# Performance Modeling and Design for Highly Modified Asphalt Pavement

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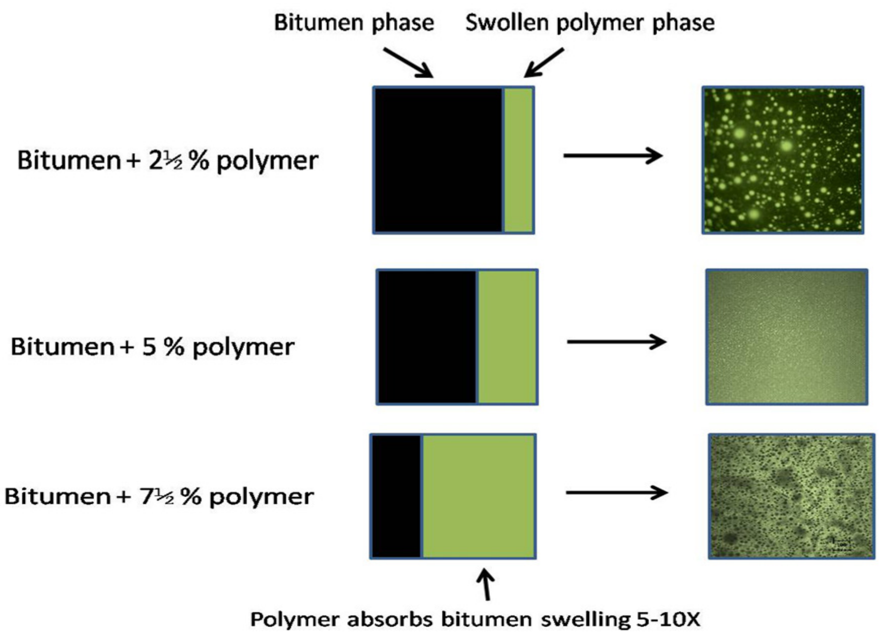
# Outline

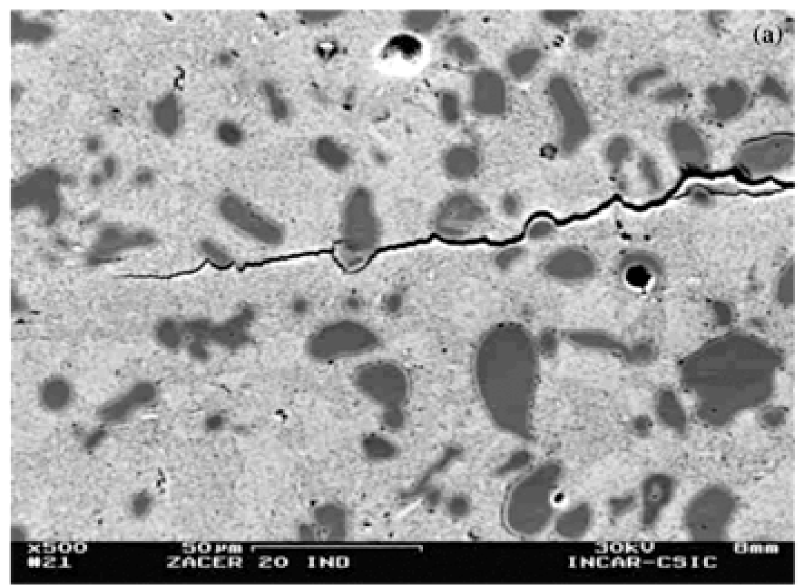
- What is highly modified asphalt?
- NCAT test track section performance
- AASHTOWare™ Pavement ME Design modeling
- FLEXPave™ software
- FLEXPave modeling
- Conclusions and where we go from here

# What Is Highly Modified Asphalt?




Over 3,000,000 tons in over 70 projects around the world have demonstrated **superior performance** at **reduced thickness**.

- Highly Modified Asphalt is exactly what it says, asphalt with more than double the normal amount of SBS polymer.
- This gives a much denser polymer network with up to 10X rutting **and** fatigue cracking resistance.

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# PMA Producer’s Perspective

- Polymer Handling
- Blending
- Storage & Pumping
- Transport

- For all, no problem—handles like normal PMA.

# HiMA Specifications North America

| Standard | AASHTO M 320 | AASHTO T301 | AASHTO M 332 | AASHTO T 350 |
|---|---|---|---|---|
| | PG specification | Elastic Recovery | PG specification | MSCR Recovery |
| Alabama | | | PG 76E-22 | 95% |
| Alaska | | | PG 64E-40 | 90% |
| Florida | | | PG 76E-28 | 90% |
| Georgia | | | PG 76E-22 | 90% |
| Missouri | | | PG 76E-22 | 90% |
| Oklahoma | | | PG 76E-28 | 95% |
| Tennessee | | | PG 76E-28 | 90% |
| Utah | | | PG 70E-34 | 90% |
| Virginia | | | PG 76E-28 | 90% |
| Florida | PG 82-22 | 90% | | |
| Iowa | PG 76-34 | 90% | | |
| Minnesota | PG 76-34 | 90% | | |
| New Hampshire | PG 76-34 | 90% | | |
| Ohio | PG 88-22M | 90% | | |
| Oregon | PG 76-28 | 90% | | |
| New York City | PG 76-34 | 90% | | |
| Utah | PG 76-34 | 90% | | |
| Vermont | PG 76-34 | 90% | | |
| Washington | PG 76-34 | 90% | | |

# National Center for Asphalt Technology Test Track

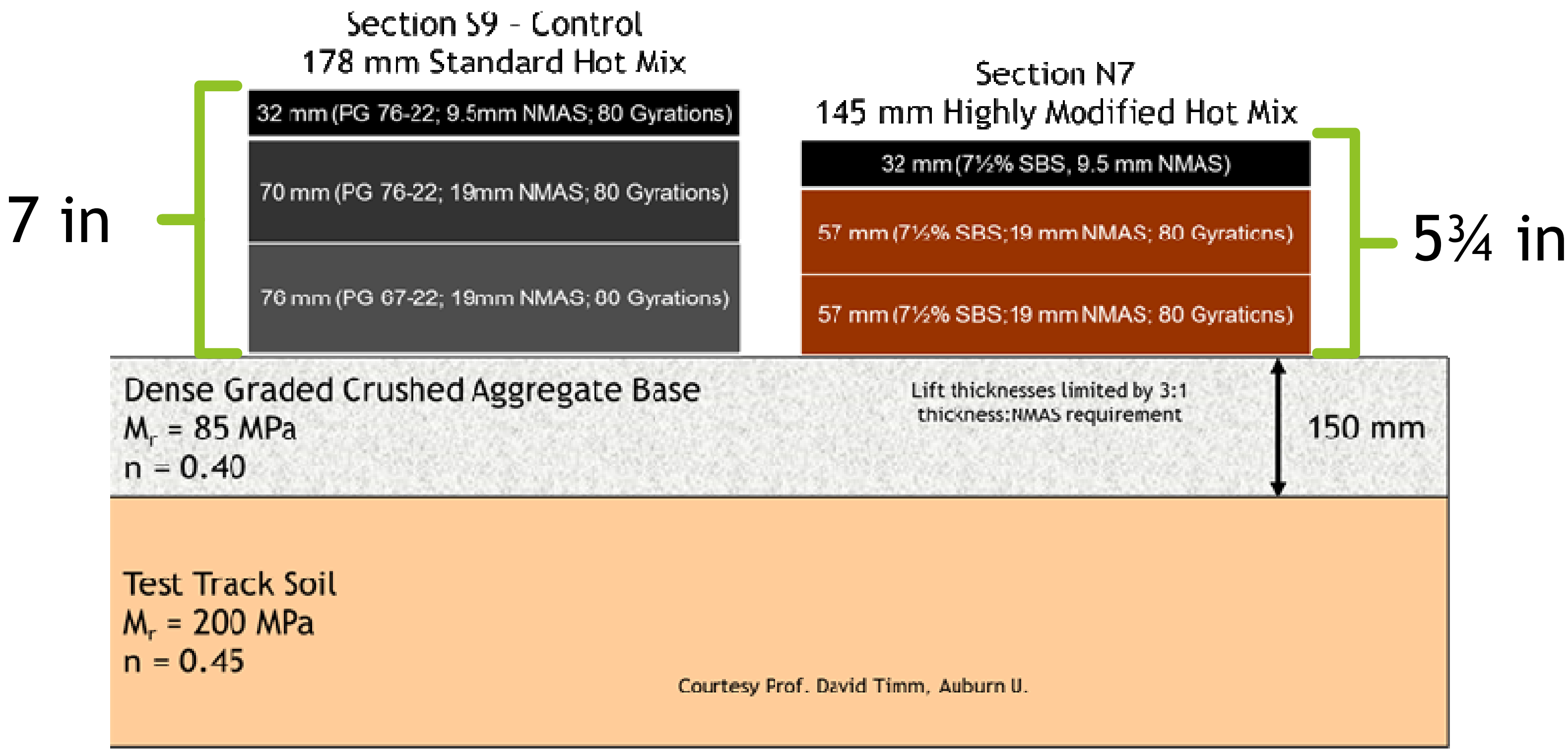
- 5 trucks, 16 h/day, 5 days/week
- Axle load: 18 kip
- Speed: 45 mph

# National Center for Asphalt Technology Test Track

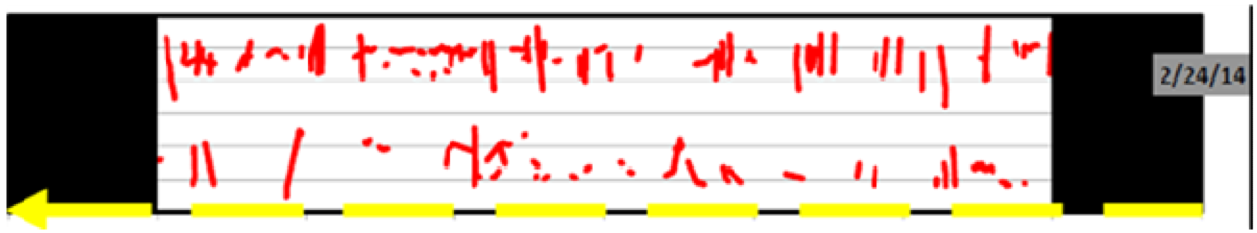
- Track cycle of 10 million ESALs simulates the design lifetime of damage in 2+ years
- ESAL = Equivalent Single Axle Load = 1 pass of 18 kip axle

- Highly Modified Asphalt (HiMA) project started in 2009 cycle
- Part of Performance Group study—6 sections including control
- Continued in 2012 cycle
- Total 20 million ESALs

