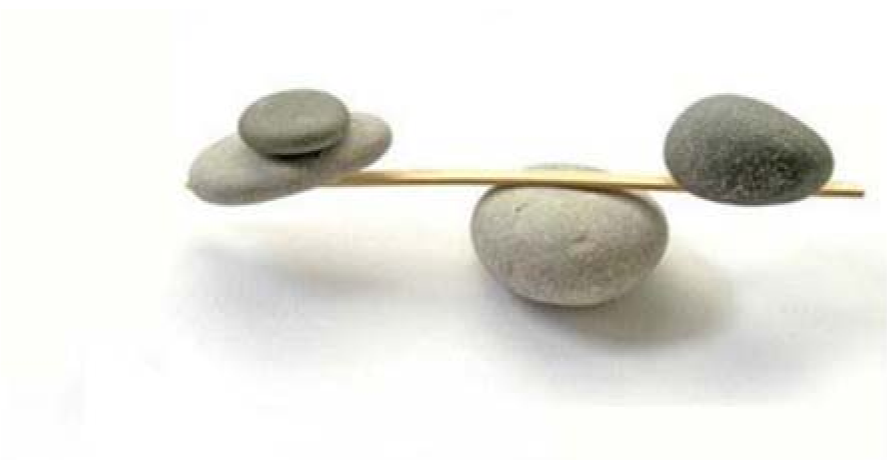
Balanced Mix Design (BMD)



ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN (APAM)

2017 ASPHALT PAVING CONFERENCE

SHANE BUCHANAN

OLDCASTLE MATERIALS

Discussion Items

- Need for Balanced Mix Design
- Performance Testing Discussion
- Balanced Mix Design Task Force Activities
- Agency Practices Related to Balanced Mix Design
- Future Work

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 (e.g., use the right tool for the job!)

Need for Balanced Mix Design

Why the Need for a New Mix Design Approach?

- **Problems:**
  - Relying on volumetrics alone 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 by 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!**

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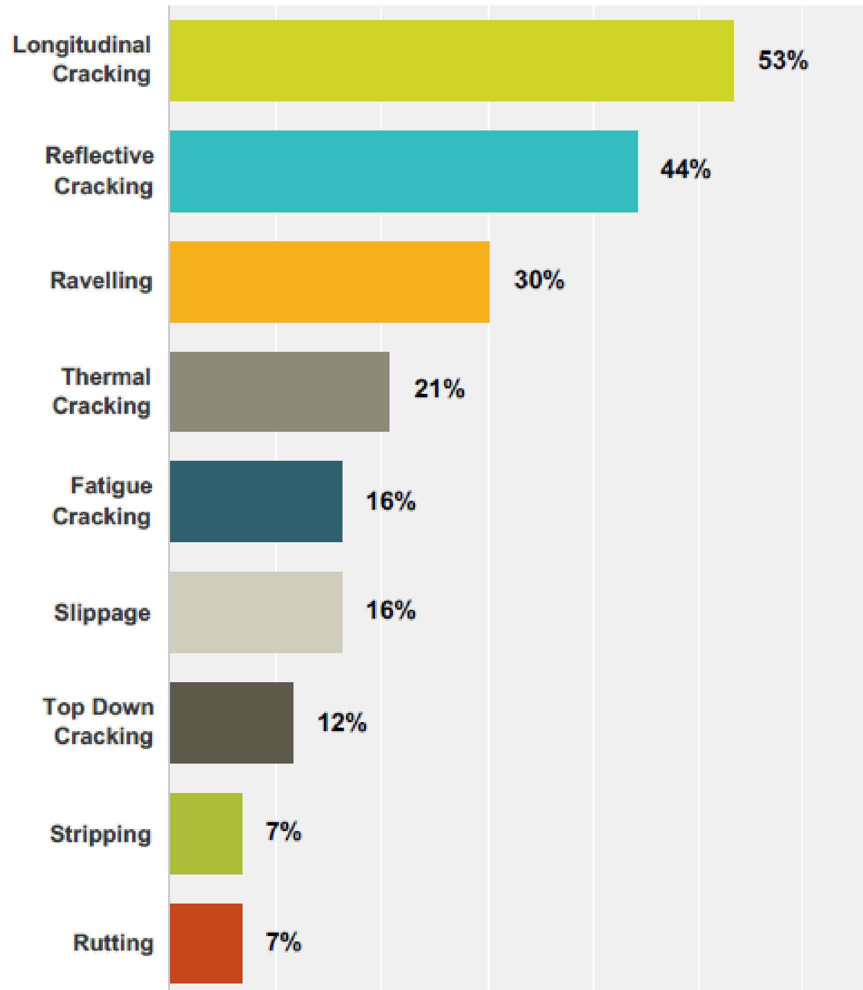
What Type Distress Is Occurring?

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



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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

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

“Marshall method” pavement testing apparatus

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

State	Gyration Level[1]
Alabama	**60**
Arkansas	50, 75, 100, 125
Colorado	75, 100
Connecticut	75, 100
Florida	50,65,**75,100**
Idaho	50,75,100, 125
Iowa	50, 60, 65, 68, 76, 86, 96, 109, 126
Kansas	**75**, 100
Kentucky	50, 75, 100
Maine	**50**, 75
Massachusetts	50, **75**, **100**
Michigan	45, 50, 76, 86, 96, 109, 126
Minnesota	40, 60, 90, 100
Mississippi	50, **65**, 85
Missouri	50, 75, **80**, 100, 125
Montana	**75**
Nebraska	40, 65, 95
Nevada	Use Hveem
New Hampshire	50, 75
New Jersey	50, **75**

State	Gyration Level[1]
New Mexico	75, **100**, 125
New York	50, **75**, 100
North Carolina	50, **65**, **75**, 100
Ohio	**65**
Oklahoma	64-22 (50), 70-28 (60) , and 76-28 (80)
Oregon	65, 80, 100
Pennsylvania	50, 75, 100
Rhode Island	**50**
Tennessee	**65** or 75 Marshall
Texas	**50**
Utah	50, **75**, 100, 125
Vermont	50, **65**, 80
Virginia	**65**
Washington	50,75,100, 125
West Virginia	50, 65, 80, 100

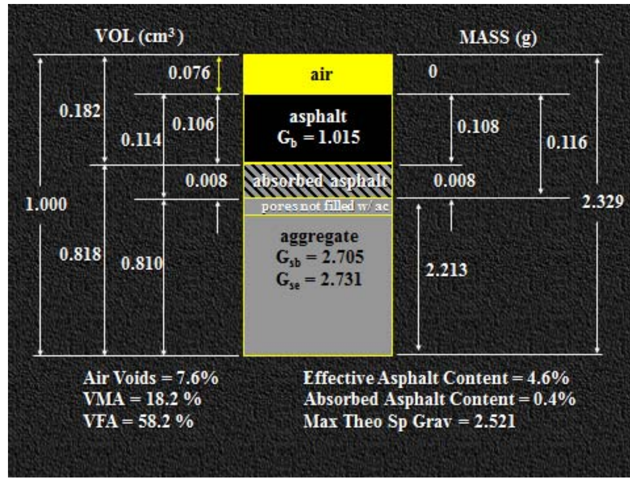
As of March 2015

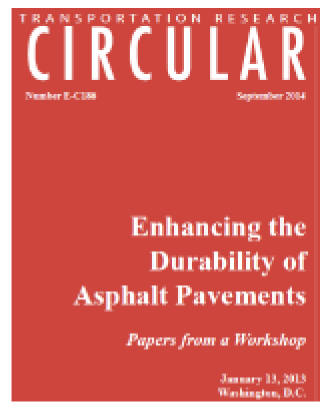
South Carolina: 50, 75, 100

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."**





Impact of Mix Design on Asphalt Pavement Durability

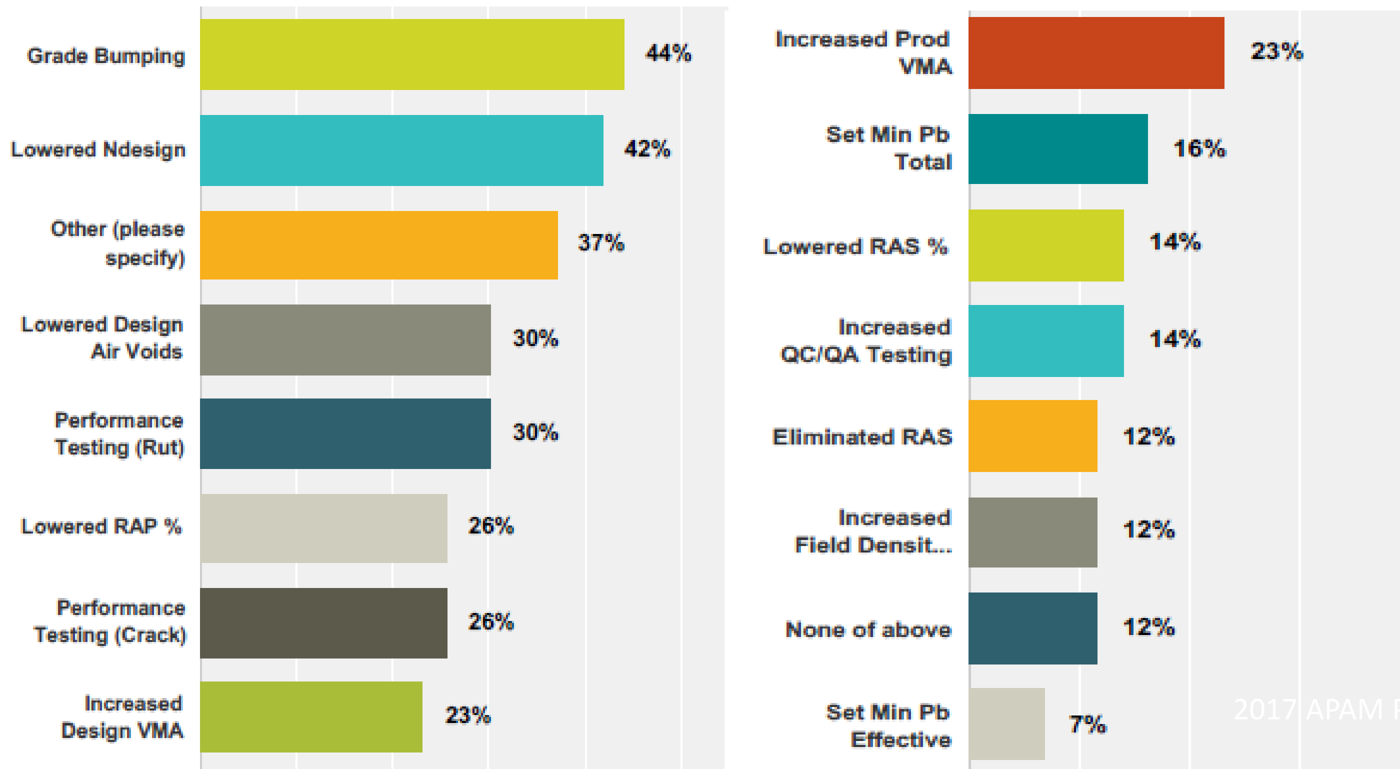
RAMON BONAQUIST
Advanced Asphalt Technologies, LLC

