PERFORMANCE AND DESIGN OF THIN, HIGHLY MODIFIED PAVEMENTS

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North Dakota Asphalt Conference – April 1, 2013

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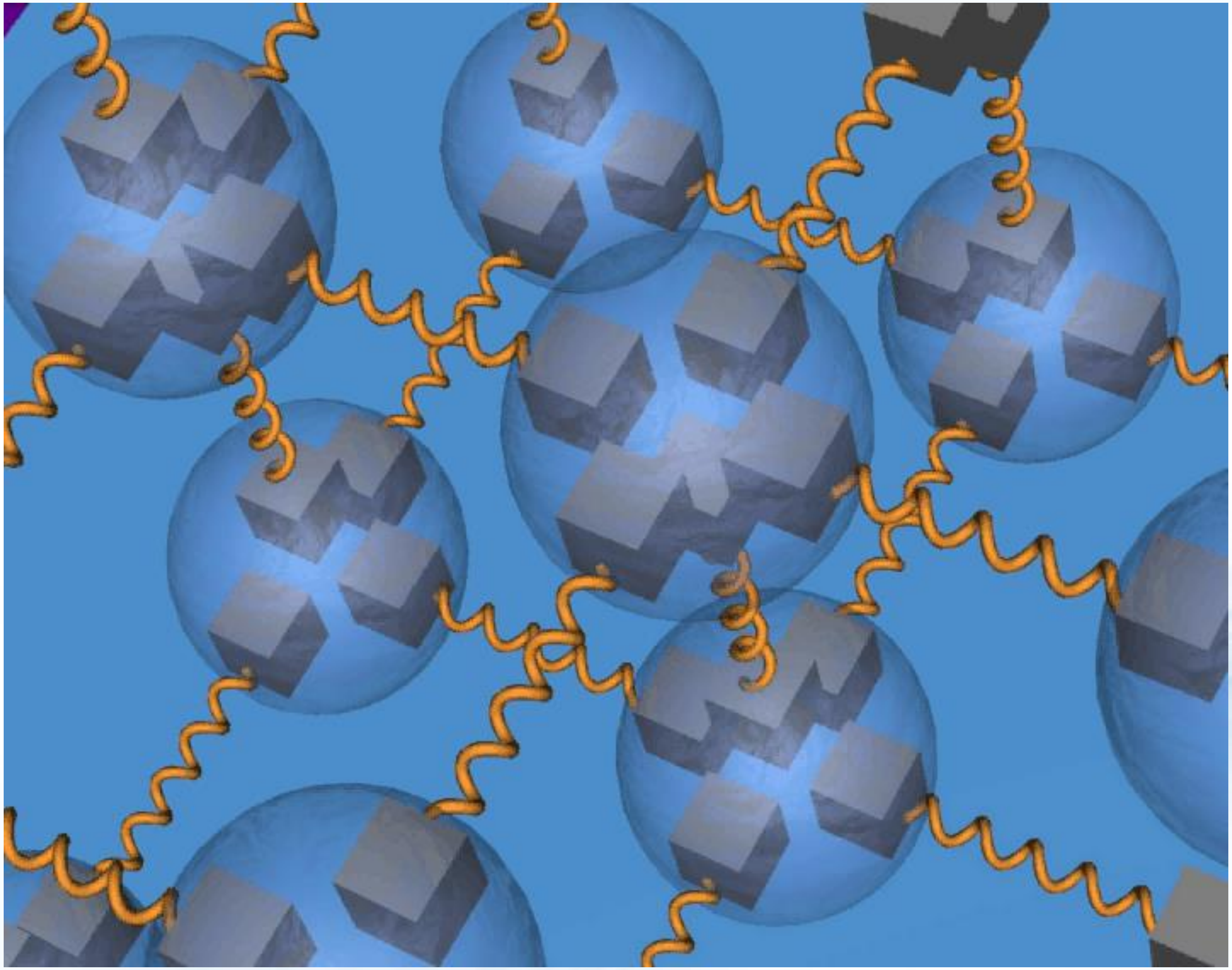
Giving Innovators Their Edge

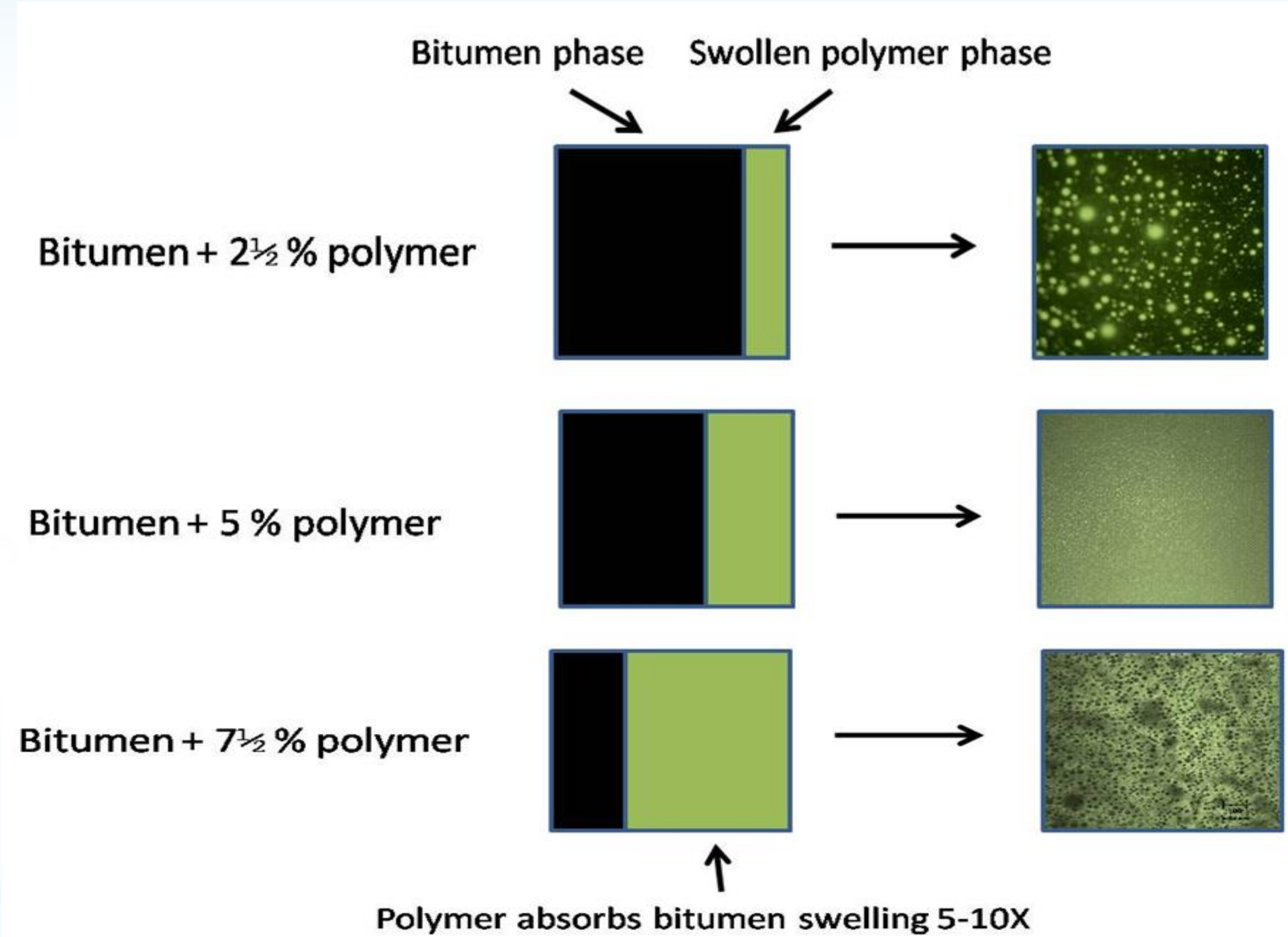
Outline

- How SBS Works in Bitumen and Asphalt Pavement
- Background of the Studies
- Material Property Testing and Advanced Modeling
- Pavement Trials
- Performance of Structural Sections
- Pavement Design
- Conclusions

