Performance and Rational Design of Thin, Highly Modified Pavements

PAVEMENT PRESERVATION & RECYCLING SUMMIT
PPRS PARIS 2015
FEBRUARY 22-25

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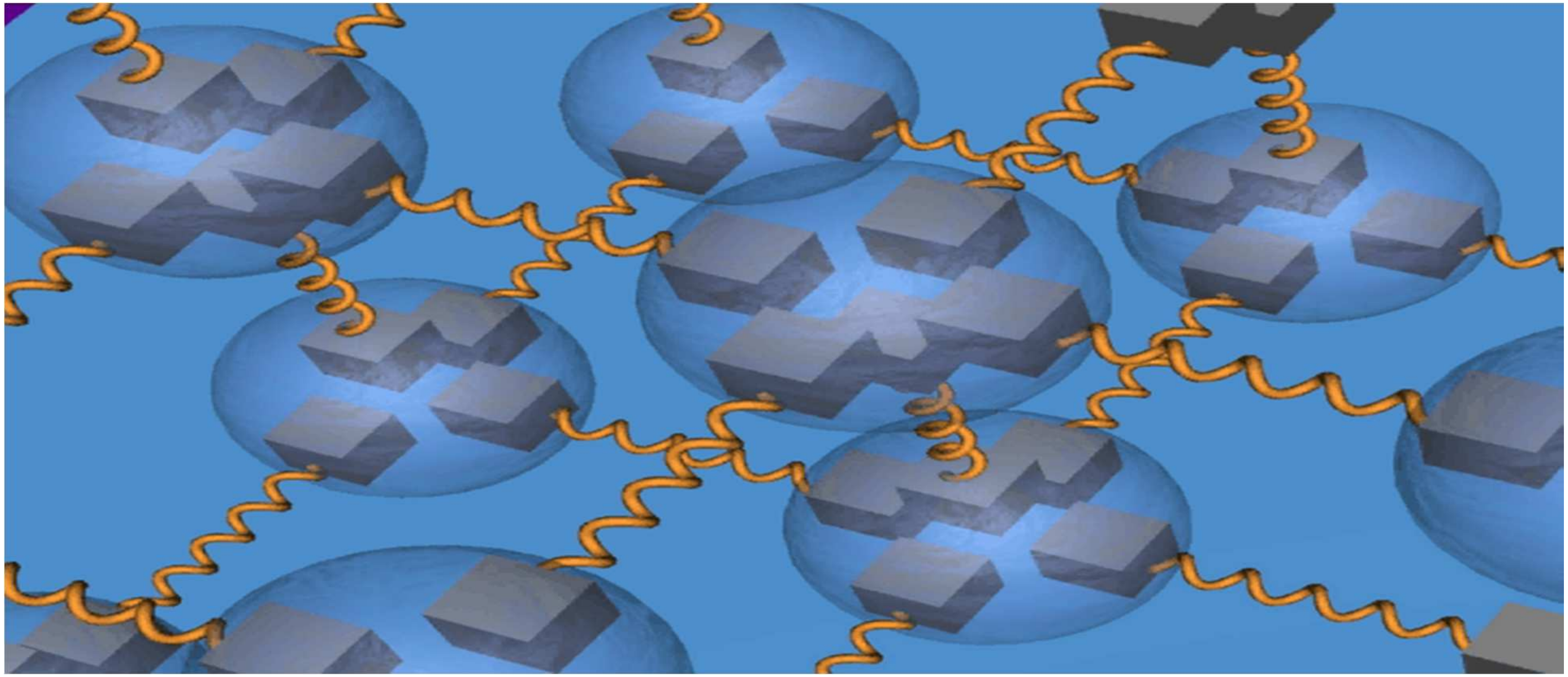
Performance
Polymers

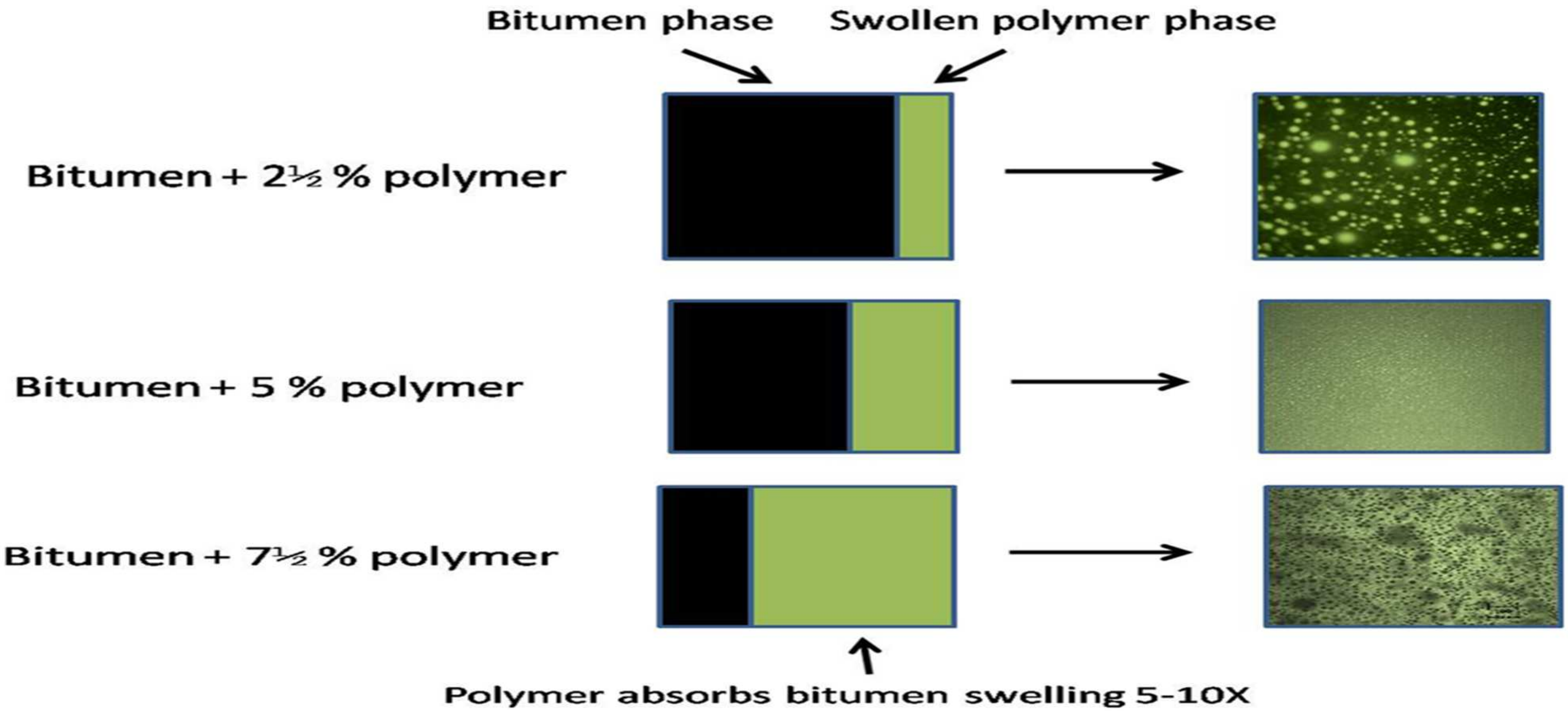
Outline

- Introduction – SBS and Highly Modified Asphalt (HiMA)
- Design and Performance at the National Center for Asphalt Technology
- Predicting Performance – AASHTOWare® Pavement ME Design Methodology
- Material Properties
- Adjusting Calibration Coefficients
- Prediction Versus Performance
- Conclusions