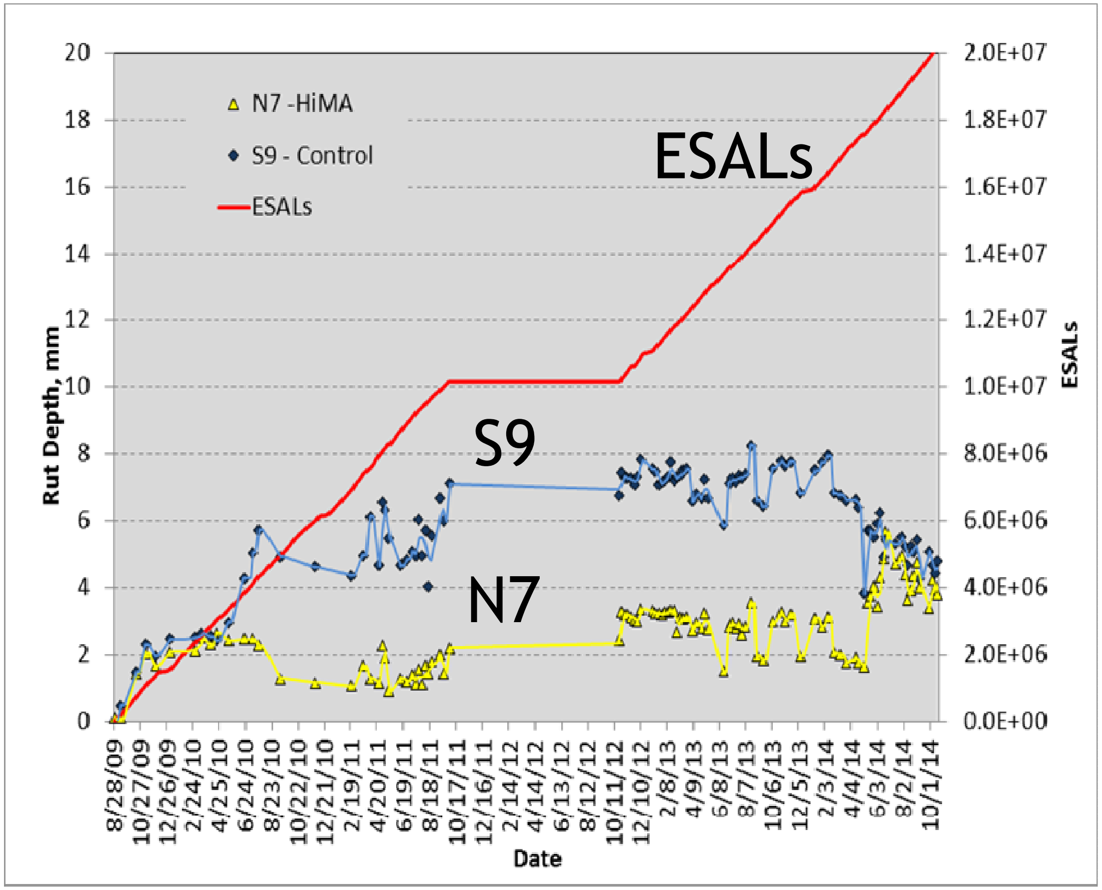
# Control (S9) and HiMA (N7) Section Designs



# Crack Maps at 17 Million ESALs

| 3/14 Rutting | | 2/14 Crack Maps |
|---|---|---|
| S9 | 6.0 mm |  |
| | | Lane - 9% Left wheel path - 12% Right wheel path - 21% |
| N7 | 1.6 mm |  |
| | | Lane - 0% Left wheel path - 0% Right wheel path - 0% |

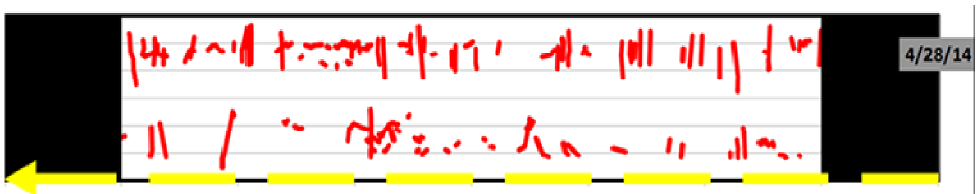
# Rutting over 20 Million ESALs



# N7 Crack Map at 20 Million ESALs

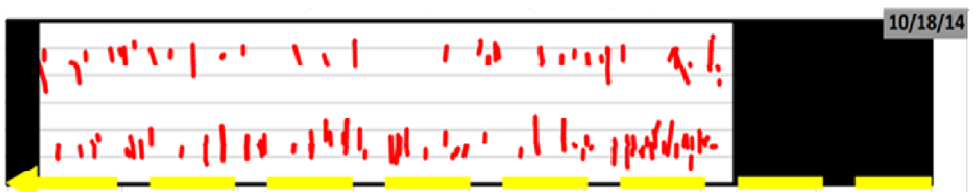
S9 resurfaced at
17 million ESALs

S9

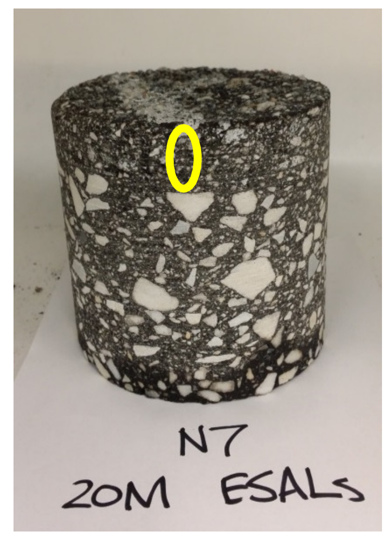



Lane - 10%  Left wheel path - 13%  Right wheel path - 21%

N7




Lane - 6%  Left wheel path - 15%  Right wheel path - 8%




N7 cracking is superficial top-down

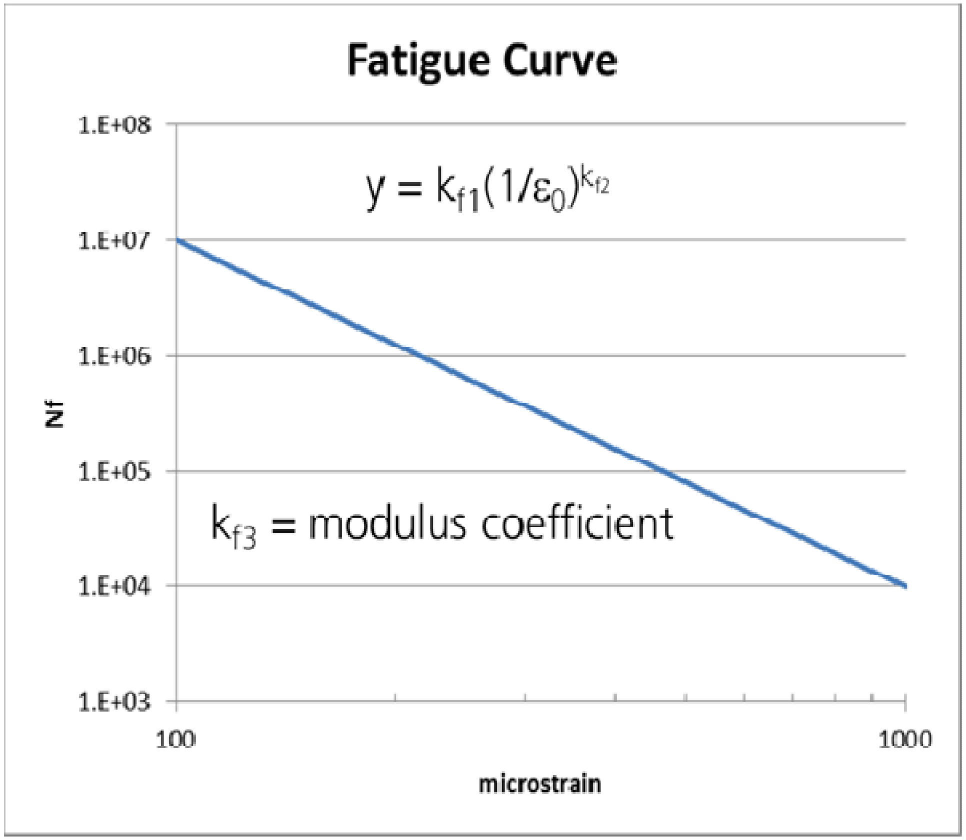
# AASHTOWare$^{TM}$ Pavement ME Design

- Traditional layered elastic model
- Comprehensive input data

- Fatigue cracking model
- $N_{f\text{-}HMA} = k_{f1}(C)(C_H)b_{f1}(\varepsilon_t)^{kf2\,bf2}(E_{HMA})^{kf3\,bf3}$

- Permanent deformation model
- $D_{p(HMA)} = \varepsilon_{p(HMA)}h_{HMA} = b_{r1}k_z\varepsilon_{r(HMA)}10^{kr1}\eta^{kr2\,br2}T^{kr3\,br3}$