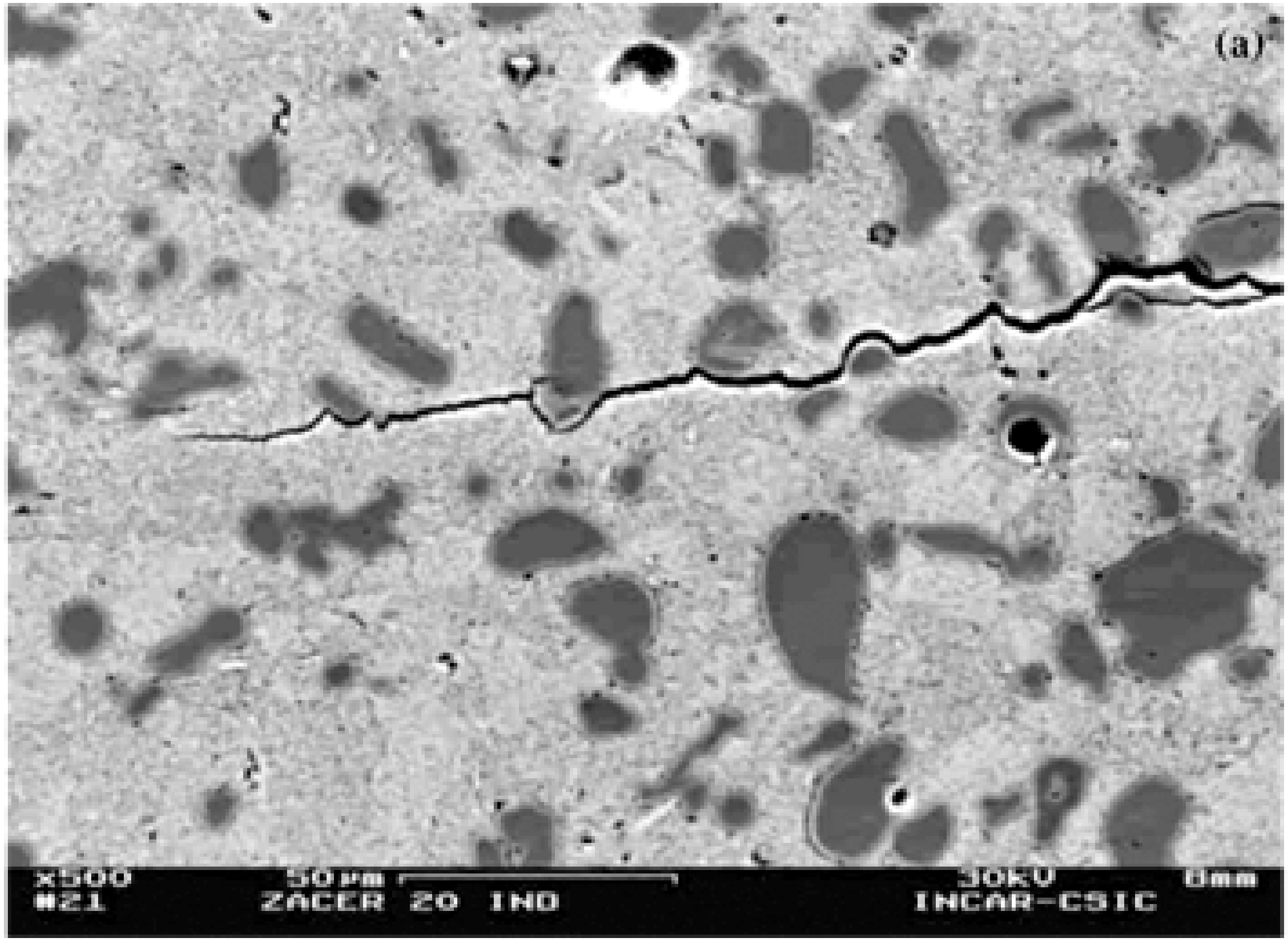
SBS in Bitumen



Phase Morphology



Crack Propagation in Toughened Composite



S. López-Esteban, J.F. Bartolemé, C. Percharromán, S.R.H. Mello Castanho, J.S. Moya, *Wet Processing and Characterization of ZrO_2/Stainless Steel Composites: Electrical and Mechanical Performance*, Materials Research, Vol. 4, São Carlos, July 2001. Used with permission.

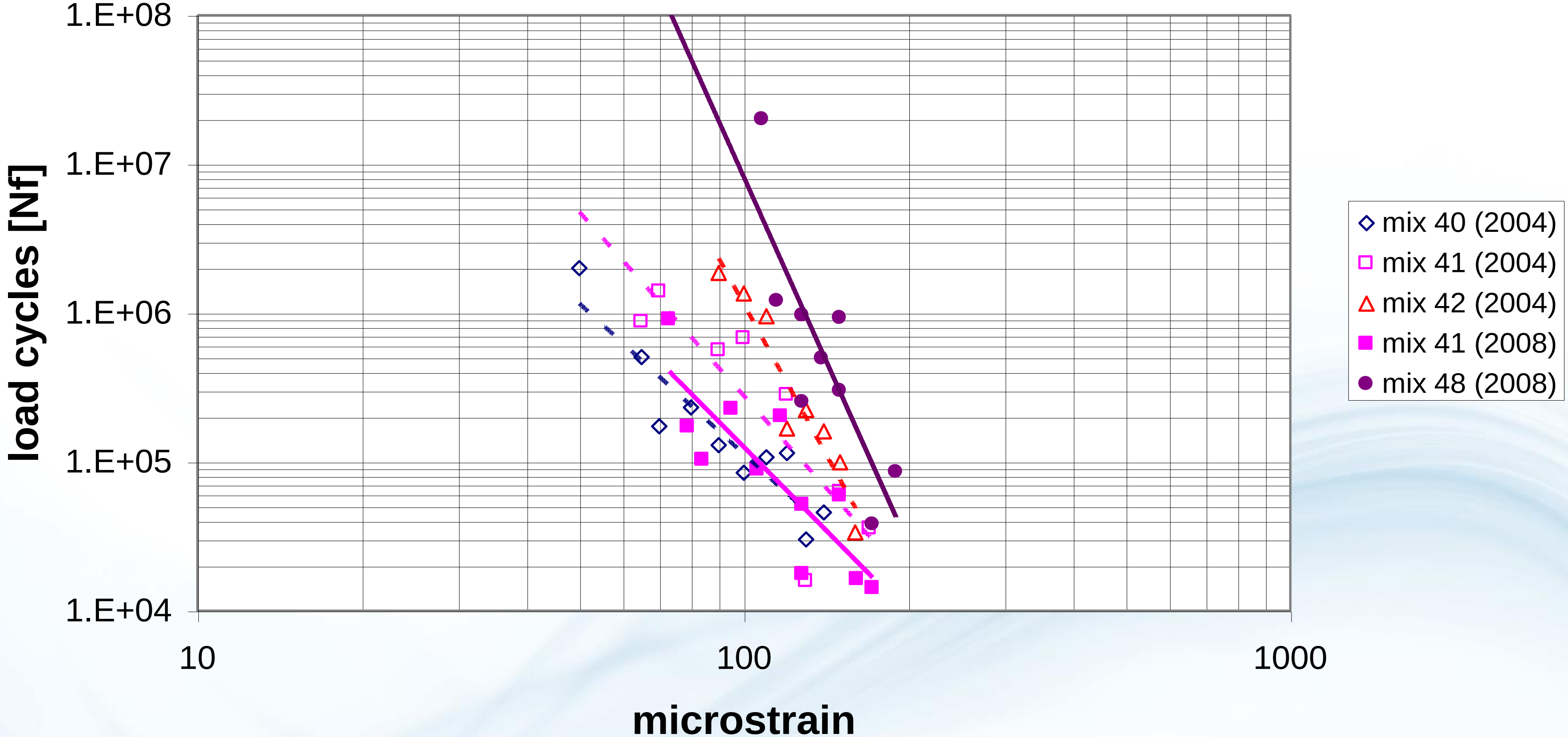
Background of the Study

- Higher traffic intensities and pavement loadings require more durable pavements.
- Higher traffic intensities also command longer maintenance intervals to increase availability of the road.
- Environmental pressure is increasing; reduction of use of natural resources such as aggregate and less emissions are highly desired.
- SBS modification has proven benefits in wearing courses over the past decades in every relevant property.

➡ Use the benefits of SBS to create a polymer modified base course asphalt that can fulfill the requirements of today and tomorrow.

➡ Technical challenge: compatibility and workability with relatively hard base bitumen.

Four Point Bending Beam Fatigue Results



Full sinusoidal loading. Cited strains are ½ amplitude

Advanced Modeling Results

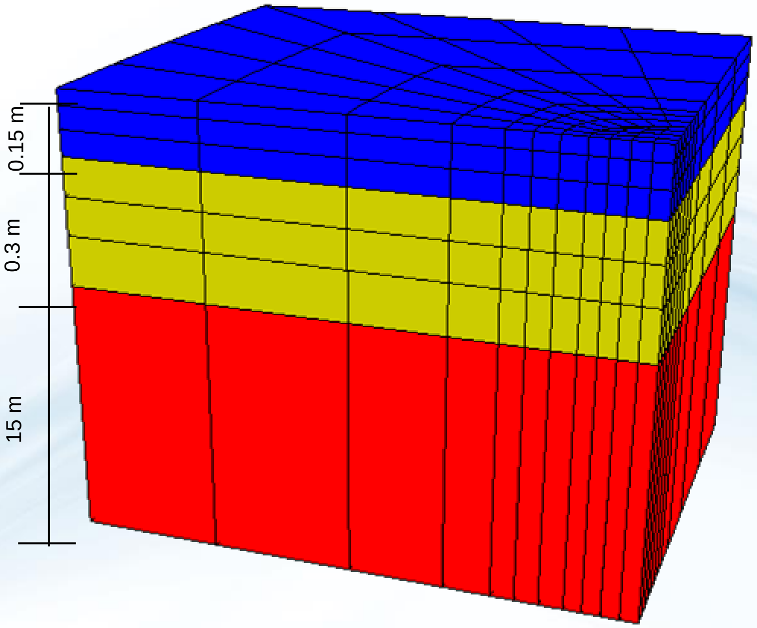
Modification type	Improvement , Reduction in Fatigue Cracking over Unmodified
46 – HiMA	68
45 – speciality SBS	58
47 – experimental SBS	34
43 – standard SBS	13
42 – standard SBS	8
41 – standard SBS	2

Pavement Structure and Loading

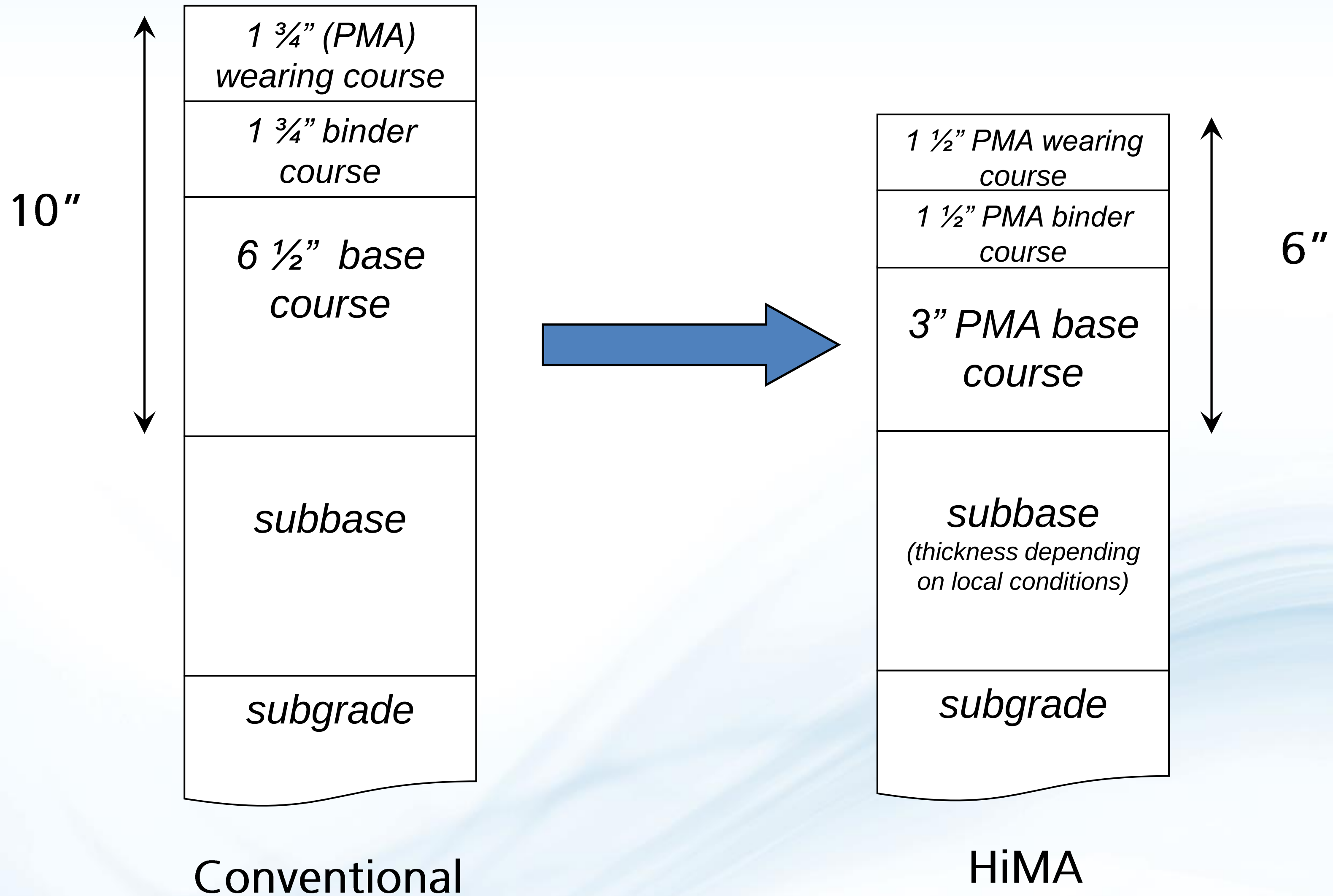
Three layers structure:
- Bound layer - E1 = 1000 MPa (145,000); h = **6″** or **10″**
- Unbound subbase - E2 = 300 MPa (43,500 psi); h = 12″
- Subgrade - E3 = 100 MPa (14,500 psi); h = 50′

