Optimized Mix Design for Performance

Northeast Asphalt User Producer Group (NEAUPG)
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Oldcastle Materials

Discussion Topics

- Need for an Optimized Mix Design (OMD) Approach
- Proposed framework
- Next steps

Optimized or Balanced Mix Design

- ***Optimized***
  - Make the best or most effective use of (a situation, opportunity, or resource):
- ***Balanced***
  - Being in proper arrangement or adjustment, proportion

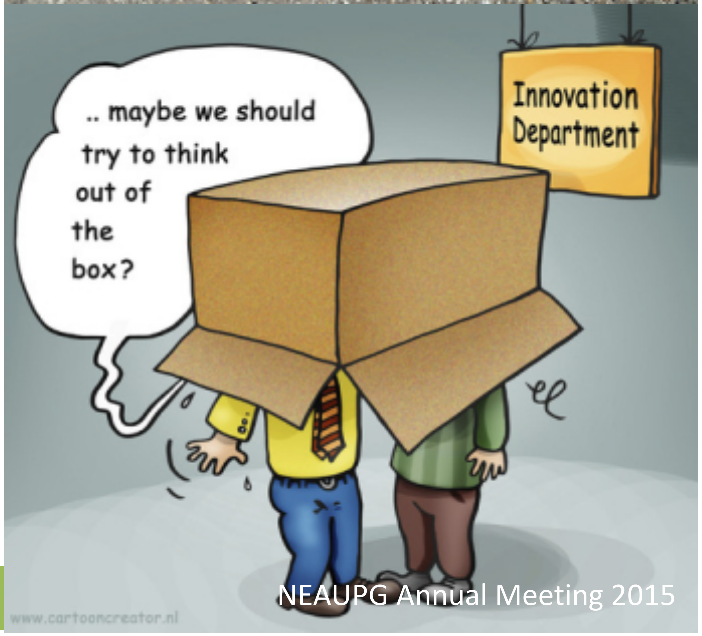
- ***Optimized Mix Design***
  - ***Optimize the mix in terms of binder content + other mix items (aggregate, grading, recycle, binder, etc.) to provide needed performance.***

Why the Need for a New Mix Design Approach?

- **Problems:**
  - Dry mixes exist in some locations
  - Continuing to increase binder replacement without addressing mix performance is not sustainable

- **Solutions:**
  - **Recognize (admit) performance issues** related to dry mixes
  - **Increase understanding** of the factors which drive mix performance
  - **Start thinking** outside of long held "rules and constraints"

  - **Innovate!**



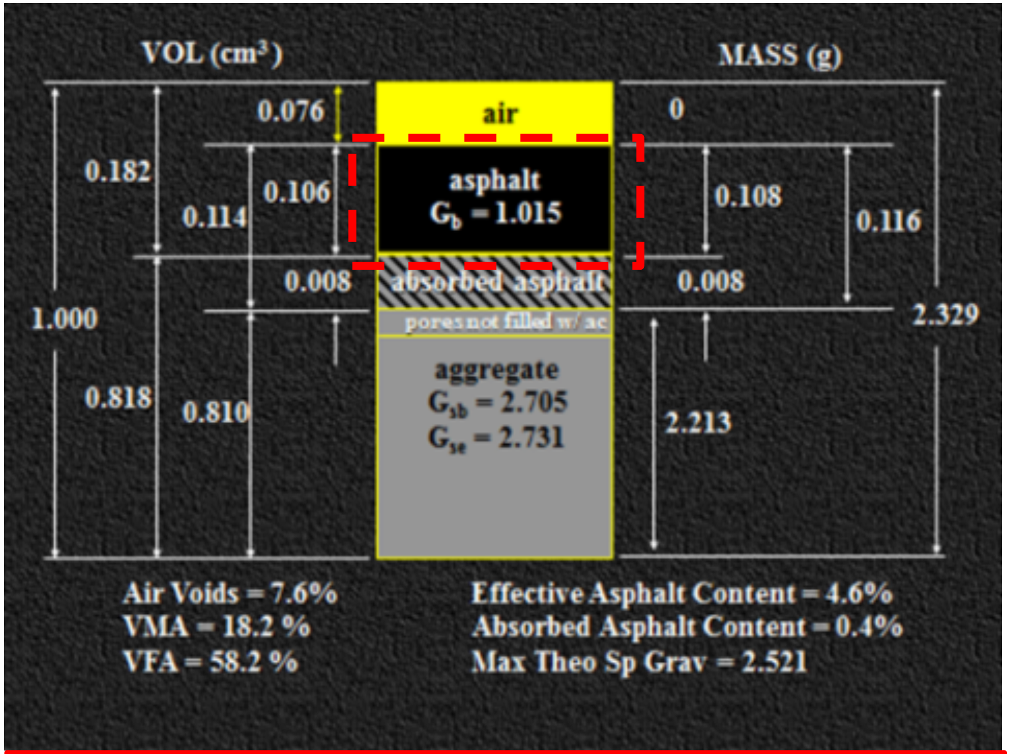
Steps Must be Taken *Now* Towards Solutions

- **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

Agencies Are Searching for Solutions

- **Superpave system is becoming unrecognizable**
- State specifications are changing rapidly as agencies search for ways to improve durability
    - *Lowering gyrations*
    - *Increasing VMA*
    - *Lowering air voids*
    - *Minimum film thickness*
    - *Minimum binder content*
    - *Limiting recycle*
    - *Softer PG binders*
    - *Rejuvenators*
- **Establishing true "cause and effect" is impossible**



GOAL: Appropriate Effective Binder Volume (Vbe) for the Given Mix and Application

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

Agencies are Searching for Solutions

- Alabama DOT
  - Ndesign = 60 gyrations for all mixes
  - Increased design VMA by 0.5%
  - Minimum total binder content for non-RAS and RAS mixes (0.2% higher)
  - 3.5% design voids for RAS mixes

1. AIR VOIDS (Va).

The design air voids for all levels of traffic is 3.5 % for mixes containing RAS and 4.0 % for all other mixes.

2. VOIDS IN MINERAL AGGREGATE (VMA).

The job mix shall be designed at a minimum VMA given in the following table.