Oldcastle Materials

Agencies Are Searching for Solutions: Spec Changes

- 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?



Michigan Ndesign

Table 501-3 Superpave Gyratory Compactor (SGC) Compaction Criteria					
Estimated Traffic (million ESAL)	Mix Type	$\%G_{mm}$ at (N_i)	Number of Gyrations (a)		
			N_i	N_d	N_m
≤0.3	LVSP	91.5%	6	45	70
≤0.3	E03	91.5%	7	50	75
>0.3 – ≤1.0	E1	90.5%	7	76	117
>1.0 – ≤3.0	E3	90.5%	7	86	134
>3.0 – ≤10	E10	89.0%	8	96	152
>10 – ≤30	E30	89.0%	8	109	174
>30 – ≤100	E50	89.0%	9	126	204

a. Compact mix specimens fabricated in the SGC to N_d. Use height data provided by the SGC to calculate volumetric properties at N_i.. Compact mix specimens at optimum P_b to verify N_m for mix design specimens only.

Michigan Air Void Regression

Table 501-1 Superpave Mix Design Criteria					
Design Parameter	Mix Number				
	5	4	3	2	LVSP
Percent of Maximum Specific Gravity (%G_{mm}) at the design number of gyrations, (N_d) (c)	96.0% (a)				
%G_{mm} at the initial number of gyrations, (N_i)	See Table 501-3				
%G_{mm} at the maximum number of gyrations, (N_m)	98.0%				
VMA min % at N_d (based on aggregate bulk specific gravity, (G_{sb})) (c)	15.00	14.00	13.00	12.00	14.00
VFA at N_d	See Table 501-2 (b)				
Fines to effective asphalt binder ratio (P_{No200}/P_{be})	0.6–1.2				
Tensile strength ratio (TSR)	80% min				

a. For mixtures meeting the definition for base course, design mixtures to 96.0% of Maximum Specific Gravity %G_{mm} at the design number of gyrations, (N_d). During field production, increase %G_{mm} at the design number of gyrations, (N_d) to 97.0%.
b. For base course or regressed shoulder mixtures, the maximum criteria limits do not apply.
c. Lower Target Air Voids by 1.0% if used in a separate shoulder paving operation, unless otherwise shown on the plans.

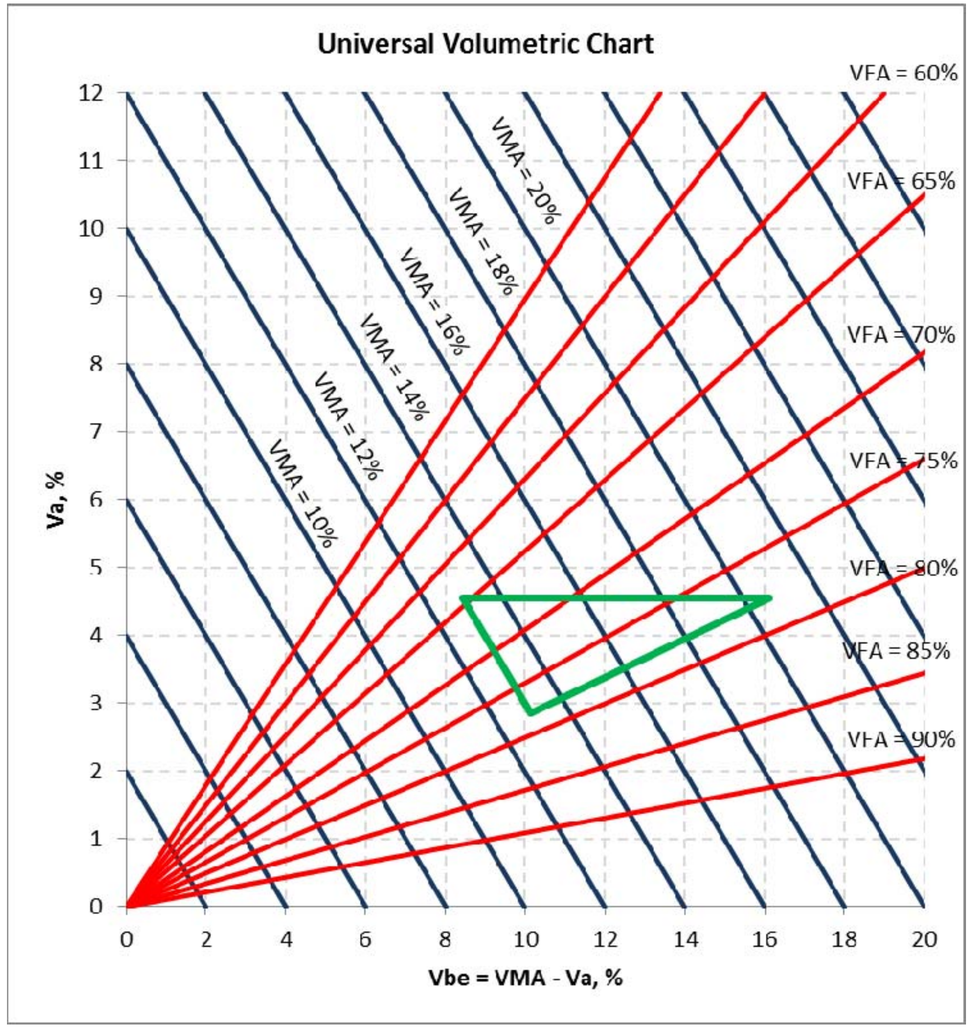
Table 501-2 VFA Minimum and Maximum Criteria			
Estimated Traffic (million ESAL)	Mix Type	Top & Leveling Courses	Base Course
≤0.3	LVSP	70–80	70–80
≤0.3	E03	70–80	70–80
>0.3 – ≤1.0	E1	65–78	65–78
>1.0 – ≤3.0	E3	65–78	65–78
>3.0 – ≤10	E10	65–78 (a)	65–75
>10 – ≤30	E30	65–78 (a)	65–75
>30 – ≤100	E50	65–78 (a)	65–75

a. The specified VFA range for mix Number 5 is 73%–76%.

Ensure Specification Items Agree

- ***Mix 3:***
  - *VMA Min. = 13%*
  - *VFA (E10) = 65 to 78%*

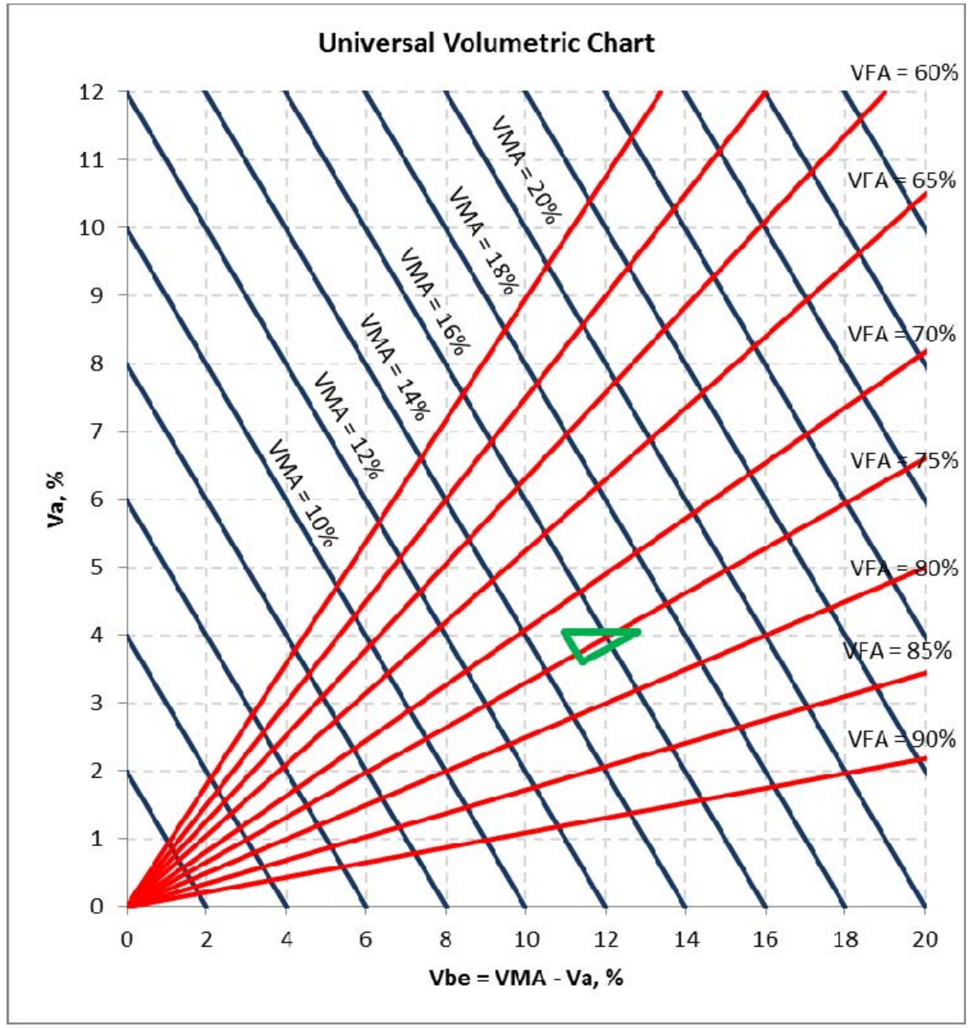
VMA Minimum, %	13
Upper VFA, %	78
Lower VFA, %	65
Effective Upper Va, %	4.55
Effective Lower Va, %	2.86
Effective Upper Vbe, %	10.14
Effective Lower Vbe, %	8.45