Constant temperature: T = 20^{o}C

Stationary dynamic load:
800 kPa (115 psi) – 25 ms



Proposed System Redesign



This an example; depending on local conditions other types may apply

Cost Comparison: Highly Modified vs. Conventional

mix type	thickness	cost per ton	per sq yd	total	cost reduction per sq yd	% cost reduction
modified wearing course	1.75 "	$84.00	$16.52			
unmodified binder course	1.75 "	$70.00	$13.77			
unmodified base course	6.5 "	$65.00	$47.48			
total	10.0 "			$77.77		
modified wearing course	1.75 "	$84.00	$16.52			
modified binder course	1.75 "	$84.00	$16.52			
modified base course	6.5 "	$91.00	$66.48	$99.52	-$21.75	-29%
	5.5 "	$91.00	$56.25	$89.29	-$11.52	-15%
	5.0 "	$91.00	$51.14	$84.18	-$6.41	-9%
	4.5 "	$91.00	$46.02	$79.07	-$1.29	-2%
	4.0 "	$91.00	$40.91	$73.95	$3.82	5%
	3.5 "	$91.00	$35.80	$68.84	$8.94	12%
	3.0 "	$91.00	$30.68	$63.73	$14.05	19%

based on example from previous slide, material costs only

base data:
SMA unmodified wearing mix: $70/ton
unmodified base mix: $65/ton

assumptions:
PMA wearing mix + 20%
PMA base mix + 40%

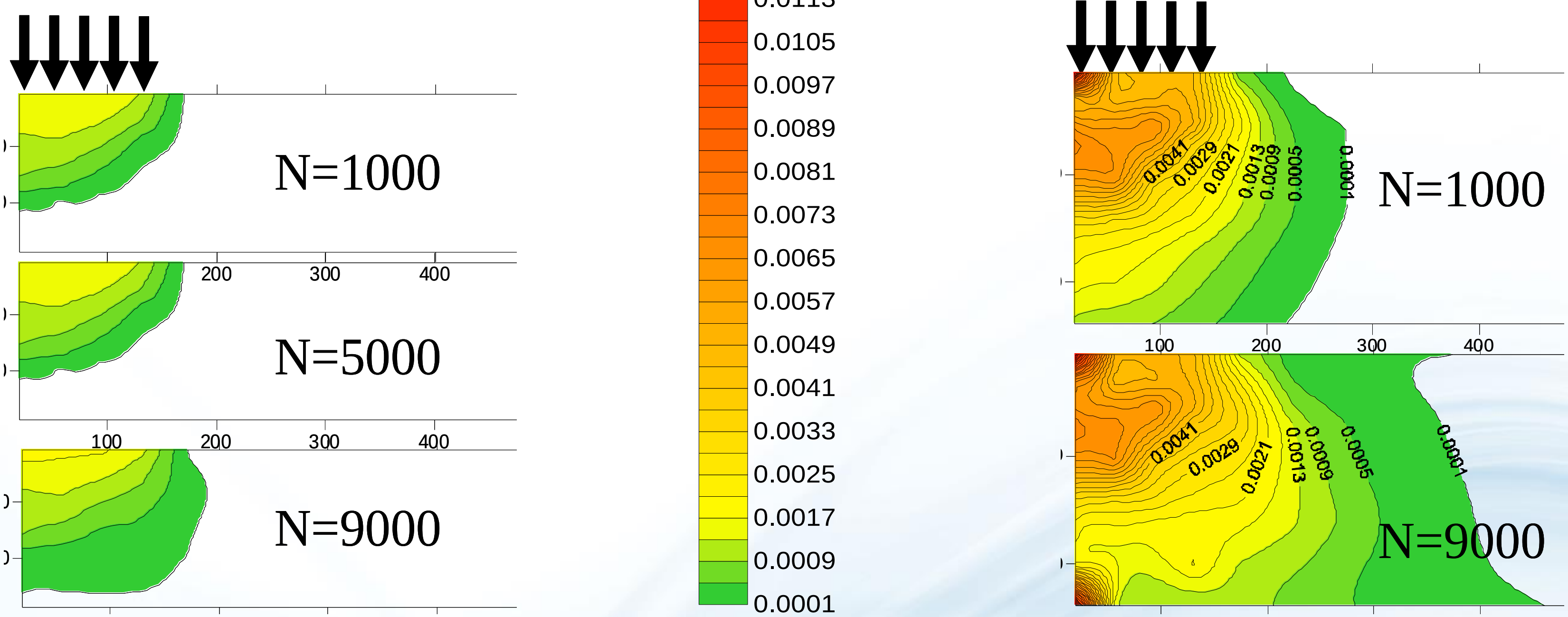
More Advanced Modeling Results

HiMA (6")

total damage

Unmodified (10")

total damage



Comparative Damage

Distress	10” unmodified	6” HiMA
Shear deformation	2.05E-2	0.78E-2
Compressive deformation	1.27E-2	0.70E-2
Longitudinal cracking	1.31E-3	0.02E-3
Vertical cracking	7.72E-4	4.41E-4
Transverse cracking	8.65E-4	0.79E-4

Applications

- Highly Modified Asphalt is a tool. It can be used to improve performance and cost effectiveness in a variety of asphalt paving applications:

- New construction and structural rehabilitation – thinner structures, lower upfront cost.
- Structural and preservation overlays – thinner structures, more resistant to thermal and reflective cracking. (Participating in AASHTO TSP2 program with NCPP)
- Micro surfacing – more resistant to cracking and raveling
- Open grade mixes – more resistant to raveling. Resistant to drain down (no need for fibers)
- Waterproof bridge decks – zero void mixes that are rut resistant and yet highly flexible
- Etc.

Paving Trials to Date

- June 2009 – Thirteen city streets in Belpre, OH. Two 1” lifts, 9.5mm NMAS fine mix PG -28 base bitumen. No production or construction problems despite inclement weather.
- July 2009 – Section N7 (part of pooled fund group program) at NCAT test track, PG -22 base bitumen. Again, no problems with production or construction. Mix behaved like conventional PG 76-22 asphalt concrete.
- May 2010 – Slow, heavy traffic intersection in Georgia. PG -28 base bitumen No construction issues. Mix ran “easier than normal 76-22”
- August 2010 – NCAT Section N8, similar structure to N7.
- October 2010 – Port of Napier, New Zealand container loading wharf
- August-September 2011 – Thin lift overlay trials in Minnesota, Vermont and New Hampshire
- February-April 2012 – Structural rehabilitation on I 40 in Oklahoma
- May 2012 – Thin lift overlay trial, I-5 in Oregon
- June 2012 – Structural rehabilitation US 231 in Alabama

Thin Overlay Trials - Minnesota

- **MN DOT TH 100 (64,000 ADT)**
  - AASHTO TSP2 thin lift HiMA paving program constructed August 2011
  - One lane for two miles; dense graded mix design with 25% RAP content at 2 inch thickness with a 1,500 feet section within the two miles at 1.5 inch thickness for a 2 inch mill and inlay contract
  - No rutting or raveling evident
  - Control section – Reflective cracking at 10% in the control lane
  - Kraton section - 50% of those cracks carrying over into the HiMA lane and 50% stopping at the HiMA lane
  - No visual differences noted between the 2 inch and 1.5 inch HiMA pavements
  - 25% thickness reduction with, to date, improved cracking resistance

- HiMA technology being evaluated for asphalt overlays on cement concrete pavements to reduce thickness

Thin Overlay Trials – New Hampshire

- **NH DOT U.S. 202 (4,600 ADT)**
  - AASHTO TSP2 thin lift HiMA paving program constructed September 2011
  - Two lanes for two miles; dense graded mix design with 25% RAP content at 1 inch thickness for a 1 inch asphalt overlay contract
  - Comparison was 1 inch PG 64-28 dense mix
  - No rutting or raveling evident on either section
  - Control section – ~10% transverse cracking
  - Kraton section – One 3 foot reflective crack and one 12 foot longitudinal crack noted over the two miles in west lane

- HiMA technology being specified on a *FHWA Highways for Life* grant to be contracted by the NHDOT in 2012

Thin Overlay Trials - Vermont

- **VT AOT U.S. 7 (4,700 ADT)**
  - AASHTO TSP2 thin lift HiMA paving program constructed September 2011
  - Two lanes and shoulders for two miles; dense graded mix design with 25% RAP content at 1 inch thickness for one mile and virgin aggregate at 1 inch thickness for one mile for a 1 inch asphalt overlay contract
  - Comparison was ¾” Novachip type C mix with PG 58-28 with latex modified tack coat
  - No rutting or raveling evident on either section
  - Control section – Novachip had ~10% reflective cracking
  - Kraton section – No evident cracking

