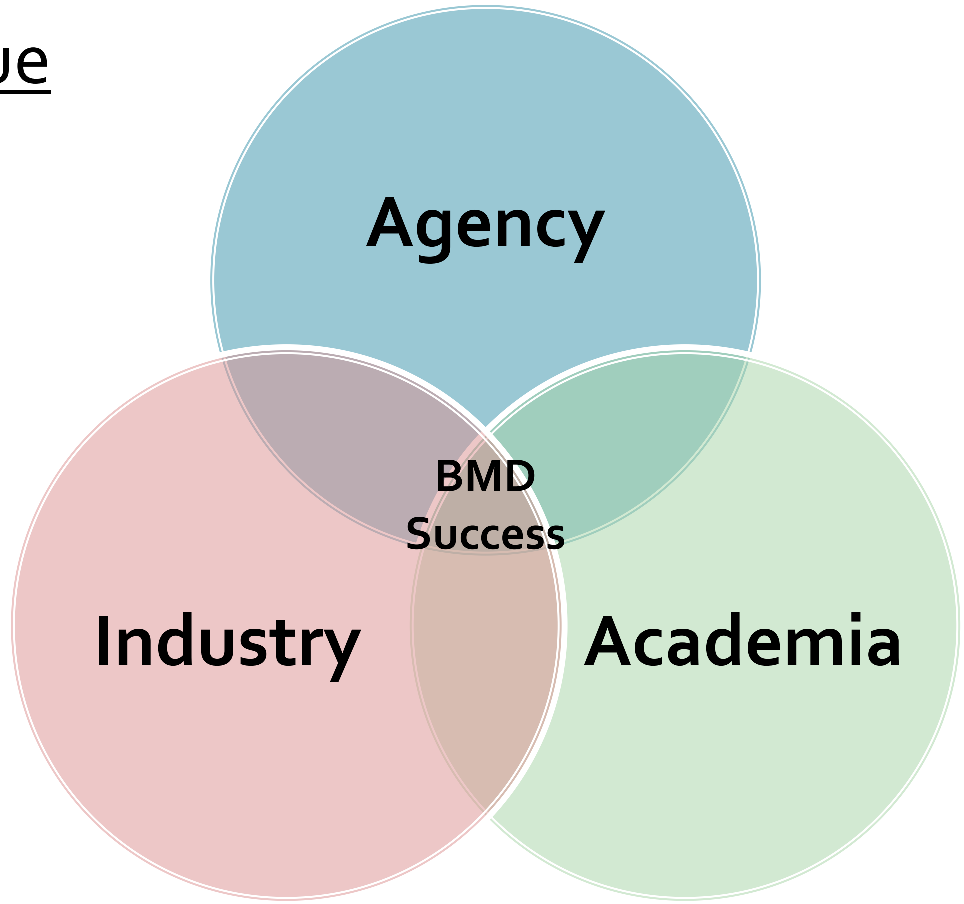
ES8: Crack the Code: A Technical Guide to Testing for Asphalt Cracking

Balanced Mix Design Case Studies Focusing on Cracking

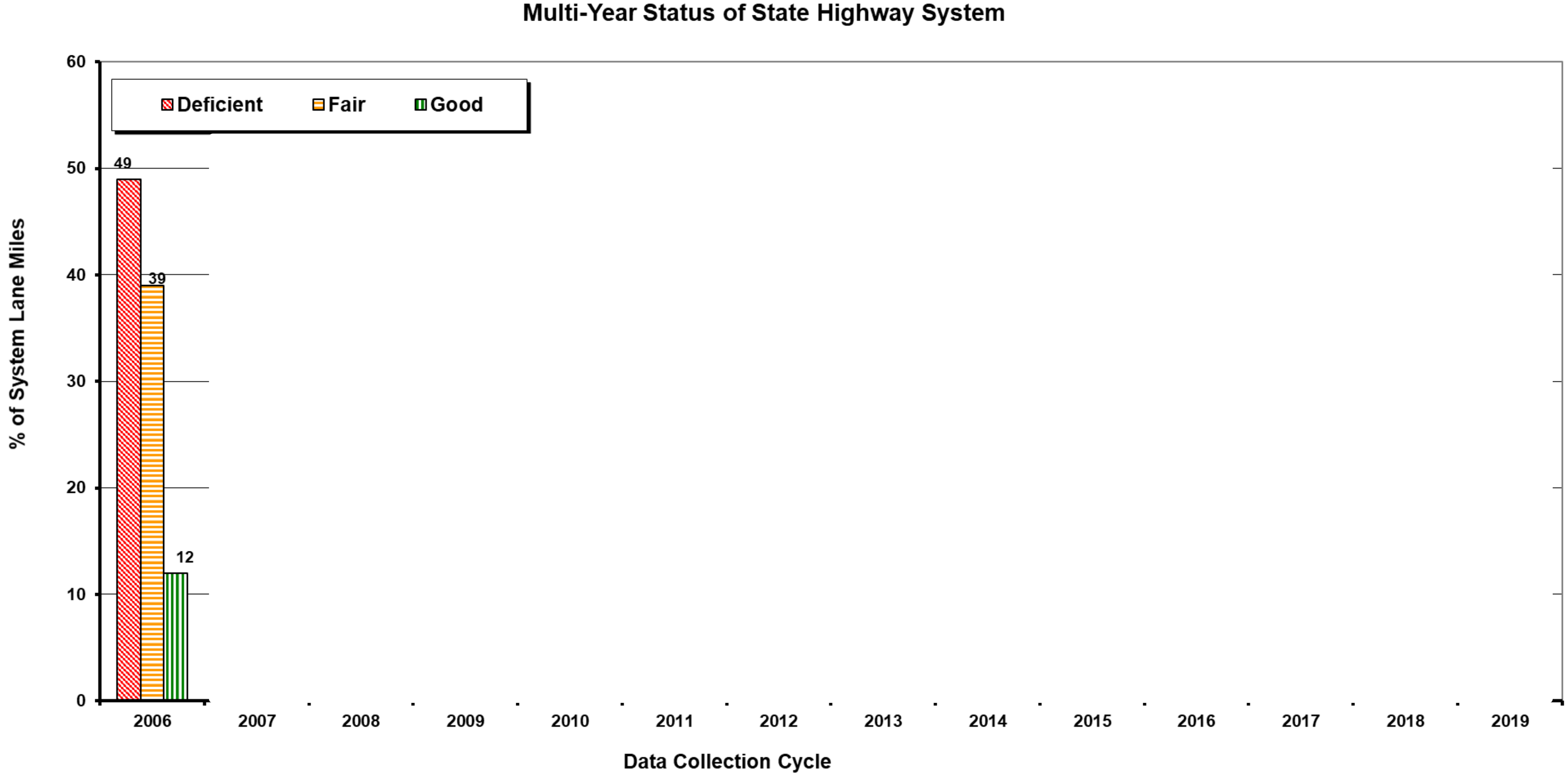
Thomas Bennert, Ph.D.
Center for Advanced Infrastructure and Transportation (CAIT)
Rutgers University

Acknowledgements

- NJDOT
  - Robert Blight, Eileen Sheehy, Bob Sauber, Sue Gresavage, Nusrat Morshed, Narinder Kholi, Stevenson Ganthier
- Asphalt Industry
  - Frank Fee, Ron Corun, Mike Worden
  - Wayne Byard, Mike Jopko, Keith Sterling
- Staff at Rutgers Asphalt Pavement Laboratory
  - Ed Wass, Ed Haas, Chris Ericson, Darius Pezeshki



The Motivation – Where it Started!



Source: NJDOT Pavement Management System

NJ's Reasoning for BMD ("Performance Based Mix Design")

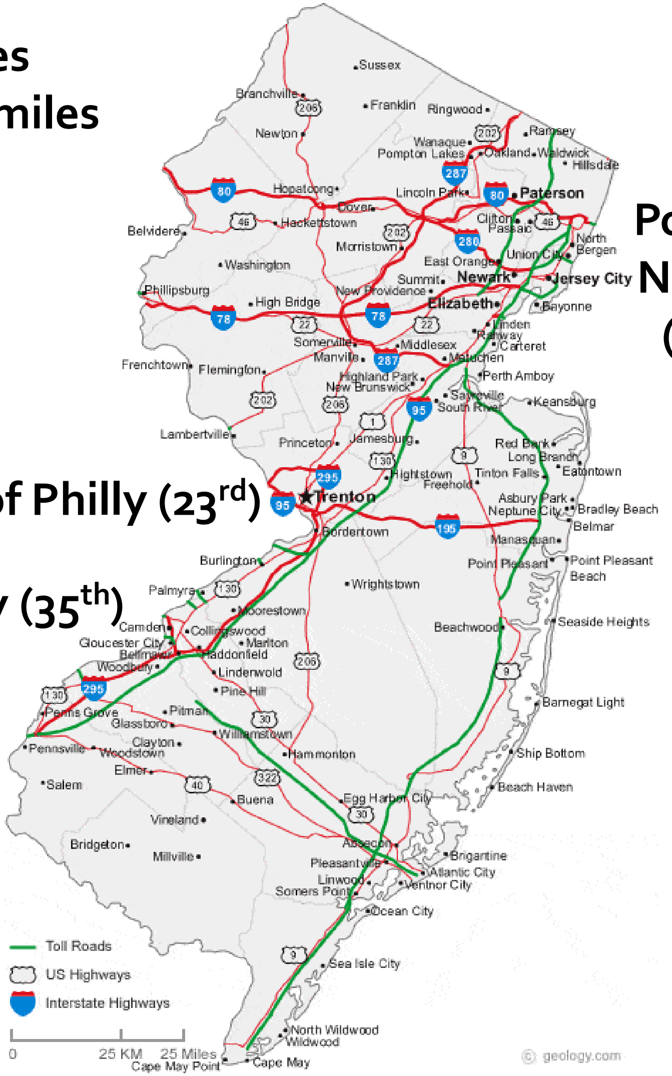
- Existing asphalt mixtures
  - Early 125 and 100 N_{des} mixes were dry
  - Significant cracking issues
    - Flexible (top-down); Composite (transverse)
- Traffic conditions
  - 29% increase from 1990 to 2006
  - 30% projected from 2006 to 2025
    - 73 billion miles traveled annually
- Climate conditions
  - Precipitation: 43 to 48 inches per year
  - Air Temperature: > 30 days over 90F;
> 80 days less than 32F
- Pavement conditions
  - Over 60% of NJDOT pavements are composite

NJ: 8700 square miles
AZ: 114,000 square miles

Port of NY/NJ (4th)

Port of Philly (23rd)

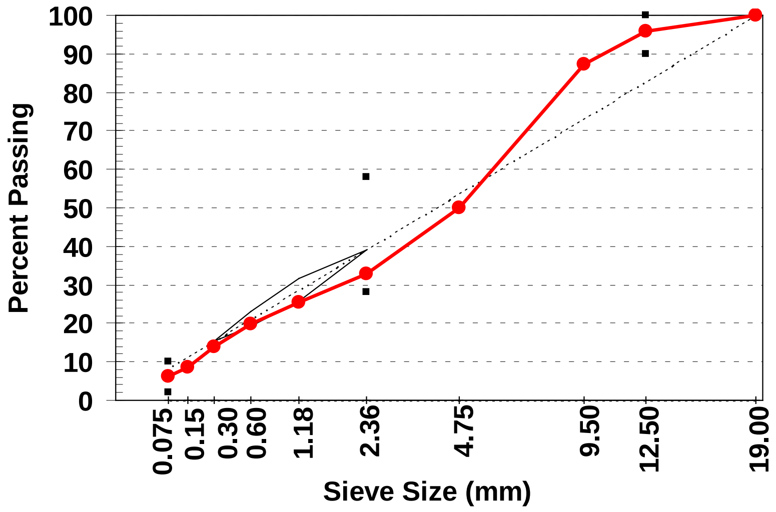
Port of S. Jersey (35th)



