Performance and Design of Thin, Highly Modified Pavements

Bob Kluttz, Kraton Polymers

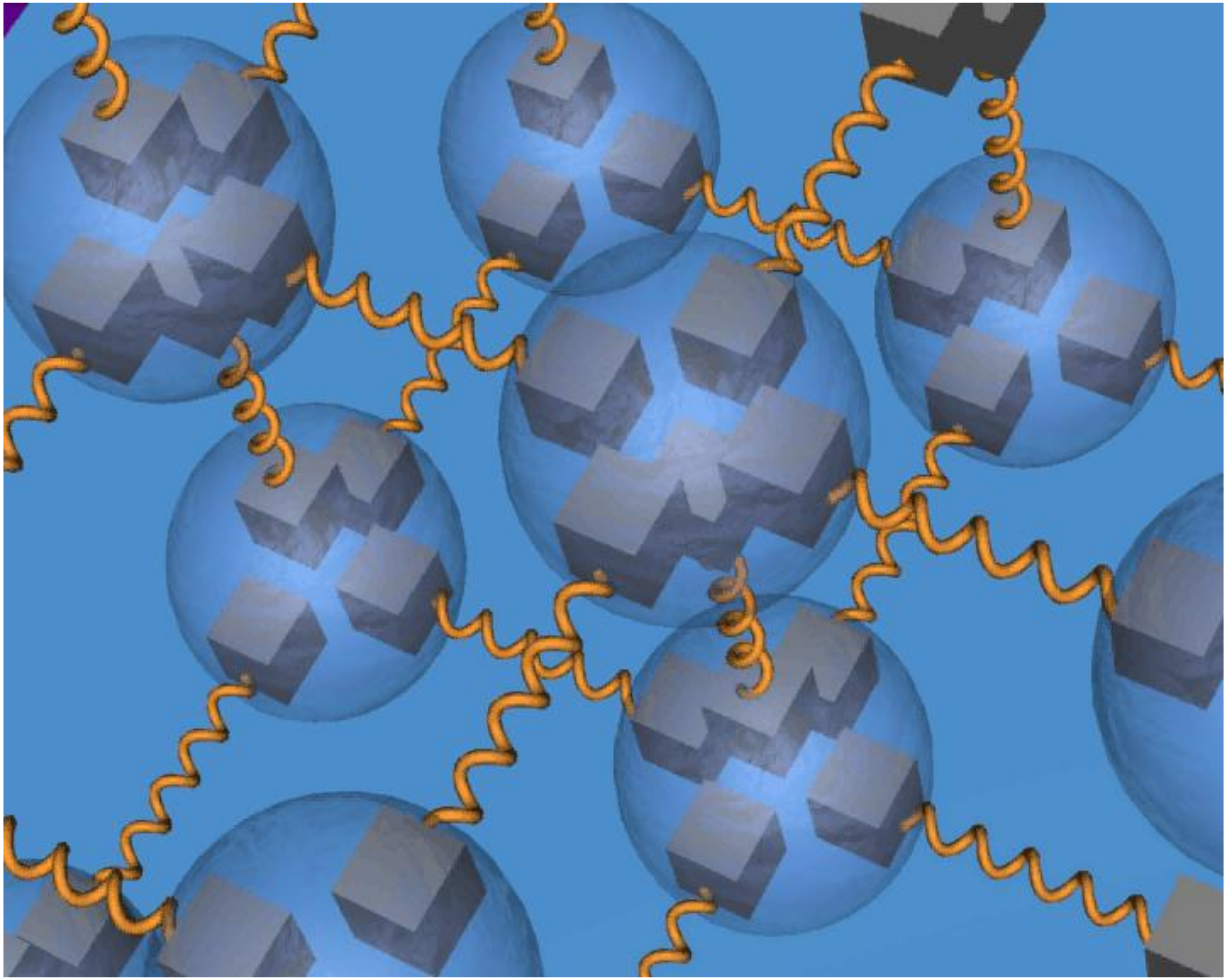
Association of Modified Asphalt Producers – 13th Annual Meeting

Santa Ana Pueblo, NM – February 9, 2012

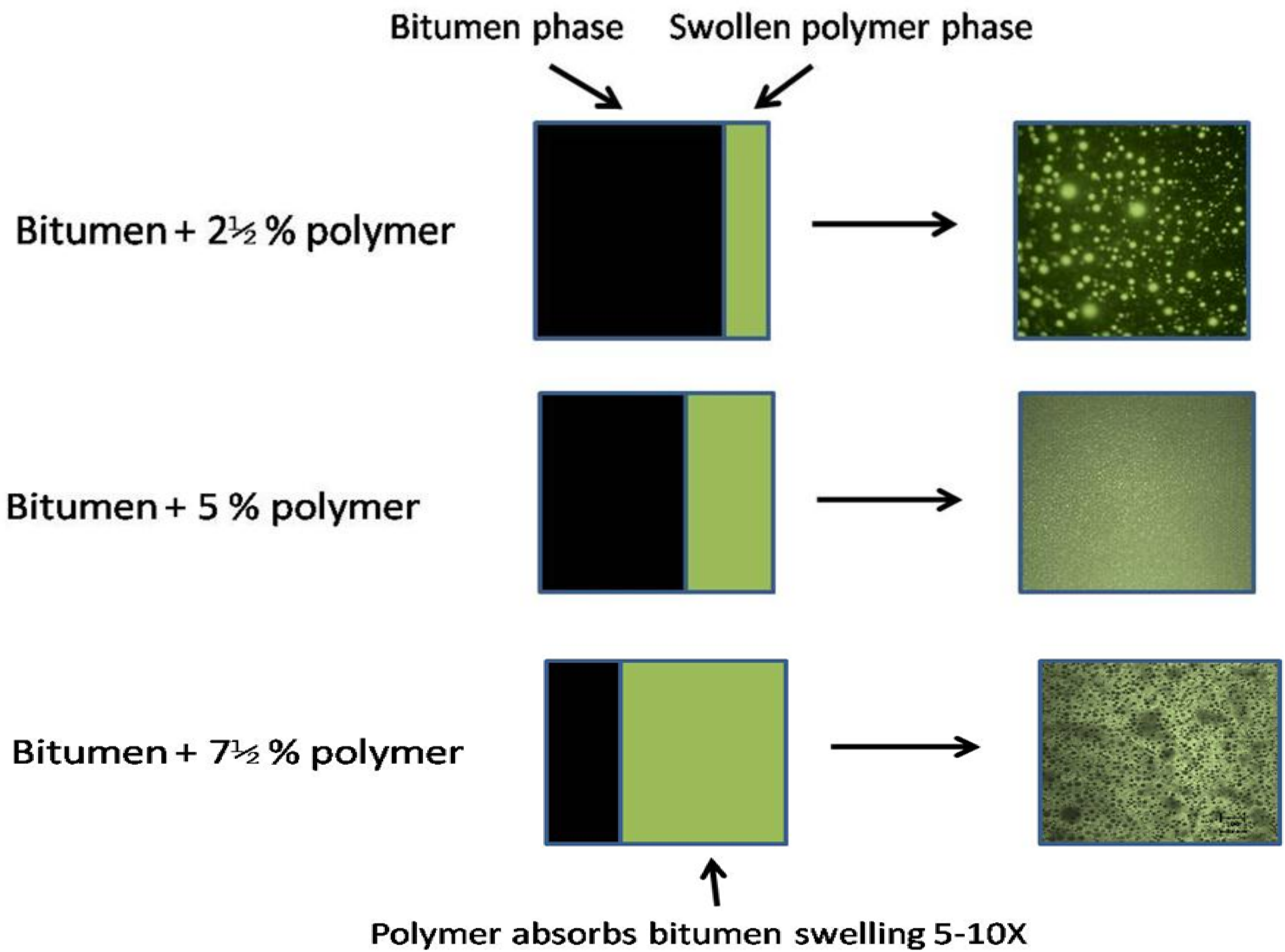
Outline

- 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

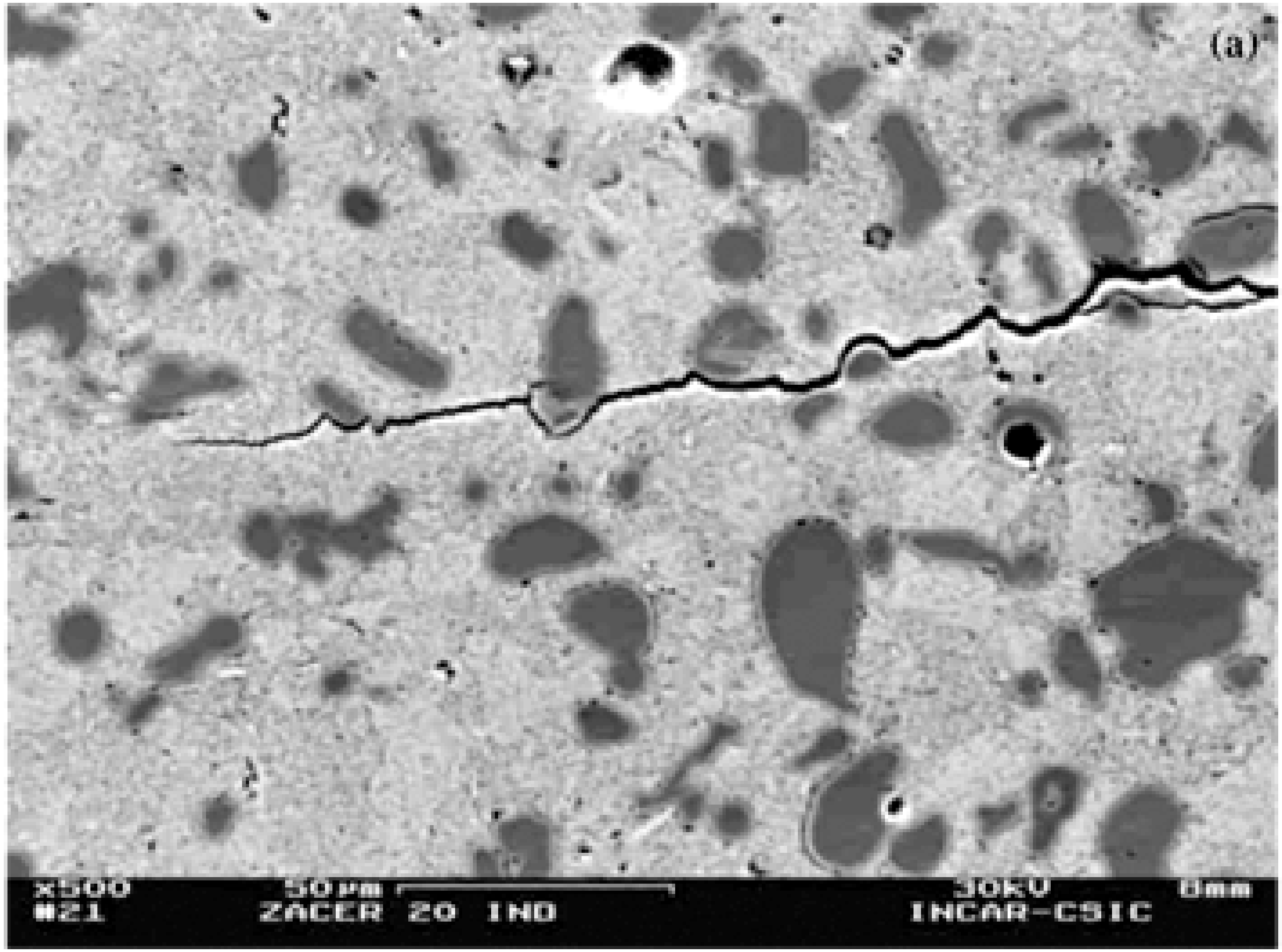
SBS in Bitumen



Phase Morphology



Crack Propagation in Toughened Composite



Source: www.scielo.br/img/fbpe/mr/v4n3/a13fig5a.gif

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.

