Performance of High RAP Percentage Mixes

Kent R. Hansen, P.E.
Director of Engineering
National Asphalt Pavement Association

NAPA
NATIONAL ASPHALT

It's a given...

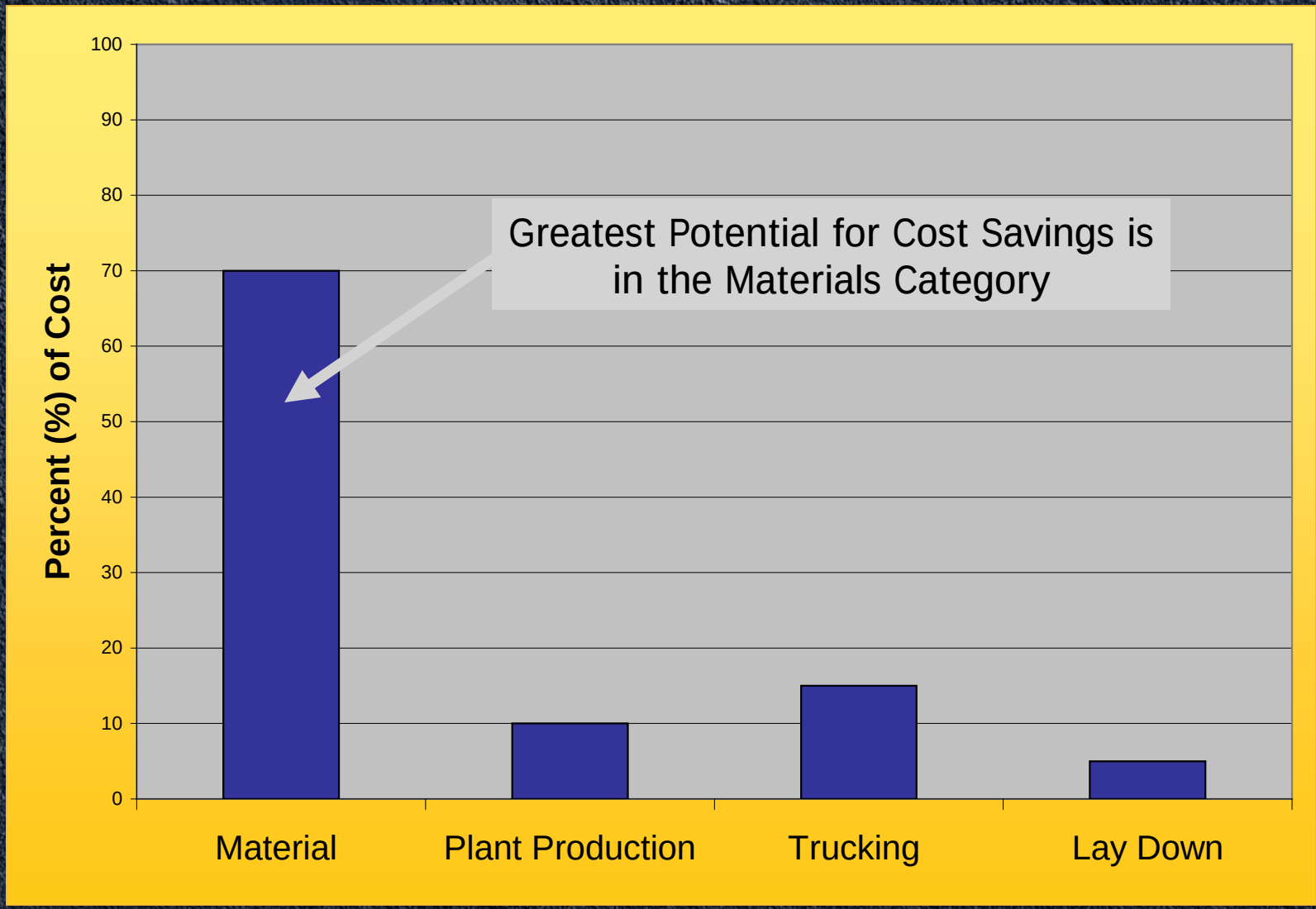
Must consider recycled materials:

- Control costs
- Remain competitive
- Mitigate material cost variability

High RAP is defined as more than 25% RAP by weight of mix.

NAPA
NATIONAL ASPHALT

Asphalt Production Cost Categories



NATIONAL ASPHALT

Top Barriers to High RAP Use

1. FEAR - Overly Conservative Specifications
2. Insuring Performance
3. Using high RAP/RAS with Superpave mix design – meeting volumetric requirements
4. Concerns about quality of the RAP

NAPA
NATIONAL ASPHALT

Common Barriers

Agency/Specifications

- Quality Concerns
- Consistency of RAP/RAS
- Binder Grade and Blending
- Mix Design Procedures
- Meeting Volumetric Requirements
- Durability
- Use with Polymers

Industry

- State Specifications
- Control of RAP/RAS
- Dust and Moisture Content
- Increased QC


Conservative
Agency
Specifications

Current Guidelines

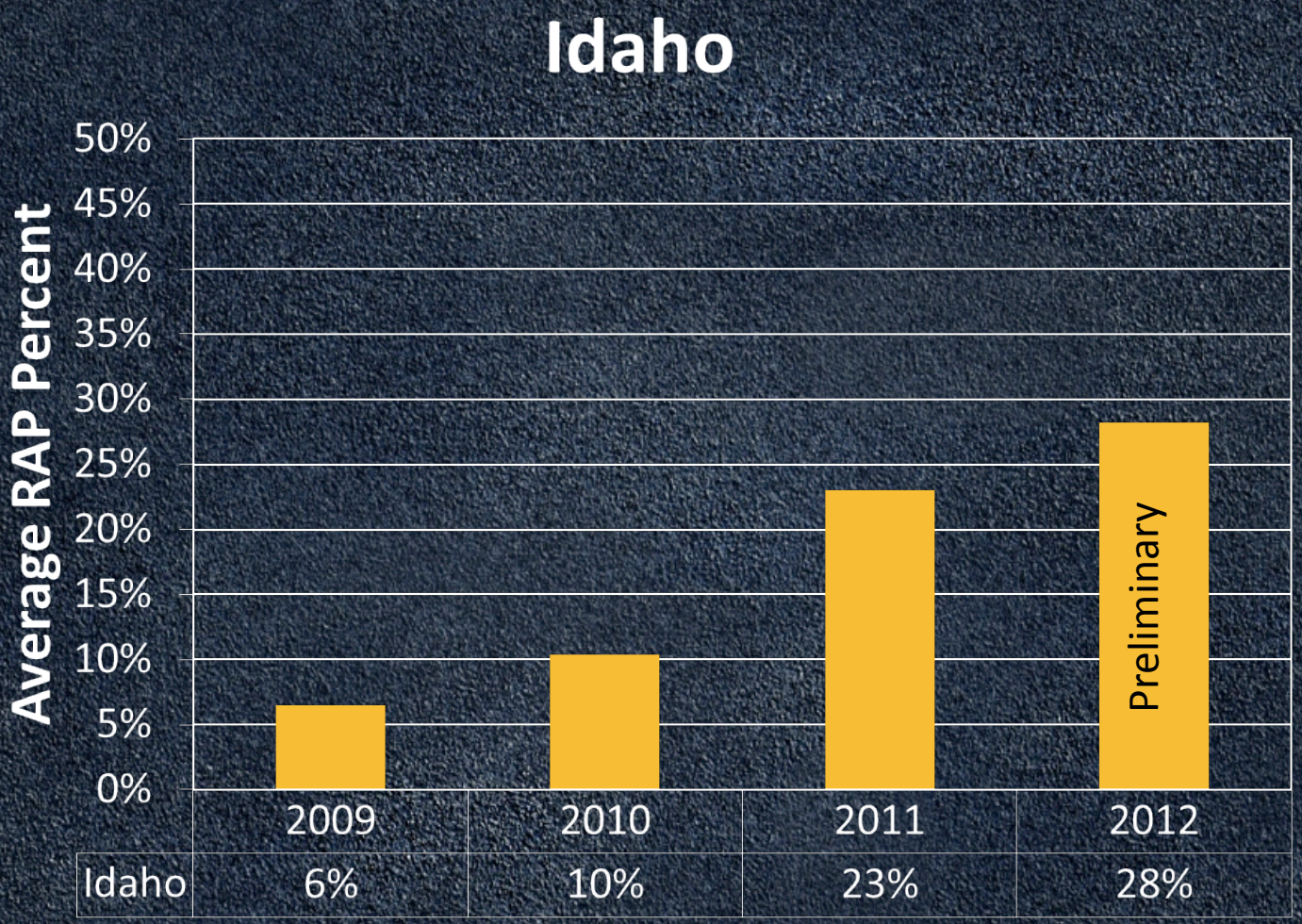
- AASHTO M 323 *Standard Specification for Superpave™ Volumetric Mix Design*

Recommended Virgin Asphalt Binder Grade	Percent (%) RAP
No change in binder selection	< 15
Select virgin binder grade one grade softer than normal	15 – 25
Follow recommendations from blending charts	> 25

- Calls for virgin binders that may be more expensive, hard to get
- Blending chart analysis is time-consuming!

RAP/RAS/WMA Survey

Reclaimed Asphalt Pavement



NAPA
NATIONAL ASPHALT

How far have we come?

The Industry from 2009 to 2011

- The amount of RAP used in HMA/WMA increased by 18%.
  - Assuming 5% liquid asphalt in RAP, this represents over 3.3 million tons of asphalt binder conserved.
- RAS use increased about 50% (0.7 – 1.2 MT)
  - Assuming 20% liquid asphalt in RAP, this represents over 0.4 MT
- The average percent RAP used in mixes has increased from about 16% to 19%.
- 98% of the contractors/branches reported using RAP and over 88% of these contractors reported excess RAP.

Room to Grow…

- Our comfort level with RAP is less than 20% by weight of mix.
- Still 5 to 10% RAP that can be used under existing specs. We can go further!
- Based on research*, Indiana found they could increase specification to allow up to 20% RAP with no binder grade change.
  - Cost savings of about $1.25 per ton of asphalt mixture.
  - Based on the amount of asphalt mixtures produced in 2010, this can result in savings of $125 million.