SBS in Bitumen



Phase Morphology



Bitumen phase

Swollen polymer phase

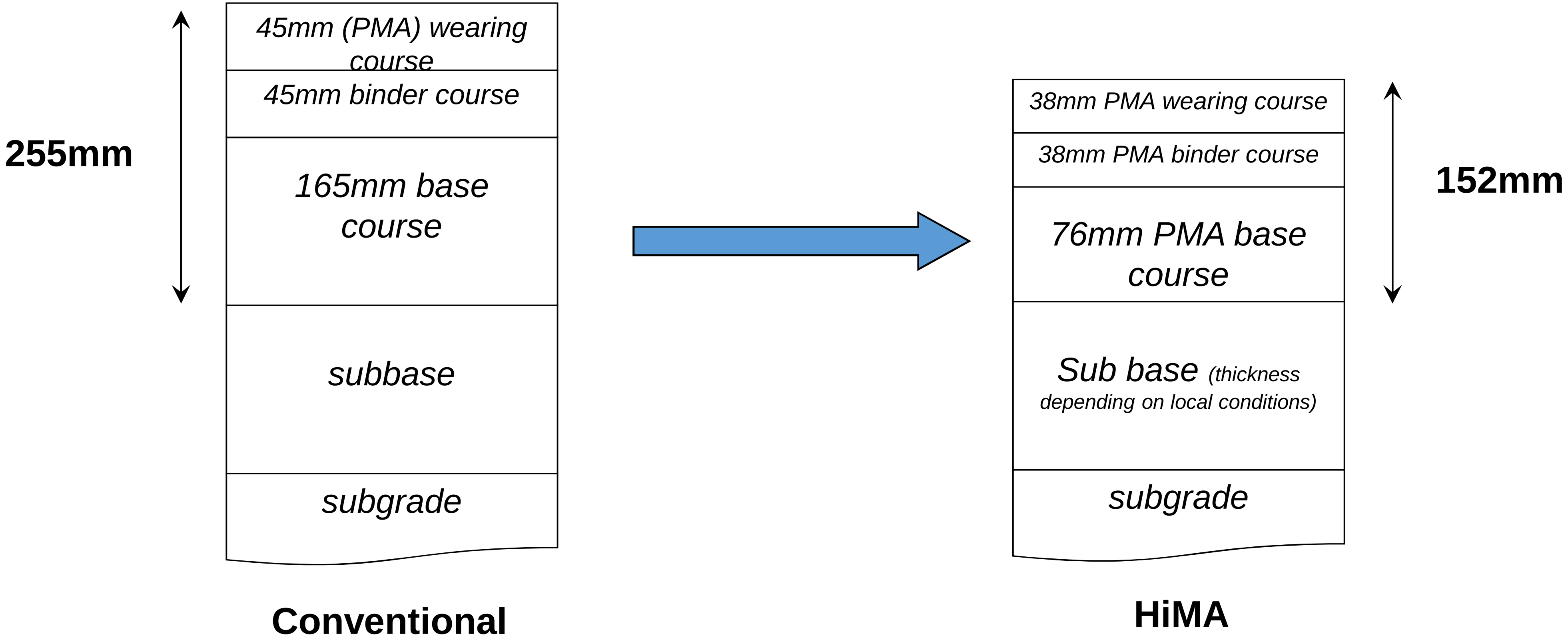
Bitumen + 2½ % polymer

Bitumen + 5 % polymer

Bitumen + 7½ % polymer

Polymer absorbs bitumen swelling 5-10X

Proposed System Redesign



255mm

45mm (PMA) wearing course

45mm binder course

165mm base course

subbase

subgrade

Conventional

38mm PMA wearing course

38mm PMA binder course

76mm PMA base course

Sub base (thickness depending on local conditions)

subgrade

152mm

HiMA

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

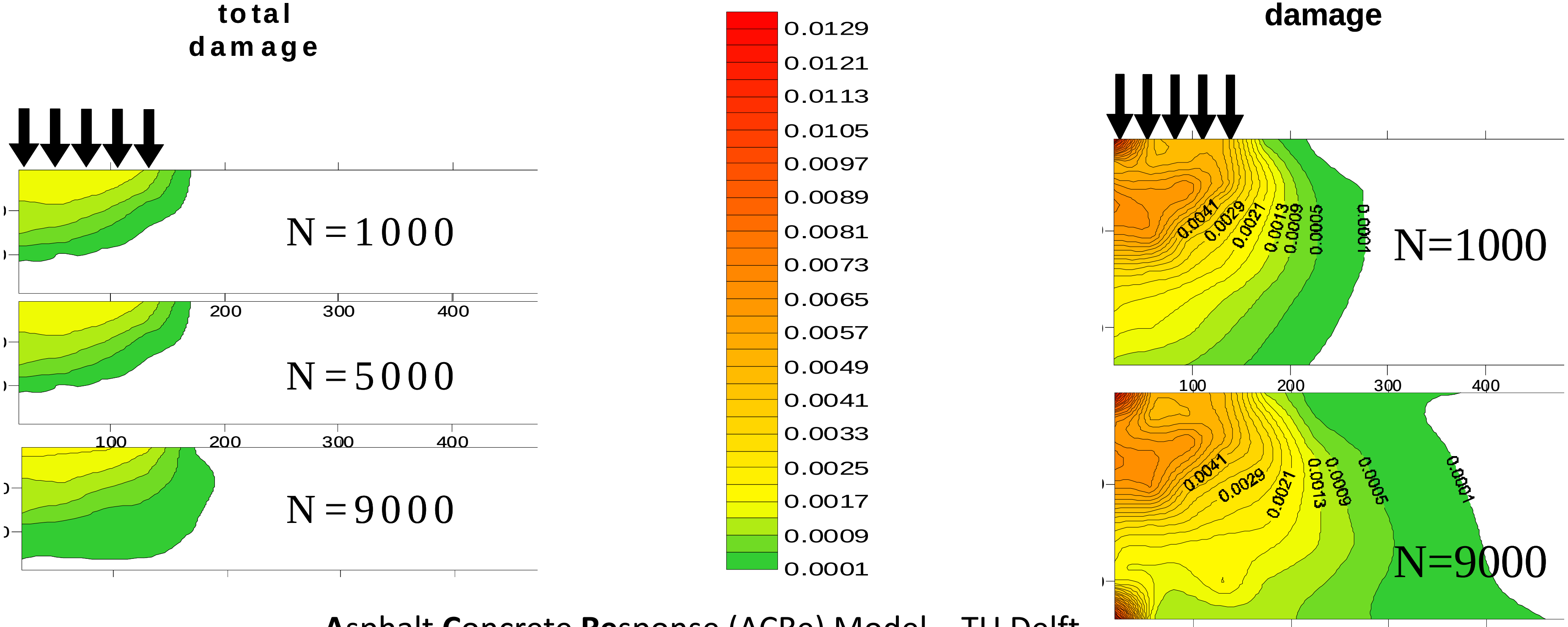
Advanced Modeling Results

HiMA (152mm)

total damage

Unmodified (255mm)

total damage



Asphalt **C**oncrete **Re**sponse (ACRe) Model – TU Delft

NCAT Trials

National Center for Asphalt Technology Auburn, Alabama

- 1.7 mile dedicated test track
- Full pavement lifetime simulated in 2+ years

Thin structural test section N7 (2009)

- 20% thinner pavement, 146mm versus 178mm control sections
- 1/3 as much rutting
- No cracking

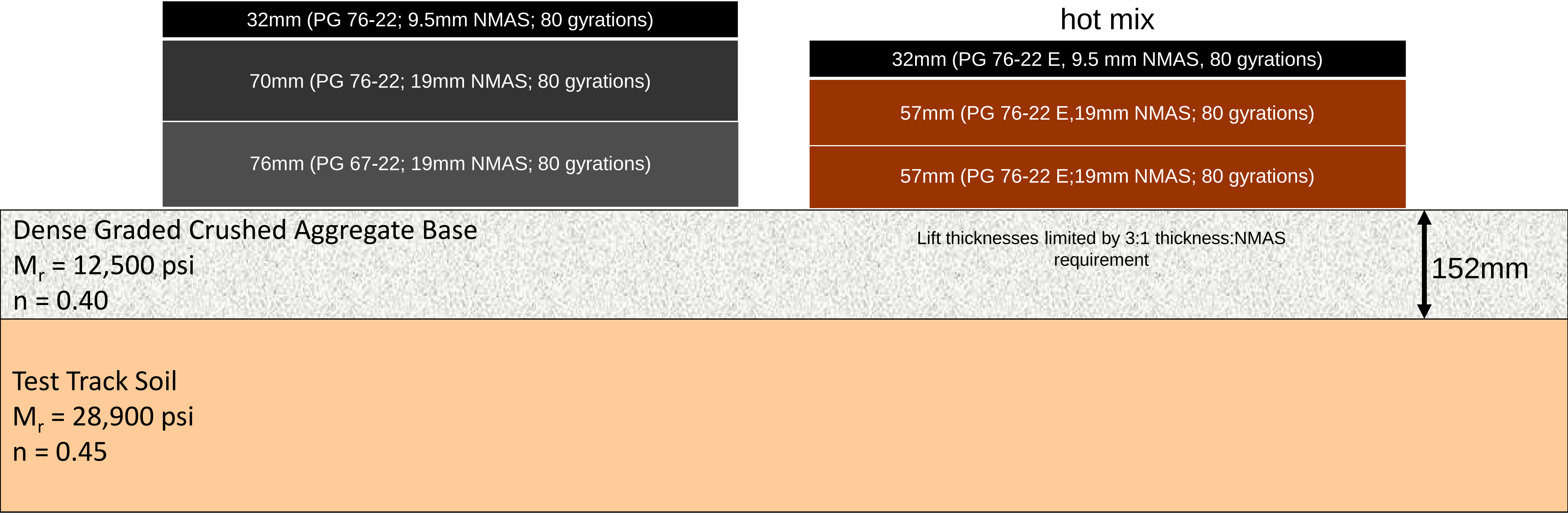
Structural rehabilitation N8 (2010)