Material Testing and Advanced Modeling

- Beam Fatigue testing in conjunction with the Road Engineering Section of Delft University of Technology
- Materials property testing with Road Engineering and advanced modeling work with the Mechanics Section at Delft.

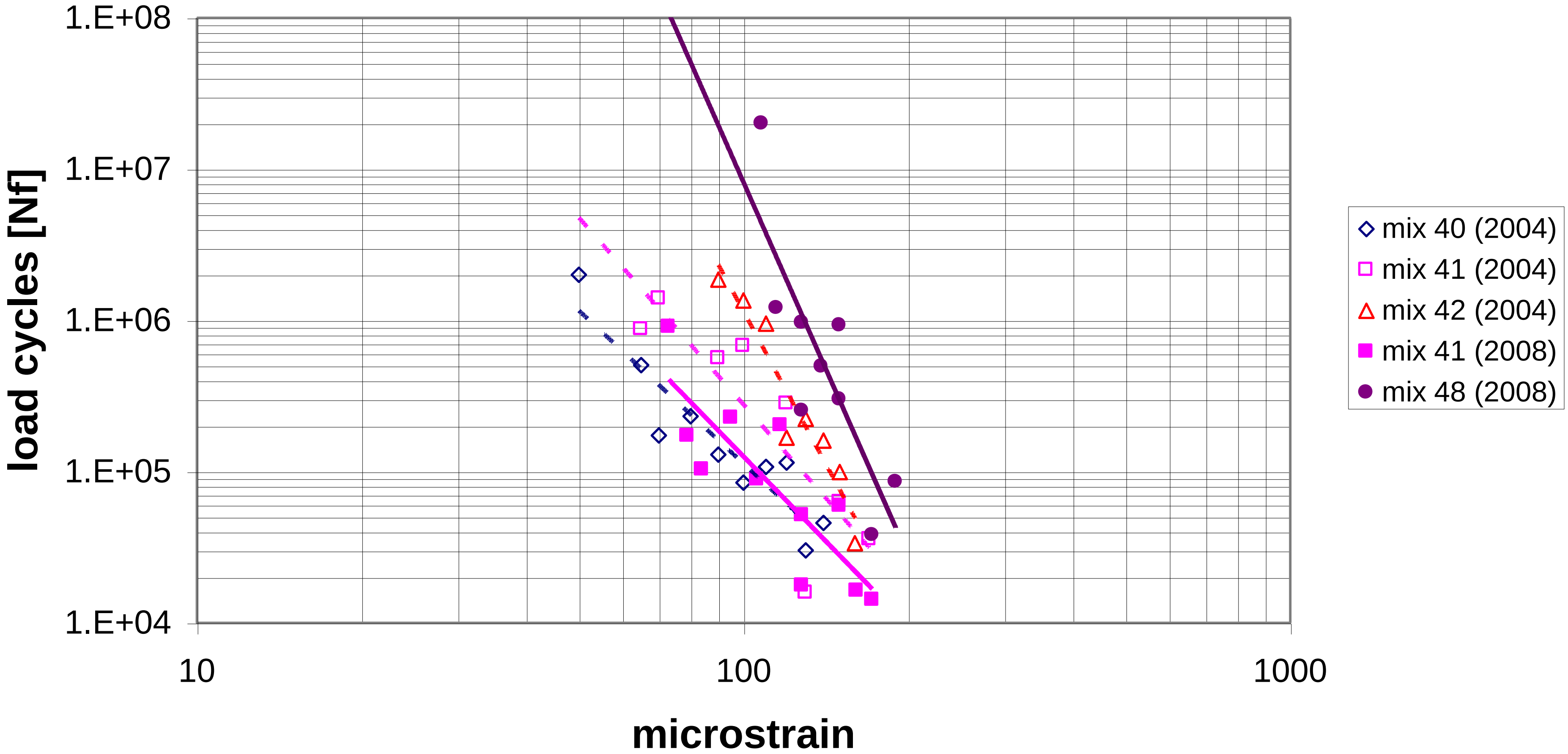
- Goal was to test the viability of high polymer content, high modulus mixtures and to understand how much performance benefit might be achieved.

- Kraton Polymers
  - Willem Vonk, Erik Jan Scholten,Bob Kluttz
- Technical University Delft – Road & Railways
  - Andre Molenaar, Martin van de Ven,Tariq Medani
- Technical University Delft - Mechanics
  - Tom Scarpas, Xueyan Liu

Initial Testing – Four-point Bending Beam

- Same 40 pen base bitumen for all binders
- Design study to determine effect of SBS polymer type and loading

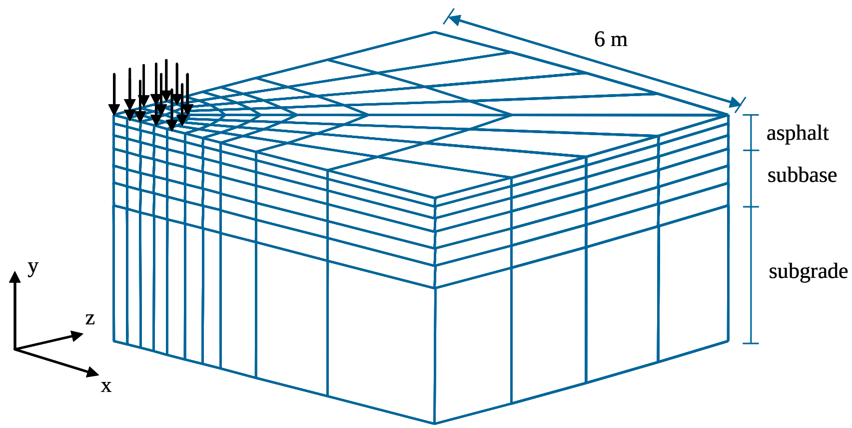
Beam Fatigue Results



Full sinusoidal loading. Cited strains are ½ amplitude

Advanced Modeling Using ACRe Model

- Asphalt Concrete Response (ACRe) model developed at Delft University
- Desai response surface for hardening and softening
- Crack plane response simulation with Hoffman surface
- CAPA 3D Finite Element Code developed at Delft University



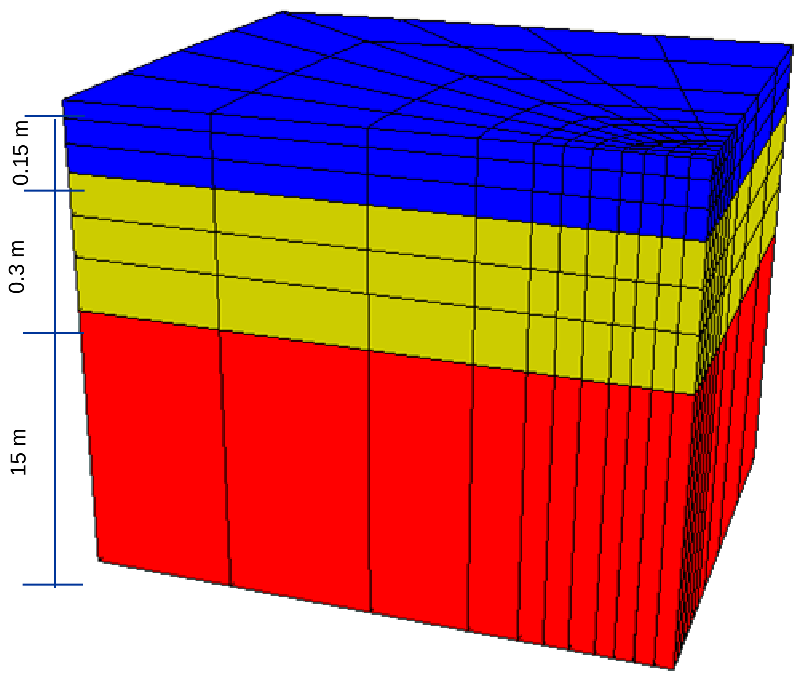
Scarpas, A, Gurp, C.A.M.P. van, Al-Khoury, R.I.N. and Erkens, S.M.J.G., Finite Element Simulation of Damage Development in Asphalt Concrete Pavements. 8th International Conference on Asphalt Concrete Pavements, Seattle, Washington, U.S.A., 1997.

Pavement Structure and Loading

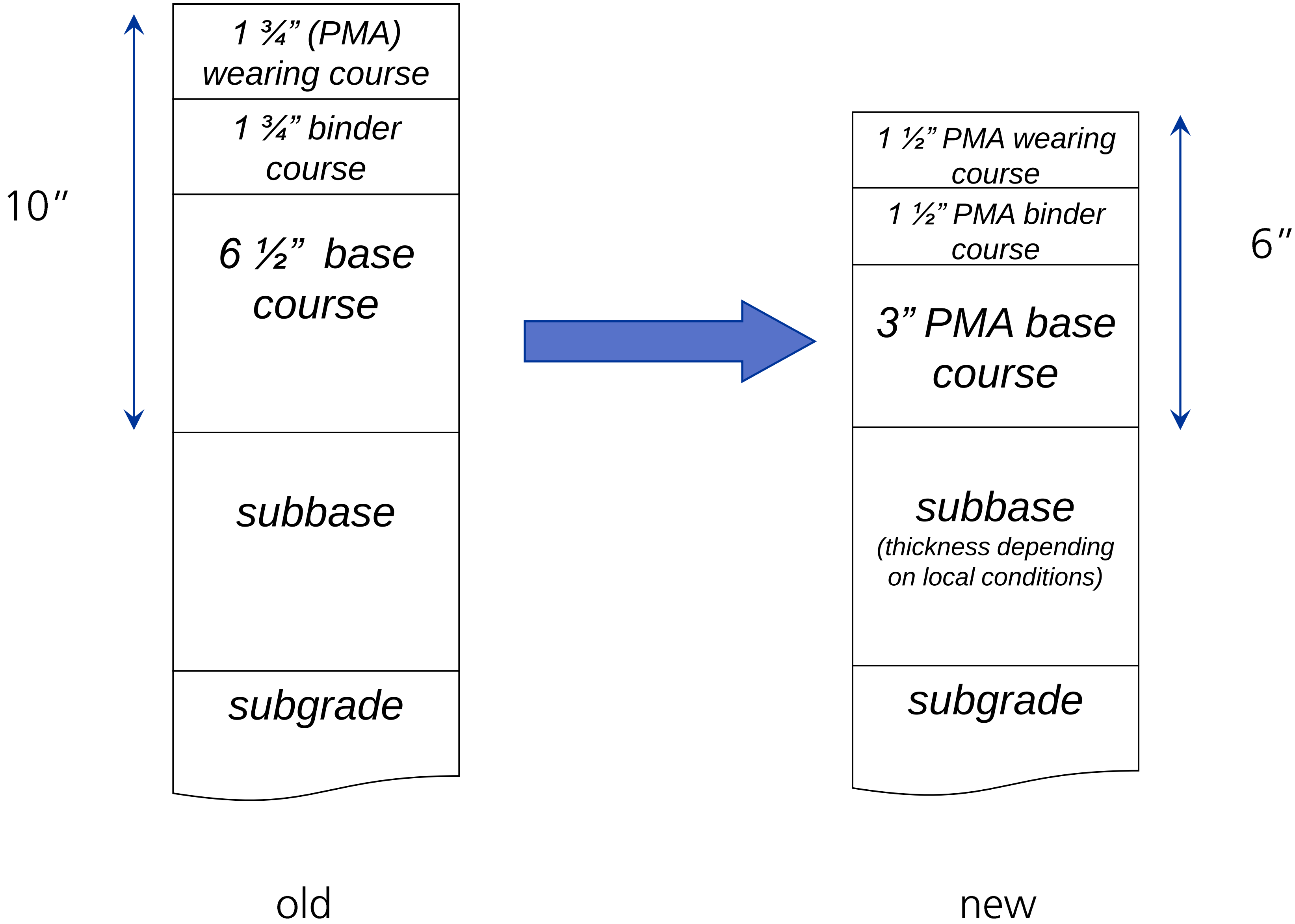
Three layers structure:
- Bound layer - E1 = 1000 MPa (145,000); h = **6″** or **10″**
- Unbound subbase - E2 = 300 MPa (43,500 psi); h = 12″
- Subgrade - E3 = 100 MPa (14,500 psi); h = 50′

