NJDOT's Strategy for Rehabilitation of Composite Pavements

Presented By:

Thomas Bennert, Ph.D.
Center for Advanced Infrastructure and Transportation (CAIT)
Rutgers University

PAPA
Pennsylvania Asphalt Pavement Association
Pennsylvania Rides on US.

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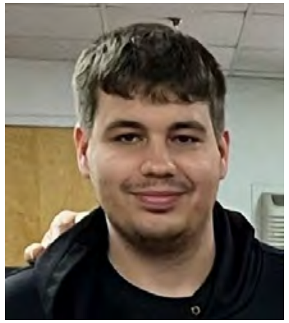

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Ed Haas

Shelby Maigis

Ed Wass, Jr.

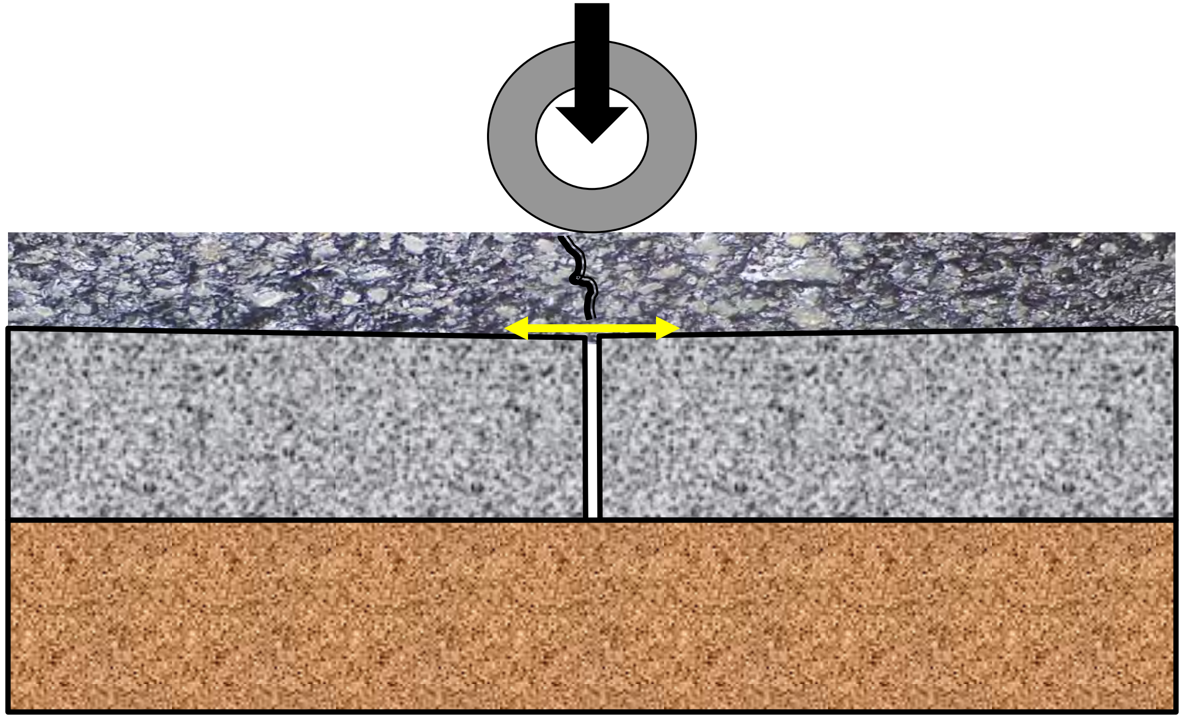
Reflective Cracking & NJ's Composite Pavements Prior to 2006

Reflective Cracking

- Reflective Cracking – the type of fatigue cracking generally witnessed when a crack in an asphalt overlay is generated immediately above the longitudinal joint and/or crack in the underlying PCC pavement
- Different loading mechanisms (or combination of) can cause reflective cracking
  - Mode 1 – Excessive Vertical Bending at PCC joint/crack (Pure Tensile Straining)
  - Mode 2 – Horizontal Deflections (PCC slab expansion and contraction) due to environmental cycling
  - Mode 3 – Poor Load Transfer at joint/crack results in independent movement of PCC slabs

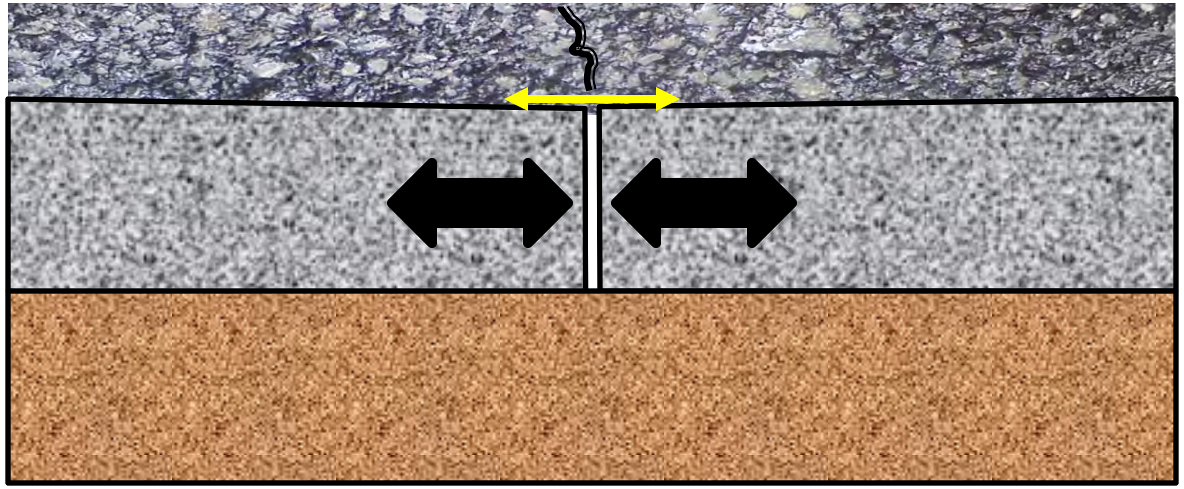
Mode 1 – Excessive Vertical Bending

- Mode 1 – Excessive Vertical Bending at PCC joint/crack (Classical Tensile Straining)
  - Applied axle load over the joint/crack area creates excessive bending
  - Generates high tensile strain at the bottom of the HMA layer
  - Cracking potential is a function of the flexural fatigue properties of the asphalt mixtures



Mode 2 – Excessive Vertical Bending

- Mode 2 – Horizontal Deflections (PCC slab expansion and contraction) due to environmental cycling
  - No traffic loading required
  - Temperature cycling
    - Most critical in colder temperatures with a significant cooling cycle
  - Function of the expansion/contraction properties of the PCC materials, slab dimension, PCC slab/base friction

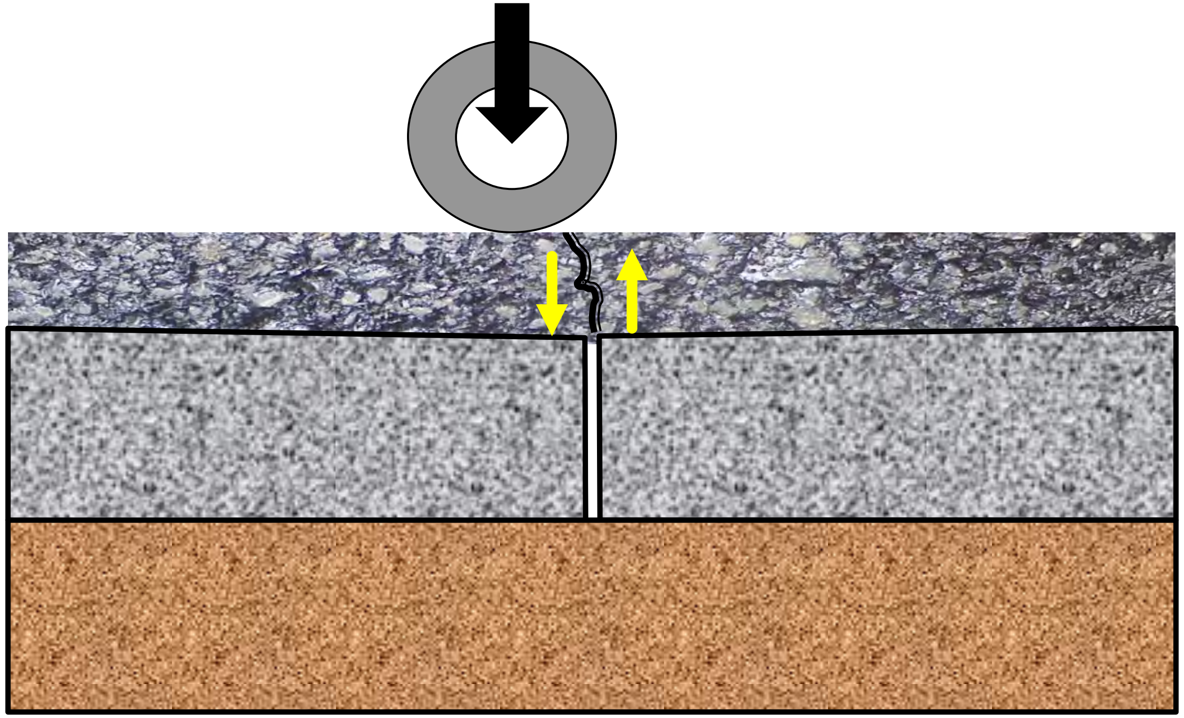


$$\Delta L = CTE(L)(\Delta T)(\beta)$$

ΔL = change in slab length; L = initial slab length
ΔT = rate of change in PCC temperature (24 hr);
β = slab/base friction coefficient

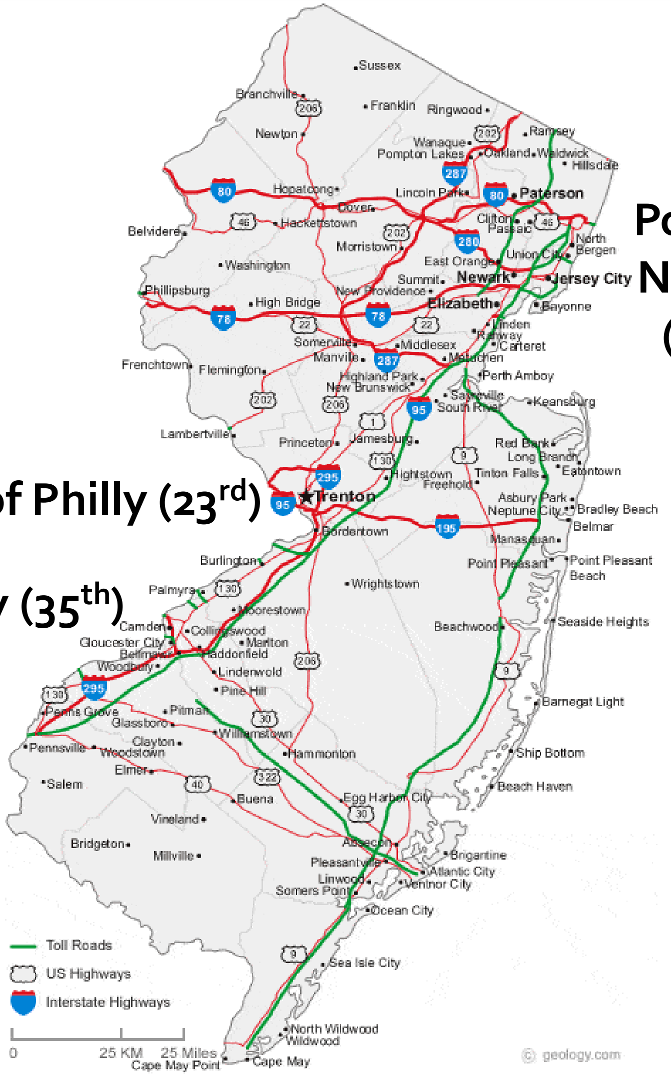
Mode 3 – Shear Due to Poor Load Transfer

- Mode 3 – Shear Load Due to Poor Load Transfer
  - Research has shown to be a crack accelerator, not necessary an initiator
  - Poor load transfer applies a shear force that accelerates the crack growth of a crack
    - Example: Thick, folded paper – hard to start a tear, but once cut, tearing is much easier



NJDOT's "Conditions"

- Prior to 2006, existing asphalt mixtures
  - Early 125 and 100 N_{des} mixes were dry
  - Significant cracking issues
    - Flexible (longitudinal); Composite (transverse)
- Traffic conditions
  - 29% increase from 1990 to 2006
  - 30% projected from 2006 to 2025
    - 99 billion miles traveled
- Climate conditions
  - Precipitation: 43 to 48 inches per year
  - Ave. State Air Temp: 53°F
  - Ave. 24 hour Temp Change: 20°F (as high as 30°F)
- Pavement conditions
  - Over 55% of NJDOT pavements are composite

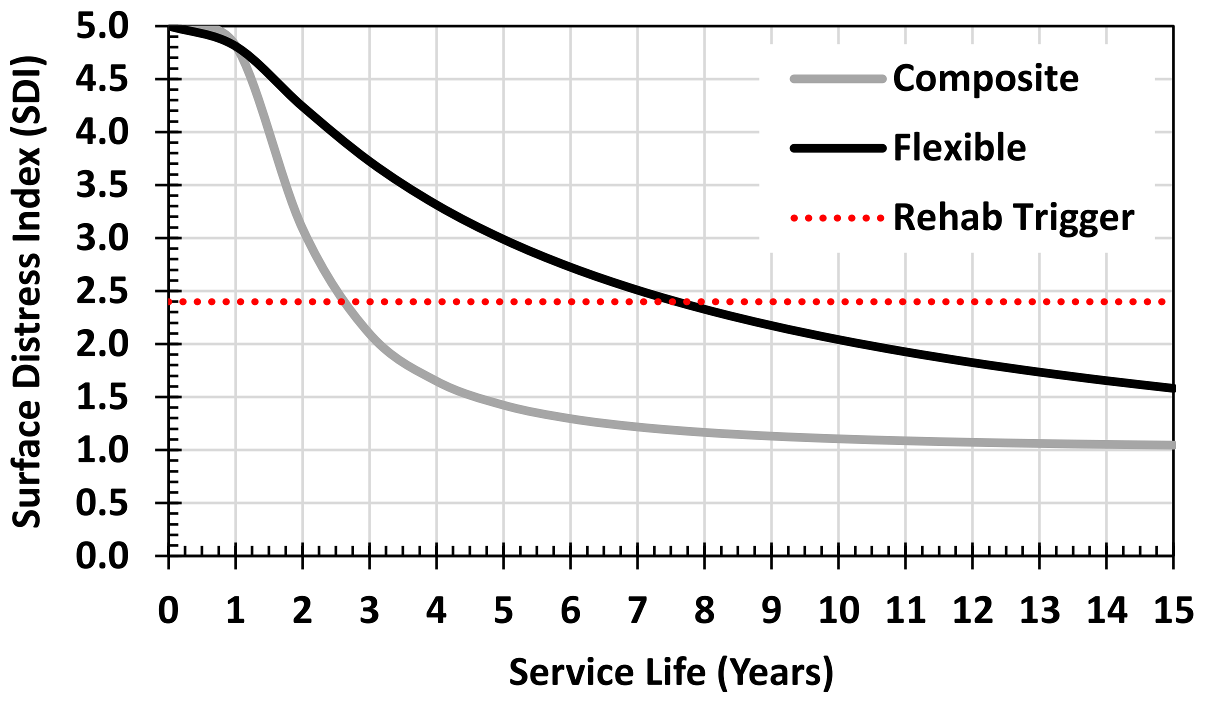


NJDOT's "Conditions"

