Durability of Pipe Materials in Soils

October 13th 2020

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Gregory Lucier, PhD
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NC STATE UNIVERSITY

Research Motivation

- A large number of culverts are installed every year in NC
- Different materials are being used

⬇

- Culvert type is selected based on structural requirements
- Less consideration and guidance on durability issues
- Overdesign vs. Underdesign → increased cost!

⬇

- Account for the durability of different materials
- Provide an estimate of service life and related cost indices

Research Objectives

- Catalog the relevant culvert exposure conditions and identify the pipe types appropriate for a given exposure condition

- Develop a robust and systematic pipe selection guide with a simple and intuitive user interface

- Perform quantitative corrosion rate measurements on galvanized and aluminized steel pipe materials with different thickness coatings to relate coating thickness to service life and to provide a “Discount Rate” – reduce payment for less thickness

- Perform a comparative cost analysis for pipe types subjected to a variety of exposure conditions

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- Perform a comparative cost analysis for pipe types subjected to a variety of exposure conditions

Exposure Conditions and Materials

Soil pH

Soil resistivity

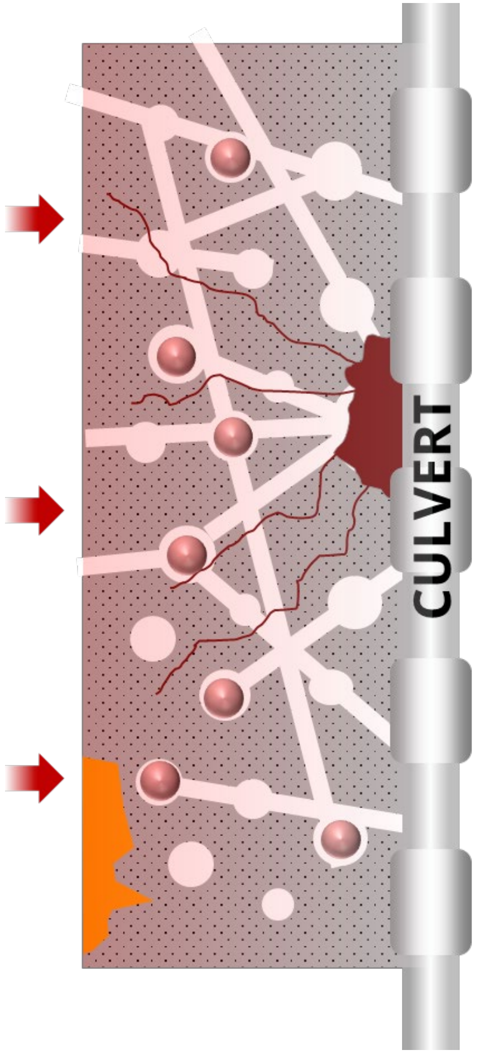
Salt exposure

Soil type

Presence of organic compounds

Soil saturation

Factors affecting on the durability of culverts



Schematic plan view

RCP **(AASHTO M170)**

Galvanized CSP **(AASHTO M218)**

Aluminized CSP **(AASHTO M274)**

Corrugated Aluminum **(AASHTO M196)**

Steel, Cast iron

HDPE **(AASHTO M294)**

PP **(AASHTO M330)**

PVC **(AASHTO M304)**

Culvert materials

Exposure Conditions and Materials

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Soil resistivity

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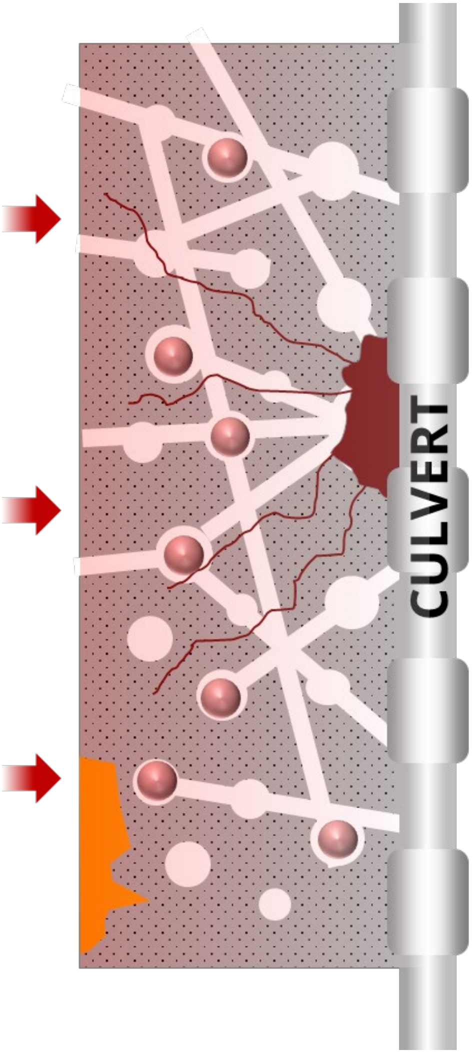
Factors affecting on the durability of culverts



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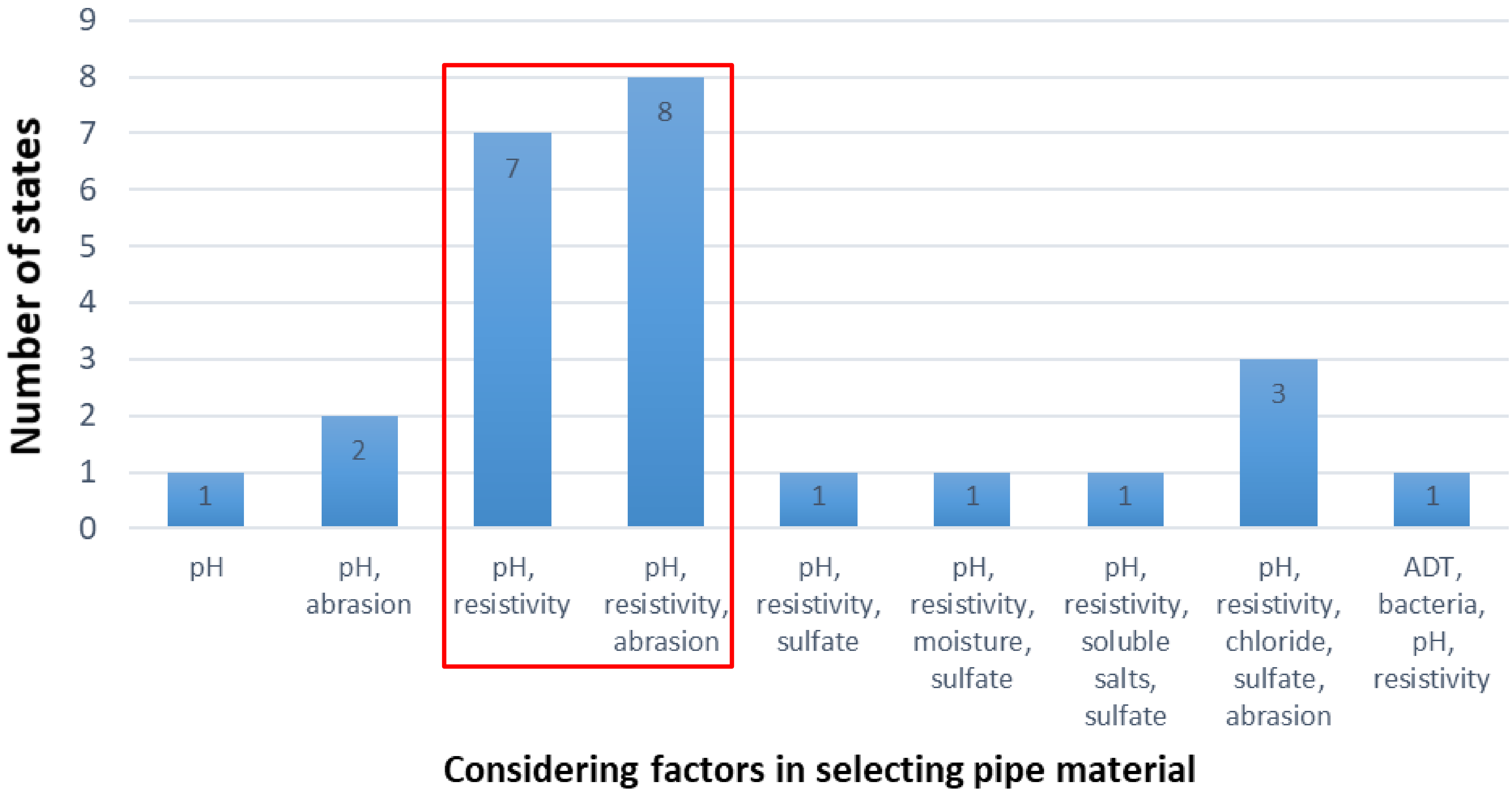
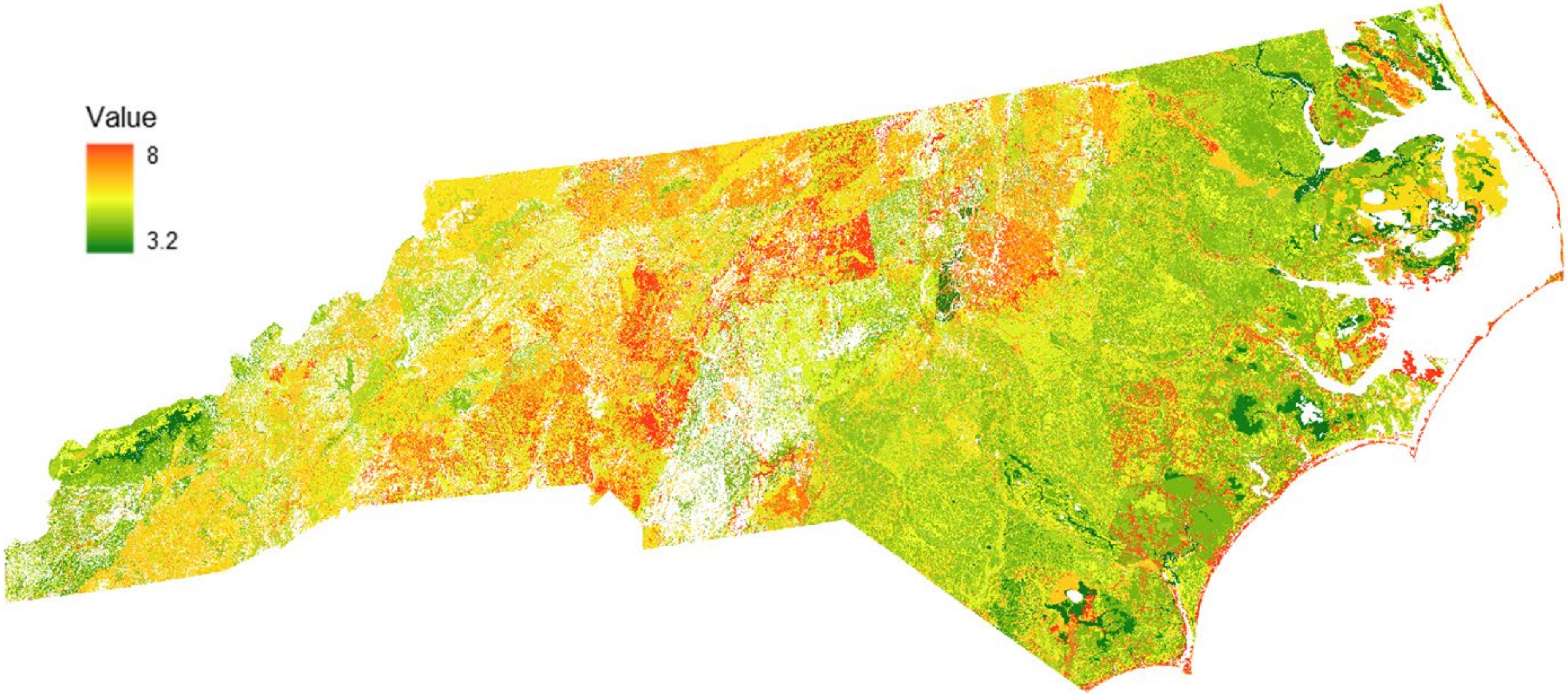
Culvert materials