VOIDS IN MINERAL AGGREGATE DESIGN VMA FOR SUPERPAVE ***		
Maximum Aggregate Size * (inches) {mm}	Nominal Aggregate Size (inches) {mm}	Minimum VMA (%)
3/8 {9.5 }	No. 4 {4.75}	16.5 **
1/2 {12.5 }	3/8 {9.5}	15.5
3/4 {19.0 }	1/2 {12.5}	14.5
1 {25.0 }	3/4 {19.0}	13.5
1.5 {37.5 }	1 {25.0}	12.5

* As defined in Subarticle 424.02(c)
** All 3/8" (9.5 mm} mixes where the ESAL range is greater than A/B shall have a maximum VMA of 18.0.
*** Production VMA may be 0.5 lower than design VMA.

LIQUID ASPHALT BINDER CONTENT (Pb) CRITERIA FOR SUPERPAVE			
Maximum Aggregate Size* (inches) {mm}	Nominal Aggregate Size (inches) {mm}	Minimum Liquid Asphalt Binder Content (Pb) by Percent of Total Mix**	Minimum Liquid Asphalt Binder Content (Pb) for mixes containing RAS by Percent of Total Mix**
3/8 {9.5 }	No. 4 {4.75}	5.90	6.1
1/2 {12.5 }	3/8 {9.5}	5.50	5.7
3/4 {19.0 }	1/2 {12.5}	5.10	5.3
1 {25.0 }	3/4 {19.0}	4.40	4.6
1.5 {37.5 }	1 {25.0}	4.20	4.4

* As defined in Subarticle 424.02(d)
** Nd = 60

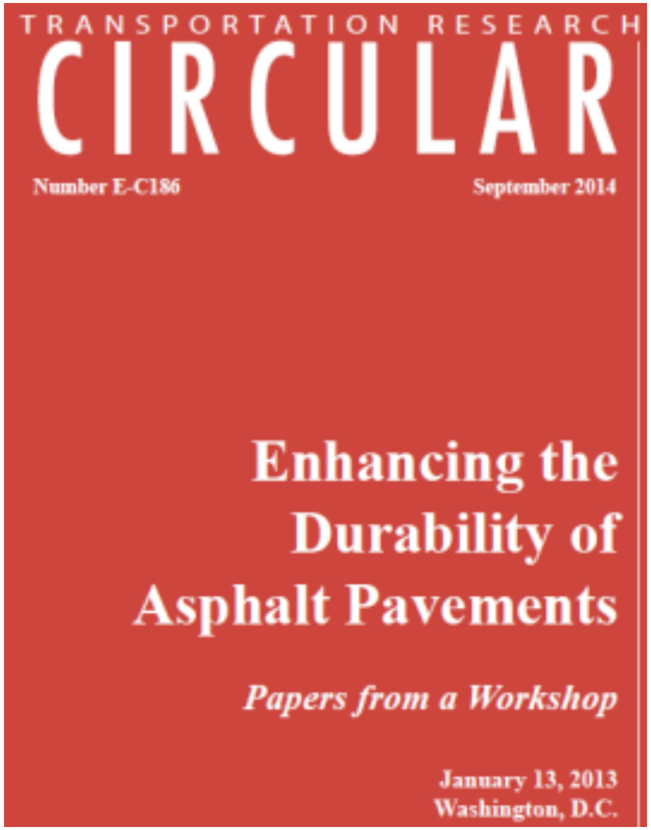
Oldcastle Materials

Enhancing the Durability of Asphalt Pavements

Impact of Mix Design on Asphalt Pavement Durability

RAMON BONAQUIST
Advanced Asphalt Technologies, LLC

- **“Volume of Effective Binder (Vbe) is the primary mixture design factor affecting both durability and fatigue cracking resistance**. “
- “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.**


TRANSPORTATION RESEARCH
CIRCULAR
Number E-C186
September 2014

Enhancing the Durability of Asphalt Pavements

Papers from a Workshop

January 13, 2013
Washington, D.C.

Mix Design Approaches - Balanced

- Balanced Mix Design Approaches are currently utilized by some Agencies
  - Texas (Hamburg + OT)
  - Louisiana (Hamburg + SCB)
  - New Jersey (APA + OT)
- **Questions**
  - Is the utilized balanced approach design appropriate for all mixes?
    - 1) Are universal volumetrics (e.g., VMA and air voids) controlling without regard to traffic?
      - Same air voids for all mixes
      - Same VMA for a NMS mix regardless of traffic
    - 2) Are the utilized performance tests appropriate for the probable mode of distress?

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/

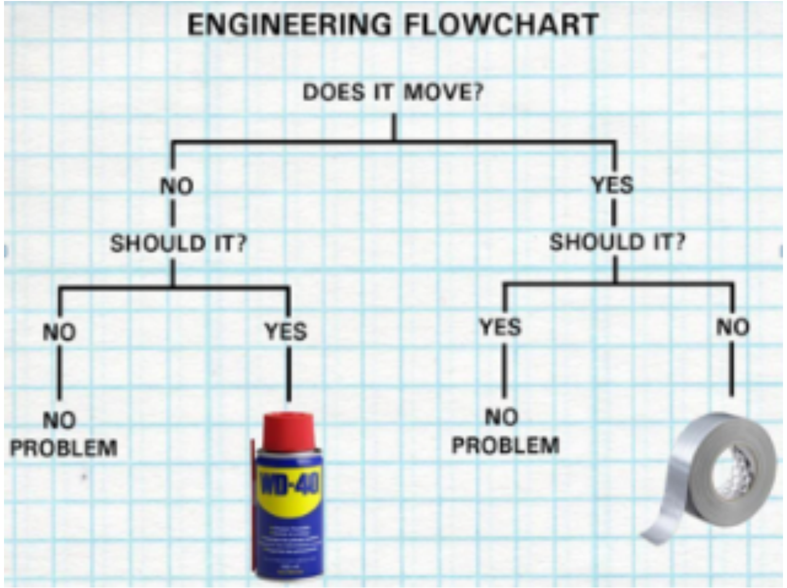
Conventional Mix Design

- Largely recipe driven (specified)
  - Aggregates
  - Blend grading
  - Volumetrics (Va, VMA, VFA, D/A, etc.)
  - PG binder type and minimum amount
  - RAP and/or RAS content
  - Other additives (e.g. WMA) use, amount, etc.
- While this may work, there are problems
  - Recipe specifications have become **convoluted and confounded**
    - Specified items compete against each other
    - New requirements get added and nothing gets removed
  - Innovation has become stifled with our knowledge outpacing specifications