- Most constructed PCC pavements
  - Length = 78'2" ft (25 m)
  - Width = 12'; Thickness = 9 inches
  - ¾" expansion joints with 1 ¼" steel dowels
- If 1st generation HMA overlay, saw and seal conducted
  - Attempts to saw & seal 2nd generation overlays difficult in finding joints
  - Generally poor construction practices

NJDOT Rehabilitation Efforts Prior to 2006

- Prior to 2006, NJDOT typically used;
  - Repair HMA
  - Mix "X", Pave "X"
    - If budget allowed, Pave "X + 2"
      - "1 Year Performance with Each 1 Inch of HMA"
  - Typical pavement performance on composite pavements was about 2 to 5 years before being flagged for rehabilitation

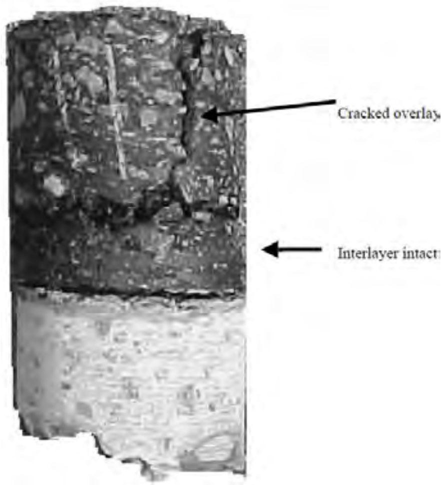


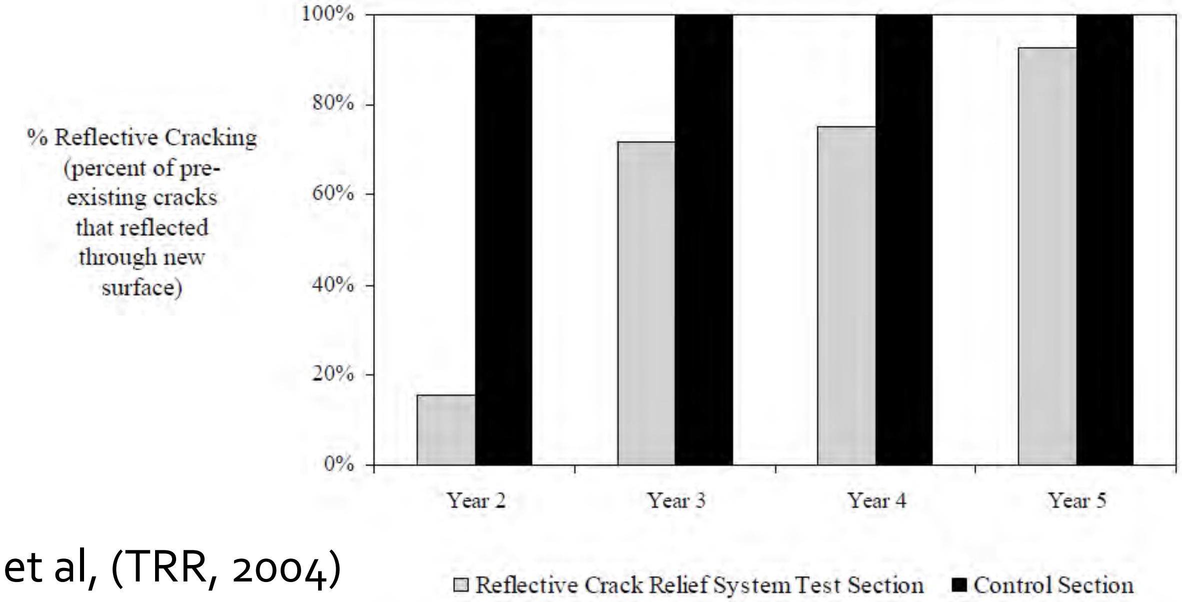
$$SDI = SDI_0 - e^{\left(A - B \cdot C^{\ln\left(\frac{1}{Age}\right)}\right)}$$

NJDOT Rehabilitation Efforts Prior to 2006

NJDOT Rehabilitation Efforts Prior to 2006

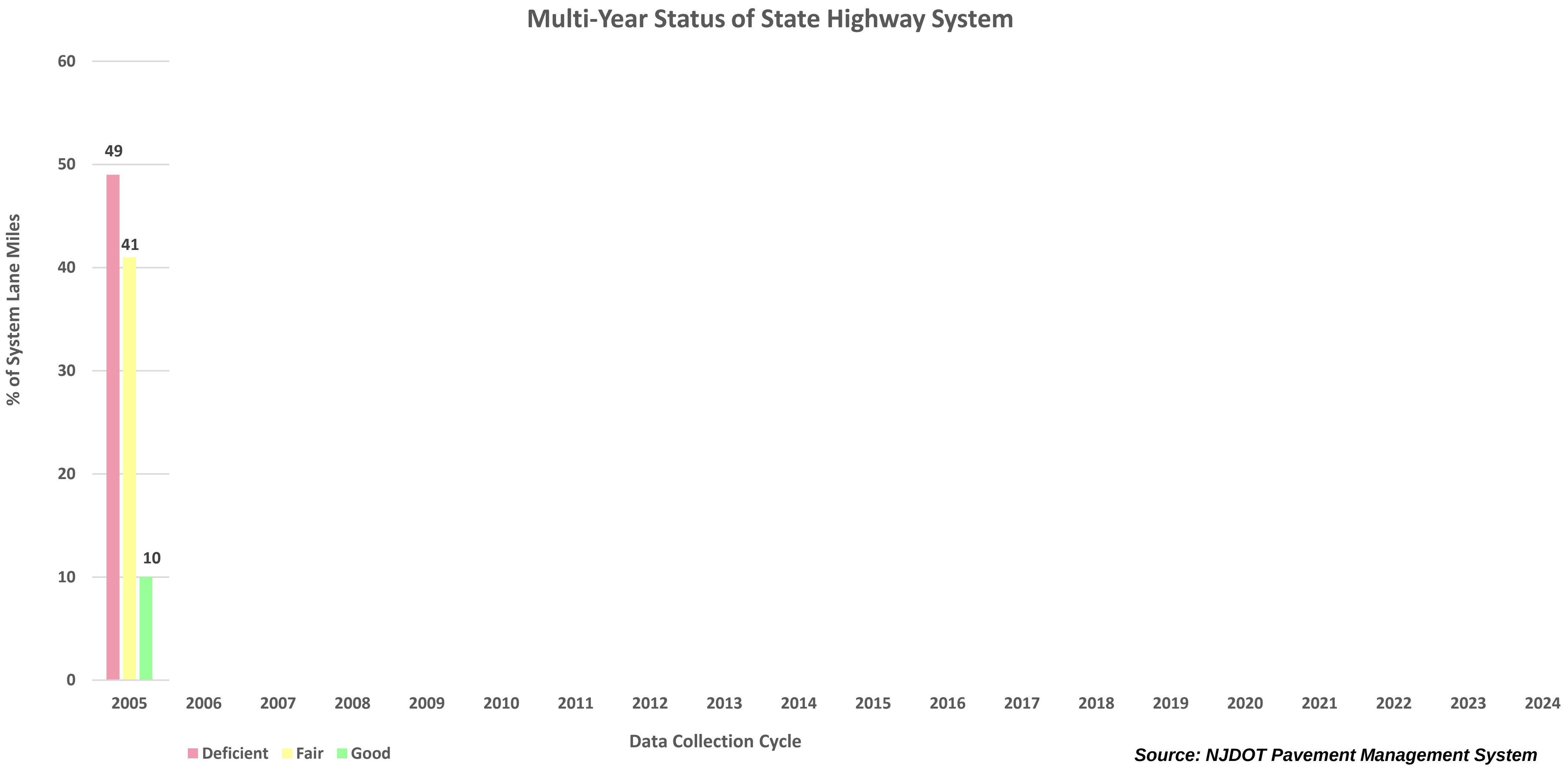
- During this time, NJDOT attempted to look at "alternatives"
- Rt 10 Reflective Crack Relief Interlayer
- Rt 1 Paving Fabric
  - No cracking in fabric section in Yr 1
  - All sections cracked equally in Yr 2





Blankenship et al, (TRR, 2004)

NJDOT Rehabilitation Efforts Prior to 2006

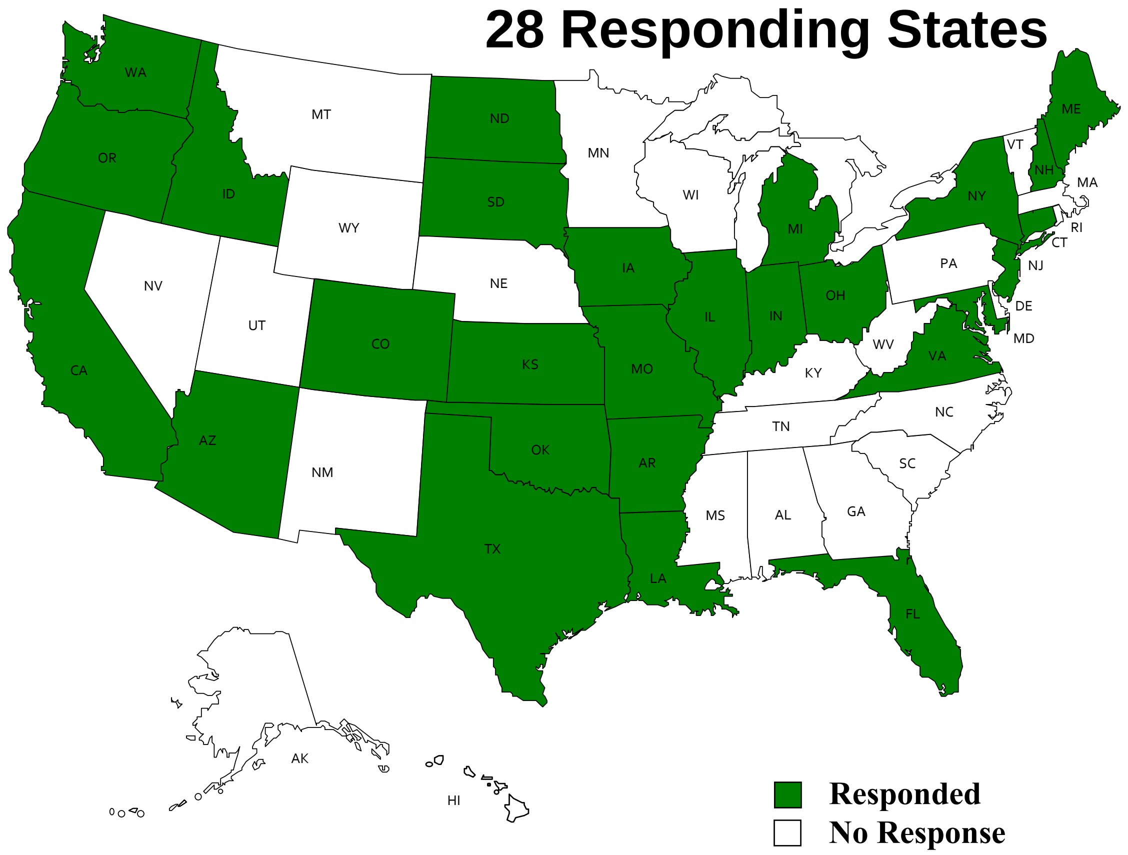


Source: NJDOT Pavement Management System

NJDOT Research Efforts on Composite Pavements

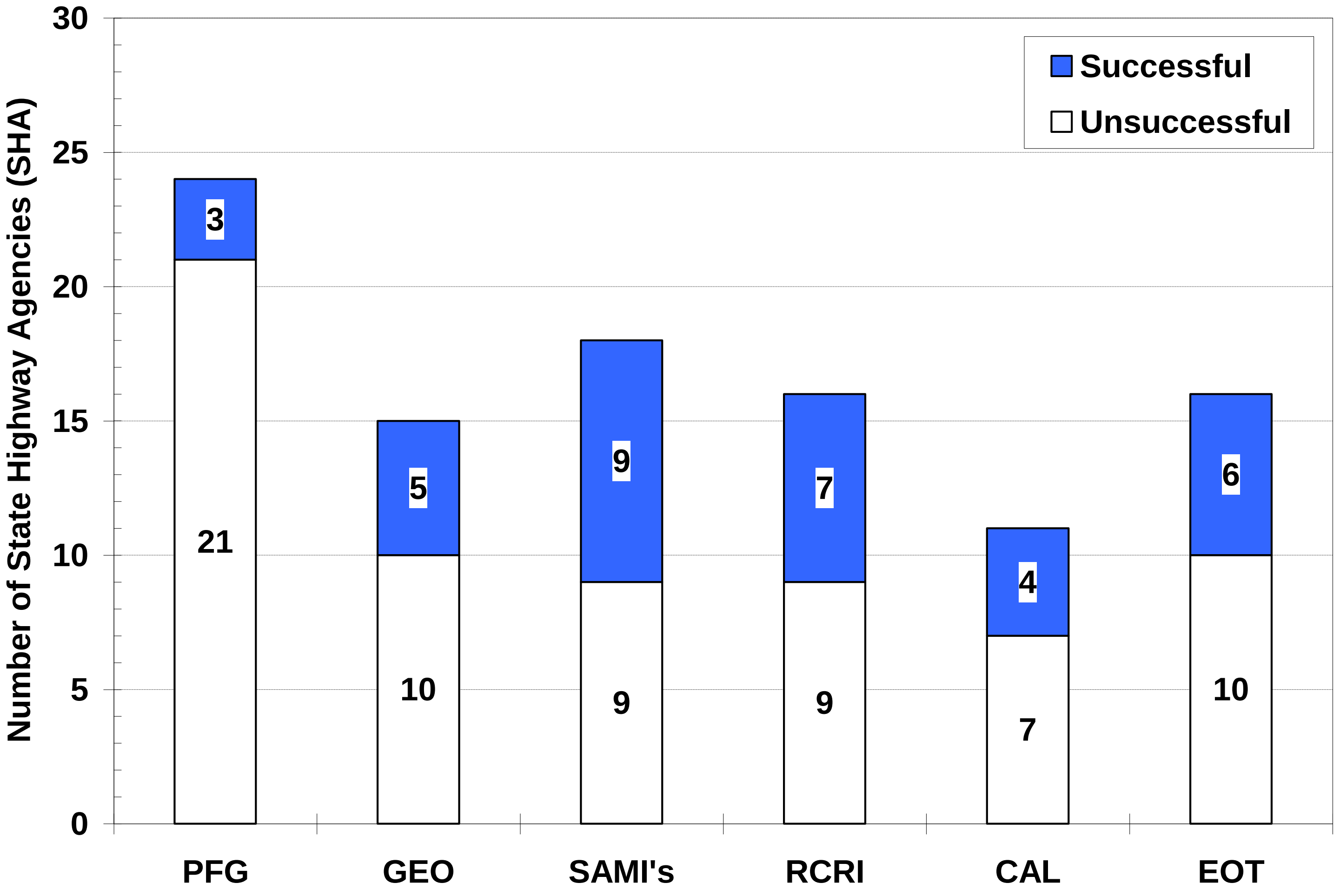
National Survey on Reflective Cracking

- Survey Overview
  - Time until reflective cracking occurs
  - Current PCC pavement characteristics (for composite pavement areas)
    - Joint spacing, joint type (contraction, expansion, etc)
    - PCC supporting base layer type
    - Traffic levels
  - HMA Overlay material characteristics
    - Typical mix designs and asphalt binder type
  - Pavement evaluation methods for design
  - Common PCC rehab prior to HMA overlay
  - Reflective cracking mitigation methods used and level of success