Constant temperature: T = 20°C

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



Proposed System



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

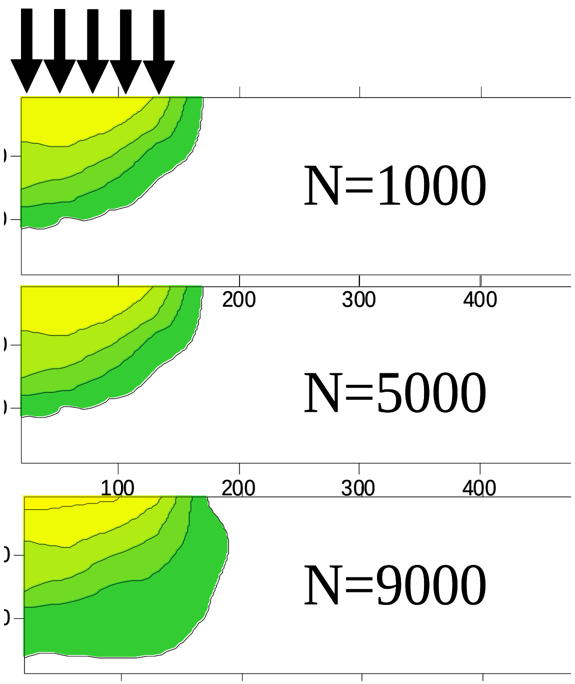
base data:
SMA unmodified wearing mix: $70/ton
unmodified base mix: $65/ton

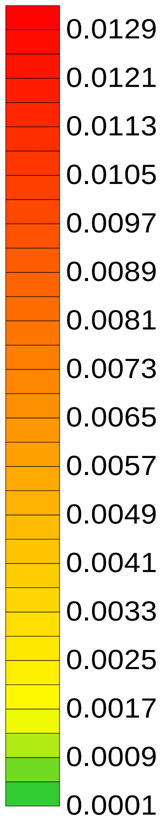
assumptions:
PMA wearing mix + 20%
PMA base mix + 40%

Modeling Results

Highly Modified (6")

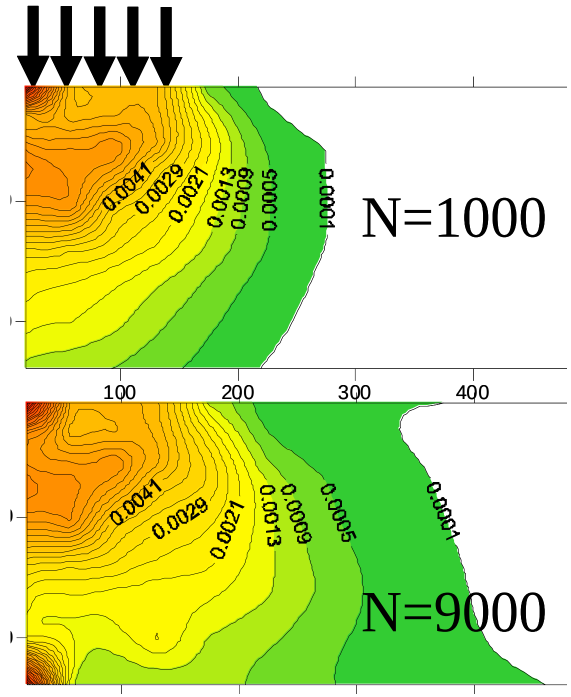
total damage





Unmodified (10")

total damage



Comparative Damage

Distress	10" unmodified	6" highly modified
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

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
- **Upcoming** – OK, OR, AL, Brazil

Cross Sections Evaluated

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Control (178mm 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 (145mm 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

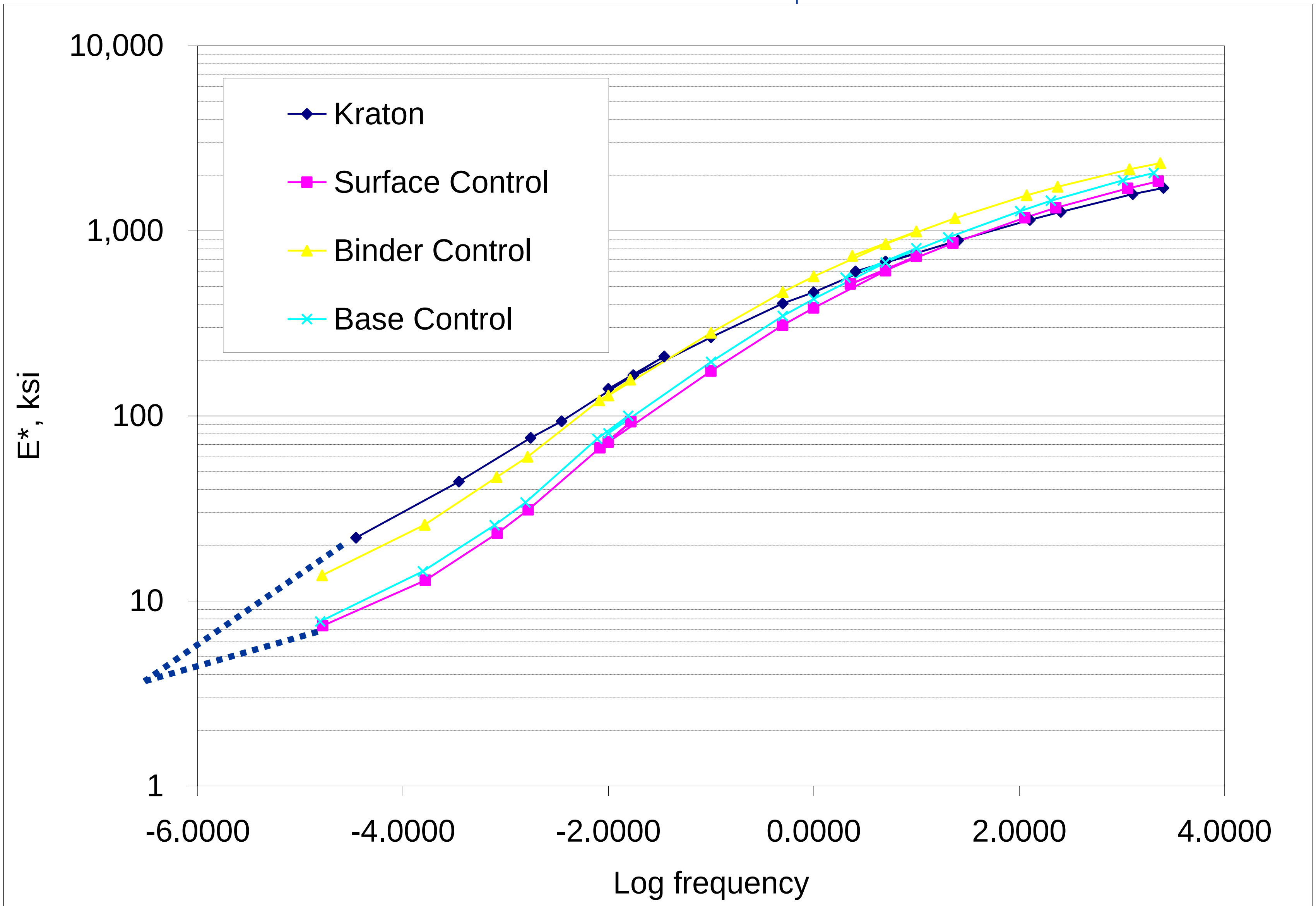
Courtesy Prof. David Timm, Auburn U.

NCAT Construction Overview

- Binder, PG 67-22 + 7½% SBS polymer, shipped 6+ hours. No issues with handling.
- Mixing temperature 340^{o}F (same used for PG 76-22 surface mixes), delivered to track 335^{o}F, temperature behind screed 300^{o}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.

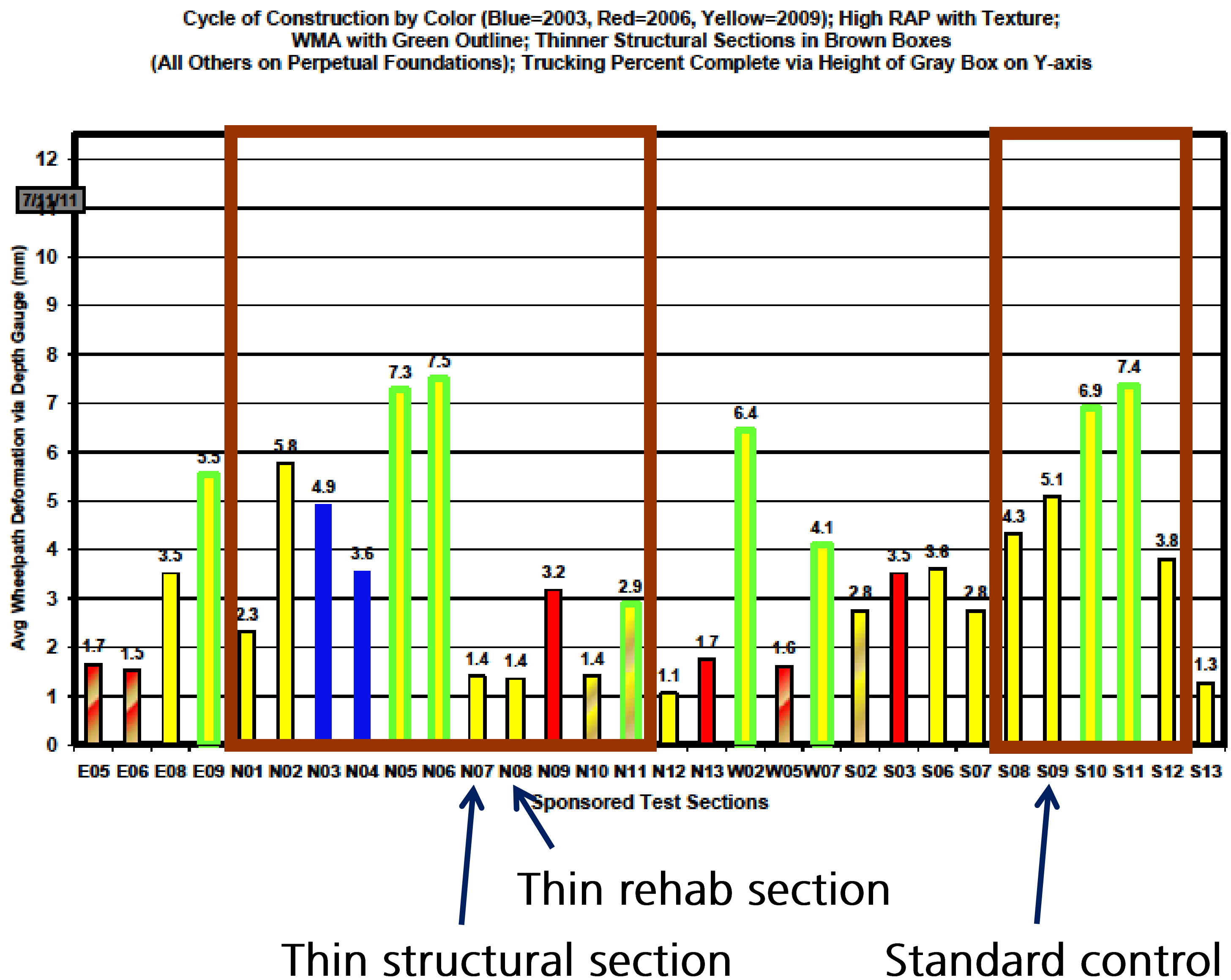
- NCAT & Auburn University – Dr. Buzz Powell, Dr. Nam Tran, Prof. Richard Willis, Prof. David Timm, Mary Robbins