Ensure Specification Items Agree

- ***Mix 5:***
  - *VMA Min. = 15%*
  - *VFA (E10) = 73 to 76%*

VMA Minimum, %	15
Upper VFA, %	76
Lower VFA, %	73
Effective Upper Va, %	4.05
Effective Lower Va, %	3.6
Effective Upper Vbe, %	11.4
Effective Lower Vbe, %	10.95



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)

Stability

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

Stability + Durability

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**

Stability + Durability

1993

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

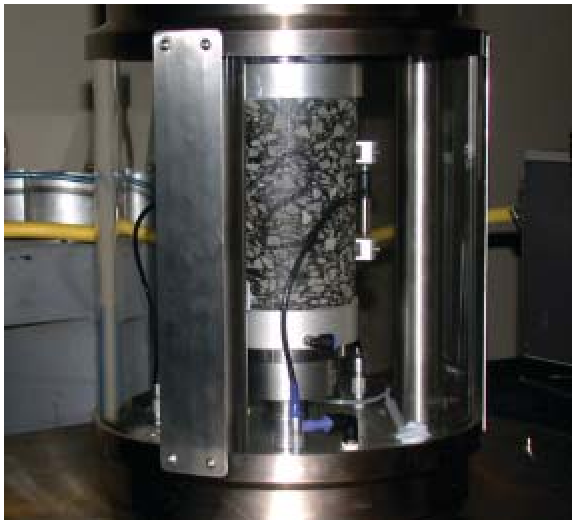
BINDER CONTENT LOWER

http://asphaltmagazine.com/history-of-asphalt-mix-design-in-north-america-part-2/

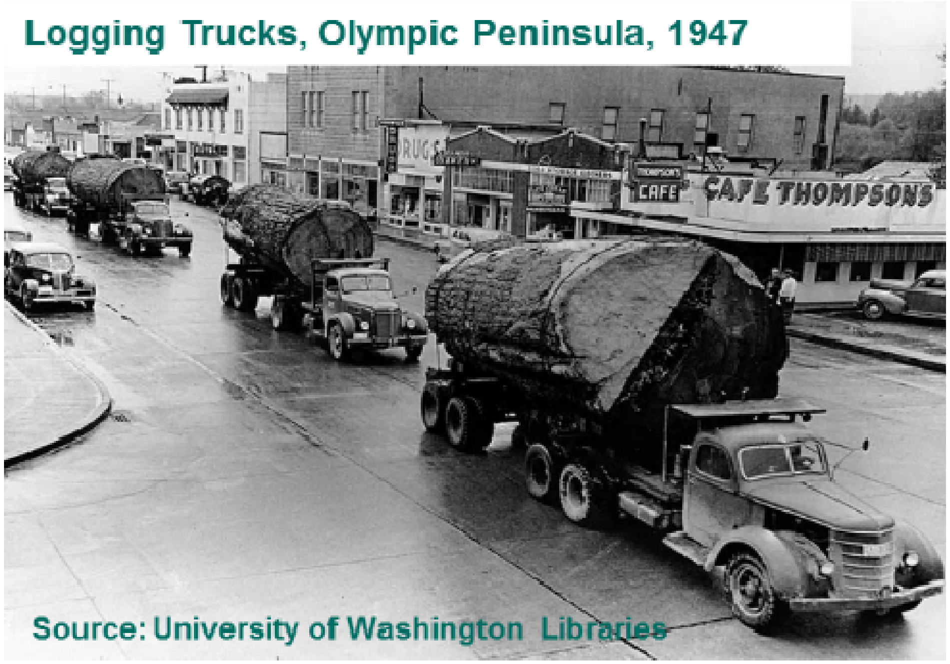
Binder Content – Design vs. Optimum (There is a difference!)

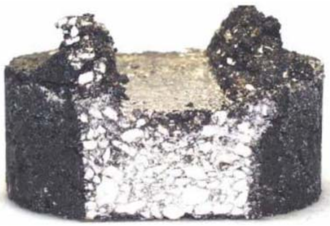
- Design and optimum binder content are often used interchangeably
  - However, they mean two different things
- There can be many design binder contents for a mix, but only one truly optimum
- Optimum indicates the best binder content based **on intended application, performance requirements/needs, and ultimately economics**
- Goal is to get as close as possible to the true **optimum** for the mix

Performance Testing of Asphalt Mixes



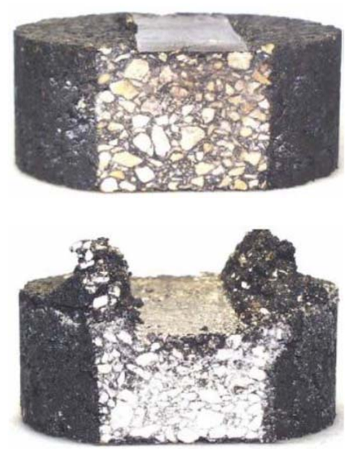
Stability Testing





Stability Evaluation

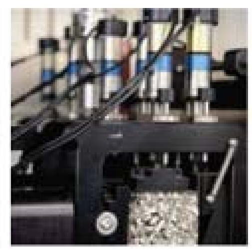
- Evaluate mix stability with one of several available “rutting” tools.
  - Hamburg, APA, AMPT Flow Number, etc.
  - Failure criteria
    - Based on best available research (local, regional, or national)
    - Function of traffic (e.g., low, medium, high) and/or mix end-use applications



Durability / Cracking Testing



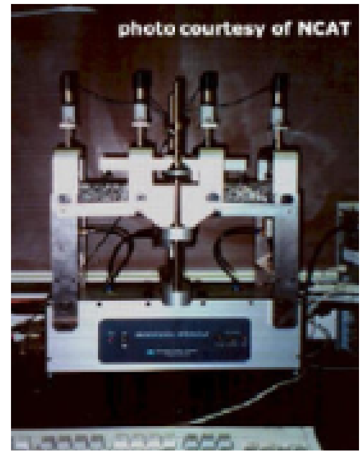


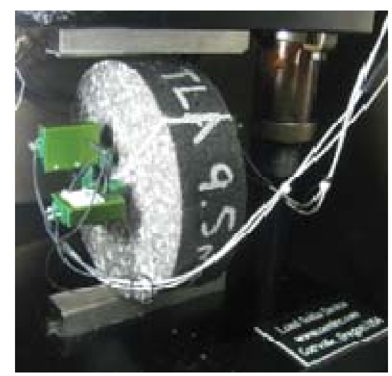




Durability/Cracking Evaluation

- 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 on the best test(s) or the appropriate failure threshold

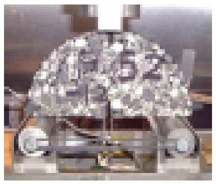
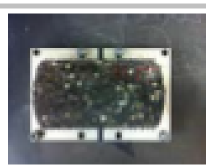
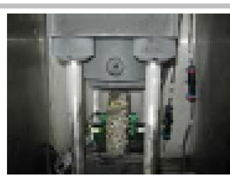
- **GOALS**
  - **MATCH THE TEST TO THE DISTRESS**
  - **SET APPROPRIATE FAILURE THRESHOLDS**