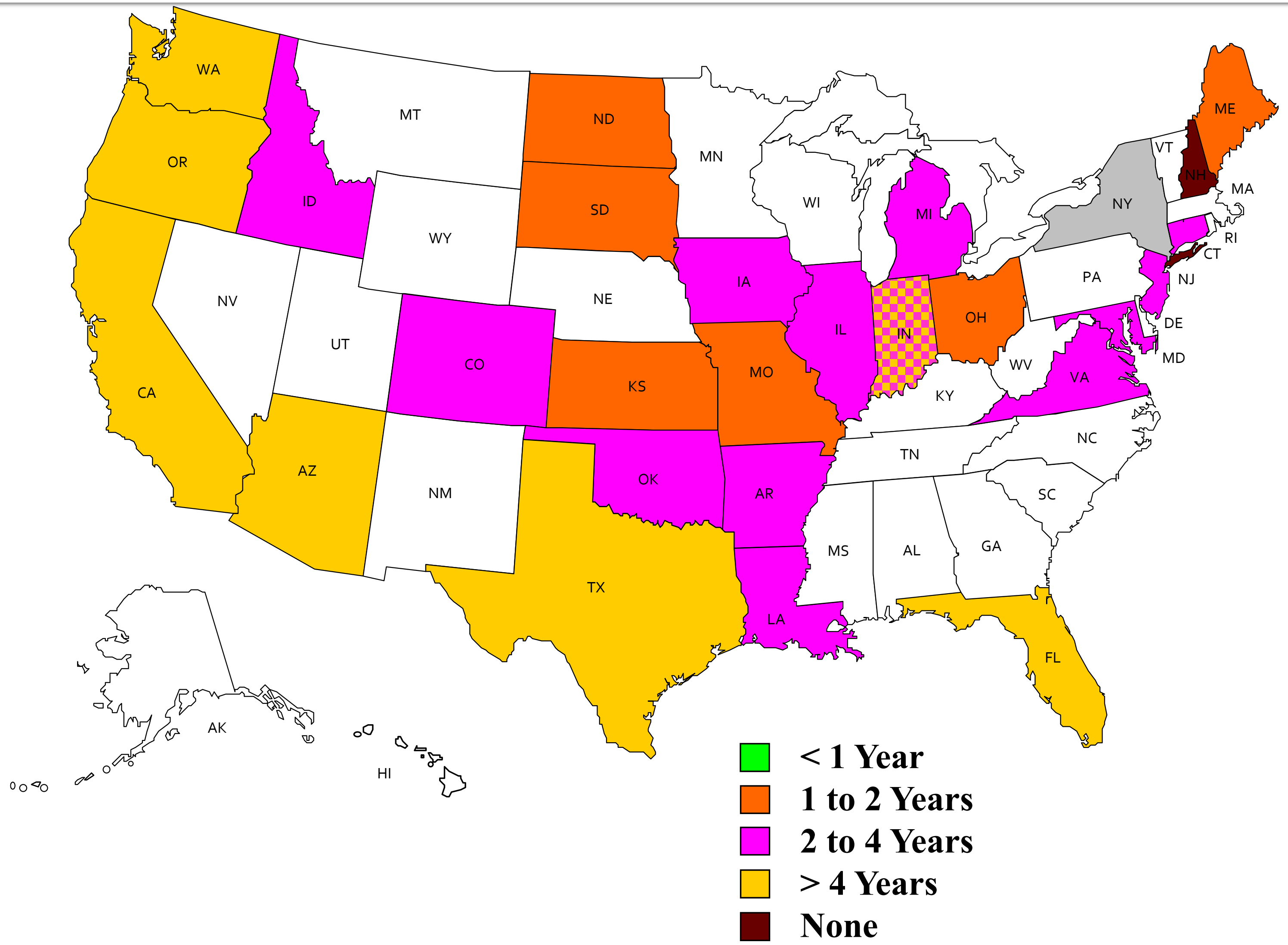
National Survey on Reflective Cracking

- Reflective cracking mitigation techniques and success rate
  - > 5 years before reflective cracking observed
  - Asphalt interlayer applications had best success rate



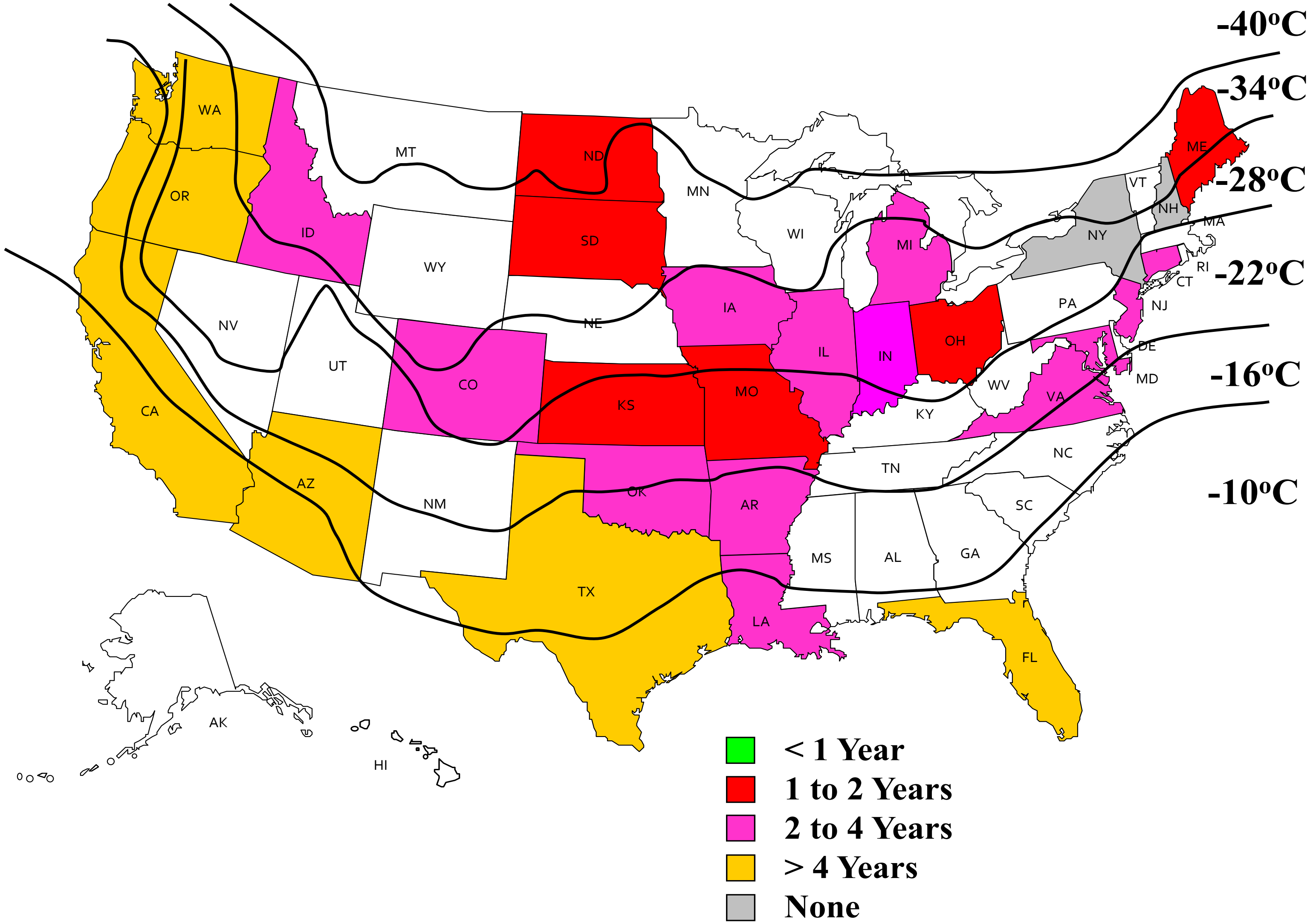
National Survey on Reflective Cracking

- Typical time after overlay until reflective cracking observed
  - Reflective cracking observed earlier in northern states compared to states with milder climates



National Survey on Reflective Cracking

- LTPPBind low temperature asphalt binder PG Grade recommendations
  - Longer delay in reflective cracking with better low temperature binder properties



National Survey on Reflective Cracking

- Reflective cracking appeared to occur equally at different traffic levels and base types
  - General trends to greater reflective cracking life at stronger base materials and shorter joint spacing
    - Lower magnitude of vertical and horizontal deflections
- HMA overlay material (asphalt binder type) had large impact on reflective cracking
  - HMA overlay needs to be resistant to cracking at low temperatures
  - Using one grade or more less than LTPPbind was more successful

National Survey on Reflective Cracking

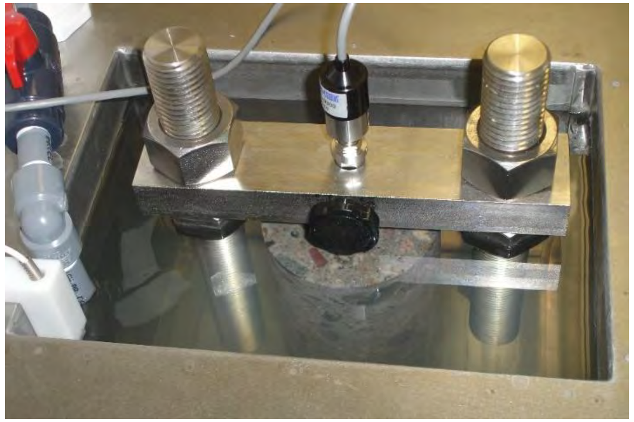
- Reflective Cracking Mitigation Methods
  - Better performing mitigation methods were asphalt based (SAMI's and RCRI mixes)
    - Both commonly use low temperature, crack-resistant binders
    - Performance influenced by RCRI overlay material
  - States in warmer/milder climates had better success with paving fabrics, geosynthetics, and geogrids (similar conclusions by Lytton and Button, 2007)

NJDOT/Rutgers Field Research Sections

NJDOT/Rutgers Field Research Sections

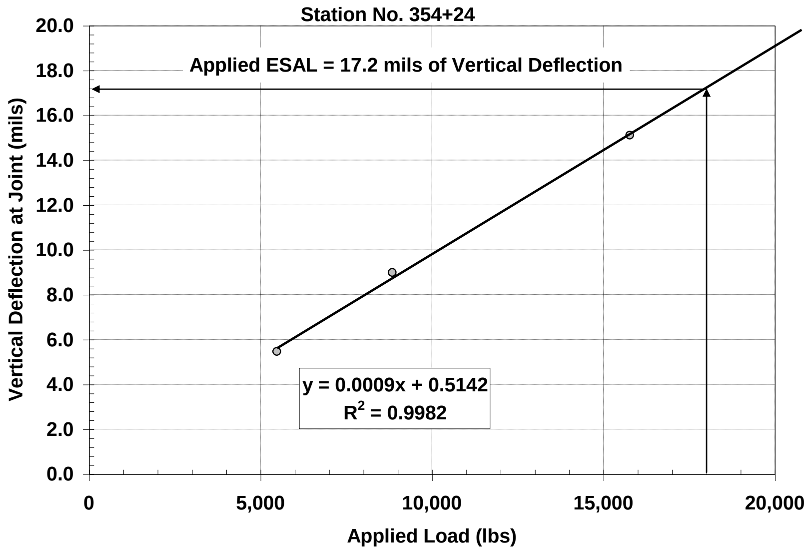
- 2007 to 2010 looked at a number of field sections
  - Interlayers
  - Different HMA designs (AC%, binder grades)
  - Portable WIM's for traffic
  - FWD at joints/cracks
  - Field cores of PCC for Coefficient of Thermal Expansion (CTE)
- Results allowed for the development of a ***design/selection methodology based on the measured performance of asphalt mixtures***