- HiMA technology being evaluated for full depth asphalt replacement pavement for deteriorated cement concrete pavements to reduce thickness

NCAT - Cross Sections Evaluated

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Control (7″ HMA)

1 ¼” (PG 76-22; 9.5mm NMAS; 80 Gyrations)

2 ¾” (PG 76-22; 19mm NMAS; 80 Gyrations)

3” (PG 67-22; 19mm NMAS; 80 Gyrations)

Experimental (5 ¾″ HMA)

1 ¼” (Kraton Modified, 9.5 mm NMAS)

2 ¼” (7½% polymer;19mm NMAS; 80 Gyrations)

2 ¼” (7½% polymer;19mm NMAS; 80 Gyrations)

Dense Graded Crushed Aggregate Base
M_r = 12,500 psi
n = 0.40

Lift thicknesses limited by 3:1 thickness:NMAS requirement

6″

Test Track Soil
M_r = 28,900 psi
n = 0.45

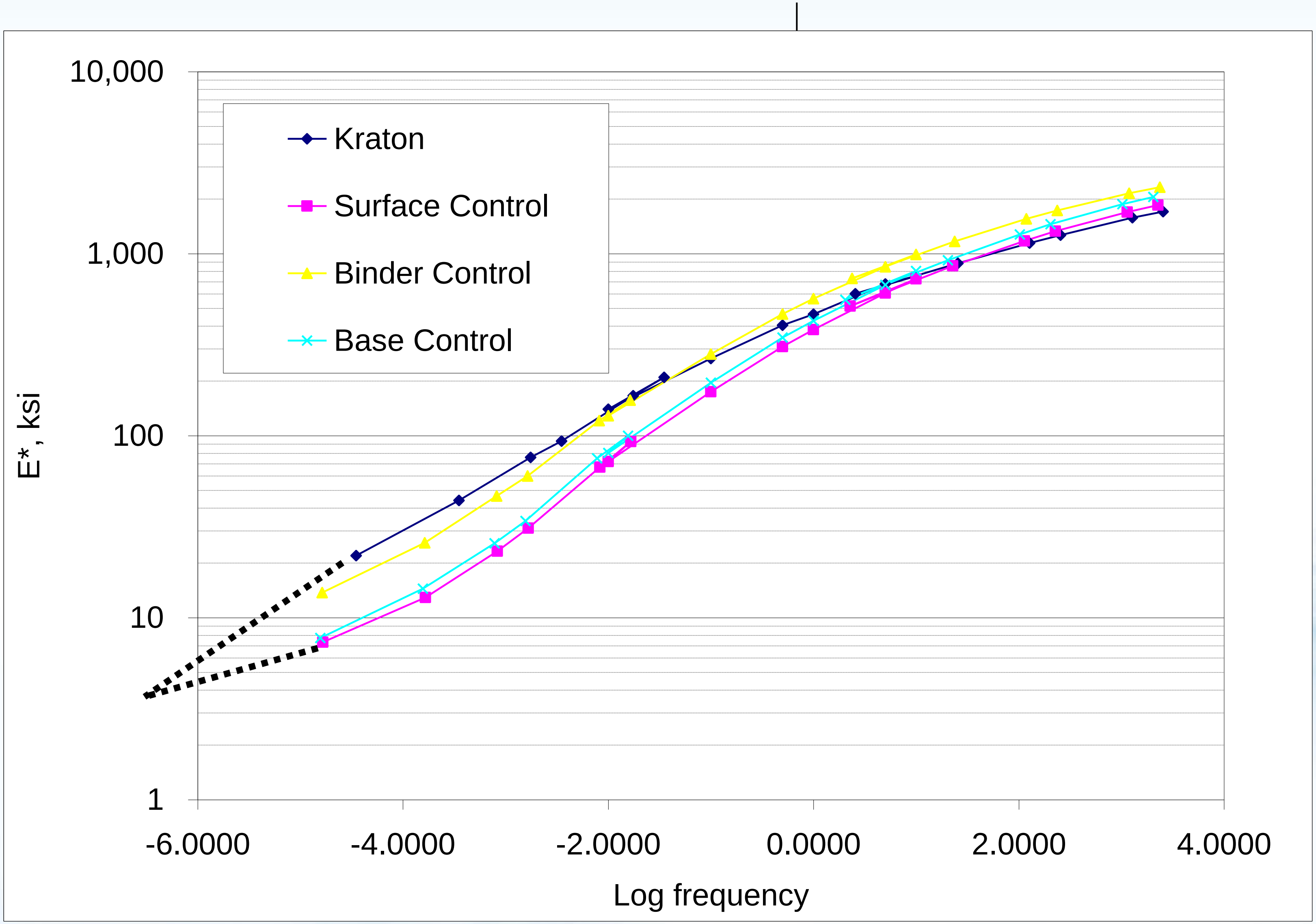
Courtesy Prof. David Timm, Auburn U.

NCAT Construction Overview

- Binder, PG 67-22 + 7½% SBS polymer, shipped 6+ hours. No issues with handling.
- Mixing temperature 340°F (same used for PG 76-22 surface mixes), delivered to track 335°F, temperature behind screed 300°F.
- Mix came out of truck cleanly. Density easily achieved with conventional rolling pattern.
- No issues with shoving, however mixture appeared to “knead” as a unit under the roller.
- Truck trafficking commenced 8/28/09.

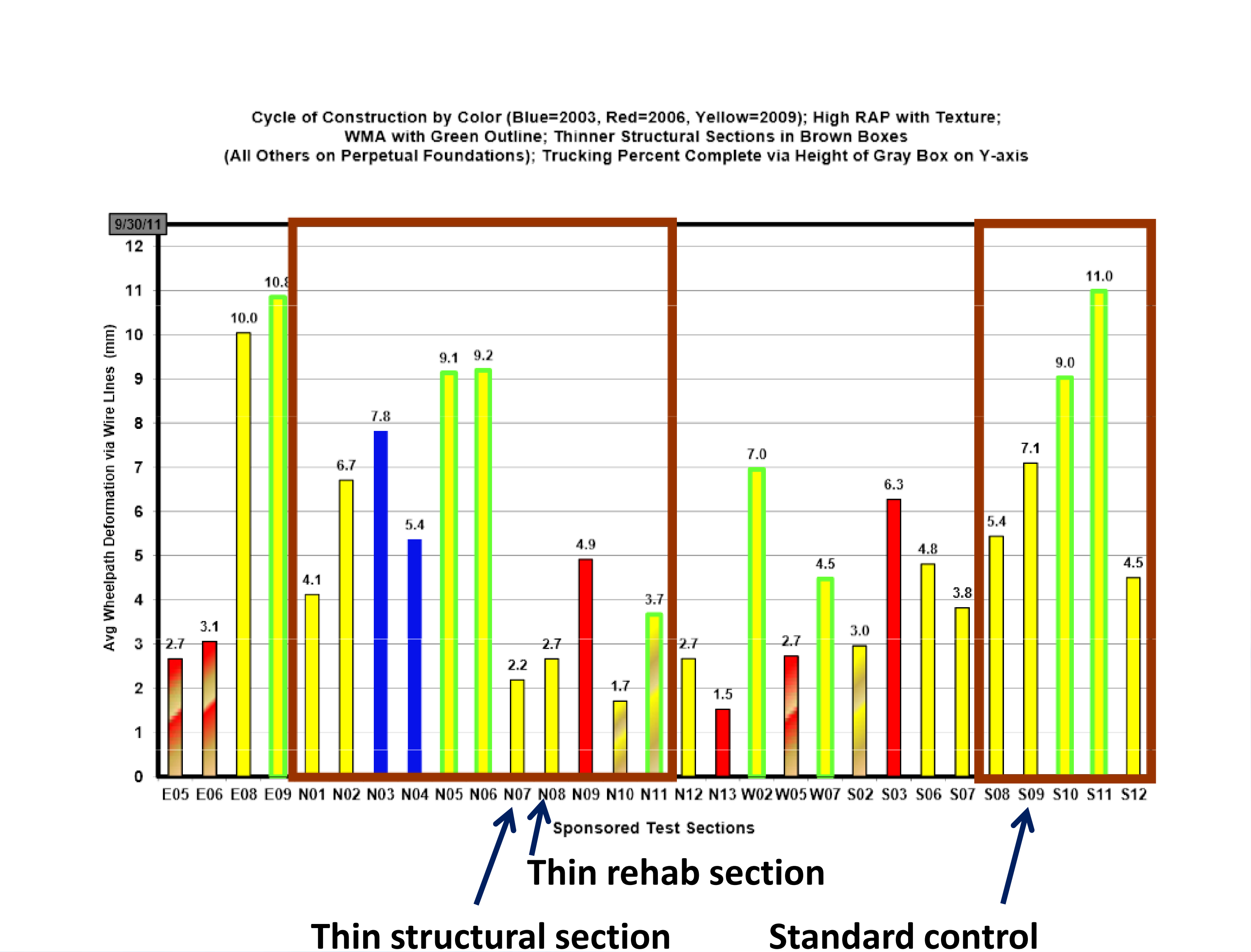
- NCAT & Auburn University – Dr. Buzz Powell, Dr. Nam Tran, Prof. Richard Willis, Prof. David Timm, Mary Robbins