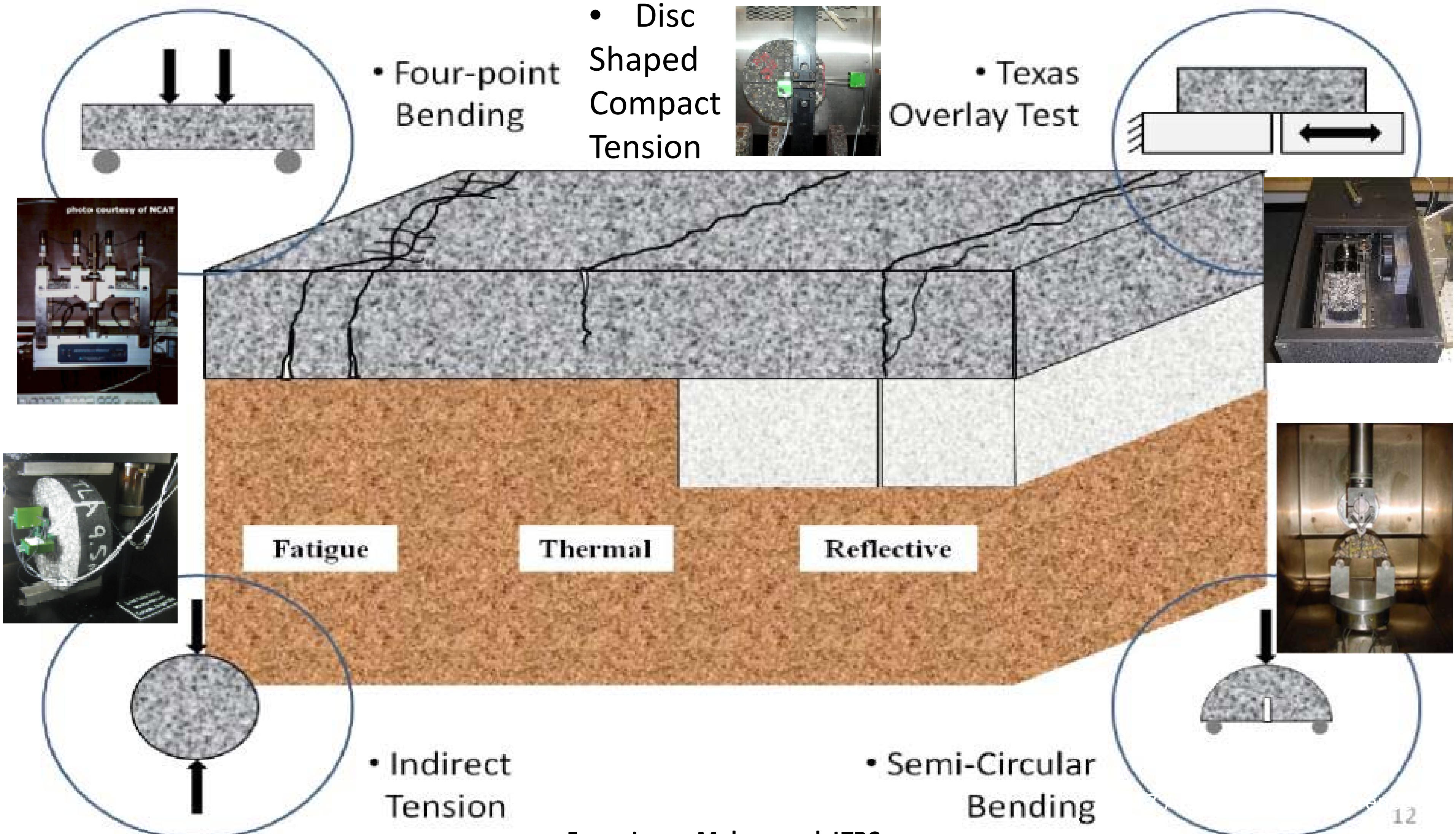


Laboratory Cracking Tests

(From: Research Report No. FHWA-ICT-15-017)

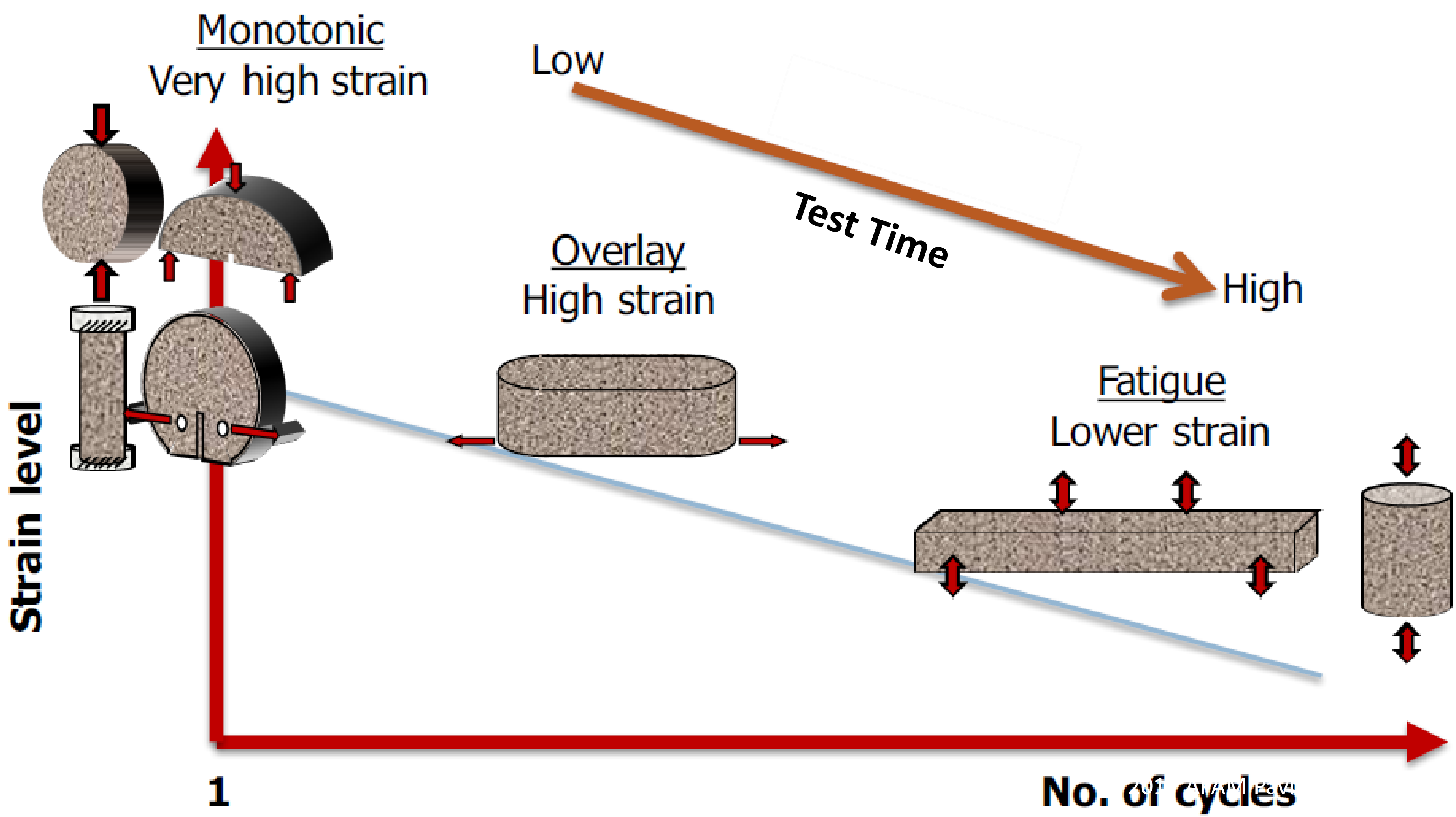
Test Type		Purpose	Specimen Dimensions	Specimen Preparation	Test Output	Pros/Cons
Semi-circular bending (SCB)		Cracking resistance	6 in (Ø) 3 in (H) 2 in (T)	Notching required = 0.6 in; external LVDTs optional	Fracture energy from load-displacement curve, peak load, critical displacement	*Inexpensive device* *Relatively easy specimen fabrication* *Easily obtained field specimens* *Two specimens per core or slice* *Simple three-point bending load representing field bending* Smaller ligament area
Disc compact tension (DCT)		Cracking resistance	6 in (Ø) 5.7 in (H) 2 in (T)	Notching required = 2.46 in; extensometer required	Fracture energy from load-displacement curve, peak load, critical displacement	*Direct tensile mode* *Easily obtained field specimens* Possible breakage close to loading holes at intermediate-temperature application Moderately expensive device
Texas overlay (TOL)		Cracking (reflective) potential	6 in (L) 3 in (W) 1.5 in (T)	Gluing required; curing time needed; external LVDTs optional	Number of cycles used as measure of crack resistance	*Cyclic loading application* High variability No fundamental property related Moderately expensive device
Direct tension (DT)		Tensile strength, cracking resistance, and ductility potential	4 in (Ø) 4 in (H)	Gluing required; overnight curing time; external LVDTs required	Tensile strain at max load used as indicator of ductility and cracking resistance potential	*Simple stress state* Possibility of load eccentricity because of end fixtures Difficult to obtain field specimens Closed-loop displacement control is difficult High variability Moderately expensive device
Indirect tension test (IDT)		Tensile strength (indirect)	6 in (Ø) 2 in (T)	External LVDTs required	Max horizontal strain at max load and strength used as indicator of ductility and cracking resistance potential	*Relatively easy specimen fabrication* *Easily obtained field specimens* *Tensile strength potentially related to cracking resistance* No fundamental property related

Match the Test to the Distress



From: Louay Mohammad, LTRC

Cracking Tests: Strain and Cycles Illustration



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

August 2016

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Responsible Senior Program Officer:
Edward T. Harrigan

Research Results Digest 399

FIELD VALIDATION OF LABORATORY TESTS TO ASSESS CRACKING RESISTANCE OF ASPHALT MIXTURES: AN EXPERIMENTAL DESIGN

This digest summarizes key findings of research conducted in NCHRP Project 09-57, "Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures," by the Texas A&M Transportation Institute, Texas A&M University, College Station, Texas. This digest is based on the project final report authored by Dr. Fujie Zhou, Dr. David Newcomb, Mr. Charles Gurganus, Mr. Seyedamin Banihashemrad, Dr. Maryam Sakhaeifar, Dr. Eun Sug Park, and Dr. Robert L. Lytton. The complete project final report and three appendixes are available to download at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3644.