"Marshall method" pavement testing apparatus

Optimized Mix Design: A Better Approach

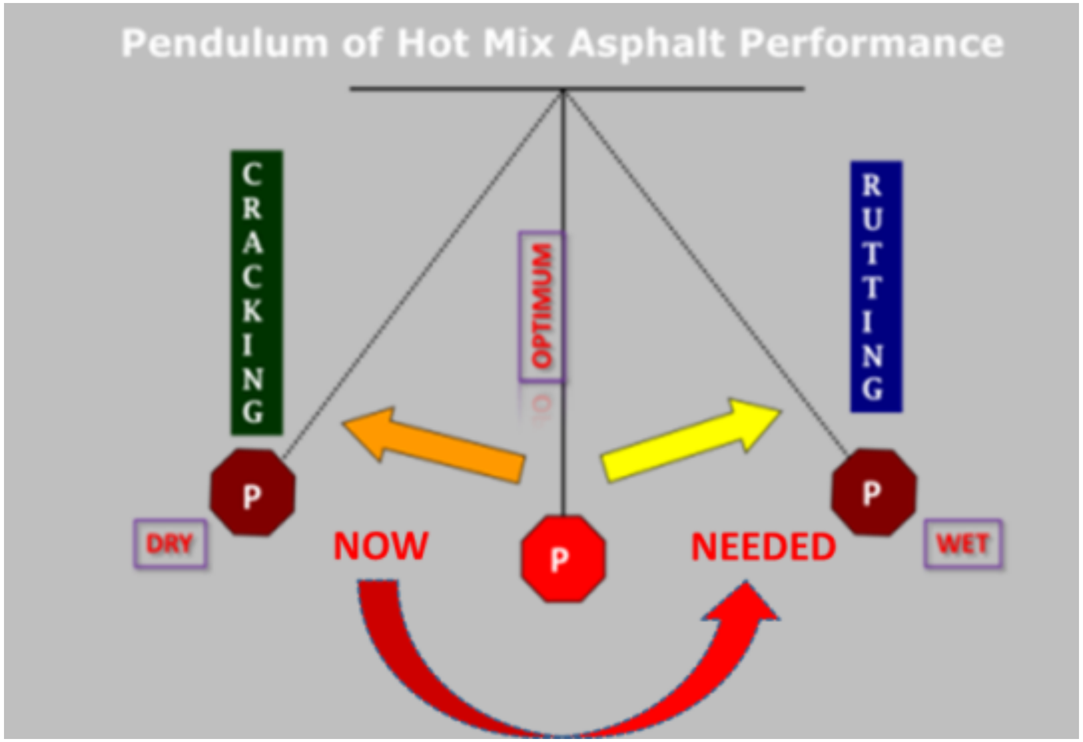
- Let's stop using a recipe to "bake the cake".
  - Define the desired product (performance) and open up the recipe to meet the end result.
  - What defines a good cake? Good Taste
  - What defines a good mix? **Performance**
- Optimized Mix Design Approach Foundational Points
  - **"Use What Works"**
  - **"Eliminate What Doesn't"**
  - **"Be Simple, Practical, and Correct"**



"Good Doesn't Have to be Complicated"

Optimized Mix Design Approach – Basic Fundamentals

- Move away from the philosophy of "putting as little binder in the mix as possible just to limit cracking"



Optimized Mix Design Overview

Optimized Mix Design Approach – Mindset Change

- Challenge historical / conventional thinking
- Open the mix design to innovation and engineering
- Reward innovative and proactive contractors
  - Let's avoid the "no contractor left behind" system
- Greatly limit the "rules and restrictions" for the mix designer

Item	Thoughts/Questions
Recycle	Does the mix suddenly become bad at 1% over the "limit"?
Blend Grading	Are the grading bands based on performance or opinion?
Aggregate	Can we use local aggregates that may perform well?
PG Binder	Do we need to bump grades as often? Polymer use?
Volumetrics	What is so sacred about 4 percent air voids?

- **OBTAIN AND MAINTAIN PERFORMANCE**

Optimized Mix DesiGn Approach (OMEGA)

I
- Material Evaluation and Selection

II
- Mixture Stability Performance Evaluation

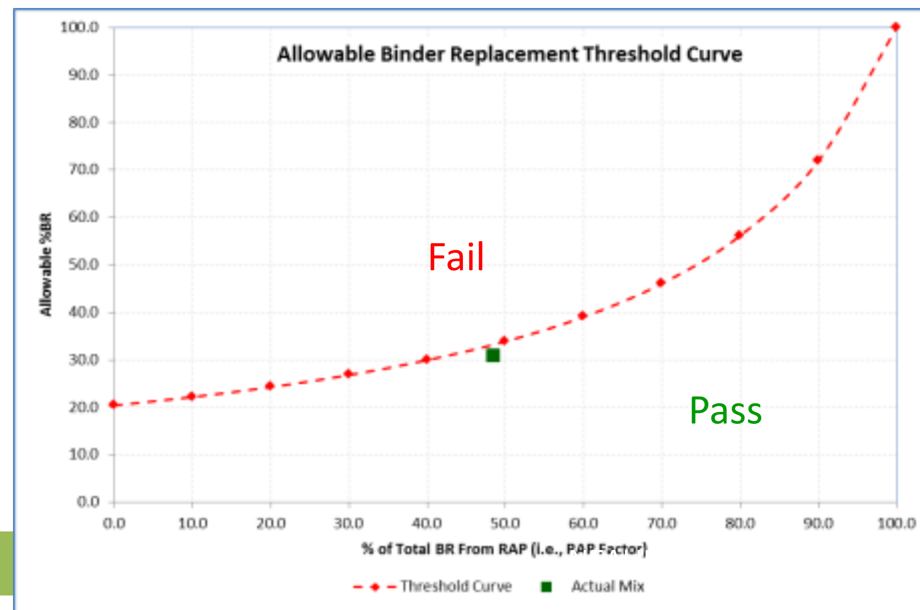
III
- Mixture Cracking/Durability Performance Evaluation