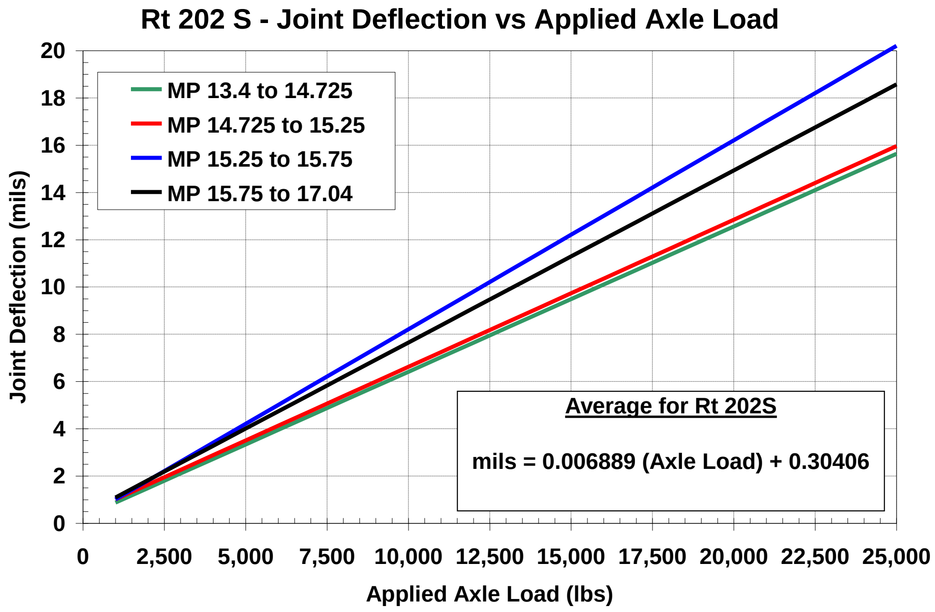


Evaluating Material Properties for Composite Pavement Design - Mode 1

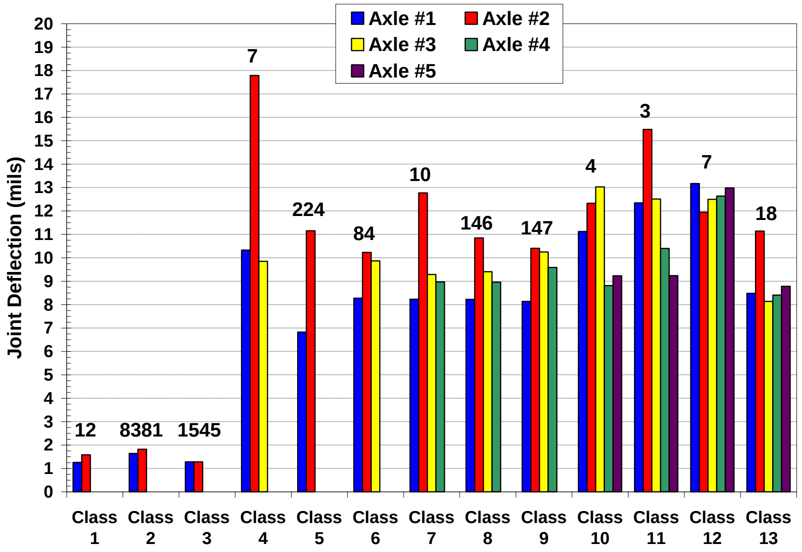
- The vertical deflection at the PCC joint/crack is a function of the applied axle load
- Magnitude of vertical deflection can be evaluated using Falling Weight Deflectometer (FWD) at different loads
- Combined with measured traffic/axle loading, a "Deflection Spectra" can be developed specifically for the pavement

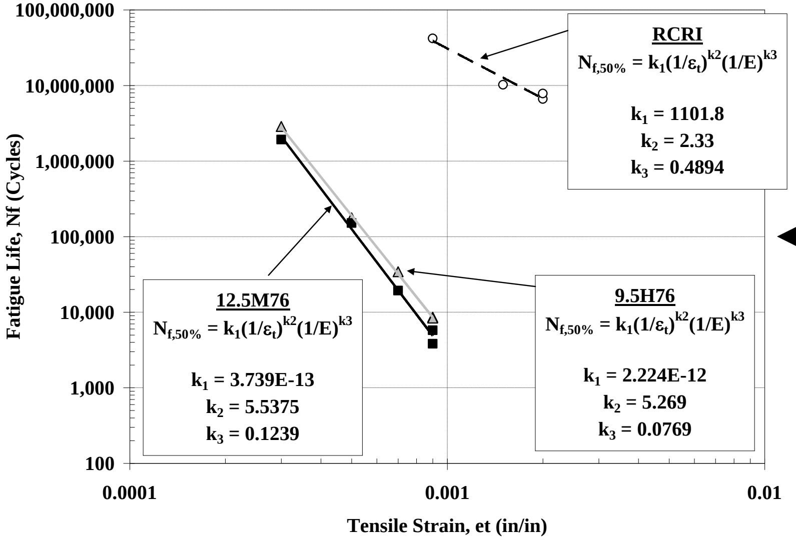


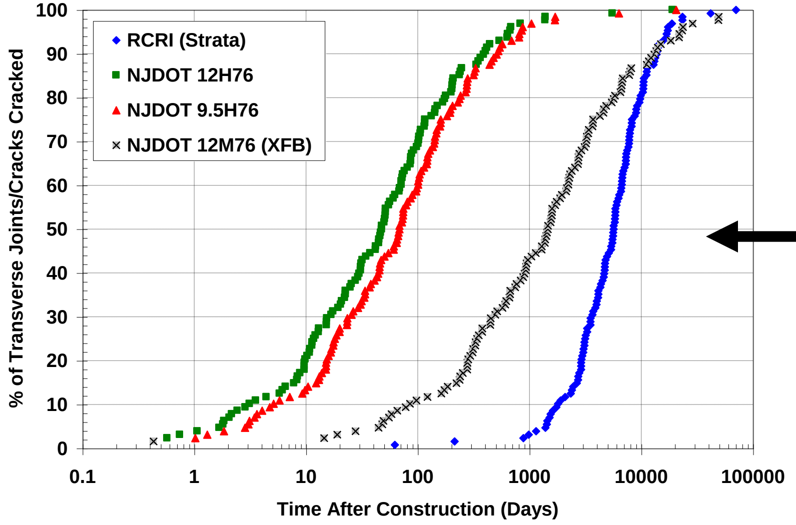


Applied Tensile Microstrain

$$\varepsilon_t = \frac{12\,\delta\,h}{(3G_o^2 - 4G_i^2)} \times 1E6$$





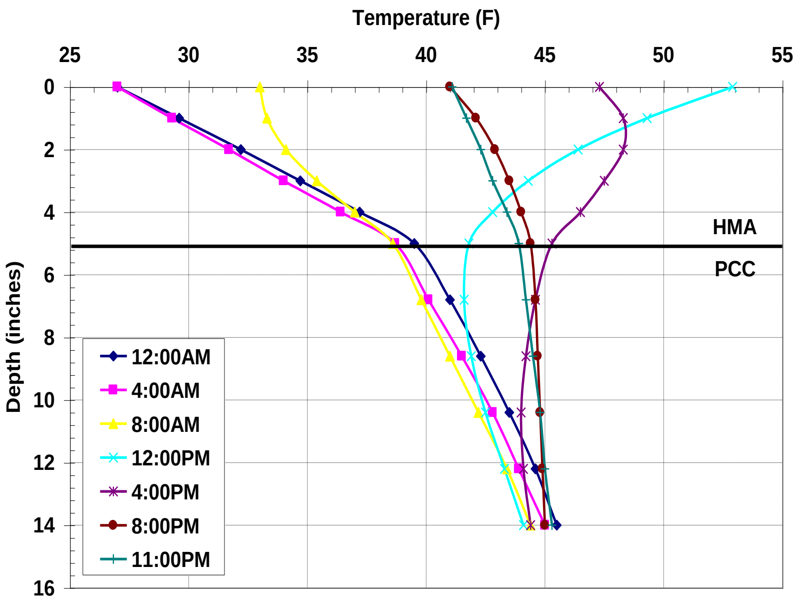


Evaluating Material Properties for Composite Pavement Design - Mode 2

- Expansion and contraction at PCC joint creates zone of tensile stress at bottom of asphalt overlay
- Horizontal deflection (ΔL) can be determined by:

$$\Delta L = CTE(L)(\Delta T)(\beta)$$

ΔL = change in slab length; L = initial slab length
ΔT = rate of change in PCC temperature (24 hr);
β = slab/base friction coefficient



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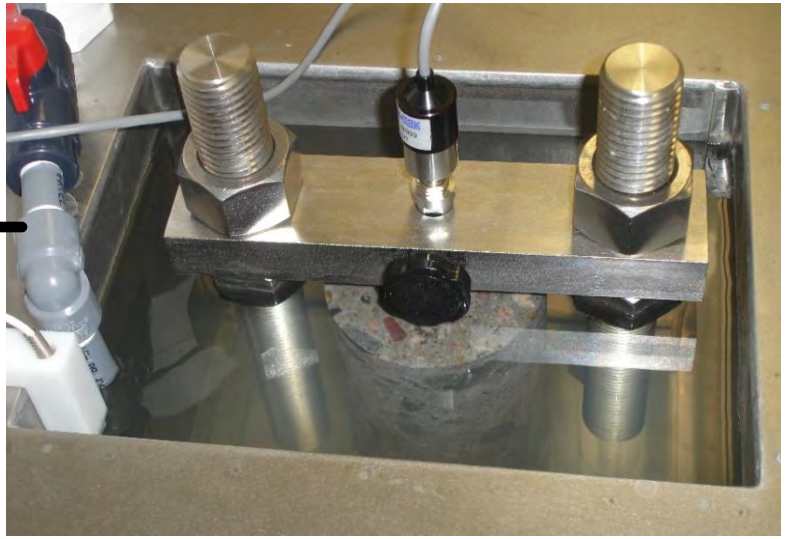
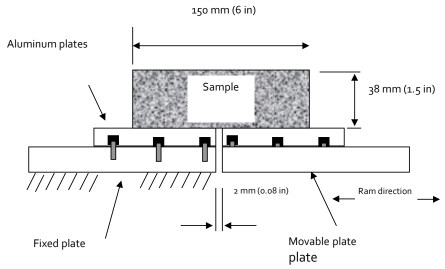
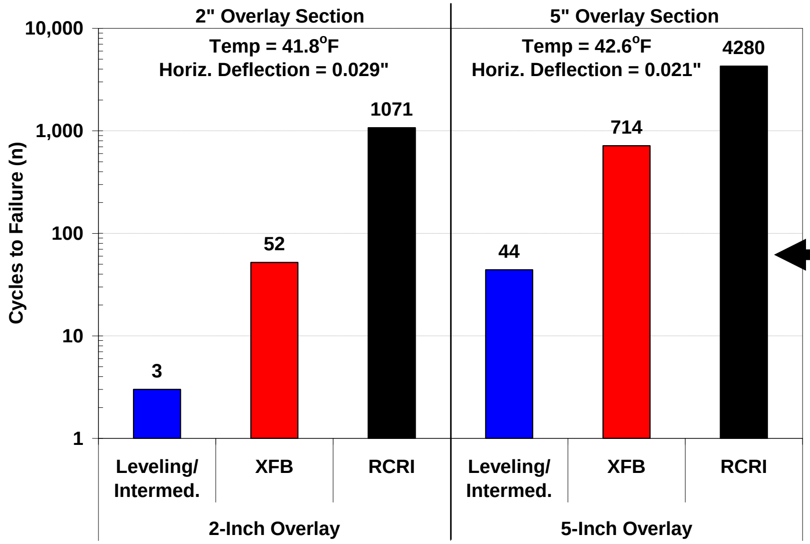


- Sample size: 6″ long by 3″ wide by 1.5″ high
- Loading: Continuously triangular displacement 5 sec loading and 5 sec unloading
- Definition of failure
  - Discontinuity in Load vs Displacement curve
  - Visible crack on surface



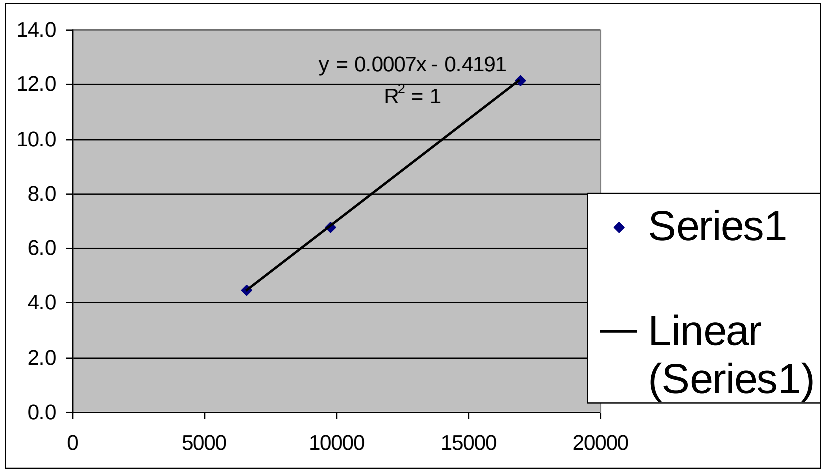


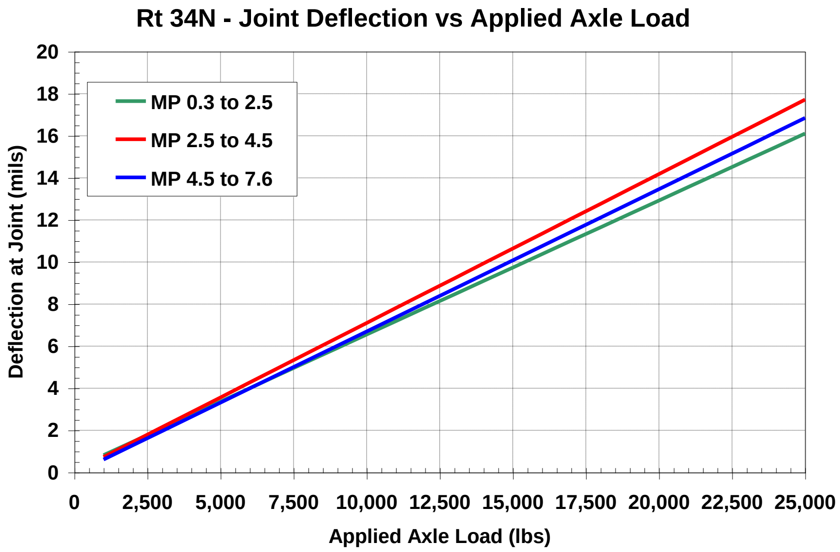
Example of Methodology and Comparison of Mixes