Balanced Mixture Design Performance

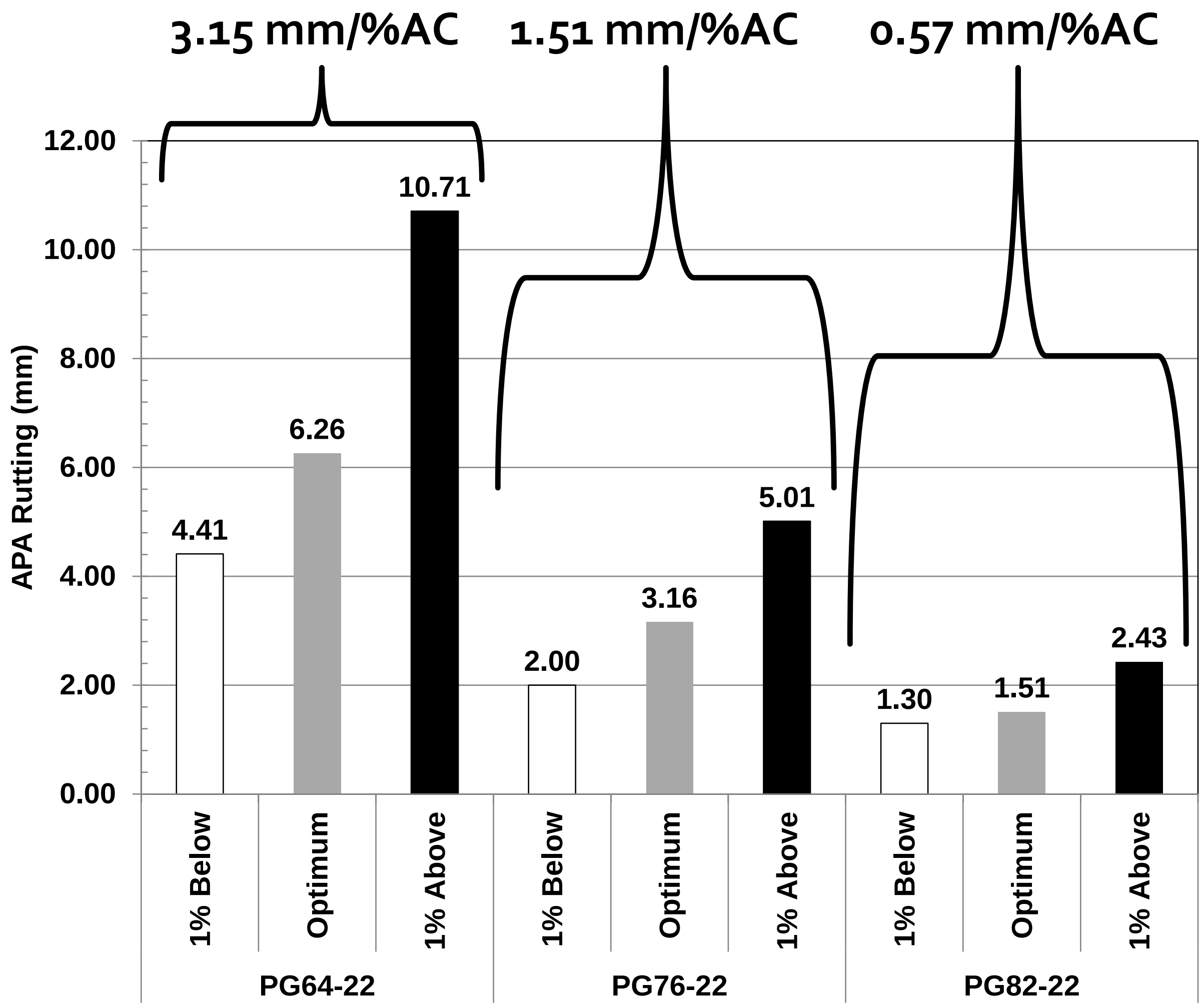
- NJDOT began utilizing performance testing in mixture design in 2006
  - BMD Approach A
- Started evaluating BMD after reading AAPT paper by Zhou et. al, (2007)
  - Asphalt content below, at, and above volumetric optimum
  - Different binder grades

Binder Content (%)	4.9%
VMA (%)	14.9%
G_{mm} (g/cm^3)	2.712
G_{sb} (g/cm^3)	2.91
Percent Passing	
19mm	100
12.5mm	95.9
9.5mm	87.3
4.75mm	50.1
2.36mm	32.9
1.18mm	25.5
0.6mm	19.9
0.3mm	13.9
0.15mm	8.7
0.075mm	6.2

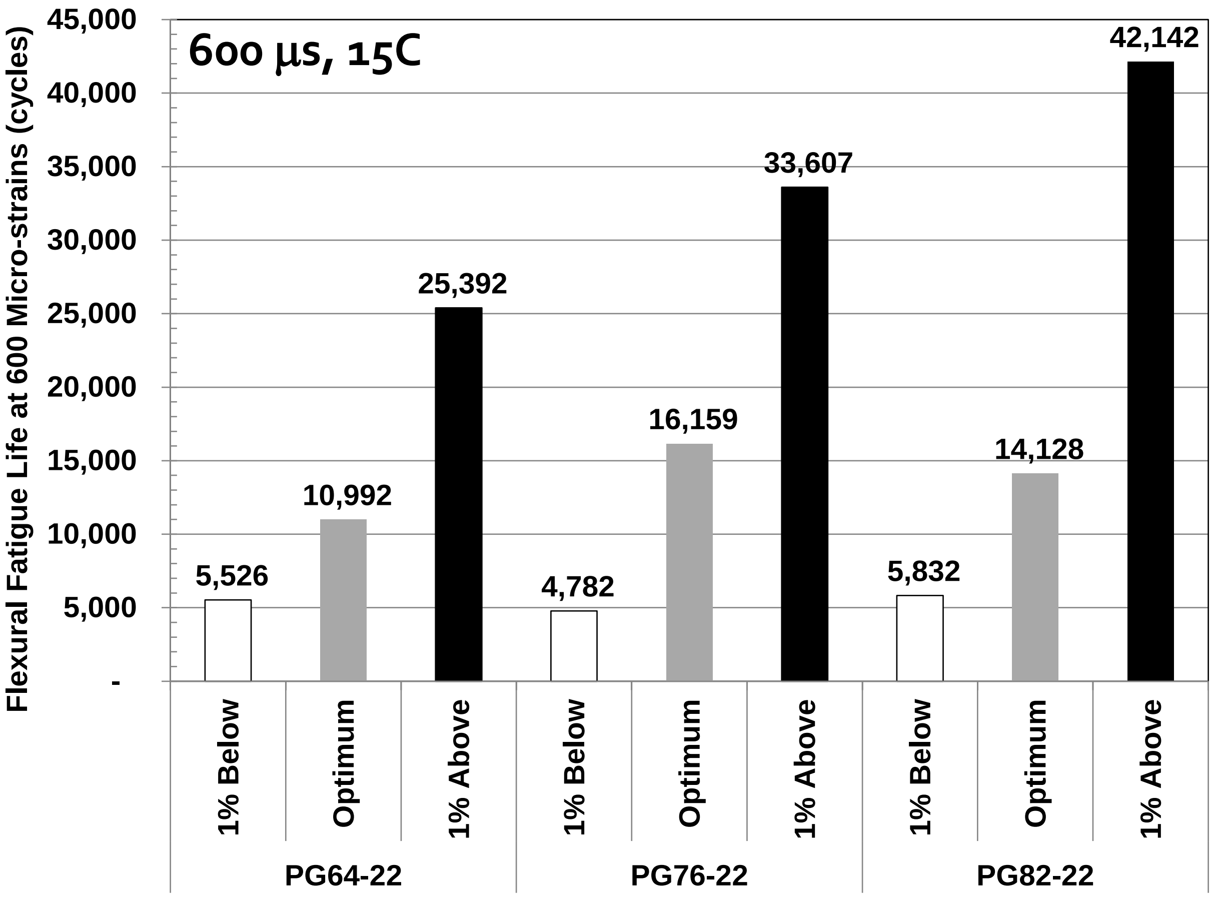


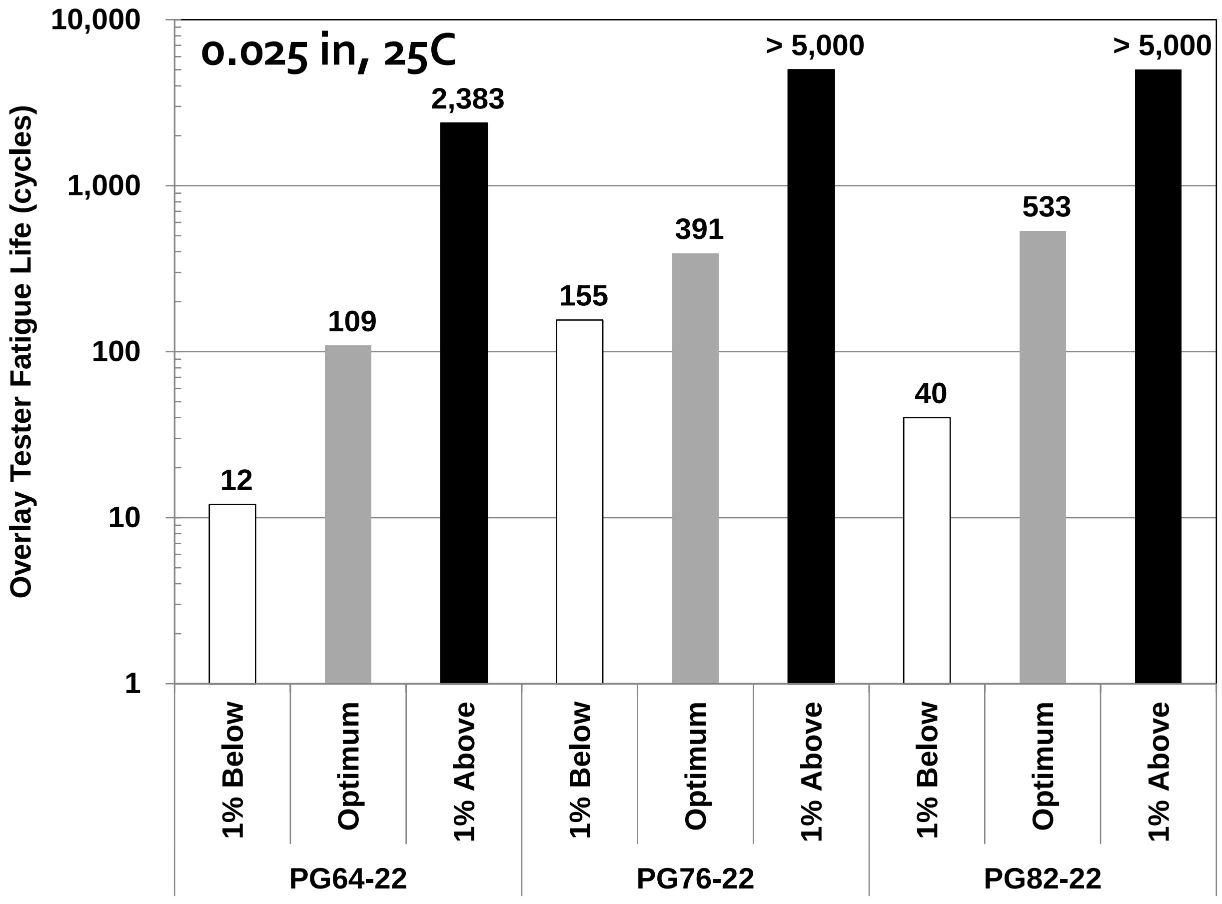
Early NJ BMD Research (2006)

- Rutting (AASHTO T340)
  - As binder content increased, rutting increased
  - But magnitude lessened when binder grade improved
- Cracking (AASHTO T321 & NJDOT B-10)
  - At below volumetric optimum and at optimum, similar fatigue properties were observed
  - At above optimum, significant improved



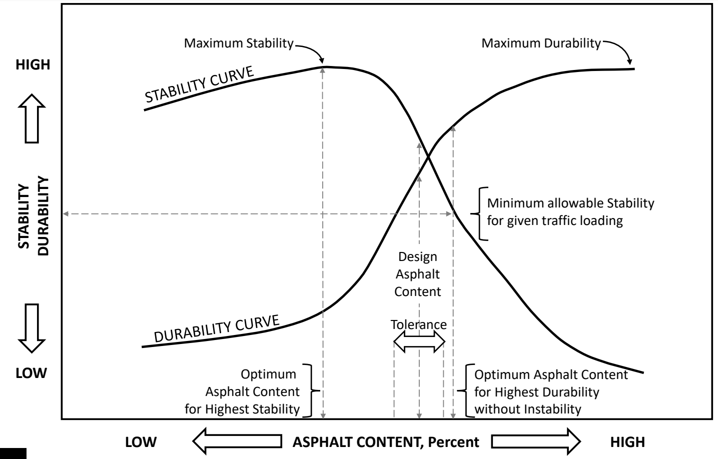
Early NJ BMD Research (2006)

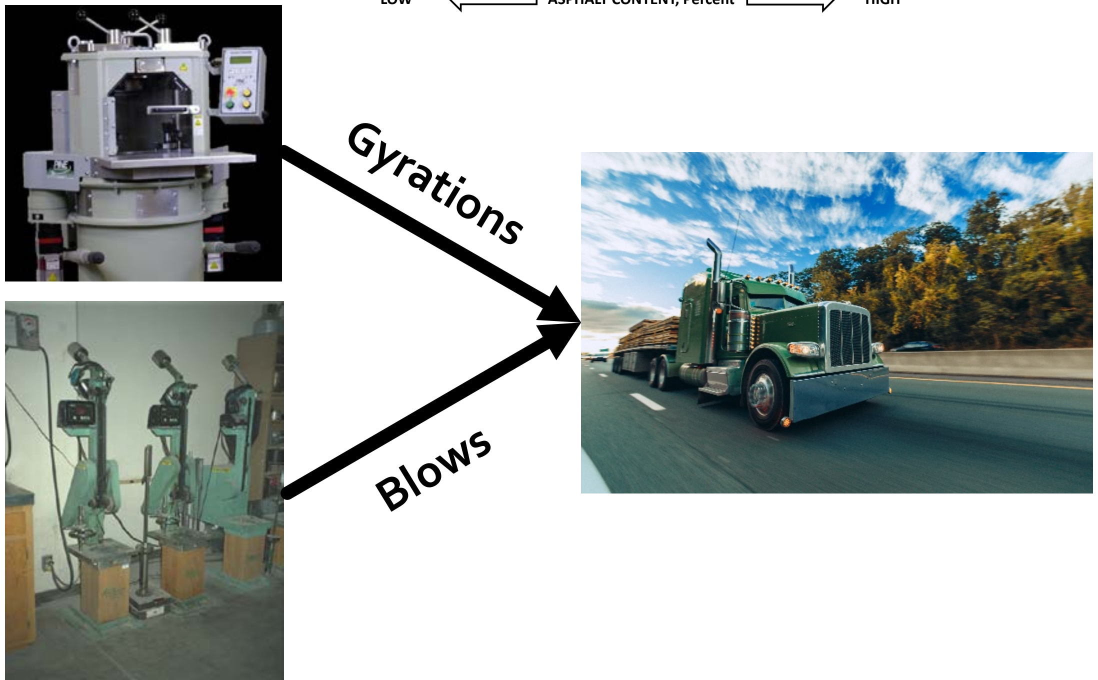




Question?