- Oklahoma sponsored section
- Standard rehab (2009) failed in 10 months
- HiMA rehabilitation 4 mm rutting and no cracking at 48 months

Continuing N7 & N8 for 2012 cycle

Invited to also participate in preservation sections, e.g. microsurfacing, for 2012 cycle

NCAT Cross Sections Evaluated



S9 - Control 178mm standard hot mix

- 32mm (PG 76-22; 9.5mm NMAS; 80 gyrations)
- 70mm (PG 76-22; 19mm NMAS; 80 gyrations)
- 76mm (PG 67-22; 19mm NMAS; 80 gyrations)

N7 – 146mm highly modified hot mix

- 32mm (PG 76-22 E, 9.5 mm NMAS, 80 gyrations)
- 57mm (PG 76-22 E,19mm NMAS; 80 gyrations)
- 57mm (PG 76-22 E;19mm NMAS; 80 gyrations)

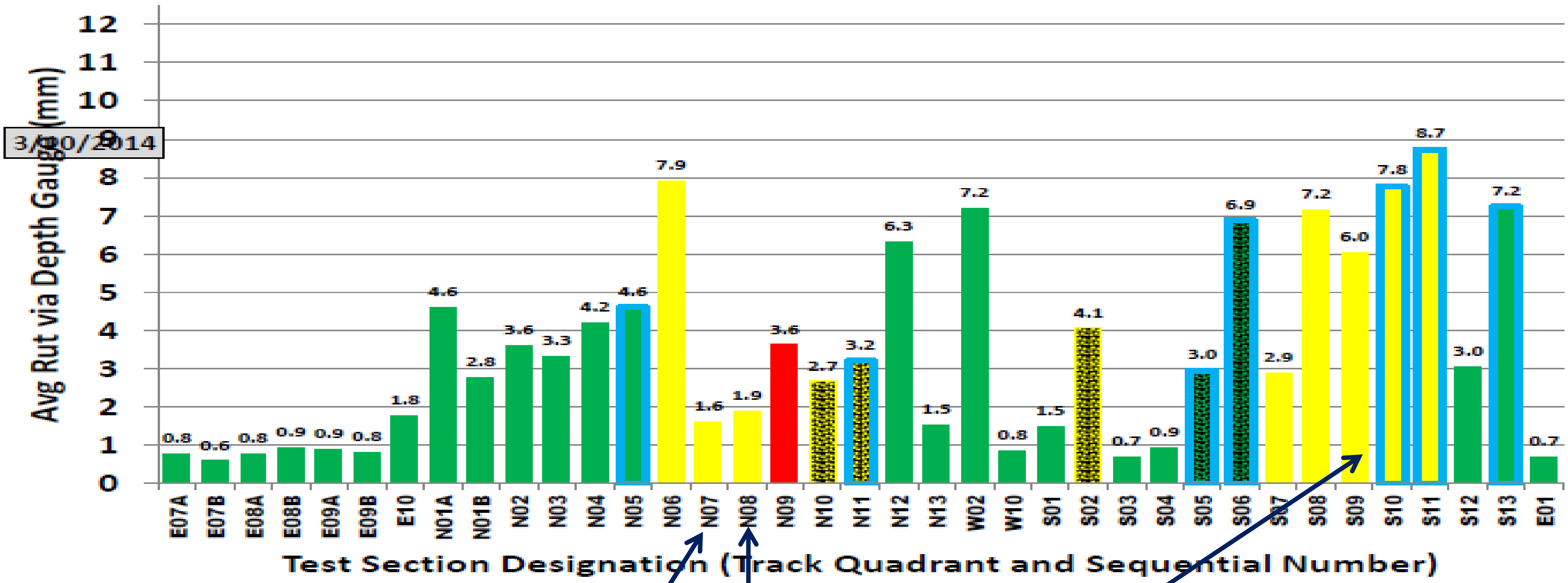
Dense Graded Crushed Aggregate Base
M_r = 12,500 psi
n = 0.40

Lift thicknesses limited by 3:1 thickness:NMAS requirement

152mm

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

NCAT Rutting & Cracking (3/14)

