question:
How does your state DOT evaluate the rutting potential of designed dense graded asphalt mixes?
Durability Testing
Durability/Cracking Evaluation

- Durability/cracking evaluation is **substantially more complicated** than stability
  - What is the mode of distress?
  - What is the aging condition?
- Cracking prediction is a known “weak” link in performance testing
  - No general consensus the best test(s) or the appropriate failure threshold

**GOALS**
- MATCH THE TEST TO THE DISTRESS
- SET APPROPRIATE FAILURE THRESHOLDS
Match the Test to the Distress

- Disc Shaped Compact Tension
- Four-point Bending
- Texas Overlay Test
- Indirect Tension
- Semi-Circular Bending

From: Louay Mohammad, LTREC
Cracking Tests: Strain and Cycles Illustration

- **Monotonic**: Very high strain
- **Overlay**: High strain
- **Fatigue**: Lower strain

- **Test Time**
- **Strain level**
- **No. of cycles**
What is the Best Cracking Test? It Depends!

- NCHRP 9-57: Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures
  - Top tests for various distresses identified by national group of academia, agency, and industry representatives

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Cracking tests selected at the workshop.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal Cracking Tests</strong></td>
<td><strong>Reflection Cracking Tests</strong></td>
</tr>
<tr>
<td>1. DCT</td>
<td>1. OT</td>
</tr>
<tr>
<td>2. SCB-IL</td>
<td>2. SCB-LTRC</td>
</tr>
<tr>
<td>3. SCB (AASHTO TP 105)</td>
<td>3. BBF</td>
</tr>
</tbody>
</table>

*OT for fatigue cracking was added later by request of the panel.

Note: SCB-IL is now I-FIT
Survey Question:
How does your state DOT evaluate the durability/cracking potential of designed dense graded asphalt mixes?
Use of Performance Testing in Design - Illinois

From: Imad Al-Qadi, University of Illinois
Use of Performance Testing in Design - Wisconsin

- **Thermal Cracking**
  - DC(t)
  - LT (-18 or -24°C)

- **Fatigue**
  - Semi-Circular Bend
  - IT (25°C)

- **Rutting**
  - Hamburg
  - HT (50°C)

**Long Term Aging – AASHTO R30 (5 days at 85°C)**
- SCB and DCT
- Recovered binder grade and ΔTc
Performance space diagrams show the performance of a mix related to multiple tests.

- Allows the mix designer to visualize the mix performance and how to engineer the mix to provide the desired performance.
- Illustrates the impact of varying mix factors on performance.

From: Dr. Bill Buttlar, University of Illinois
<table>
<thead>
<tr>
<th></th>
<th>Fatigue Cracking</th>
<th>Rutting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Air Voids</strong></td>
<td>40% increase</td>
<td>22% decrease</td>
</tr>
<tr>
<td>For every 1% increase</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Design VMA</strong></td>
<td>73% decrease</td>
<td>32% increase</td>
</tr>
<tr>
<td>For every 1% increase</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Compaction Density</strong></td>
<td>19% decrease</td>
<td>10% decrease</td>
</tr>
<tr>
<td>For every 1% lower in-place Air Voids</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>(Increasing Density Improved Both!)</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Courtesy of Nelson Gibson
• Design at 5% air voids and compact to 5% voids in field (95% $G_{mm}$)

• Lower design gyration to increase in-place density
  • No change in rutting resistance
  • No change in stiffness
  • Improve pavement life
    • Reduced aging

• Maintained Volume of Eff. Binder ($V_{be}$)
  • Increased VMA by 1%

Courtesy of Gerald Huber
Balanced Mix Design Task Force
- Development and Work
At the request of the National Pavement Implementation Executive Task Group (PIETG) the Balanced Mix Design Task Force formed at the September 2015 FHWA Mixture and Construction ETG meeting

Focus Areas
- Define Balanced Mix Design
- Determine the current “state of practice” of BMD
- Present approaches/concepts for immediate use
- Recommend future needs (potential research) to advance BMD approaches
- Disseminate information
## BMD Task Force Membership