Rt. 34 Northbound

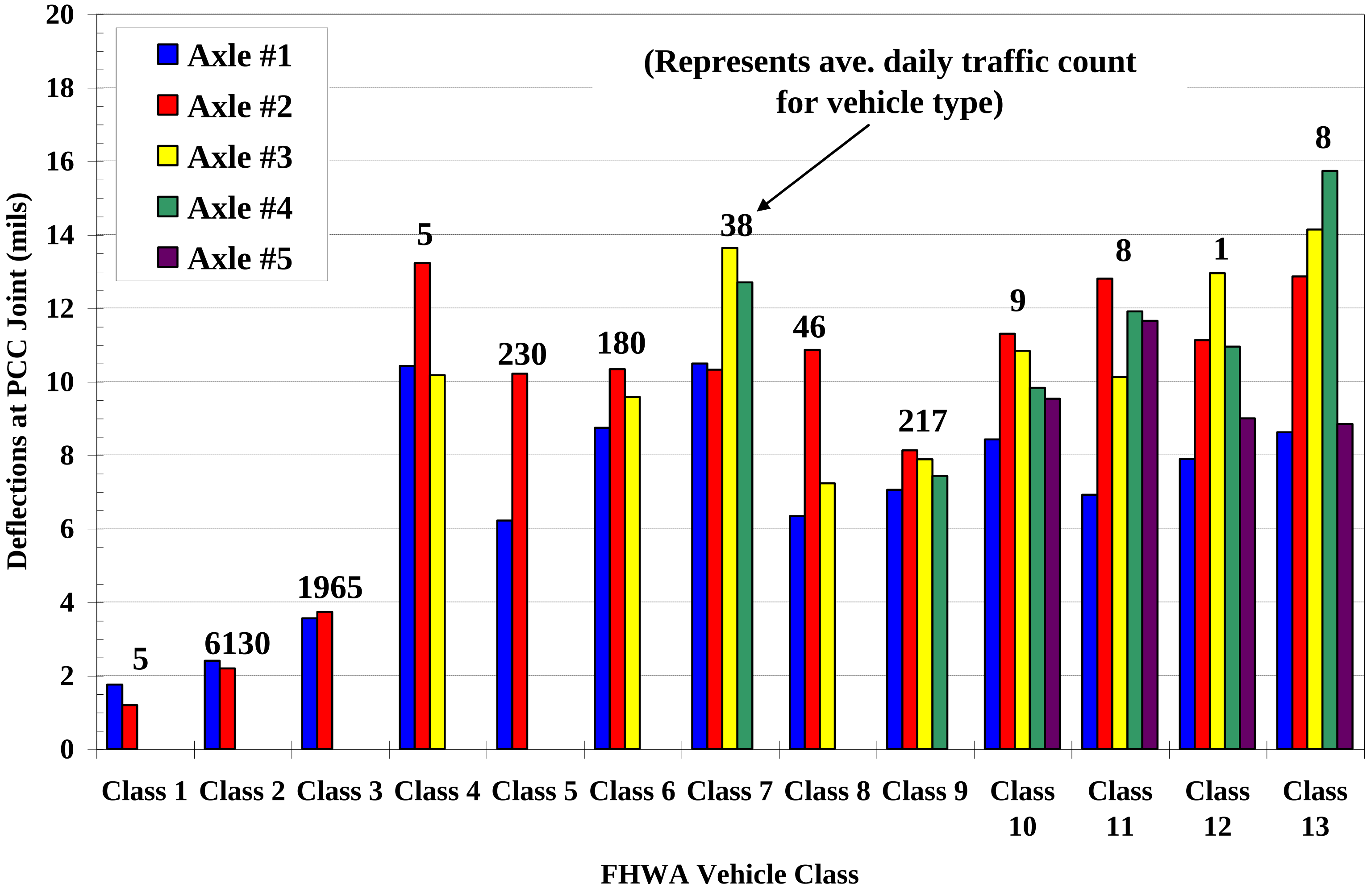
Mode 1 - Step 1. Deflection vs Axle Load

- Conducted at different loading magnitudes
  - Main goal to obtain deflections at joint and Load Transfer Efficiency at Joint
  - 6.5, 10, 16 kips
  - Linear relationship between deflection at joint and applied load
  - Use WIM data (axle load) to input into regression equations to determine deflection at joint due to traffic loading

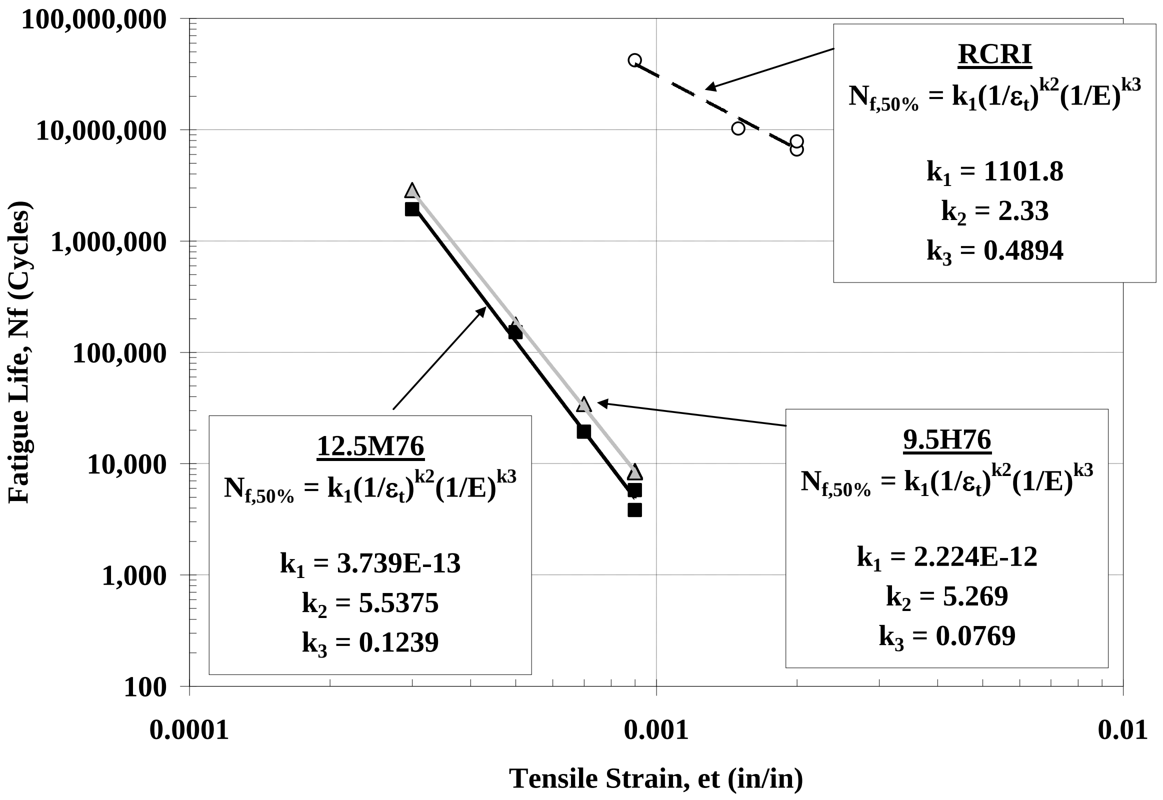


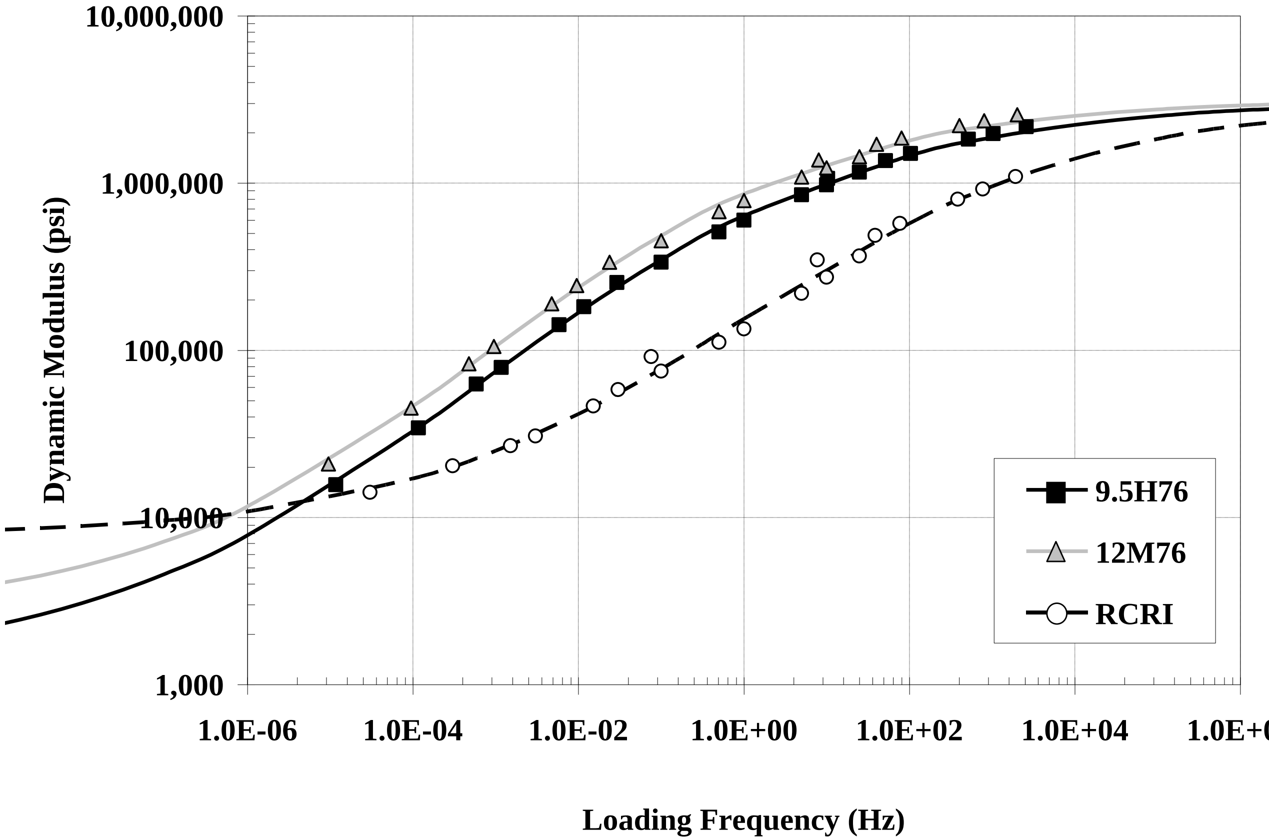


Mode 1 - Step 2. Deflection Spectra



Mode 1 - Step 3. Fatigue Life & E* Evaluation





Mode 1 – Step 4. Miner's Damage Accumulation

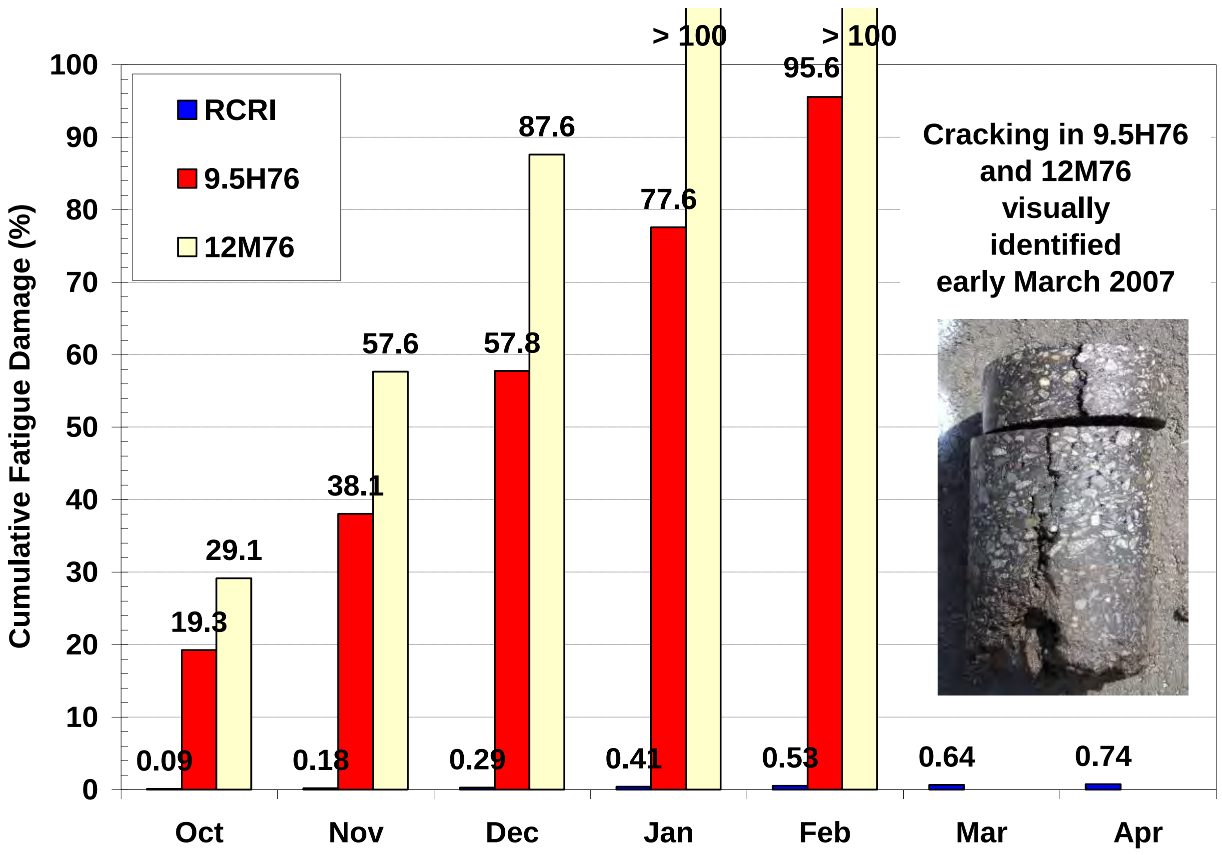
$$D = \sum_{i=1}^{T} \frac{n_i}{N_i}$$

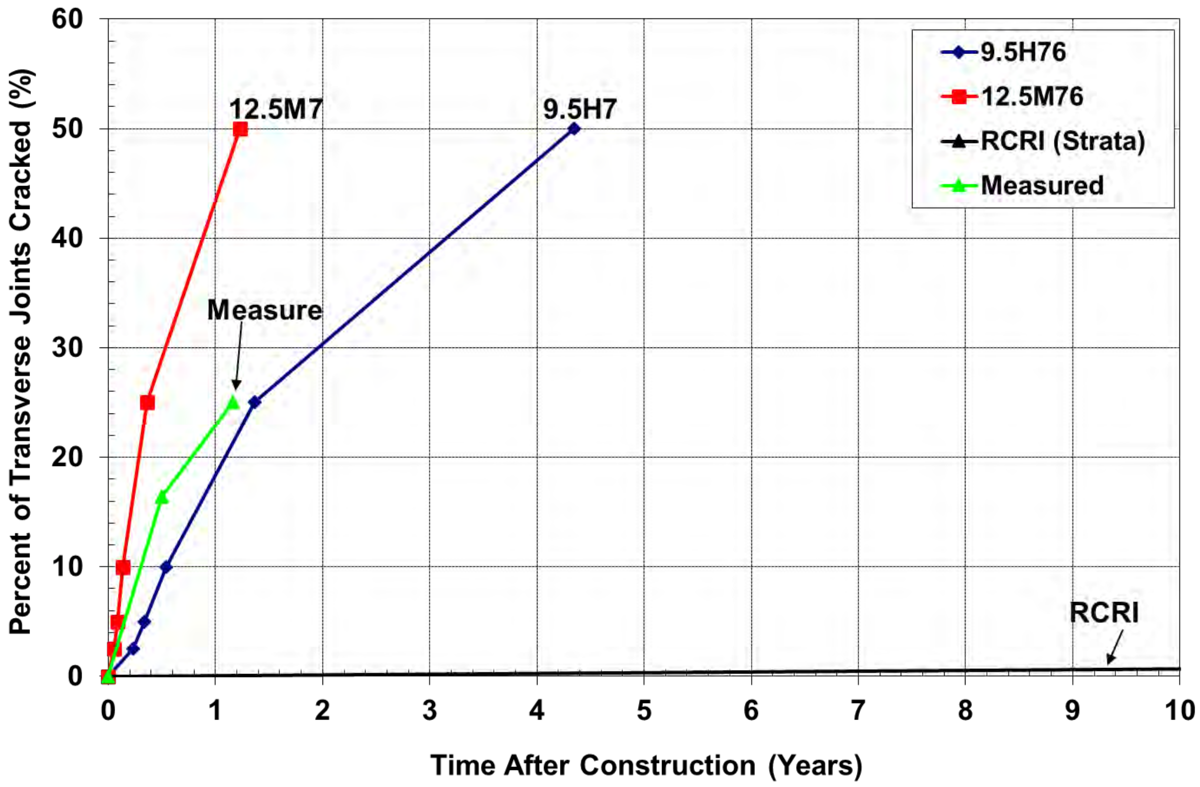
where:

D = damage;
T = total number of periods;
n_i = actual traffic for period i; and
N_i = allowable failure repetitions under conditions prevailing in period i.