*McDaniel, et al. *Investigation of Low- and High-Temperature Properties of Plant-Produced RAP Mixtures.* Publication No. FHWA-HRT-11-058, Federal Highway Administration, Washington, DC, 2011.
http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/11058/11058.pdf

NAPA
NATIONAL ASPHALT


Long-Term
Performance

Primary Performance Concerns

- Fatigue Cracking
  - Aging characteristics – virgin vs. RAP binder
- Low Temperature Cracking
- Durability (Raveling)
  - Moisture content

12

NATIONAL ASPHALT

Evaluating RAP Performance

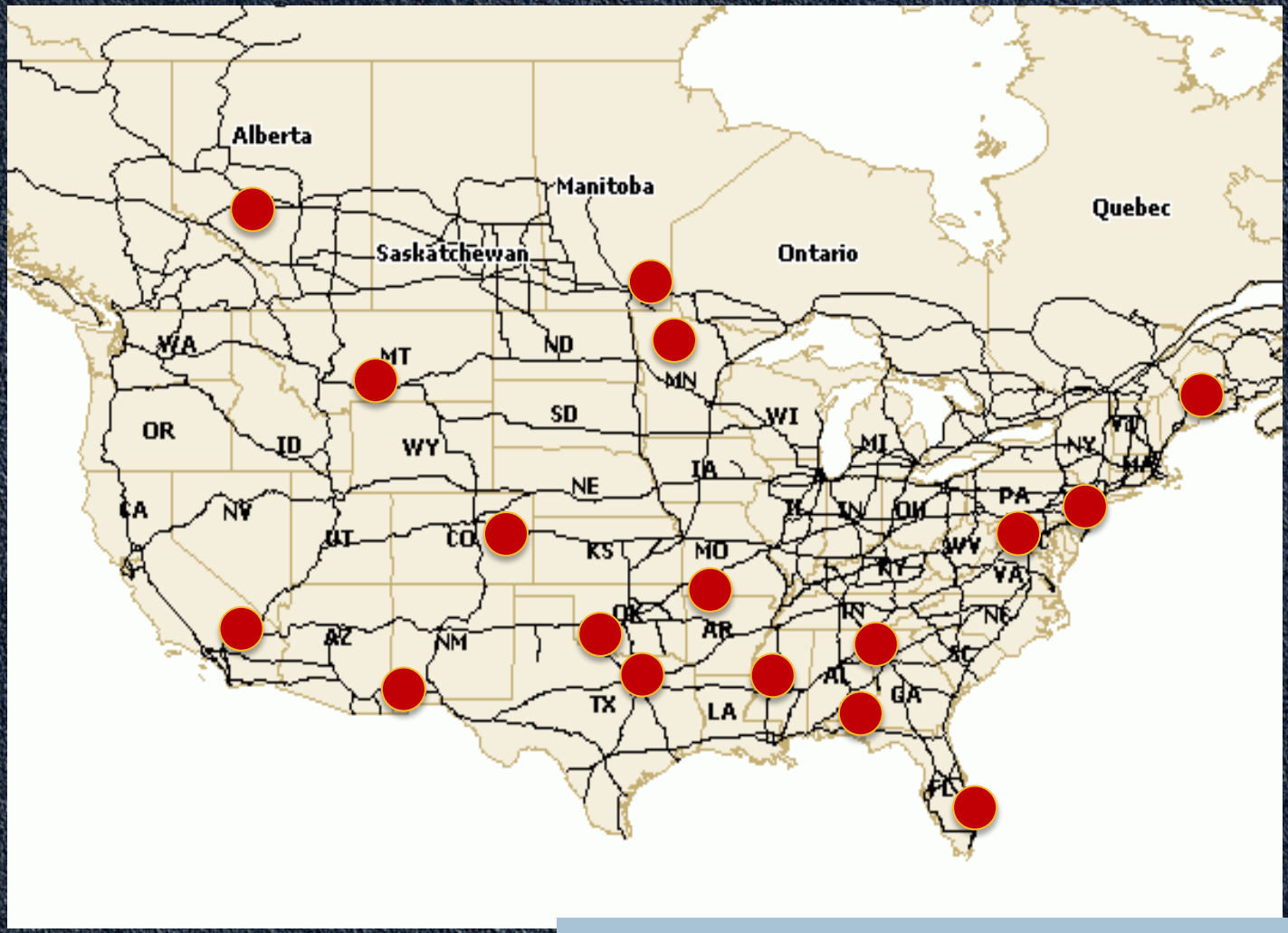
National Center for Asphalt Technology
NCAT
at Auburn University

- Long Term Pavement Performance SPS-5 sections
  - Virgin
  - 30% RAP
  - Milled and non-milled surface
  - 50 and 125 mm thick
  - Oldest is over 17 years