IV
- Mixture Workability Evaluation

Optimized Mix Design Approach – Materials Selection

- Strong emphasis on using **local materials, maximizing recycle, and engineering the binder** to obtain the necessary performance
  - Better understanding/control of material properties (e.g., virgin aggregate grading consistency, RAP aggregate gravity and recycled binder continuous grading)
  - WMA and rejuvenator use where appropriate
  - Binder blending analysis to evaluate needed grades for locations

BINDER BLENDING ANALYSIS	
Maximum % RAP Allowed (100% RAP BR)	100.0
Maximum % RAS Allowed (100% RAS BR)	5.1
Desired % RAP (Weight of Total Mix)	15
Desired % RAS (Weight of Total Mix)	4
% BR from RAP	15.0
% BR from RAS	16.0
% BR Total (Actual)	31.0
% of Total BR from RAP	48.4
% of Total BR from RAS	51.6
% BR Total (Allowable)	33.25
Pass or Fail	***PASS***
Achieved PG Low Temperature, C	-16.5
Desired PG Low Temperature, C	-16.0



Optimized Mix Design Approach – Binder Estimation

- Estimate the **target effective binder volume (Vbe)** based on NMAS and traffic level
- Adjust virgin binder content as a function of RAP and RAS addition to compensate for lack of 100% recycled binder contribution
- Utilize M323 VMA requirement for required high volume mix Vbe
- Increase the Vbe by 0.5 and 1.0% for medium and low volume traffic respectively.
  - **0.2% Vbe ~ 0.1% Pbe**
- Ultimately, select appropriate Vbe based on mix performance

NMS	M323 VMA	Air Voids	VMA Target at Traffic Level			Target Minimum Binder Volume at Traffic Level			Estimated Effective Binder Content (Pbe) @ Gsb = 2.65		
			Low	Medium	High	Low	Medium	High	Low	Medium	High
4.75	16	4	17	16.5	16	13.0	12.5	12.0	5.69	5.46	5.22
9.5	15	4	16	15.5	15	12.0	11.5	11.0	5.22	4.99	4.75
12.5	14	4	15	14.5	14	11.0	10.5	10.0	4.75	4.52	4.29
19	13	4	14	13.5	13	10.0	9.5	9.0	4.29	4.06	3.83
25	12	4	13	12.5	12	9.0	8.5	8.0	3.83	3.61	3.39
37.5	11	4	12	11.5	11	8.0	7.5	7.0	3.39	3.17	2.94

Recycle Binder Adjustment

- **Assumption:** 90 and 70%, respectively of the RAP and RAS binder effectively contributes to the total mix binder.
- Additional Virgin Binder % = 0.005 (RAP%) + 0.055 (RAS%)
    - Is this correct? No one knows!
        - 20% RAP or 2% RAS = +0.10% Virgin Binder
        - Typical RAP/RAS Addition
            - 17% RAP/4% RAS = +(0.085 + 0.22) = +0.31%

20% RAP Comparison (100% and 90% Binder Contribution)

Recycle Value Illustrator (100% RAP Binder Contribution)

INPUT	**Materials and Mix Characteristics**	
	RAP Binder Content, %	5.0
	RAS Binder Content, %	20.0
	Effective RAP Binder Contribution, %	100.0
	Effective RAS Binder Contribution, %	100.0
	Total Mix Asphalt Binder Content, %	5.5
	Material Costs	
	Virgin Asphalt Binder Cost / Ton, $	500.00
	Virgin Aggregate Blend Cost, $	10.00
	RAP Cost / RAP Ton, $	8.00
	RAS Cost / RAS Ton, $	20.00
CALCULATED	**Material Costs (As Used in Mix)**	
	RAP Cost / Mix Ton, $	1.60
	RAS Cost / Mix Ton, $	0.00
	RAP + RAS Cost / Mix Ton, $	1.60
	Binder Replacement	
	RAP Binder Provided, %	1.00
	RAS Binder Provided, %	0.00
	Total Recycle Binder Provided, %	1.00
	Binder Replacement from Recycled, %	18.18
	Savings	
	RAP Net Savings / Mix Ton, $	5.30
	RAS Net Savings / Mix Ton, $	0.00
	RAP + RAS Net Savings / Mix Ton, $	5.30
INPUT	RAP %	20
	RAS %	0

Recycle Value Illustrator (90% RAP Binder Contribution)

INPUT	**Materials and Mix Characteristics**	
	RAP Binder Content, %	5.0
	RAS Binder Content, %	20.0
	Effective RAP Binder Contribution, %	90.0
	Effective RAS Binder Contribution, %	100.0
	Total Mix Asphalt Binder Content, %	5.5
	Material Costs	
	Virgin Asphalt Binder Cost / Ton, $	500.00
	Virgin Aggregate Blend Cost, $	10.00
	RAP Cost / RAP Ton, $	8.00
	RAS Cost / RAS Ton, $	20.00
CALCULATED	**Material Costs (As Used in Mix)**	
	RAP Cost / Mix Ton, $	1.60
	RAS Cost / Mix Ton, $	0.00
	RAP + RAS Cost / Mix Ton, $	1.60
	Binder Replacement	
	RAP Binder Provided, %	0.90
	RAS Binder Provided, %	0.00
	Total Recycle Binder Provided, %	0.90
	Binder Replacement from Recycled, %	16.36
	Savings	
	RAP Net Savings / Mix Ton, $	4.80
	RAS Net Savings / Mix Ton, $	0.00
	RAP + RAS Net Savings / Mix Ton, $	4.80
INPUT	RAP %	20
	RAS %	0

RAP Savings Impact

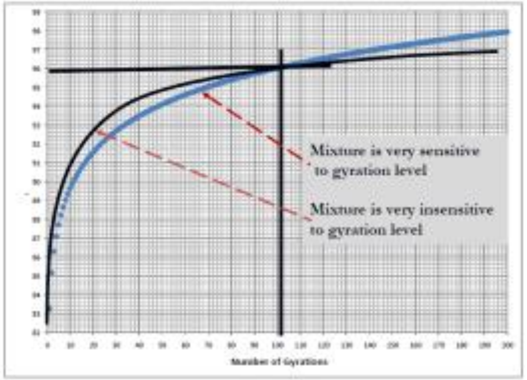
- Lost savings ($0.50/ton) from using 90% effective RAP binder contribution can be recovered by using a relatively small amount more RAP.
  - 23% vs 20% in this example.
  - 23% @ 90% contribution = $5.52 compared to $5.30 (20% at 100% contribution)