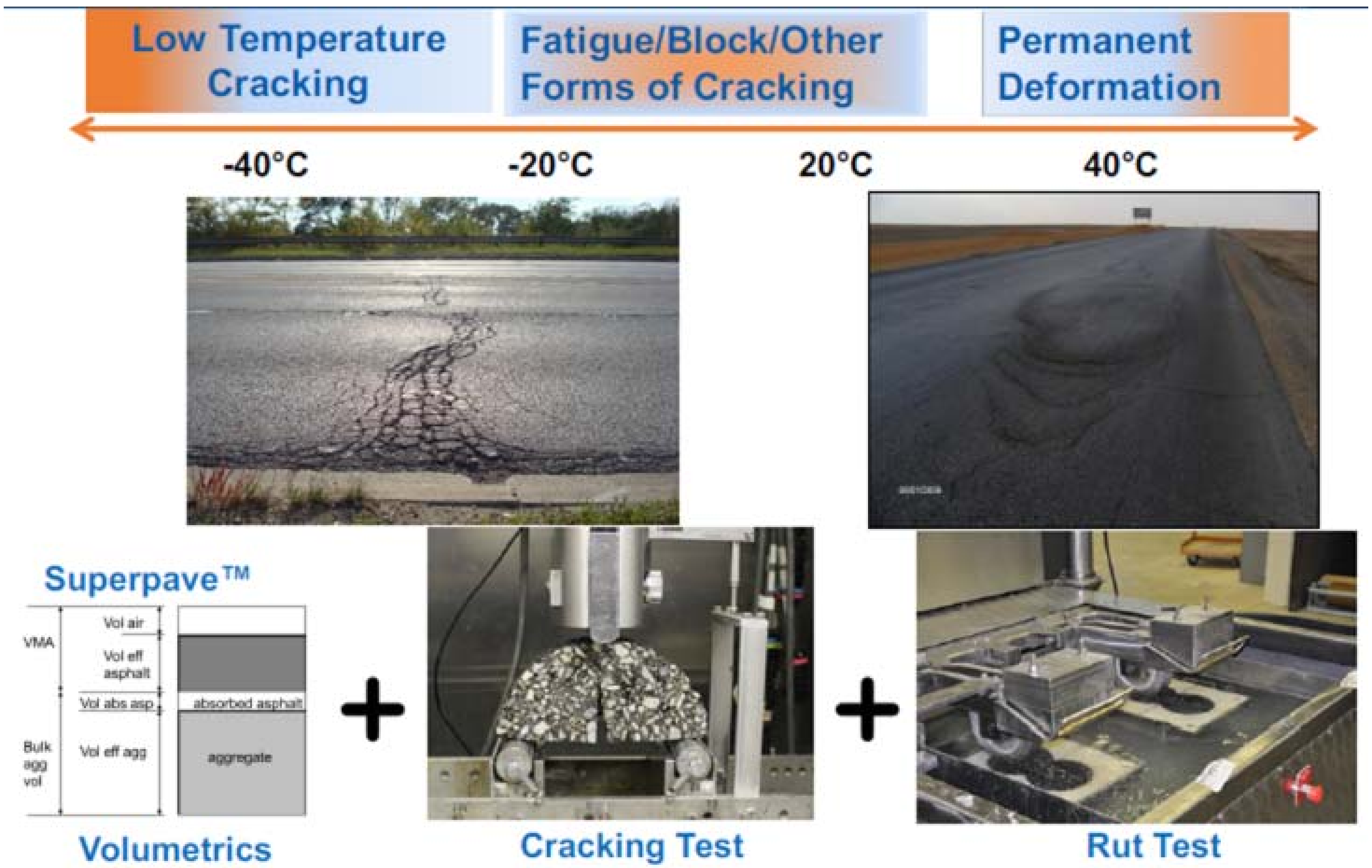
Table 3 Cracking tests selected at the workshop.

Thermal Cracking Tests	Reflection Cracking Tests	Bottom-Up Fatigue Cracking Tests	Top-Down Cracking Tests
1. DCT	1. OT	1. Beam fatigue	1. IDT-Florida
2. SCB-IL	2. SCB-LTRC	2. SCB-LTRC	2. SCB-LTRC
3. SCB (AASHTO TP 105)	3. BBF	3. OT*	

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

Note: SCB-IL is now I-FIT

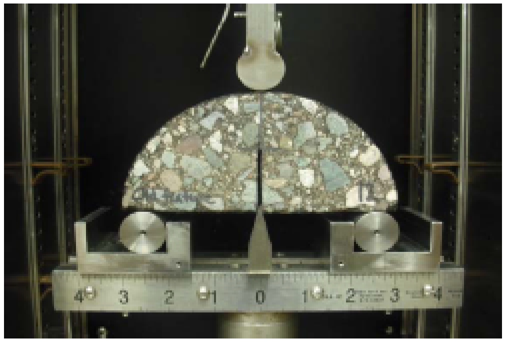
Use of Performance Testing in Design - Illinois



From: Imad Al-Qadi, University of Illinois

Use of Performance Testing in Design - Wisconsin

Thermal Cracking	Fatigue	Rutting
DC(t)	Semi-Circular Bend	Hamburg



LT (-18 or -24°C) IT (25°C) HT (50°C)

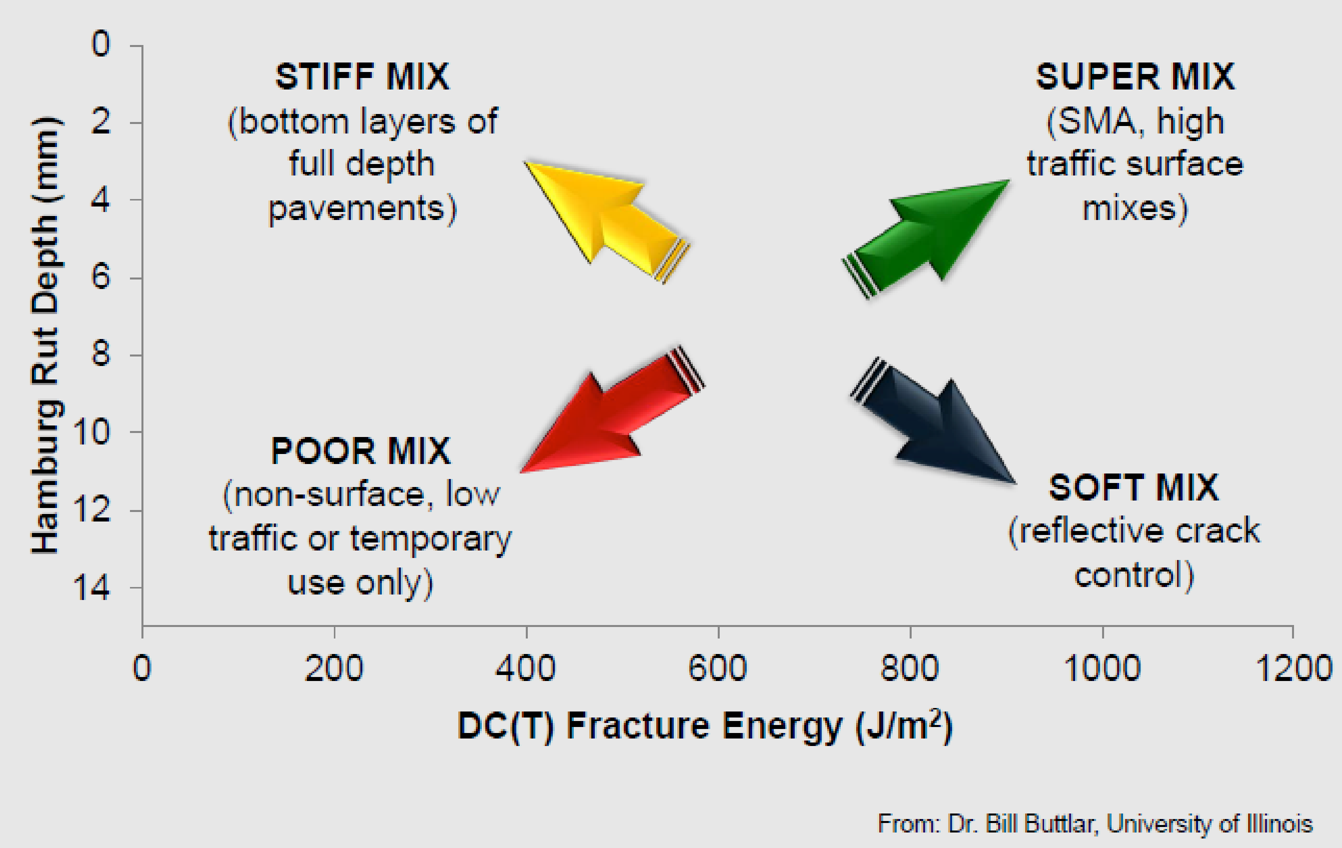
Long Term Aging – AASHTO R30 (5 days at 85°C)

- SCB and DCT
- Recovered binder grade and ΔTc

From: Erv. Dukatz, Mathy Construction, TRB 2015

Using Performance Results to Optimize Performance

- 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



Balanced Mix Design Task Force - Development and Work

Oldcastle Materials

Pavement Implementation Executive Task Group (PIETG)

- **At the *<u>request of the National Pavement Implementation Executive Task Group (PIETG)</u>* a Balanced Mix Design Task Force formed at the September 2015 FHWA Mixture and Construction ETG meeting**
- The PIETG is focused on the strategic program level challenges and opportunities in the deployment of pavement technologies.
- Focus areas include:
  - ***Pavement Design and Analysis;***
  - ***Pavement Materials and Quality Assurance;***
  - Pavement Surface Characteristics;
  - Construction Technology;
  - Pavement Sustainability;
  - Technical Capacity; and
  - Field Support/Technical Assistance.