Master Curve Comparison



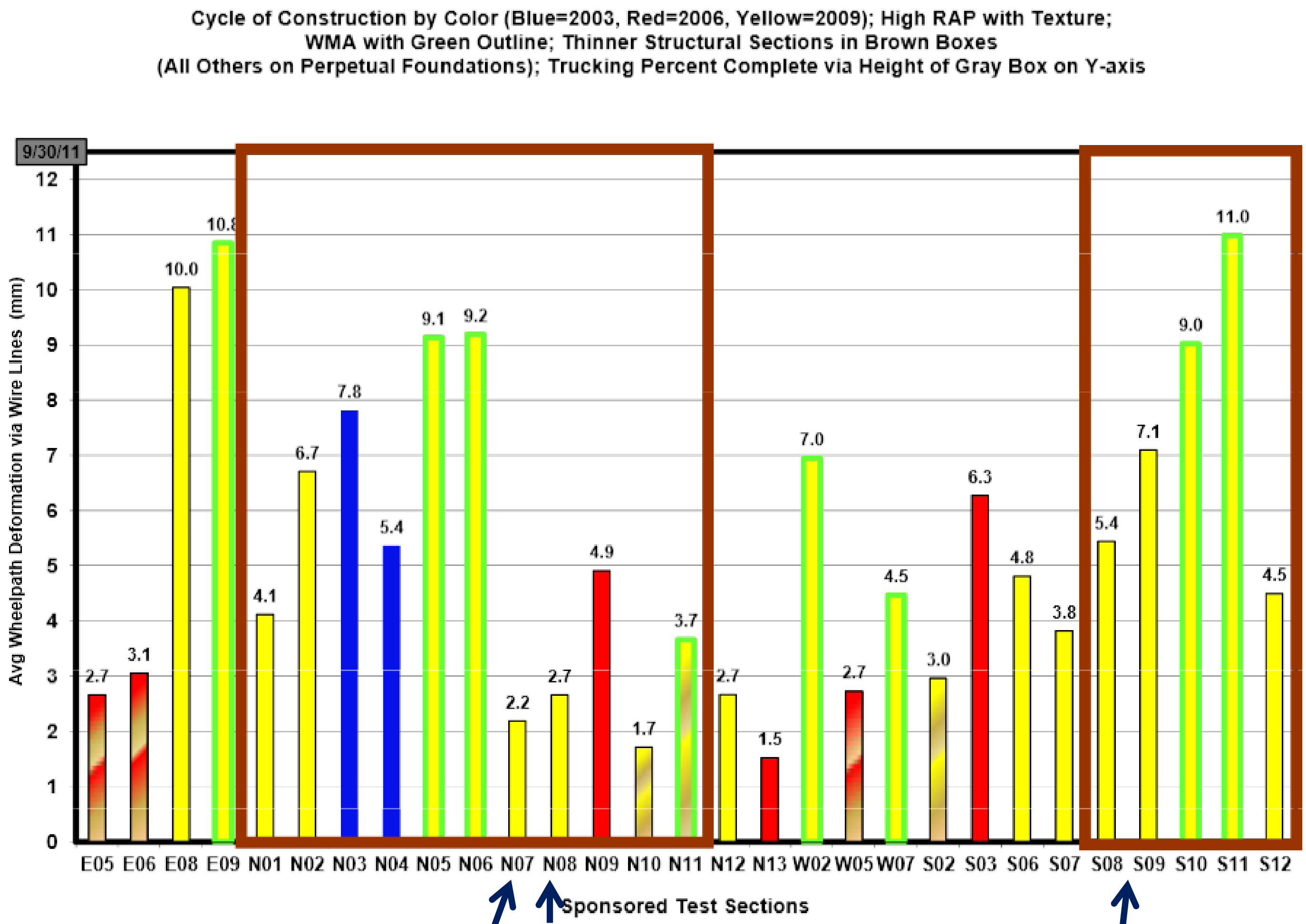
Courtesy Prof. David Timm, Auburn U.

NCAT Rutting & Cracking as of 7/11/11



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

NCAT Rutting & Cracking as of 9/30/11



Thin rehab section

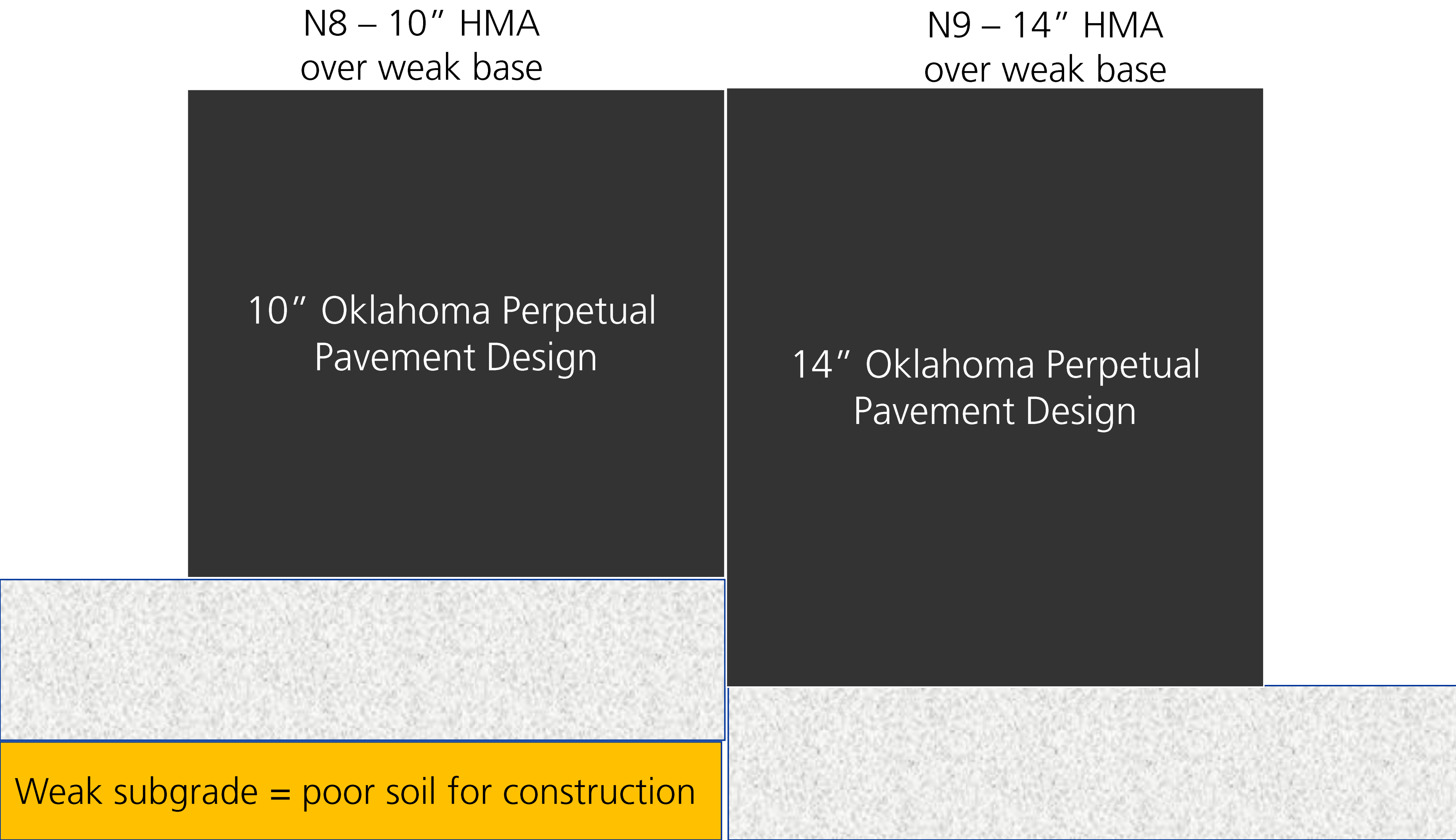
Thin structural section

Standard control

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

2006 NCAT Construction Cycle

Oklahoma Perpetual
Pavement Experiment



2009 NCAT Construction Cycle – August 2009

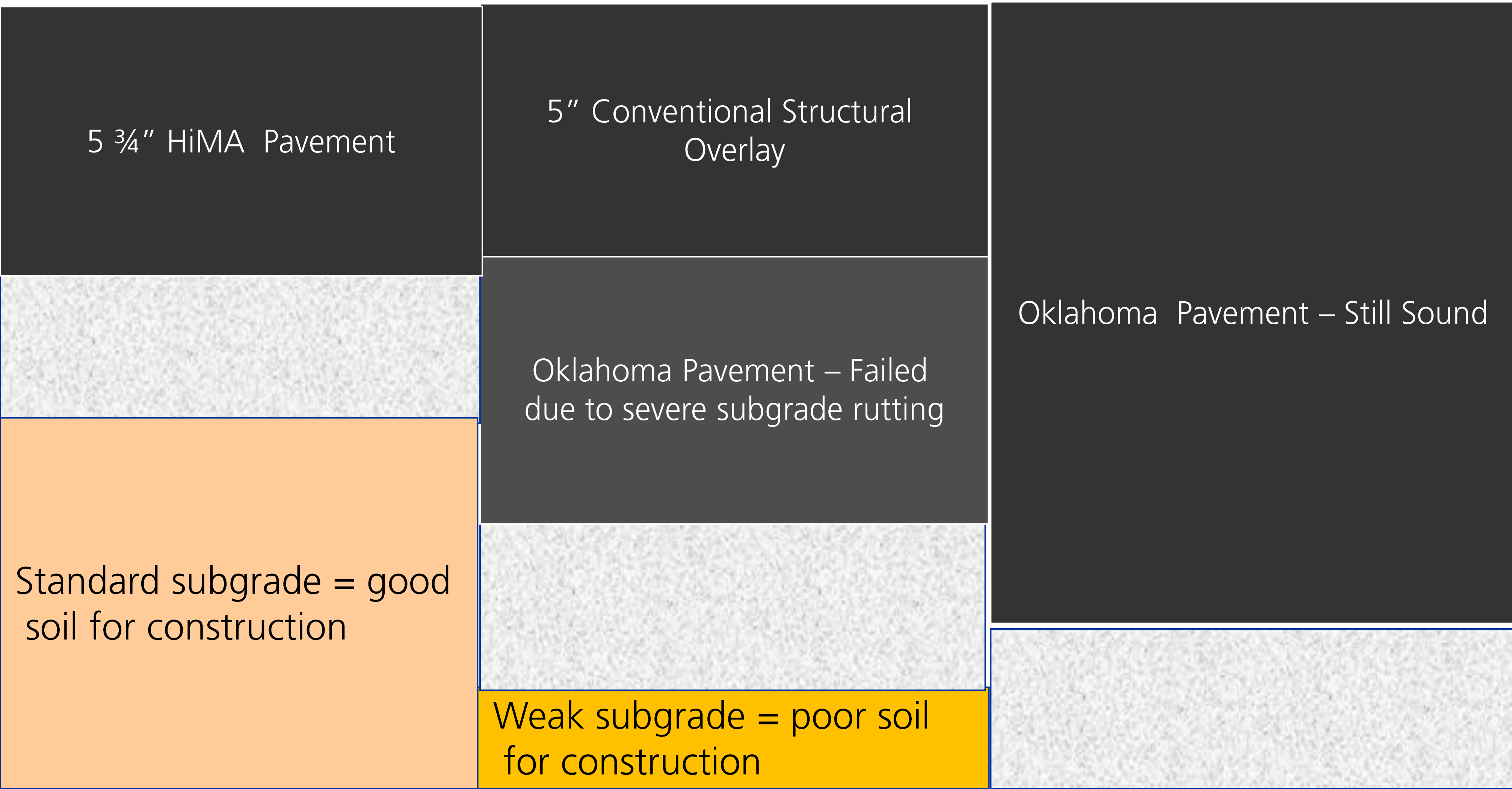
Kraton Polymers HiMA Experiment

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

2009 NCAT Construction Cycle – August 2010

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Oklahoma proposed design modification