LONG TERM Pavement PERFORMANCE

NAPA
NATIONAL ASPHALT

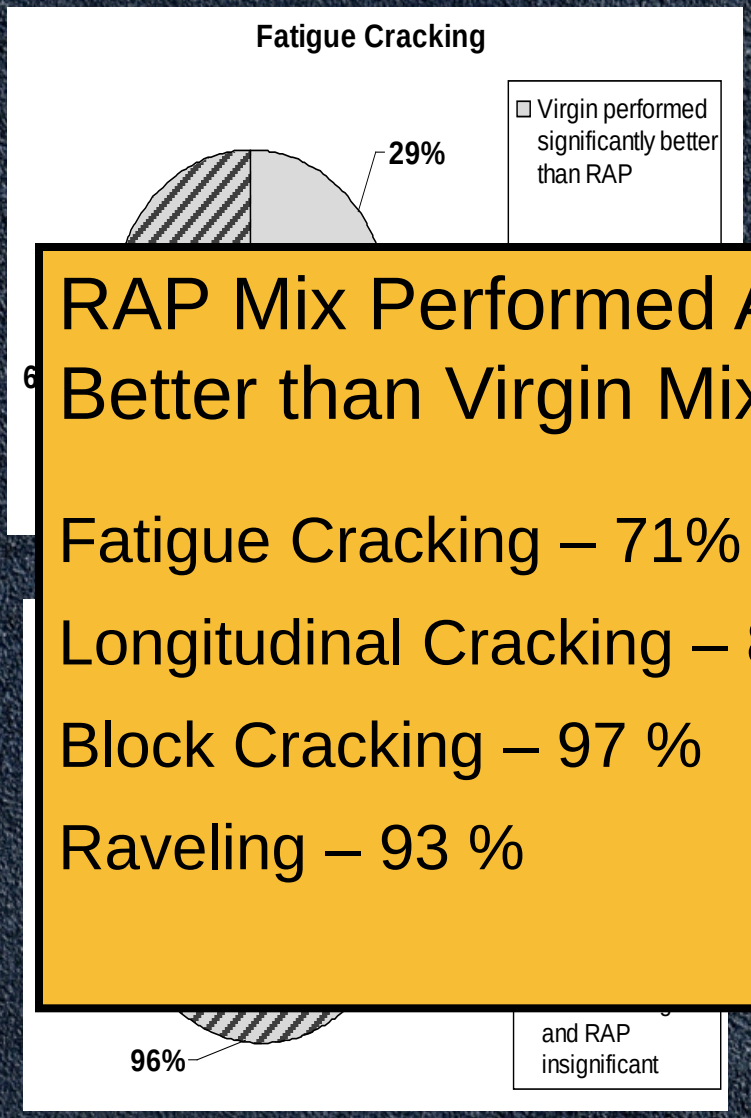
SPS-5 Project Locations

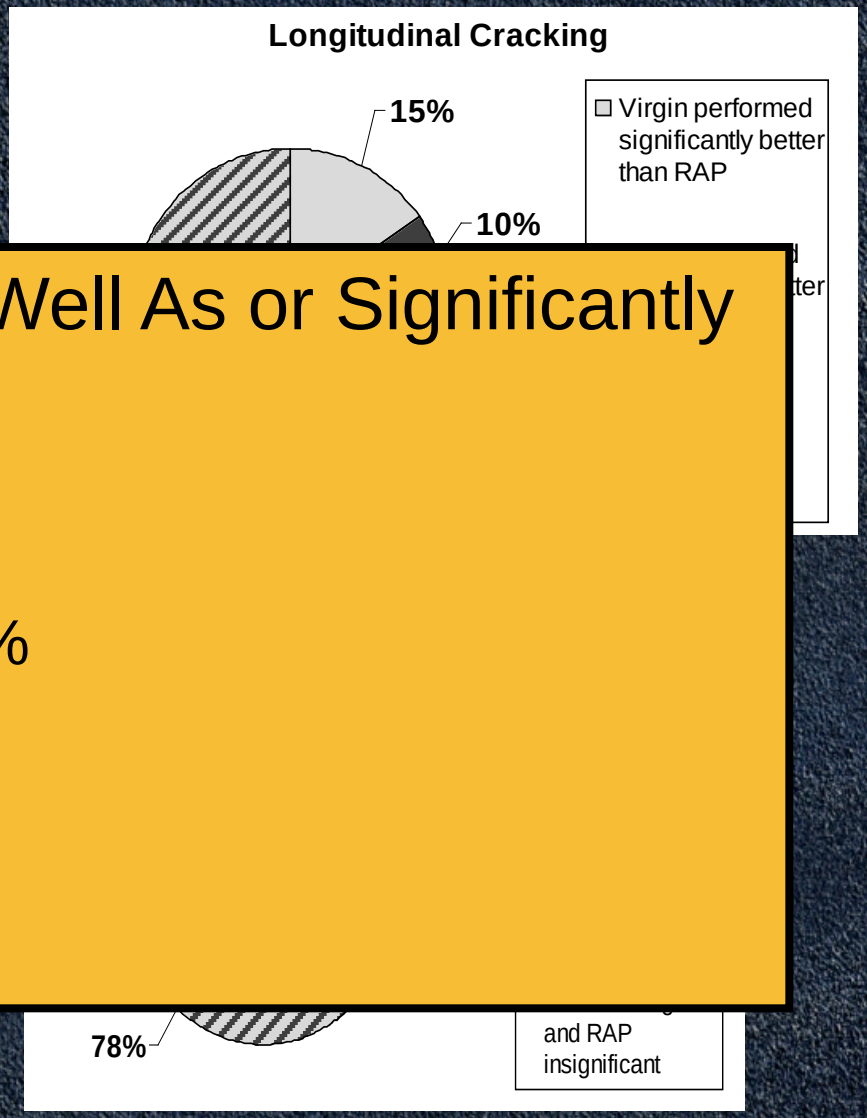


LONG TERM Pavement PERFORMANCE

NAPA
NATIONAL ASPHALT

LTPP Study Results





RAP Mix Performed As Well As or Significantly Better than Virgin Mix

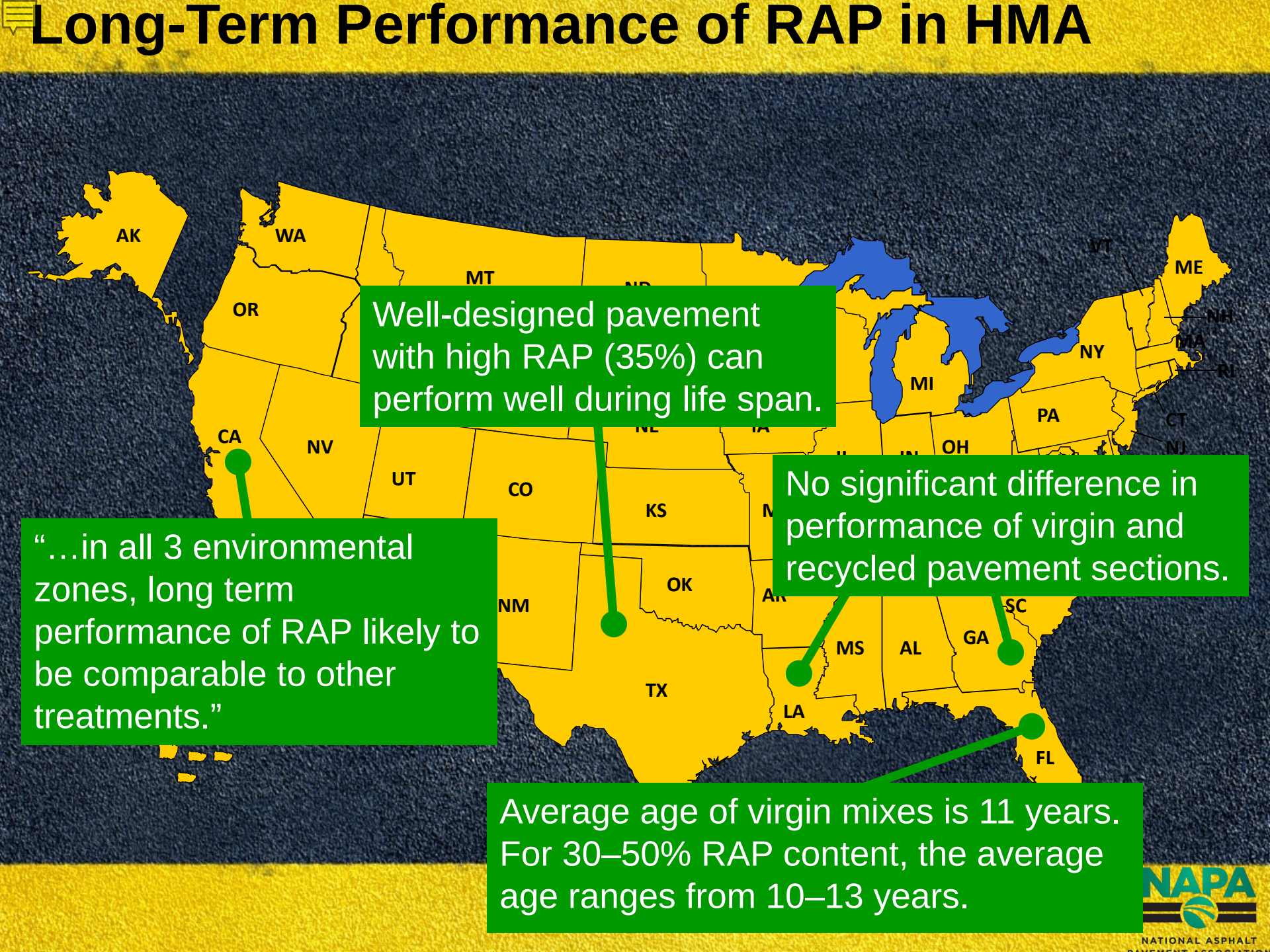
Fatigue Cracking – 71%

Longitudinal Cracking – 85 %

Block Cracking – 97 %

Raveling – 93 %

Long-Term Performance of RAP in HMA



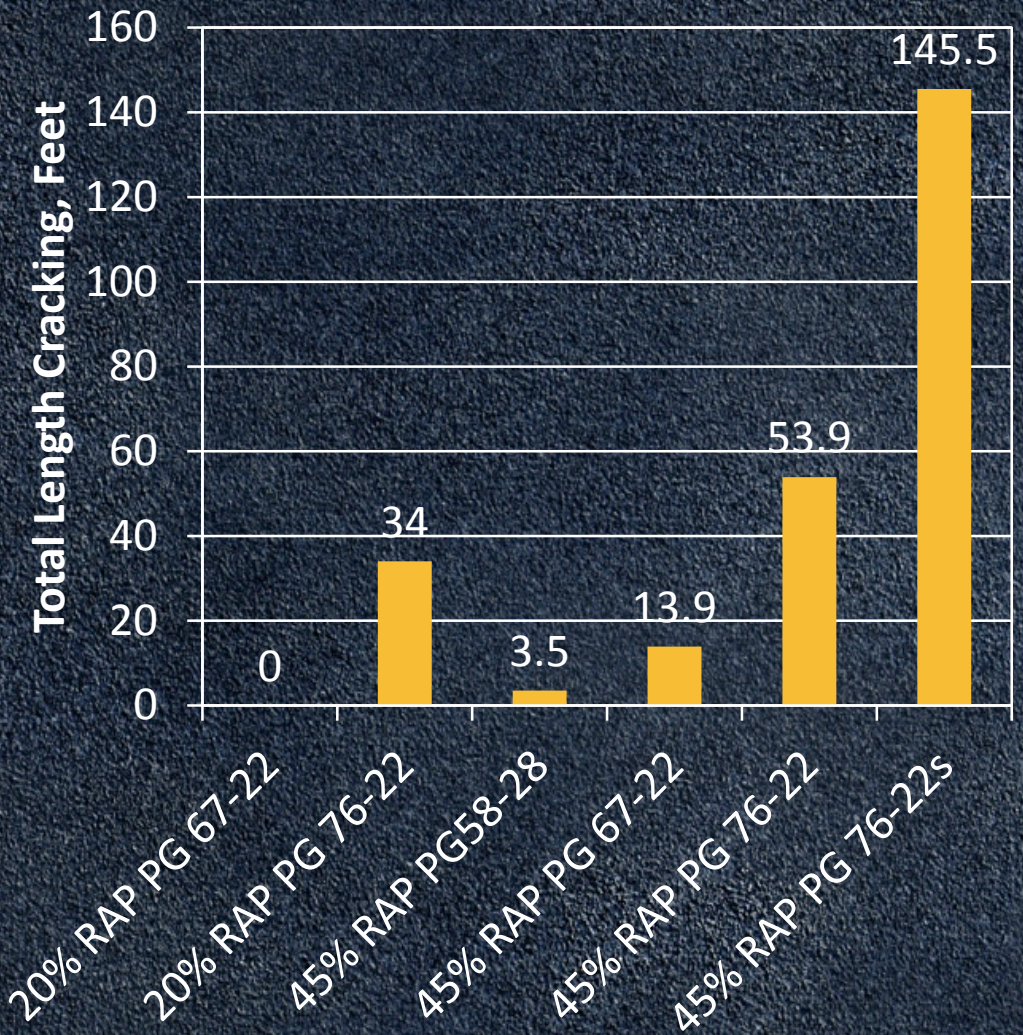
NAPA
NATIONAL ASPHALT

NCAT Test Track High RAP Sections

- 2006 – 4 Sections with 45% RAP
  - PG 67-22
  - PG 76-22
  - PG 76-22s (Sasobit)
  - PG 52-28 (blending chart)
- 20 MESAL
  - Less than 5 mm rutting
  - Very minor cracking after 4 years
    - 52-28 least amount
  - 45% RAP PG52-28 lowest texture change (least raveling)

NAPA
NATIONAL ASPHALT

NCAT 2006 High RAP Sections

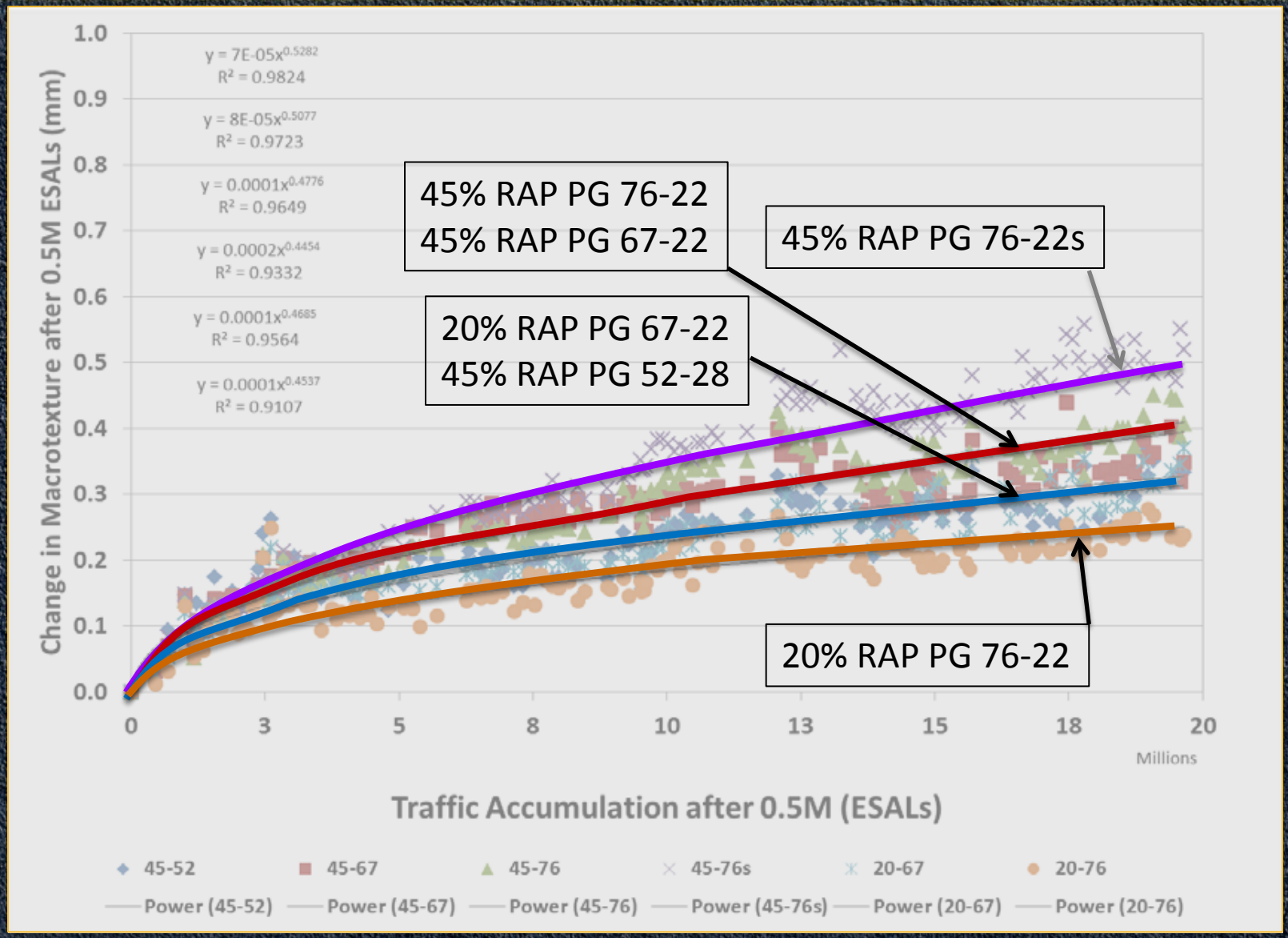


45% RAP PG 52-28 Crack

45% RAP PG 76-22s Crack

NAPA
NATIONAL ASPHALT

NCAT 2006 High RAP Sections



NAPA
NATIONAL ASPHALT

2009 NCAT High RAP Sections

- One Mill & Fill (Mississippi)
- Two Structural Sections (50% RAP)
  - HMA & WMA – 7” thick
  - Compare structural response & short term performance
  - Laboratory performance tests
  - Virgin control – PG 76-22 surface & intermediate. PG 67-22 base
  - 50% RAP – PG 67-22 all layers
  - RAP binder replacement
    - 37% surface, 50% intermediate & base

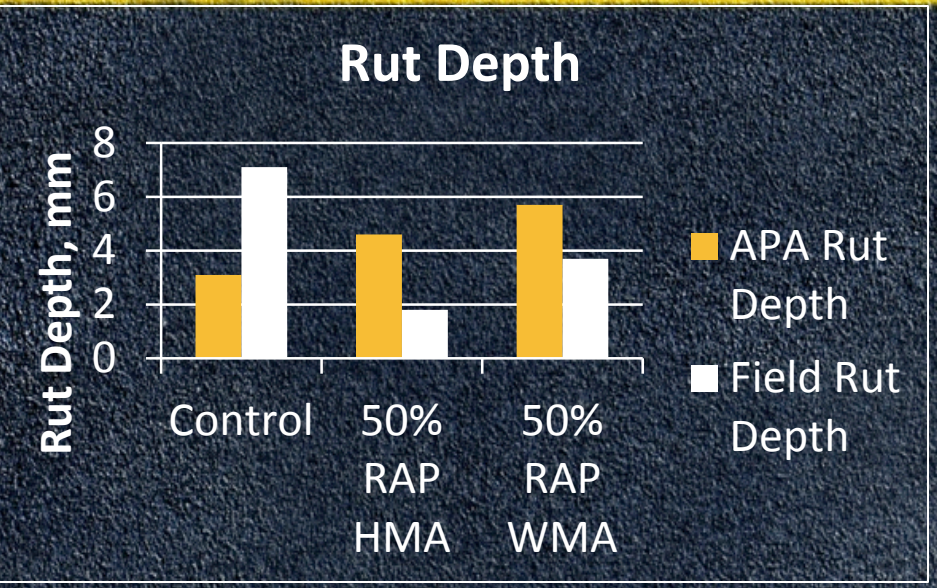
NAPA
NATIONAL ASPHALT

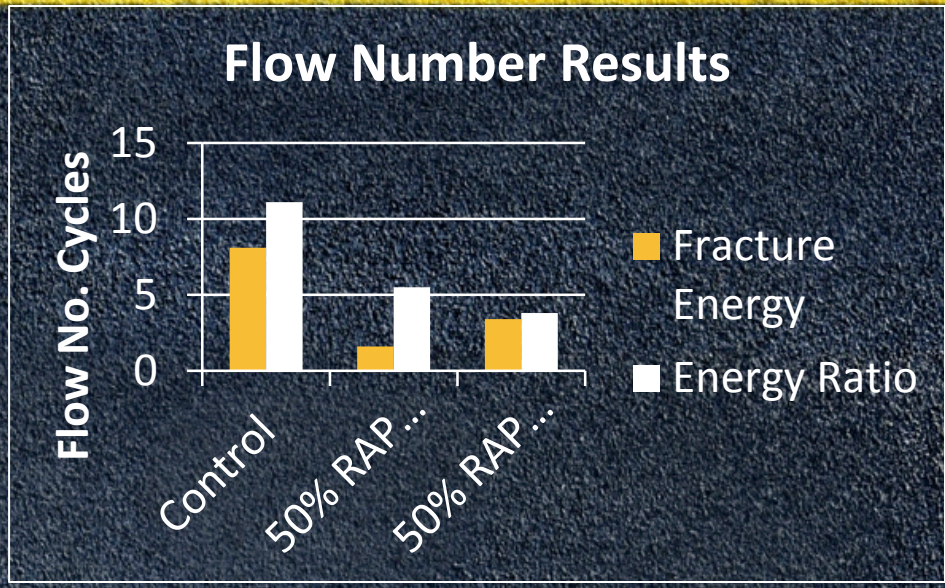
2009 NCAT High RAP Structural Experiment