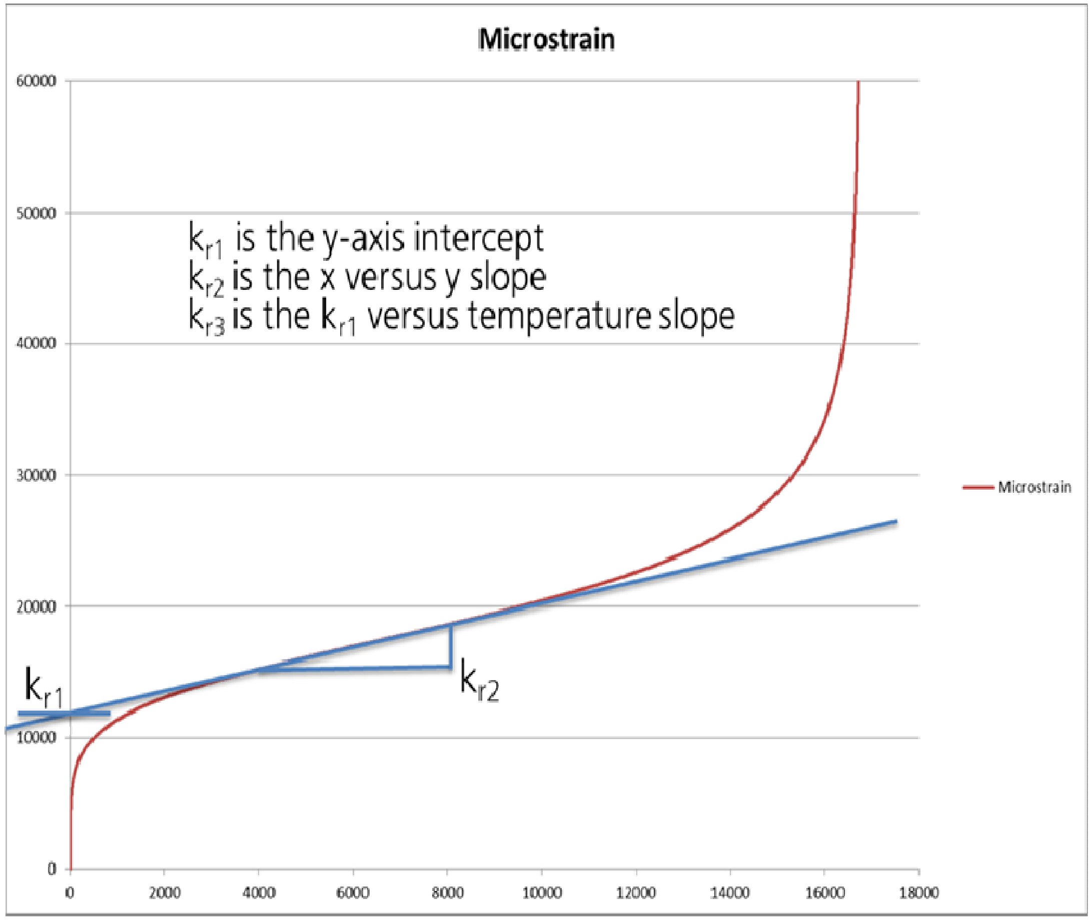
# Fatigue Global Calibration Parameters



# 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 |

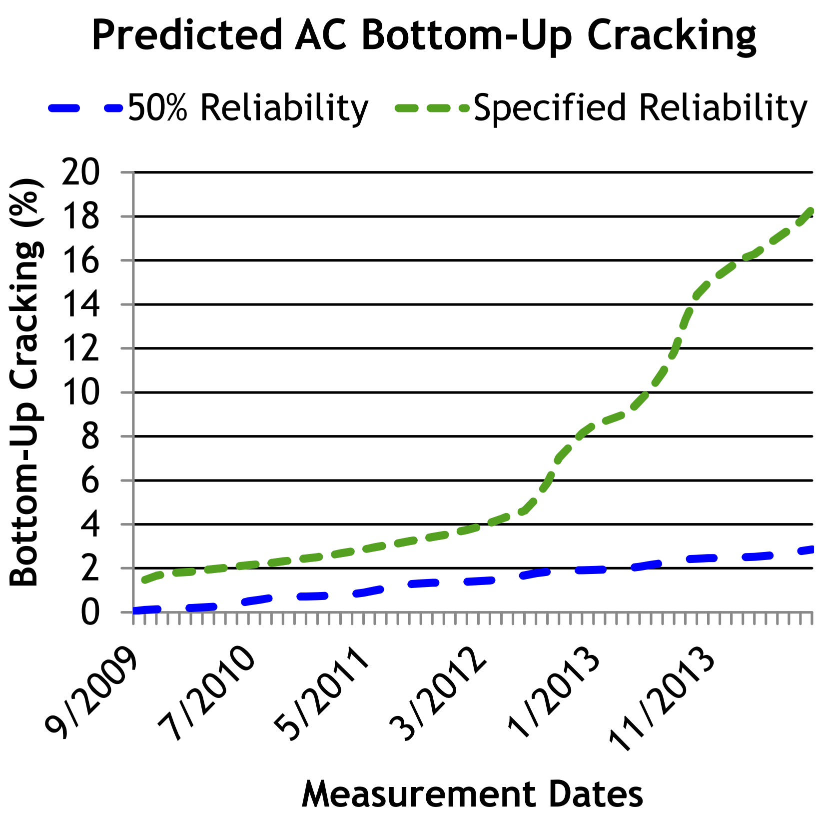
# Rutting Global Calibration Parameters

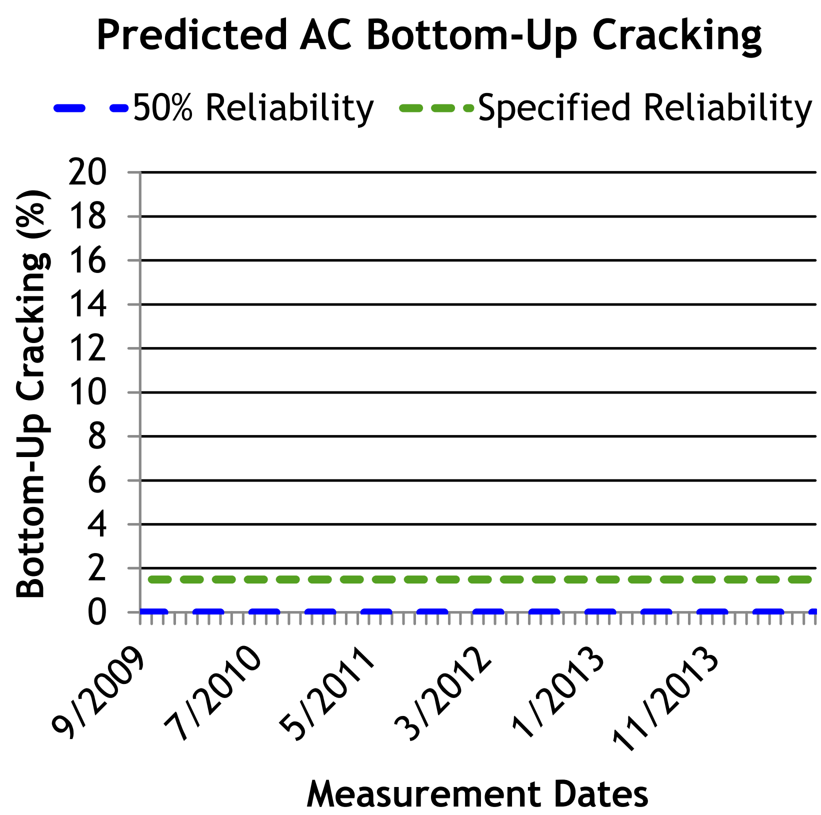


# Rutting Calibration Factors for Section N7

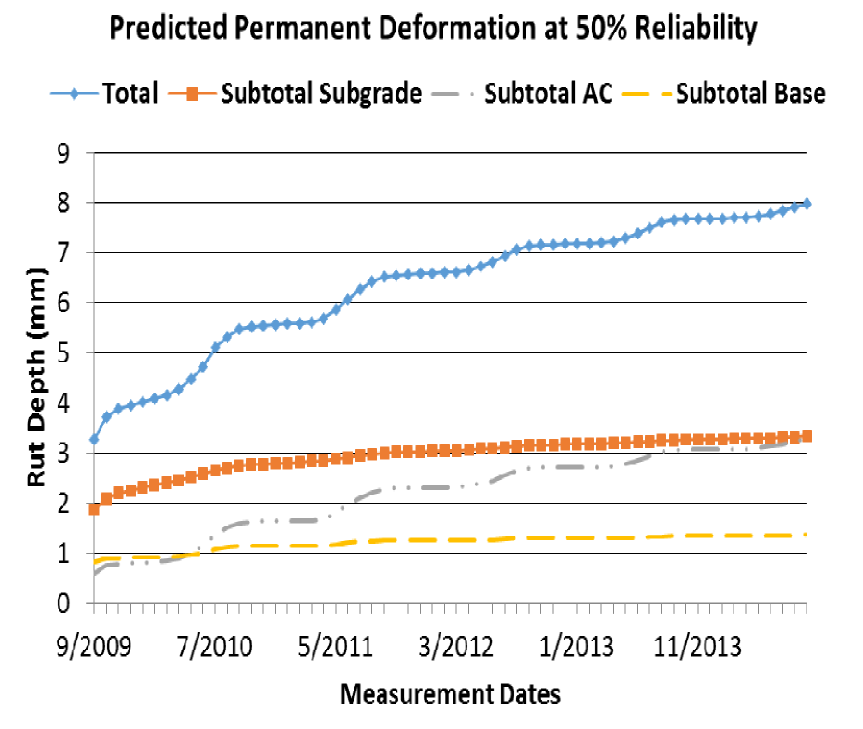
| | $k_{r1}$ | $k_{r2}$ | $k_{r3}$ |
|---|---|---|---|
| **MEPDG Standard Values** | -3.3541 | 0.4719 | 1.5606 |
| **S9 Calculated Values** | -3.7902 | 0.4719 | 1.5606 |
| **Ratios** | 0.8045 | 0.4791 | 1.0000 |
| **N7 Adjusted Values** | -2.6985 | 0.2261 | 1.5606 |

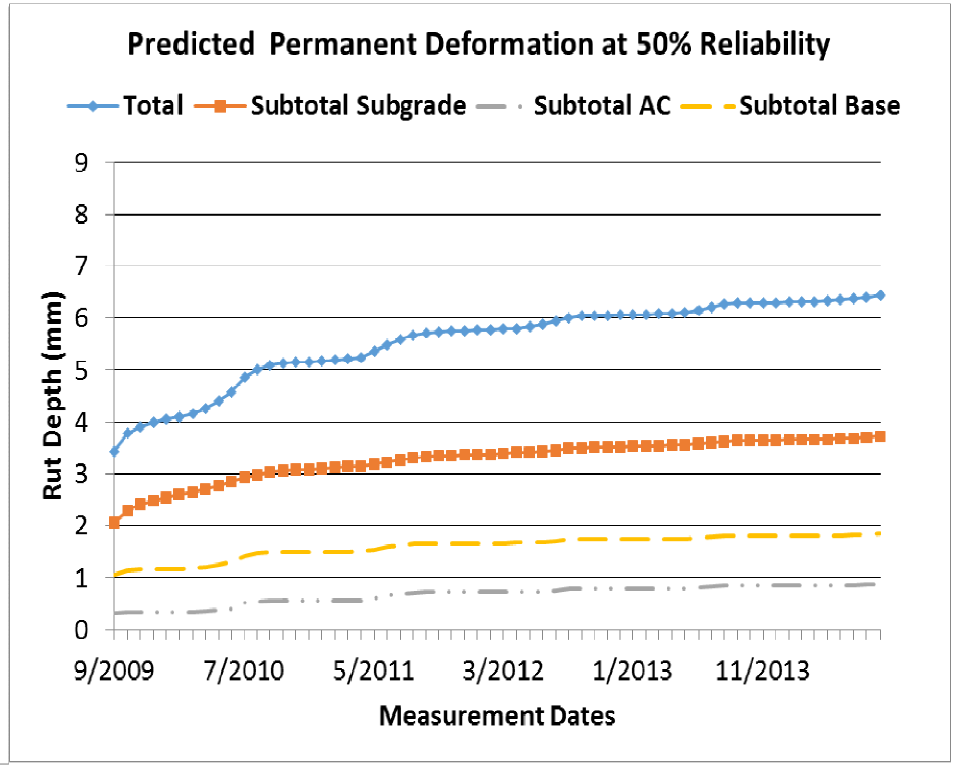
# S9 Predicted Cracking N7



# S9 Predicted Rutting N7

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# Predicted damage summary

| Pavement Distress | S9 | N7 |
|---|---|---|
| Total Permanent Deformation, mm | 10.2 | 8.4 |
| AC Permanent Deformation, mm | 6.4 | 1.5 |
| Bottom-Up Cracking, % Area | 18 | 1.5 |

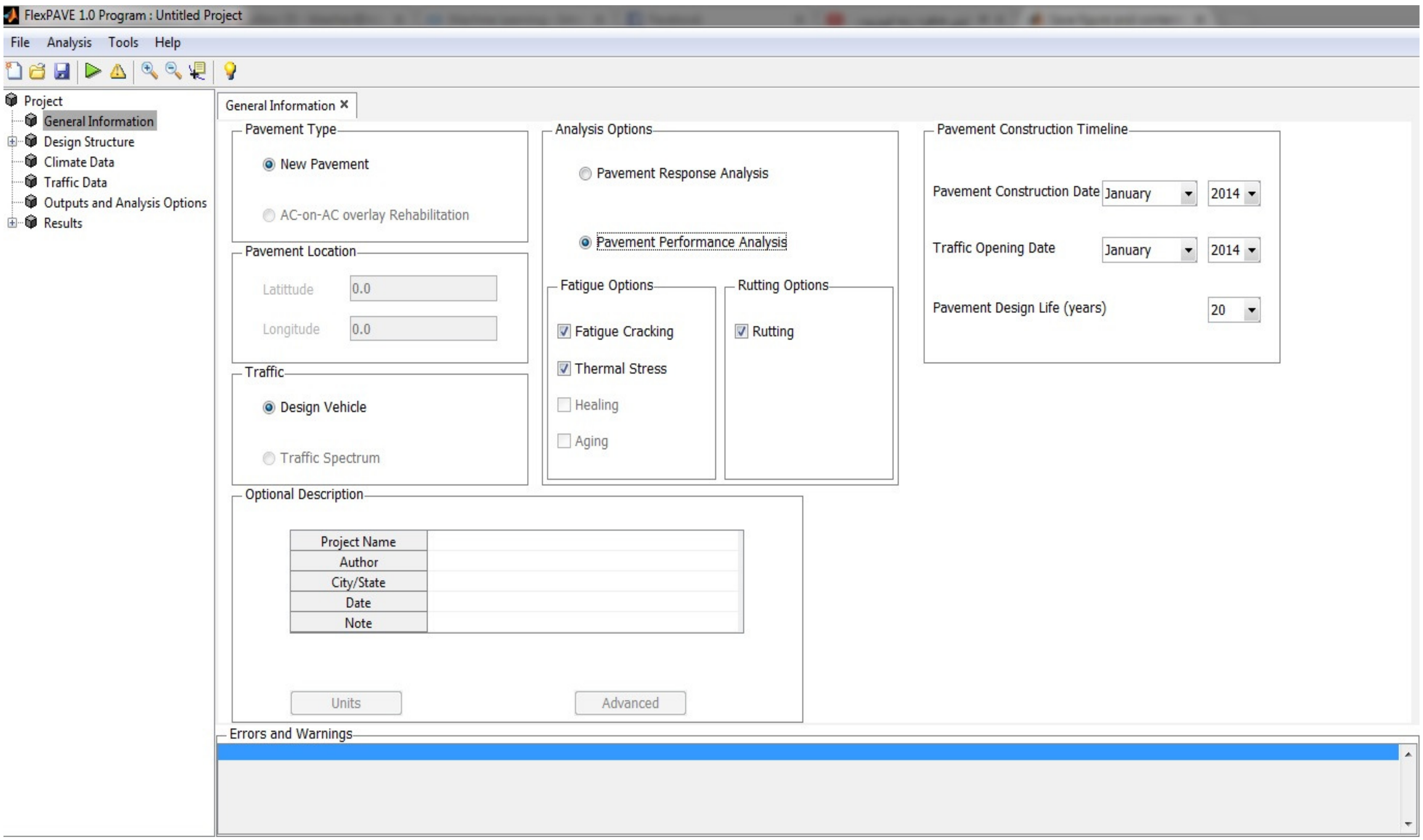
# Measured damage summary

| Pavement Distress | S9 | N7 |
|---|---|---|
| Total Permanent Deformation, mm | 6.0 | 1.6 |
| AC Permanent Deformation, mm | 6.0 | 1.6 |
| Bottom-Up Cracking, % Area | 10 | 0 |