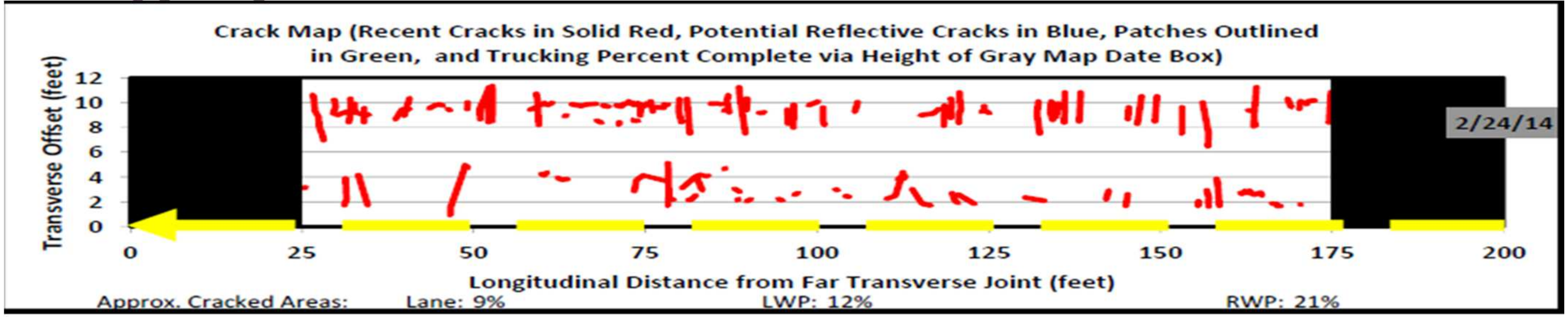


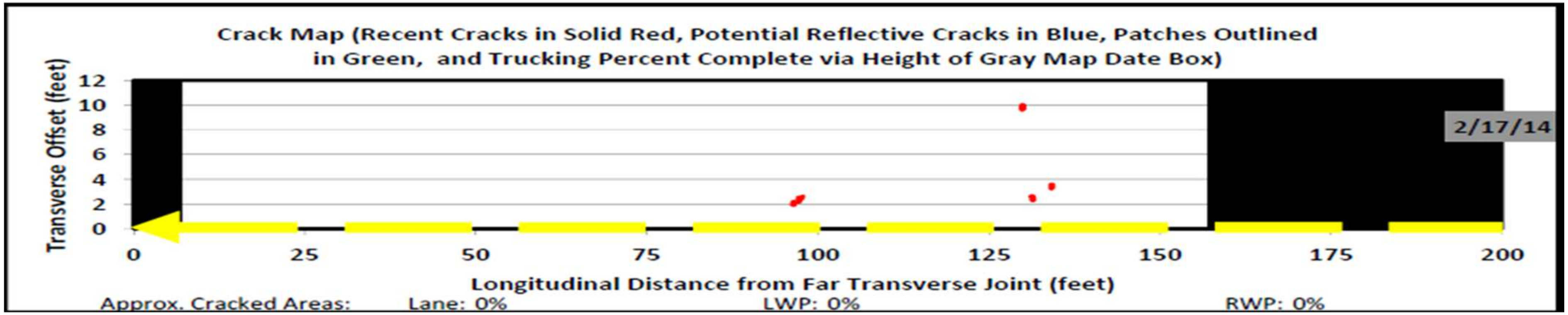
Thin rehab section

Thin structural section

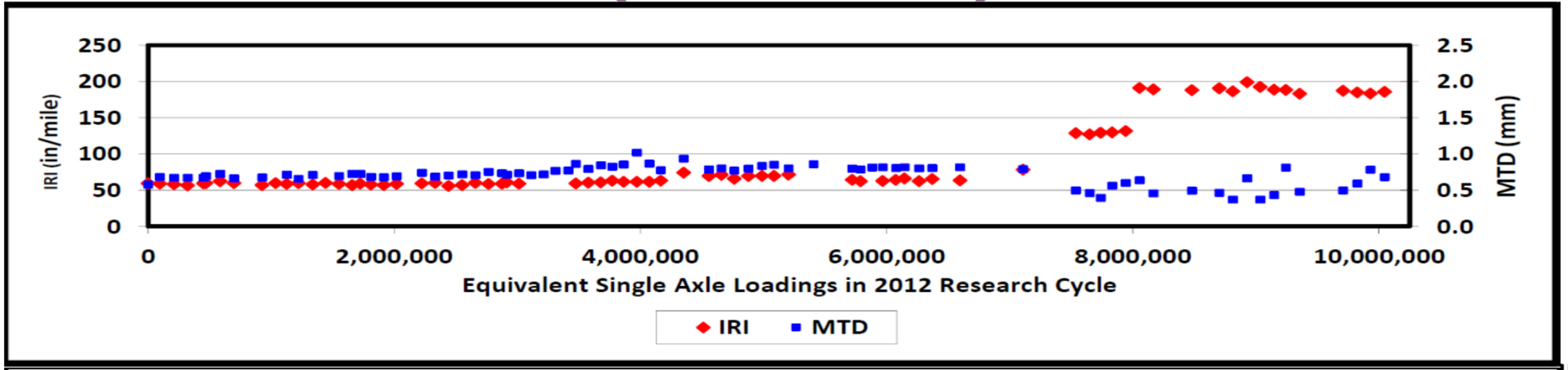
Standard control

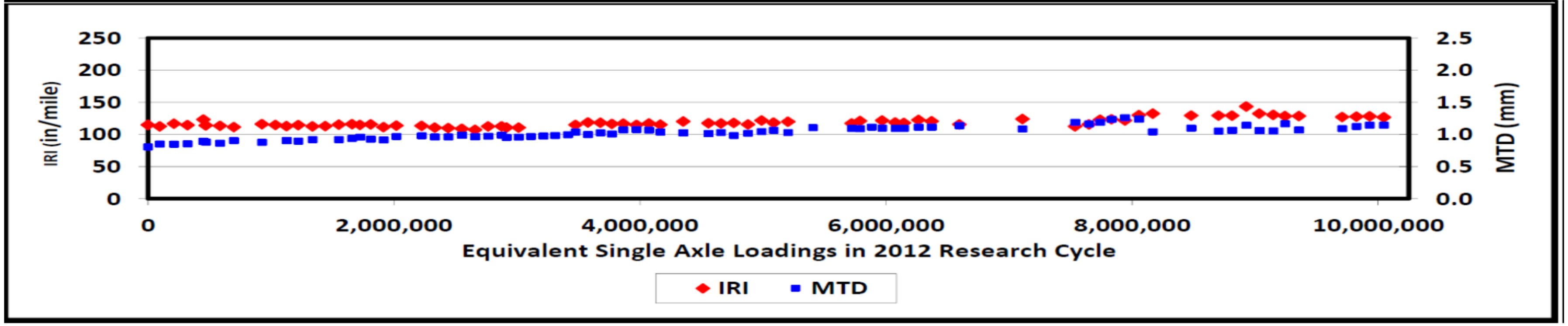
Performance of Control S9 Section and Highly Modified N7 Section – 17 MM ESALs



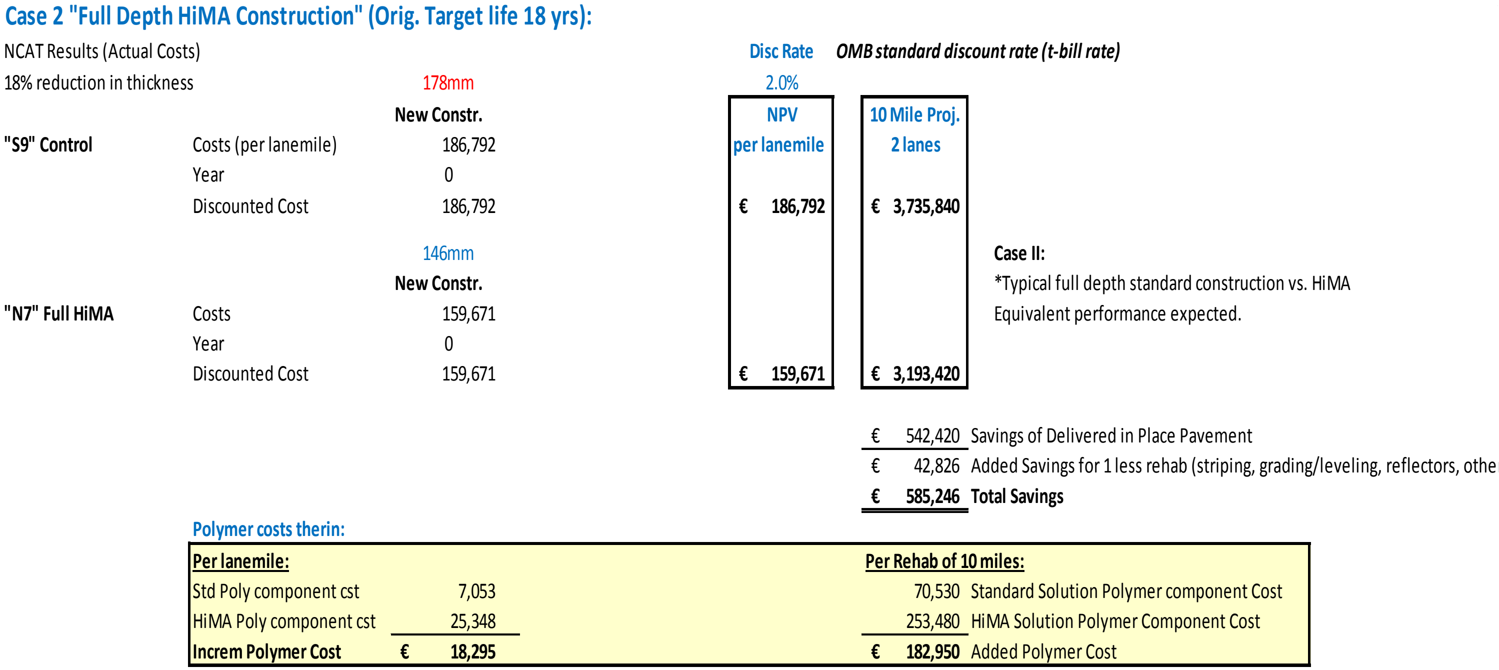


NCAT IRI for Control and Highly Modified Sections (10k ESALS)





S9 Control VS N7 HiMA Section Cost Calc.



Case 2 "Full Depth HiMA Construction" (Orig. Target life 18 yrs):

NCAT Results (Actual Costs)

18% reduction in thickness

Disc Rate 2.0% *OMB standard discount rate (t-bill rate)*

			NPV per lanemile	10 Mile Proj. 2 lanes
		178mm		
		New Constr.		
"S9" Control	Costs (per lanemile)	186,792		
	Year	0		
	Discounted Cost	186,792	€ **186,792**	€ **3,735,840**
		146mm		
		New Constr.		
"N7" Full HiMA	Costs	159,671		
	Year	0		
	Discounted Cost	159,671	€ **159,671**	€ **3,193,420**

Case II:
*Typical full depth standard construction vs. HiMA
Equivalent performance expected.