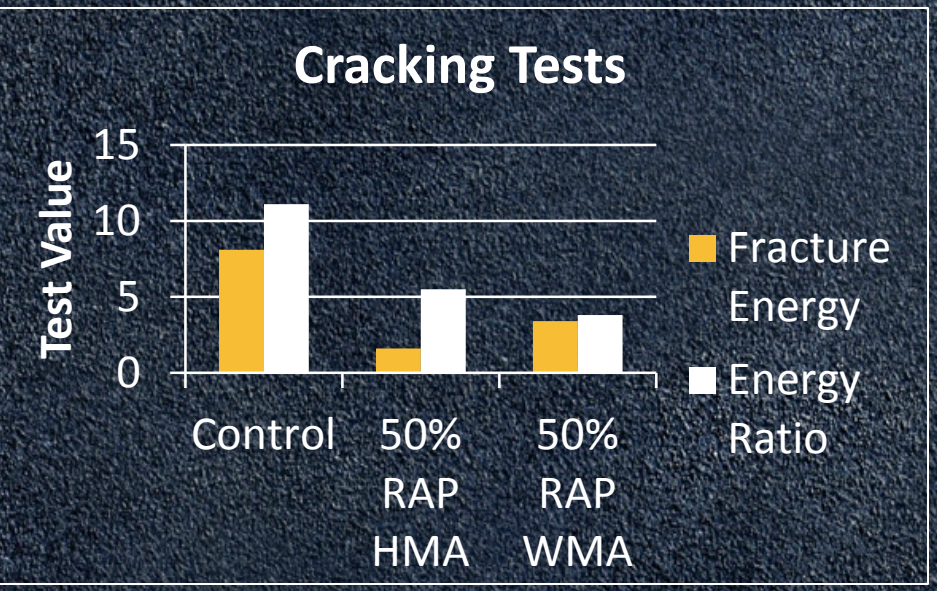
- Performance
  - Rutting
    - RAP less than 5 mm
    - Control 7.1 mm
  - No cracking
  - Steady IRI
  - Very small changes in texture
- Will remain until threshold distresses reached

NAPA
NATIONAL ASPHALT

2009 NCAT High RAP Structural Experiment

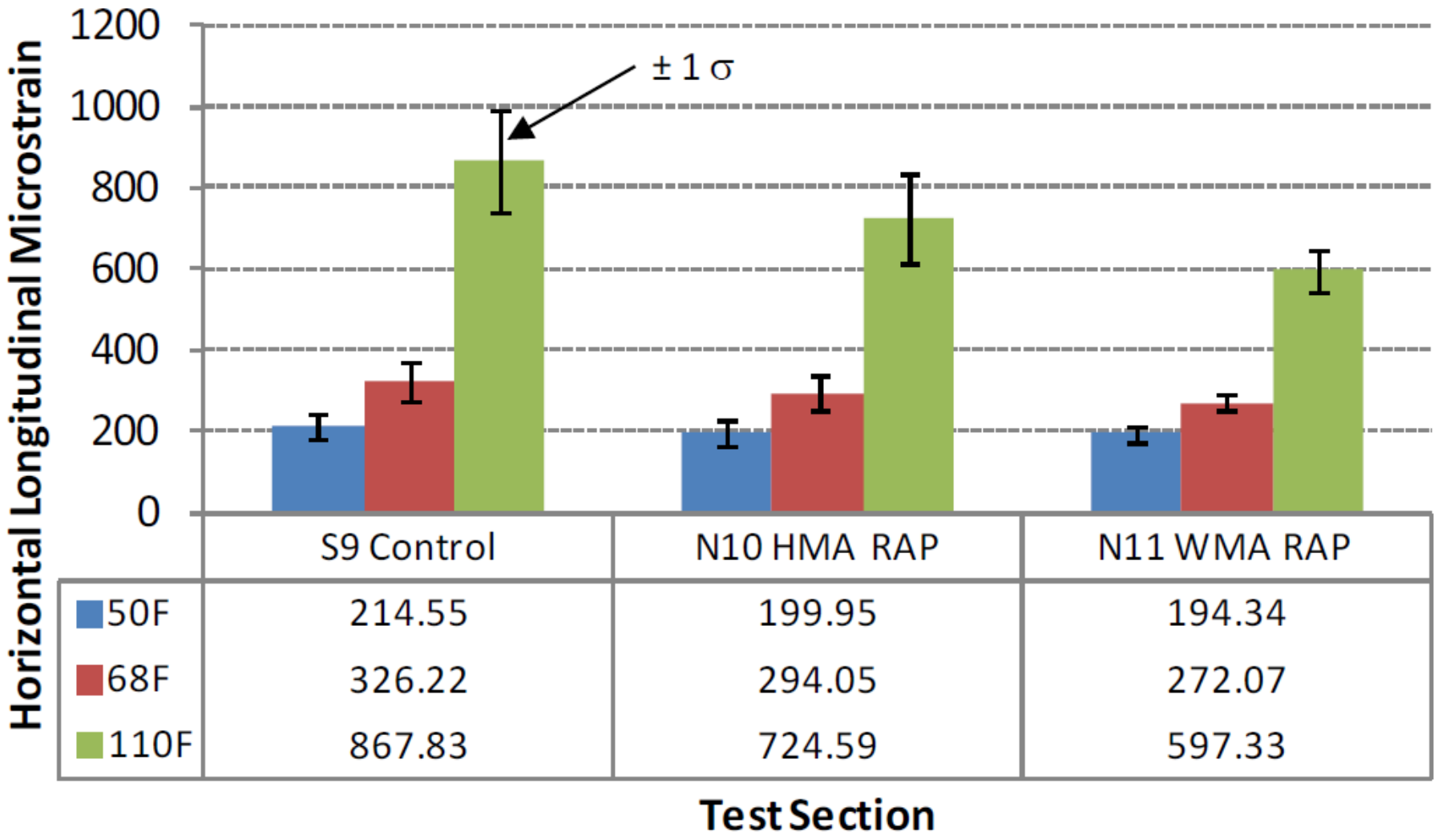






NAPA
NATIONAL ASPHALT PAVEMENT ASSOCIATION

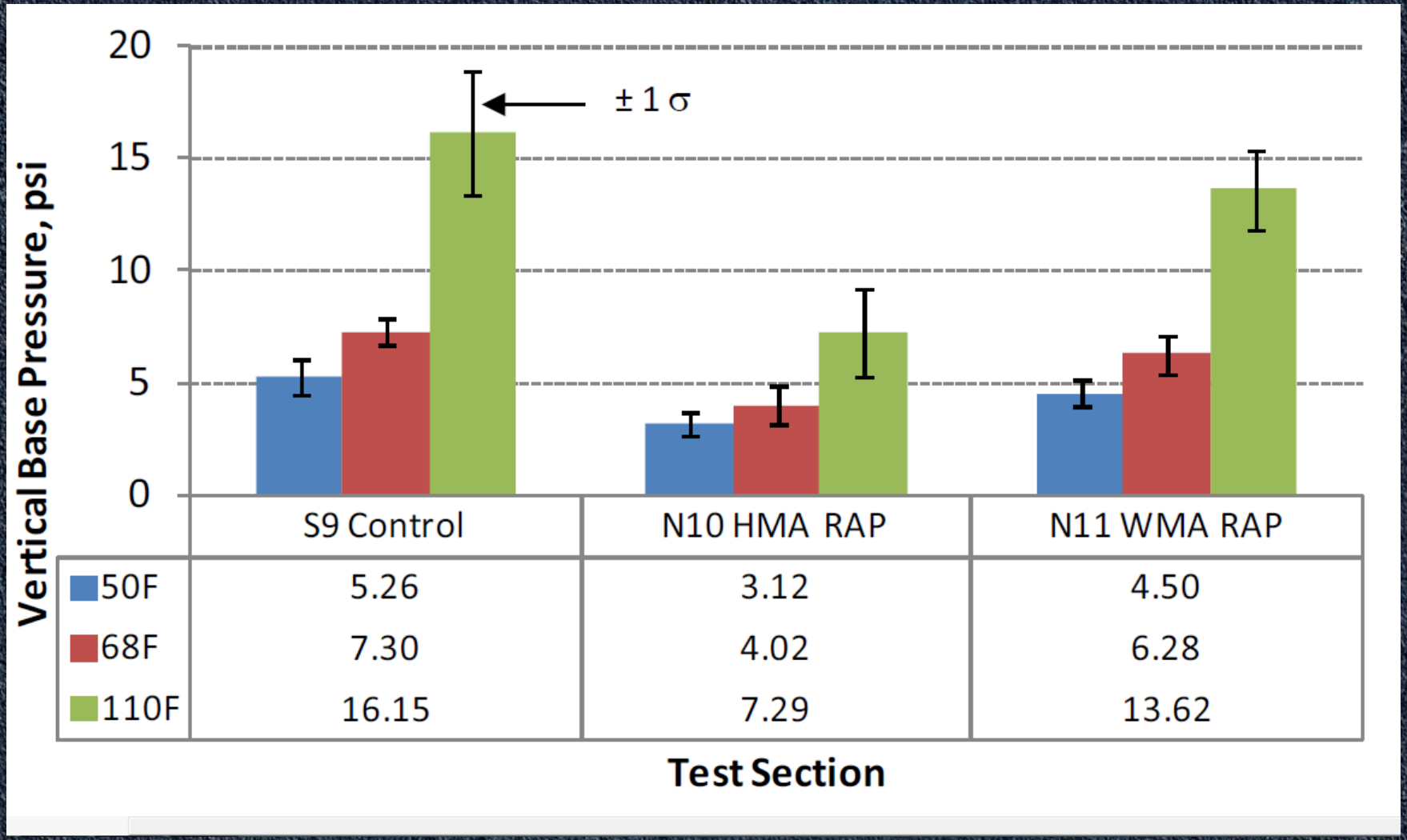
2009 NCAT High RAP Structural Experiment



	S9 Control	N10 HMA RAP	N11 WMA RAP
50F	214.55	199.95	194.34
68F	326.22	294.05	272.07
110F	867.83	724.59	597.33