FHWA #	# of Reps	Joint Deflection (mils)	Beam Deflection (mm)	Micro-strain	Fatigue Life	Fatigue Damage (%)
Class 1	5	0.84	0.02129	42.58	100,769,842,698	4.9618E-09
	5	0.92	0.02336	46.72	60,251,665,892	8.29853E-09
Class 2	6130	2.33	0.05927	118.54	347,468,260	0.001764046
	6130	2.09	0.05300	106.01	645,107,165	0.000950152
Class 4	5	8.97	0.22774	455.48	201,180	0.002547464
	5	11.66	0.29606	592.11	47,064	0.010889451
	5	8.73	0.22178	443.56	233,023	0.002199356
Class 7	38	9.17	0.23295	465.89	177,515	0.021406626
	38	9.82	0.24934	498.67	121,824	0.03119258
	38	11.52	0.29264	585.29	50,185	0.075719482
	38	10.50	0.26664	533.27	84,024	0.045225192

Mode 1. Deflection Spectra Predicted vs Actual Rt 34N

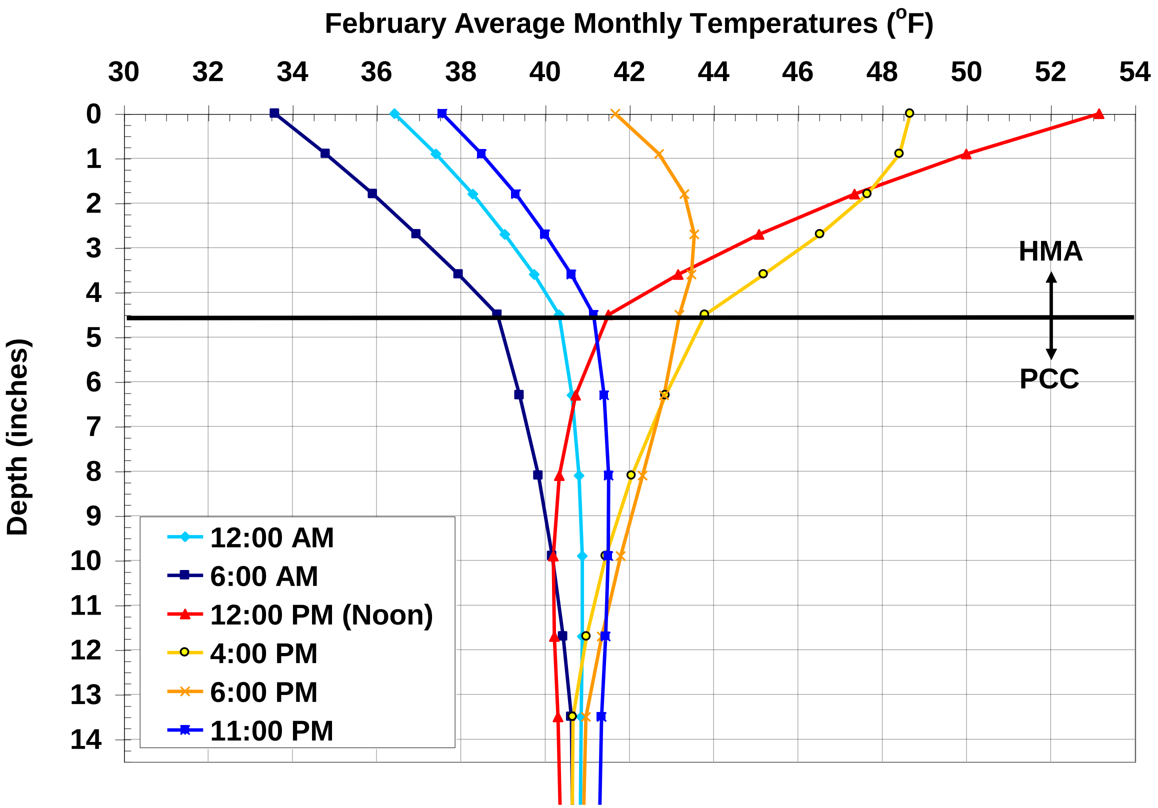




Mode 2 – Step 1. CTE Results (AASHTO T336)

$\Delta L = CTE(L)(\Delta T)(\beta)$

ΔL = change in slab length
L = initial slab length
ΔT = change in PCC temperature
= 6°C at PCC surface
β = Coefficient of PCC/Base Friction
= 0.73 (from LTPP data, FHWA-RD-02-088)



- Based on 4.5" HMA Overlay on PCC
- Used EICM to predict temp profile and took maximum based on 2002 and 2003 data

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ΔT = change in PCC temperature
= 6°C at PCC surface
β = Coefficient of PCC/Base Friction
= 0.73 (from LTPP data, FHWA-RD-02-088)

$\Delta L = (12.34E\text{-}6)(40 \times 12)(6)(.73)$

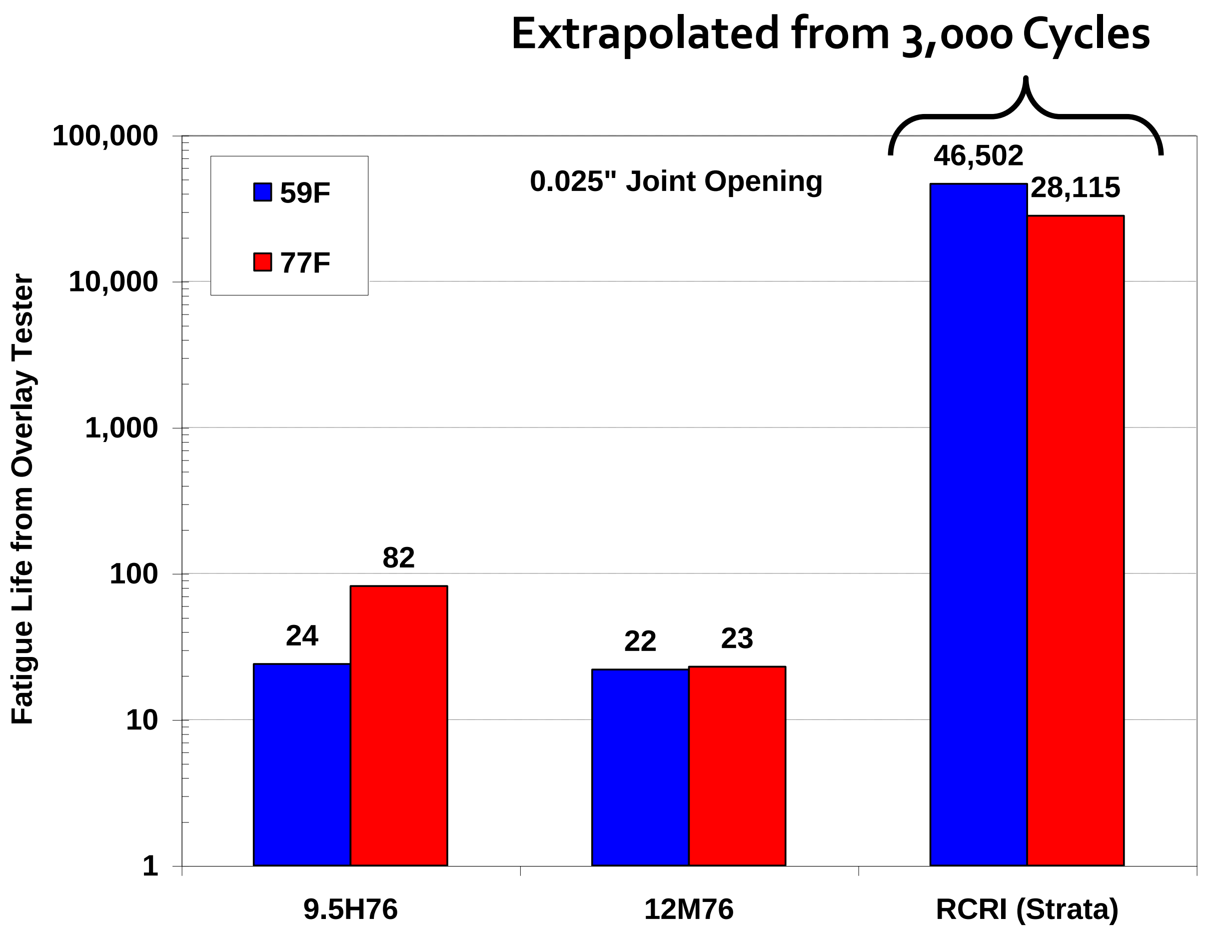
ΔL = 0.026 inches (Assumed 0.025 inches)

NJ Rt 34N PCC:

- 40 ft slabs
- Measured CTE of Cores = 12.34E-6 in/in/°C

- Based on 4.5" HMA Overlay on PCC
- Used EICM to predict temp profile and took maximum based on 2002 and 2003 data

Mode 2 – Step 2 & 3. Results of Overlay Tester



Example of Methodology and Comparison of Mixes

Rt. 34 Northbound – How was final performance?

March 2007
(5 Months After Construction)

Rt 34N - MP 0.3
Just North of Traffic Light

March 2007
(5 Months After Construction)

Rt 34N - MP 0.35
In front of Investors Bank

March 2007
(5 Months After Construction)

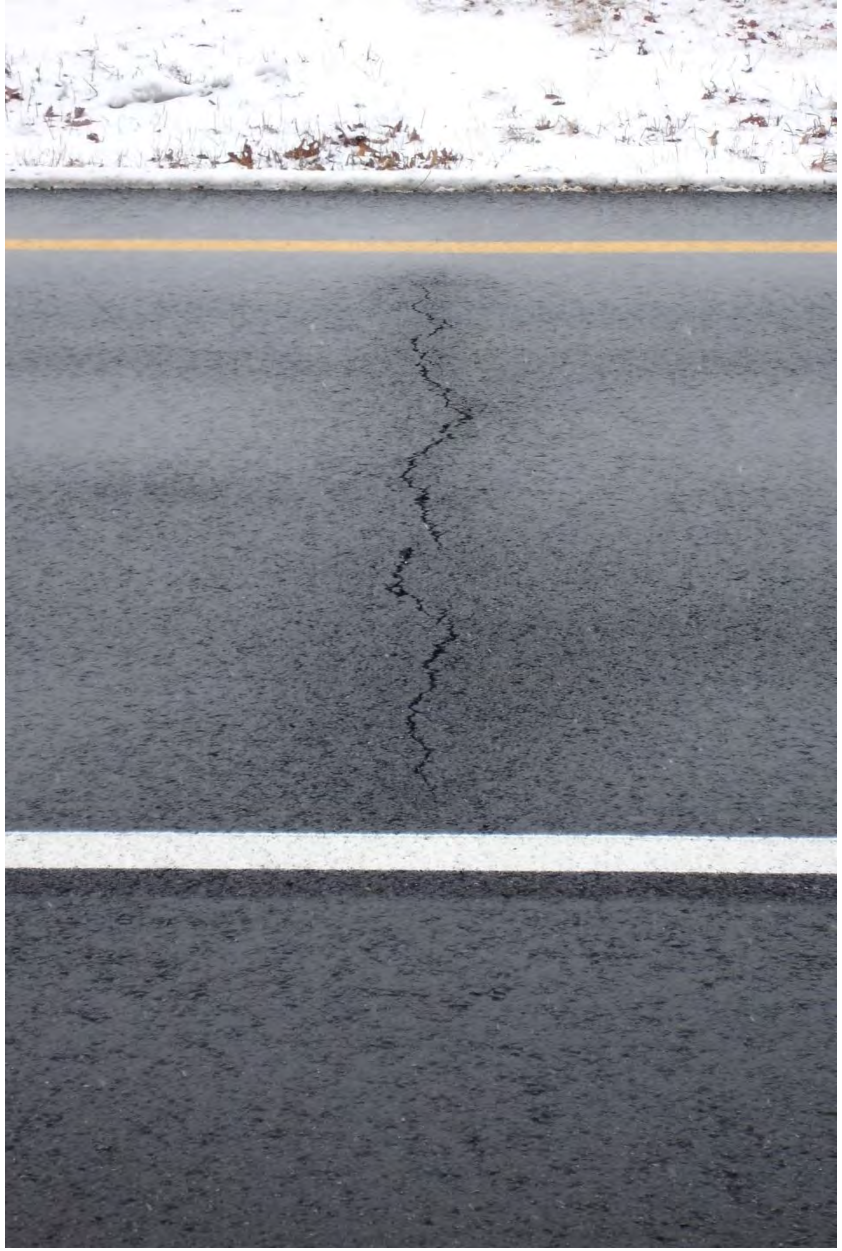
Rt 34N - MP 0.35
In front of Harbor Lights

March 2007
(5 Months After Construction)

Rt 34N - MP 0.35
Close-up of Crack by Harbor Lights

March 2007
(5 Months After Construction)

Rt 34N - MP 0.45
Just North of Hully Plaza



Rt 34N - MP 0.5

North of Hully Plaza and South of Traffic Light

March 2007

(5 Months After Construction)

Rt 34 N - MP 7.0

March 2007
(5 Months After Construction)

Lessons Learned from Research

NJDOT/Rutgers Field Research Sections – Lessons Learned

- Material selection!
  - Interlayers work but still need good overlays!
    - Composite pavement design needs to be thought of as a "system approach"
      - Asphalt immediately over PCC needs to be able to withstand horizontal and vertical deflection
      - Surface course must still be able to withstand vertical deformation
        - Compatibility is required between asphalt materials – can not have very flexible overlaid by very stiff
    - Example: Massachusetts I495

(Worden, 2008)

NJDOT/Rutgers Field Research Sections – Lessons Learned

- Material selection!
  - "Crack jumping" on MA I495
  - Interlayer worked, leveling course and intermediate layer cracked with 7 months of paving!
    - Too stiff to withstand horizontal deflections (leveling course) and residual vertical deflections (intermediate course)
    - Stress Absorbing Membrane Interlayers (SAMI's)
      - Is this term misleading?