€ 542,420	Savings of Delivered in Place Pavement
€ 42,826	Added Savings for 1 less rehab (striping, grading/leveling, reflectors, othe
€ **585,246**	**Total Savings**

Polymer costs therin:

Per lanemile:		**Per Rehab of 10 miles:**	
Std Poly component cst	7,053	70,530	Standard Solution Polymer component Cost
HiMA Poly component cst	25,348	253,480	HiMA Solution Polymer Component Cost
Increm Polymer Cost	€ **18,295**	€ **182,950**	Added Polymer Cost

Description	Mix type	Binder	Thickness (mm)	OK I-40 Prices (Eur/ton)	Price per Mile 3.66m wide Lane
N7 - Original	Dense	HiMA	31.8	€ 79.35	€ 38,755.00
	Dense	HiMA	57.2	€ 68.77	€ 60,458.00
	Dense	HiMA	57.2	€ 68.77	€ 60,458.00
	Subtotal				€ **159,671.00**
S9 - Original	Dense	PG 76-22	31.8	€ 70.53	€ 34,449.00
	Dense	PG 76-22	108	€ 60.46	€ 100,406.00
	Dense	PG 64-22	76.20	€ 50.26	€ 51,937.00
	Subtotal				€ **186,792.00**
S9 – Resurf 1	Dense	PG 76-22	31.8	€ 70.53	€ 34,449.00
	Milling		0.84m2	€ 1.19	€ 8,377.60
	Subtotal				€ **42,826.60**

- *Incremental polymer cost low to value gained*

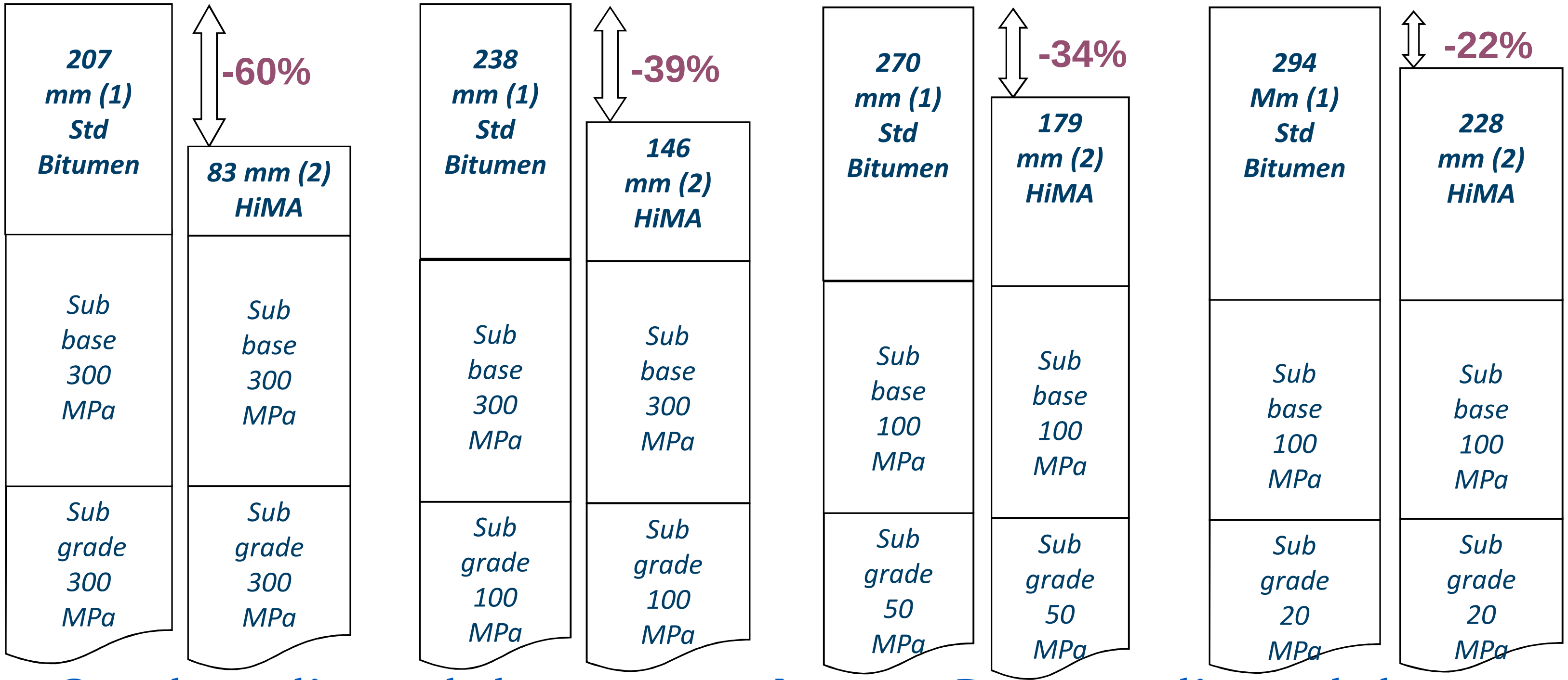
Pavement Performance Prediction

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

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)/ AASHTOWare ®Pavement 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

Design Examples



207 mm (1) Std Bitumen	**83 mm (2) HiMA**	**238 mm (1) Std Bitumen**	**146 mm (2) HiMA**	**270 mm (1) Std Bitumen**	**179 mm (2) HiMA**	**294 Mm (1) Std Bitumen**	**228 mm (2) HiMA**
	-60%		-39%		-34%		-22%
Sub base 300 MPa	*Sub base 300 MPa*	*Sub base 300 MPa*	*Sub base 300 MPa*	*Sub base 100 MPa*	*Sub base 100 MPa*	*Sub base 100 MPa*	*Sub base 100 MPa*
Sub grade 300 MPa	*Sub grade 300 MPa*	*Sub grade 100 MPa*	*Sub grade 100 MPa*	*Sub grade 50 MPa*	*Sub grade 50 MPa*	*Sub grade 20 MPa*	*Sub grade 20 MPa*

Good quality sub base → Poor quality sub base

(1) Thickness determined by asphalt strain criterion

HiMA = Highly Modified Asphalt

(2) Thickness determined by sub grade strain criterion

Pavement ME – Level 1 Input

- Mixture master curve (dynamic modulus)at -12, 5, 20, 38 & 54°C.
- Endurance limit – default is 100 με
- Binder master curve – dynamic modulus at same temperatures
- Indirect tensile data at 0 °C, -10 °C and -20 °C for thermal cracking
- For unbound base/Subgrade – Poisson’s ratio and modulus or CBR

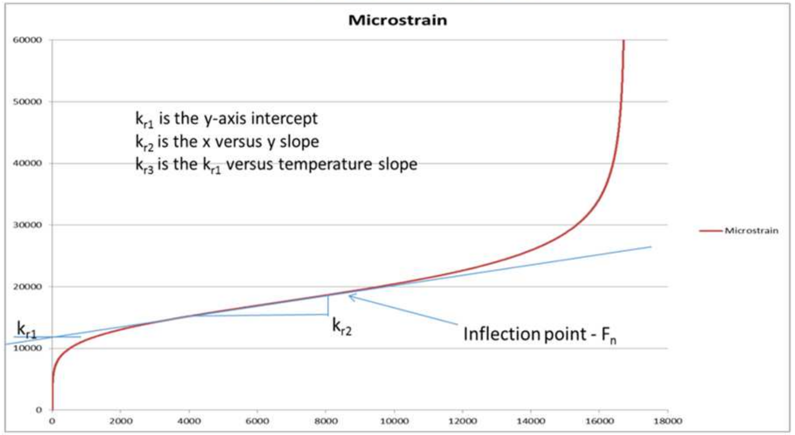
HiMA Strategy-

- Mixture master curve including 54°C data.
- Endurance limit from fatigue testing
- Revised fatigue global calibration factors from fatigue testing
- Revised rutting global calibration factors from deformation testing

Calibration

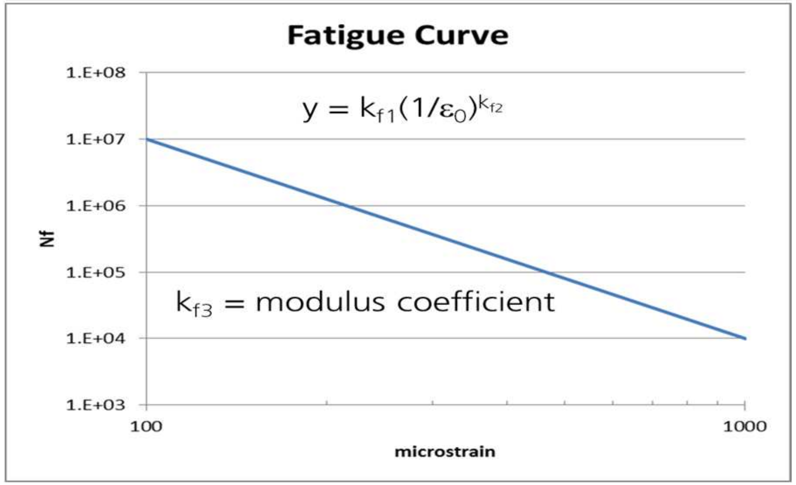
- Rutting
  - NCHRP 9-30A Protocol (Hamburg or APA)
  - Run AMPT Flow Number (F_n) at 20 °C, 39.5 °C, 59 °C
  - k_{r1} = y axis intercept of secondary flow tangent
  - k_{r2} = slope of secondary flow
  - k_{r3} = slope of k_{r1} versus temperature plot
- Fatigue
  - Standard 4 point bending beam, NCSU OR AATS-VECD model and procedure using AMPT
  - Determine N_f versus strain curve
  - Fit k_{f1} and k_{f2} to curve
  - Measure modulus and reverse fit k_{f3}
  - Extrapolate to N_f = 50MM for endurance limit