NAPA
NATIONAL ASPHALT

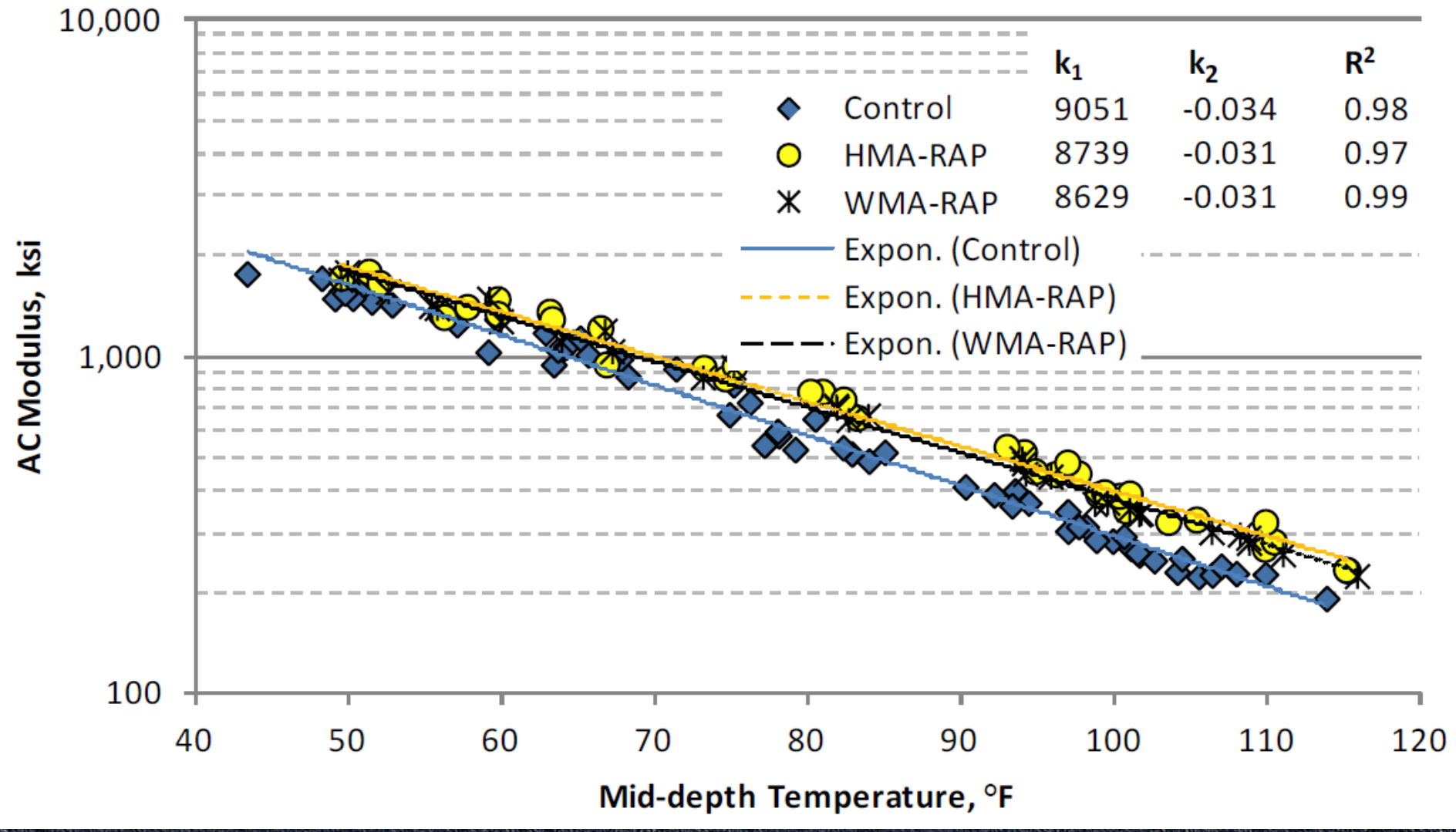
2009 NCAT High RAP Structural Experiment



	S9 Control	N10 HMA RAP	N11 WMA RAP
50F	5.26	3.12	4.50
68F	7.30	4.02	6.28
110F	16.15	7.29	13.62

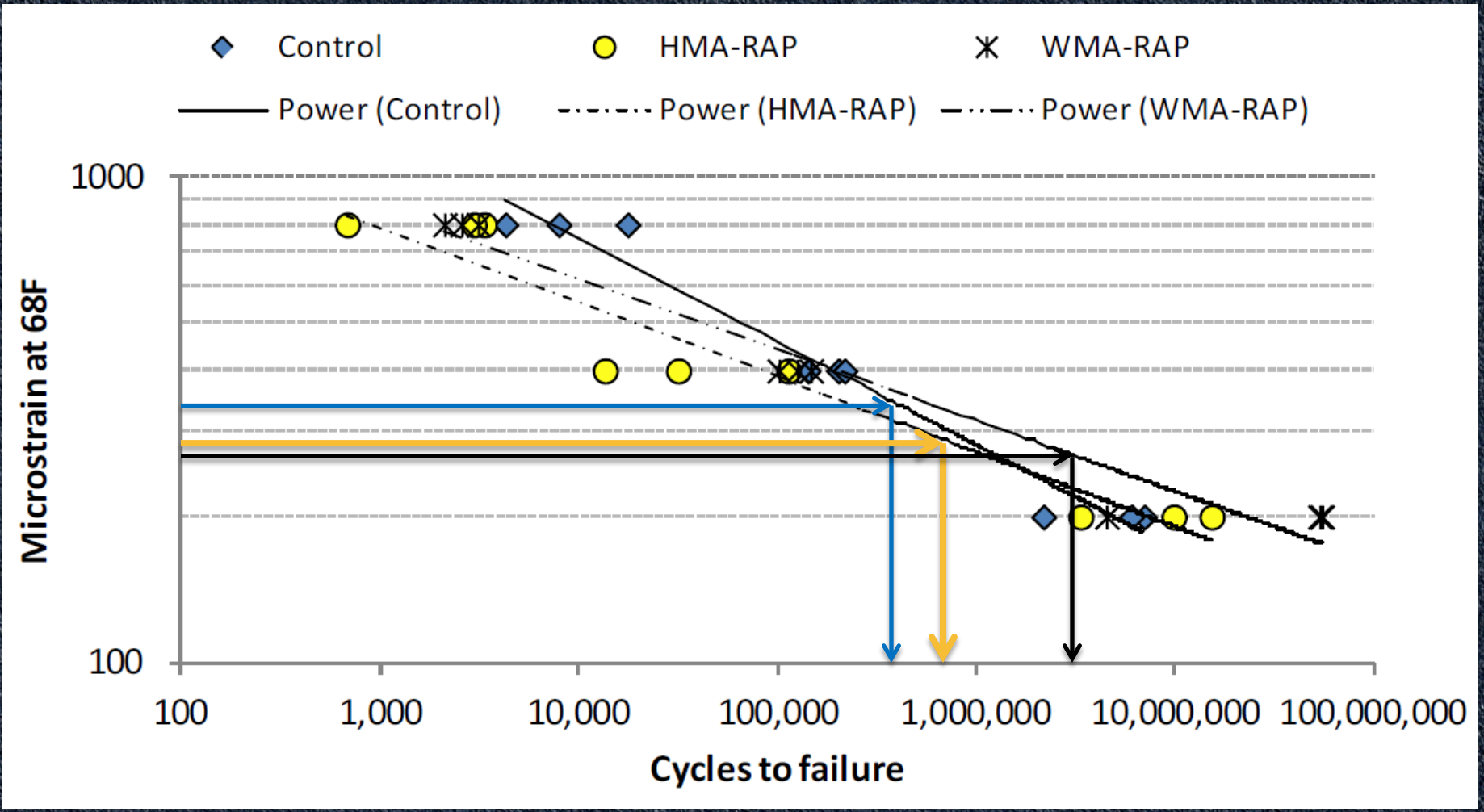
NAPA
NATIONAL ASPHALT

2009 NCAT High RAP Structural Experiment



NAPA
NATIONAL ASPHALT

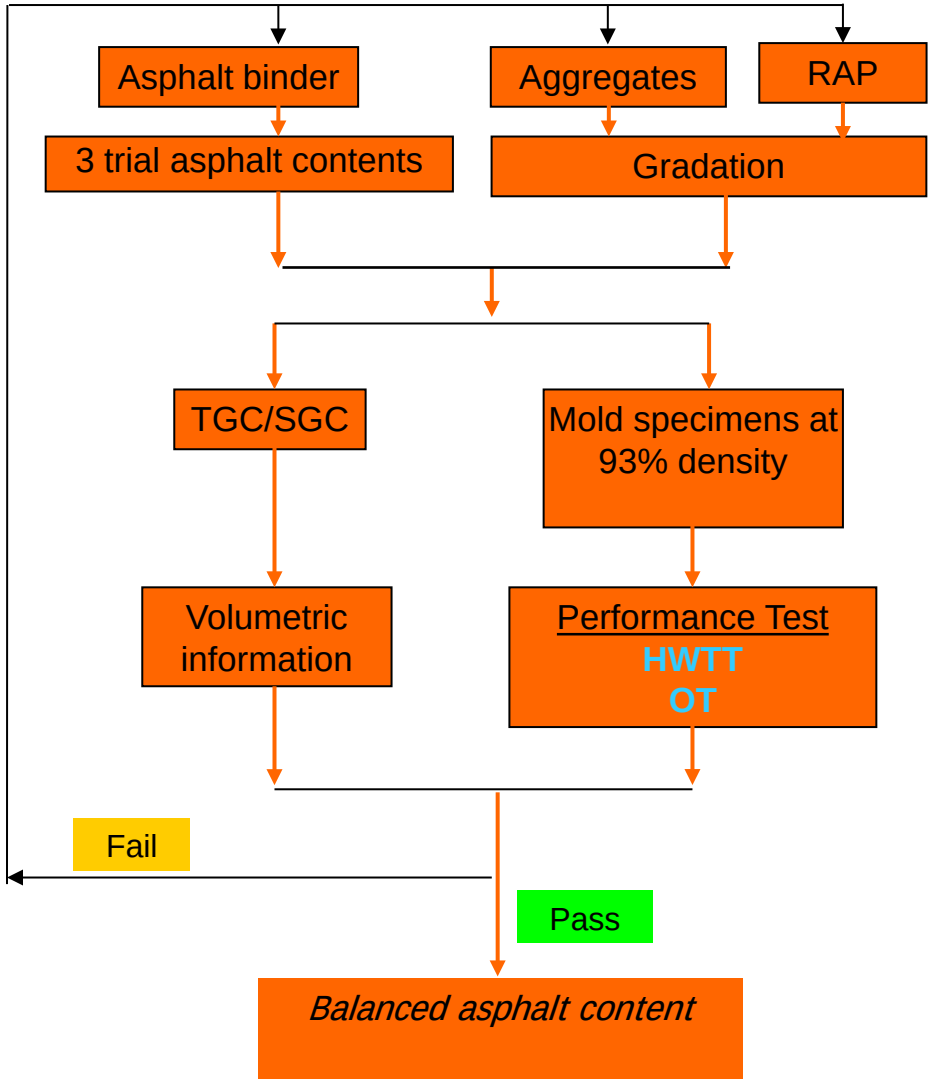
2009 NCAT High RAP Structural Experiment