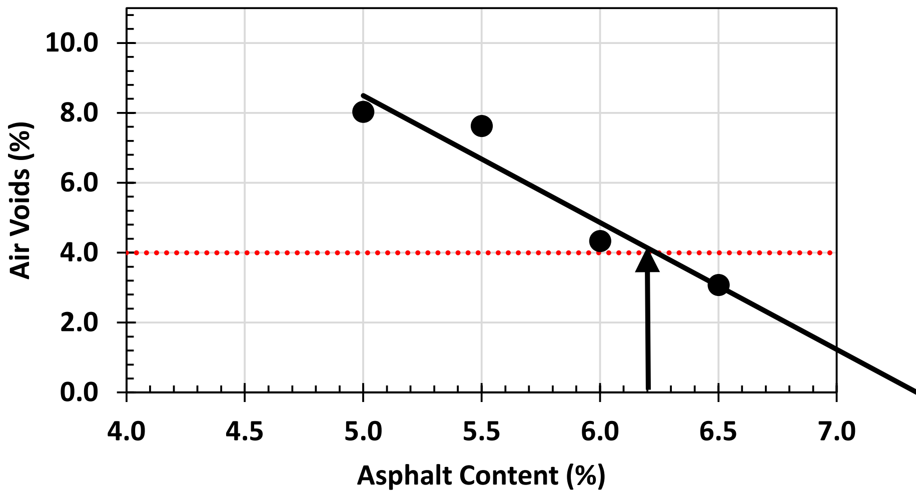
- Have we been doing asphalt mixture design incorrectly for modified asphalt binders?
- NCHRP 9-9A
  - Hveem – less emphasis on sample air voids and more emphasis on stability but recognized importance of air voids on durability.
  - Marshall (USACE) – calibrated laboratory compaction effort to densification that occurred with accelerated loading sections
    - General approach taken today where field densification levels are "calibrated" to gyrations
      - ***But what if we have binders that are more resistant to field densification than others?***





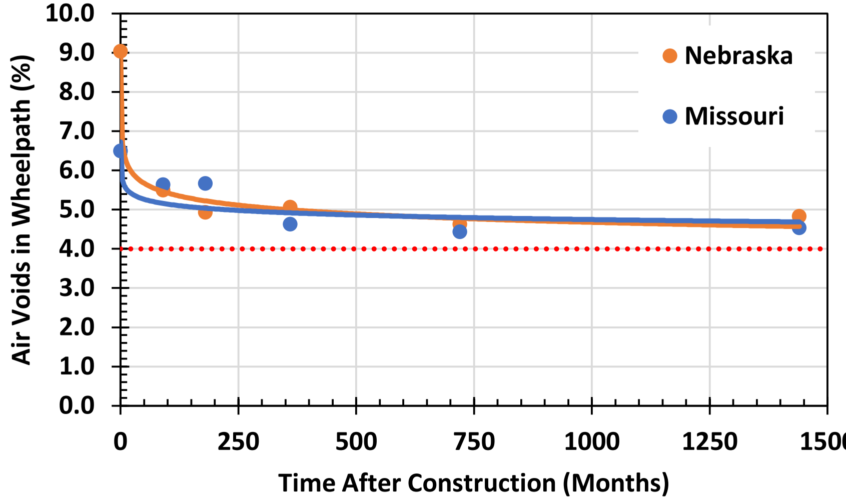
Wheelpath Densification

- Wheelpath Densification
  - Mix design assumes we want to optimize asphalt content to provide stable and durable mix after densification has taken place (i.e. ≈ 4% air voids)
    - Example: NCHRP 9-9A (Nebraska & Missouri)



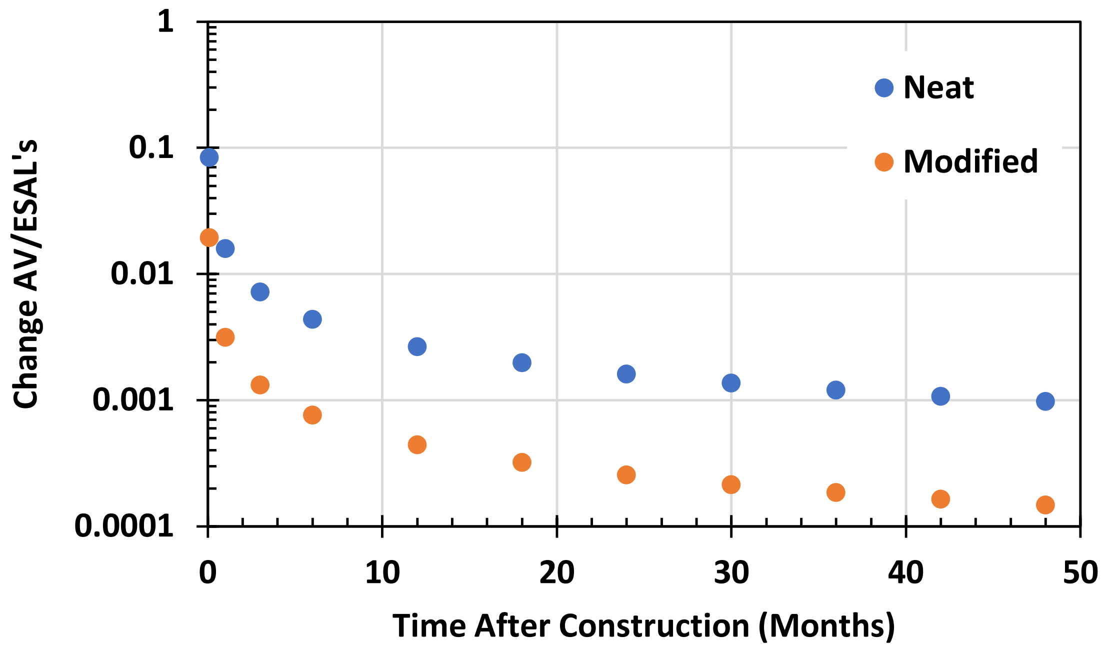
State	Initial AV%	4 Yr ΔAV%	4 Yr MESAL
Nebraska	9.0	-4.8%	0.068
Missouri	6.5	- 2.0%	8.4

Unmodified PMA



Wheelpath Densification

- NCHRP 9-9A Data
  - Pavements with neat binders consolidated at a rate 6 times more than modified binders (40 projects)
  - According to volumetric mix design rules, if air voids above 4% after compaction, additional asphalt binder added
    - For same aggregate gradation; lower gyration level ≈ increased AC

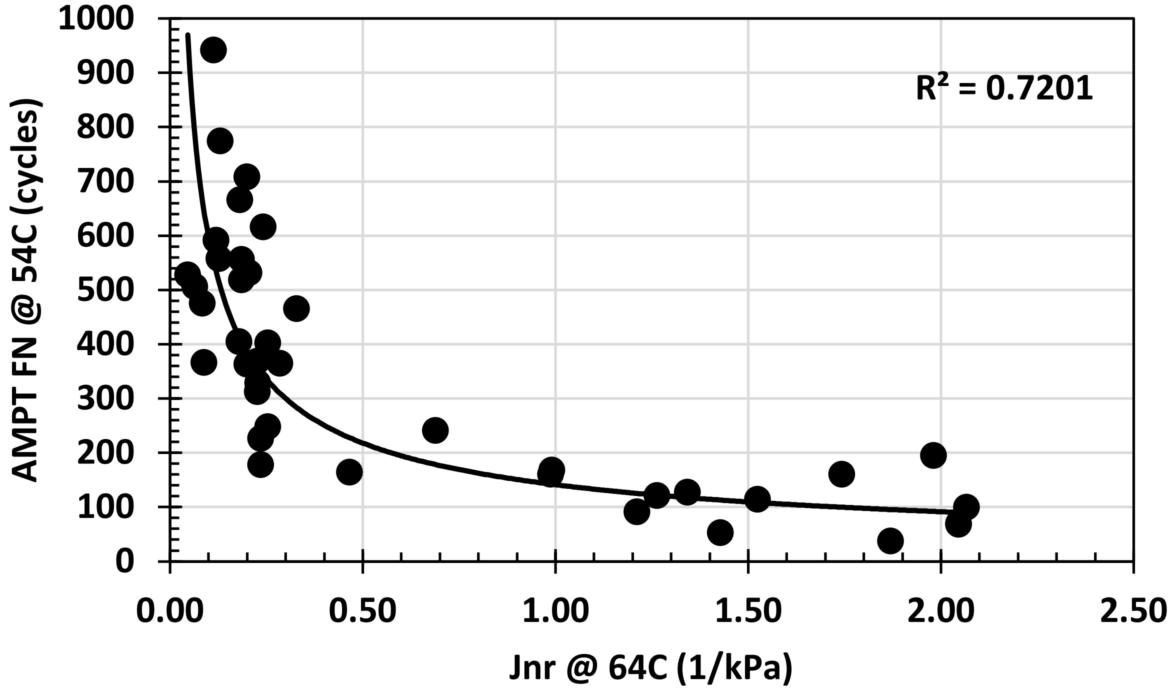


20 Yr MESAL's	N_{des} (<PG76)	N_{des} (>PG76)
< 0.3	50	N.A.
0.3 to 3	65	50
3 to 30	80	65
> 30	100	80

(Prowell & Brown, 2007)