Master Curve Comparison



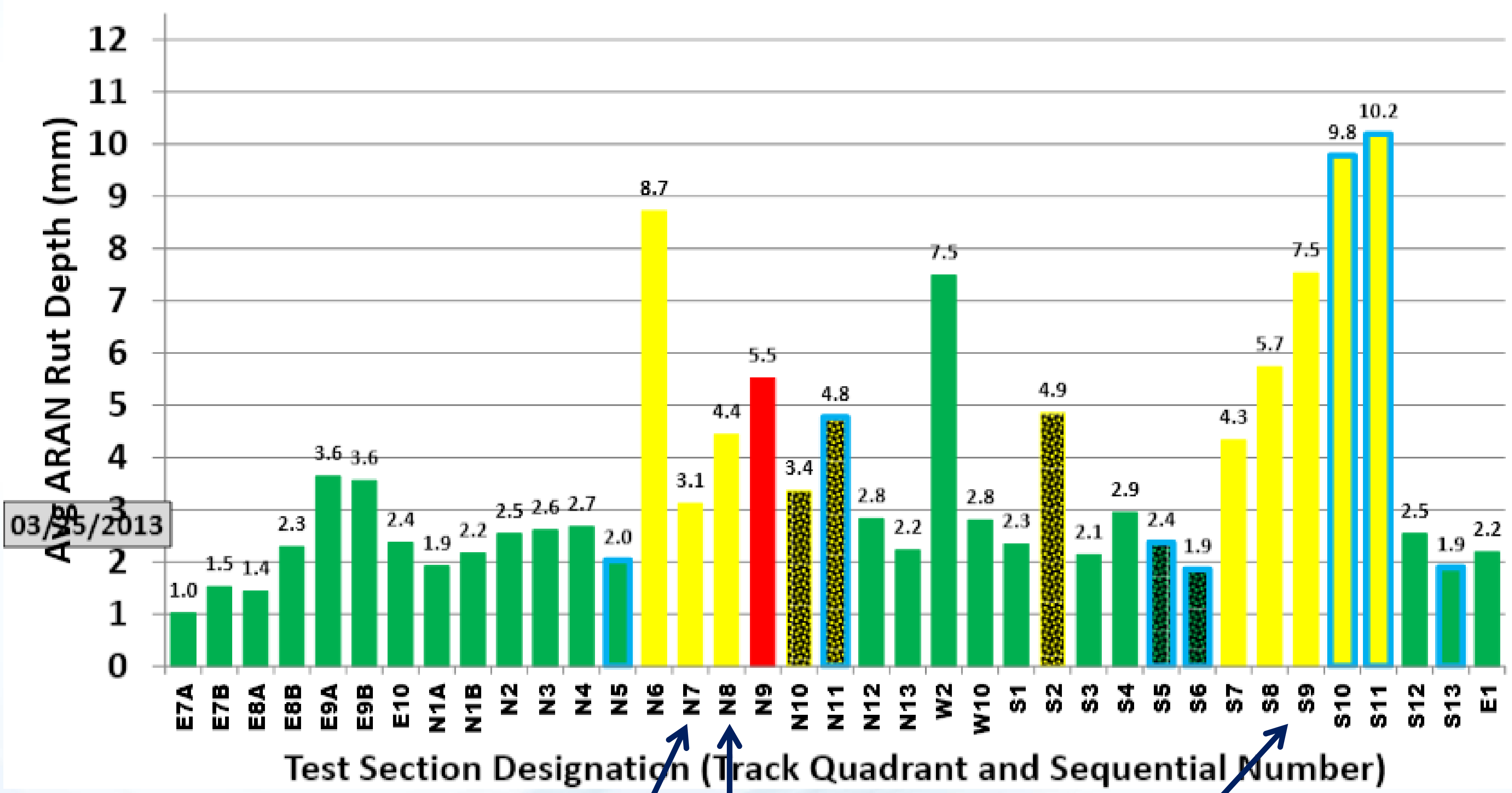
Courtesy Prof. David Timm, Auburn U.

NCAT Rutting & Cracking as of 9/30/11



So far, no cracking on any of the pooled fund group experiment sections

NCAT Rutting & Cracking as of 3/25/13



Thin rehab section

Thin structural section

Standard control

Half of Group Experiment showing early cracking. No cracking on either N7 or N8.

2006 NCAT Construction Cycle

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Oklahoma Perpetual
Pavement Experiment

N8 – 10″ HMA
over weak base

10″ Oklahoma Perpetual
Pavement Design

N9 – 14″ HMA
over weak base

14″ Oklahoma Perpetual
Pavement Design

Weak subgrade = poor soil for construction

2009 NCAT Construction Cycle

- In July 2009 NCAT constructed our HiMA test section N7.
- Oklahoma wished to continue trafficking their 2006 perpetual pavement sections.
- N9 – the 14” section was still performing well and was left as is.
- N8 – the 10” section was experiencing serious subgrade rutting (in the intentionally weakened soil under the pavement structure). This lead to rutting and cracking in the pavement.
- In order to maintain safety and reasonable pavement surface, the N8 section was milled to a depth of 5” and rebuilt. This would be considered major rehabilitation.

2009 NCAT Construction Cycle - August 2009

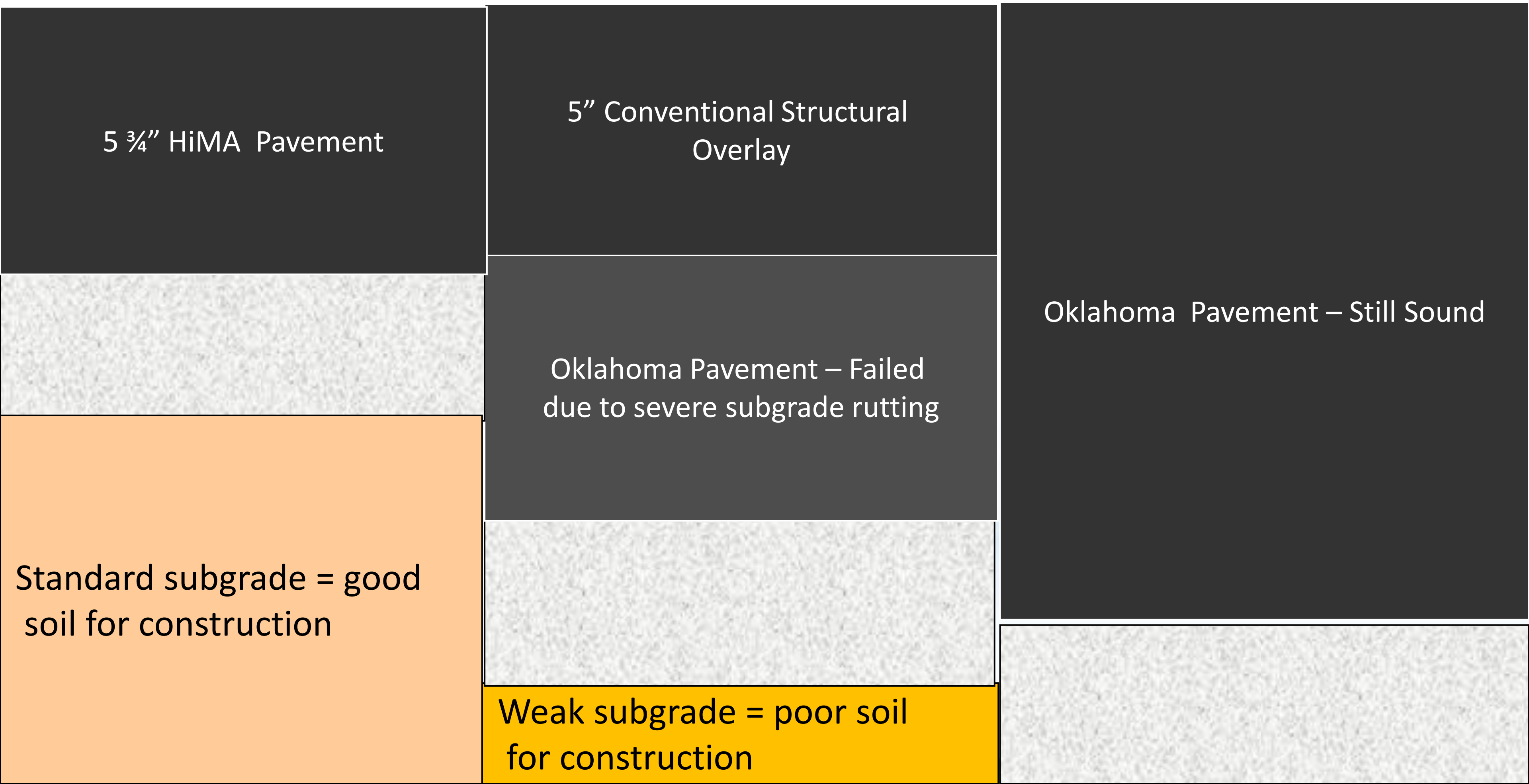
Kraton Polymers HiMA Experiment

Oklahoma Perpetual Pavement Experiment

N7 - 5 ¾" HIMA over sound base

N8 – 10" HMA over weak base

N9 – 14" HMA over weak base



Section N8 – June 29, 2010 – 4.0 MM ESALs

10″ pavement
paved Aug. 2006
5″ rehabilitation
Aug. 2009
10 months old

Section N8 - June 29, 2010 - 4.0 MM ESALs

10" pavement
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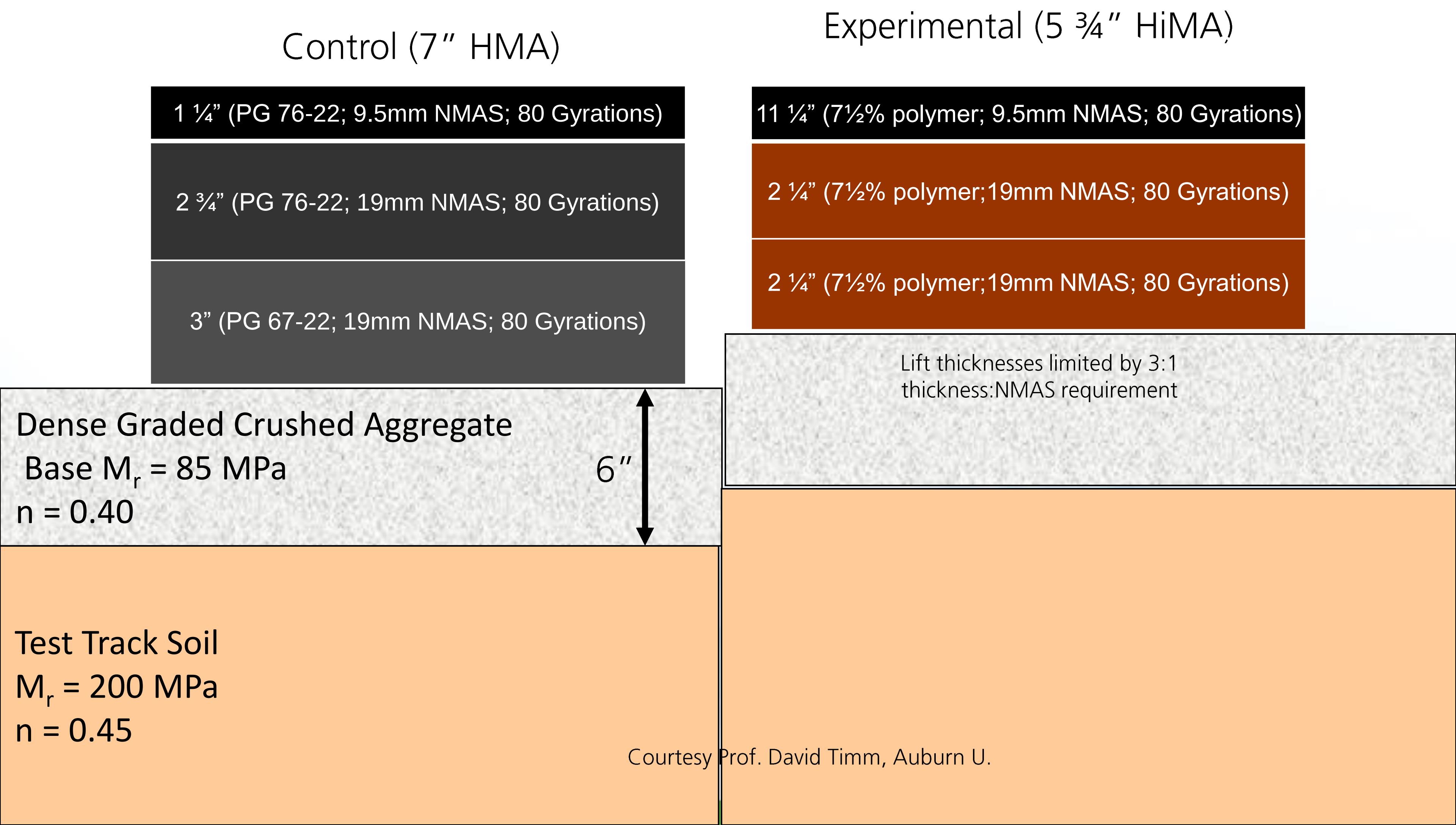
Reminder - NCAT Cross Sections