US DOTs with Durability Guidelines

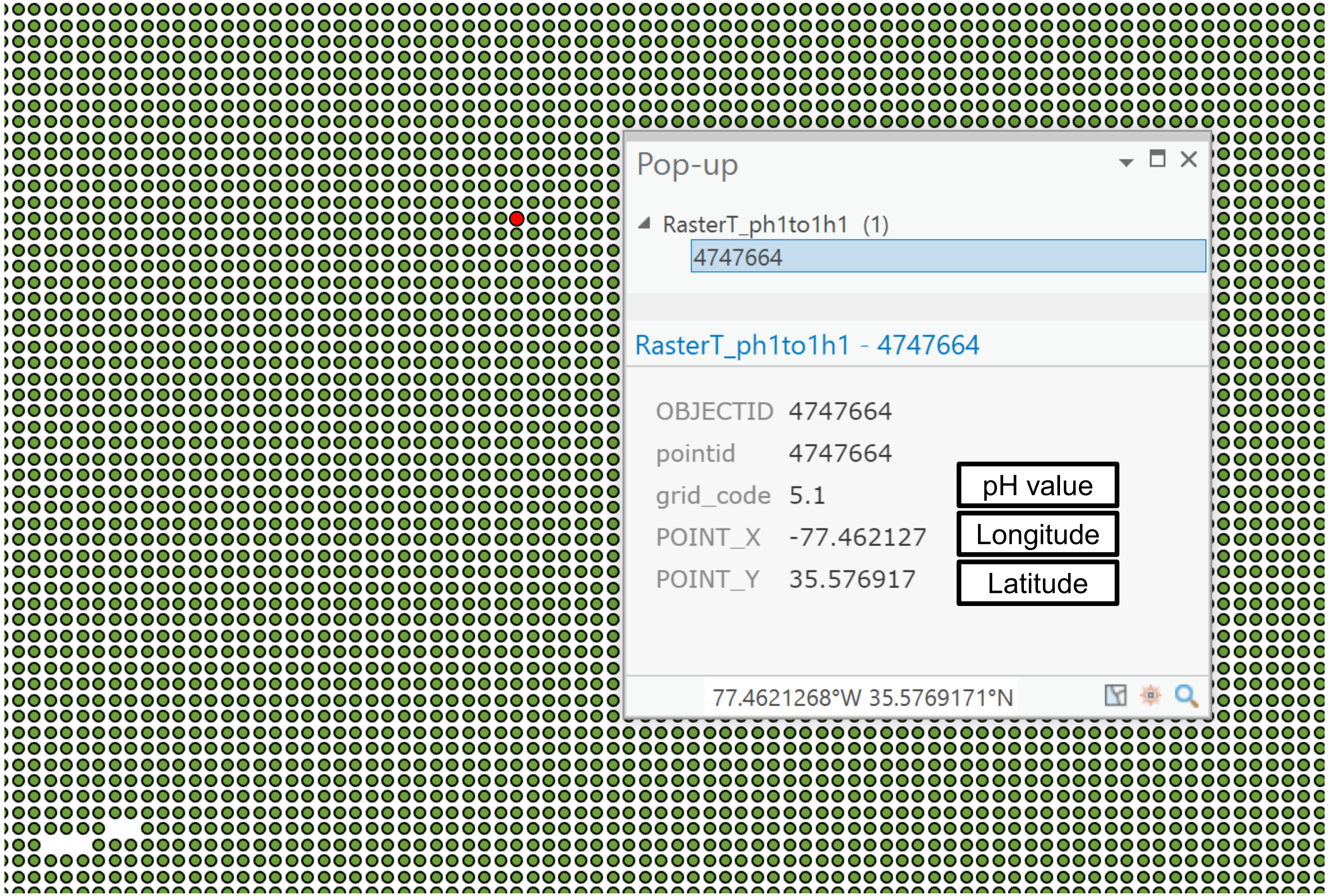


Arc GIS – Exposure Condition (pH)



National Atmospheric Deposition Program

Arc GIS – Exposure Condition (pH)



Pipe Selection Guide

NCDOT PIPE MATERIAL SELECTION GUIDE

USER INPUT[1]				
pH	Resistivity (ohm-cm)	Abrasion level[3]	Chloride[4]	Nominal Diameter (in) of Cast Iron[5]
6.2	10000	1	Low	16

GPS COORDINATES[2]	
LONGITUDE	LATITUDE
-78.638	35.779

*Note that the value of longitude should be negative

pH and resistivity

Chloride

SERVICE LIFE ESTIMATION (Years)									
RCP[6] (REINFORCED CONCRETE PIPE) AASHTO M170	CSP[7] (CORRUGATED STEEL) AASHTO M36			CAAP[7,9] (CORRUGATED ALUMINUM) AASHTO M196	Steel[7,10]	Cast Iron[11]	Plastic Pipe[12]		
		Galvanized CSP[8] AASHTO M218	Aluminized Type 2 CSP[9] AASHTO M274				HDPE AASHTO M294	PP ASTM F2764 OR AASHTO M330	PVC ASTM F949 OR AASHTO M304
33.4	18	49.6	-	-	23.8	140.1	75 +		
	16	62.0	86.4	224.2	31.0				
	14	80.5	112.3	291.5	38.1				
	12	111.5	155.5	403.6	52.4				
	10	142.5	198.8	515.7	66.7				
	8	173.5	242.0	627.8	81.0				

1: Each section can also be filled by engineer; recommendation is to input measured field data.
2: Values of pH, resistivity, chloride and sulfate will be appeared according to input coordinates.
3: The range of abrasion level is from 1 to 4 based on the reference tab; See the reference tab.
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6: Service life of RCP is calculated using Life-365; Life-365 considers time to corrosion initiation plus 6 years for a propagation and onset of damage.
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11: Service life of Cast Iron pipe is calculated based on Rajani model (2000).
12: Service life of Plastic pipes is a constant as 75+ years.

Pipe Selection Guide

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pH and resistivity

Chloride

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Pipe Selection Guide

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pH and resistivity

Chloride

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Pipe Selection Guide

GPS COORDINATES[2]	
LONGITUDE	LATITUDE
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pH and resistivity

Chloride

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33.4	**18**	49.6	-	-	23.8	140.1	75 +		
	16	62.0	86.4	224.2	31.0				
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Life-365 (chloride)

AISI, FDOT, CALTRANS model (pH, resistivity)

Rajani model (2000)

Plastic Pipe Institute (PPI)

Gage number

Asheville (Mountain)

NCDOT PIPE MATERIAL SELECTION GUIDE

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5.4	10000	1	Low	16

GPS COORDINATES[2]	
LONGITUDE	LATITUDE
-82.551	35.595

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pH and resistivity

Chloride

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33.4	18	42.3	-	-	20.3	140.1	75 +		
	16	52.8	73.7	89.7	26.4				
	14	68.7	95.8	116.5	32.5				
	12	95.1	132.6	161.4	44.7				
	10	121.5	169.4	206.2	56.9				
	8	147.9	206.3	251.0	69.1				

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Raleigh (Piedmont)

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6.2	10000	1	Low	16

GPS COORDINATES[2]	
LONGITUDE	LATITUDE
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pH and resistivity

Chloride

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Wilmington (Coastal plains)

NCDOT PIPE MATERIAL SELECTION GUIDE

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pH	Resistivity (ohm-cm)	Abrasion level[3]	Chloride[4]	Nominal Diameter (in) of Cast Iron[5]
4.6	10000	1	Very high	16

GPS COORDINATES[2]	
LONGITUDE	LATITUDE
-77.886	34.21

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pH and resistivity

Chloride

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7.2	18	37.1	-	-	17.8	140.1	75 +		
	16	46.3	64.6	49.6	23.2				
	14	60.2	84.0	64.5	28.5				
	12	83.4	116.3	89.3	39.2				
	10	106.6	148.7	114.1	49.9				
	8	129.8	181.0	138.9	60.6				

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Concluding Remarks

- The first version of the pipe selection guide was developed; it has been once presented to NCDOT engineers

- Since then, the program have been updated and we are planning to have another meeting to show the detail of the program and collet their inputs to make sure that the program we delivered is useful and suitable for their application

- We are working on developing the program to calculate discount rate for galvanized and aluminized steel pipes that do not meet the minimum coating thickness requirements

Acknowledgements

- Project funding provided by the NCDOT
- Many thanks to the NCDOT steering committee and engineers for valuable comments

NC STATE UNIVERSITY

Department of Civil, Construction, & Environmental ENGINEERING

Q&A

Email: hchoi24@ncsu.edu

NC STATE UNIVERSITY

Observations of Recycled and Virgin Material Blending in RAP and RAS Mixtures

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Associate Professor
North Carolina State University
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NCDOT Research and Innovation Summit
October 13, 2020

Acknowledgements

- Sonja Pape
  - Graduate Research Assistant

- Financial support from the NCDOT under RP 2019-21

Introduction

- Recycled materials are included in the majority of asphalt mixtures produced in North Carolina, which can include:
  - Reclaimed asphalt pavement (RAP); and
  - Recycled asphalt shingles (RAS).

- Critical question for reliable mixture design:
  - Do recycled binders act as “black rocks” or blend with the virgin asphalt?