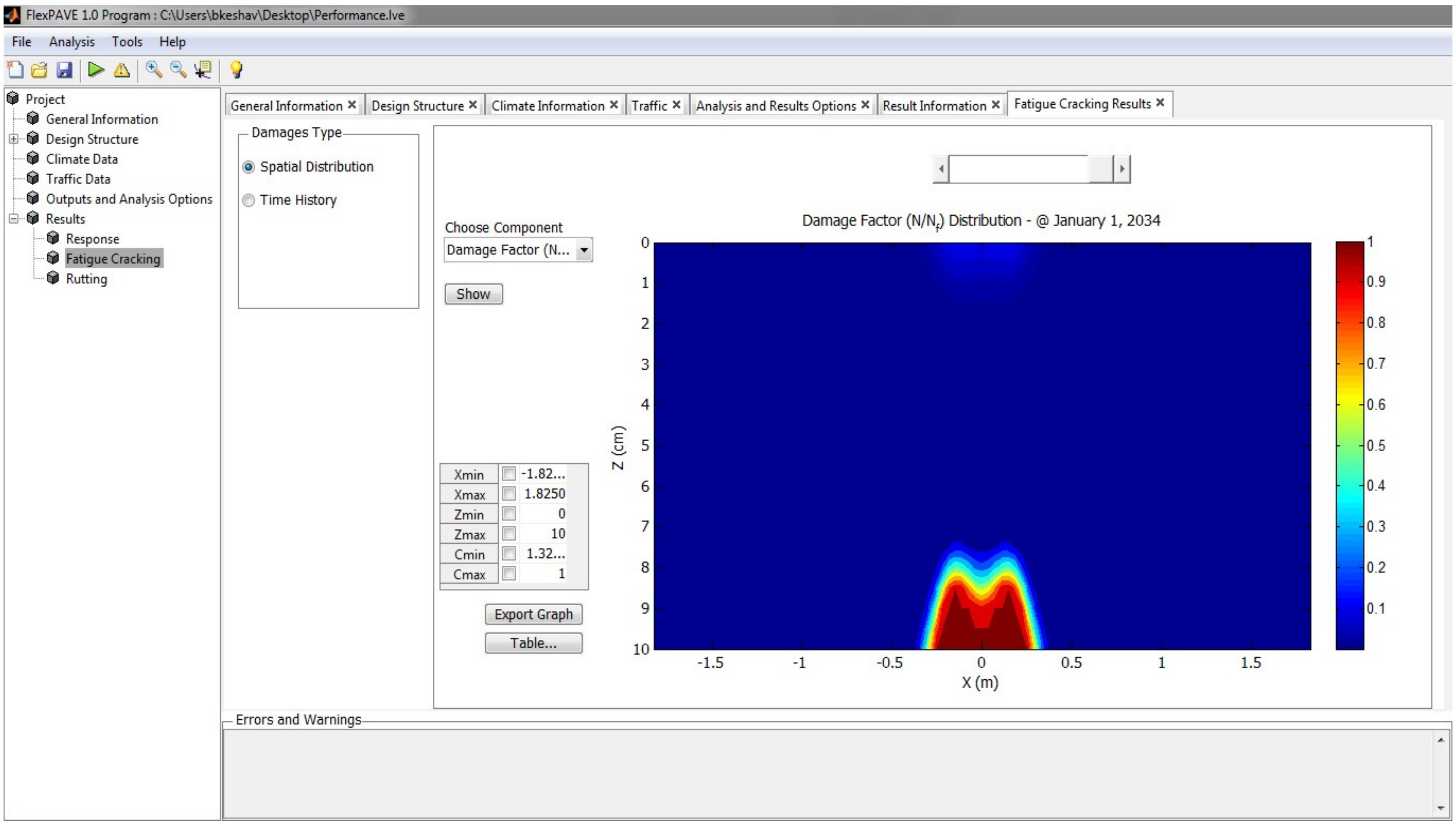
# FlexPAVE™ 1.0

- Three dimensional layered viscoelastic analysis for moving loads and thermal stresses
- Fatigue performance analysis based on Viscoelastic Continuum Damage (VECD) Model
- Rutting performance analysis based on the shift model
- Support for multiple axle and multiple wheel loading
- Integrated with EICM software to capture temperature variation for thermal stress analysis and material properties
- Integrated GUI that includes pre and post processors

# General Information

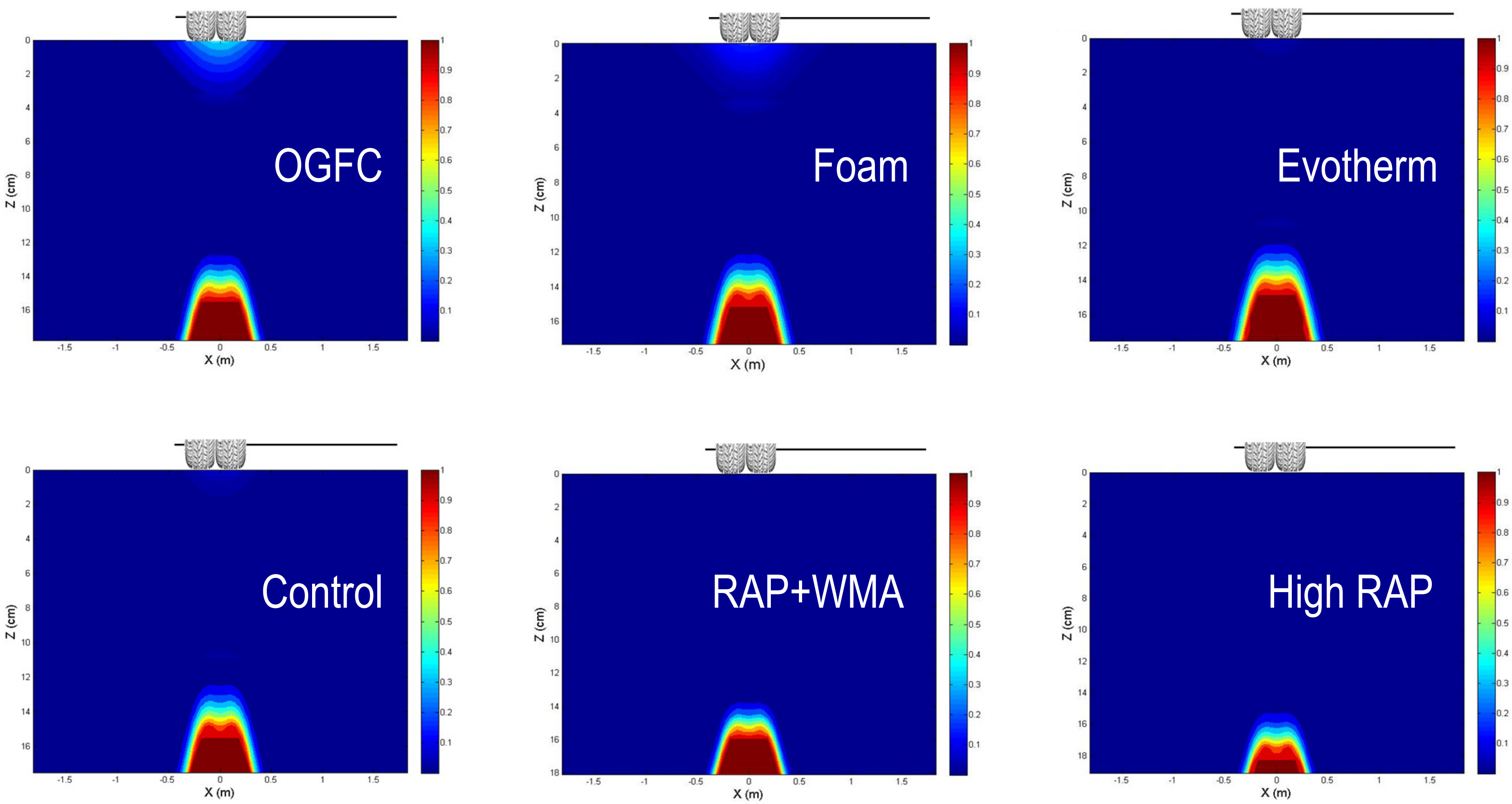


# Damage Contour



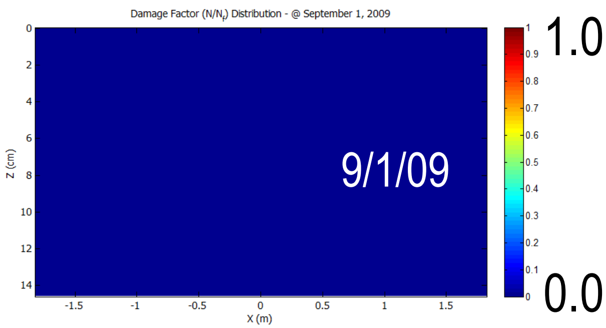
# FlexPAVE™ Simulation

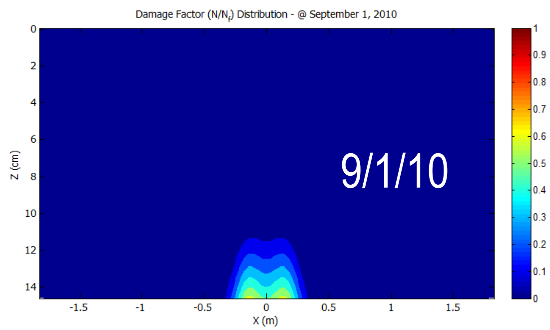
## *NCAT Test Track 2009 Performance Group*