Courtesy Prof. David Timm, Auburn U.

NCAT Proposal

- NCAT proposes duplicating our N7 structure as a structural overlay for the failing N8 section.
- Their main concern is preventing rutting so that the trucking can continue through the remainder of the 2009 cycle (though spring 2012).
- There is also a significant chance of reflective cracking as the existing pavement is severely damaged throughout.
- We proposed a couple of alternatives to balance rut resistance vs. crack resistance.
- NCAT had a strong preference to mitigate rutting as that is their primary concern, and we agreed.
- Still need okay from Oklahoma.

2009 NCAT Construction Cycle - July 2010

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After 10 months, Section N8 structural overlay is already failing
NCAT approaches Kraton in July proposing HiMA solution

N7 - 5 ¾″ HIMA over sound base

1 ¼” (7½% polymer; 9.5 mm NMAS)

2 ¼” (7½% polymer;19mm NMAS; 80 Gyrations)

2 ¼” (7½% polymer;19mm NMAS; 80 Gyrations)

Standard subgrade = good soil for construction

N8 – 10″ HMA over weak base

1 ¼” (7½% polymer, 9.5 mm NMAS)

2 ¼” (7½% polymer;19mm NMAS; 80 Gyrations)

2 ¼” (7½% polymer;19mm NMAS; 80 Gyrations)

Oklahoma Pavement – Failed due to severe subgrade rutting

Weak subgrade = poor soil for construction

N9 – 14″ HMA over weak base

Oklahoma Pavement – Still Sound

NCAT/OK Proposal

- Oklahoma came back with good news—and interesting news.
- First, they not only support the project, they are enthusiastic about it as an opportunity.
- Second, they are more in our camp and would like to try to do more to mitigate cracking.
- Their proposal—keep the binder, wearing course and binder course the same, but replace the base course mix with surface course mix.
- Surface—smaller rock = smoother, less stiff, more crack resistant.
- Base—larger rock = rougher, stiffer, less crack resistant.
- This design concept, stiff middle layer with normal surface and crack resistant bottom layer, is common in perpetual pavement design.
- Ergon has produced the asphalt binder at their Memphis facility and delivered it to NCAT late Sunday. Paving commences Monday AM.
- Construction cost paid out of NCAT maintenance budget.

2009 NCAT Construction Cycle - August 2010

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Oklahoma proposed design modification

N7 - 5 ¾″ HIMA
over sound base

1 ¼” (7½% polymer; 9.5 mm NMAS)

2 ¼” (7½% polymer;19mm NMAS; 80 Gyrations)

2 ¼” (7½% polymer;19mm NMAS; 80 Gyrations)

Standard subgrade = good soil for construction

N8 – 10″ HMA
over weak base

1 ¼” (7½% polymer; 9.5 mm NMAS)

2 ¼” (7½% polymer;19mm NMAS; 80 Gyrations)

2 ¼” (7½% polymer; 9.5mm NMAS; 80 Gyrations)

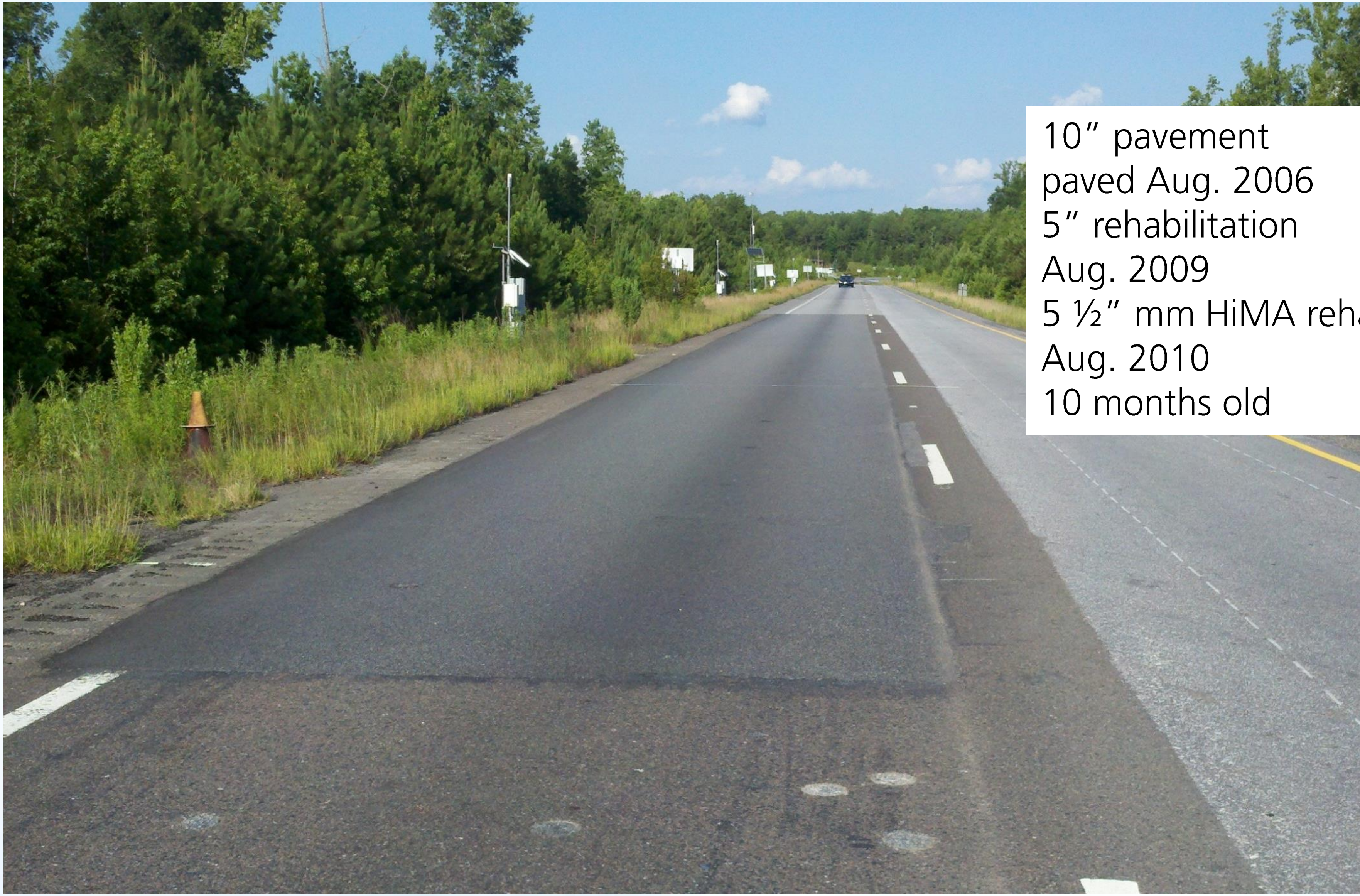
Oklahoma Pavement – Failed due to severe subgrade rutting

Weak subgrade = poor soil for construction

N9 – 14″ HMA
over weak base

Oklahoma Pavement – Still Sound

Section N8 – June 20, 2011 – 4.2 MM ESALs



10″ pavement
paved Aug. 2006
5″ rehabilitation
Aug. 2009
5 ½″ mm HiMA rehab
Aug. 2010
10 months old

Section N8 - Sept. 12, 2011 - 5.27 MM ESALs as of 3/31/13 - 7.2 MM ESALs

10" pavement
paved Aug. 2006
5" rehabilitation
Aug. 2009
5 ½" HiMA rehab
Aug. 2010
13 months old

Similar crack appeared in first overlay at 2.7 MM ESALs
Oklahoma will sponsor this section through the 2012 cycle to monitor further deterioration and evaluate preservation strategies.

Pavement Performance Prediction

- So how do we design pavements to meet performance needs?
- What (realistic and practical) methodology of pavement design will accurately predict performance?
- What mixture properties and specifications?
- What changes to mix design?
- What binder properties and specifications?

- Do not currently have adequate models for reflective cracking! Needed to address preservation strategies.