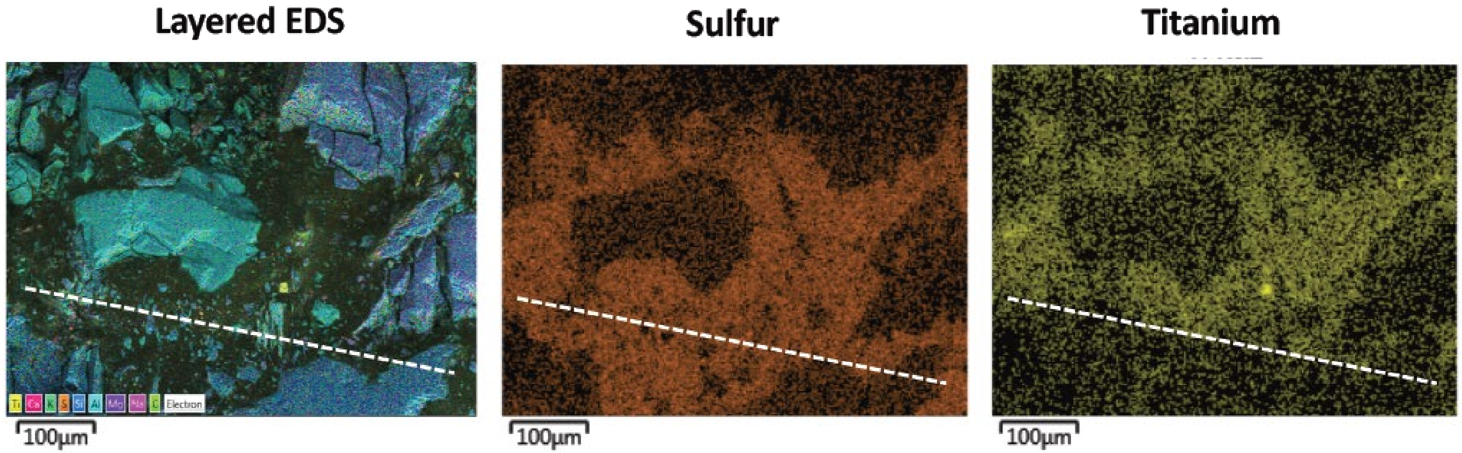
Methodology

Use of a Tracer to Track the Virgin Binder

- Titanium dioxide (0.2 μm) particles added to virgin binder prior to fabricating asphalt mixture in the lab.

Submerged Photos

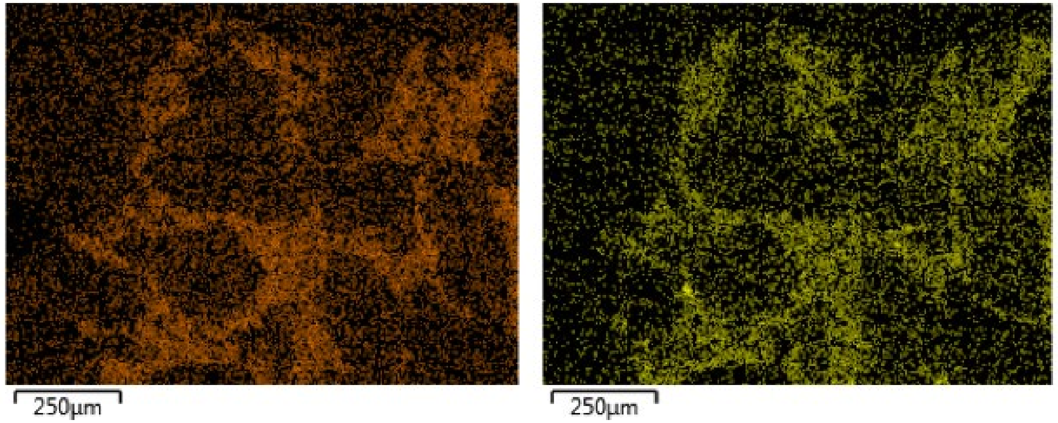
Energy Dispersive X-Ray Spectroscopy Scanning Electron Microscopy (EDS-SEM)



Methodology

Quantitative Inferences of Recycled Binder Contribution

Sulfur Titanium



Map Sum Spectrum	Wt%	σ
C	63.3	0.1
O	25.4	0.1
Si	8.6	0.0
Al	0.8	0.0
Ca	0.5	0.0
Ti	0.4	0.0
Na	0.3	0.0
S	0.3	0.0
K	0.2	0.0
Fe	0.2	0.0
Cl	0.1	0.0

$$\text{RBC} = \frac{\left(\frac{Virgin_{Ti:S}}{Blend_{Ti:S}} - 1\right) \times (AC - RC) \times \frac{S_V}{S_R}}{RC} \times 100\%$$

where RBC = percentage of the total recycled binder within the virgin binder matrix;
$Virgin_{Ti:S}$ = Ti:S ratio in the virgin binder;
$Blend_{Ti:S}$ = Ti:S ratio in the location of interest;
AC = total asphalt content;
RC = recycled binder content;
S_V = sulfur content of the virgin binder; and
S_R = sulfur content of the recycled binder.

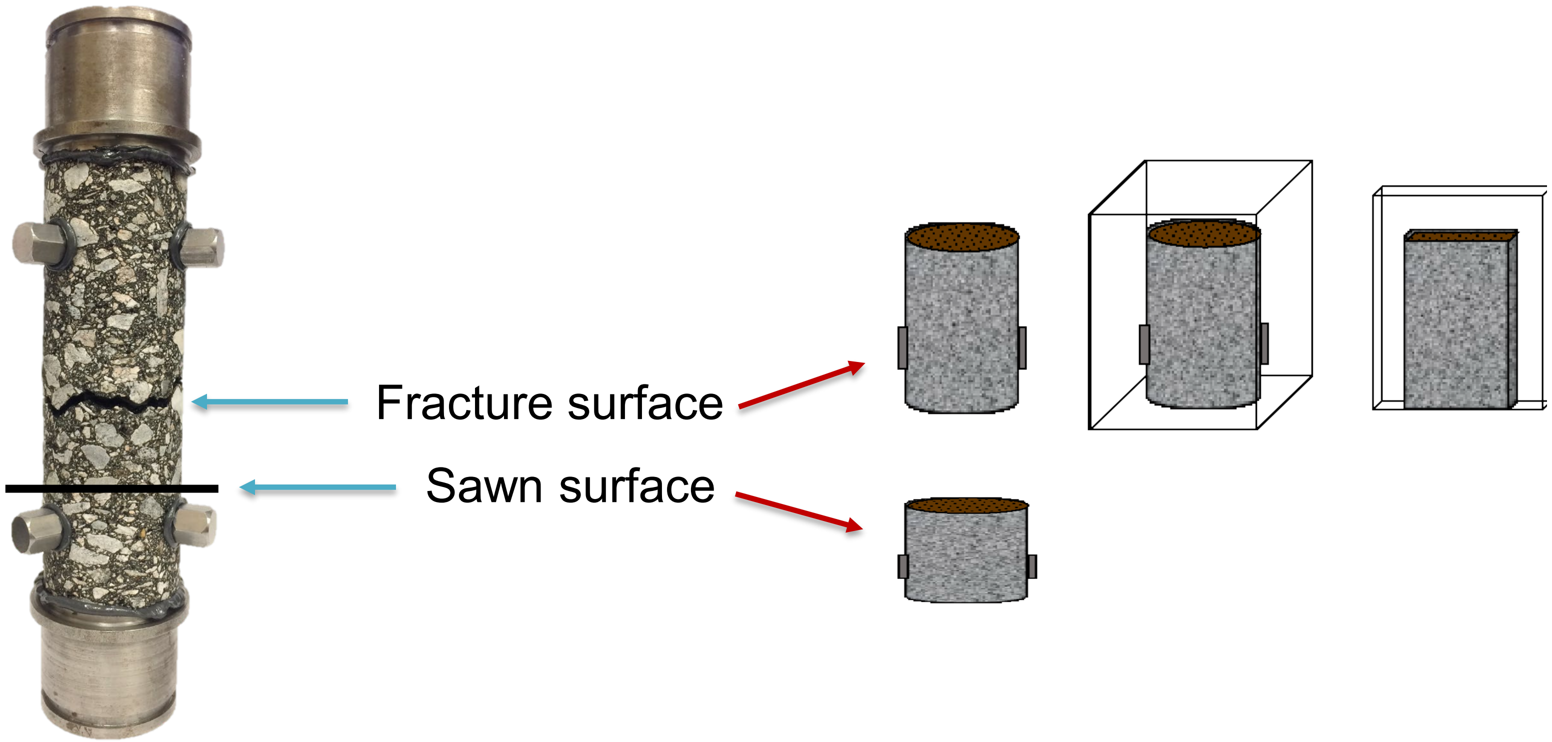
Jiang et al. (2018)

Materials

- 9.5-mm Nominal Maximum Aggregate Size (NMAS) mixture
  - 25 percent RAP
  - 4 percent post-consumer RAS
  - 6.3 percent total asphalt binder
  - 29 percent Recycled Binder Ratio (RBR%)
    - 15 percent from RAP
    - 14 percent from PRAS
  - PG 58-28 virgin binder

Sample Fabrication

- Lab-mixed, lab-compacted gyratory sample prepared.
  - 38-mm diameter by 110-mm tall specimens extracted from the gyratory and subjected to cyclic fatigue loading.