N7 - 5 ¾" HIMA over sound base	N8 – 10" HMA over weak base	N9 – 14" HMA over weak base
1 ¼" (7½% polymer; 9.5 mm NMAS)	1 ¼" (7½% polymer; 9.5 mm NMAS)	Oklahoma Pavement – Still Sound
2 ¼" (7½% polymer;19mm NMAS; 80 Gyrations)	2 ¼" (7½% polymer;19mm NMAS; 80 Gyrations)	
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	
Standard subgrade = good soil for construction	Weak subgrade = poor soil for construction	

Section N8 – June 20, 2011 – 4.2 MM ESALs

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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

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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.

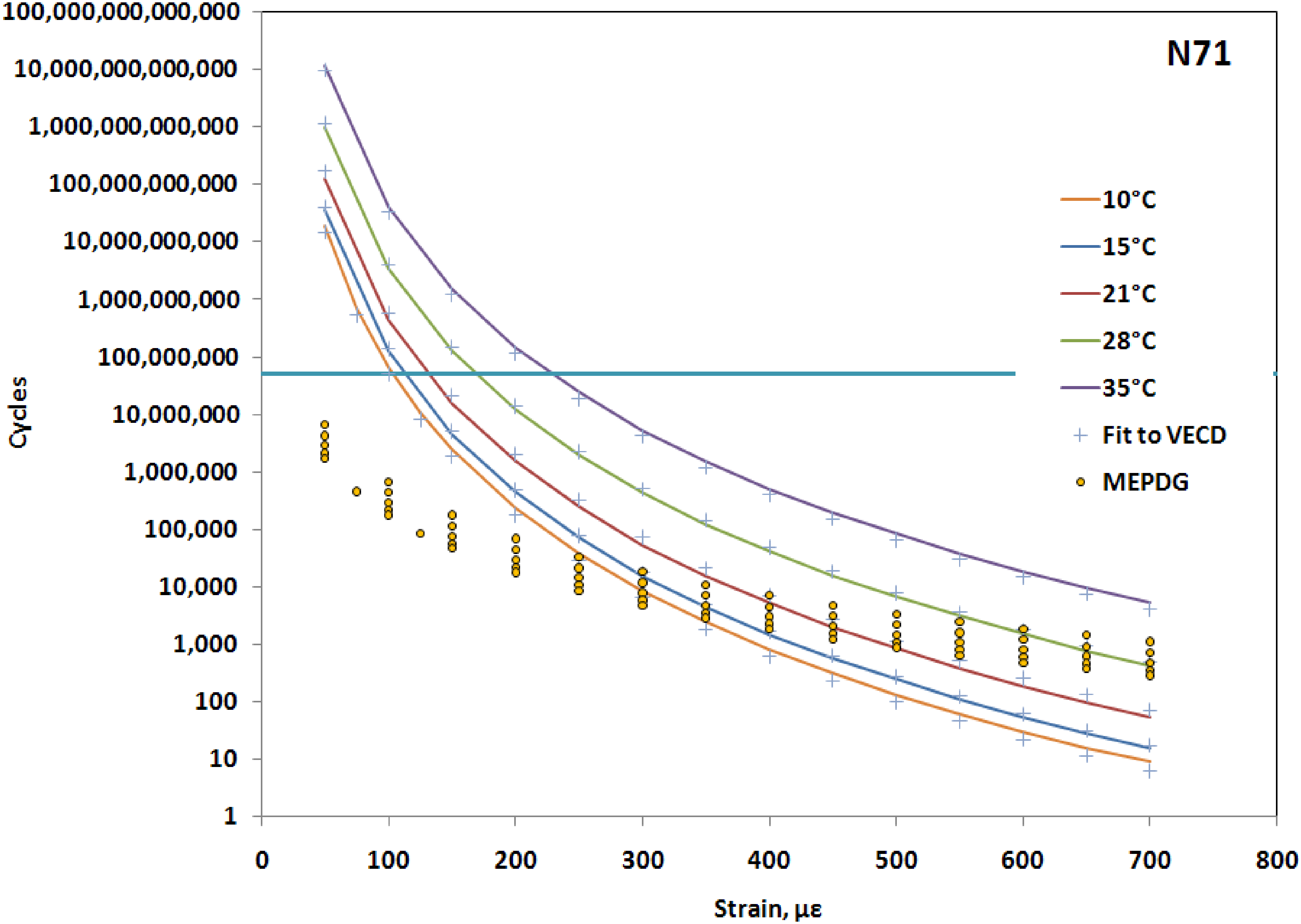
Performance Prediction – Mixture – 1

- **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.

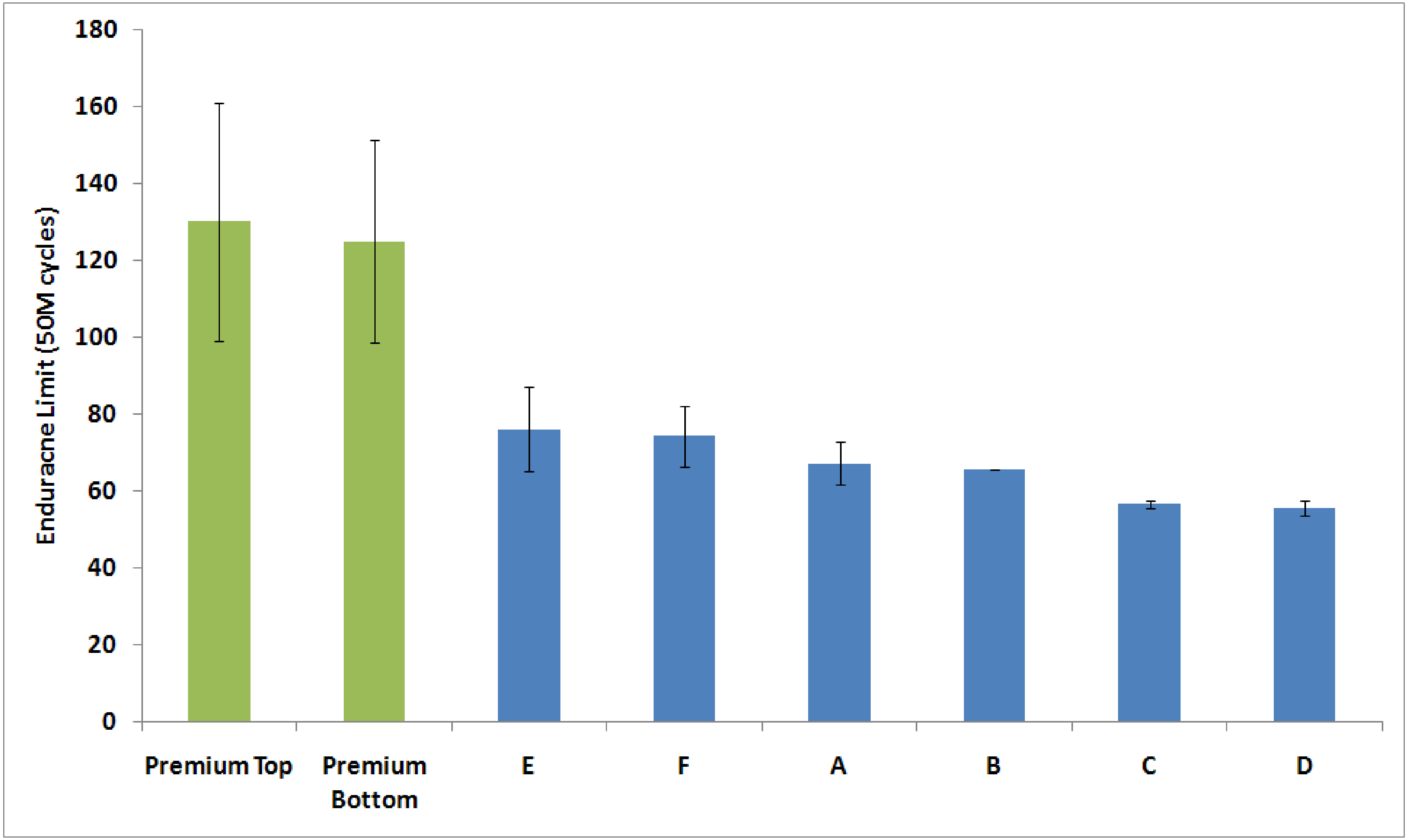
- TFHRC – Nelson Gibson, Xin Jun Li
- NCSU - Richard Kim, Shane Underwood
- NCAT - Nam Tran, Randy West, Buzz Powell
- DLSI – Raj Dongré
- AAT - Don Christensen and Ray Bonaquist