Pavement Design Methods

- Empirical Tables
  - No flexibility
- Design Models – Layered Elastic Continuum Damage Models
- Shell Pavement Design Manual – SPDM 3.0
  - Allows endurance limit input
  - No longer commercially available
- AASHTO Design Guide DARWin 3.1
  - Structural parameter
- PerRoad – Auburn U / APA
- Mechanistic Empirical Pavement Design Guide – MEPDG/DARWin ME
  - Most sophisticated/comprehensive input (traffic, aging, etc.)
  - Adjustable calibration coefficients
- Advanced Continuum Damage Models, e.g., Asphalt Concrete Response (ACRe)
  - Very flexible input, but too complex for routine use

Pavement Design Strategies

- MEPDG / DARWin ME
  - Use Level 1 Design
  - Determine dynamic modulus (AMPT)
  - Revise fatigue calibration (AMPT or 4 point bending beam)
  - Revise rutting calibration (any deformation test, APA, Hamburg, AMPT Fn)
  - Compare Highly Modified design with conventional design

- AASHTO 93 / DARWin 3.1
  - Run MEPDG on standard design
  - Run MEPDG on Highly Modified design (see above)
  - Adjust Highly Modified thickness to give equal performance prediction
  - Thickness ratio gives adjusted structural number.

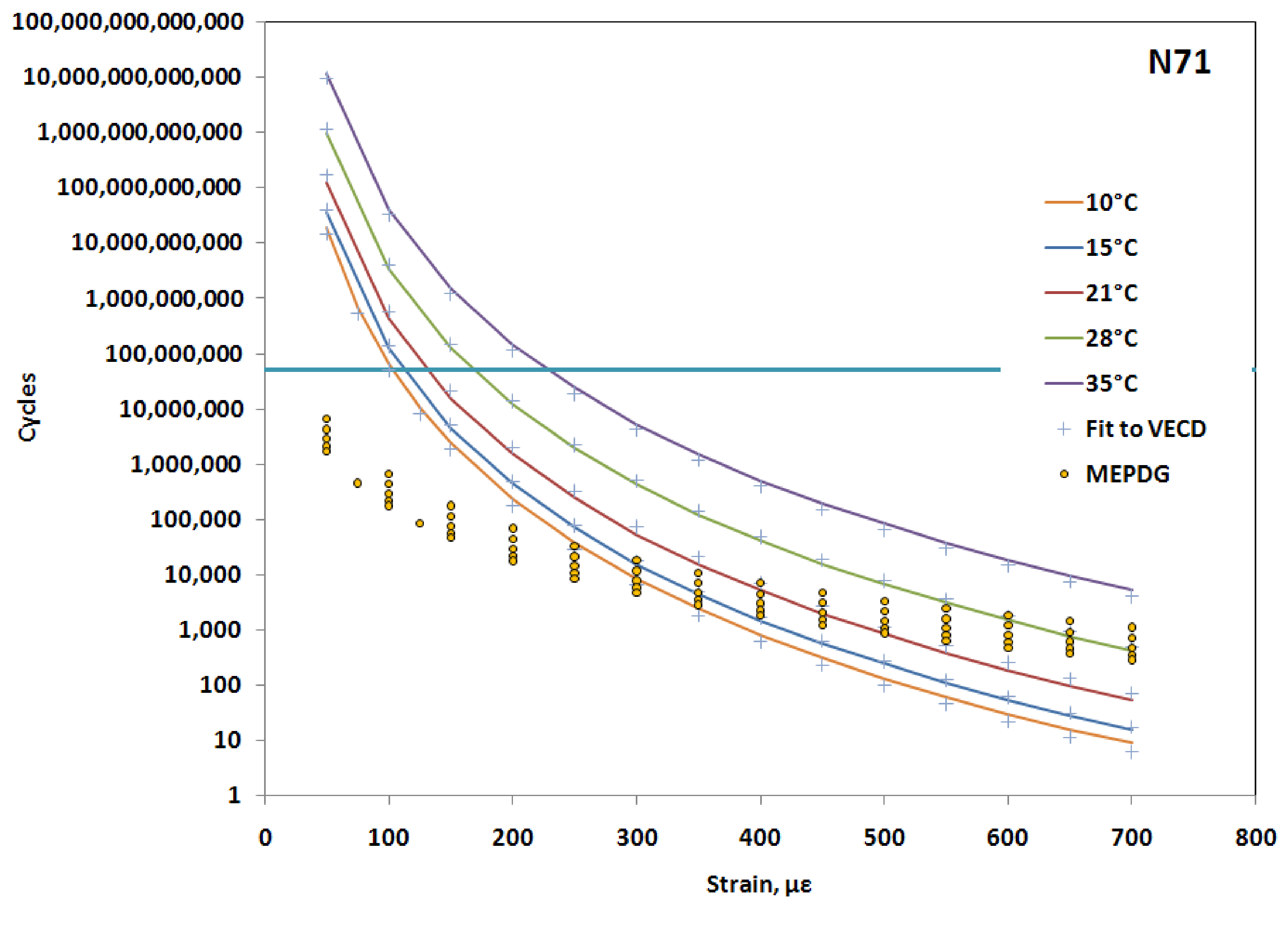
Performance Prediction - Mixture - 1

- **Modeling Results from TFHRC and NCSU**

- Modeling fatigue behavior from basic material properties (AMPT) using a Simplified Viscoelastic Continuum Damage (S-VECD) model
- Testing conducted at Turner Fairbank Highway Research Center and the National Center for Asphalt Technology
- Data presented at the Models and Mixture Expert Task Group meetings, March 2011.

- TFHRC – Nelson Gibson, Xin Jun Li
- NCSU - Richard Kim, Shane Underwood
- NCAT - Nam Tran, Randy West, Buzz Powell
- DLSI – Raj Dongré
- AAT - Don Christensen and Ray Bonaquist

Results – Premium Polymer Modification



Results - Premium Polymer Modification

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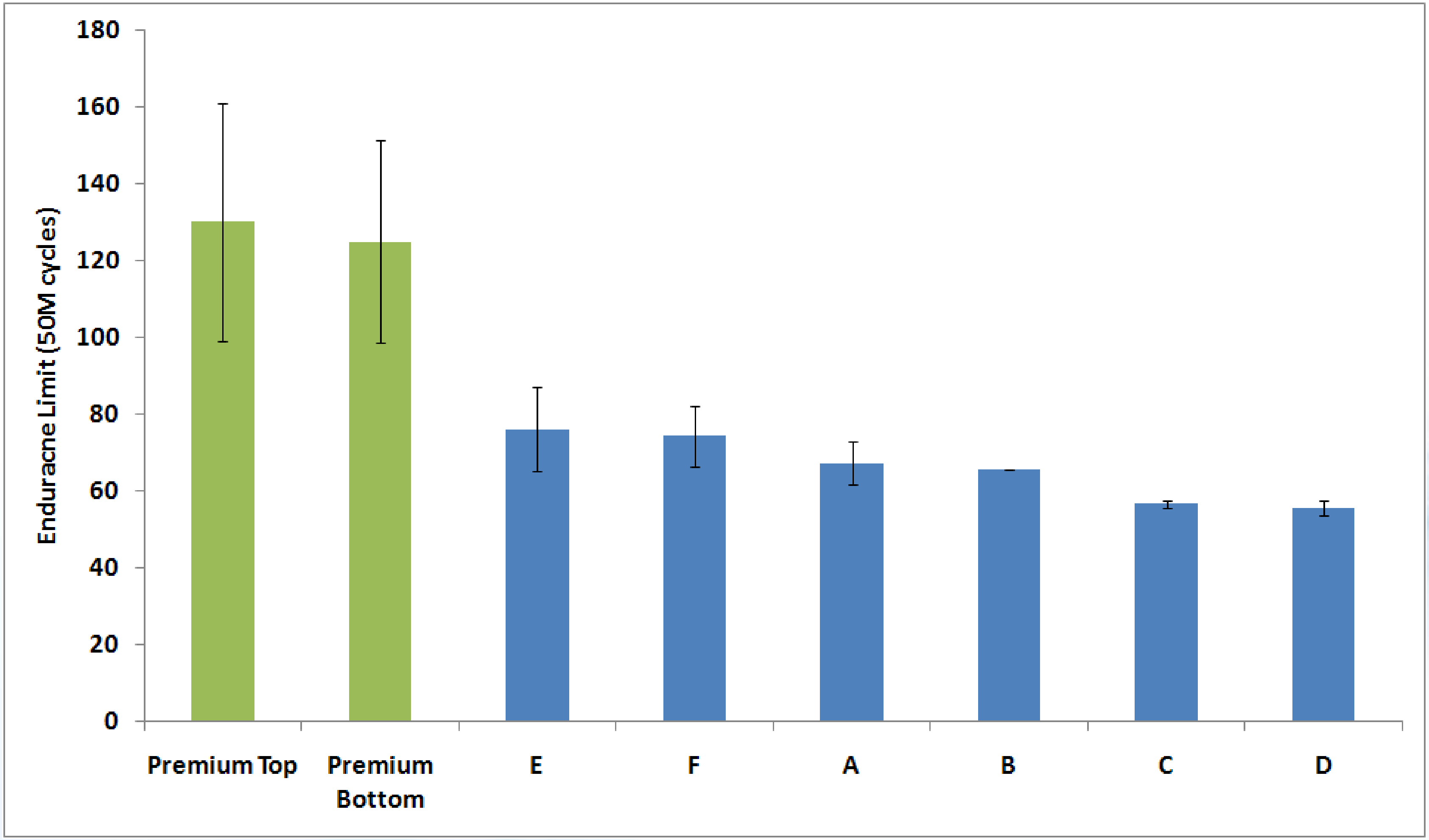
Endurance Limit (50M cycles) from range of temperatures