Observations

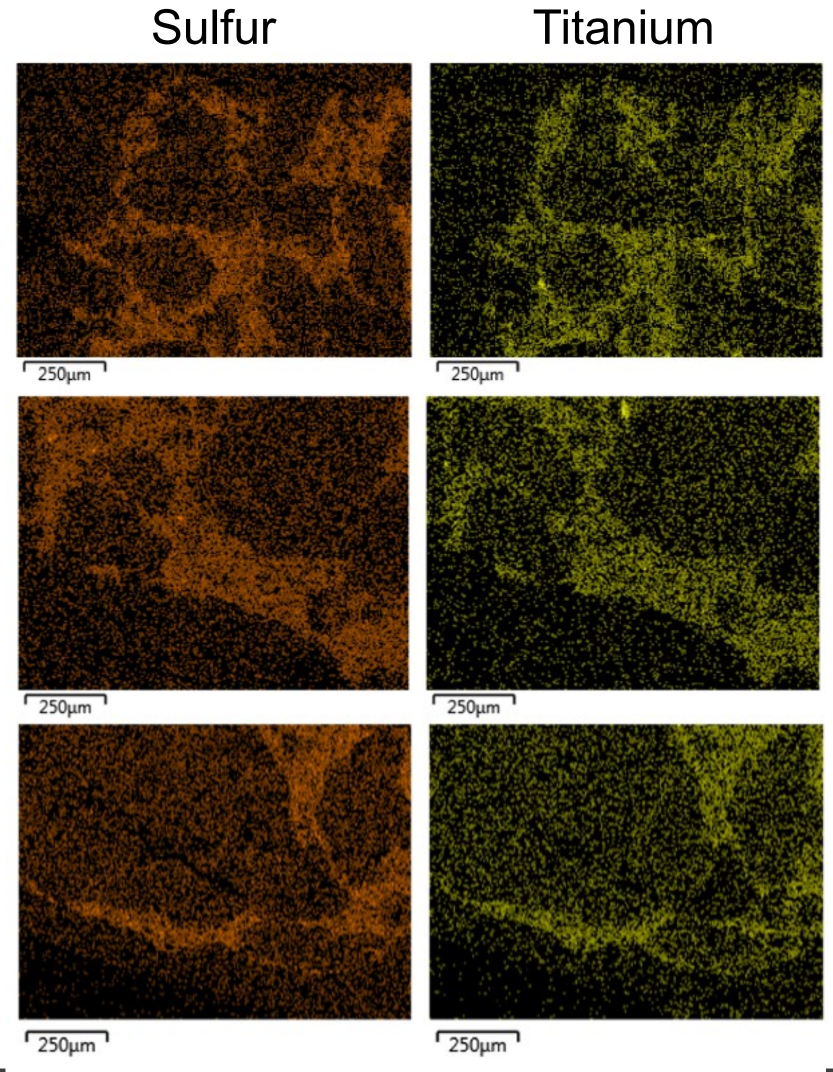
Visual

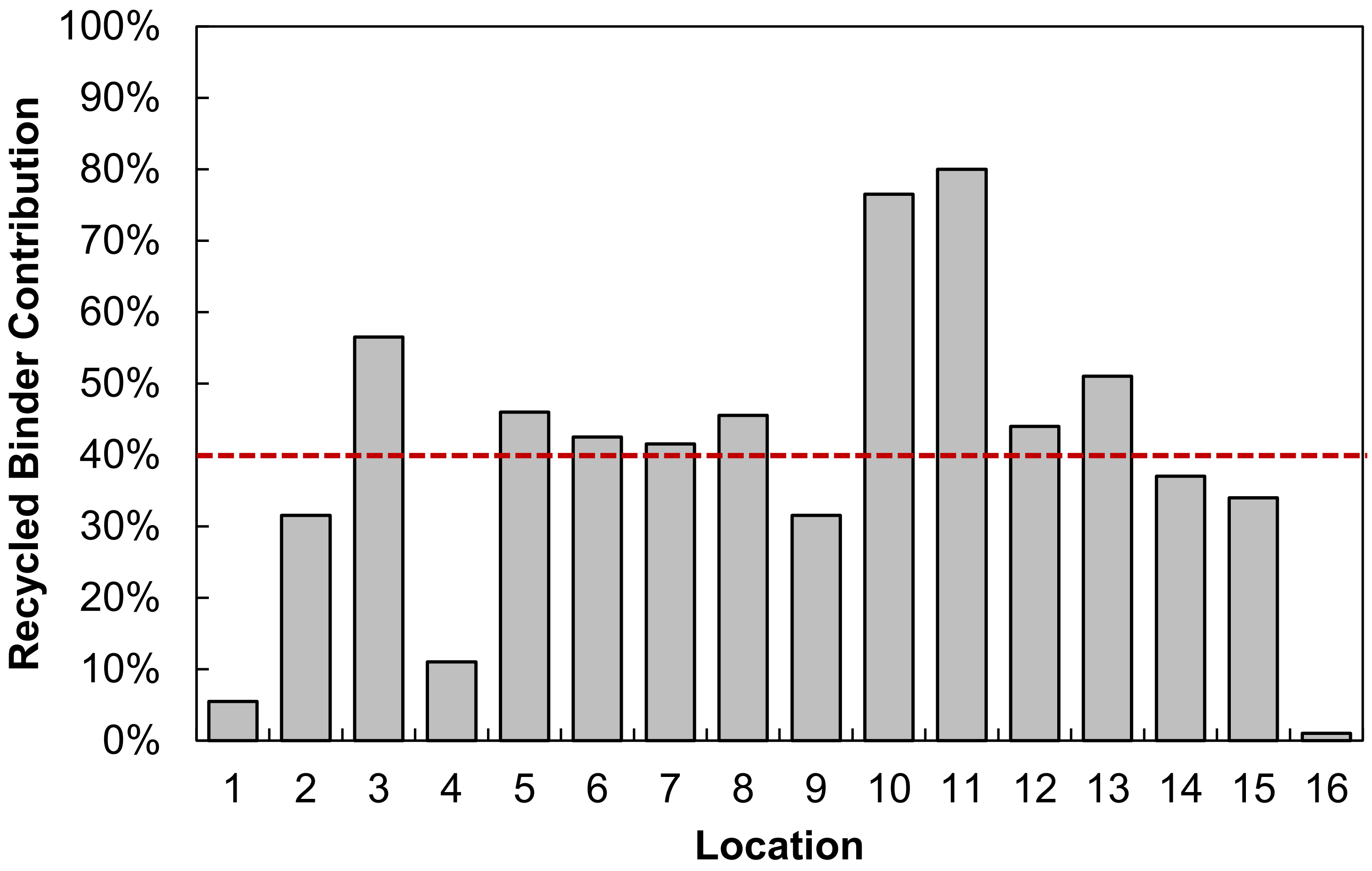
Fracture Surface

Sawn Surface

Observations

Elemental Composition of Fracture Surface





Summary

- Clusters of recycled materials prohibited complete blending of virgin and recycled binders in the asphalt mixture investigated.
- The fracture surface of the asphalt mixture contained no clusters, indicated the fracture propagated through the surrounding binder matrix.
- The binder matrix along the fracture surface of the mixture indicated an average recycled binder contribution of 40 percent, indicating that approximately 60 percent of the total recycled binder did not blend with the virgin asphalt.

Implications to Volumetric Asphalt Mixture Design

- Credited recycled binder
  - Results suggest that giving credit to all of the recycled binder can be erroneous and may result in insufficient virgin asphalt contents.
- Virgin binder grade selection
  - Results suggest that using a softer virgin binder grade in all high recycled material content mixtures may lead to a softer binder film than intended.
- Gradation
  - Clustering of the recycled material alters the effective gradation of the recycled aggregate.

NC STATE UNIVERSITY

Thank you!

Cassie Castorena

cahintz@ncsu.edu

NC STATE UNIVERSITY

Interface Shear Strength of Different Geosynthetic Interlayers

Lei Gabriel Xue
Nithin Sudarsanan
Y. Richard Kim

2020 NCDOT Research and Innovation Summit

October 13, 2020

Acknowledgment

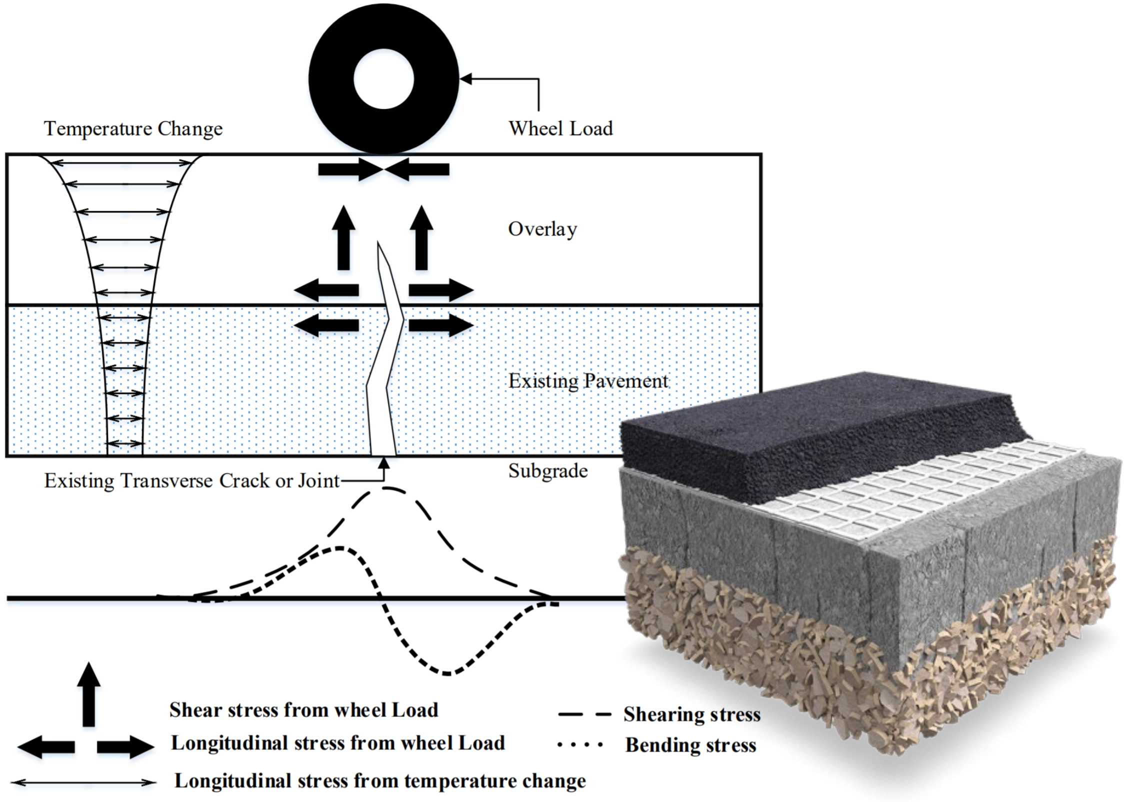
- Financial support from NCDOT through RP-2019-19 project
- Geosynthetic manufacturers and GMA for providing materials and information

Presentation Outline

- Research Background and Objective
- Research Approach
- Materials and Test Method
- Pavement Response Analysis Using FlexPAVE^{TM}
- Proposed Interface Shear Strength Test and Acceptance Criterion
- Conclusions

Research Background

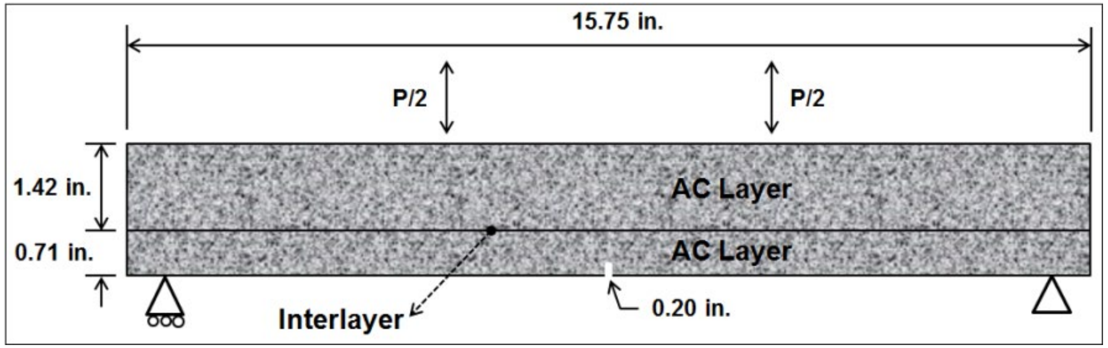
- **Reflective cracking** – Major distress in asphalt overlay
  - Due to temperature change and repeated traffic load
- **Geosynthetic interlayer** acts as the reinforcing, stress absorbing system and prevents water infiltration into the old pavements, thereby, reduces reflective cracking.
- **No standard performance tests** available for geosynthetic interlayer products