Pavement Implementation Executive Task Group (PIETG)

FHWA		
John Bukowski	Materials Team Leader	FHWA
Christopher Wagner	Pavment and Materials Tech. Srvs. Team Leader	
Gina Ahlstrom	Pavement Design and Analysis Team Leader	
Jeff Withee	Pavement Materials Engineer	
Mark Swanlund	Infrastructure R&D Program Coordinator	
Bryan Cawley	Construction Mgmt. Team Leader	
Stephen Gaj	Asset Mgmt. Team Leader	
Hari Kalla	Director, Office of Asset Mgmt., Pavement & Construction	
INDUSTRY		
Mike Acott	President	NAPA
Audrey Copeland	VP, Engineeering, Tech. and Research	NAPA (attendee)
Gerald Voigt	President/CEO	ACPA
Leif Wathne	VP, Highways and Federal Affairs	ACPA (alternate)
Jim Duit	President	Duit Construction Co.
Dave Howard	President/CEO	Koss Construction
Ron Sines	VP - Asphalt Performance	Oldcastle Materials
Jay Winford	President	Prairie Contractors, Inc.
DOTs		
Carlos Braceras	Executive Director	Utah DOT
Dave Huft	Research Program Mgr.	South Dakota DOT
Richard Tetreault	Deputy Secretary	Vermont Agency of Transportation
Russell McMurry	Commissioner	Georgia DOT
Garrett Moore	Chief Engineer	Virginia DOT
ACADEMIA		
Peter Taylor	Associate Director	Iowa State University
Kevin Hall	Professor and Head	University of Arkansas (CE)
David Newcomb	Senior Research Scientist	Texas A&M Transportation Institute
Paul Tikalsky	Dean of Engineering	Oklahoma State University

Balanced Mix Design Task Force

- BMD TF 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

- **Cross sectional membership**
  - FHWA
  - State Agency
  - Industry
  - Academia/Research
  - Consultant

Balanced Mix Design Task Force

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Agency Practices Related to BMD

State Agency Practice

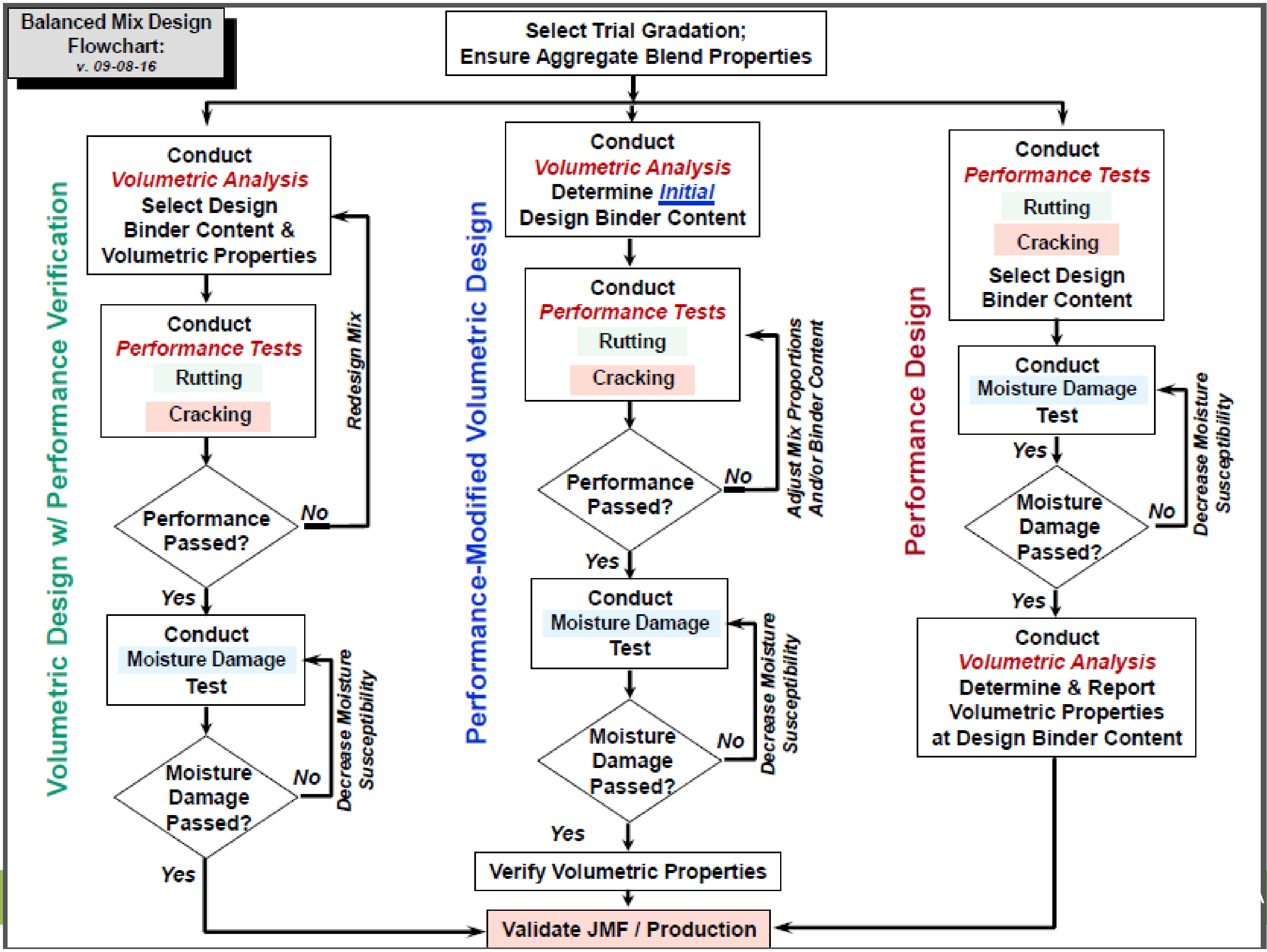
- A number of SHAs have begun to either explore or adopt BMD approaches and others are in the process of investigating performance testing (specifically cracking tests) for integration into their mixture designs.
  - Other states are considering/evaluating approaches (Minnesota, Ohio, Utah, Maryland, Florida, Georgia, etc.

State	Approach	Stability Test	Conditioning (S)	Durability/Cracking Test	Conditioning (D)
California	Performance Mod Vol Design	SST Repeated Shear, Hamburg	Short Term	Bending Beam Fatigue (BBF)	Long Term
Illinois	Vol Design w/ Performance Verification	Hamburg	Short Term	Semi Circular Bend (IFIT)	Long Term
Louisiana	Vol Design w/ Performance Verification	Hamburg	Short Term	Semi Circular Bend (LTRC)	Long Term
New Jersey	Vol Design w/ Performance Verification	Asphalt Pavement Analyzer	Short Term	Texas Overlay Test (OT)	Long Term
Texas	Vol Design w/ Performance Verification	Hamburg	Short Term	Texas Overlay Test (OT)	Long Term
Wisconsin	Vol Design w/ Performance Verification	Hamburg	Short Term	Disc Shaped Compact Tension + Bending Beam Fatigue (IFIT)	Long Term

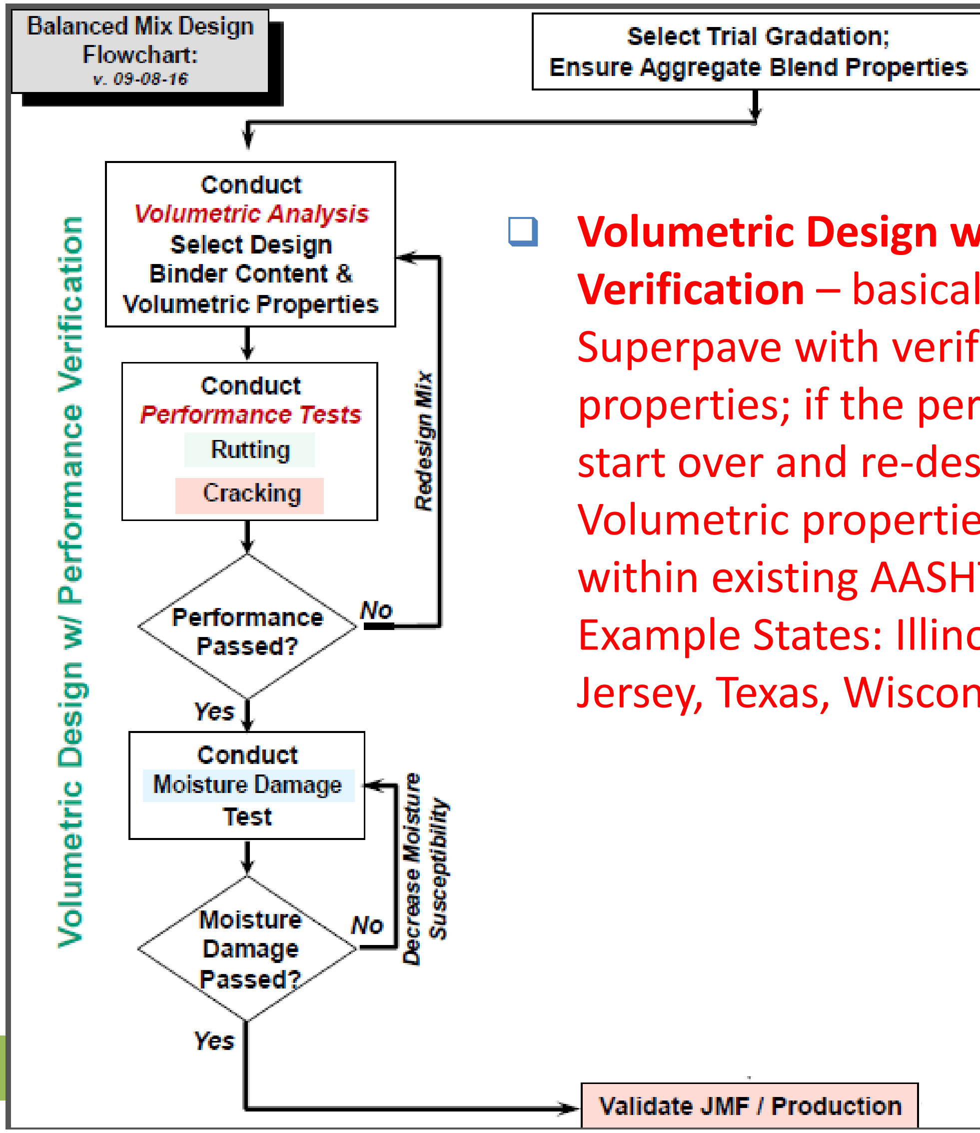
What Typically Drives a State Agency Practice?