Results – Premium Polymer Modification

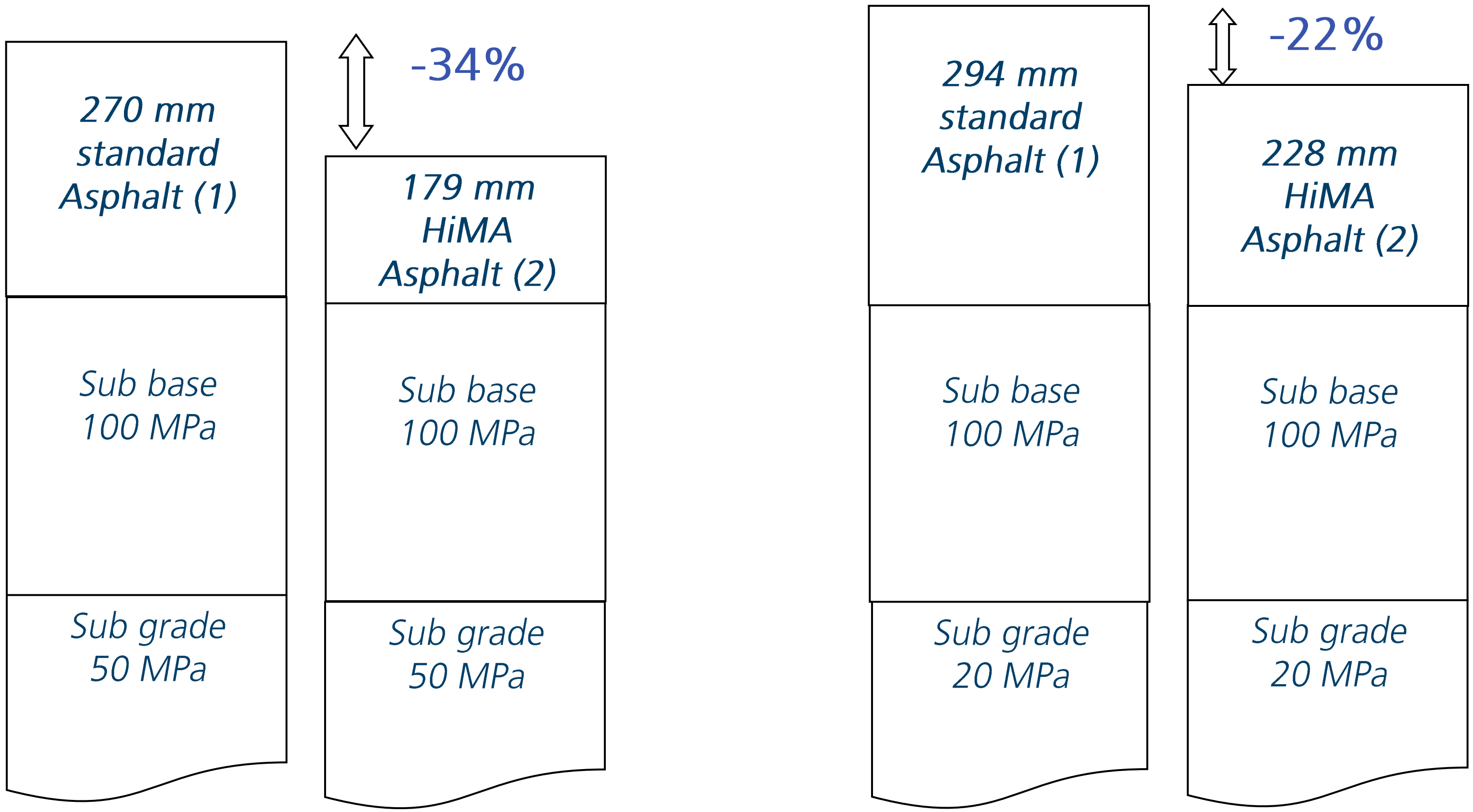


Results – Premium Polymer Modification

Endurance Limit (50M cycles) from range of temperatures



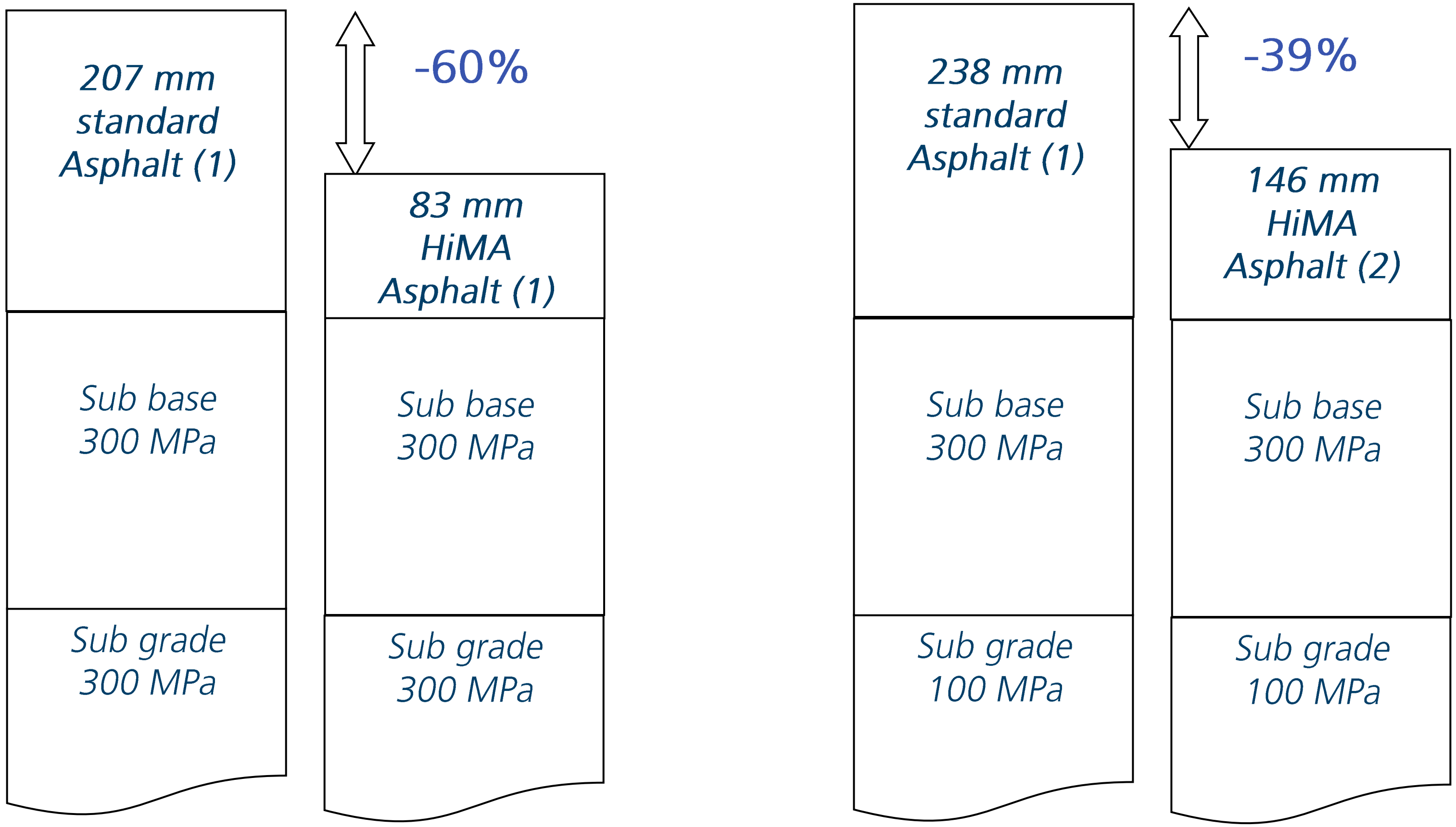
Thickness reduction capability with weak sub grades



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

HiMA = Highly Modified Asphalt

Thickness reduction capability with good 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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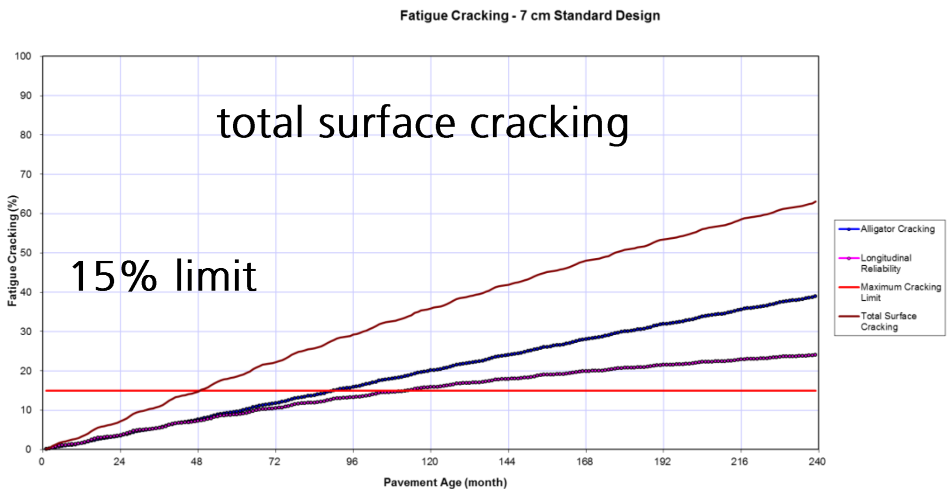
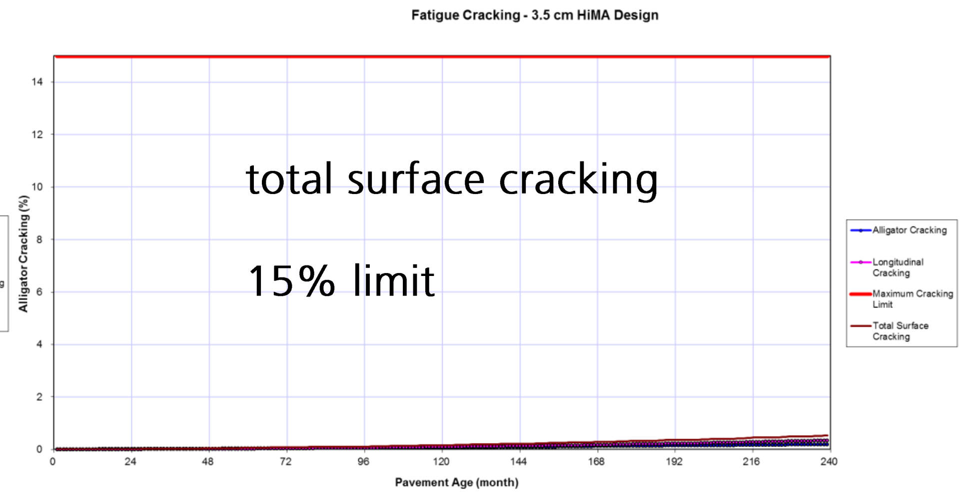
7.0 cm mill & unmodified overlay

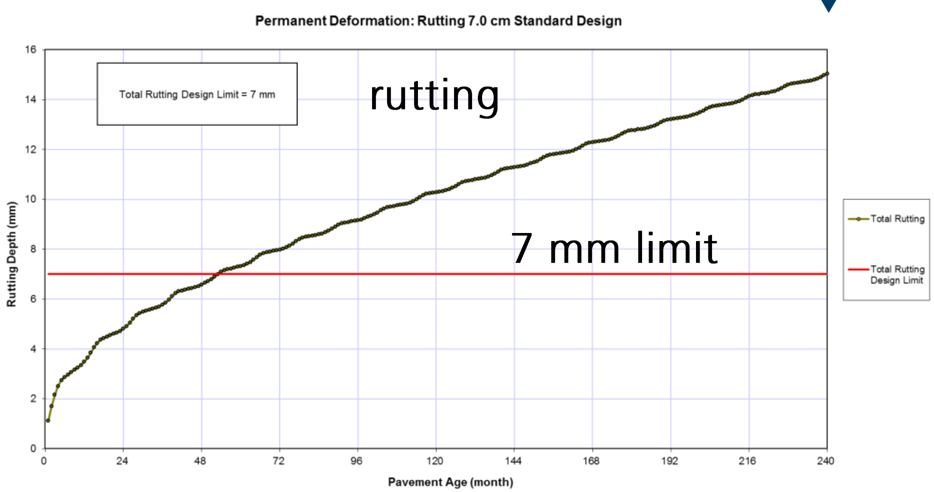
3.5 cm mill & HiMA overlay

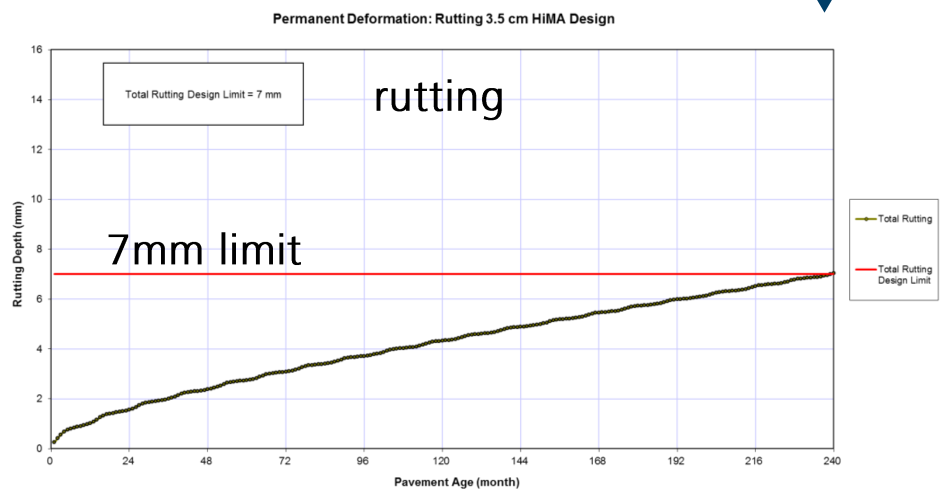




20 years

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.