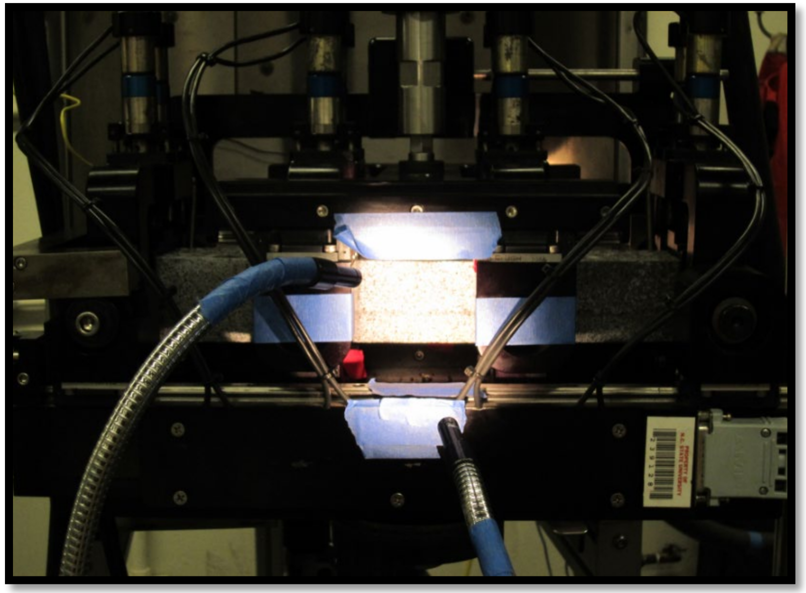


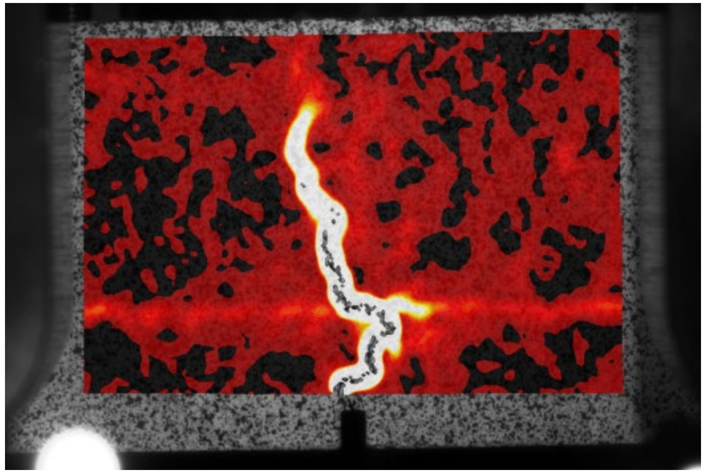
NCDOT RP-2019-19 Project

- Title: Development of Geosynthetic Pavement Interlayer Improvements
- Objective: Develop **performance testing methodologies and performance criteria** for geosynthetics used in pavement interlayer applications that can be used in performance specifications and product selection guidelines by the NCDOT
- Scope: Geosynthetic interlayer products that are placed between asphalt layers

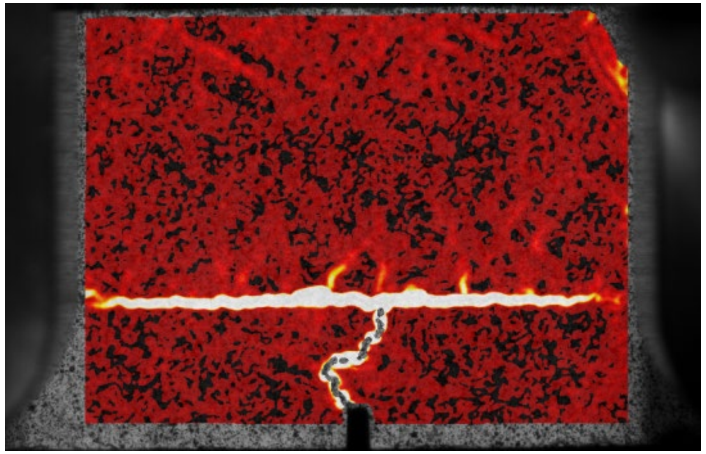
Distresses in Asphalt Overlays





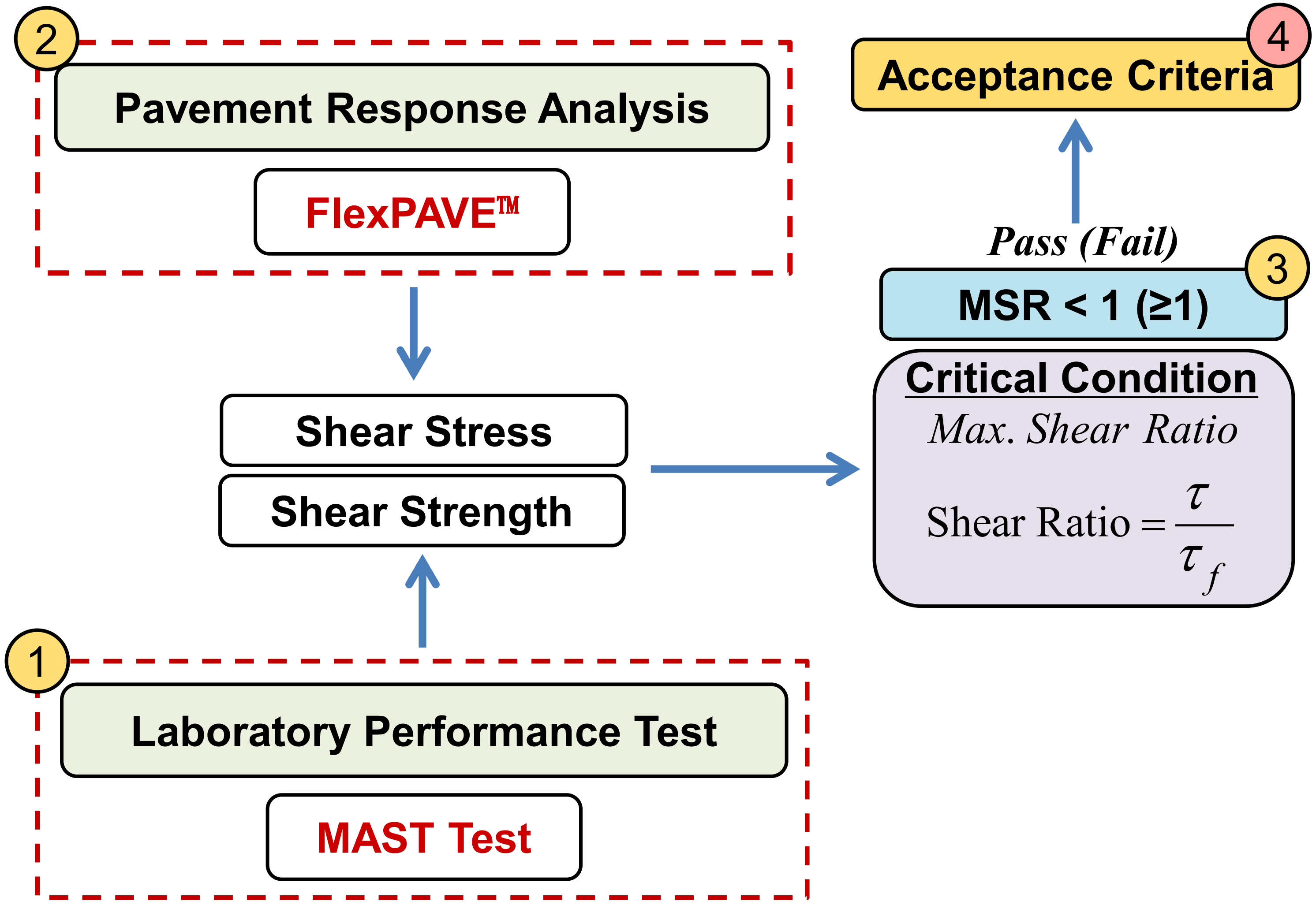


No interlayer with good bonding

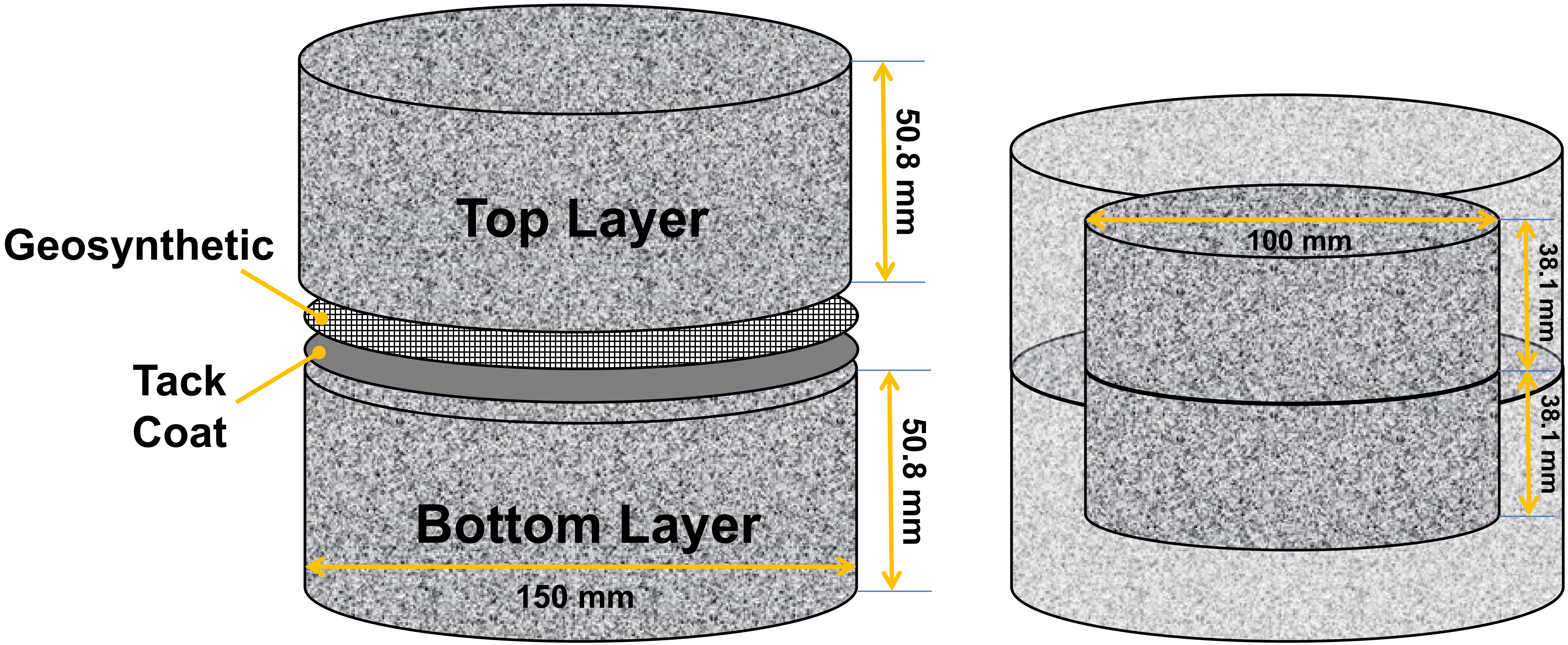


Interlayer with poor bonding

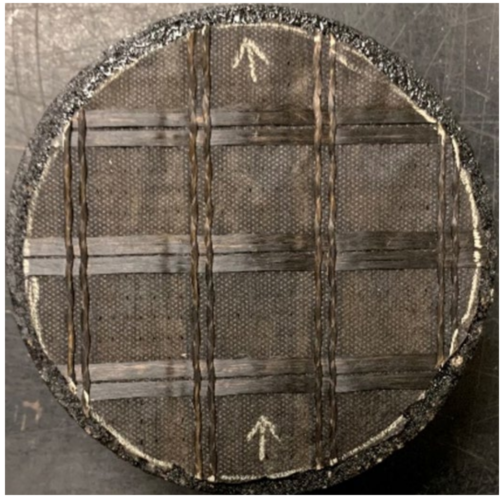
Research Approach to Debonding Evaluation