Thickness reduction capability - SPDM 3.0

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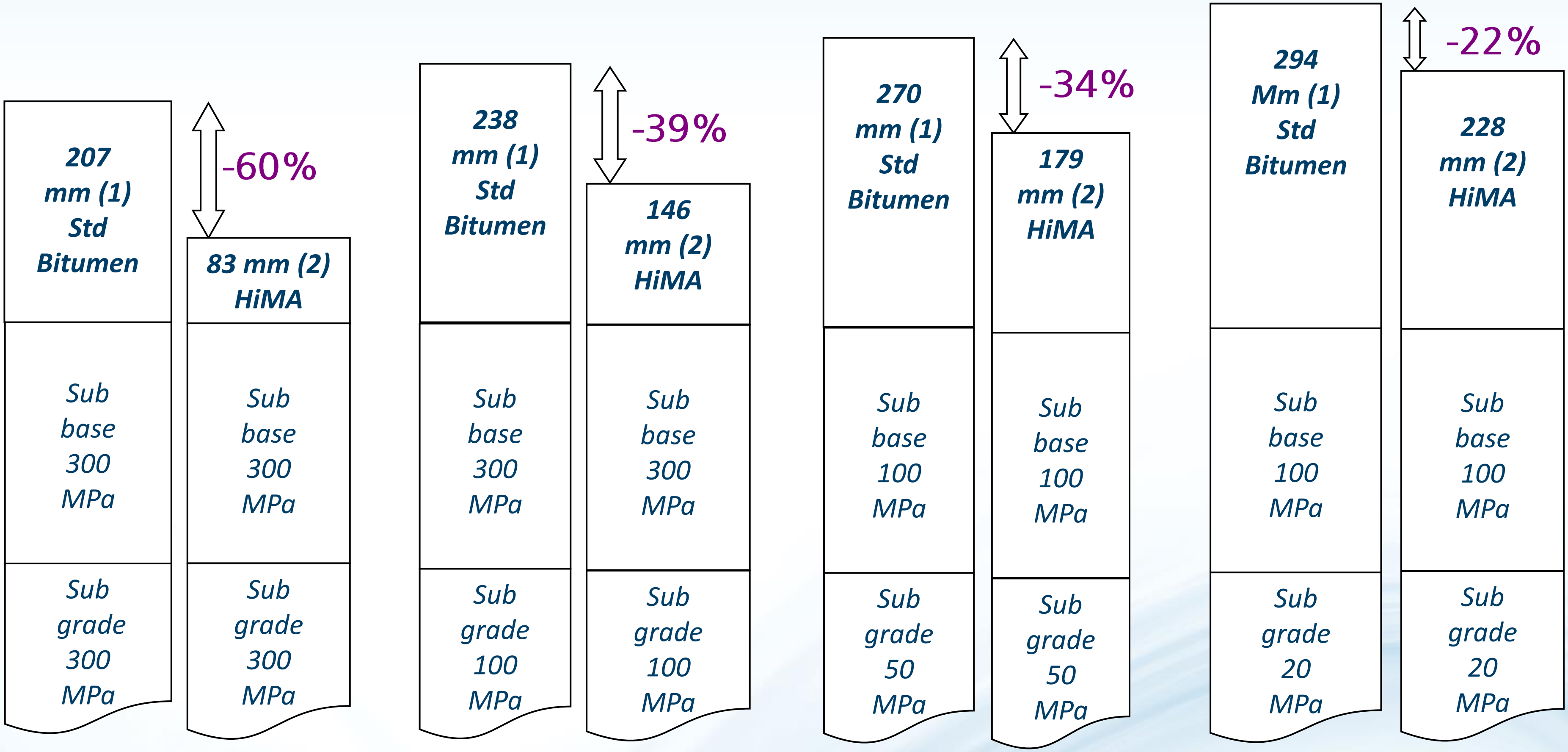

Good quality sub base □ Poor quality sub base

(1) Thickness determined by asphalt strain criterion
(2) Thickness determined by sub grade strain criterion

HiMA = Highly Modified Asphalt

Performance Prediction - Pavement - 2

- **Modeling Using MEPDG and Revised Estimated Endurance Limits**

- Estimate endurance limit from AMPT mastercurve and IDT strength testing.
- Adjust MEPDG calibration factors accordingly.
- Full depth construction project in Parana, Brazil to be paved in December.

- ARA – Harold von Quintus
- DLSI – Raj Dongré
- UF – Rey Roque

Performance Prediction - Pavement - 3

- **Modeling Using MEPDG**
- **Revised Estimated Endurance Limits using beam fatigue and/or S-VECD model**

- Estimate endurance limit from AMPT mastercurve and push-pull fatigue testing or from 4-point bending beam fatigue data.
- Adjust MEPDG calibration factors accordingly.
- Rehabilitation project SP 300 near São Paulo, Brazil. Due to strong substructure, bound layer thickness reduced by 50%.

- TFHRC – Nelson Gibson, Xin Jun Li
- NCSU - Richard Kim, Shane Underwood
- NCAT - Nam Tran, Randy West, Buzz Powell
- DLSI – Raj Dongré

Comparative MEPDG Models Using S-VECD Coefficients

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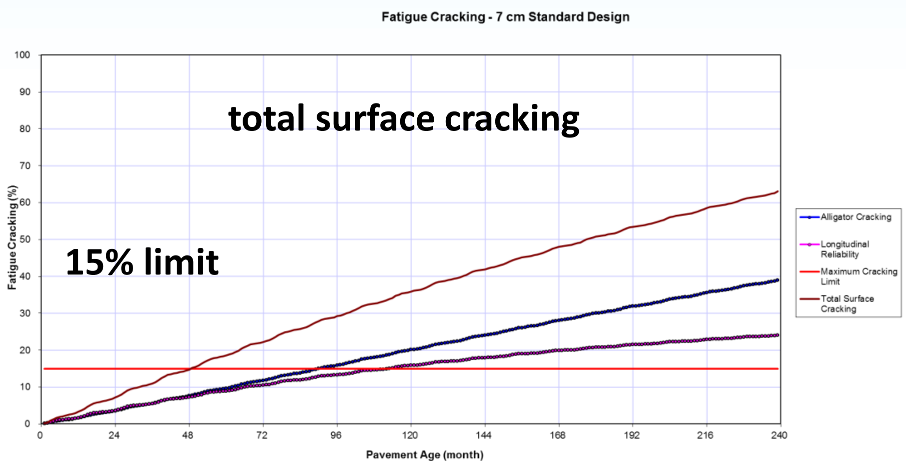
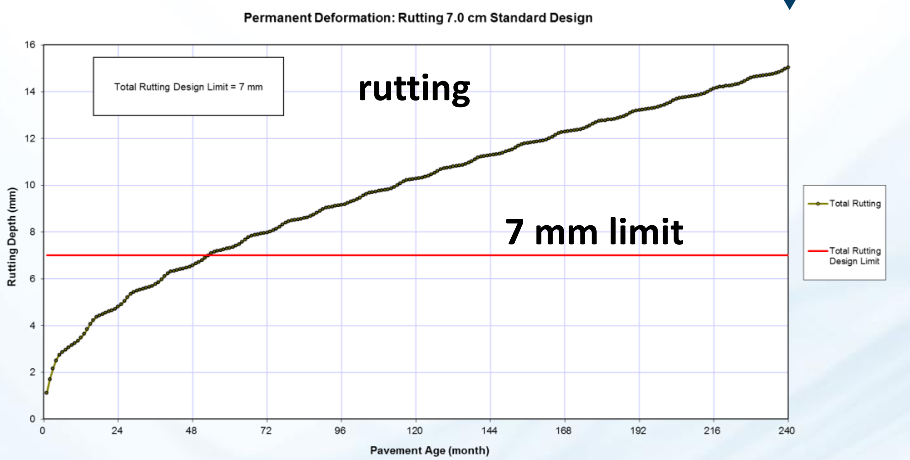
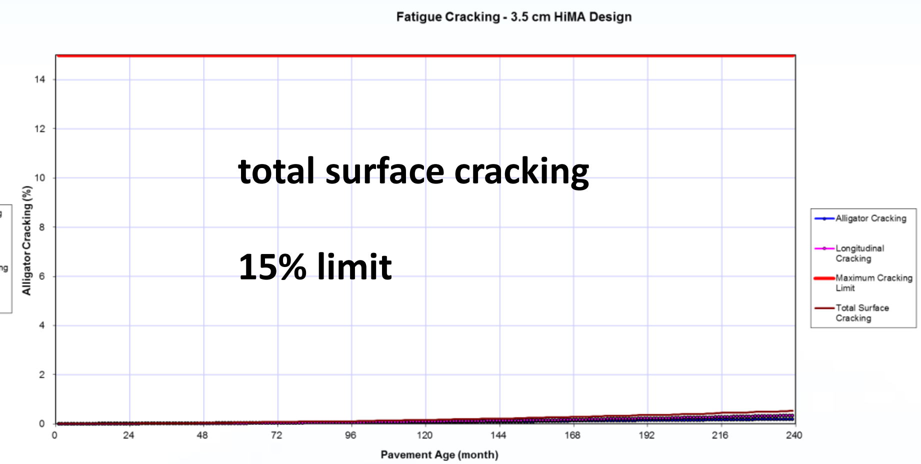
7.0 cm mill & unmodified overlay



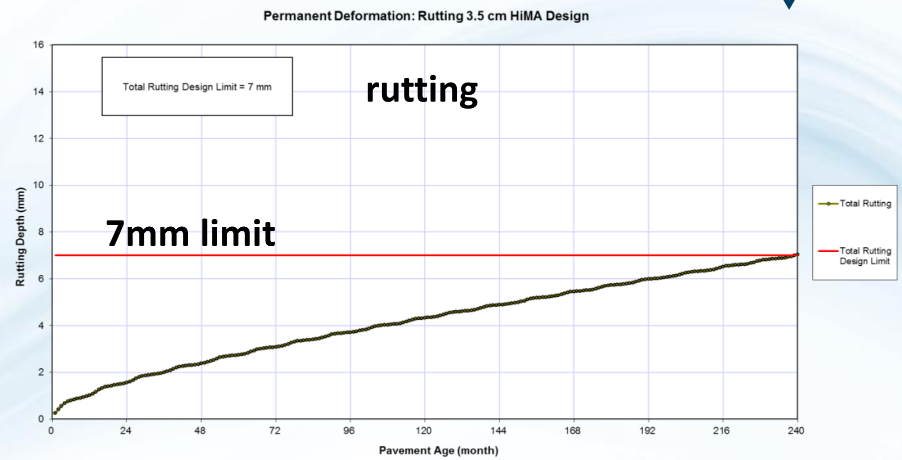
20 years



3.5 cm mill & HiMA overlay



20 years



Binder Performance/Specifications

- Low Temperature – current BBR is generally good. T_c and or ABCD may offer improvement.
- High Temperature – MSCR J_{nr} is suitable.
- Fatigue??
  - UWM Linear Amplitude Sweep test?
  - Queen's U/MTO Double Edge Notched Tensile test?
  - Other?
- A key issue is the appropriate test temperature – How to determine? Equi-modulus temperature?

Conclusions

- Highly modified binders can give dramatic improvement in pavement resistance to rutting and fatigue damage.
- Thickness reduction can more than offset increased material costs.
- In severe distress situations, highly modified binders can possibly double pavement life.
- Current modeling and design software may be used to predict material performance characteristics and rationally design pavements.
- Current field trials in the northeast will help determine if there is benefit for preservation strategies.

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