(Worden, 2008)

NJDOT/Rutgers Field Research Sections – Lessons Learned

- Material selection!
  - "Crack jumping" on MA I495
  - Interlayer worked, leveling course and intermediate layer cracked with 7 months of paving!
    - Too stiff to withstand horizontal deflections (leveling course) and residual vertical deflections (intermediate course)
    - ~~Stress Absorbing Membrane Interlayers~~ (SAMI's)
    - Strain Tolerant Asphalt Materials (STAM's)

(Worden, 2008)

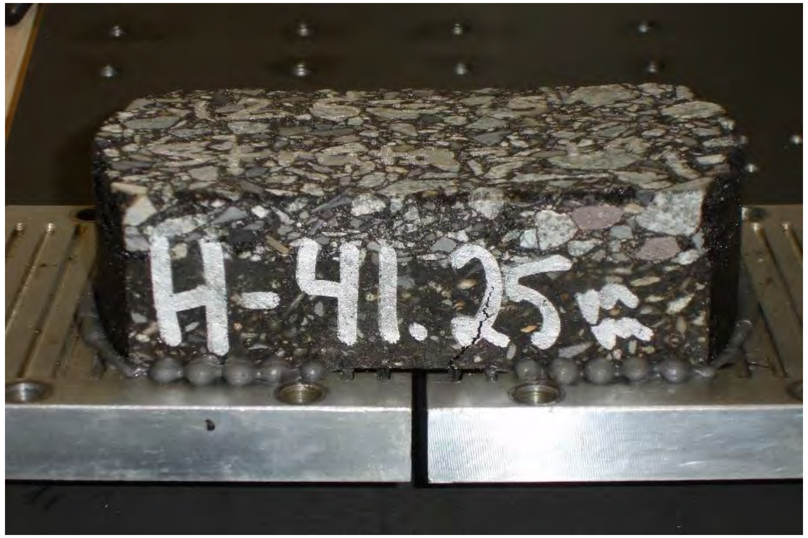
NJDOT/Rutgers Field Research Sections – Lessons Learned Interlayer Thickness Influence

NJDOT/Rutgers Field Research Sections – Lessons Learned - Interlayer Thickness Influence

5 Cycles (0 inches)

0.035" Opening
15°C (59°F)

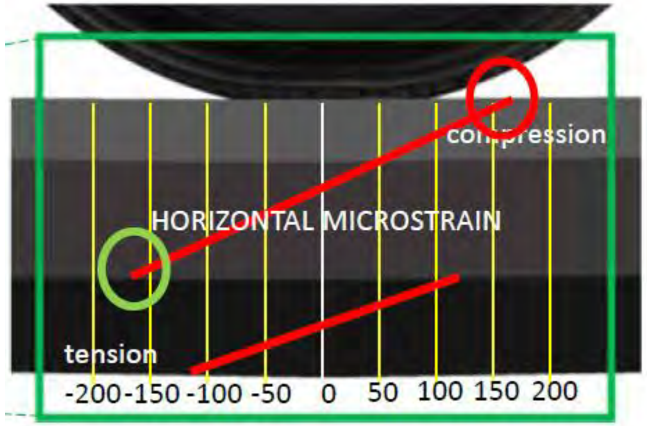
278 Cycles (0.5 inches)



>2,800 Cycles (1.0 inches)

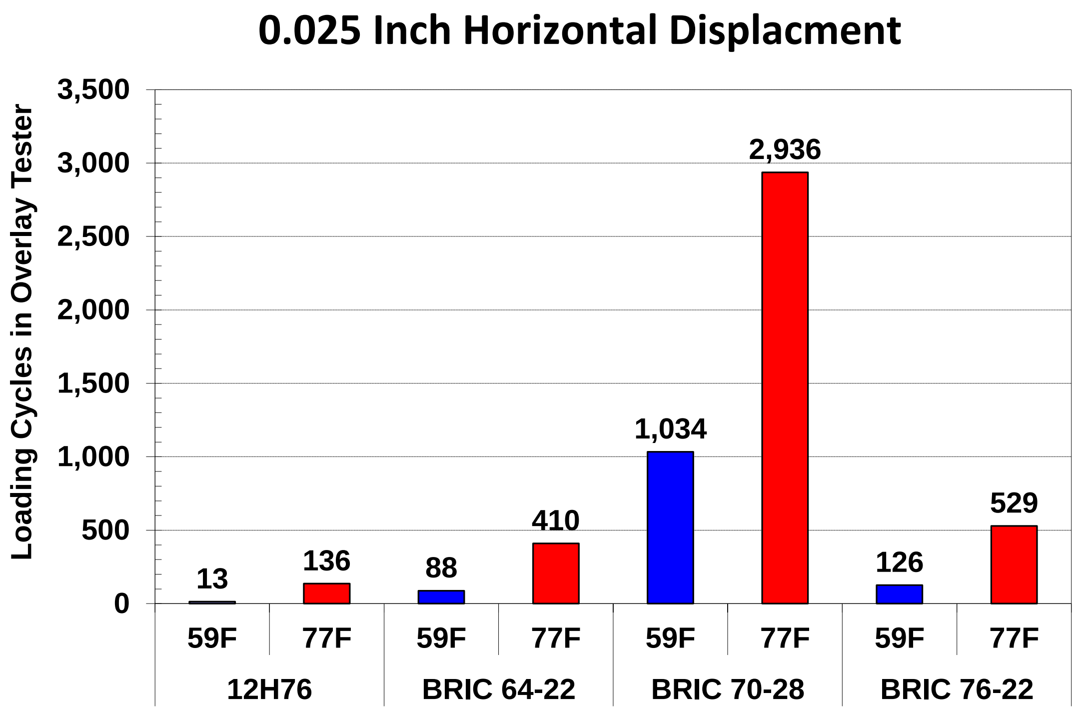
NJDOT/Rutgers Field Research Sections – Lessons Learned - Bonding of Asphalt Layers

- Proper tack coat/bond strength
  - Composite pavements have high vertical deflections at PCC joints/crack
  - Important to ensure good bonding to properly distribute stress
    - If unbonded, surface lift will take majority of applied stress and bottom-up cracking will occur in that lift solely



Bituminous Rich Intermediate Layer (BRIC)

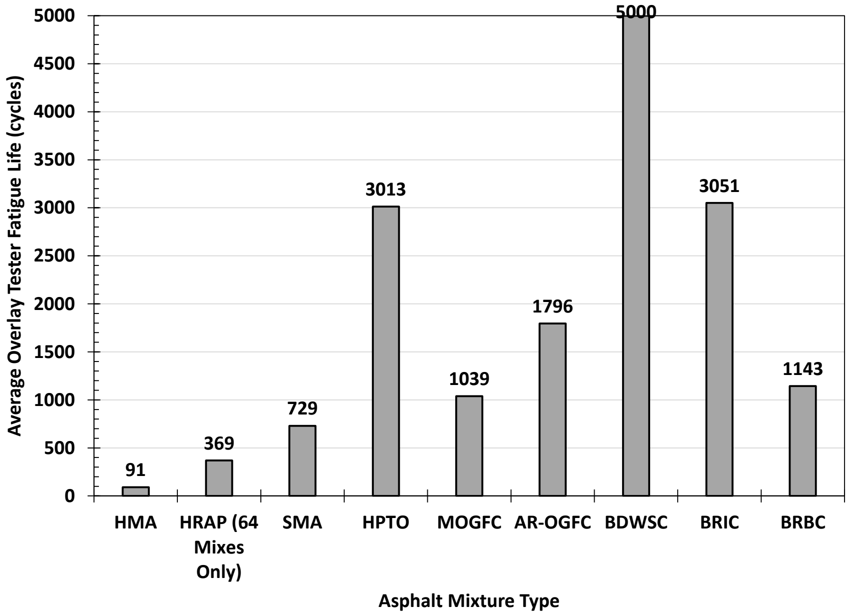
- Originally based off TxDOT Crack Attenuating Mix (CAM)
  - Placed at 1" thick
  - 4.75mm NMAS; No natural sand
  - PG70-28 asphalt binder
  - Minimum Asphalt Content 7%
- Performance Testing
  - Originally APA only (binder grade, AC% & VMA controlling fatigue)
  - Incorporated Overlay Tester after experience – eliminated binder grade requirement
    - Acceptance (design, test strip, production) based solely on performance testing results



NJDOT Final Design Approach for Composite Pavements

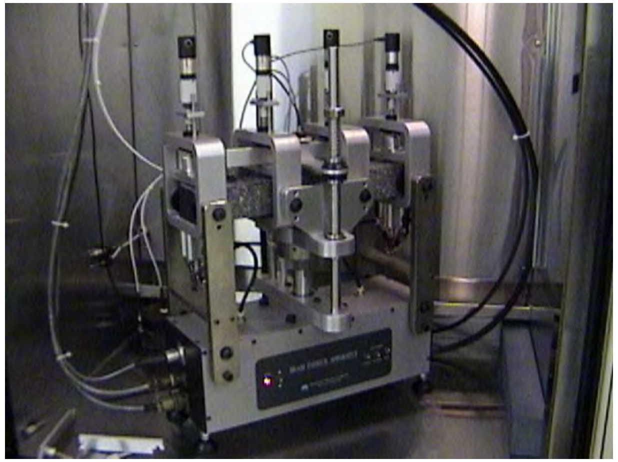
NJDOT Design Approach for Composite Pavements

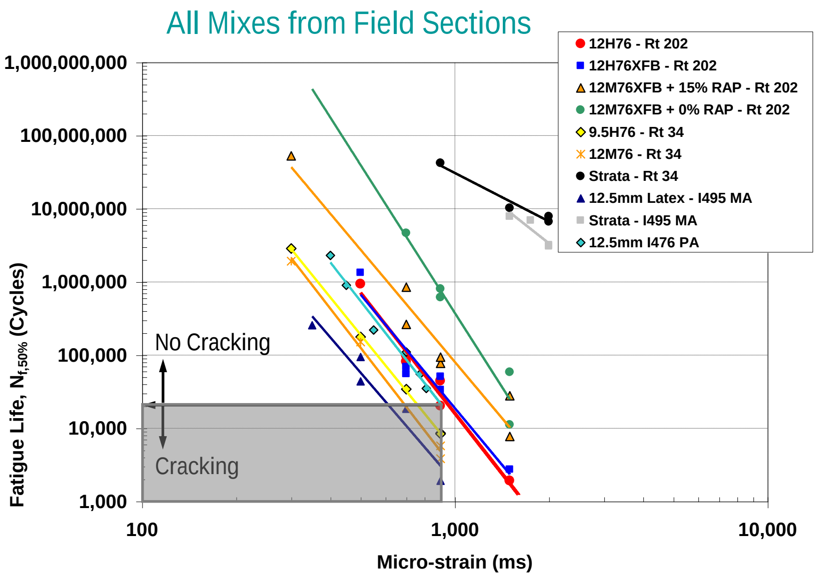
- Assumptions
  - Good construction and not using excessive overlay thickness (EOT)
- Step 1: Find material to withstand expected horizontal deflections (Mode 2)
  - Analysis found this to be controlling factor
  - Developed Bituminous Rich Intermediate Course (BRIC)
    - Originally required PG70-28
    - Currently have Overlay Tester as performance criteria for cracking



NJDOT Design Approach for Composite Pavements

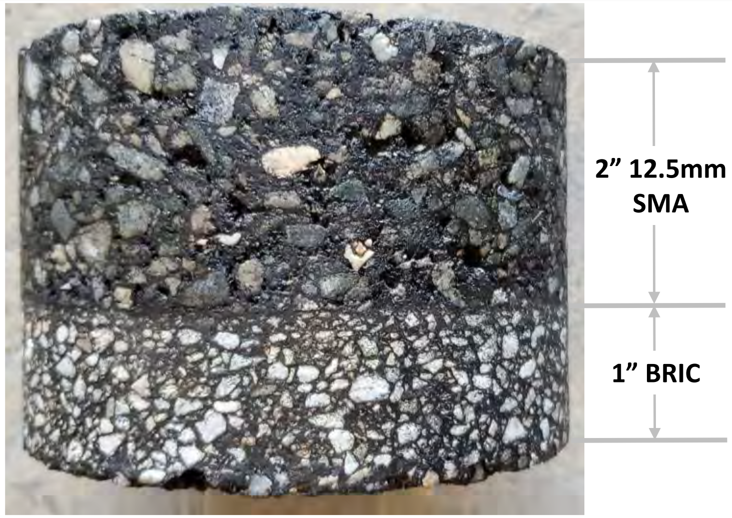
- Step 2: Find surface/intermediate course capable of withstanding residual vertical deflections
  - Analysis found compatibility of asphalt layers important
    - Flexural fatigue and rut resistant
    - Thicker asphalt overlays will have lower flexural fatigue requirements due to reduction in vertical deflections
      - Obviously vice versa!