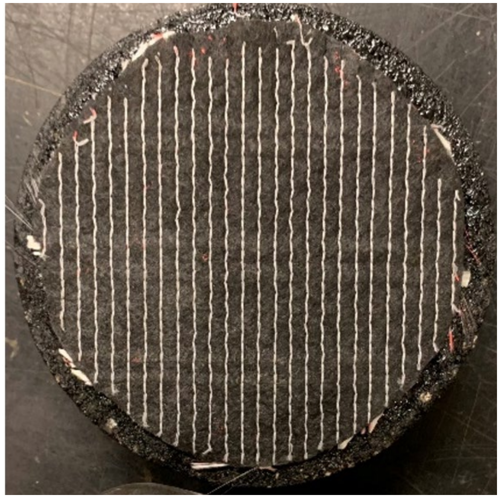
Geosynthetic-Reinforced Specimen



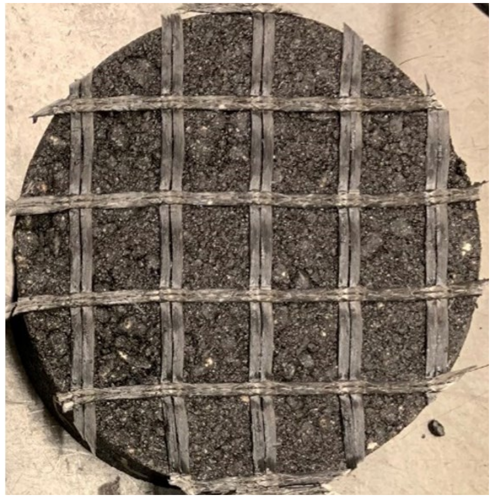
Study Geosynthetic Interlayers



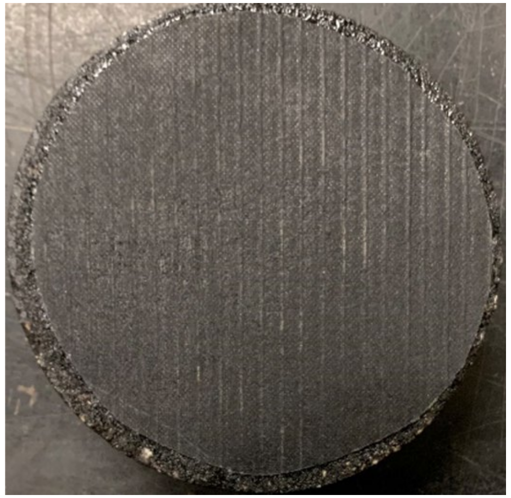
PC#1



PC#2



PaG



PM

PF

- PG 64-22 binder as a tack coat
- Manufacturer recommended tack coat application rates were used.

Modified Asphalt Shear Tester (MAST)

1

2

3

4

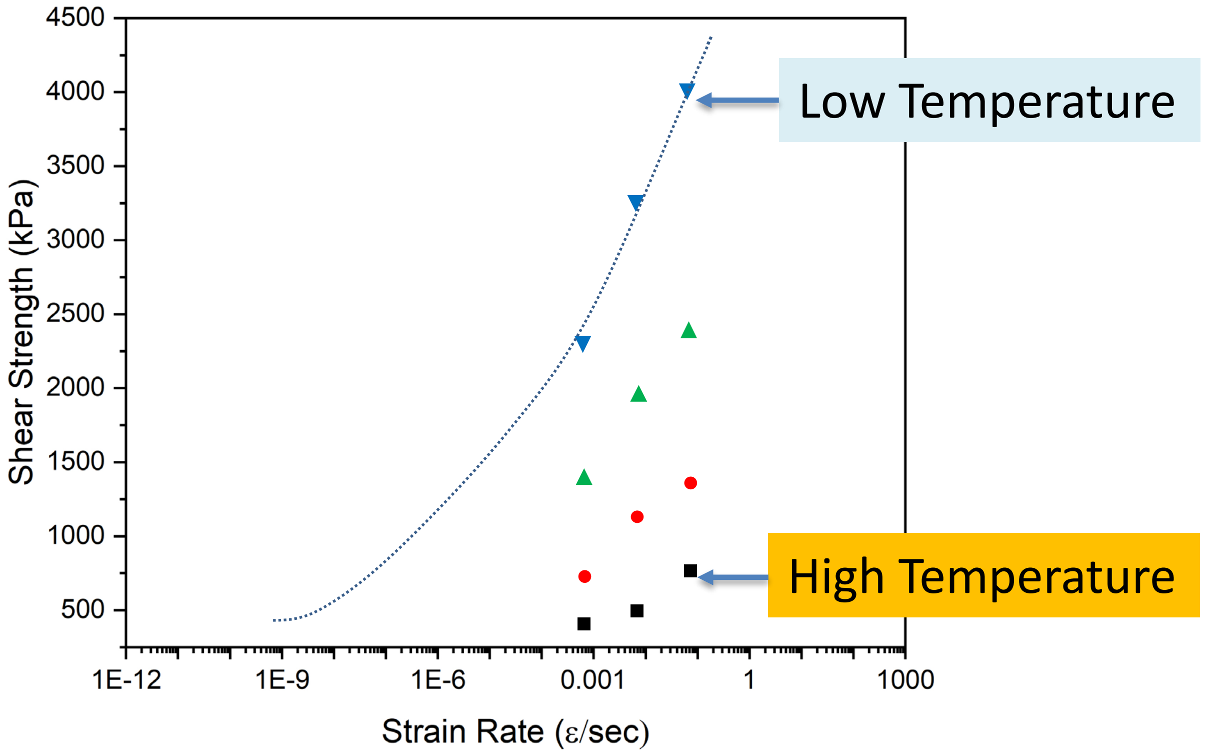
5

DIC View

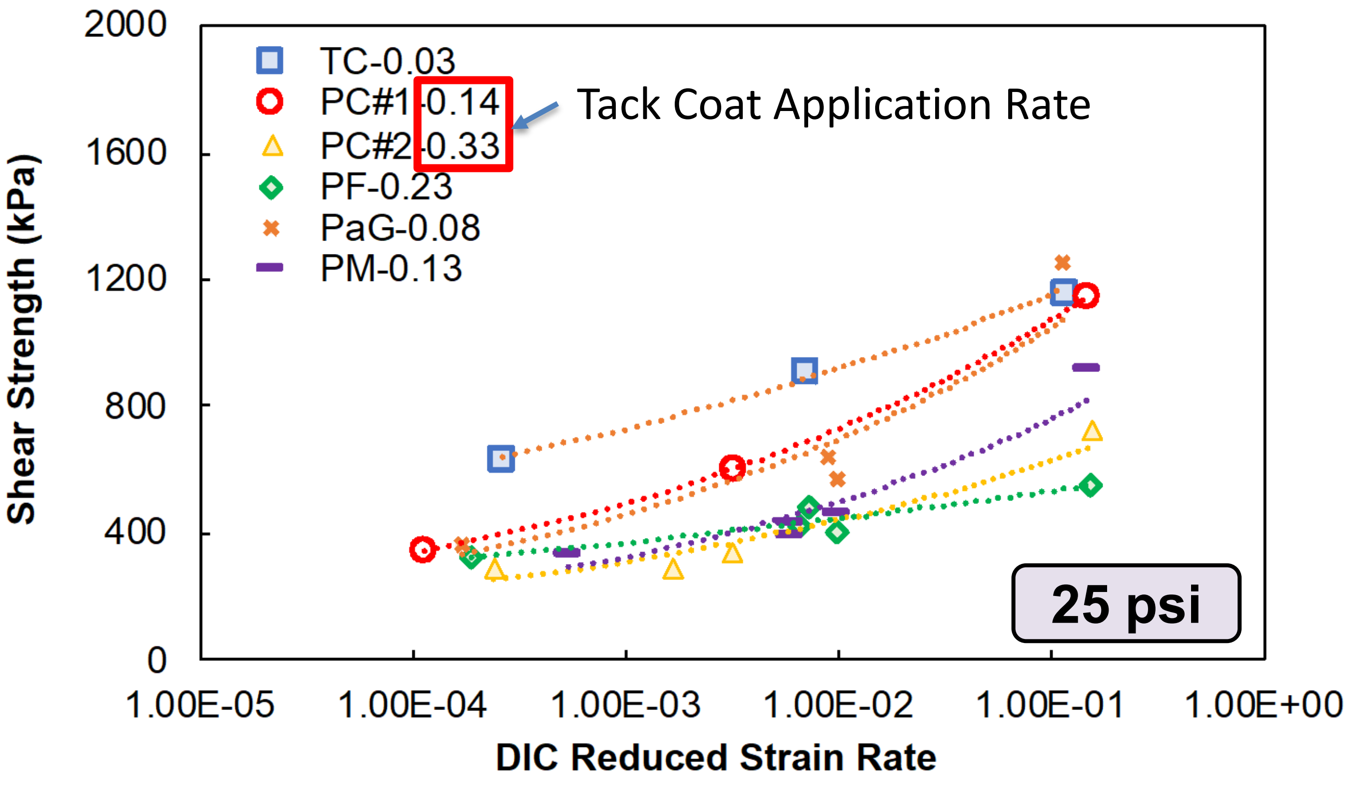
ISS Test Experimental Design

Factors	Conditions				
Geosynthetic Types	PC#1	PC#2	PM	PF	PaG
Test Temperature	23°C, 35°C, 54°C				
Application Rate	Dry, Optimal, Wet				
Loading Rate	5.08 mm/min (0.2 in./min)				
Confinement (Normal Stress)	172 kPa (25 psi), 276 kPa (40 psi), 483 kPa (70 psi)				