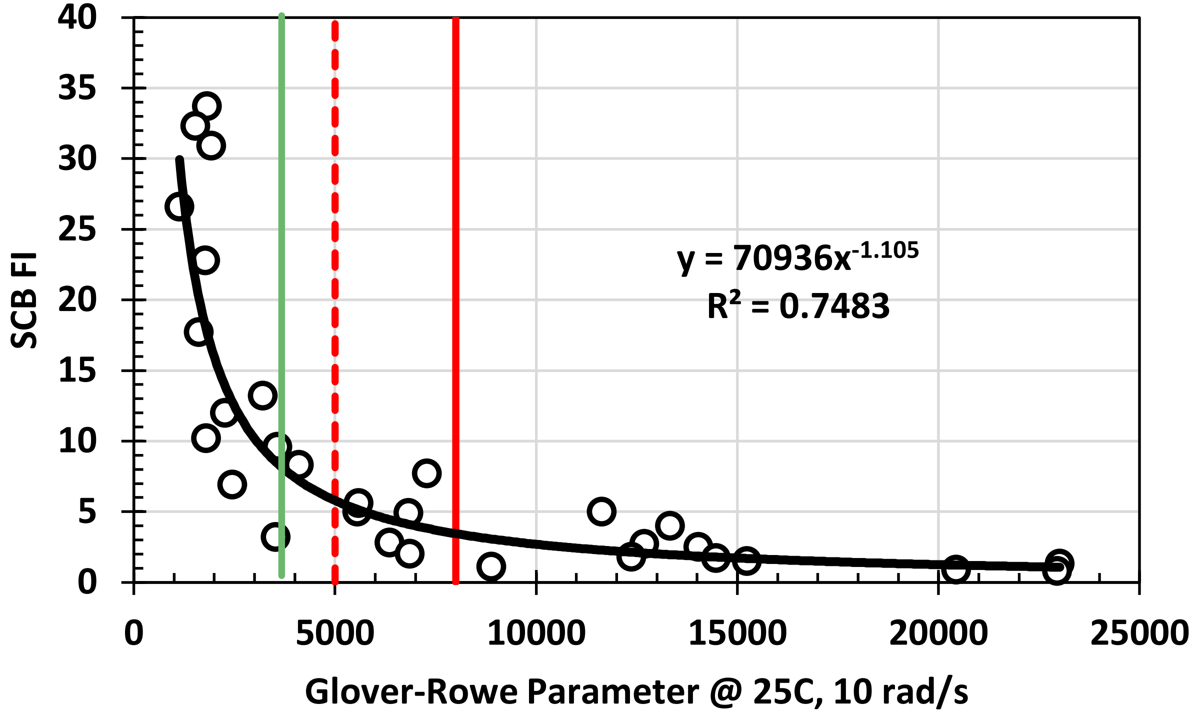
Binder Properties & Mixture Performance

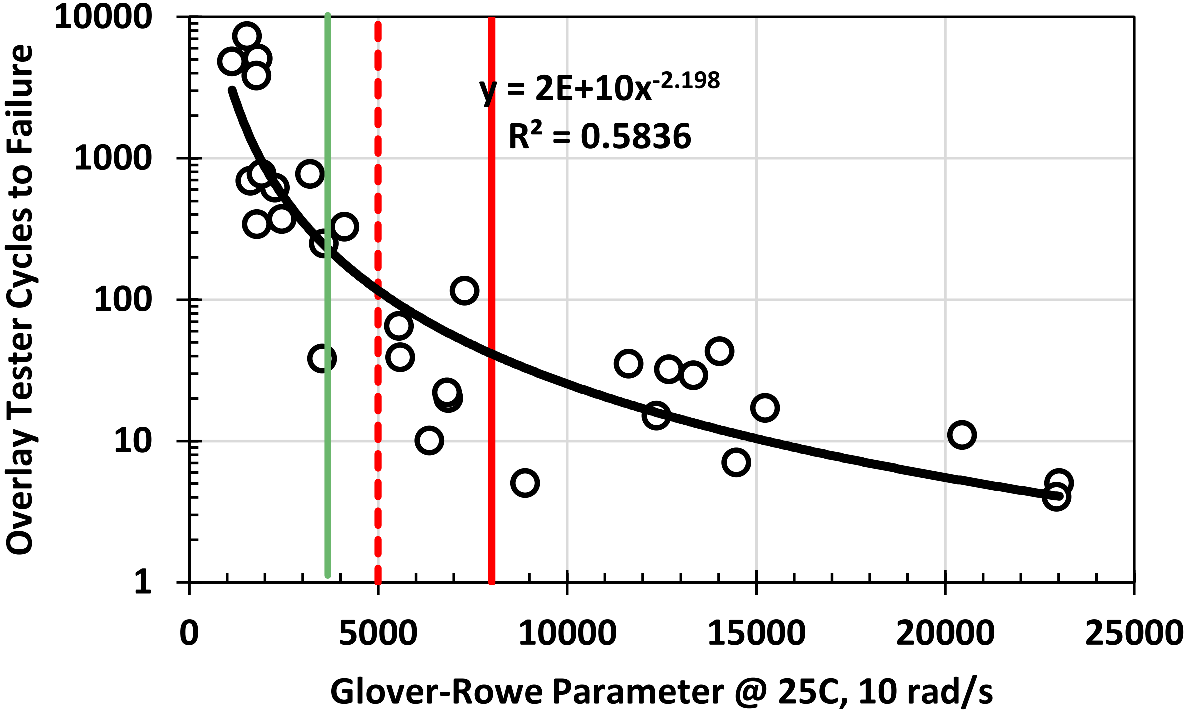
- Permanent Deformation



Traffic Level, Million ESALs	Minimum Flow Number
< 3	---
3 to < 10	53
10 to < 30	190
≥ 30	740

Binder Properties & Mixture Performance



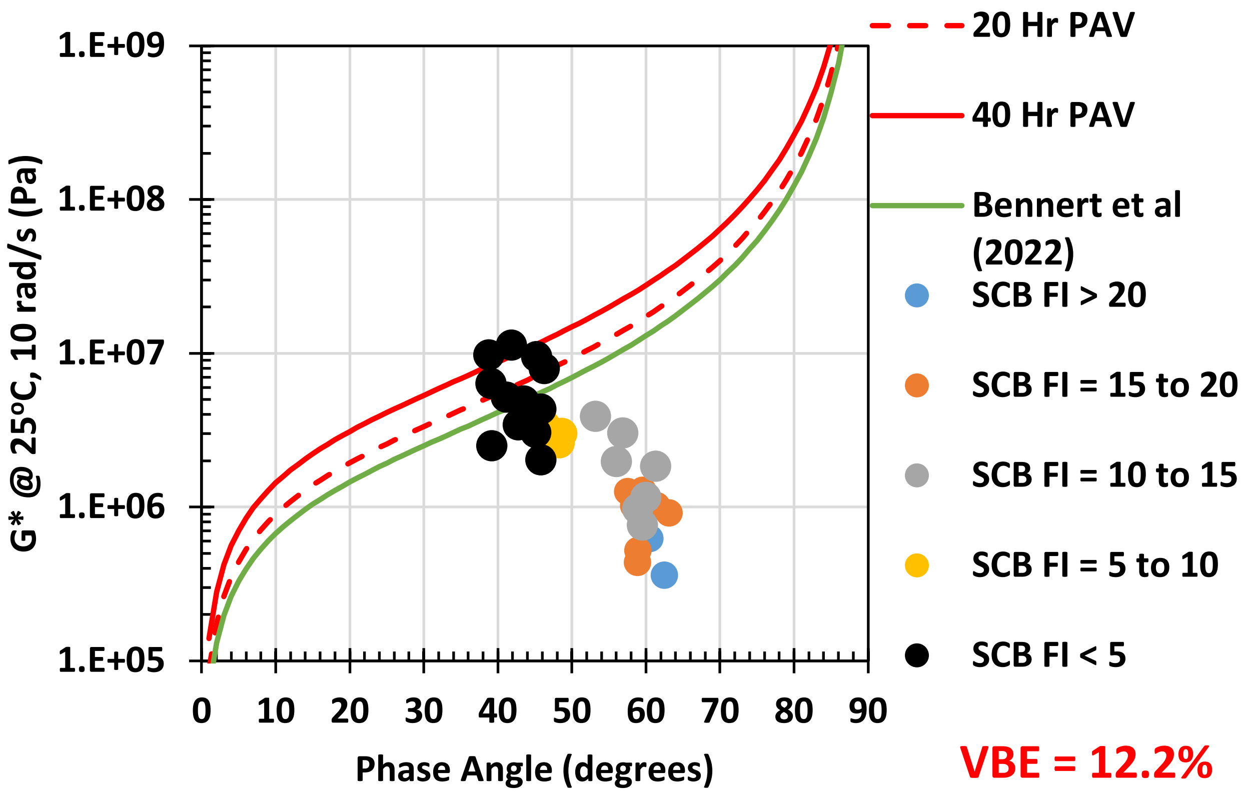


$$\frac{G'}{\eta'/G'} = \frac{|G^*| \cdot (\cos\delta)^2}{\sin\delta} \cdot \omega$$

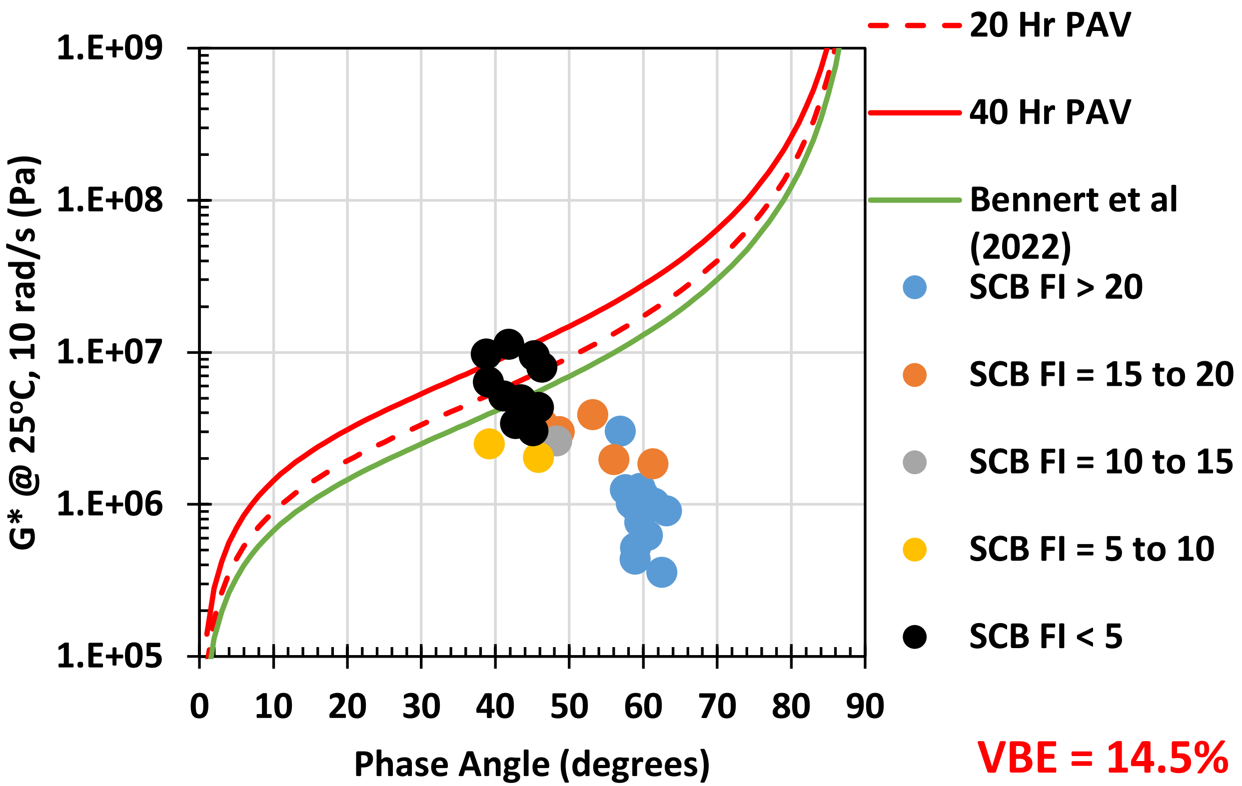
GRP @ 25C (kPa)	SCB FI @ 25C	OT Cycles @ 25C
3750	8.0	279
5000	5.8	148
8000	3.5	53

Binder Performance-Volumetric Interaction

- Glover-Rowe (NCHRP9-59) effective way to look at asphalt binder properties: Binders ranged from Neat PG58-28 to Neat 70-22 to Modified 64-34 to 76-28
  - Lower effective asphalt content by volume (VBE) results in lower mixture fatigue cracking even when achieving same asphalt binder property