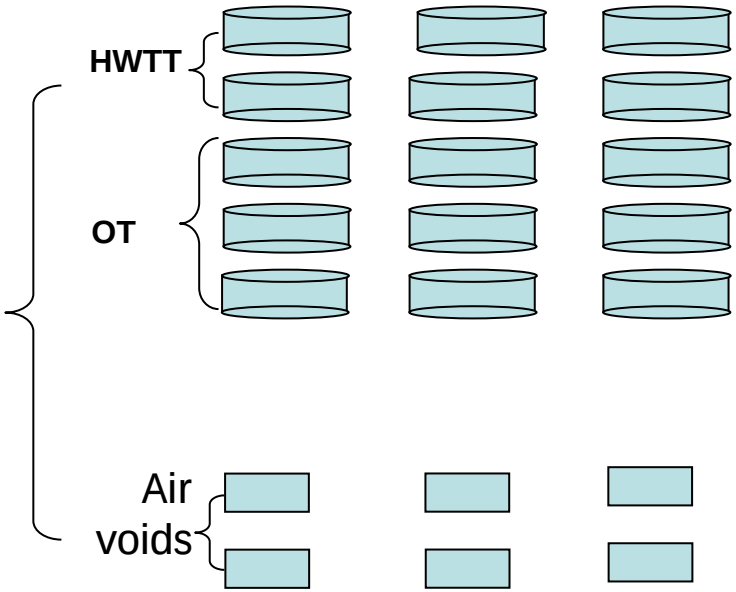


NAPA
NATIONAL ASPHALT


Balanced Mix
Design

Balanced RAP Mix Design





Field Test Sections to Demonstrate Balanced Design for High RAP Mixes

- RAP test sections on IH40, Amarillo, Texas
  - 4-inch overlay
  - Very cold weather
  - Extremely high traffic
  - Severe transverse cracking before overlay
- RAP test sections on FM1017, Pharr, Texas
  - 1.5 inch surface HMA layer and new construction
  - Hot weather
  - Low volume road

Four Test Sections on IH40, Amarillo

- Section 0: 20% RAP section designed by contractor
- Section 1: 0% RAP section designed by contractor
- Section 2: 35% RAP section designed by TTI
- Section 3: 20% RAP section designed by TTI

Balanced RAP Mix Design for Section 2: 35% RAP+PG58-28

TEXAS DEPARTMENT OF TRANSPORTATION

HMACP MIXTURE DESIGN : SUMMARY SHEET

File Version: 07/15/08 13:33:34

SAMPLE ID:	31290	SAMPLE DATE:	
LOT NUMBER:		LETTING DATE:	JULY 2008
SAMPLE STATUS:		CONTROLLING CSJ:	168-09-155
COUNTY:	RANDALL	SPEC YEAR:	2004
SAMPLED BY:		SPEC ITEM:	341
SAMPLE LOCATION:		SPECIAL PROVISION:	
MATERIAL CODE:	HMAC	MIX TYPE:	ITEM341_C_Coarse_Surface
MATERIAL NAME:			
PRODUCER:	R.K.HALL CONSTRUCTION LTD.		
AREA ENGINEER:	JOE CHAPPELL P.E.	PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:		CONTRACTOR DESIGN # :	31290

Target Density, %:	**98.0**
Number of Gyrations:	

CRM* Content

TEST SPECIMENS							Mixture Evaluation @ Optimum Asphalt Content			
								Hamburg Wheel Tracking Test		
Asphalt Content (%)	Specific Gravity Of Specimen (Ga)	Maximum Specific Gravity (Gr)	Effective Gravity (Ge)	Theo. Max. Specific Gravity (Gt)	Density from Gt (Percent)	VMA (Percent)	Indirect Tensile Strength (psi)	Number of cycles	Rut depth (mm)	*Overlay Tester Min. Number of Cycles*
4.7	2.382	2.477	2.660	2.464	96.7	14.2				
5.2	2.387	2.440	2.637	2.446	97.6	14.4				
5.7	2.383	2.423	2.638	2.429	98.1	15.0				

Effective Specific Gravity:	2.645
Optimum Asphalt Content :	**5.6**
VMA @ Optimum AC:	**14.9**

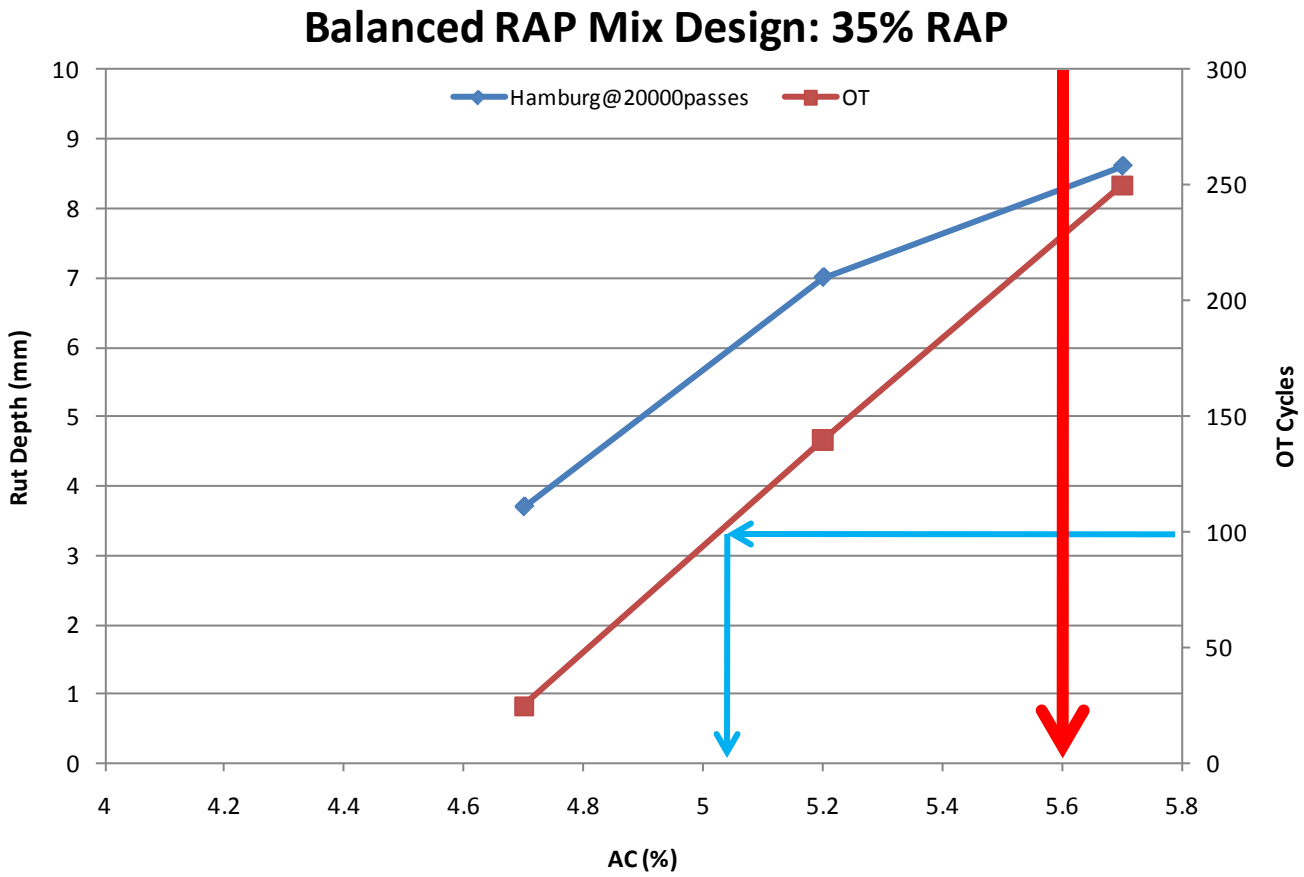
Interpolated Values	
Specific Gravity (Ga):	2.384
Max. Specific Gravity (Gr):	2.426
Theo. Max. Specific Gravity (Gt):	2.432

Remarks:

5.6%
Upper limit for AC@98% Density

Balanced RAP Mix Design for Section 2: 35% RAP+PG58-28

- Upper AC limit: 5.6%
- Hamburg: no problem
- OT: min. 100
- Final AC: 5.5%



Summary: RAP mix design on IH40

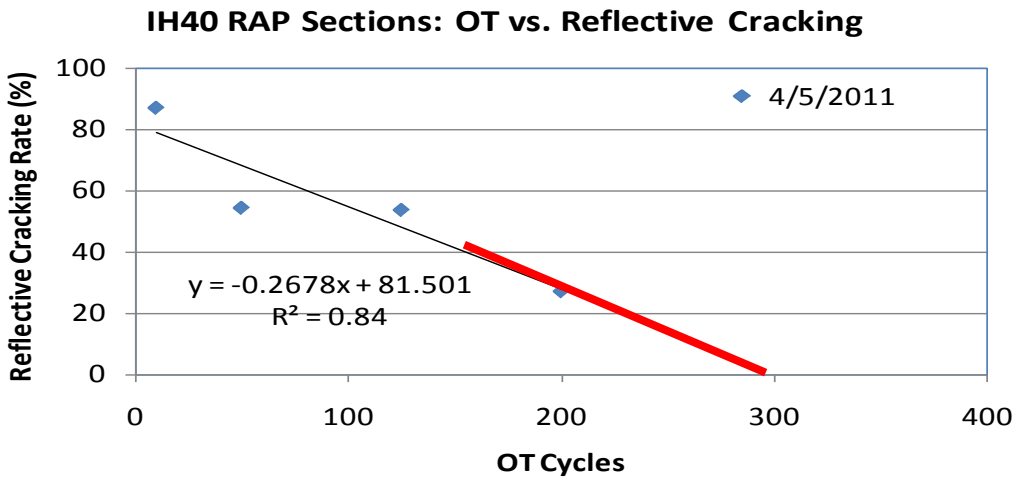
Section	RAP (%)	Virgin binder	Mix design approach	AC (%)	Hamburg rut depth @20000	OT cycles
0	20	PG64-28	Item 340-Type C	5.0	3.7 mm	10
1	0	PG64-28	Item 340-Type C	4.8	4.4 mm	50
2	35	PG58-28	Balanced mix design	5.5	8.0 mm	200
3	20	PG64-28	Balanced mix design	5.3	7.4 mm	125

Performance of 4 Sections on IH40

- Construction
  - August 11, 2009
- 1st survey
  - April 22, 2010
- 2nd survey
  - September 8, 2010
- 3rd survey
  - April 5, 2011

Performance of 4 Sections on IH40

Sections	Reflective Cracking Rate (%)				OT cycles
	8/11/2009	4/22/2010	9/8/2010	4/5/2011	
20% RAP-contractor	0	0	34	87	10
0% RAP-contractor	0	0	18	55	50
35% RAP-TTI	0	0	0	27	200
20% RAP-TTI	0	0	4	54	125



Three Test Sections on FM1017, Pharr

- 0% RAP: contractor designed
- 20% RAP: contractor designed
- 35% RAP: TTI designed
- Mix Design Summary

Section	RAP (%)	Virgin binder	Mix design approach	AC (%)	Hamburg rut depth @20000	OT cycles
1	20	PG64-22	Item 340-Type D	5.0	3.4 mm	2
2	35	PG64-22	Balanced mix design	6.4	9.3 mm	16
3	0	PG76-22	Item 340-Type D	4.9	2.2 mm	4

Performance of 3 Sections on FM1017

- Construction:
  April 6, 2010

- Latest survey:
  March 1, 2012
  - No rutting
  - Minor raveling on 35% RAP section

Lessons from Field Test Sections

- High RAP mixes can be designed with better performance than virgin mixes, but it must be engineered (i.e. balanced mix design approach).