AMPT Flow Number Data



k_{r1} is the y-axis intercept
k_{r2} is the x versus y slope
k_{r3} is the k_{r1} versus temperature slope

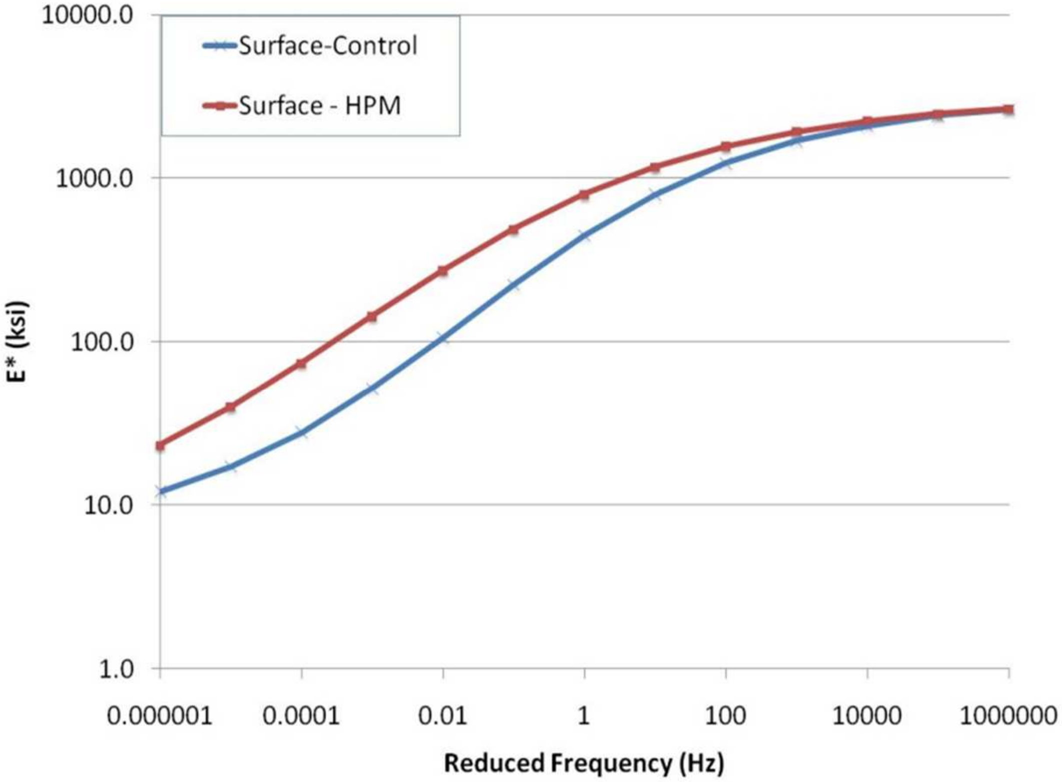
Inflection point - F_n

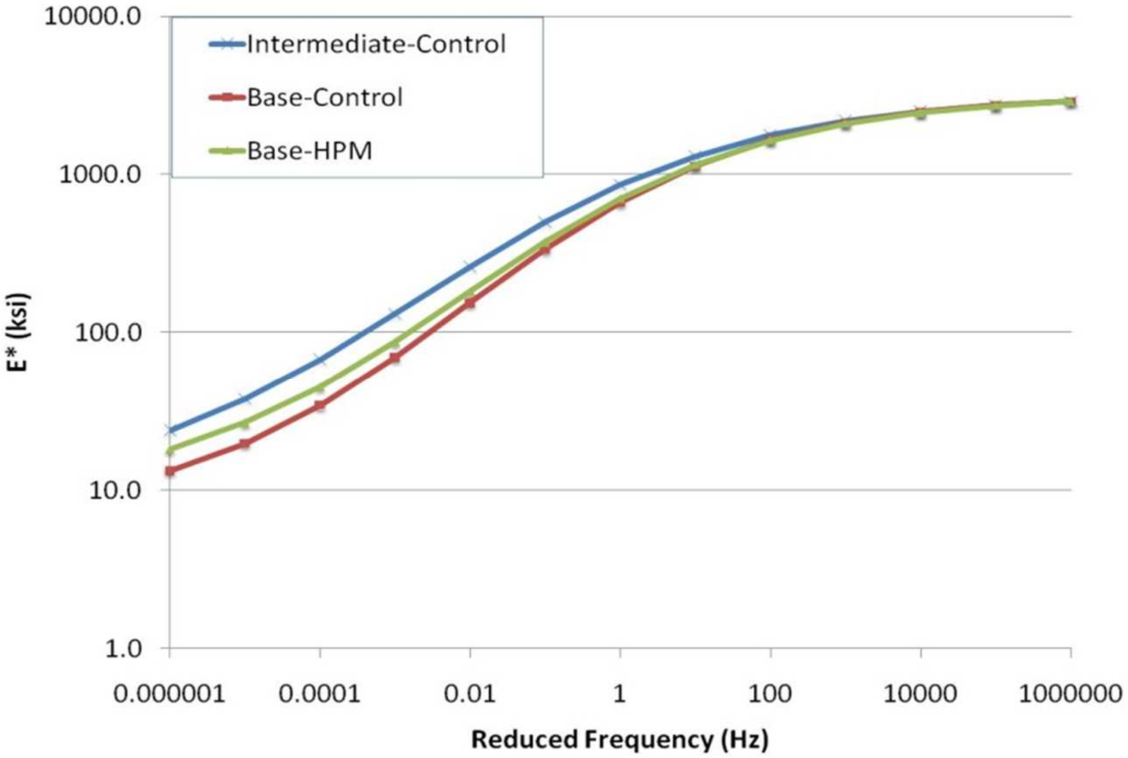


$y = k_{f1}(1/\varepsilon_0)^{k_{f2}}$

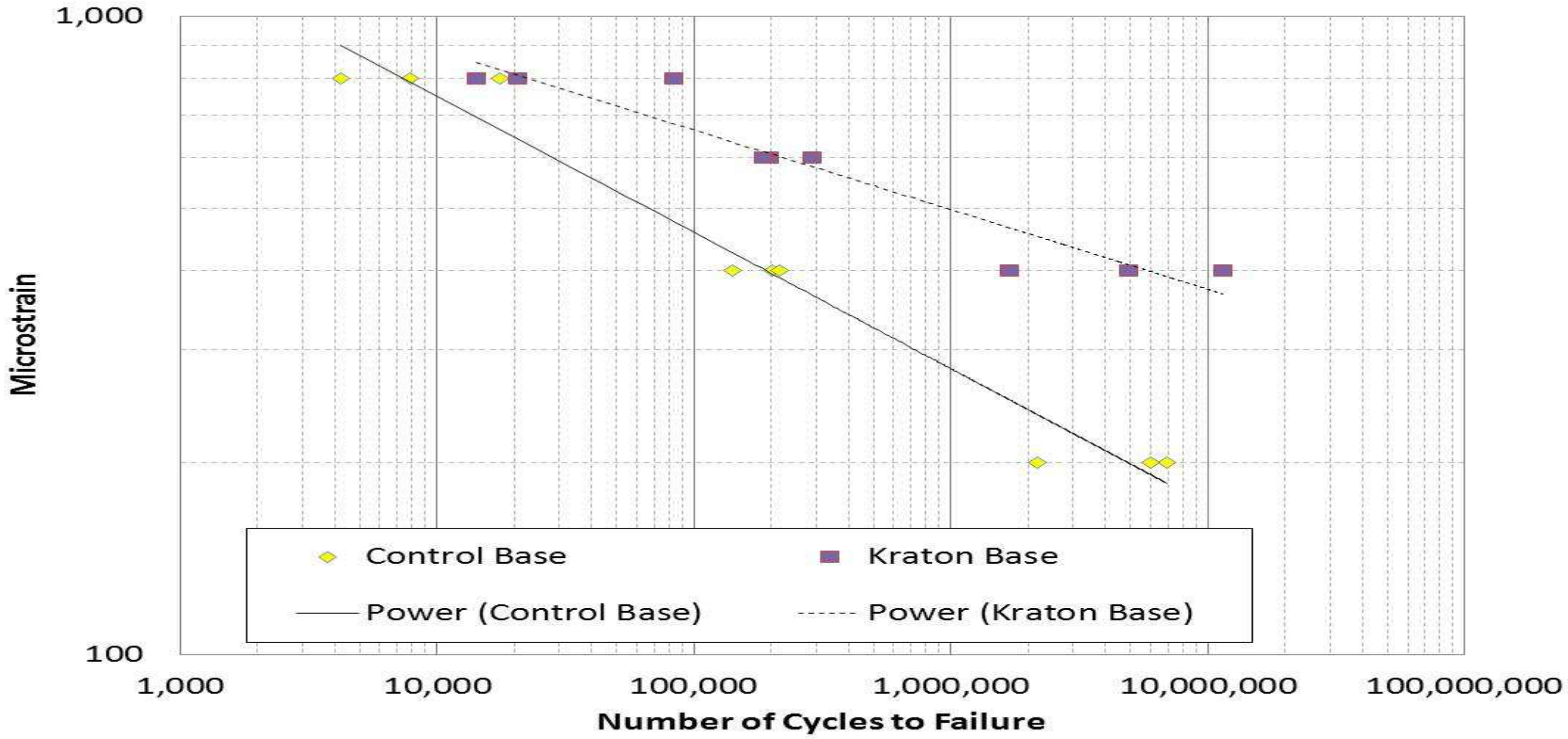
k_{f3} = modulus coefficient

Dynamic Modulus Testing Results





Comparison of Fatigue Resistance for Mixtures



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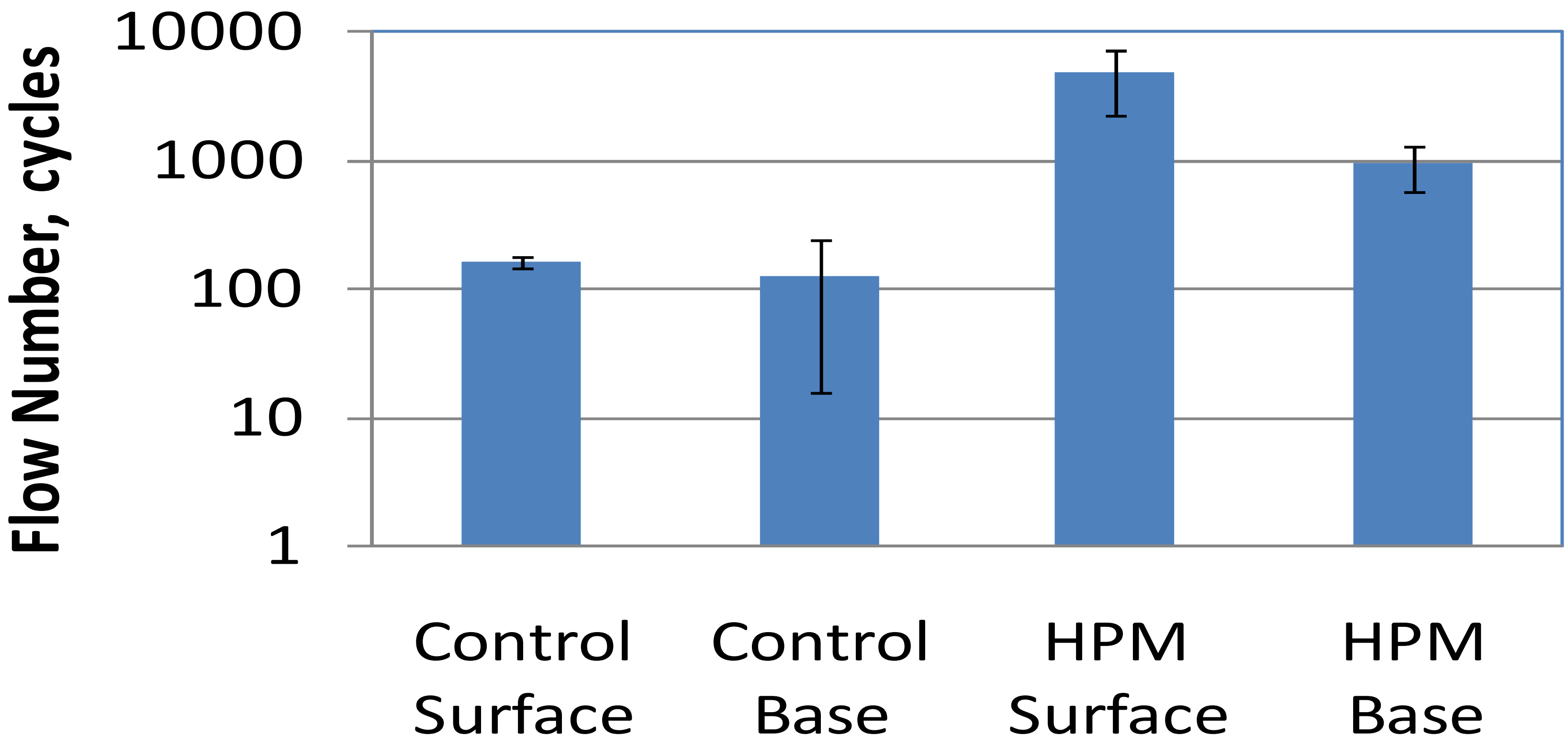


MEPDG Models – Fatigue Damage – Alligator (bottom up) and Longitudinal (top down)

$$N_{f\text{-}HMA} = k_{f1}(C)(C_H)\beta_{f1}(\varepsilon_t)^{k_{f2}\beta_{f2}}(E_{HMA})^{k_{f3}\beta_{f3}}$$

- Where:
- $N_{f\text{-}HMA}$ = Allowable axle load applications
- ε_t = Tensile strain
- E_{HMA} = Dynamic modulus measured in compression
- $k_{f1,f2,f3}$ = Global field calibration parameters
- $\beta_{f1,\ f2,\ f3}$ = local or mixture field calibration factors
- C = volumetrics parameter (asphalt content and air voids)
- C_H = Thickness correction term (depends on type of cracking)

MEPDG Models – Permanent Deformation