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

Net Savings	Effective Binder Contribution From RAP, %										
$ 4.80	**50.0**	**55.0**	**60.0**	**65.0**	**70.0**	**75.0**	**80.0**	**85.0**	**90.0**	**95.0**	**100.0**
RAP, %											
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	2.10	2.29	2.48	2.66	2.85	3.04	3.23	3.41	3.60	3.79	3.98
16	2.24	2.44	2.64	2.84	3.04	3.24	3.44	3.64	3.84	4.04	4.24
17	2.38	2.59	2.81	3.02	3.23	3.44	3.66	3.87	4.08	4.29	4.51
18	2.52	2.75	2.97	3.20	3.42	3.65	3.87	4.10	4.32	4.55	4.77
19	2.66	2.90	3.14	3.37	3.61	3.85	4.09	4.32	4.56	4.80	5.04
20	2.80	3.05	3.30	3.55	3.80	4.05	4.30	4.55	***4.80***	5.05	5.30
21	2.94	3.20	3.47	3.73	3.99	4.25	4.52	4.78	5.04	5.30	5.57
22	3.08	3.36	3.63	3.91	4.18	4.46	4.73	5.01	5.28	5.56	5.83
23	3.22	3.51	3.80	4.08	4.37	4.66	4.95	5.23	5.52	5.81	6.10
24	3.36	3.66	3.96	4.26	4.56	4.86	5.16	5.46	5.76	6.06	6.36
25	3.50	3.81	4.13	4.44	4.75	5.06	5.38	5.69	6.00	6.31	6.63
26	3.64	3.97	4.29	4.62	4.94	5.27	5.59	5.92	6.24	6.57	6.89
27	3.78	4.12	4.46	4.79	5.13	5.47	5.81	6.14	6.48	6.82	7.16
28	3.92	4.27	4.62	4.97	5.32	5.67	6.02	6.37	6.72	7.07	7.42
29	4.06	4.42	4.79	5.15	5.51	5.87	6.24	6.60	6.96	7.32	7.69
30	4.20	4.58	4.95	5.33	5.70	6.08	6.45	6.83	7.20	7.58	7.95
31	4.34	4.73	5.12	5.50	5.89	6.28	6.67	7.05	7.44	7.83	8.22
32	4.48	4.88	5.28	5.68	6.08	6.48	6.88	7.28	7.68	8.08	8.48
33	4.62	5.03	5.45	5.86	6.27	6.68	7.10	7.51	7.92	8.33	8.75
34	4.76	5.19	5.61	6.04	6.46	6.89	7.31	7.74	8.16	8.59	9.01
35	4.90	5.34	5.78	6.21	6.65	7.09	7.53	7.96	8.40	8.84	9.28
36	5.04	5.49	5.94	6.39	6.84	7.29	7.74	8.19	8.64	9.09	9.54
37	5.18	5.64	6.11	6.57	7.03	7.49	7.96	8.42	8.88	9.34	9.81
38	5.32	5.80	6.27	6.75	7.22	7.70	8.17	8.65	9.12	9.60	10.07
39	5.46	5.95	6.44	6.92	7.41	7.90	8.39	8.87	9.36	9.85	10.34
40	5.60	6.10	6.60	7.10	7.60	8.10	8.60	9.10	9.60	10.10	10.60

Optimized Mix Design Approach – Compaction

- **Mix Compaction (Key Points)**
  - Utilize a single gyration level used (e.g., locking point), ~60 to 75 gyrations is typical
  - Lock, DON'T crush the aggregate!
  - Compact specimens four binder contents (Vbe min, Vbe min-0.50, Vbe min - 1.0, Vbe min + 0.50)
    - Record specimen volumetrics and proceed to performance testing

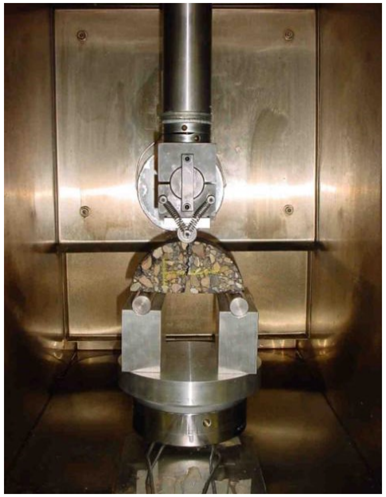


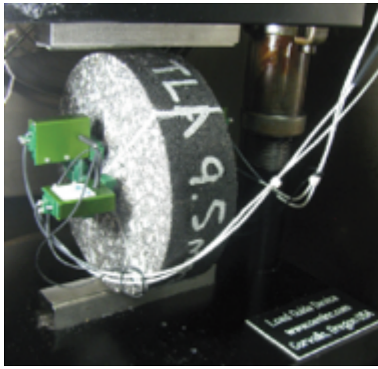
Optimized Mix Design Approach – Stability Evaluation

- Utilize one of several available “rutting” evaluation tools.
  - Hamburg, APA, AMPT Flow Number, etc.
  - Failure criteria based on best available research (local, regional, or national)
    - Specific criteria as a function of traffic (e.g., low, medium, high)