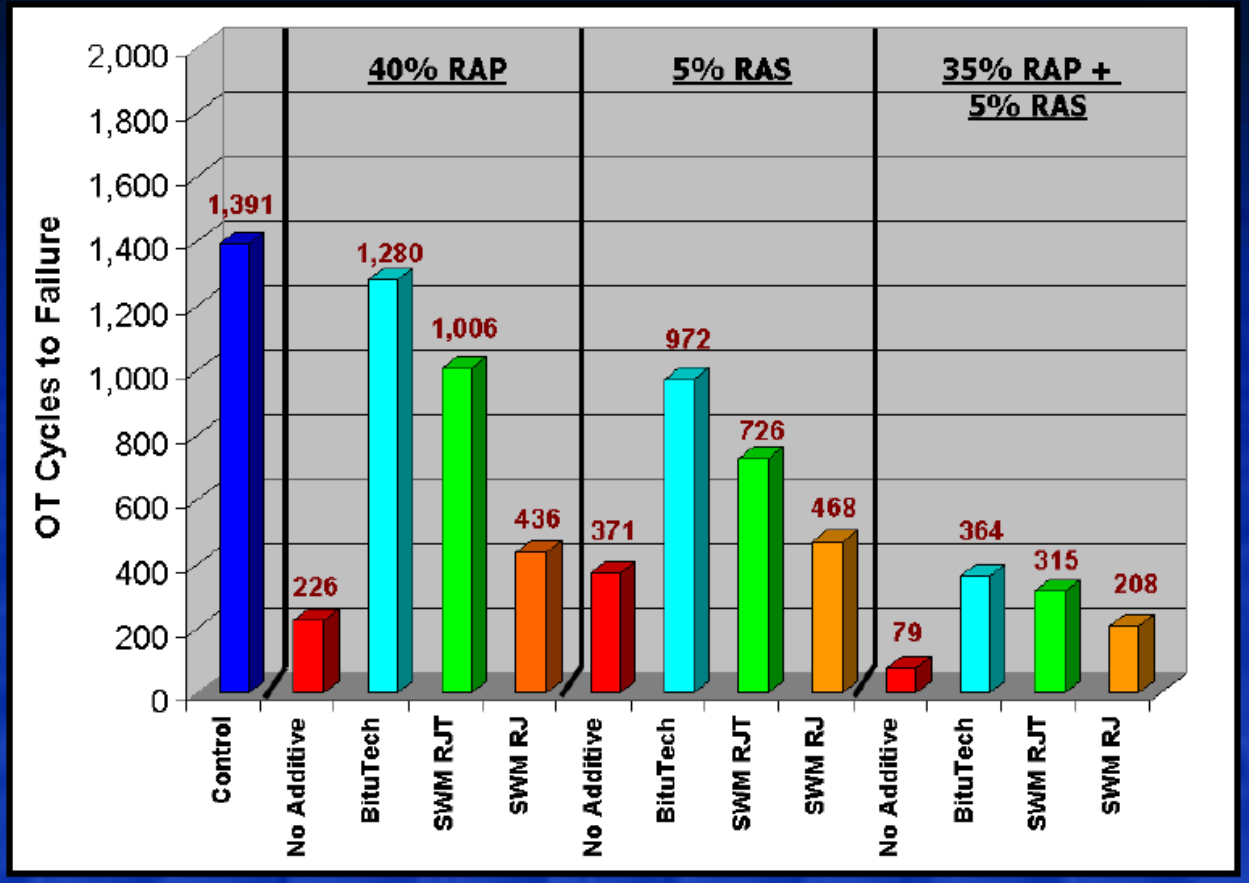
- Mix cracking requirement should vary, depending
  - Traffic level
  - Weather
  - Overlay vs. new construction
  - Location within pavement structure

Summary and Conclusions

- Texas' RAPs, in terms of aggregate gradation and asphalt content, have low variability.
- Use of RAP improves rutting/moisture damage resistance, but decreases cracking resistance.
- High RAP mixes can be designed with better performance using balanced mix design approach.
- Mix cracking requirement should vary, depending on application scenarios.

University of Massachussetts

Highly Recycled + Rejuvenator



Northeast Pavement Preservation Partnership

Northeast Pavement Preservation Partnership

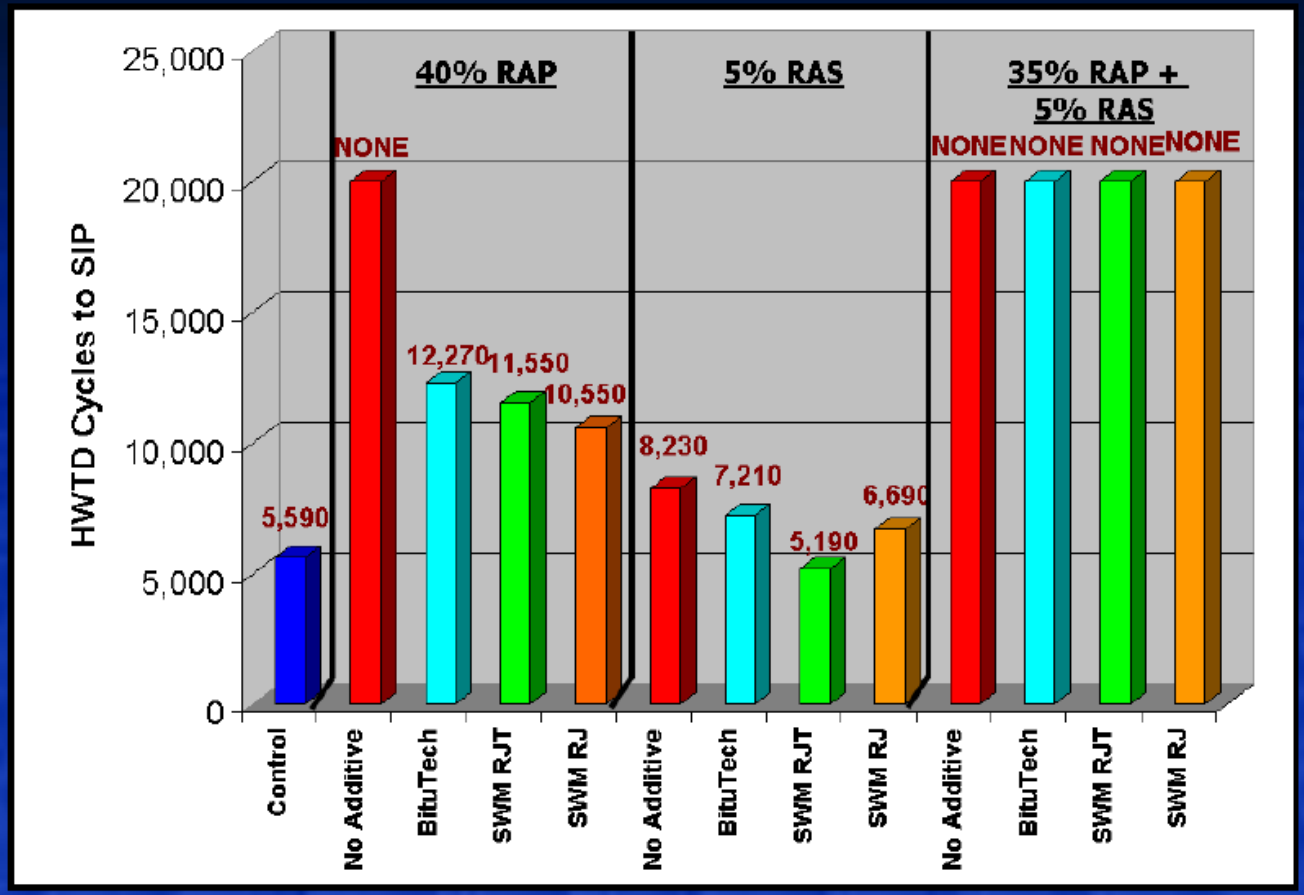
April 30th, 2013 ▪ Annapolis, Maryland

HSRC Highway Sustainability Research Center

NAPA NATIONAL ASPHALT PAVEMENT ASSOCIATION

University of Massachussetts

Highly Recycled + Rejuvenator



Northeast Pavement Preservation Partnership

Northeast Pavement Preservation Partnership

April 30th, 2013 ▪ Annapolis, Maryland

AHSRC Highway Sustainability Research Center

NAPA NATIONAL ASPHALT PAVEMENT ASSOCIATION

NCHRP Report 752

National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

Recommended Revisions to AASHTO R 35 and M323

High RAP Content Mix Design

- Aggregates properties – meet Superpave criteria
- Virgin Binder Selection: based on RAP Binder Ratio

RAP Binder Ratio: RBR = $(Pb_{RAP} \times RAP\%)/Total\ Pb$

  - RBR < 0.25 - use the virgin binder grade required for the environment, traffic, and structural layer (i.e. may include polymer modified binder)

- Virgin Binder Selection:
  - RBR ≥ 0.25 - determine the virgin binder grade using the formula:

$$\frac{(\qquad\qquad)}{\qquad\qquad\qquad\qquad}$$

T_{crit} *(virgin)* = *critical temperature (high, intermediate, or low) of the virgin asphalt binder*

T_{crit} *(need) = critical temperature (high, intermediate, or low) needed for the climate and pavement layer.*

T_{crit} *(RAP Binder) = critical temperature (high, intermediate, or low) of the RAP binder determined from extraction, recovery, and PG grading.*

Recommendations for Performance Testing for Mixes with RBR ≥ 0.25

- Moisture Susceptibility (always)
  - TSR or Hamburg
- Permanent Deformation (mixes within top 50 mm)
  - AMPT Flow Number, APA, or Hamburg
- Fatigue (surface or base mixes) *for information purposes only*
  - No cracking test or criteria recommended at this time
- Low Temperature (for cold climates)
  - IDT Creep Compliance & Strength, SCB, or DCT

RAP Publications from FHWA

Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice

PUBLICATION NO. FHWA-HRT-11-021

APRIL 2011

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

INFOBRIEF

High Reclaimed Asphalt Pavement Use

FHWA Publication No.: FHWA-HRT-11-057

FHWA Contact: Audrey Copeland, HRDI-10, (202) 493-3097, audrey.copeland@dot.gov

With changes in construction materials economics, stricter environmental regulations, and an emphasis on "green" technologies (e.g., warm mix asphalt) and sustainable pavements, the highway community is reassessing the economic and environmental benefits of allowing higher percentages of reclaimed asphalt pavement (RAP) in premium pavements and asphalt surfaces while maintaining high-quality pavement infrastructure. In 2007, the Federal Highway Administration created the RAP Expert Task Group (ETG) to advance the use of recycled materials such as RAP and recycled asphalt shingles in asphalt paving applications. The purpose of the ETG is to provide State transportation departments and the industry with information that emphasizes the production of high-quality, high-content RAP mixtures, the performance of asphalt mixtures containing RAP, technical guidance on high-content RAP projects, and RAP research activities. Members of the RAP ETG consist of representatives from State highway agencies, industry, and academia. This InfoBrief summarizes the accomplishments of the RAP ETG and resources available for increased RAP use. More information may be found online at www.fhwa.dot.gov/pavement/recycling or at www.moreRAP.us, as well as through the National Asphalt Pavement Association and the Asphalt Institute.

U.S. Department of Transportation
Federal Highway Administration

http://www.fhwa.dot.gov/research/

RAP Defined

Existing asphalt materials are commonly removed during resurfacing, rehabilitation, and reconstruction operations. Once removed and processed, the pavement materials become reclaimed asphalt pavement (RAP), which contains valuable asphalt binder and aggregate. RAP is a valuable, high-quality material that can replace more expensive virgin aggregates and binders. The most economical use of RAP is in the intermediate and surface layers of flexible pavements where the less expensive binder from RAP can replace a portion of the more expensive virgin binder. While RAP has been used for decades, there is a current interest in using higher RAP contents. High RAP content mixtures have greater than 25 percent RAP by weight of the mix.