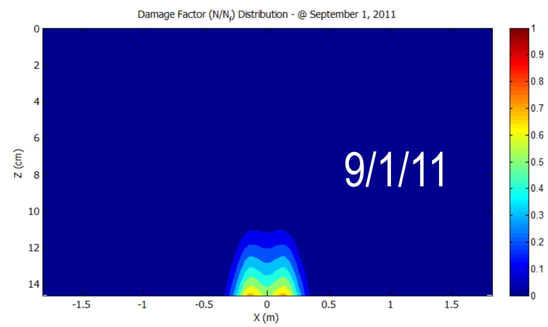


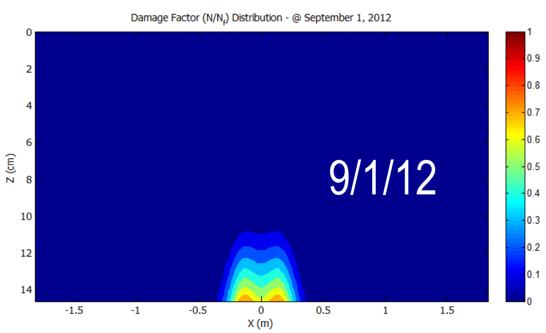
# FlexPAVE$^{TM}$ Simulation

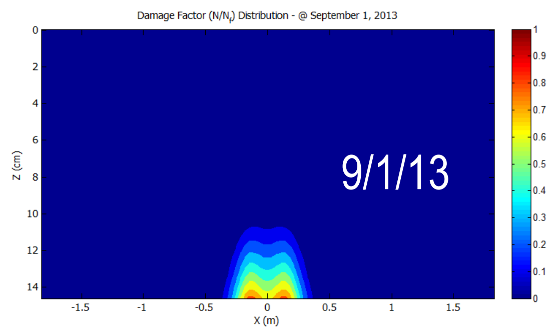
## *NCAT Test Track 2009 Section N7*

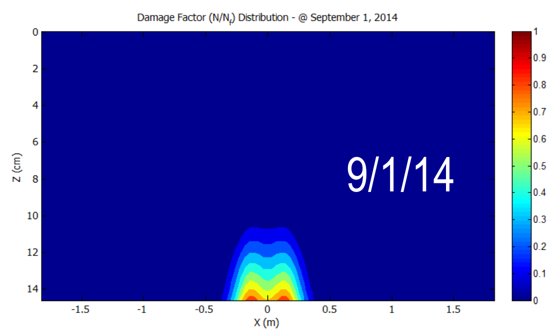


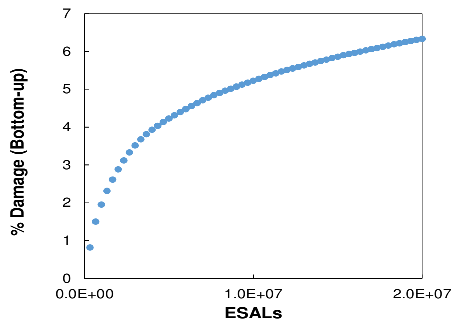



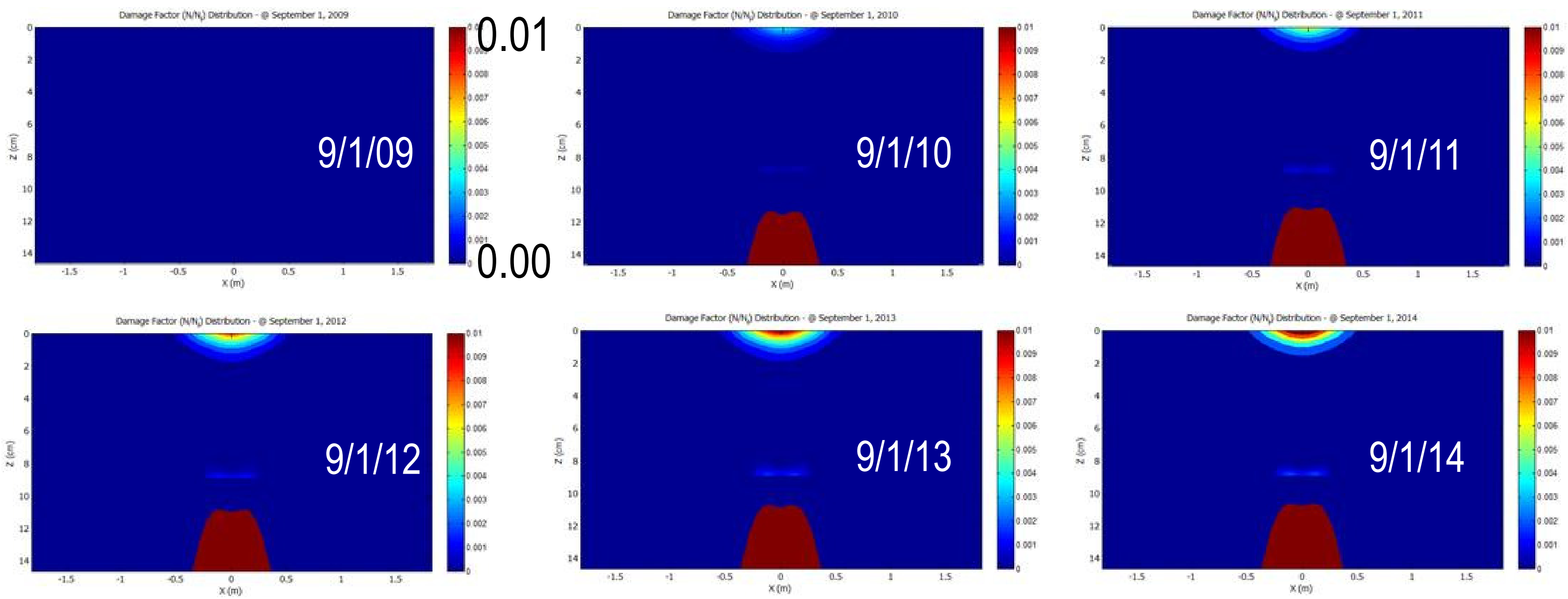



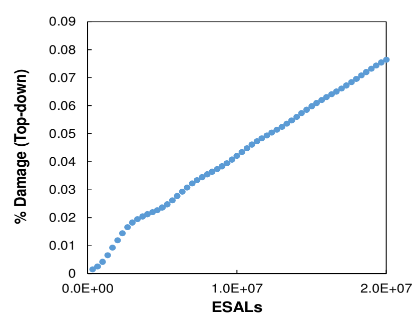



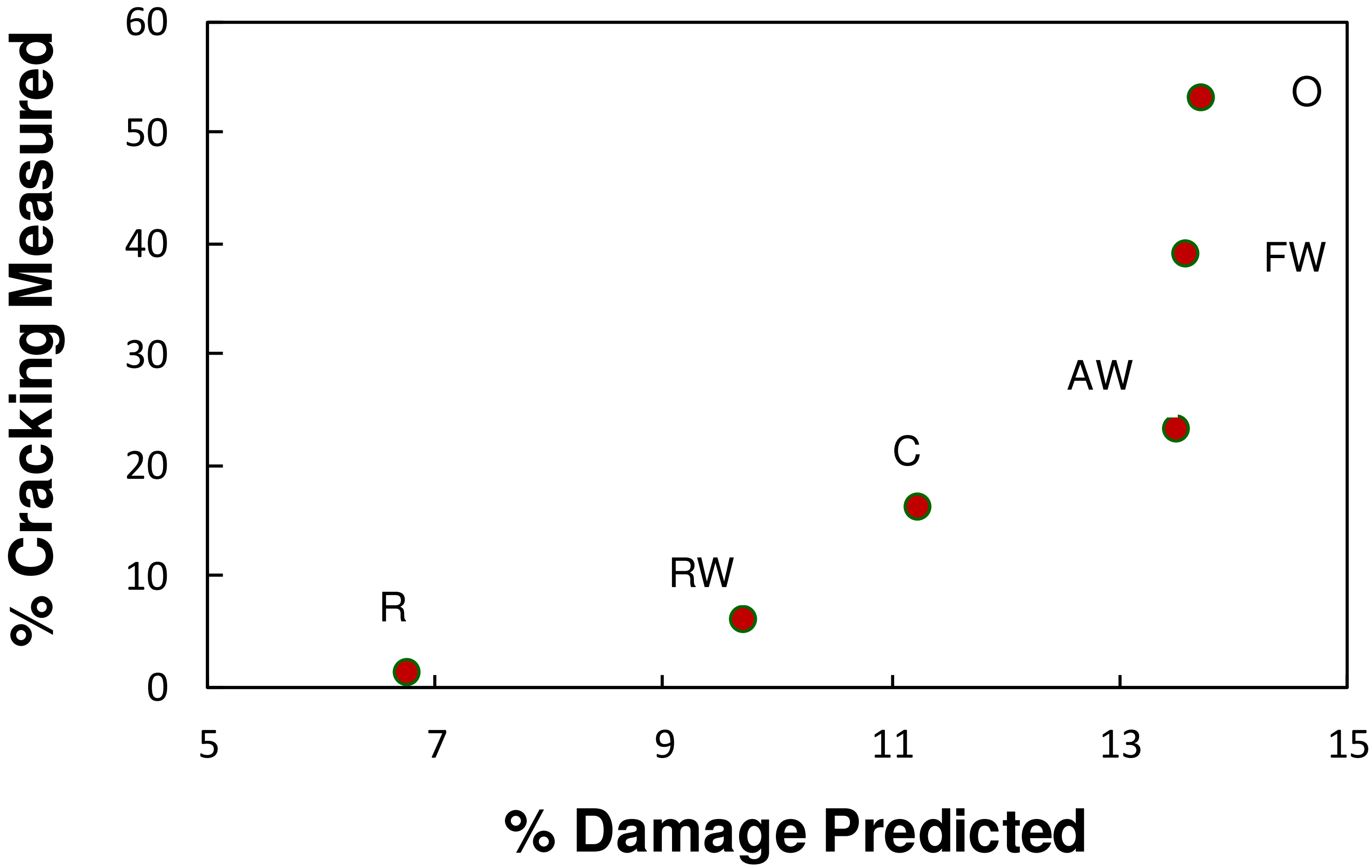
# FlexPAVE™ Simulation

## *NCAT Test Track 2009 Section N7 Expanded Scale*



# NCAT Test Track Prediction



# Conclusions

- NCAT section N7 developed fine surface cracking late in its life, but forensic analysis showed that the cracking was minor top down cracking not impacting the structural integrity of the pavement.
- Highly modified asphalt may be useful in perpetual pavement design.
- Demonstrated performance up to 20 million ESALs shows that the thickness of pavement structures may be reduced while retaining or even improving long term performance.

# Conclusions

- AASHTO M332 specifications (plus elastic recovery) have been effective to specify HiMA binders for commercial applications.
- Standardized test methods in increasingly common use are adequate to characterize HiMA mixtures for the purpose of pavement design.
- The current Pavement ME Design protocol is suited to designing perpetual pavements with highly modified asphalts. Relative global calibration factor adjustment with Level 1 design gives performance predictions that agree well with actual field performance relative to known structures.

# Conclusions

- Both AASHTOWare Pavement ME Design$^{TM}$ and FlexPAVE$^{TM}$ are effective design tools.
- ME Design currently lacks a validated model for top-down cracking.
- FlexPAVE currently lacks a built-in aging model and so required aged material properties.
- We will be doing follow up modeling with both to compare!

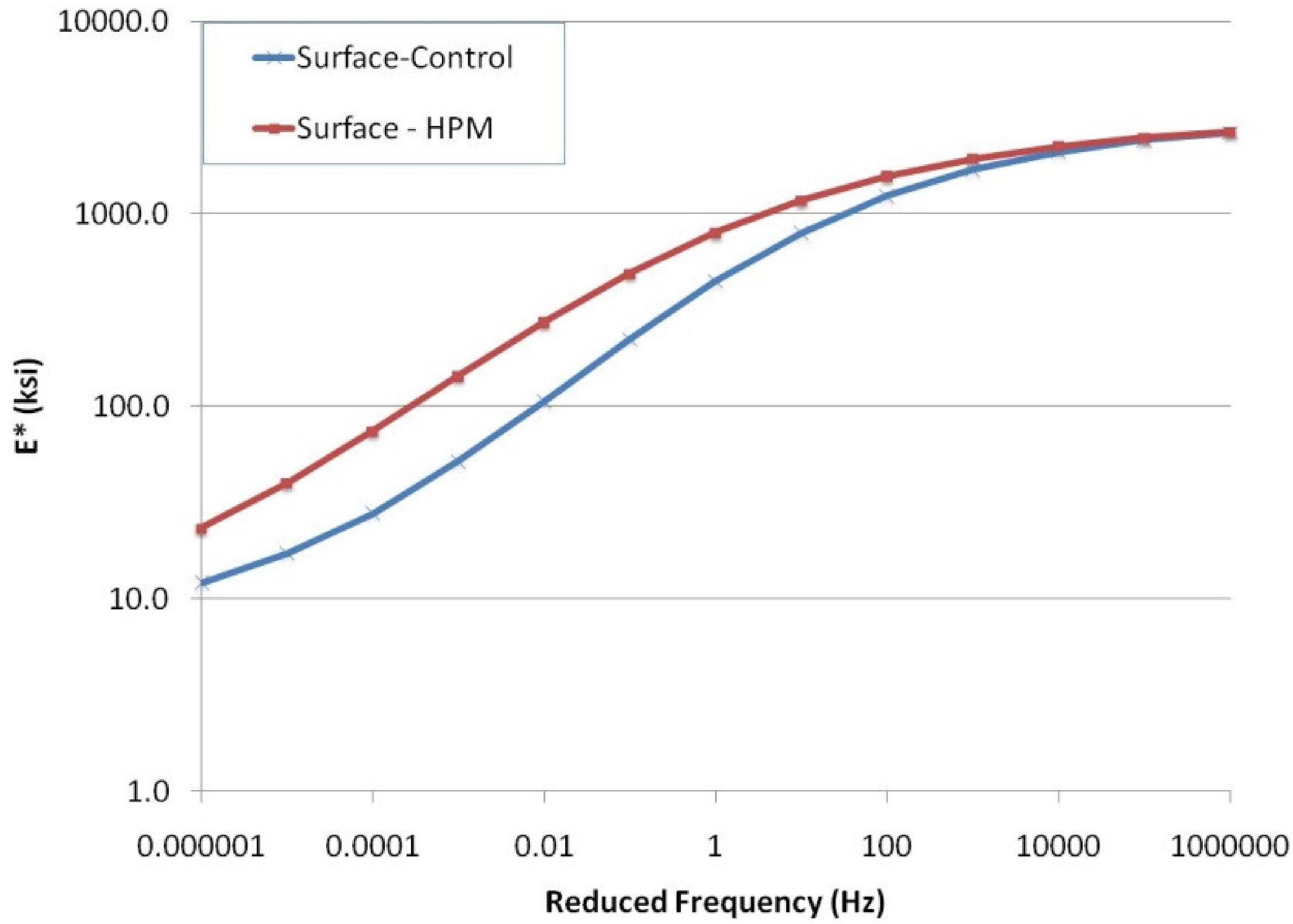
# HiMA Market Applications – Where Does it Add Value?