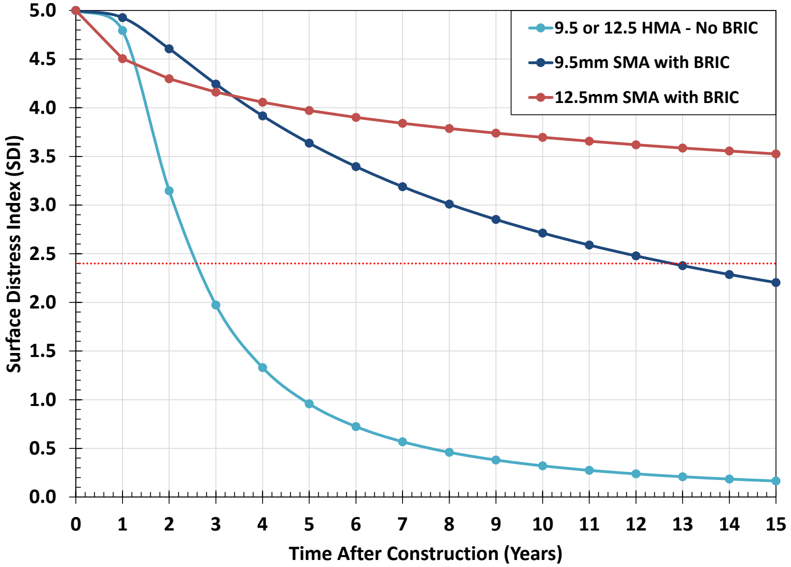




NJDOT Design Approach for Composite Pavements

- Developed an Excel macro for NJDOT on asphalt mixture selection
- Considered horizontal and vertical movements
- Due to overlay thickness restrictions and deflections magnitude, majority of composite pavements in NJ are constructed with;
- Recommendations as of 2009
  - 2″ SMA Surface
    - Good rutting & flexural fatigue resistance
    - Stiffness compatible with BRIC
  - 1″ BRIC
    - Excellent at withstanding horizontal deflections





Examples: Rt 9 – Ocean County

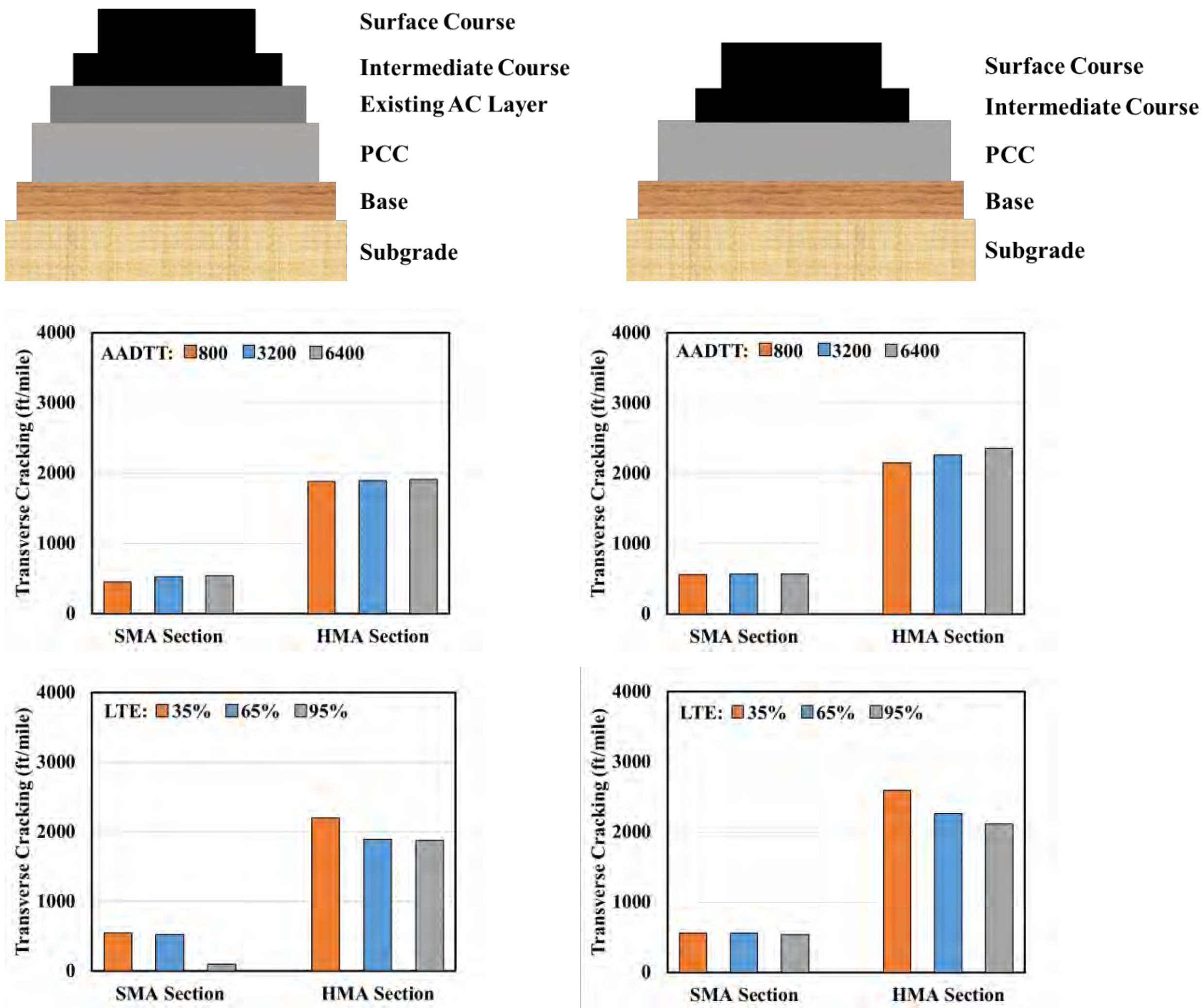
- 20 year ESAL's = 5 million
- Existing 2-3" HMA over 8" JRCP
  - Built 1920's with 50' joint spacing
  - SDI = 2.1; IRI = 222 in/mile
- Resurface in 2011
  - Mill 3"
  - 2" SMA over 1" BRIC
  - SDI = 5.0; IRI = 78 in/mile
- 2020 PMS Data
  - SDI = 4.6; IRI = 83 in/mile

Examples: Rt 1 & 9 – Hudson County

- 20 year ESAL's = 80 million
- Existing 3-4" HMA over 10" JRCP
  - Built 1930/40's with 56' joint spacing
  - SDI = 0.67; IRI = 165 in/mile
- Resurface in 2011
  - Mill 3"
  - 2" SMA over 1" BRIC
  - SDI = 5.0; IRI = 59 in/mile
- 2020 PMS Data
  - SDI = 3.4; IRI = 93 in/mile

Rutgers 2024 PAVEMENT-ME Validation

- Rutgers has been working with NJDOT over past 10 years to calibrate PAVEMENT-ME
  - Traffic families
  - Materials Catalog
  - Mix specific calibration models
- LCCA conducted for different pavement scenarios
  - Net Present Value (NPV) and Equivalent Uniform Annual Cost (EUAC) analyses concluded SMA+BRIC most cost-effective approach to conventional HMA overlays



NJDOT Rehabilitation Efforts - Now

- Current;
  - Concrete good condition (0 – 10% repairs)
    - Small repairs and diamond grind for ride
    - Some slab stabilization if faulting identified
  - Concrete good condition (0 – 10% repairs)
    - 1" HPTO: low to moderate traffic, low risk
    - 1" HPTO over slurry seal: low to moderate traffic, moderate risk
    - 1" UHPTO over slurry seal: moderate to high traffic
  - Concrete fair condition (> 10% repairs)

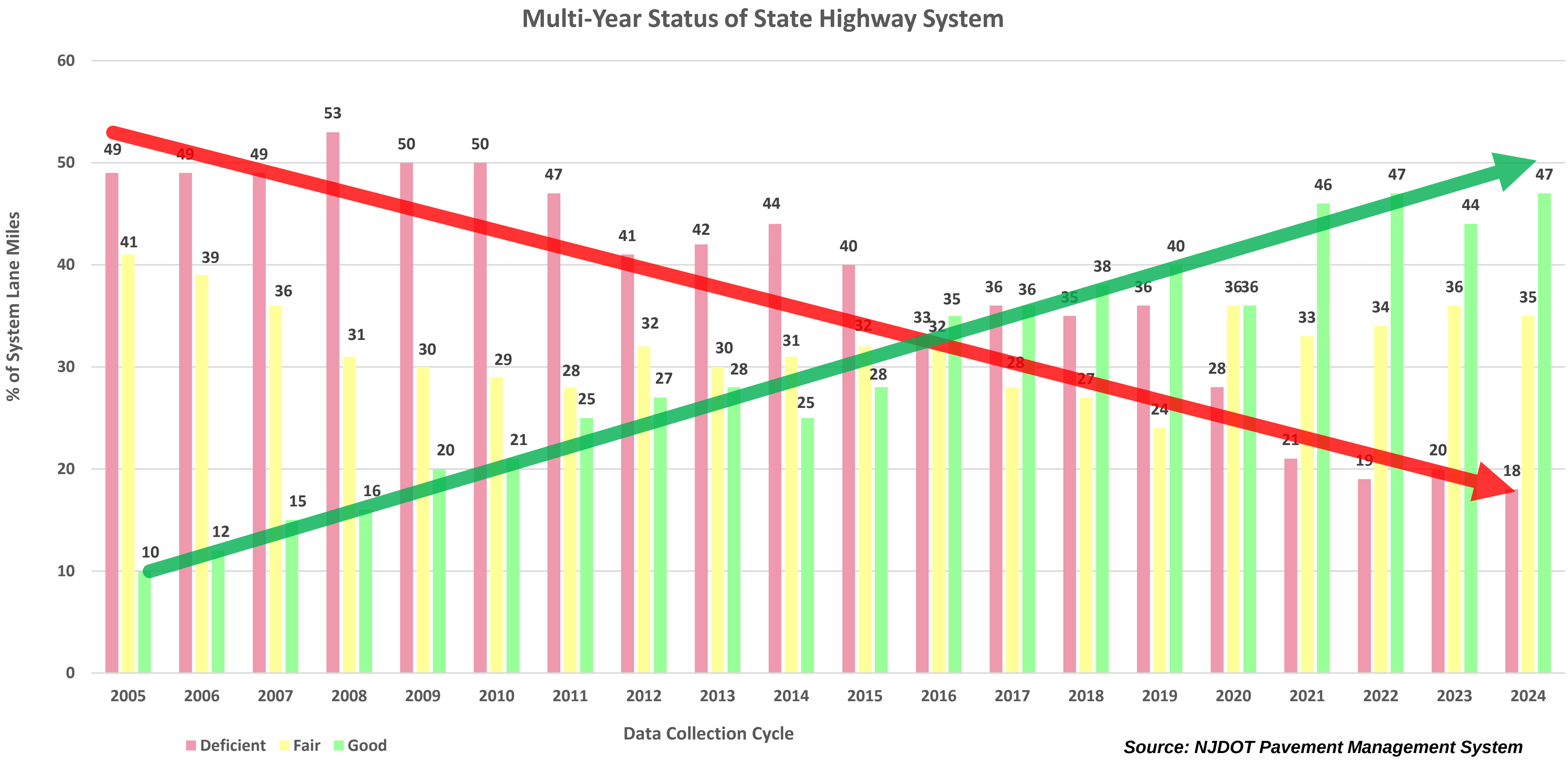
UHPTO
- **HPTO gradation and volumetrics**
- **HiMA binder**
- **From plant produced material**
  - **IDEAL-CT > 750**
  - **OT cycles > 5000 cycles**
  - **APA rutting < 2.0 mm**

NJDOT Rehabilitation Efforts - Now

- Current;
  - Concrete good condition (0 – 10% repairs)
  - Concrete good condition (0 – 10% repairs)
  - Concrete fair condition (> 10% repairs & depending on NJDEP runoff constraints)
    - 1" UHPTO
    - 1" HPTO or 1" UHPTO over 1" BRIC
    - 2" SMA over 1" BRIC

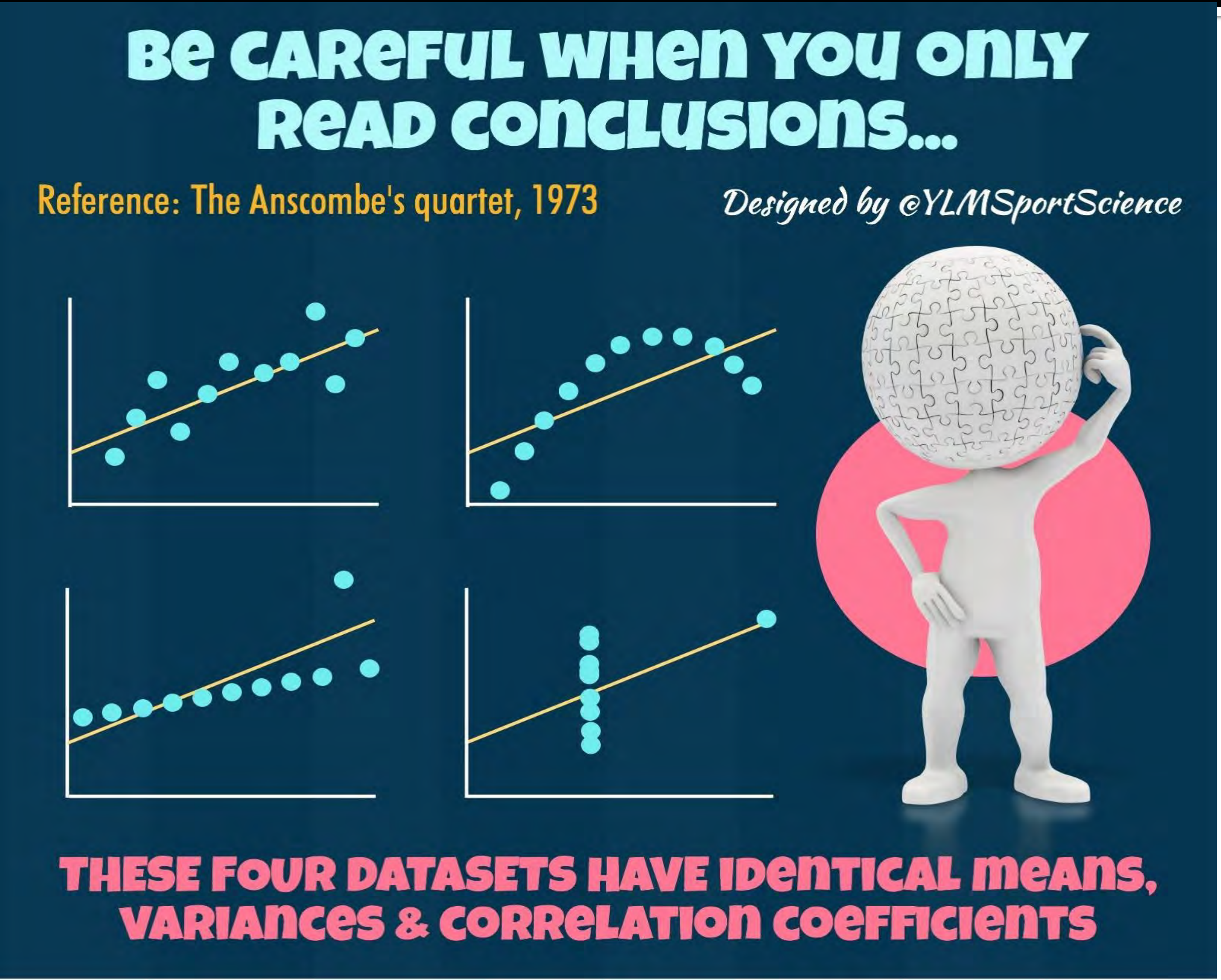
Test	NJDOT UHPTO	PATP HiMA SMA
APA Rutting	1.65 mm	1.24 mm
OT Cycles	> 5000	> 5000
OT CPR	0.144	0.118

NJDOT Network Status as of 2024 Data



Source: NJDOT Pavement Management System

Thank you for your time!
Questions?



Thomas Bennert, Ph.D.
Rutgers University
609-213-3312
bennert@soe.rutgers.edu