Disclaimer

HiMA Projects in Europe

Turkey

- Massive plans to upgrade and widen existing roads
- Interest for HiMA originates in layer thickness (cost) reduction
- Preparation for trial project in 2011 ongoing
- Cooperation with KGM (national road authority), Isfalt (Istanbul road authority) and Delft University of Technology

Slovenia

- Highway network heavily loaded with transit traffic
- Better performing wearing course in combination with layer thickness reduction
- Cooperation with local partner

Projects in preparation in Poland, Germany and France

HiMA Project New Zealand

Port of Napier container terminal (east coast New Zealand)

- Base course mix with HiMA binder paved in 2010 at loading area of container wharf
- Existing pavement had severe rutting due to doubled container traffic in past 10 years
- Front axle load of forklifts is 110 metric tonnes!
- Paving went smoothly; high polymer loading did not have a negative effect on paving and compaction effort
- After successful application in September 2010 on one side of the wharf, another, bigger, section was paved in November 2010
- Project executed by integrated local contractor

Brazil: Scenario of Road Transport

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- The transport system is highly dependent on road transportation (60%)
- The Brazilian fleet of vehicles grew by 36.8% from 2004 to 2008, representing an average annual growth rate of 8.1%.
- The Brazil has a large potential market for automobiles, since Brazil has 150 cars per thousand inhabitants, while the average rate in countries of Europe is 600 (cars) per thousand inhabitants.
- The Brazil beat Germany this year and occupies fourth place among the largest vehicle markets in the world. In 2010 the trend is that the market will grow at a rate of 8.2%, with a record 3.4 million vehicles sold.
- Need for investments in roads due to demand of vehicles: US$ 100 billion
- According to the 2009 Survey Road, the cost of freight transport by road, in Brazil is on average 28% more expensive than would be if roads present ideal conditions.
- Brazil has 51 private companies (concessionaires)operating in nine states in the country and operates 14.621 km of highways – 7% of the total paved roads, high value compared to 2% of world average.

Project 1: Compasa – HiMA Full Depth Pavement

Compasa contracted with DOT PR to rebuild a road in Parana State (total length is almost 35km), supplier of asphalt, mass asphalt and construction services.

Current Design

Wearing course:

Thickness: 4cm

Mass type: dense grade, type of asphalt: PMA (PG 72) - CAP 50/70 MODIFIED with 4% SBS

Modulo Resilient: 50000 / 70000 kg/cm ^{2}

Binder course:

Thickness: 5cm, Mass type: dense grade, type of asphalt: CAP 50/70

Modulo Resilient: 30000 / 50000 kg/cm ^{2}

SAMI: Stress Absorption Membrane Intermediate (double chip seal)

Thickness: 2,5cm

Intermediate layer between binder and the base layer, the function of this layer is to block the cracks arising from the base layer, which will be a rigid layer (RAP with cement).

type of asphalt: PMA - CAP 50/70 MODIFIED with 4% or more 1101

Base course:

Thickness: 17cm

Mass type: RAP with 2,5% of cement and , type of asphalt: CAP 50/70

Modulo Resilient: 20000 kg/cm ^{2}

Project 1: Compasa – HiMA Full Depth Pavement

Kraton Proposal:

We are proposing a alternative pavement to simplify the structure, reduce thickness and add performance using a HiMA full depth pavement design where base, binder and wearing course are modified with HiMA technology.

Design Partner: Harold von Quintus

Goal: to do a test section around 1,0 km using Full Depth HiMA Pavement. Will be the first reference in Brazil. Paving scheduled for November 2011.

Project 2: ITA Prof. Regis and CCR Group

- Project: comparing the fatigue performance (as used in the calculation of asphalt pavement) among some types of asphalt mix and different types of bitumens (without polymer, standard modified and HiMA)
- Coordinator: Prof. Regis ITA university
- Goal: Show to Regis and CCR group the better fatigue performance of HiMA asphalt and get dates to use in a road structure calculation.
- Situation: Betunel is preparing the samples to sent all different asphalt types required in order to shape bitumen's specimens in the laboratory of Nova Dutra (Group CCR) will be made where the fatigue tests
- The specimens will be molded by late April.
  Our partners in this test are:
  Group CCR - Labs of Nova Dutra
  Professor Regis - ITA
  Betunel

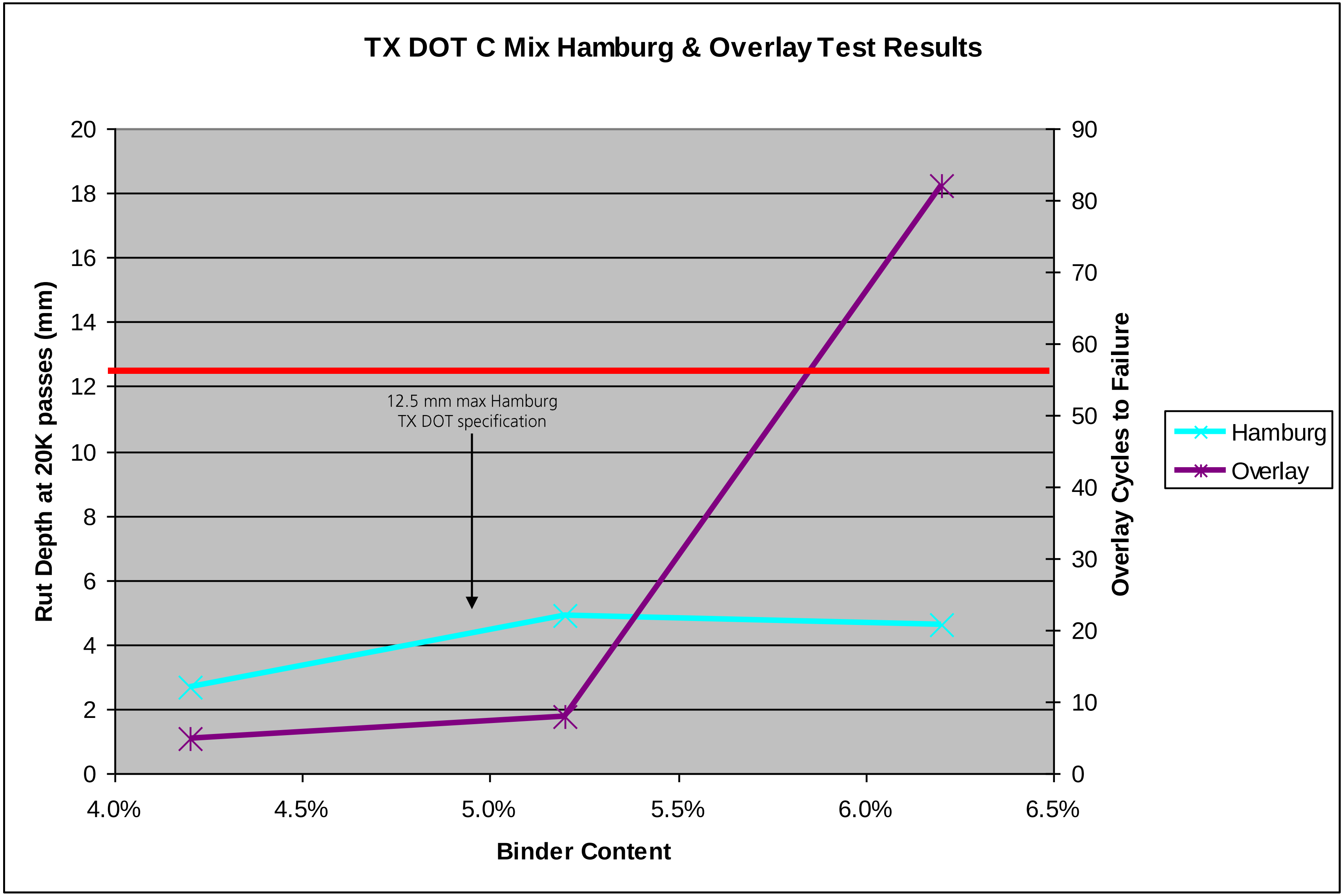
National Center for Pavement Preservation Projects

- Thin lift overlays as preservation strategy.
- Mix design and testing done with Prof. Walaa Mogawer at U Mass Dartmouth.
- Interest from numerous states including MN, TN, VT, NH, RI, PA and NJ.

Testing for Overlay Applications

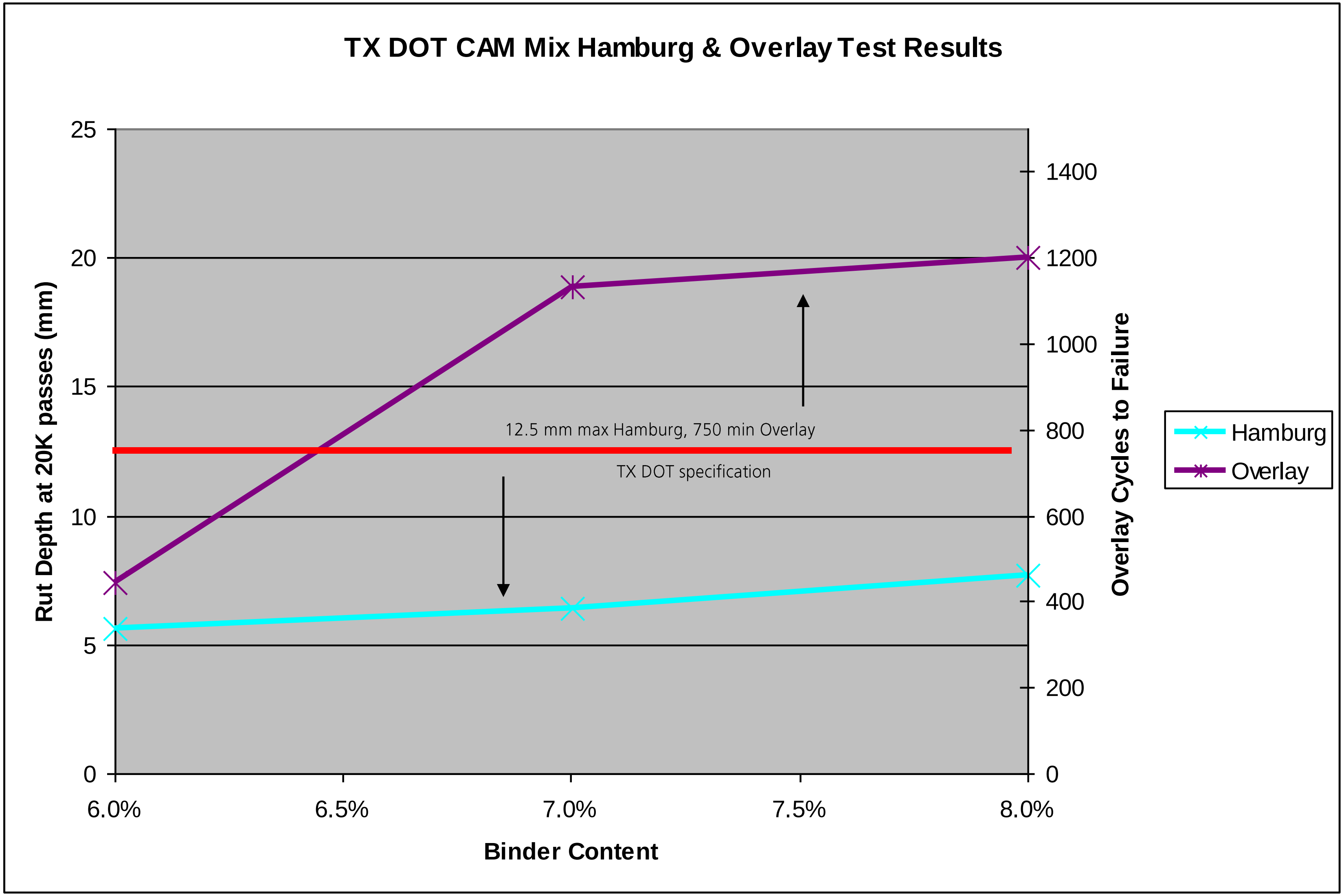
- Evaluations for TX DOT specs on Hamburg wheel track and TX DOT overlay tester.
- Evaluations for NJ DOT specs on APA and high strain beam fatigue.