Time-Temperature Superposition of ISS

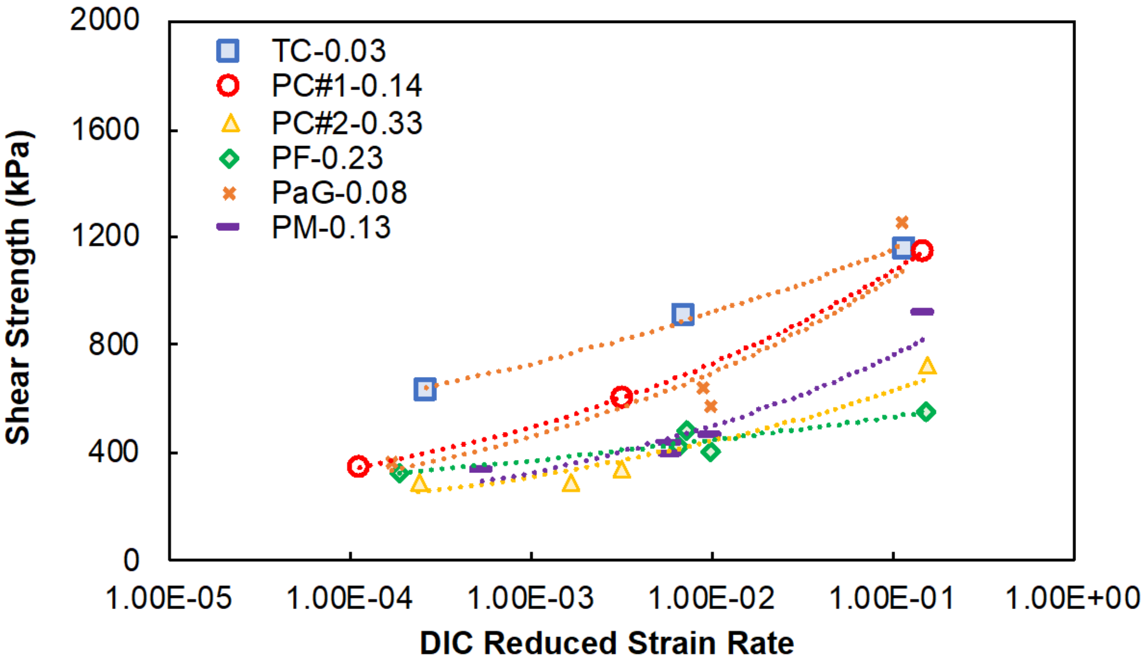


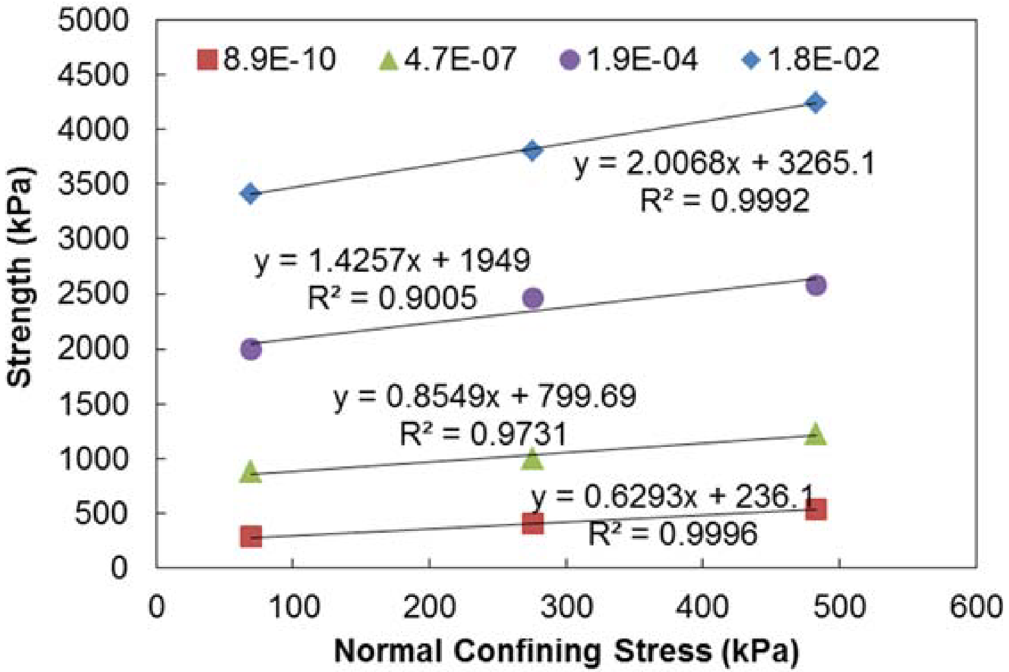
ISS Observations



- Presence of any type of geosynthetic interlayer at any testing condition reduces the ISS.
- ISS decreases with an increase of temperature and decrease of loading rate.
- ISS increases with an increase of confining pressure.
- Paving composite #1 and paving grid display higher ISS than paving composite #2, paving mat, and paving fabric.
- Effect of tack coat application rate on the ISS is not clear.

ISS Prediction Model

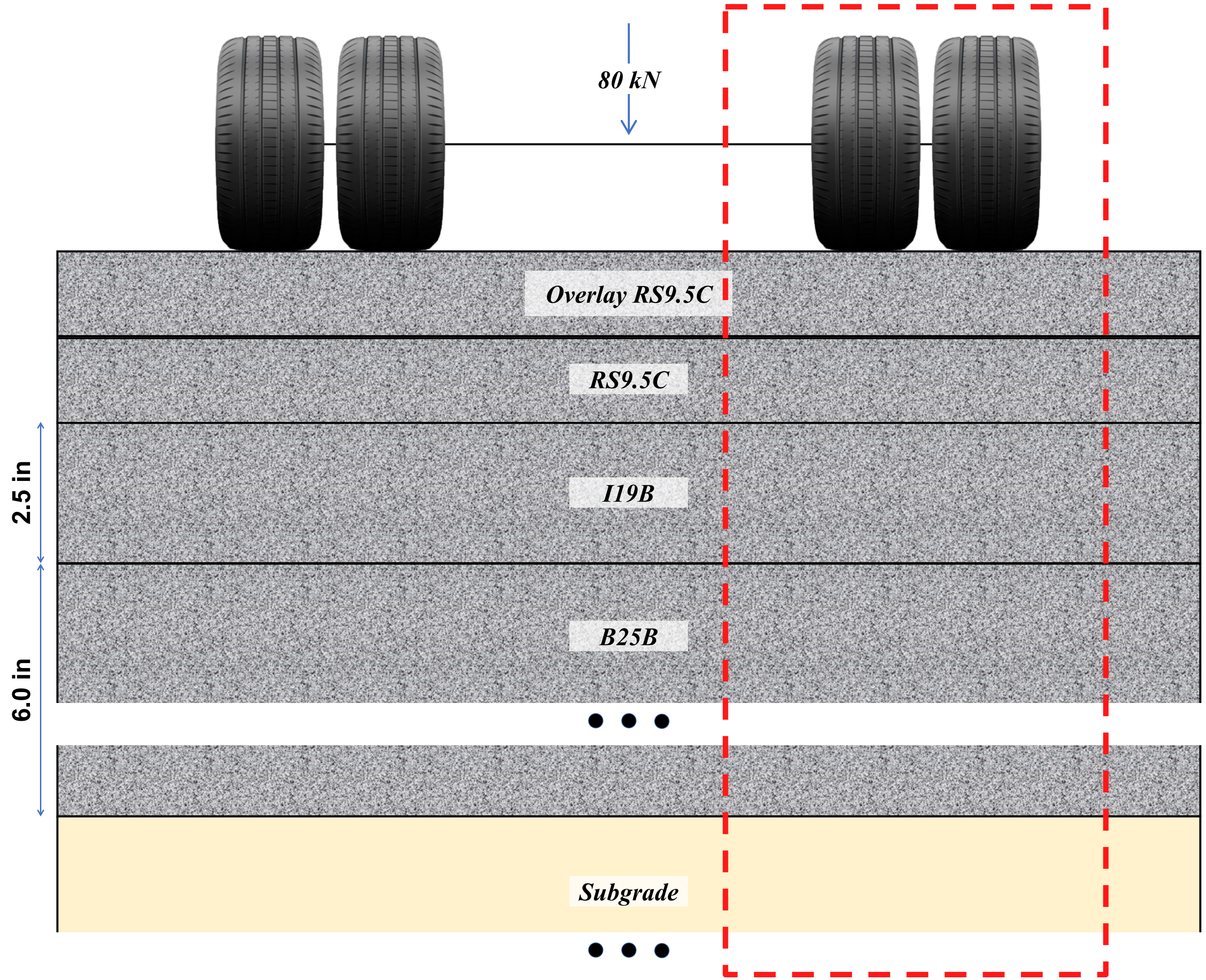


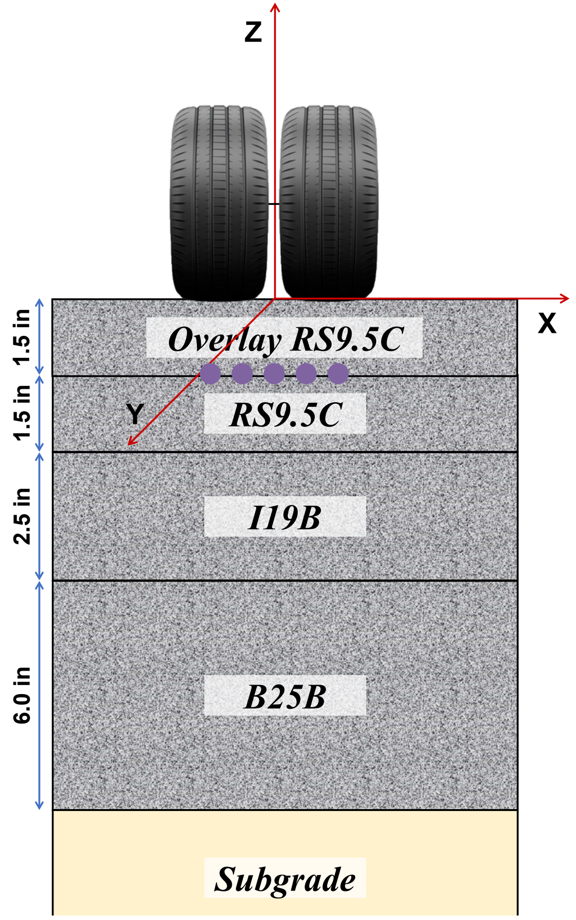


$$\tau_f = (a \times \dot{\gamma}_R{}^b) \times \sigma_c + c \times \dot{\gamma}_R{}^d + e \times \sigma_c = (a \times \dot{\gamma}_R{}^b + e) \times \sigma_c + c \times \dot{\gamma}_R{}^d$$

Geosynthetic Type	a	b	c	d	e	R^2
PC#1	227.80	2.48	893.70	0.13	0.55	0.991
PM	44.92	14.17	1130.00	0.22	0.77	0.821

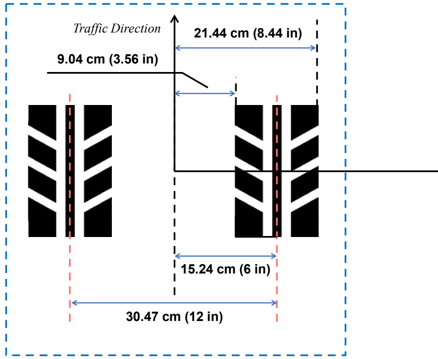
Pavement Structure for FlexPAVE™ Analysis