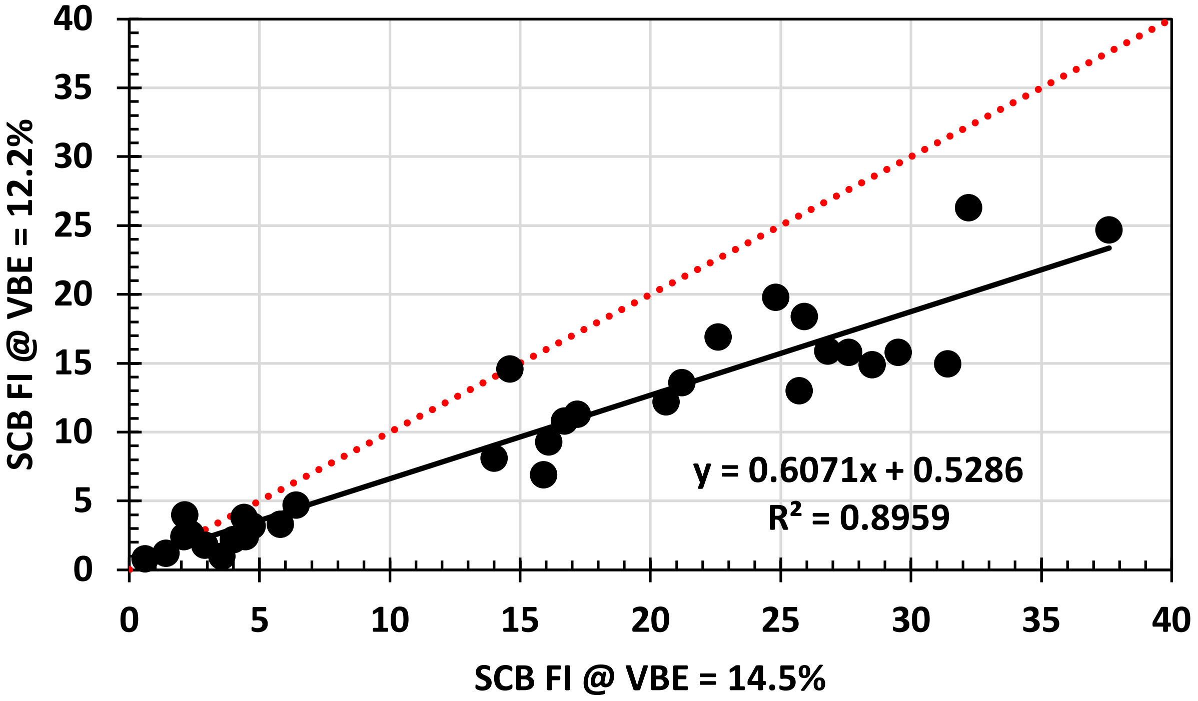
VBE = 12.2%

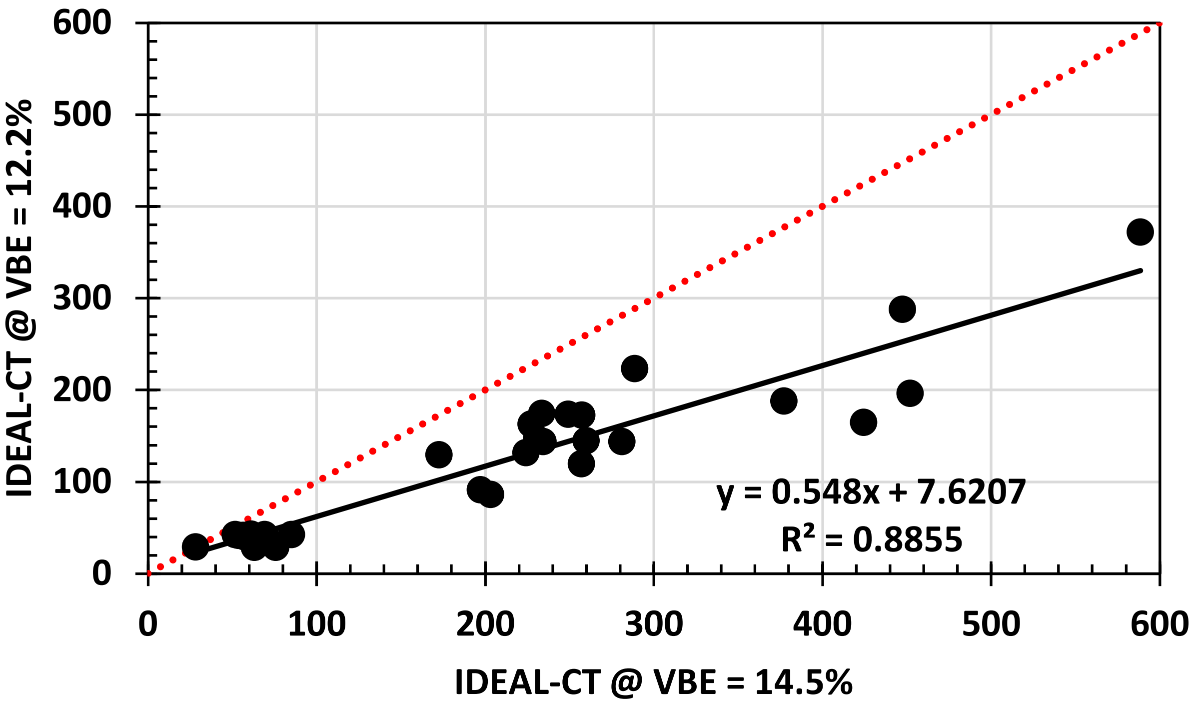


VBE = 14.5%

Binder-Volumetric Interaction

- A change in VBE makes a significant change in mixture cracking performance
  - SCB FI: 2.3% decrease in VBE decreased SCB FI by almost 40%
  - IDEAL-CT: 2.3% decrease in VBE decreased IDEAL-CT by almost 45%
    - VBE (%) = %VMA - %AV





Classical AI Fatigue Equation (1982)

- Effective asphalt content drives fatigue cracking performance!

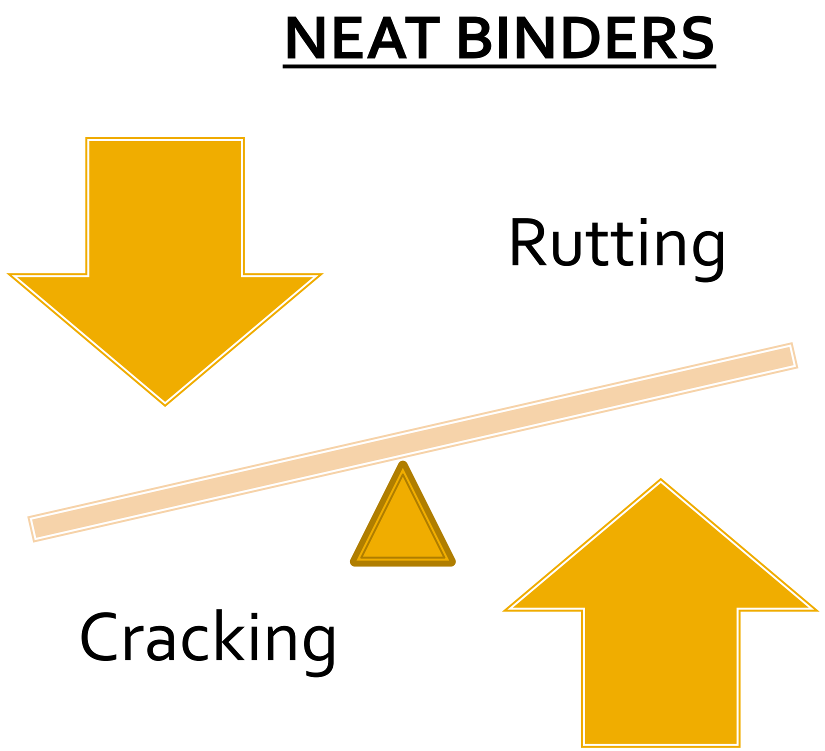
$$N_f = 18.4 \times 0.00432 \times 10^{[4.84 \times (VFA - 0.69)]} \times \left(\frac{1}{\varepsilon_t}\right)^{3.291} \times \left(\frac{1}{|E^*|}\right)^{0.859}$$

Volumetric Effect

Where:
N_f = number of 18 kip ESALs
18.4 = lab to field adjustment
VFA = voids filled with asphalt
ε_t = tensile strain
$|E^*|$ = dynamic modulus

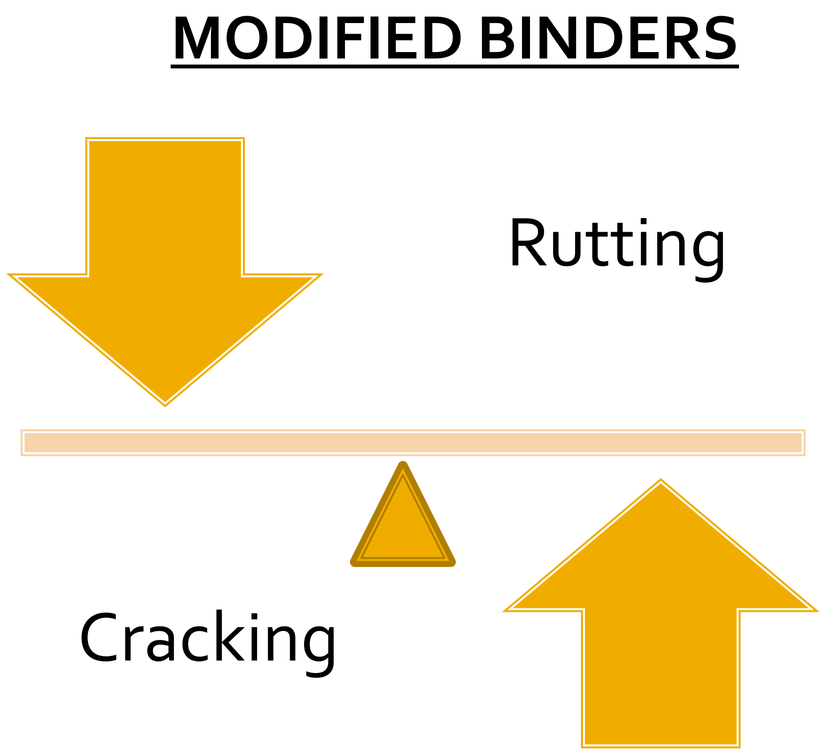
Better Mixture/Field Performance for HMA

- Better field performance is commonly associated with good rutting resistance and good cracking resistance
  - Not easy to balance when a change in a mixture parameter can have opposing impact
    - Increase VBE



Better Mixture/Field Performance for HMA

- Better field performance is commonly associated with good rutting resistance and good cracking resistance
  - Not easy to balance when a change in a mixture parameter can have opposing impact
    - Increase VBE to improve cracking performance
    - Use modified binder to improve rutting performance

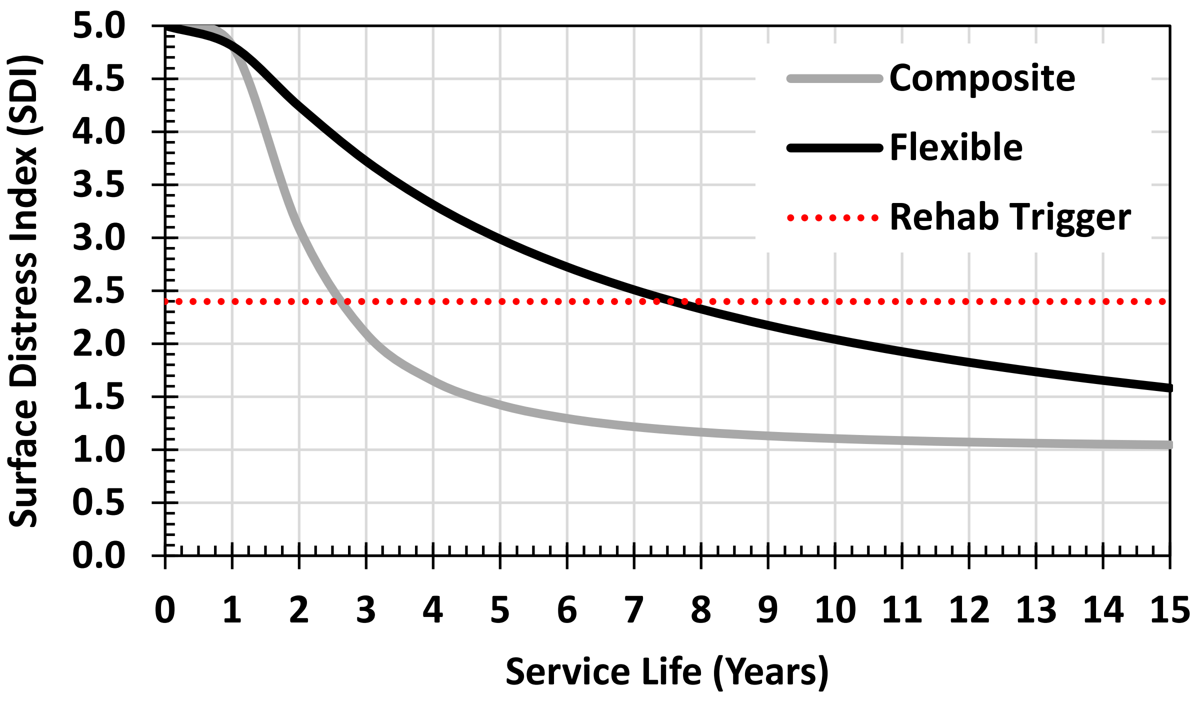


BMD and Modified Binders – Perfect Together!