- Structural Applications
  - With a sound base, thinner pavements with lower upfront cost
  - Demonstrated in many field applications & Ohio University APLF
  - With weak base, much longer lifetime can be achieved
- Thin Overlays
  - Superior resistance to reflective cracking BUT requires finer, richer mix.
- Preservation Surfacing such as micro surfacing
- Open Grade Mixes for Reduced Raveling
- SAMI Layers
- High Stress Applications – ramps, intersections
- AASHTOWare® Pavement ME Design works for HiMA designs

# In General Terms, What Does HiMA Do to Mixture and Performance Characteristics?

- Modulus
- Cracking Resistance
- Rutting Resistance
- Cracking Versus Rutting
- Structural Integrity

# Dynamic Modulus Testing Results – 9.5 mm NMAS Mixtures

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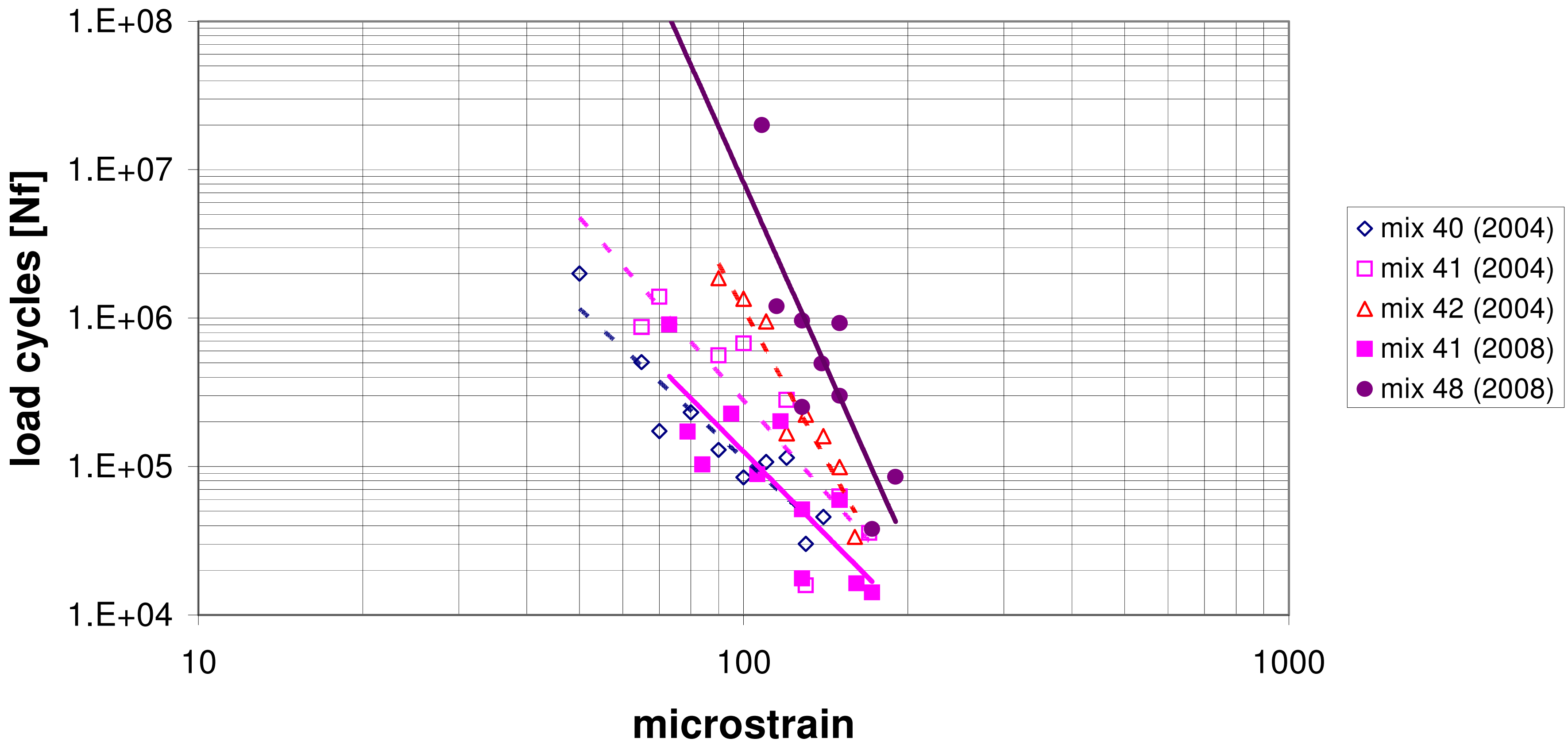
# Four Point Bending Beam Fatigue Results




Full sinusoidal loading. Cited strains are ½ amplitude

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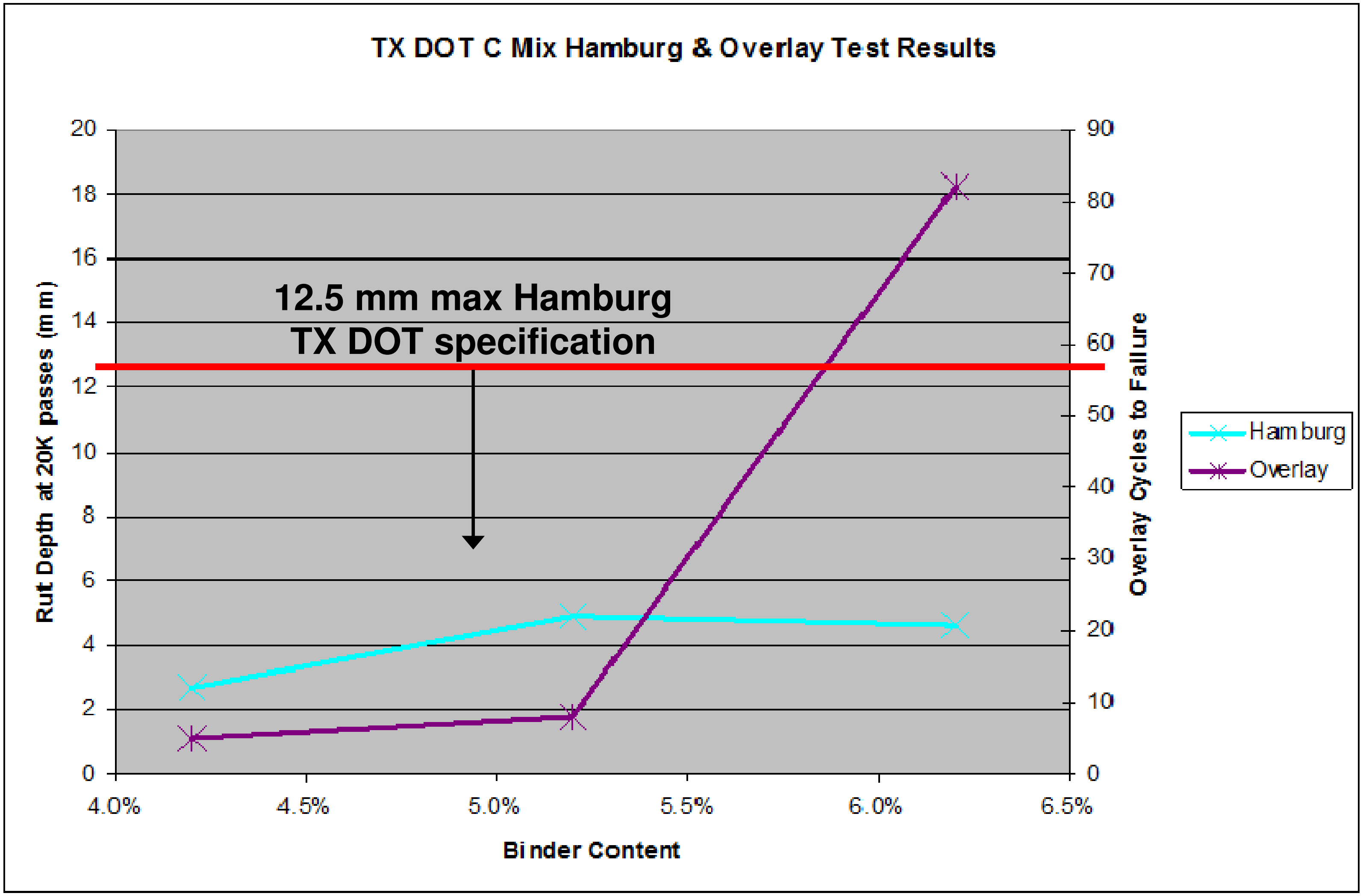
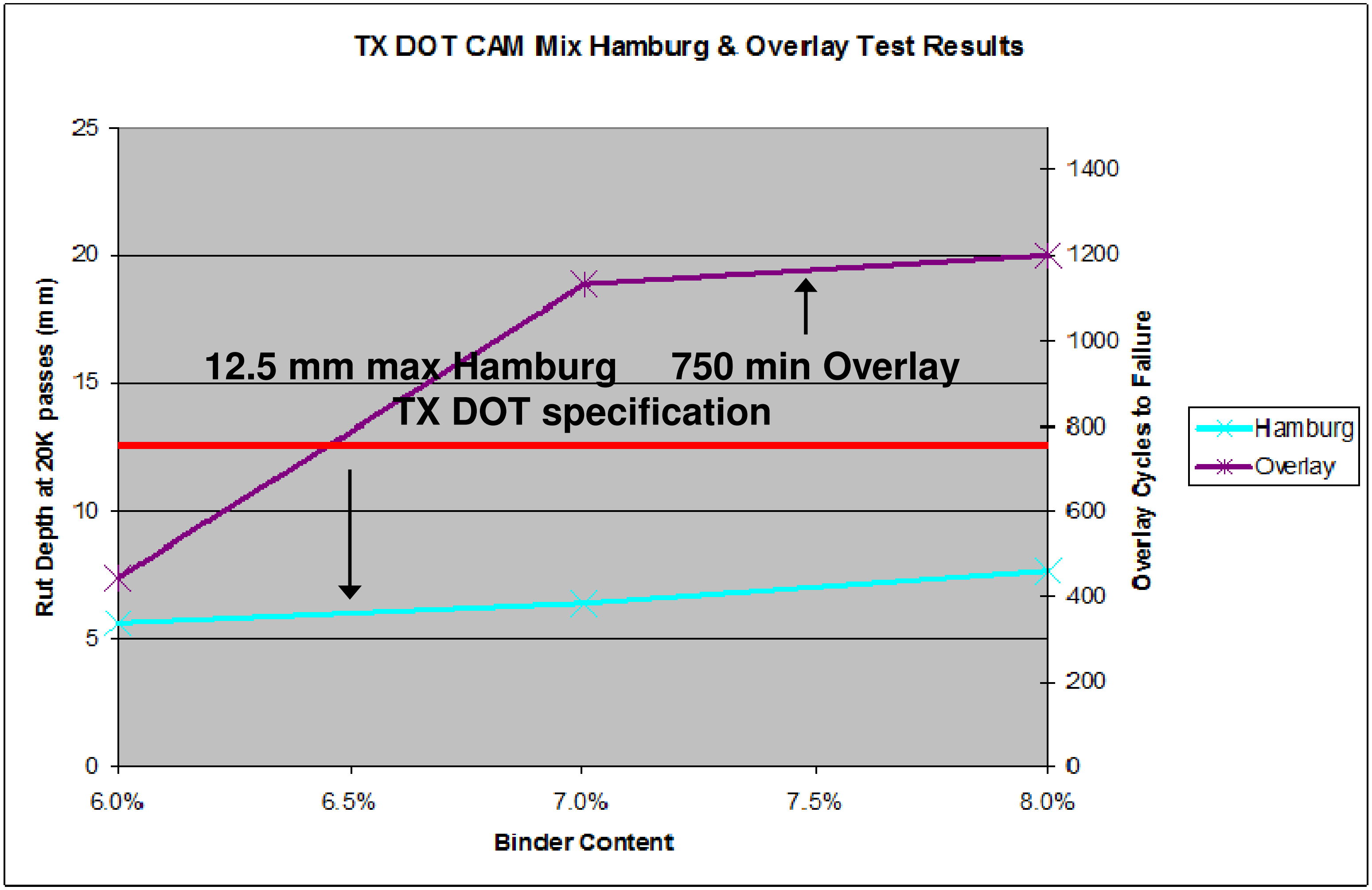
# TX DOT Overlay Specifications – Coarse Dense Mix