› $\Delta_{p(HMA)} = \varepsilon_{p(HMA)} h_{HMA} = \beta_{r1} k_z \varepsilon_{r(HMA)} 10^{kr1} \eta^{kr2 \beta r2} T^{kr3 \beta r3}$

- Where:
- $\Delta_{p(HMA)}$ = Accumulated vertical plastic (permanent) deformation
- $\varepsilon_{p(HMA)}$ = Accumulated axial plastic strain
- $\varepsilon_{r(HMA)}$ = Calculated mid-depth resilient strain
- h_{HMA} = Thickness
- η = number of axle load repetitions
- T = pavement temperature
- k_z = depth confinement factor
- $k_{r1,r2,r3}$ = global field calibration parameters
- $\beta_{r1,r2,r3}$ = local or mixture field calibration factors

Fatigue Calibration Factors for Section N7

	k_{f1}	k_{f2}	k_{f3}
MEPDG Standard Values	7.566E-3	3.9492	1.2810
S9 Calculated Values	1.4964E-2	3.9492	1.2810
N7 Calculated Values	7.5721E-5	7.3135	2.3655
Ratios	0.9762	0.7595	0.0491
N7 Adjusted Values	7.386E-3	2.9994	0.0630

Rutting Calibration Factors for Section N7

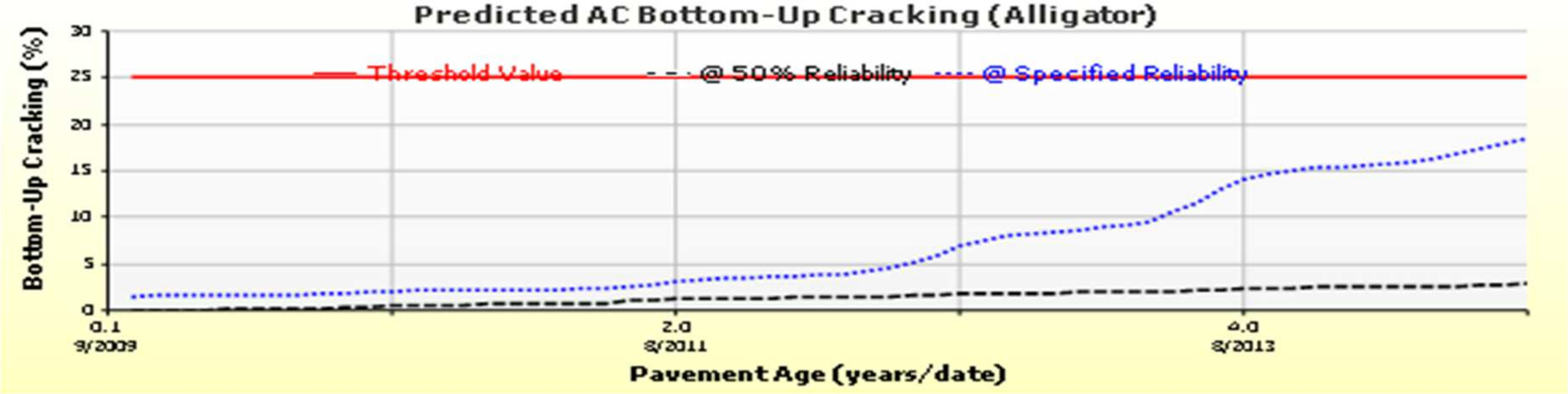
	k_{r1}	k_{r2}	k_{r3}
MEPDG Standard Values	-3.3541	0.4719	1.5606
S9 Calculated Values	-3.7902	0.4719	1.5606
Ratios	0.8045	0.4791	1.0000
N7 Adjusted Values	-2.6985	0.2261	1.5606