NJDOT Efforts

NJDOT – Field Performance Comparisons

- Change in Mix Design Practice
  - Clear that performance could be improved if using modified binders with mix design procedures/criteria to encourage higher asphalt contents
- Implementation
  - Started in 2007 with performance criteria initially developed using mix testing database and "engineering judgement"
    - Tackled one issue at a time



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

NJDOT High Performance Thin Overlay (HPTO)

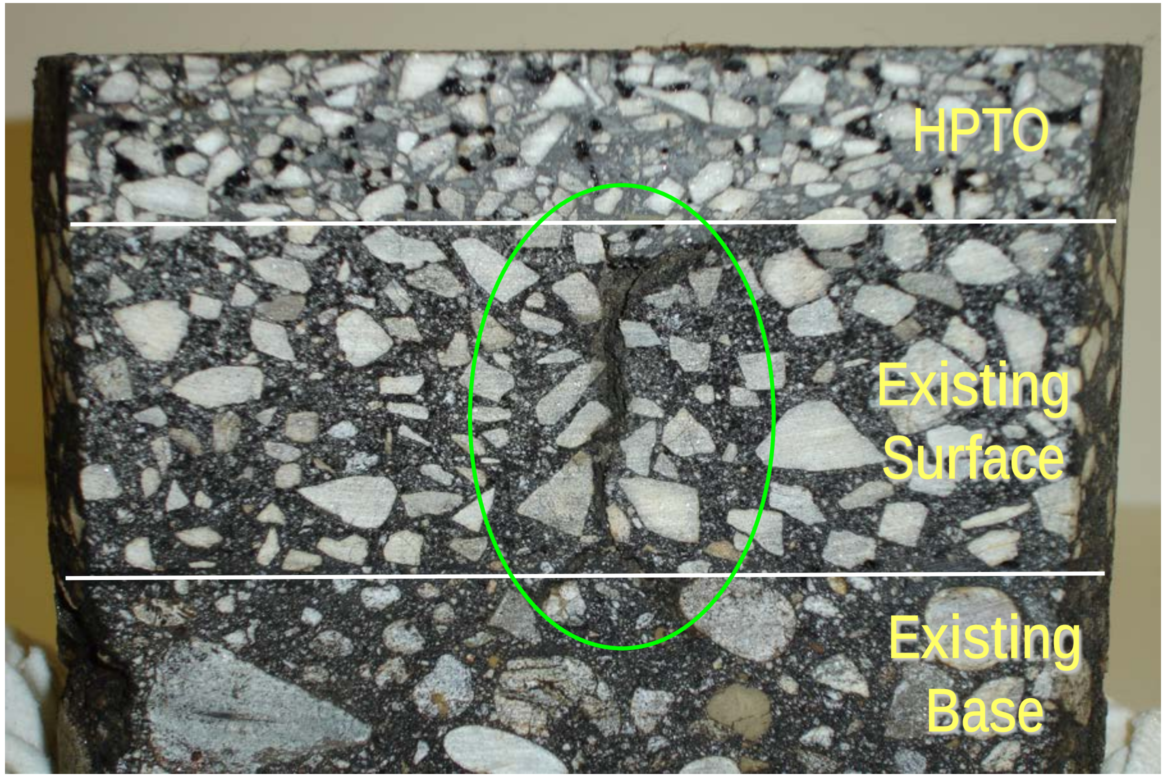
- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 14%
  - VFA 65 – 78%
  - RAP ≤ 15%
  - No performance test requirements

1" Thick Lift with or without milling

- HPTO
  - Design AV = 3.5%
  - N_{des} = 50
  - VMA ≥ 18%
  - Min AC% ≥ 7%
  - No RAP
  - APA Rutting ≤ 4.0mm
  - Overlay Tester ≥ 600 cycles

NJDOT High Performance Thin Overlay (HPTO)

- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 14%
  - VFA 65 – 78%
  - RAP ≤ 15%
  - No performance test requirements

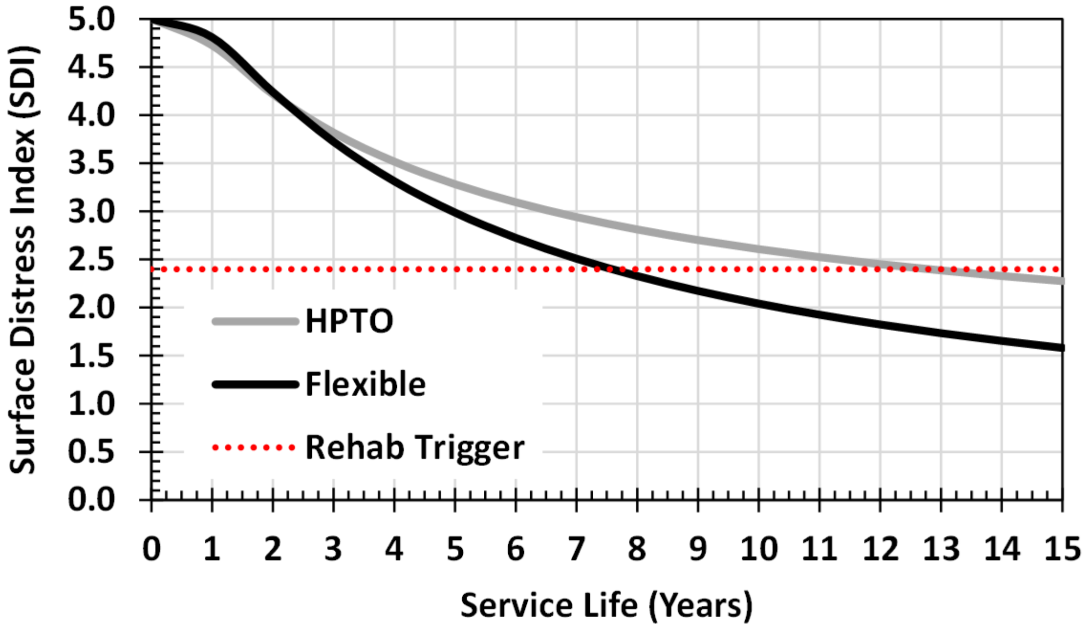


1" Thick Lift with or without milling

- HPTO
  - Design AV = 3.5%
  - N_{des} = 50
  - VMA ≥ 18%
  - Min AC% ≥ 7%
  - No RAP
  - APA Rutting ≤ 4.0mm
  - Overlay Tester ≥ 600 cycles

NJDOT High Performance Thin Overlay (HPTO)

- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 14%
  - VFA 65 – 78%
  - RAP ≤ 15%
  - No performance test requirements



Improvement of > 5 Years of Service Life

- HPTO
  - Design AV = 3.5%
  - N_{des} = 50
  - VMA ≥ 18%
  - Min AC% ≥ 7%
  - No RAP
  - APA Rutting ≤ 4.0mm
  - Overlay Tester ≥ 600 cycles

Stone Matrix Asphalt (SMA) with Bituminous Rich Intermediate Course (BRIC) for Composite Pavements

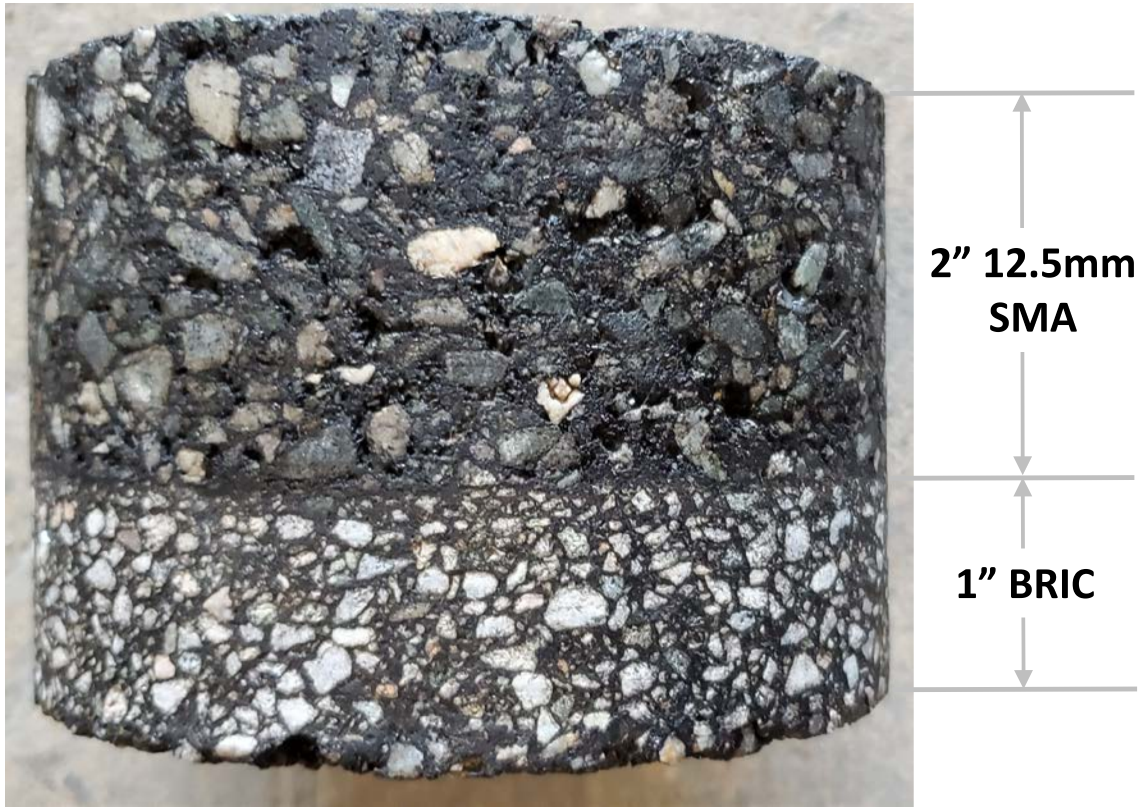
- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 14%
  - VFA 65 – 78%
  - RAP ≤ 15%
  - No performance test requirements

- SMA
  - Design AV = 3.5%
  - N_{des} = 75
  - VMA ≥ 17%
  - Min. AC% ≥ 6%
  - No RAP
- BRIC

Over 60% of NJDOT Pavements are Composite

Stone Matrix Asphalt (SMA) with Bituminous Rich Intermediate Course (BRIC) for Composite Pavements

- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 14%
  - VFA 65 – 78%
  - RAP ≤ 15%
  - No performance test requirements

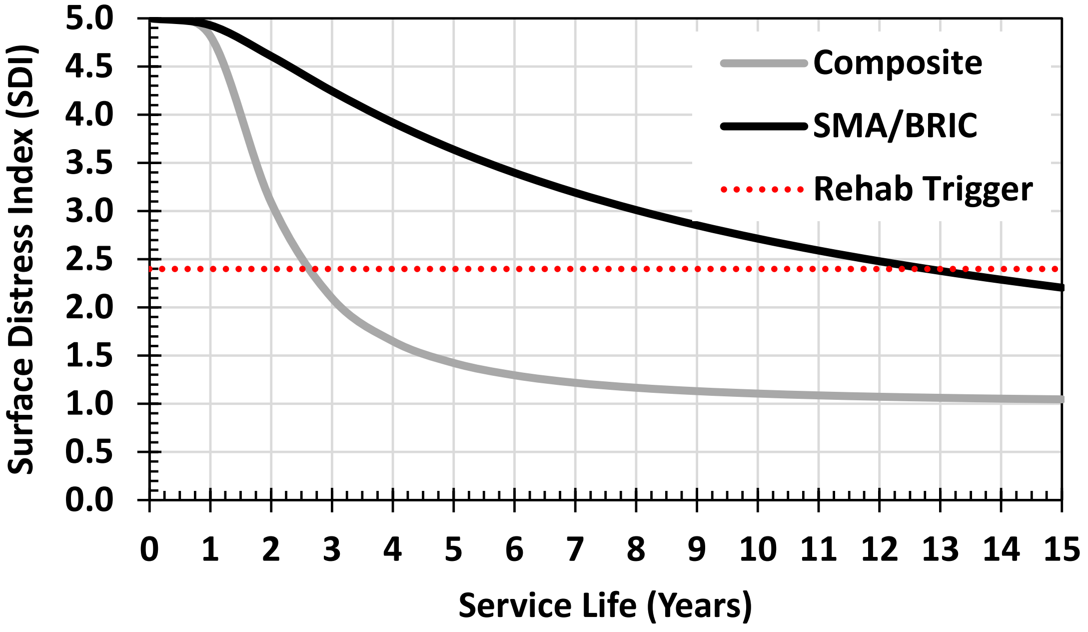


Combining modified asphalt mixtures as system to mitigate reflective cracking

- SMA
- BRIC
  - Design AV = 2.5%
  - N_{des} = 50
  - VMA ≥ 18%
  - Min AC% ≥ 7%
  - No RAP
  - APA Rutting ≤ 6.0mm
  - Overlay Tester ≥ 700 cycles

Stone Matrix Asphalt (SMA) with Bituminous Rich Intermediate Course (BRIC) for Composite Pavements

- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 14%
  - VFA 65 – 78%
  - RAP ≤ 15%
  - No performance test requirements



Improvement of > 10 Years of Service Life

- SMA
- BRIC
  - Design AV = 2.5%
  - N_{des} = 50
  - VMA ≥ 18%
  - Min AC% ≥ 7%
  - No RAP
  - APA Rutting ≤ 6.0mm
  - Overlay Tester ≥ 700 cycles

High Recycled Asphalt Pavement (HRAP) Mixtures

- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 14%
  - VFA 65 – 78%
  - RAP ≤ 15%
  - No performance test requirements