# TX DOT Overlay Specifications – Fine Rich Mix

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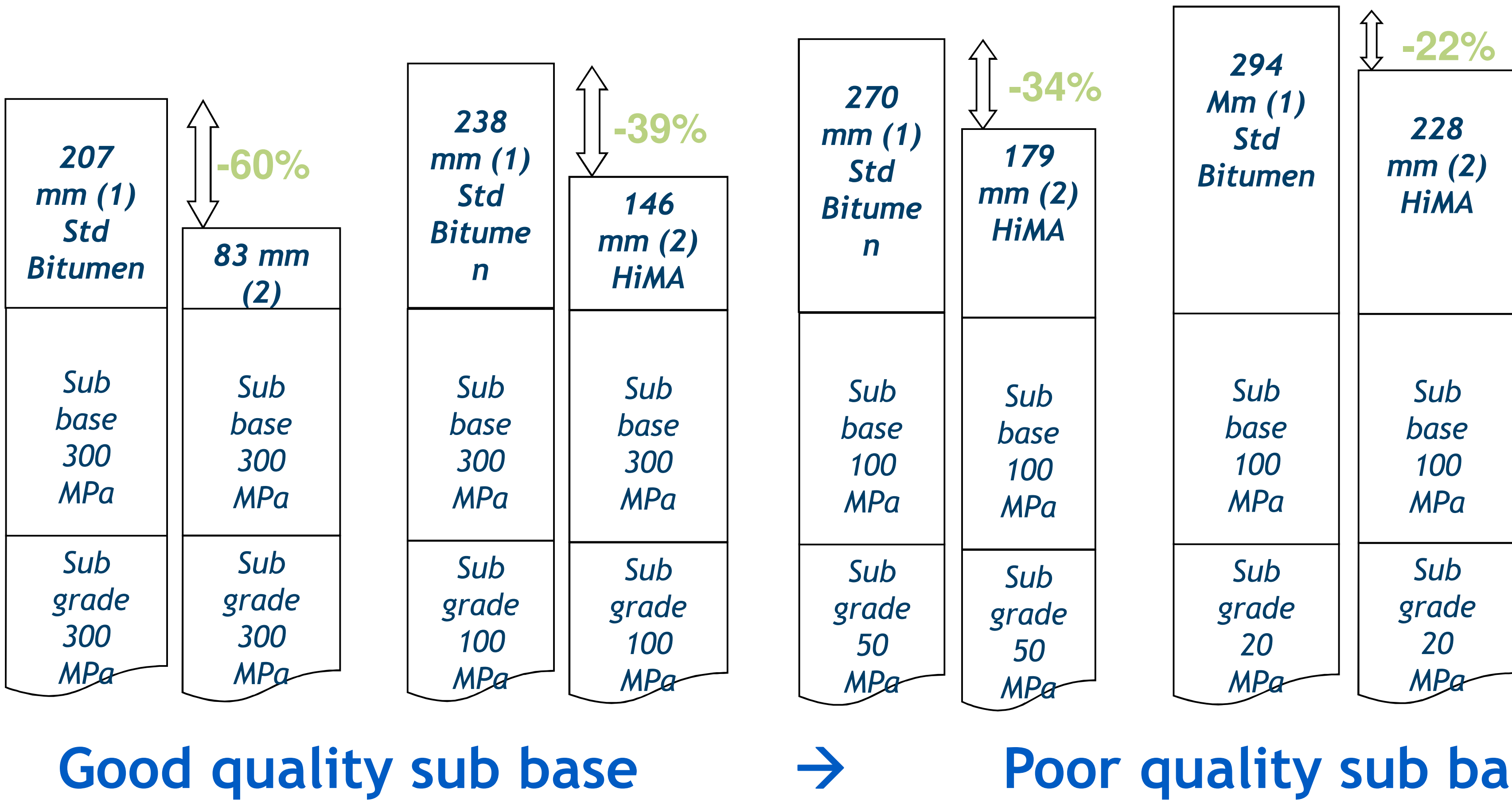
# Thickness Reduction Capability




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

HiMA = Highly Modified Asphalt

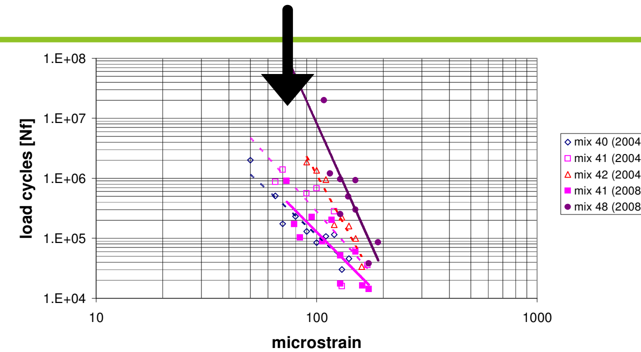
# HiMA Mixture and Pavement Design Concepts

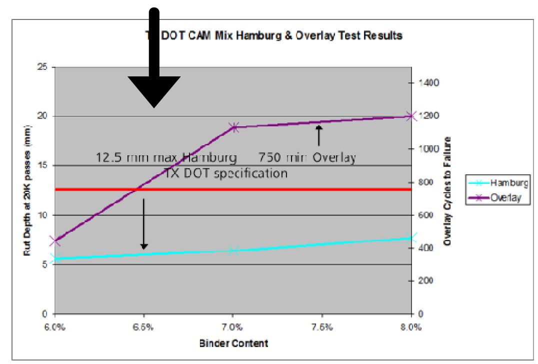
- So how should these observations apply to design principles?
- Structural Pavement – Strong Base
- Structural Pavement – Weak Base
- Overlay – Undamaged Pavement
- Overlay – Damaged Pavement
- Waterproof Bridge Deck
- SAMI

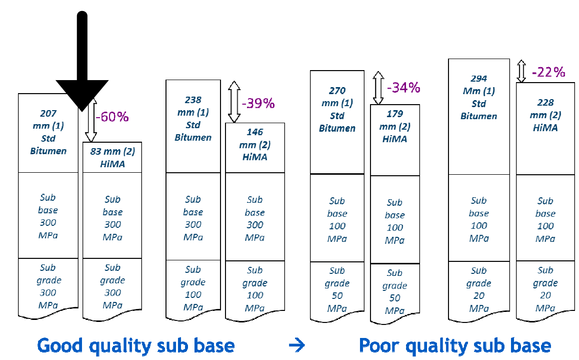
# Structural Pavement – Strong Base

- Lowest strain. Best Case!
- Key distress—bottom up fatigue cracking
- Solution—standard mix design, perhaps slightly richer, 0.2-0.3%.
- Thinner pavement design for lower up front cost and life cycle cost for a perpetual pavement.

| |
|---|
| 1 ¼” (PG 76-22 E, 9.5 mm NMAS, 80 gyrations) |
| 2 ¼” (PG 76-22 E,19mm NMAS; 80 gyrations) |
| 2 ¼” (PG 76-22 E;19mm NMAS; 80 gyrations) |

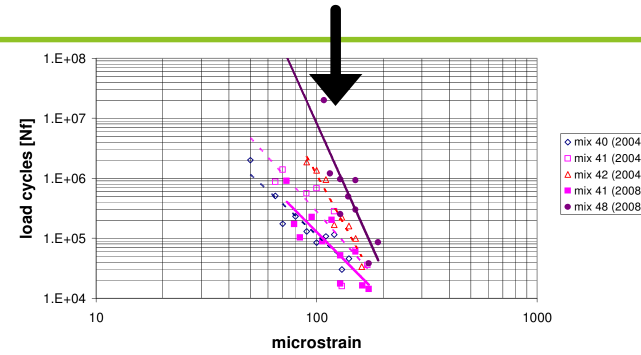


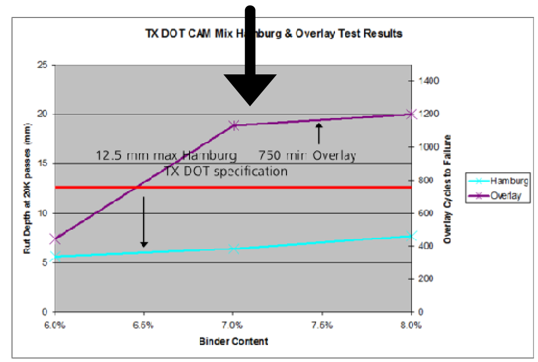



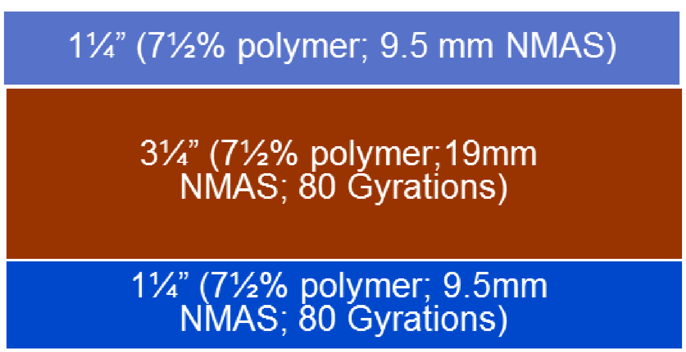



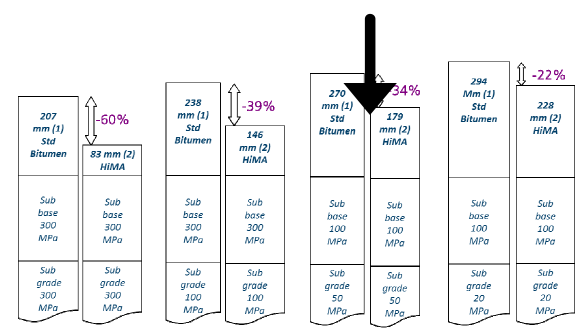
# Structural Pavement – Weak Base

- Moderate strain.
- Key distress—risk of subbase, subgrade damage, bottom up cracking.
- Solution—rich bottom layer, little or no thickness reduction.
- Likely more expensive up front cost, but perpetual pavement vs. rehab every few years.