- The state of practice examples indicate that **SHAs are selecting different performance tests.**
- Variance is **driven by different pavement distress considerations** (e.g., thermal cracking in Minnesota versus top-down cracking in Florida).
- Additionally, SHAs are **sometimes selecting performance tests based on the intended mix application or mix component of interest.**
  - For example,
    - Caltrans is addressing high traffic mixtures,
    - WisDOT and IDOT are addressing recycled materials,
    - LADOTD is focusing on wearing and binder course mixtures, and
    - TxDOT and NJDOT are both focused on high-performance and specialty mixtures.

Agency Approaches – 3 Main Approaches Identified

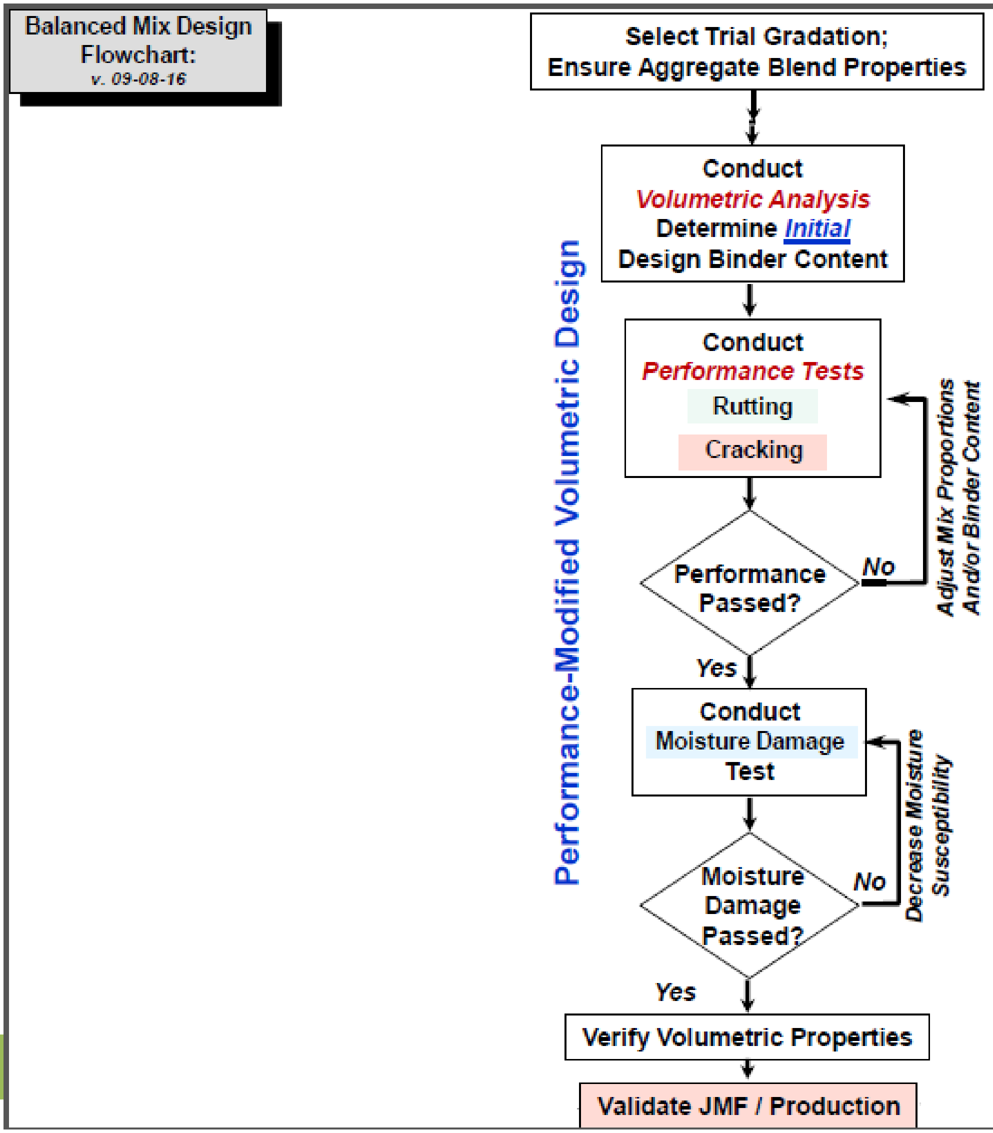


Volumetric Design w/ Performance Verification



- **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 AASHTO M323 limits. Example States: Illinois, Louisiana, New Jersey, Texas, Wisconsin

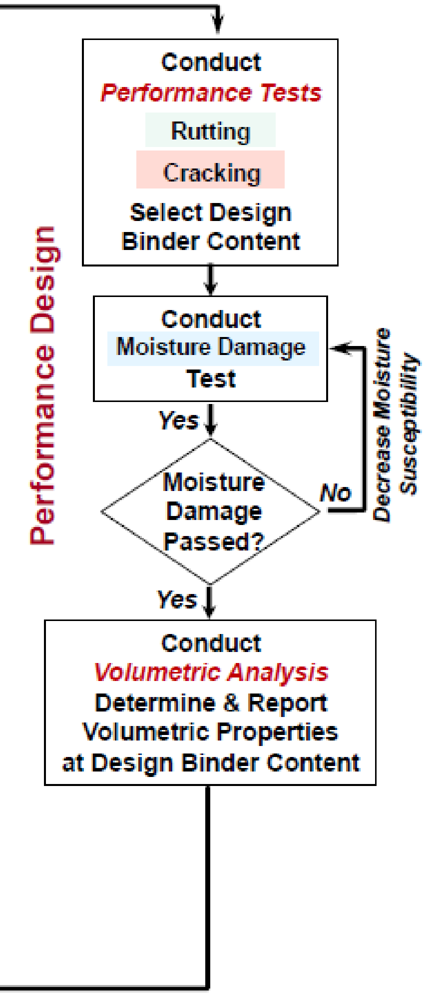
Performance Modified Volumetric Design



- **Performance-Modified Volumetric Design** – the initial design binder content is selected using AASHTO 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 AASHTO M323 limits. Example State: California

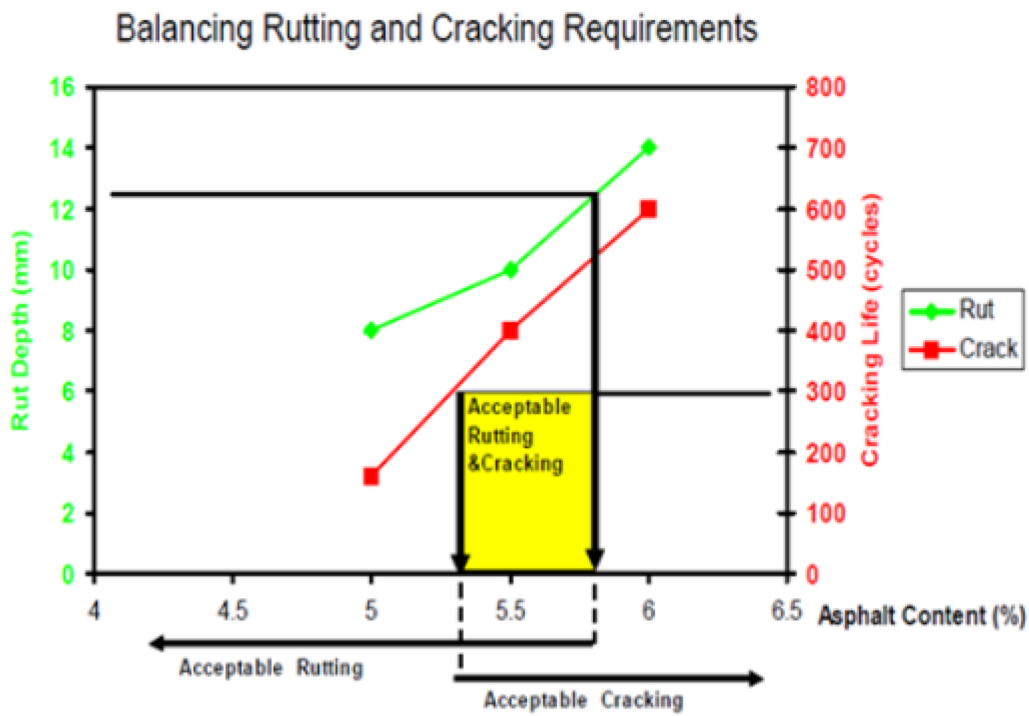
Performance Design

- **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 AASHTO M323 limits. Example States: New Jersey w/ draft approach