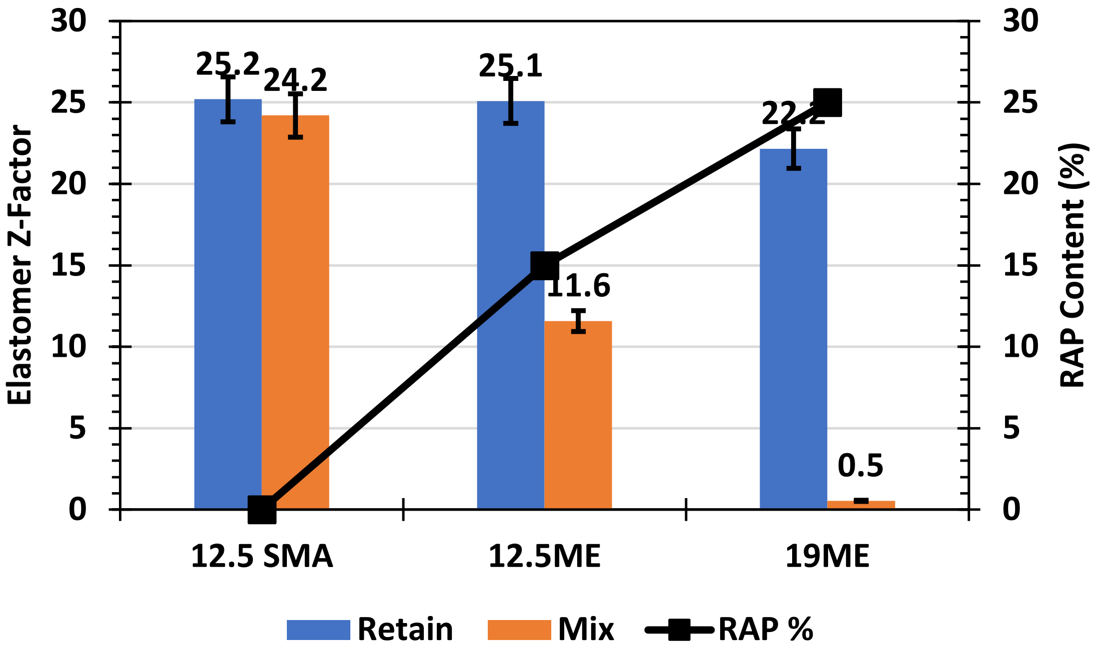
Test	Requirement			
	Surface Course		Intermediate Course	
	PG 64-22	PG 76-22	PG 64-22	PG 76-22
APA @ 8,000 loading cycles (AASHTO T 340)	< 7 mm	< 4 mm	< 7 mm	< 4 mm
Overlay Tester (NJDOT B-10)	> 200 cycles	> 275 cycles	> 100 cycles	> 150 cycles

Performance criteria based on 0% RAP mix

- HRAP
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 1% over Volumetric
  - VFA 65 – 85%
  - Unlimited RAP%
  - Modified binders, WMA, Recycling Agents

High Recycled Asphalt Pavement (HRAP) Mixtures

- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 14%
  - VFA 65 – 78%
  - RAP ≤ 15%
  - No performance test requirements

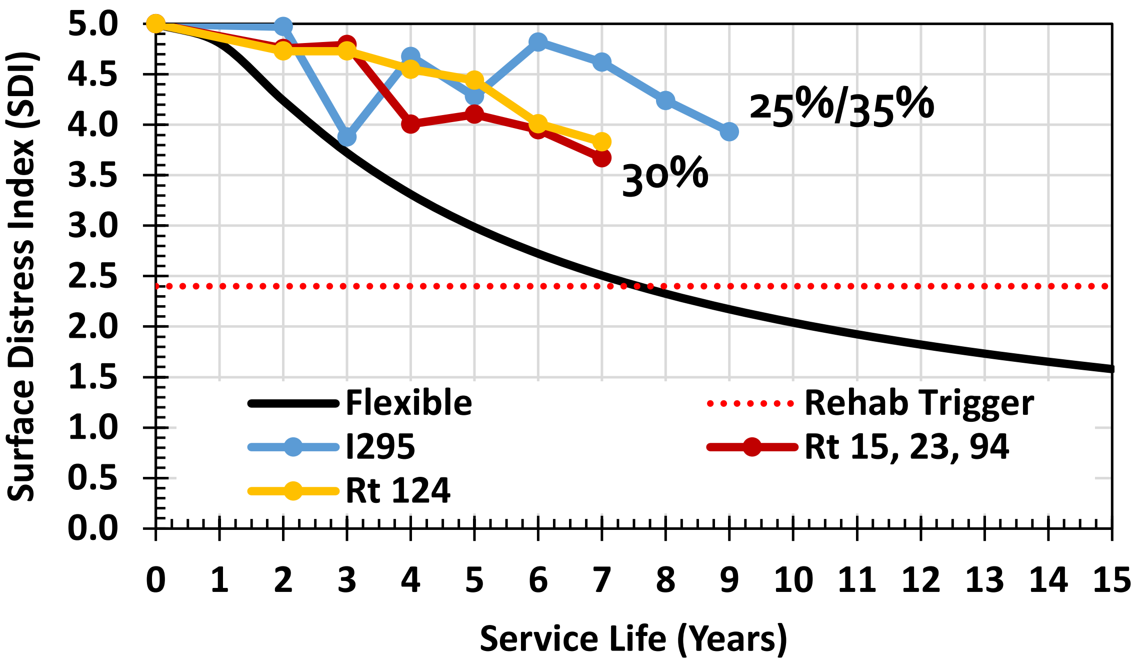


- HRAP
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 1% over Volumetric
  - VFA 65 – 85%
  - Unlimited RAP%
  - Modified binders, WMA, Recycling Agents

Addition of RAP reduces elastomeric properties. Need to increase VBE to include more virgin liquid. Compensates for lack of RAP binder transfer to virgin aggregate.

High Recycled Asphalt Pavement (HRAP) Mixtures

- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 14%
  - VFA 65 – 78%
  - RAP ≤ 15%
  - No performance test requirements

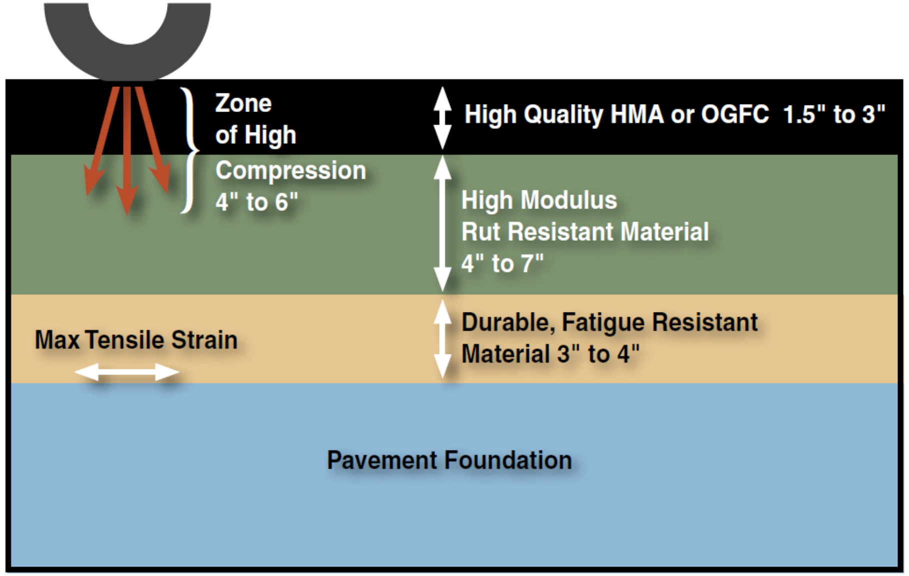


- HRAP
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 1% over Volumetric
  - VFA 65 – 85%
  - Unlimited RAP%
  - Modified binders, WMA, Recycling Agents

Only 3 projects with significant field performance, but projected 5 to 8 years benefit

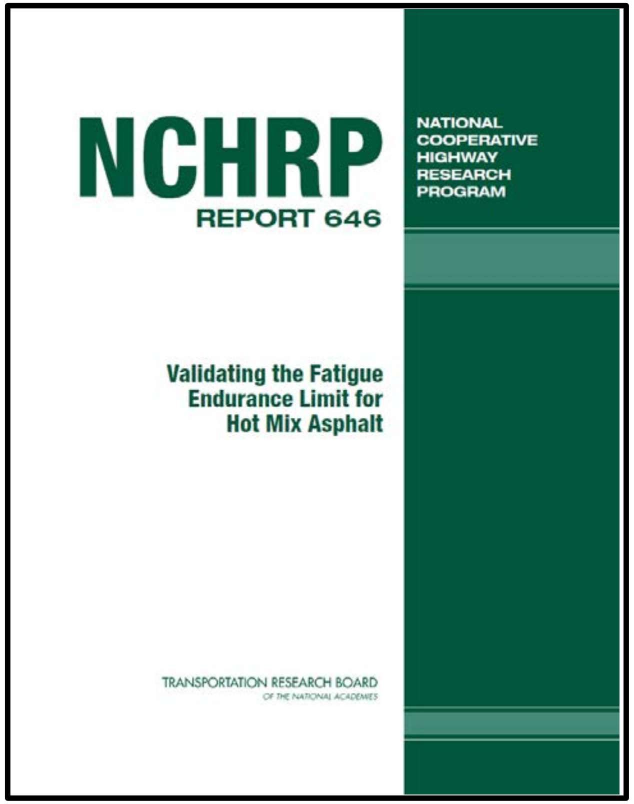
Bituminous Rich Base Course (BRBC)

- Aging concrete pavements, when applicable, rubblized
- Utilized as base aggregate course for perpetual pavement design
  - Option #1
    - Design and construct the pavement to achieve a high stiffness, resulting in a pavement structure with minimal deflections/strains
      - Traditionally done with excessive thickness and cement treated base/subbase and subgrades
  - Option #2
    - Design/construct the asphalt materials, especially the base course, to be strain tolerant (i.e. – design the asphalt material to bend without cracking under resultant tensile strains)



Changing Design Methodology – Design Materials to Meet Structural Needs of Pavement ("Design Role Reversal")

- Evaluated maximum tensile strain with selected HMA thickness over rubblized PCC
  - Used JULEA software – same in MEPDG
- Used methodology in NCHRP Report 646
- Conduct flexural beam fatigue at 400 and 800ms
  - 3 samples each
- Use 95% confidence interval with a selected # of repetitions
  - Designing HMA to meet pavement performance needs – "Role Reversal"



Bituminous Rich Base Course (BRBC)

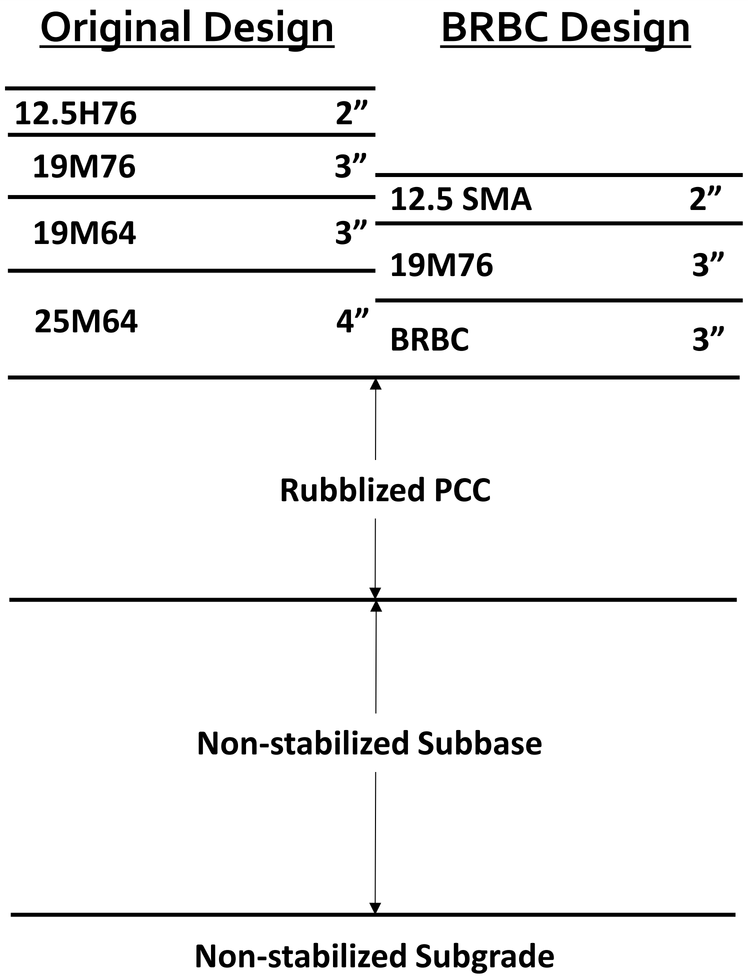
- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 13%
  - VFA 65 – 78%
  - RAP ≤ 25%
  - No performance test requirements

- BRBC
  - Design AV = 3.5%
  - N_{des} = 50
  - VMA ≥ 13.5%
  - No RAP
  - PG76-28
  - APA Rutting ≤ 5.0mm
  - Flexural Beam Fatigue (Based on project needs)

Example: NJ I295, MP45 to 57.3; 23 Overpass Structures Requiring Undercutting

Bituminous Rich Base Course (BRBC)

- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 13%
  - VFA 65 – 78%
  - RAP ≤ 25%
  - No performance test requirements