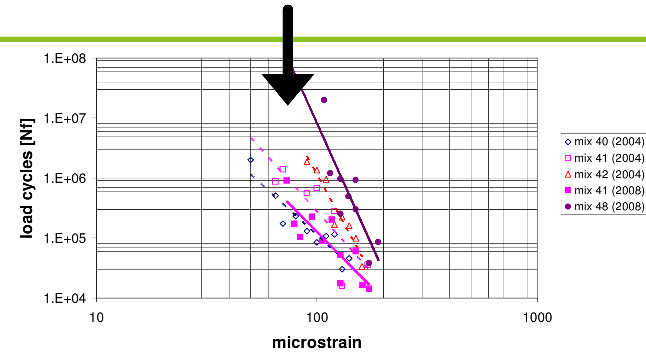



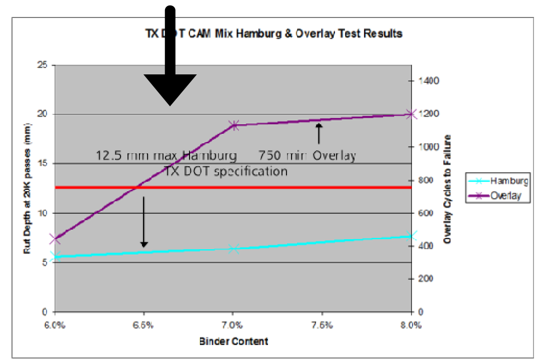



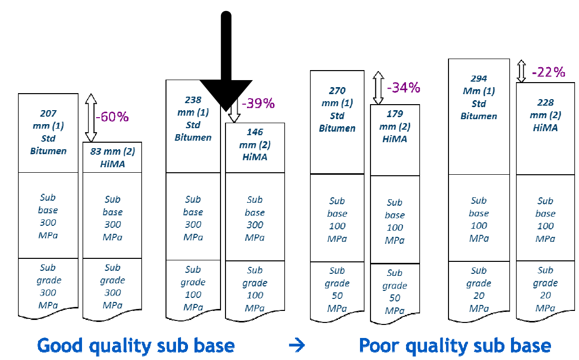



# Overlay – Undamaged Pavement

- Low strain.
- Key distress—should be able to achieve substantial thickness reduction, but be aware of potential for rutting below surface.
- Solution—standard mix design, perhaps 0.2-0.3% richer to be on the safe side.
- Thinner pavement for lower up front cost and life cycle cost.



# Overlay – Damaged Pavement

- Very high localized strain.
- Key distress—reflective cracking.
- Solution—take advantage of rutting resistance with a finer, richer mix than standard, e.g., New Jersey HPTO mix
- Mix expensive up front mix, but much better life cycle cost analysis.

**SECTION 406 – HIGH PERFORMANCE THIN OVERLAY (HPTO)**

**406.01 DESCRIPTION**

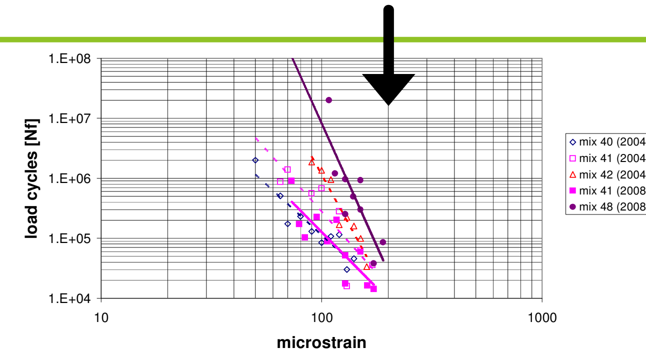
This Section describes the requirements for constructing high performance thin overlay (HPTO).

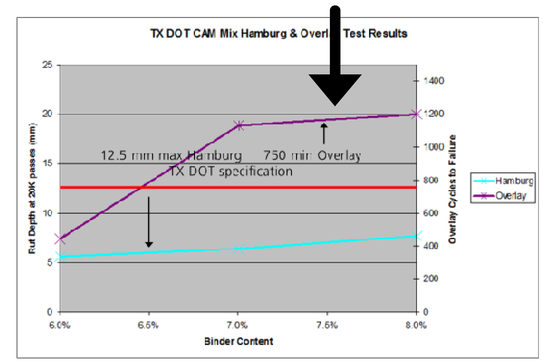
**406.02 MATERIALS**

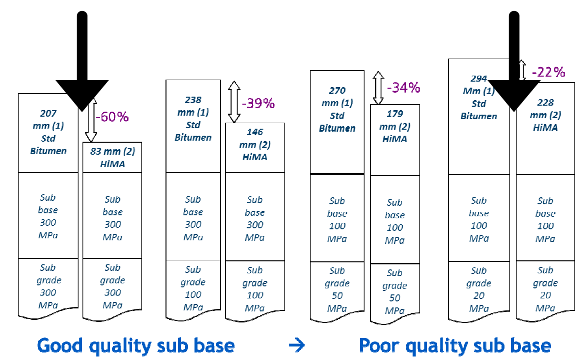
**406.02.01 Materials**

Provide materials as specified:

Tack Coat:
Emulsified Asphalt, Grade RS-1, SS-1, SS-1h, Grade CSS-1 or CSS-1h .................... 902.01.03
HPTO .................... 902.08

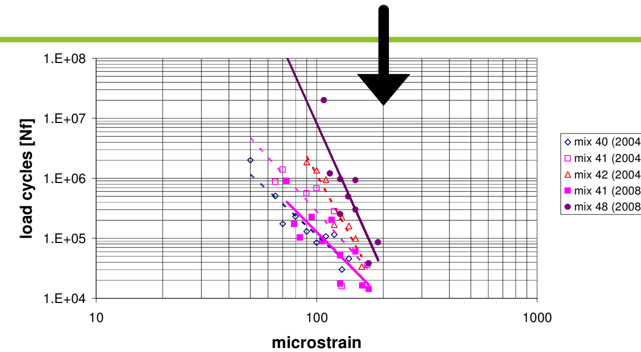


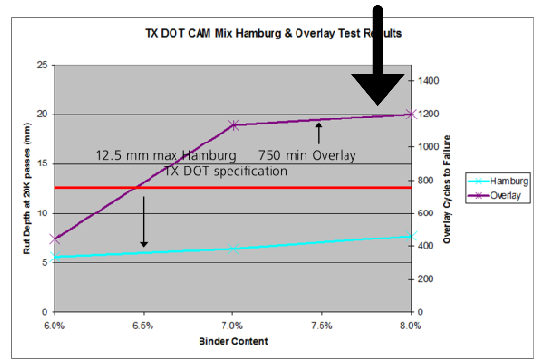



# Waterproof Bridge Deck Mix

- High strain. “Zero” voids.
- Key distress—fatigue cracking, water permeation
- Solution—very rich fine mix with <2% voids.
- Lower cost & far better workability than alternatives.




SECTION 555 - BRIDGE DECK WATERPROOF SURFACE COURSE

**555.01 DESCRIPTION**

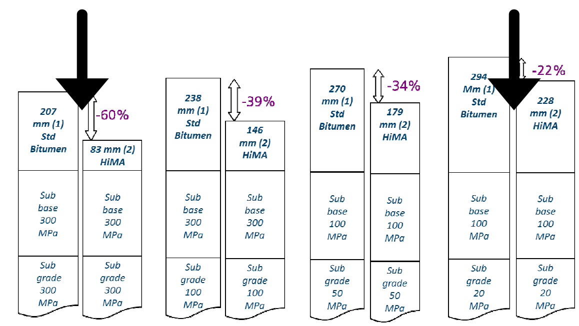
This Section describes the requirements for constructing bridge deck waterproof surface course (BDWSC).

**555.02 MATERIALS**

**555.02.01 Materials**

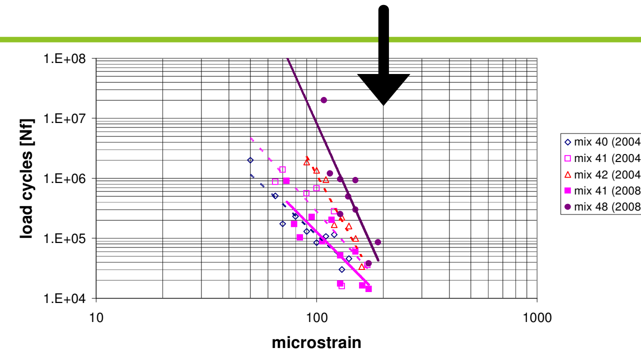
Provide materials as specified:

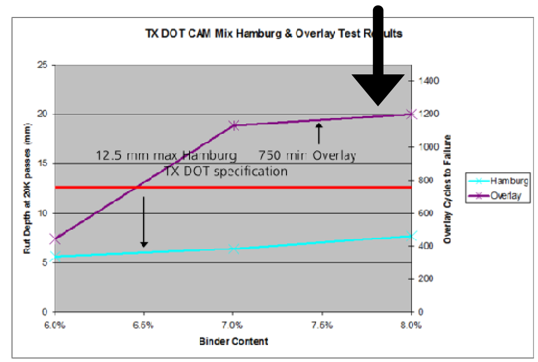
Tack Coat 64-22, PG 64-22 ....................902.01.01
Tack Coat:
Cut-Back Asphalt, Grade RC-70 ....................902.01.02
Emulsified Asphalt, Grade RS-1, SS-1, SS-1h, Grade CSS-1 or CSS-1h ....................902.01.03
Joint Sealer, Hot Poured ....................914.02
Polymerized Joint Adhesive ....................914.03

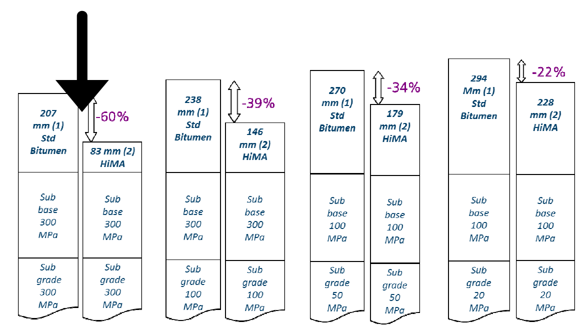


# Stress Attenuating Mix Interlayer (SAMI)

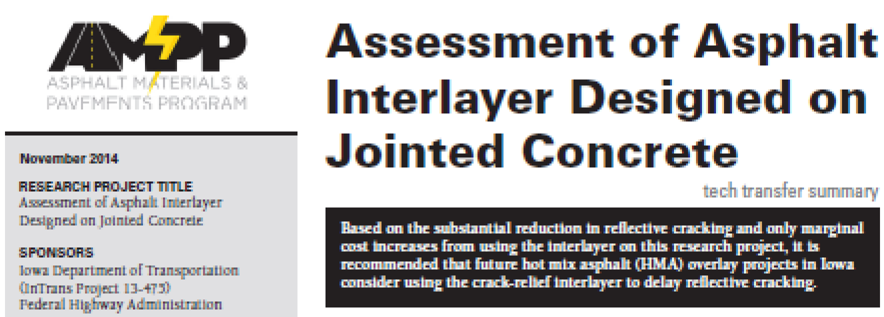
- High strain. Low voids.
- Key distress—reflective cracking.
- Solution—very rich fine mix with low voids.
- Lower cost than thick structural layer.




Good quality sub base → Poor quality sub base




November 2014

RESEARCH PROJECT TITLE
Assessment of Asphalt Interlayer Designed on Jointed Concrete

SPONSORS
Iowa Department of Transportation (InTrans Project 13-475)
Federal Highway Administration

**Assessment of Asphalt Interlayer Designed on Jointed Concrete**

tech transfer summary

Based on the substantial reduction in reflective cracking and only marginal cost increases from using the interlayer on this research project, it is recommended that future hot mix asphalt (HMA) overlay projects in Iowa consider using the crack-relief interlayer to delay reflective cracking.

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