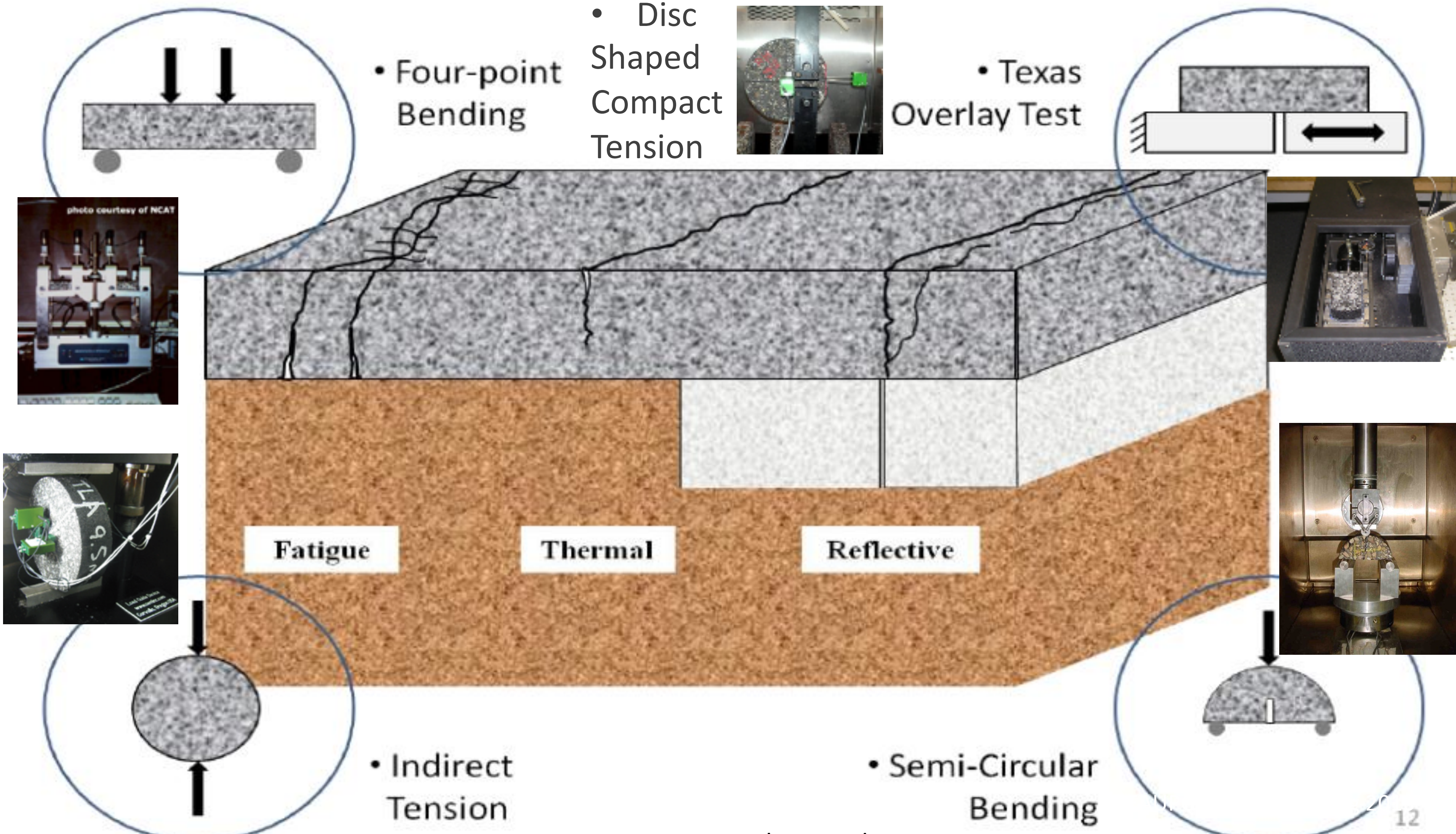
Optimized Mix Design Approach – Durability/Cracking Evaluation

- 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 what is the best test or the appropriate failure threshold
- **GOALS**
  - **MATCH THE TEST TO THE DISTRESS**
  - **SET APPROPRIATE FAILURE THRESHOLDS**





Match the Test to the Distress



From: Louay Mohammad, LTRC

Match the Test to the Distress

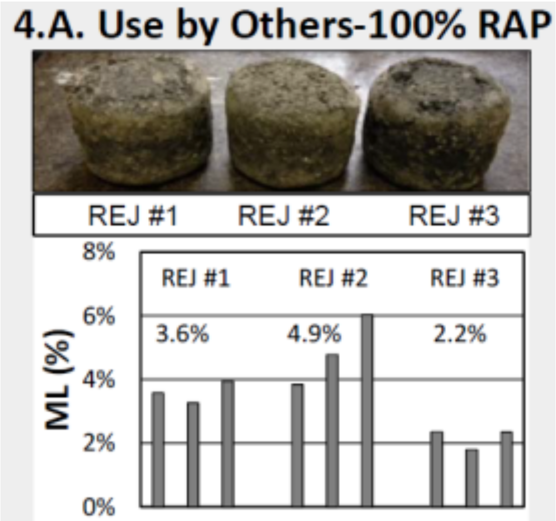
- **NCHRP 9-57: Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures**
- Cracking Workshop held in early 2015
- Top tests for various distresses identified by national group of academia, agency, and industry representatives

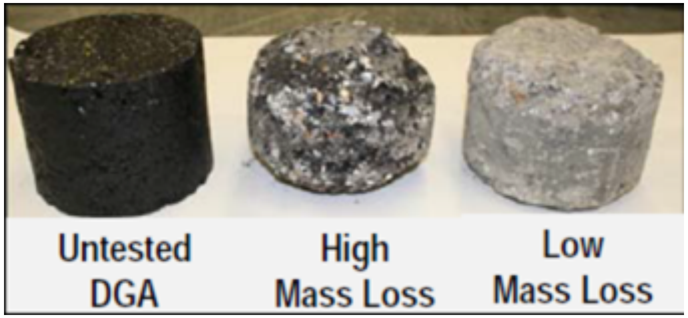
Items	Thermal Cracking	Reflection Cracking	Bottom-up Fatigue Cracking	Top-down Fatigue Cracking
Selected cracking tests	1. DCT 2. SCB-IL 3. SCB at low temp.	1. OT 2. SCB at intermediate temp. 3. BBF	1. BBF 2. SCB at intermediate temp.	1. SCB at intermediate temp. 2. IDT-UF

From: Dave Newcomb, TTI

Alternate Durability Test/Check - Cantabro

- Cantabro test can provide a very quick, low cost durability measurement
  - **Relative** indication of mix durability
  - Almost too easy not to try!
- Specimen in LA drum, no spheres, 300 revolutions





From: Issac Howard, SEAUPG 2014

Cantabro Testing – Dense Graded Mixes

- Limited research available on Cantabro testing of dense grade mixes
- Research performed on mixes from various airfield projects
  - Analyzed variables were gradation, binder type, plant produced vs. lab produced mix, aggregate source, air void content and conditioning.