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Category</th>
<th>e-mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dave Newcomb</td>
<td>Texas Transportation Institute</td>
<td>Academia/Research</td>
<td><a href="mailto:d-newcomb@ttimail.tamu.edu">d-newcomb@ttimail.tamu.edu</a></td>
</tr>
<tr>
<td>John Haddock</td>
<td>Purdue University</td>
<td>Academia/Research</td>
<td><a href="mailto:jhaddock@purdue.edu">jhaddock@purdue.edu</a></td>
</tr>
<tr>
<td>Kevin Hall</td>
<td>University of Arkansas</td>
<td>Academia/Research</td>
<td><a href="mailto:kdhall@uark.edu">kdhall@uark.edu</a></td>
</tr>
<tr>
<td>Louay Mohammad</td>
<td>Louisiana State University</td>
<td>Academia/Research</td>
<td><a href="mailto:Louaym@Lsu.edu">Louaym@Lsu.edu</a></td>
</tr>
<tr>
<td>Brian Pfeifer</td>
<td>Illinois DOT</td>
<td>Agency</td>
<td><a href="mailto:Brian.Pfeifer@illinois.gov">Brian.Pfeifer@illinois.gov</a></td>
</tr>
<tr>
<td>Bryan Engstrom</td>
<td>Massachusetts DOT</td>
<td>Agency</td>
<td><a href="mailto:Brian.Pfeifer@illinois.gov">Brian.Pfeifer@illinois.gov</a></td>
</tr>
<tr>
<td>Charlie Pan</td>
<td>Nevada DOT</td>
<td>Agency</td>
<td><a href="mailto:cpan@dot.state.nv.us">cpan@dot.state.nv.us</a></td>
</tr>
<tr>
<td>Curt Turgeon</td>
<td>Minnesota DOT</td>
<td>Agency</td>
<td><a href="mailto:curt.turgeon@state.mn.us">curt.turgeon@state.mn.us</a></td>
</tr>
<tr>
<td>Derek Nener-Plante</td>
<td>Maine DOT</td>
<td>Agency</td>
<td><a href="mailto:derek.nener-plante@maine.gov">derek.nener-plante@maine.gov</a></td>
</tr>
<tr>
<td>Eliana Carlson</td>
<td>Connecticut DOT</td>
<td>Agency</td>
<td><a href="mailto:Eliana.Carlson@CT.gov">Eliana.Carlson@CT.gov</a></td>
</tr>
<tr>
<td>Howard Anderson</td>
<td>Utah DOT</td>
<td>Agency</td>
<td><a href="mailto:handerson@utah.gov">handerson@utah.gov</a></td>
</tr>
<tr>
<td>Oak Metcalfe</td>
<td>Montana DOT</td>
<td>Agency</td>
<td><a href="mailto:rmetcalfe@mt.gov">rmetcalfe@mt.gov</a></td>
</tr>
<tr>
<td>Robert Lee</td>
<td>Texas DOT</td>
<td>Agency</td>
<td><a href="mailto:Robert.Lee@txdot.gov">Robert.Lee@txdot.gov</a></td>
</tr>
<tr>
<td>Steven Hefel</td>
<td>Wisconsin DOT</td>
<td>Agency</td>
<td><a href="mailto:Steven.Hefel@dot.wi.gov">Steven.Hefel@dot.wi.gov</a></td>
</tr>
<tr>
<td>Frank Fee</td>
<td>Consultant</td>
<td>Consultant</td>
<td><a href="mailto:frank.fee@verizon.net">frank.fee@verizon.net</a></td>
</tr>
<tr>
<td>John D'Angelo</td>
<td>Consultant</td>
<td>Consultant</td>
<td><a href="mailto:john_dangelo@dangeloconsultingllc.com">john_dangelo@dangeloconsultingllc.com</a></td>
</tr>
<tr>
<td>Lee Gallivan</td>
<td>Consultant</td>
<td>Consultant</td>
<td><a href="mailto:lee@gallivanconsultinginc.com">lee@gallivanconsultinginc.com</a></td>
</tr>
<tr>
<td>Richard Duval</td>
<td>FHWA - Turner Fairbank</td>
<td>FHWA Agency</td>
<td><a href="mailto:Richard.Duval@dot.gov">Richard.Duval@dot.gov</a></td>
</tr>
<tr>
<td>Tim Aschenbrener</td>
<td>FHWA - Denver</td>
<td>FHWA Agency</td>
<td><a href="mailto:timothy.aschenbrener@dot.gov">timothy.aschenbrener@dot.gov</a></td>
</tr>
<tr>
<td>Andrew Hanz</td>
<td>Mathy Construction</td>
<td>Industry</td>
<td><a href="mailto:Andrew.Hanz@mteservices.com">Andrew.Hanz@mteservices.com</a></td>
</tr>
<tr>
<td>Chris Abadie</td>
<td>Pine Bluff S&amp;G</td>
<td>Industry</td>
<td><a href="mailto:abadie3522@icloud.com">abadie3522@icloud.com</a></td>
</tr>
<tr>
<td>Erv Dukatz</td>
<td>Mathy Construction</td>
<td>Industry</td>
<td><a href="mailto:Ervin.Dukatz@mathy.com">Ervin.Dukatz@mathy.com</a></td>
</tr>
<tr>
<td>Gerry Huber</td>
<td>Heritage Research</td>
<td>Industry</td>
<td><a href="mailto:Gerald.huber@hrglab.com">Gerald.huber@hrglab.com</a></td>
</tr>
<tr>
<td>Shane Buchanan</td>
<td>Oldcastle Materials</td>
<td>Industry</td>
<td><a href="mailto:sbuchanan@oldcastlematerials.com">sbuchanan@oldcastlematerials.com</a></td>
</tr>
<tr>
<td>Anne Holt</td>
<td>Ontario Ministry of Transportation</td>
<td>Provincial Agency</td>
<td><a href="mailto:Anne.Holt@ontario.ca">Anne.Holt@ontario.ca</a></td>
</tr>
<tr>
<td>Randy West</td>
<td>NCAT</td>
<td>Research</td>
<td><a href="mailto:westran@auburn.edu">westran@auburn.edu</a></td>
</tr>
</tbody>
</table>
Balanced Mix Design Definition
Balanced Mix Design Definition

- “Asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure.”