TX DOT Overlay Specifications



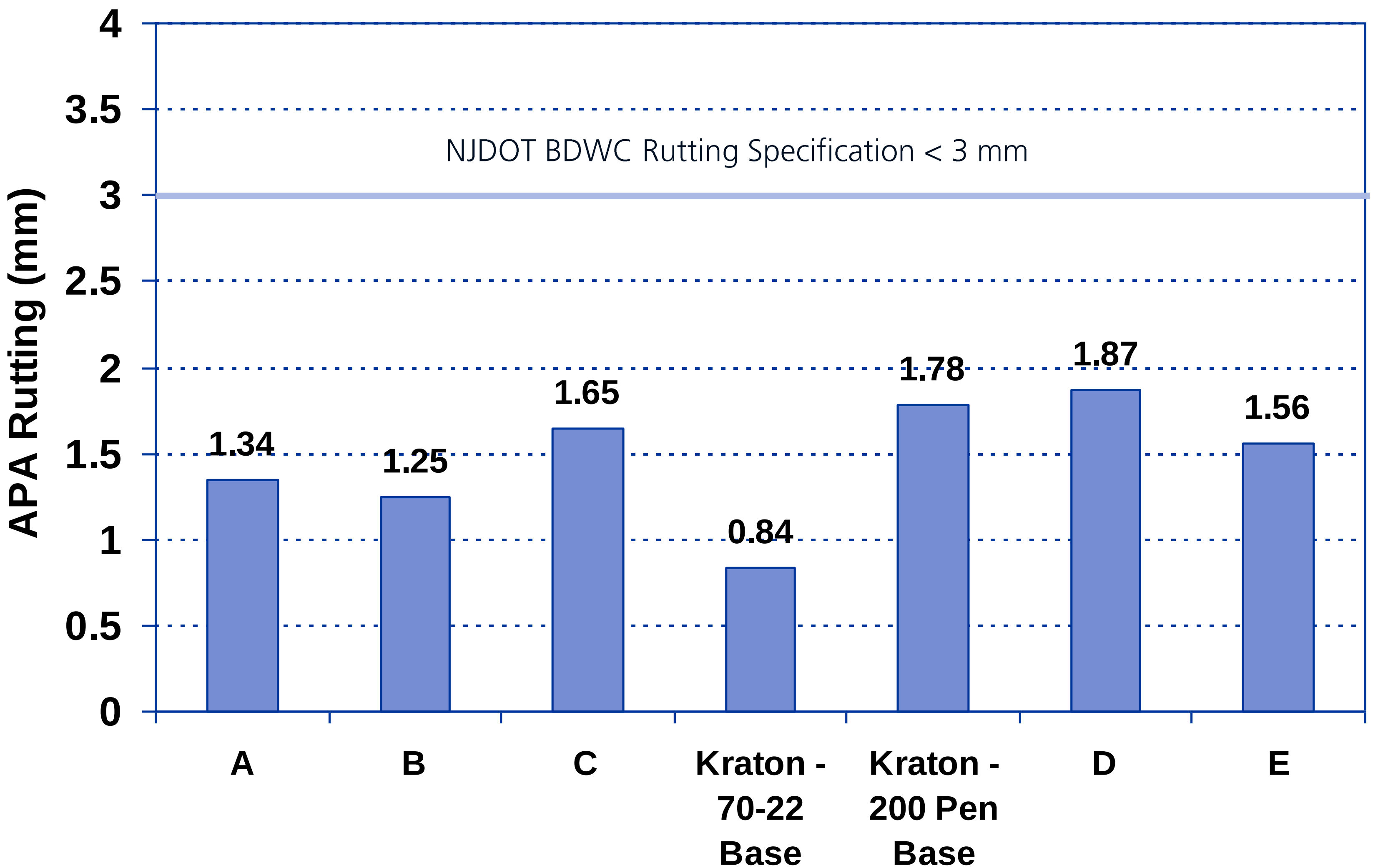
NCAT binder, based on PG 67-22

TX DOT Overlay Specifications



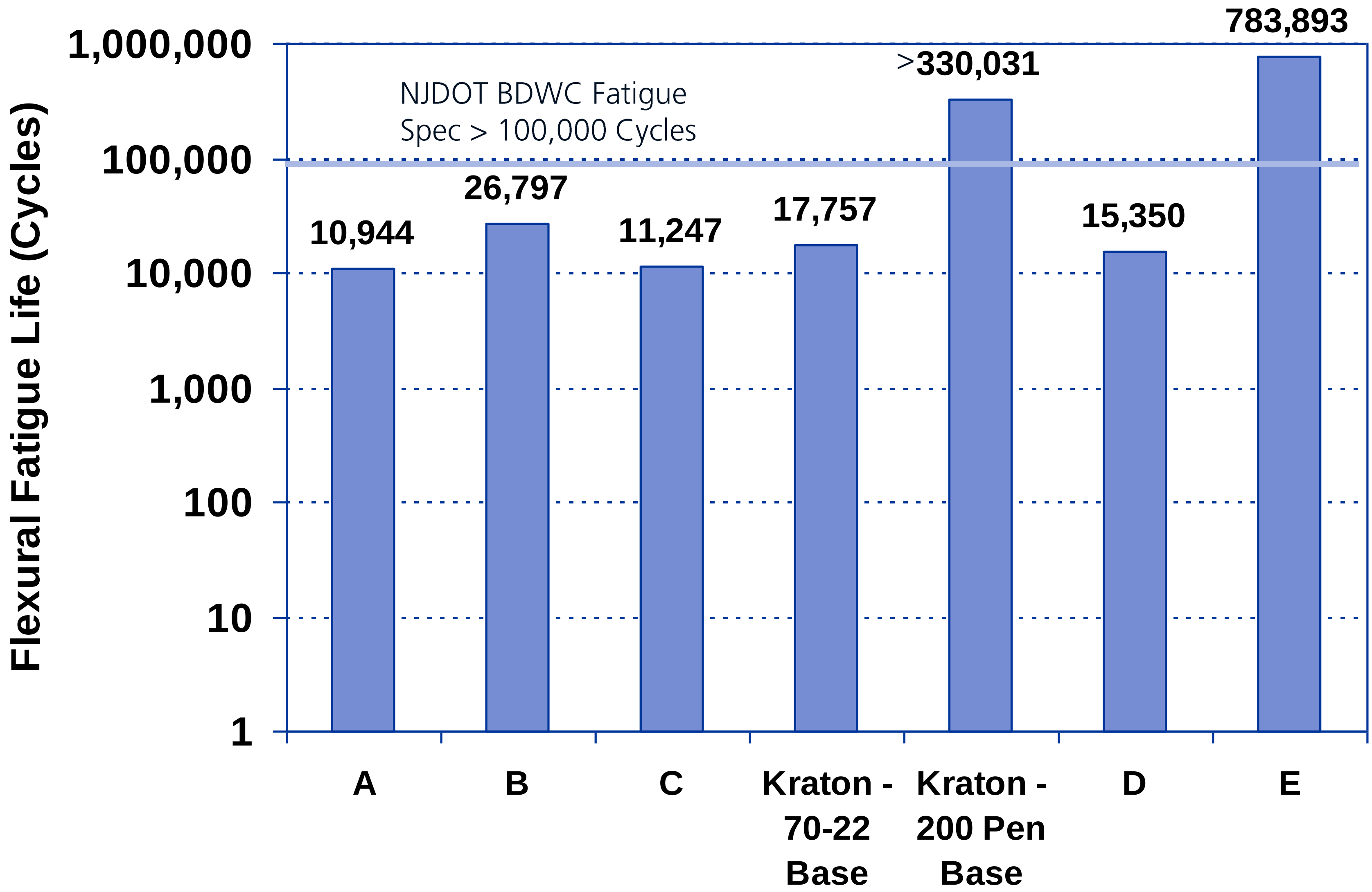
NCAT binder, based on PG 67-22

NJ DOT Flexible Bridge Deck Specifications



Asphalt Pavement Analyzer: 64 ˚ C, 100 lb Wheel Load, 100 psi Hose Pressure
Courtesy Tom Bennert, Rutgers U.

NJ DOT Flexible Bridge Deck Specifications



Flexural Beam Fatigue: 15 ˚ C, 1500 micro-strain, 10 Hz Courtesy Tom Bennert, Rutgers U.

Test Sections/Wheel Tracking

- Discussions underway with several agencies in US, Europe, Middle East and Asia for potential test sections.
- Wheel tracking trials in planning at TRL, the UK Transportation Research Laboratory and/or TFHRC accelerated loading facility
- Bridge deck project in New Jersey.
- Overlay project in Louisiana.
- Full depth construction trial in Utah.

Future work

- Advanced mix testing and modeling based on NCAT mixtures.
- Evaluation in softer binders to define value in high strain environments such as overlays on cracked pavements.
- Development of suitable binder specifications for purchase specifications.
  - MSCR
  - ABCD / M320 Table 2
  - Force ductility energy
  - Fatigue torture test (?)

Accelerated Loading Facility Tests to Complement Test Track

- Comparative testing for permanent deformation and fatigue cracking versus thicker conventional structure.
- Material characterization of NCAT mixes to be used for viscoelastic continuum damage (VECD) modeling for design of pavements.
- Full or partial funding through state pooled fund?

Highly Modified Mix from NCAT

- Objective
  - To evaluate the degree to which two similar VECD protocols can rank the same material's fatigue performance at different levels of temperature and strain and stress.
  - Can their data be used interchangeably

FHWA TFHRC Characterization Efforts
Highly Modified Mix from NCAT

- Material Quantities
  - 18 pails 9.5mm PG76-22 mix
  - 18 pails 19mm Kraton High Polymer mix
  - 2 pails PG76-22 binder
  - 2 pails Kraton high polymer binder

- Equipment
  - AMPT with Fatigue Fixture
    - Christensen & Bonaquist Protocol
  - MTS Universal
    - Other simplified VECD protocol (NCSU / TFHRC)

Highly Modified Mix from NCAT

- Experimental Design
  - Unaged / As-Produced
    - AMPT |E*| + IDT |E*|
    - AMPT Fatigue 150mm x 100mm
    - Simpl. VECD Fatigue 150mm x 71mm
    - Simpl. VECD Fatigue Reduced Scale 100mm x 38mm, but only partial combination of temp & stress/strain conditions
  - Long Term Oven Aged
    - IDT |E*|
    - Simplified VECD Reduced Scale 100mm x 38mm