- Results followed "expected" trends:
  - Mass loss (ML) increased with Va increase
  - ML decreased with polymer modified binders
  - ML increased w/ coarser gradings
  - ML increased w/ aging

From: "Performance oriented guidance for airfield asphalt pavements within the Superpave context", Robert James, PhD Dissertation, Mississippi State University, August 2014

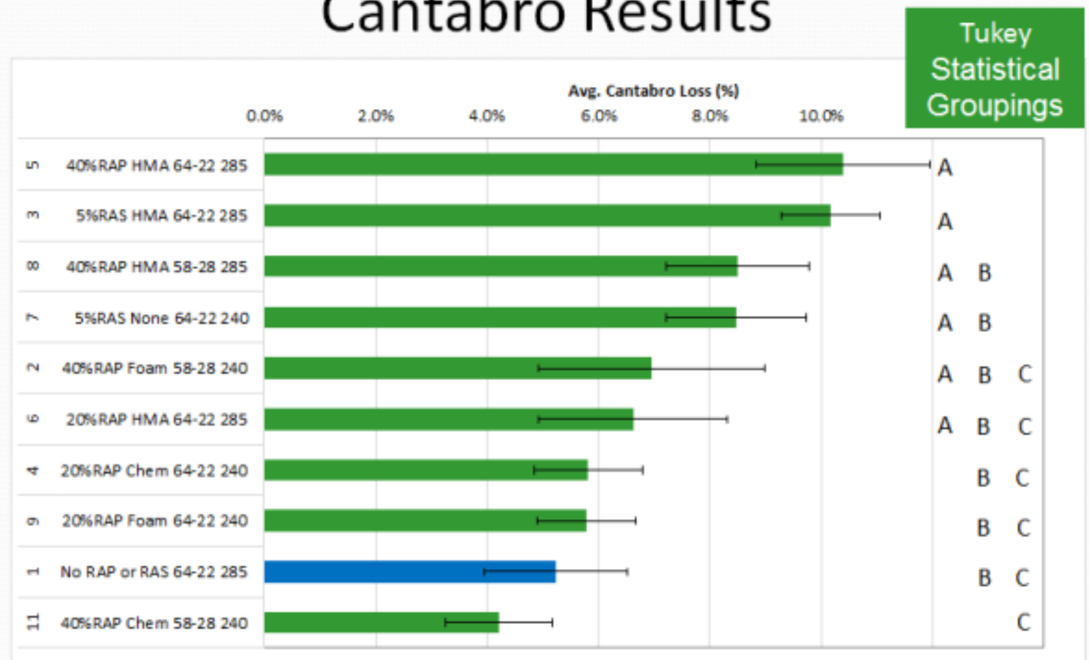
Cantabro Testing – NCAT Testing of FHWA ALF Mixes

- 2013 FHWA ALF experimental mixes were evaluated with several "practical tests".
- Cantabro was able to statistically differentiate the virgin mix from any other experimental mix.

ALF Experimental Design

Recycle Content \ Warm Mix Technology \ Production HMA / WMA Temperature	300°F - 320°F		240°F - 270°F	
	-		Foam	Chem.
0%	✔ PG64-22		-	-
20% ABR RAP ≈ 23% by weight	✔ PG64-22		✔ PG64-22	✔ PG64-22
20% ABR RAS ≈ 6% Shingle by weight	✔ PG64-22	✔ PG58-28		
40% ABR RAP ≈ 44% by weight	✔ PG64-22	✔ PG58-28	✔ PG58-28	✔ PG58-28

Cantabro Results



Average COV = 19%

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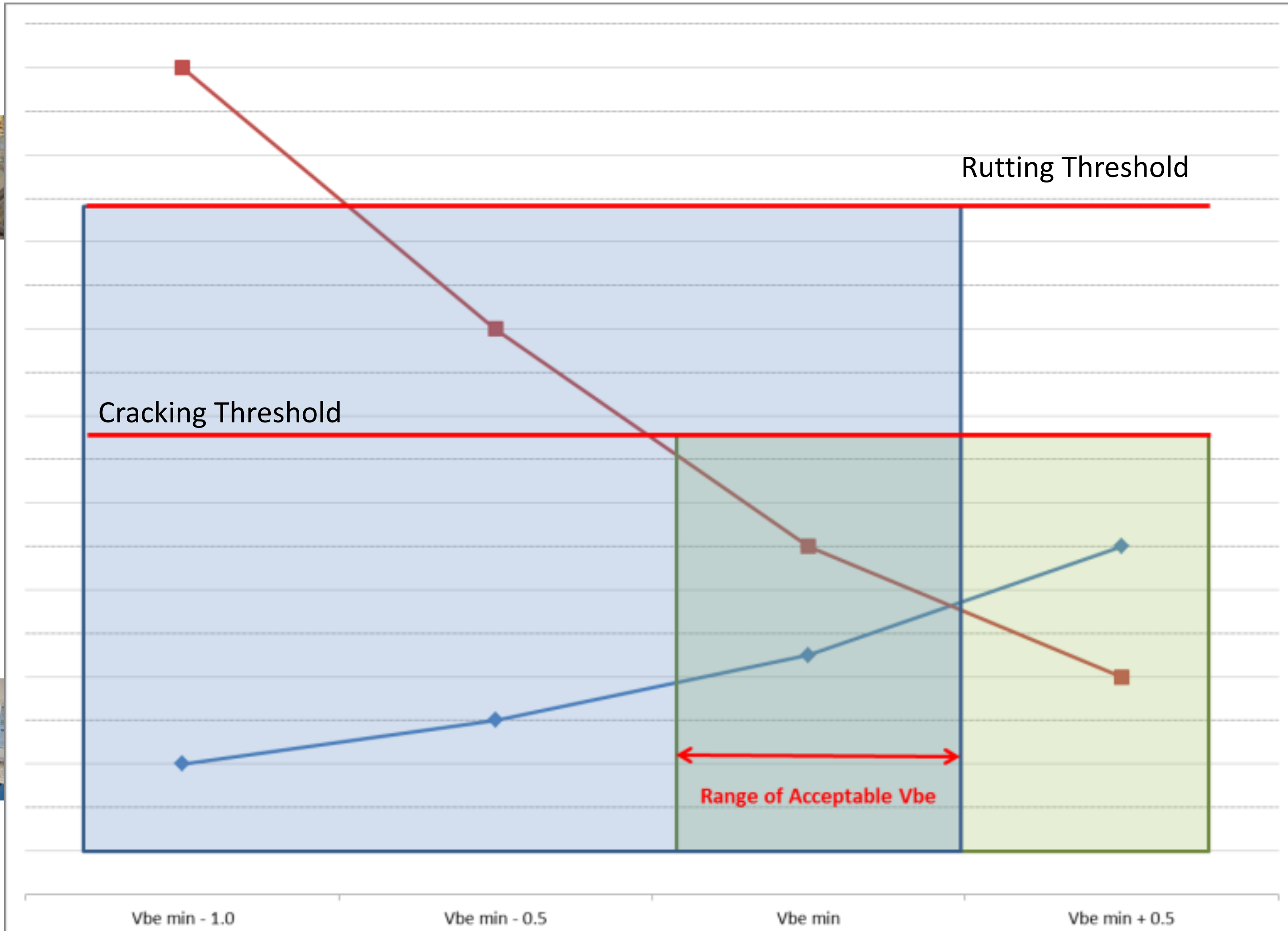
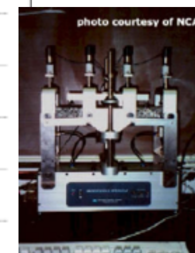
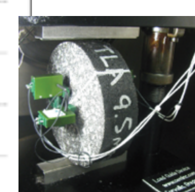
National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