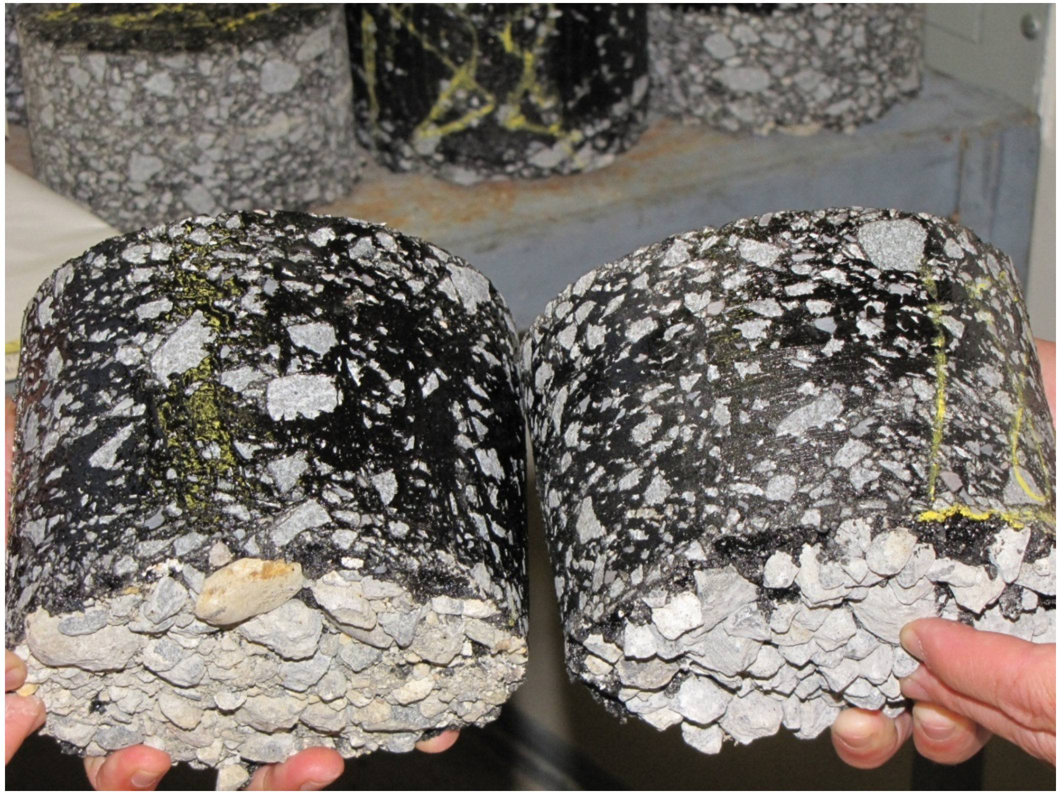


- BRBC
  - Design AV = 3.5%
  - N_{des} = 50
  - VMA ≥ 13.5%
  - No RAP
  - PG76-28
  - APA Rutting ≤ 5.0mm
  - Flexural Beam Fatigue (Based on project needs)

Example: NJ I295, MP45 to 57.3; 23 Overpass Structures Requiring Undercutting

Bituminous Rich Base Course (BRBC)

- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 13%
  - VFA 65 – 78%
  - RAP ≤ 25%
  - No performance test requirements



Project Saved:

- **Over 170,000 tons HMA**
- **Over 2700 round trips of delivery trucks**
- **Approximately $7 million**

- BRBC
  - Design AV = 3.5%
  - N_{des} = 50
  - VMA ≥ 13.5%
  - No RAP
  - PG76-28
  - APA Rutting ≤ 5.0mm
  - Flexural Beam Fatigue (Based on project needs)

APA ASPHALT PAVEMENT ALLIANCE

Bituminous Rich Base Course (BRBC)

- Volumetric
  - Design AV = 4%
  - N_{des} = 75
  - VMA ≥ 13%
  - VFA 65 – 78%
  - RAP ≤ 25%
  - No performance test requirements

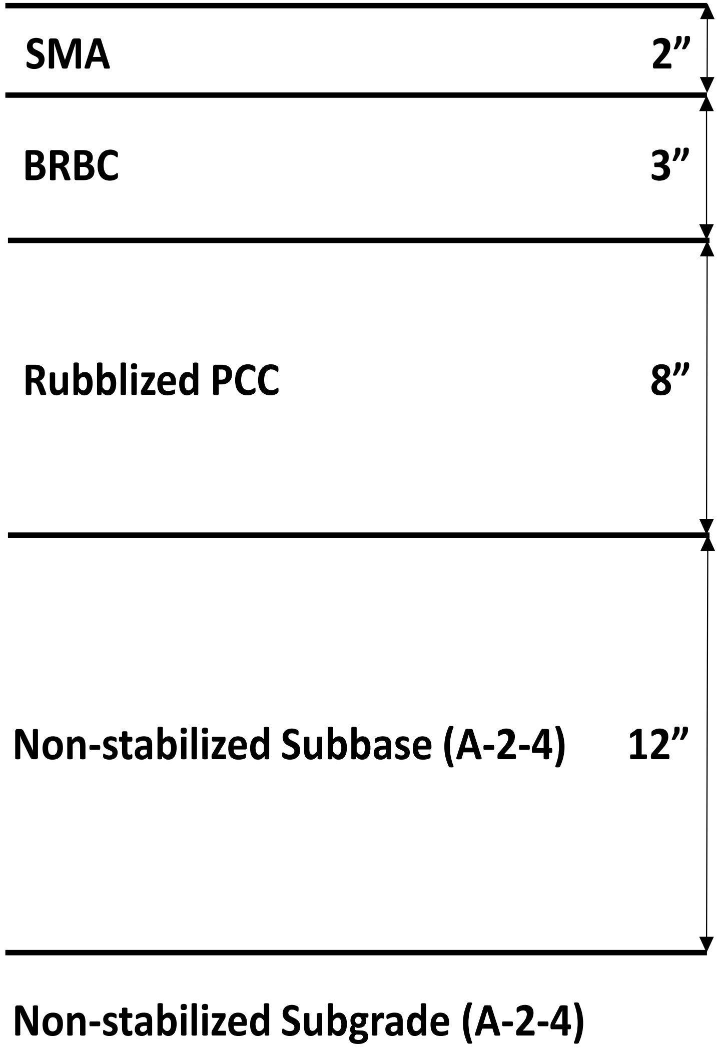
- BRBC
  - Design AV = 3.5%
  - N_{des} = 50
  - VMA ≥ 13.5%
  - No RAP
  - PG76-28
  - APA Rutting ≤ 5.0mm
  - Flexural Beam Fatigue (Based on project needs)

Example: NJ I295, MP45 to 57.3

After 10 years, 2022 saw 1st Pavement Preservation treatment

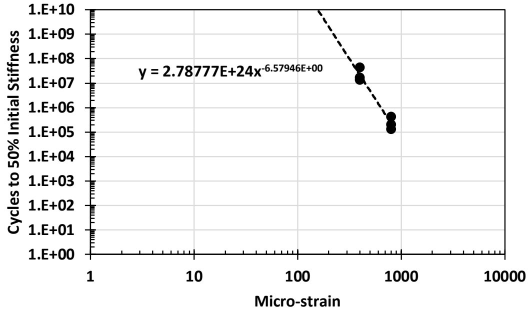
2019 BRBC – Rt 70 (Pinelands Conservation Commission)

- More aggressive design/ construction on NJ Rt 70 through conservation preserve
  - Greatly limited overlay thickness due to runoff regulations
  - Completed in 2020 and performing very well



Test Data

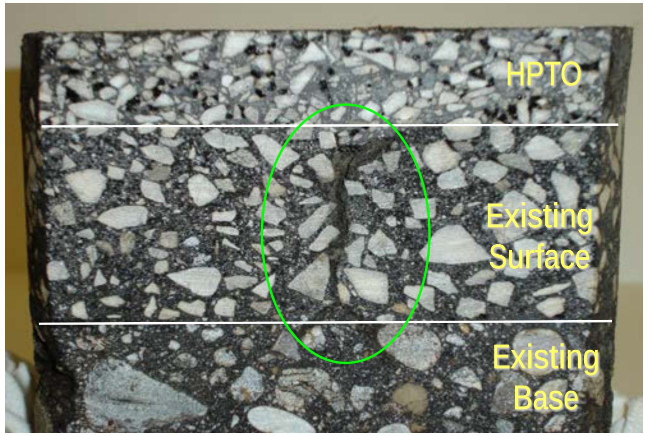
Sample ID	Micro-Strain	Fatigue Life (Nf)
#12	400	42,514,195
#14	400	13,202,300
#15	400	16,830,701
#3	800	421,489
#16	800	201,036
#17	800	127,461

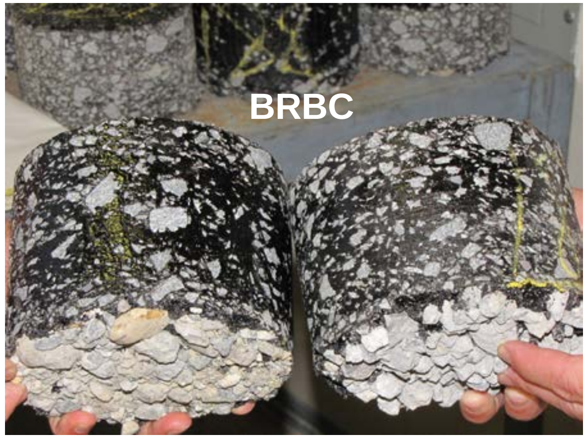


Final Thoughts and Conclusions

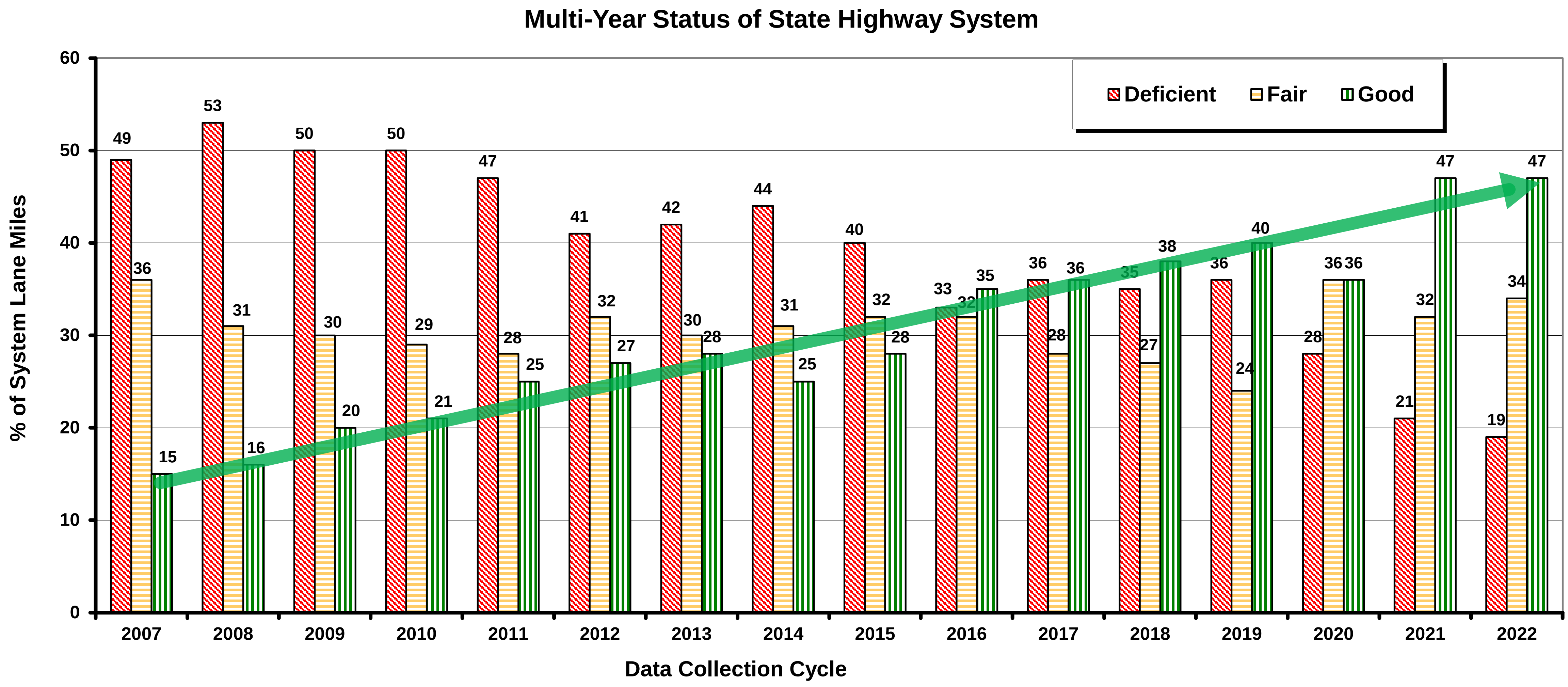
Final Thoughts and Conclusions

- Cracking was primary field distress in NJ
- Implementation of BMD (Approach A) in NJ has:
  - Resulted in improved field performance
    - Increase 5 to 10 years of service life!
  - The increase service life provides;
    - A more sustainable system
    - Allocate $ sooner for preserving Good pavements
    - Allocate $ rehab/reconstruct Average to Poor
- Where is it going?





Where It's Going!



Source: NJDOT Pavement Management System

As Ted Lasso reminded us..
"Be curious, not judgmental…"

Thank you for your time!

Thomas Bennert, Ph.D.
Center for Advanced Infrastructure and Transportation (CAIT)
Rutgers University
bennert@soe.rutgers.edu
609-213-3312