RAP Use Today

The RAP ETG, in partnership with the American Association of State Highway and Transportation Officials (AASHTO), conducts a RAP use survey every 2 years. The survey was conducted in 2007, 2009, and 2011. In 2007, the typical hot mix asphalt (HMA) mixture contained about 12 percent RAP. From 2007 to 2009, about 27 States increased the amount of RAP permitted in asphalt mixtures, and, as of 2009, 23 States have experience with high RAP mixtures. The results of the 2007 and 2009 surveys are summarized in the *Public Roads* article "Reclaiming Roads."[1] As of 2011, the majority of State highway agencies (more than 40) allow more than 30 percent RAP; however, only 11 report actually using 25 percent RAP or more.[2]

Providing Technical Information

Designing High RAP Mixes

The RAP ETG developed and disseminated technical information for high RAP use. In the first major effort, the Federal Highway Administration partnered with AASHTO and the National Asphalt Pavement Association to create *Designing HMA Mixtures with High RAP Content: A Practical Guide*, which provides guidance for designing high RAP mixtures.[3] As a follow-up and in conjunction with the Transportation Research Board, the RAP ETG conducted the webinar *Design and Production of High Reclaimed Asphalt Pavement Mixes*.[4]

Management and Production Best Practices

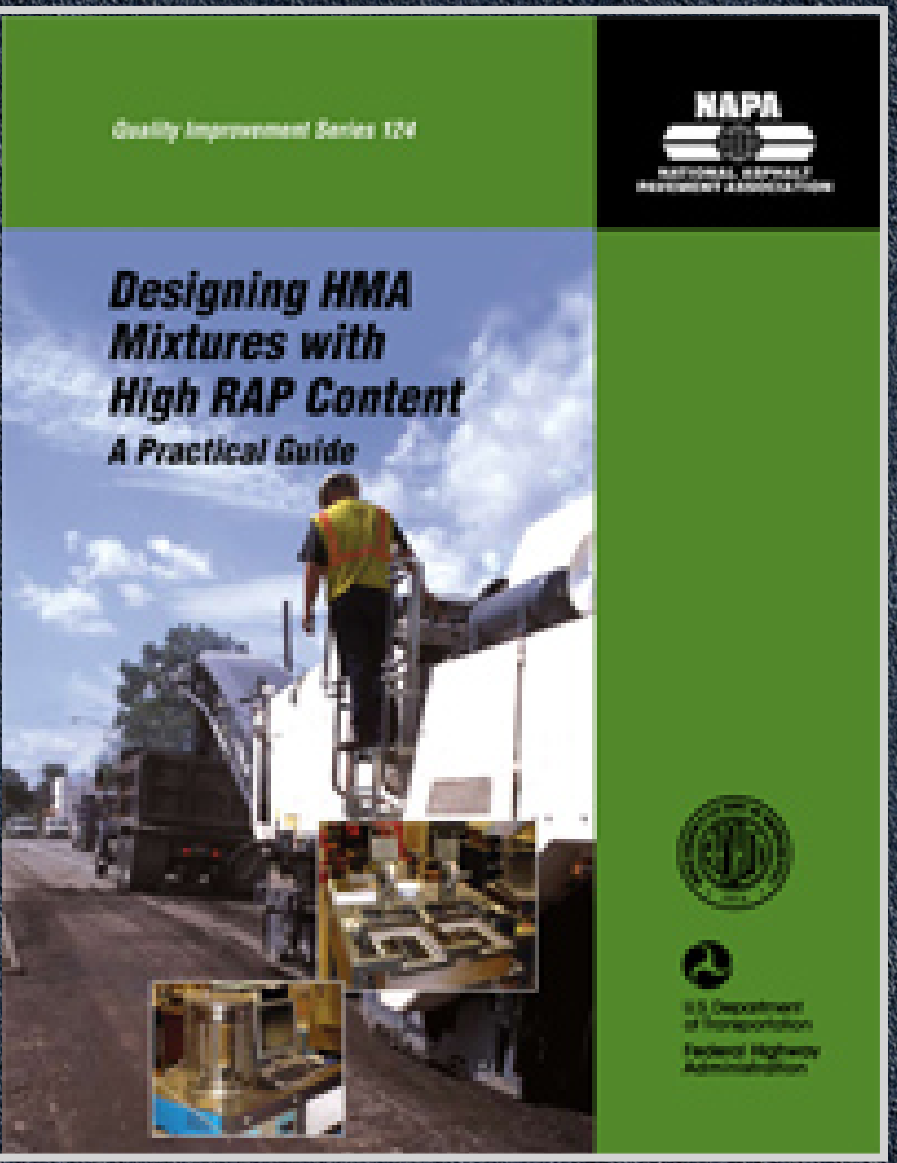
There are two best practices reports available.[5,6] In addition, presentations by three RAP ETG members are available, which provide a historical

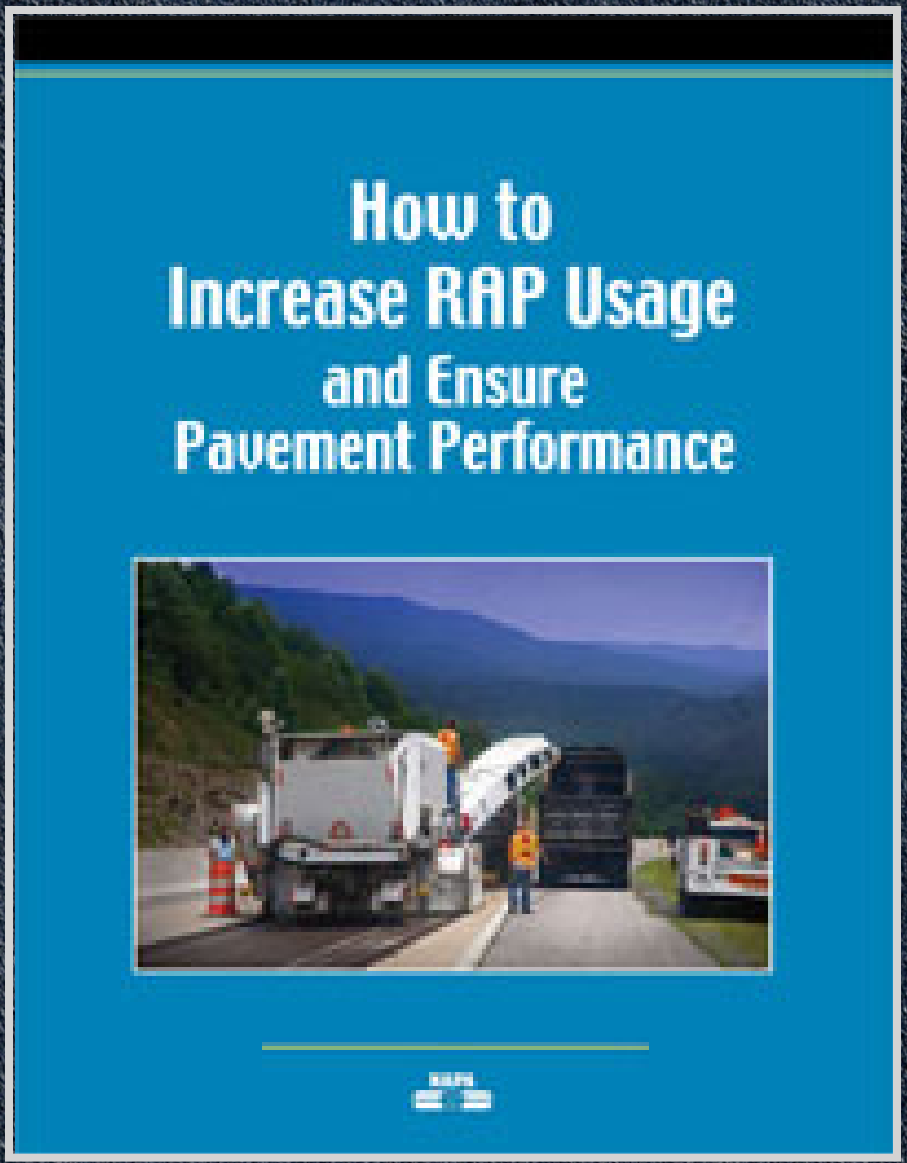
Research, Development, and Technology Turner-Fairbank Highway Research Center 6300 Georgetown Pike, McLean, VA 22101-2296

http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/11021/11021.pdf
http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/11057/11057.pdf

NAPA
NATIONAL ASPHALT

RAP Publications



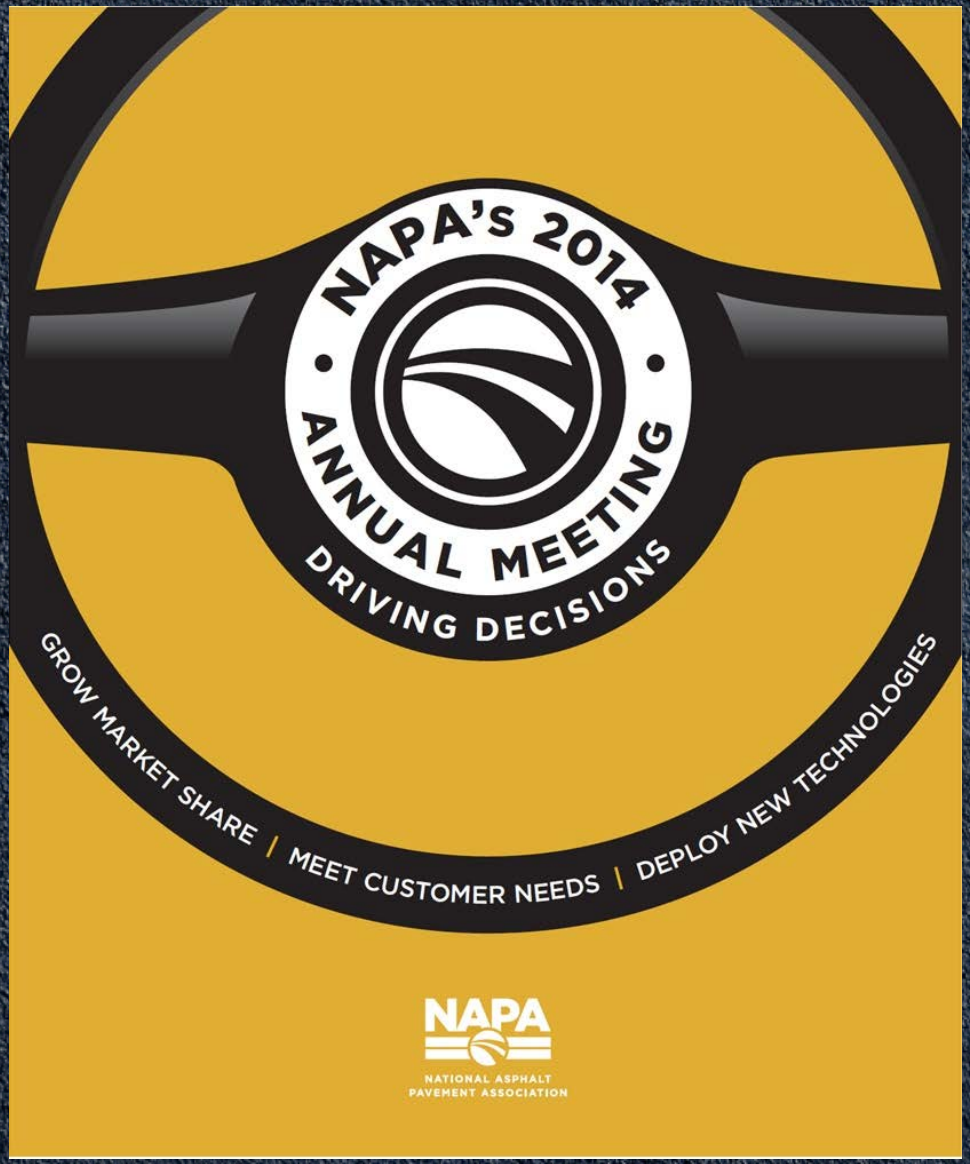


NAPA
NATIONAL ASPHALT PAVEMENT ASSOCIATION

High RAP Mixes

- High RAP mixes can perform as well as or better than virgin mixes.
- Changing binder grade at 15% too conservative.
- Performance testing of mixes can move us to higher RAP content.
- View RAP as a valuable resource.
- Treat RAP as you would other ingredients.
- Offer yourself maximum flexibility in using RAP.

NAPA
NATIONAL ASPHALT



February 2-5, 2014

Boca Raton, Florida

NAPA
NATIONAL ASPHALT

NATIONAL ASPHALT