Design Performance Curves – Possible Binder Range Example



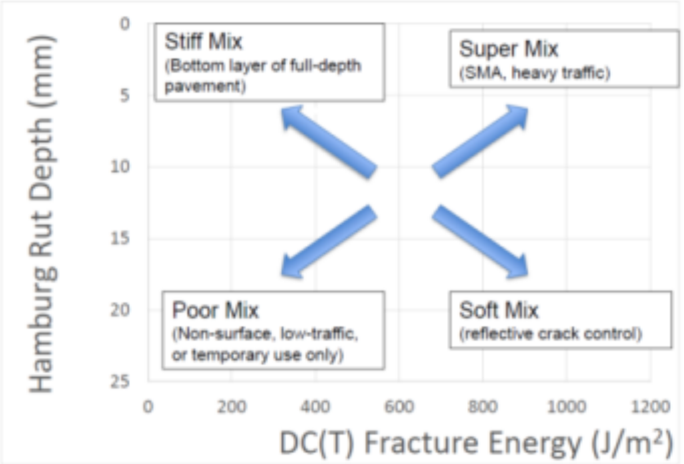




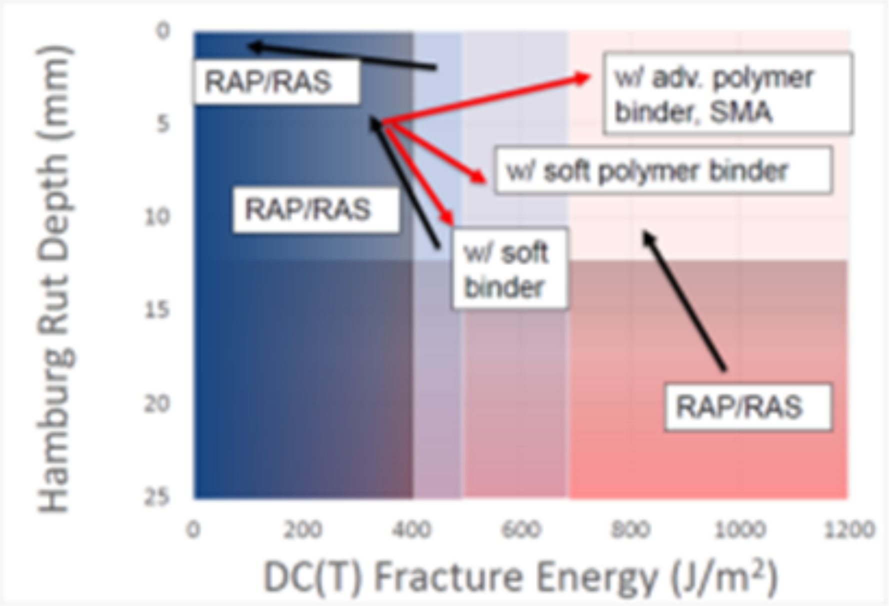
Mix Performance Space Diagram

- Performance testing can help guide mix improvement (optimization)
- ***Example shows Hamburg + DCT, but other stability + durability/cracking test can be substituted w/ same application***

“Performance-Space” Diagram



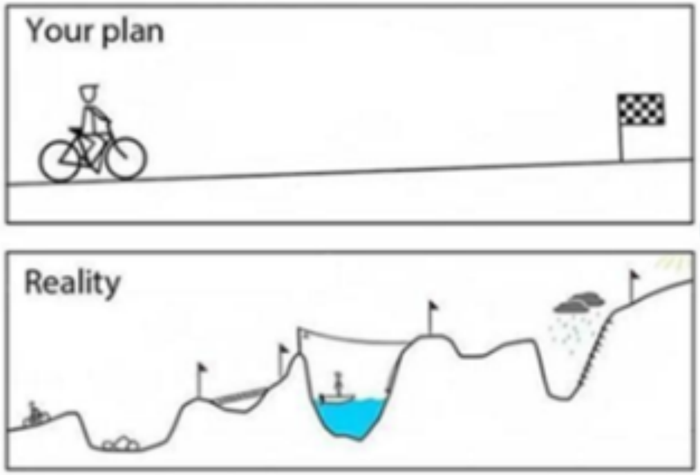
Mix Affects: Recycling



From: Dr. Bill Buttlar, University of Illinois

The Path Forward

- Must continue with theoretical research/modeling efforts, but not be afraid to utilize practical approaches to find solutions.
- We need to **move incrementally in the appropriate direction** to limit risk of mix performance issue.
- FHWA Mix ETG Task Group formed (September 2015) to define the current state of "Balanced Mix Design" approaches and offer guidance for BMD use.
- **Recognize that this is a long term effort with ups/downs, but we must start now.**



Thoughts and Questions?

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