BMD Basic Example – Volumetric Design w/ Performance Verification

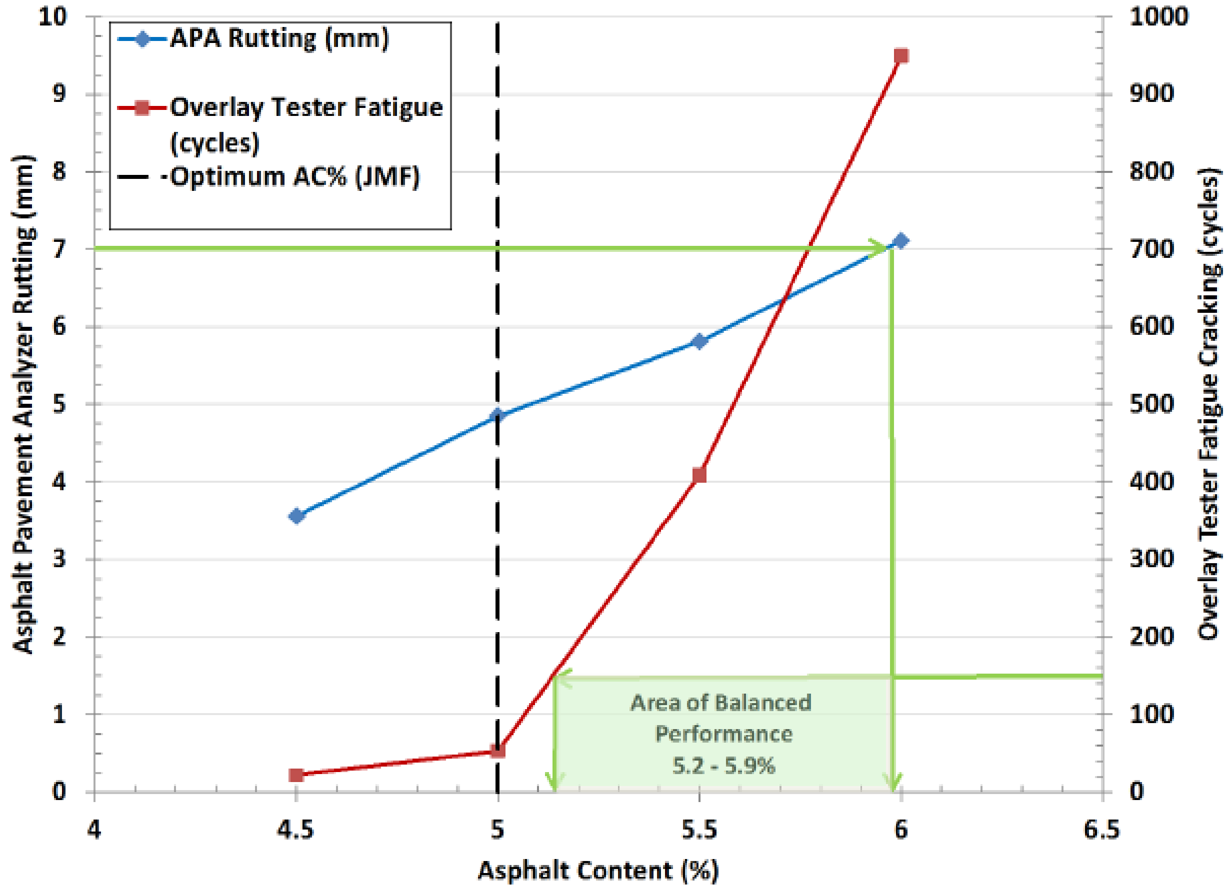
- **Texas DOT**
  - Volumetric design conducted
  - Hamburg Wheel Tracking Test (HWTT) AASHTO T 324
  - Overlay Tester (OT) Tex-248-F
  - Three asphalt binder contents are used: optimum, optimum +0.5%, and optimum -0.5%.
  - The HWTT specimens are short-term conditioned.
  - The OT specimens are long-term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



Within this acceptable range (5.3 to 5.8 percent), the mixture at the selected asphalt content must meet the Superpave volumetric criteria.

BMD Basic Example – Volumetric Design w/ Performance Verification

- **New Jersey**
  - APA (Rutting)
  - Texas OT (Cracking)
  - Mixes are designed to optimize performance not around a target air void content



Courtesy of Tom Bennert

FHWA Technical Brief - Draft

- Technical Brief being developed to provide a current summary of the BMD TF efforts.
- Under review by FHWA Public Affairs

TechBrief

The Asphalt Pavement Technology Program is an integrated, national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the

Balanced Mixture Design Approaches for Asphalt Pavement Construction

DRAFT

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 Upcoming: NCHRP Project 20-07/Task 406

- **Development of a Framework for Balanced Asphalt Mixture Design**
- Objective is to develop a framework that addresses alternate approaches to devise and implement balanced mix design procedures incorporating performance testing and criteria.

NCHRP
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Proposals Received and Being Evaluated by the Project Panel (as of 2/8/17)

NCHRP Project 20-07/Task 406, FY 2017

Development of a Framework for Balanced Asphalt Mixture Design

Funds Available: $100,000

Contract Time: 12 months (includes 3 months for NCHRP review and for contractor revision of the final report)

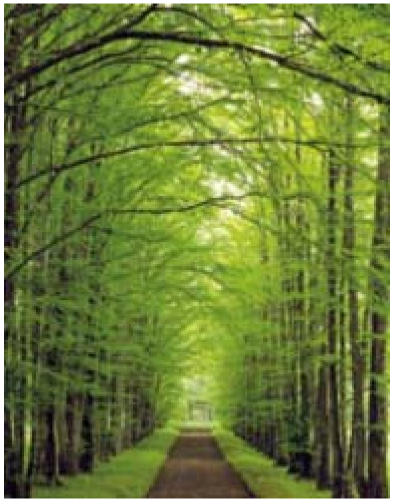
Staff Responsibility: Edward Harrigan, 540-454-2149 (email: eharriga@nas.edu)

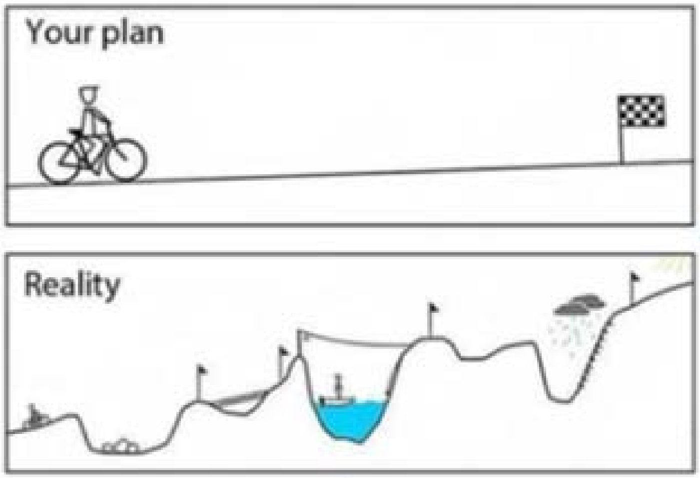
Authorization to Begin Work: 04/01/2017 (estimated)

Proposal Due Date: 01/26/2017

The Path Forward for Balanced Mix Design

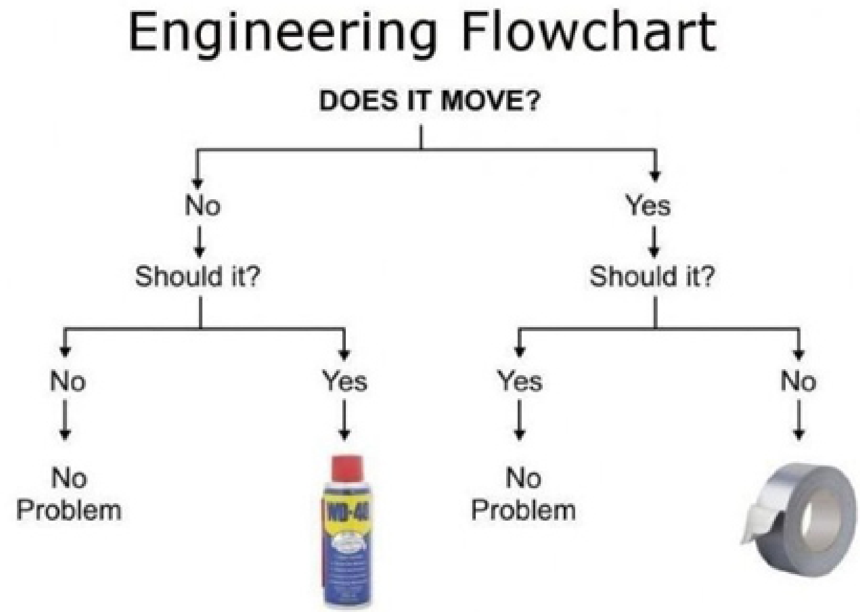
- Recognize the need and move incrementally in the appropriate direction to limit risk of mix performance issues.
- Must continue with theoretical research/modeling efforts, but not be afraid to utilize practical approaches to find solutions.
- **Recognize that this is a long term effort with ups/downs, 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 <u>Correct</u>”**



“Good doesn’t have to be complicated and complicated isn’t always good!”

Thoughts and Questions?