- Basically, it consists of designing the mix for an intended application and service requirement.
Agency Practices Related to BMD
Agency Approaches – 3 Main Approaches Identified

Balanced Mix Design Flowchart: v. 09-08-16

1. Conduct Volumetric Analysis
   - Select Design Binder Content & Volumetric Properties
   - Conduct Performance Tests
     - Rutting
     - Cracking
   - Performance Passed?
     - Yes: Conduct Moisture Damage Test
     - No: Redesign Mix
   - Moisture Damage Passed?
     - Yes: Conduct Moisture Damage Test
     - No: Decrease Moisture Susceptibility
   - Decrease Moisture Susceptibility
   - Yes: Validate JMF / Production

2. Select Trial Gradation; Ensure Aggregate Blend Properties

3. Conduct Volumetric Analysis
   - Determine Initial Design Binder Content
   - Conduct Performance Tests
     - Rutting
     - Cracking
   - Performance Passed?
     - Yes: Conduct Moisture Damage Test
     - No: Adjust Mix Proportions And/or Binder Content
   - Moisture Damage Passed?
     - Yes: Determine & Report Volumetric Properties at Design Binder Content
     - No: Decrease Moisture Susceptibility
   - Decrease Moisture Susceptibility
   - Yes: Validate JMF / Production
Volumetric Design w/ Performance Verification – basically, it is straight Superpave with verifying performance properties; if the performance is not there, start over and re-design the mix. Volumetric properties would have to fall within existing M323 limits. Example States: Illinois, Louisiana, New Jersey, Texas, Wisconsin
Performance Modified Volumetric Design – the initial design binder content is selected using M323/R35 prior to performance testing; the results of performance testing could ‘modify’ the mixture proportions (and/or) adjust the binder content – and the final volumetric properties may be allowed to drift outside existing M323 limits. Example State: California
Performance Design – this involves conducting a suite of performance tests at varying binder contents and selecting the design binder content from the results. Volumetrics would be determined as the ‘last step’ and reported – with no requirements to adhere to the existing M323 limits. Example States: New Jersey w/ draft approach
BMD Basic Example – Volumetric Design w/ Performance Verification

- **Texas DOT**
  - Volumetric design conducted
  - Hamburg Wheel Tracking Test (HWTT) AASHTO T 324
  - Overlay Tester (OT) Tex-248-F
  - Three asphalt binder contents are used: optimum, optimum +0.5%, and optimum -0.5%.
  - The HWTT specimens are short-term conditioned.
  - The OT specimens are long-term conditioned.

Within this acceptable range (5.3 to 5.8 percent), the mixture at the selected asphalt content must meet the Superpave volumetric criteria.
• Balanced Mixture Design Concept
• Mixes are designed to optimize performance
  • Not around a target air void content
• Take an existing virgin mix design
  • Start at a “dry” binder content
  • Add binder at 0.5% increments – measure rutting and cracking
  • Determine range where rutting and cracking are optimized
  • Conduct volumetric work
• Performance criteria (limits) already determined based on virgin mixes
• Most NJ mixes found to be below (dry) of the balanced area
• Plant QC air voids requirements need to be re-evaluated to account for the added binder
• Changes in production volumetrics are likely required to move the mixes in the right direction
• Technical Brief being developed to provide a current summary of the BMD TF efforts.
• Target publication of end 2016 (or sooner).

Balanced Mixture Design Approaches for Asphalt Pavement Construction

This Technical Brief provides an overview of balanced mixture design (BMD) approaches currently used by states in asphalt pavement construction. These approaches are still under development and this document will attempt to show the current status and some of the issues that will need to be addressed in the future.
Research Proposal: NCHRP 20-07 Project

- Research Problem Statement prepared and submitted last week to AASHTO for a NCHRP 20-07 Project.
  - Development of a Framework for Balanced Asphalt Mixture Design and Gap Analysis

- Goals
  - Survey of all state highway agencies (SHAs) to determine the use and status of BMD practices
  - Review of literature for the development and state-of-the-practice for performance testing,
  - Develop a practice that is a framework for BMD for implementation of performance testing in the design of asphalt mixtures,
  - Develop research problem statements with funding needs based on gaps identified for development of a more detailed standard practice for BMD, and
  - Prepare a final report that documents results, summarizes findings, draws conclusions, and presents the (a) proposed practice and (b) research problem statements based on identified gaps with funding needs and a recommended plan for submittal.
The Path Forward for Balanced Mix Design

- Recognize the need and move incrementally in the appropriate direction to limit risk of mix performance issues.

- Must continue with theoretical research/modeling efforts, but not be afraid to utilize practical approaches to find solutions.

- Recognize that this is a long term effort with ups/downs, but we must start now.
Final Thoughts on Mix Design

- Key Points to Keep in Mind
  1. “Use What Works”
  2. “Eliminate What Doesn’t”
  3. “Be as Simple as Possible, Be Practical, and Be Correct”

“Good doesn’t have to be complicated and complicated isn’t always good!”
What is Achievable?