Pavement ME Level 1 Analysis

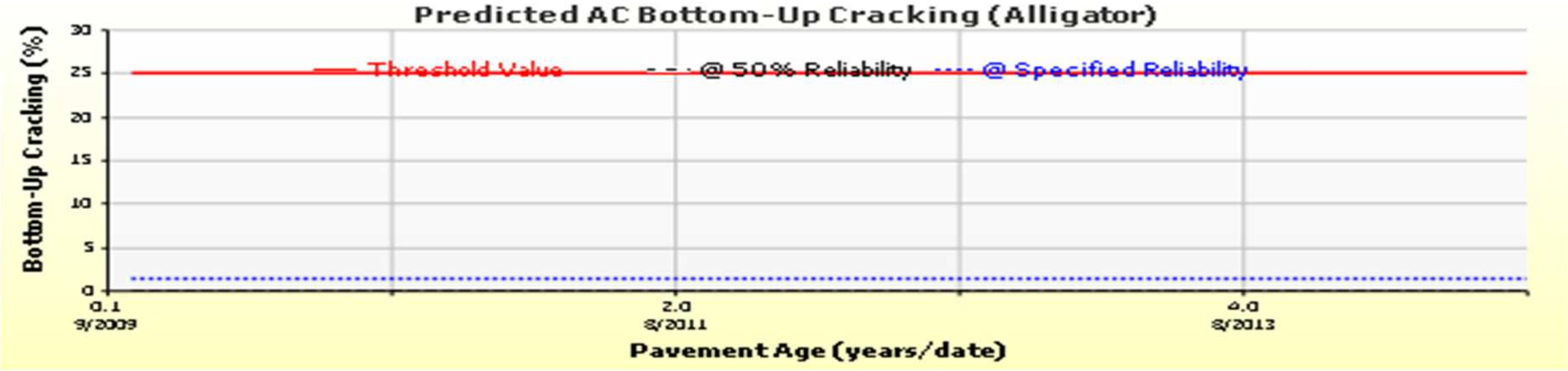
- Sections S9 and N7 run
- Basic Pavement ME Inputs
  - Climate data for Montgomery, AL
  - AADTT = 1465; Speed 45 mph; No growth
  - Subbase Modulus = 15000 psi
  - Subgrade Modulus = 32000 psi

Predicted AC Bottom-Up Cracking (Alligator)

S9

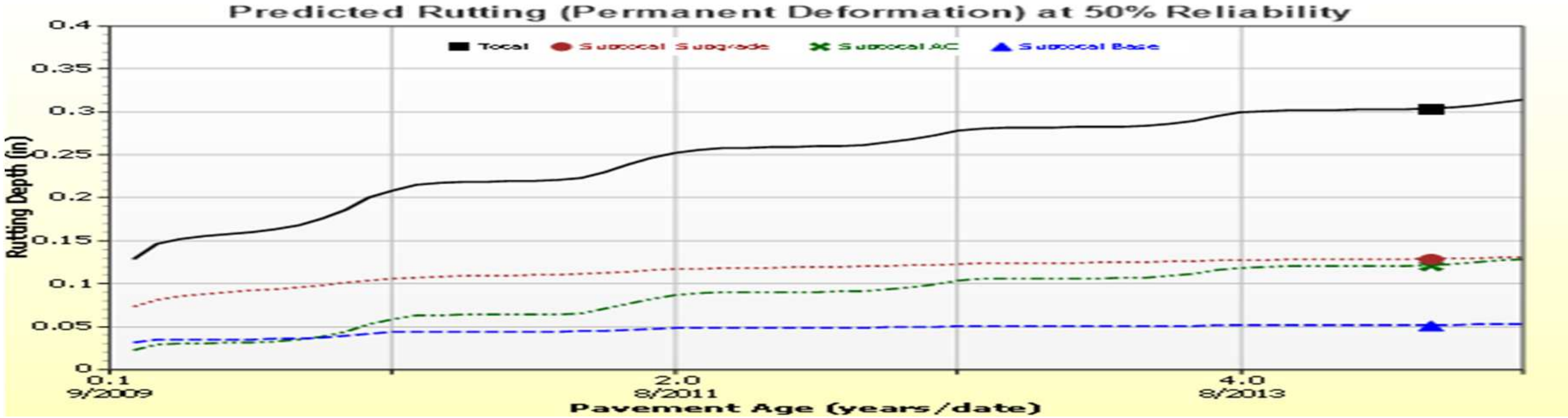


N7

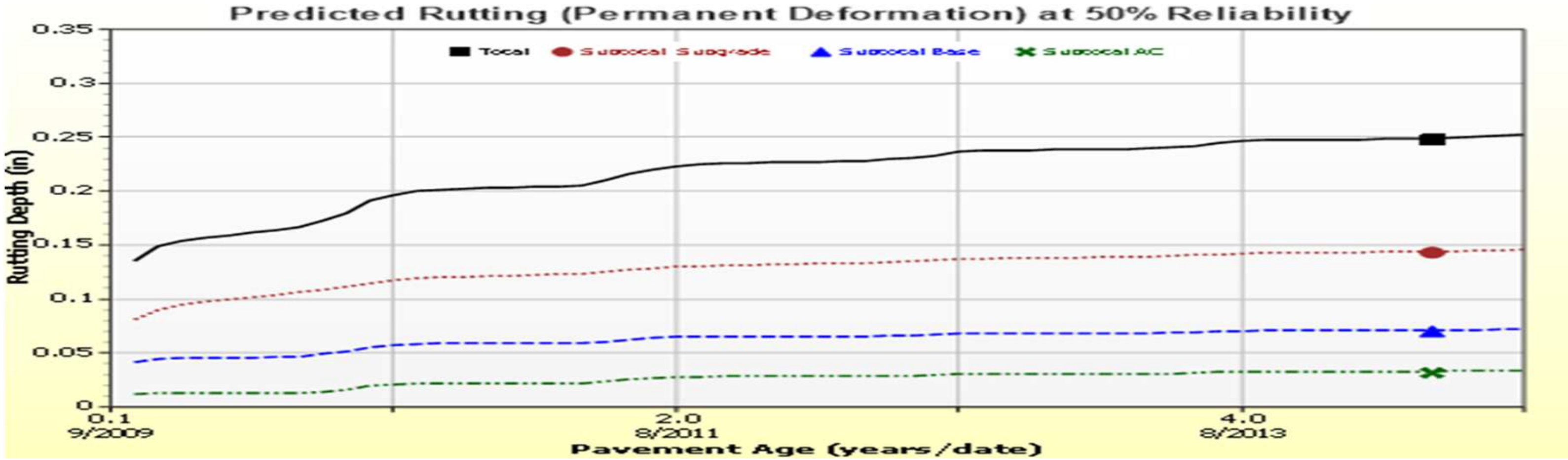


Predicted Rutting

S9



N7



Predicted Damage Summary 90% Reliability

	Section S9		Section N7	
Pavement Distress	**Calc**	**Measured**	**Calc**	**Measured**
Total Pavement Deformation (mm)	**10.2**	**N/A**	**8.4**	**N/A**
AC Permanent Deformation (mm)	**6.3**	**6.0**	**1.5**	**1.6**
Bottom-up Cracking, %Area	**18**	**14 (9,12,21)**	**1.5**	**~1.5**

- Note:
- Reliability assumes standard errors
- Current Pavement ME uses single damage model

CONCLUSION

- Highly modified binders can give dramatic improvement in pavement resistance to rutting and fatigue damage.
- Thickness reduction can more than offset increased material costs.
- Current modeling and design software may be used to predict *relative* material performance characteristics and rationally design pavements.
- Performance predictions agree well with our current field performance observations

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