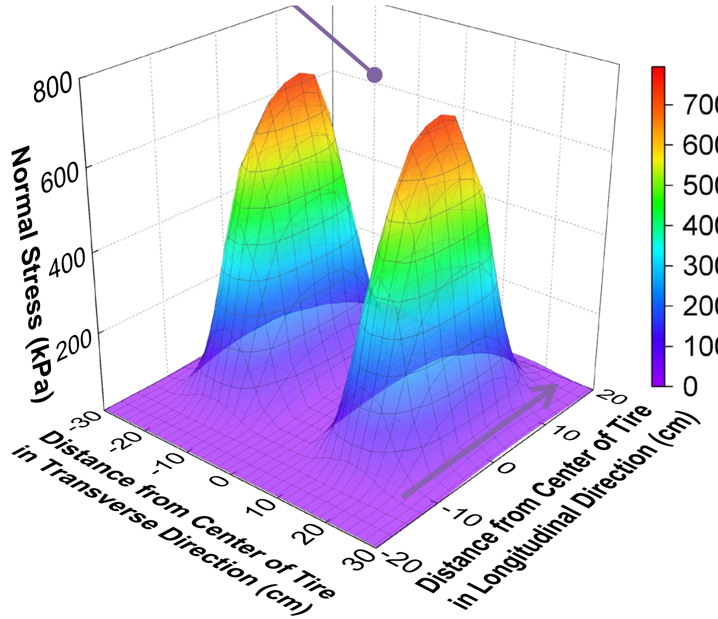


Pavement Response Analysis

Thick Pavement, 1 mph, 50°C, 1.5 in. Depth

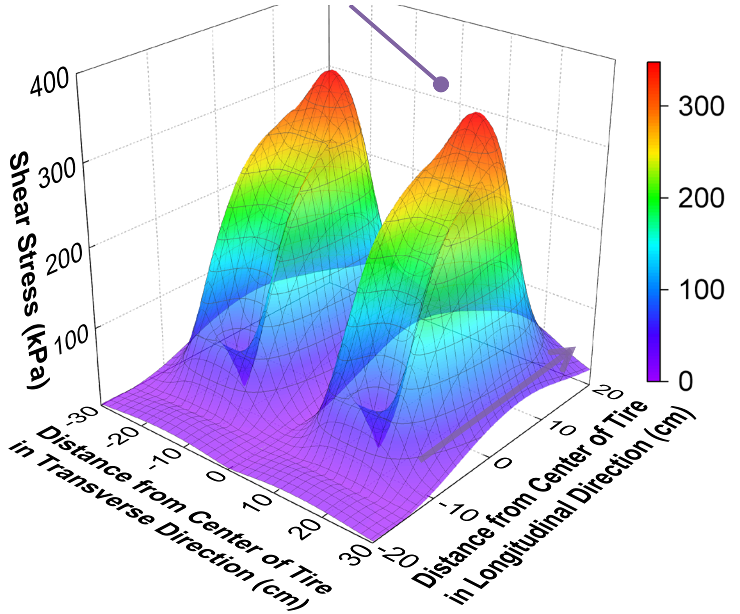


Maximum Normal Stress = 794 kPa

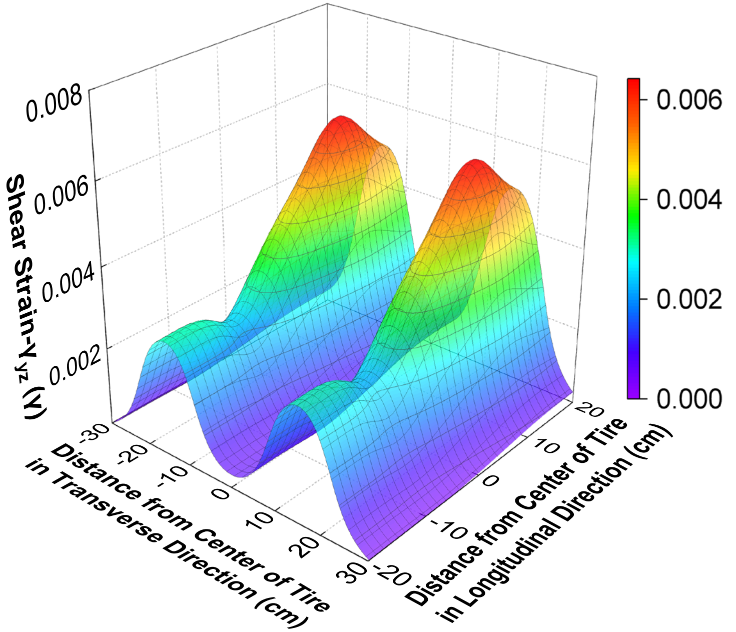


Normal Stress

Maximum Shear Stress = 370 kPa

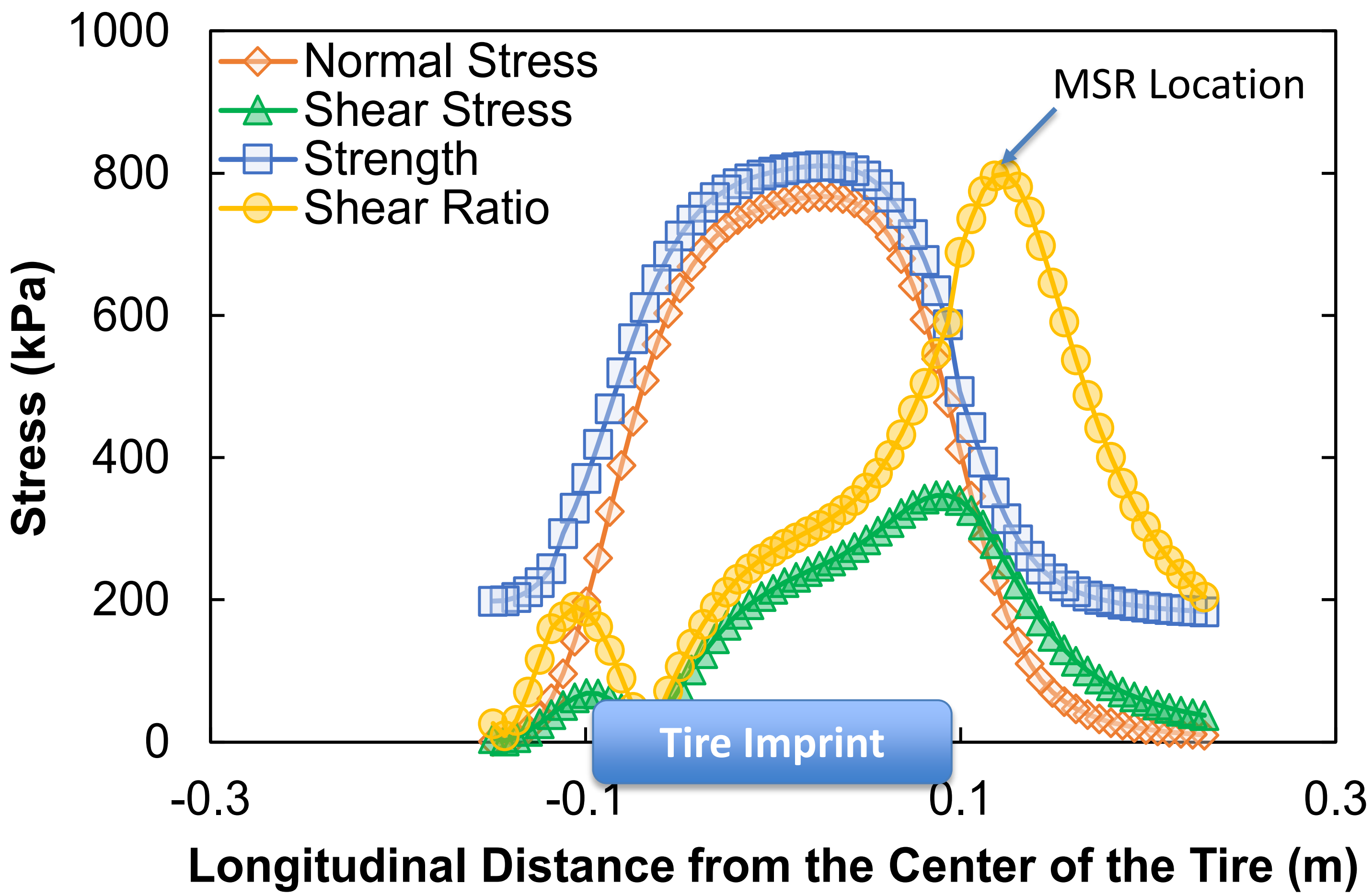


Shear Stress

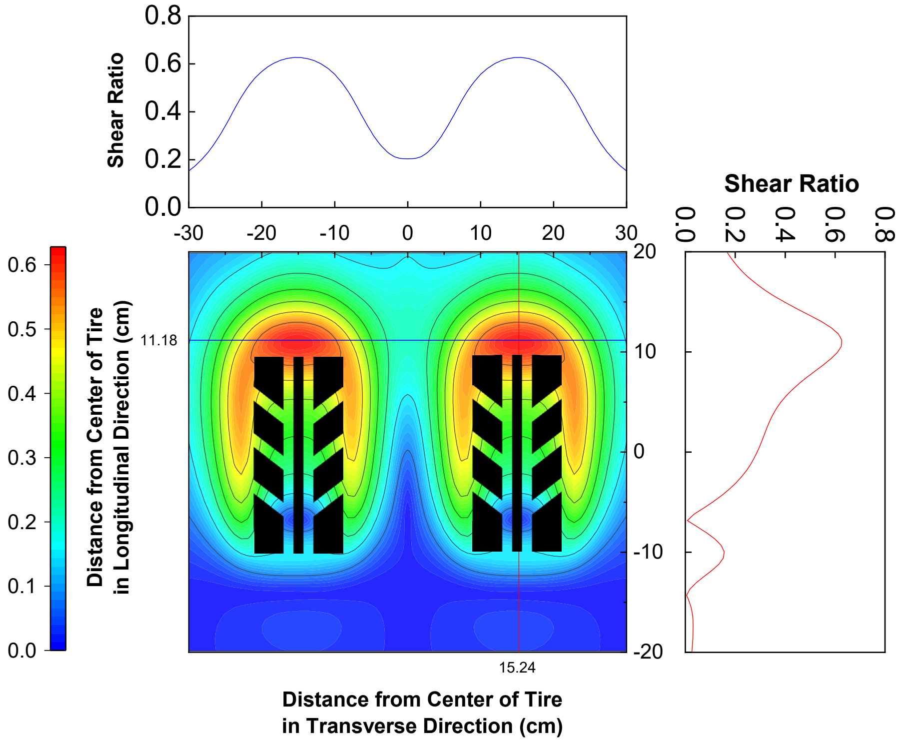


Shear Strain-yz

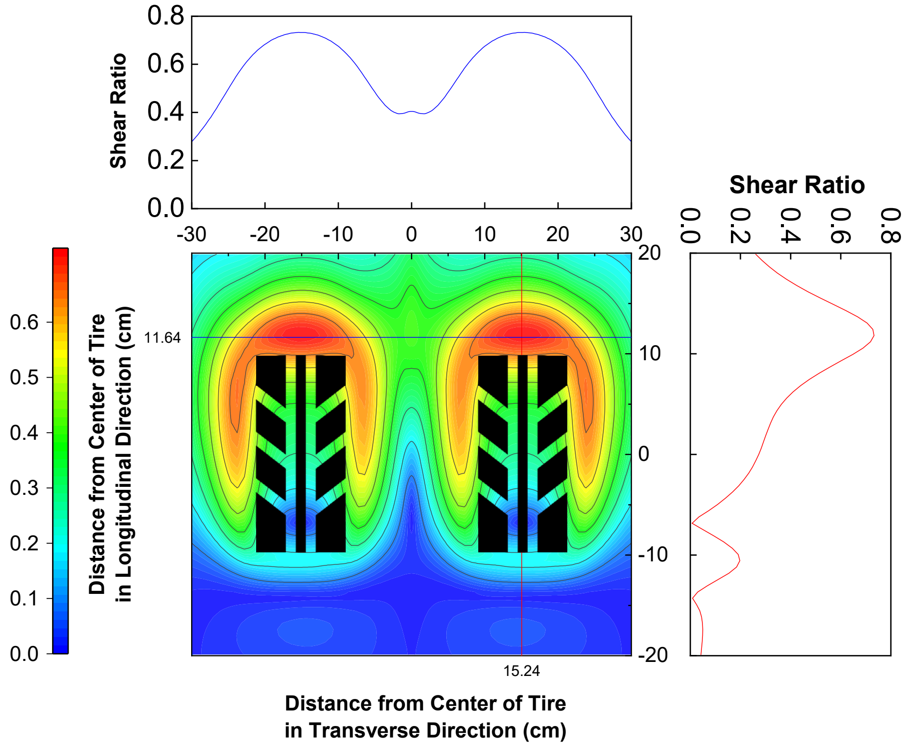
Pavement Response Analysis



MSR of PC#1 and PM

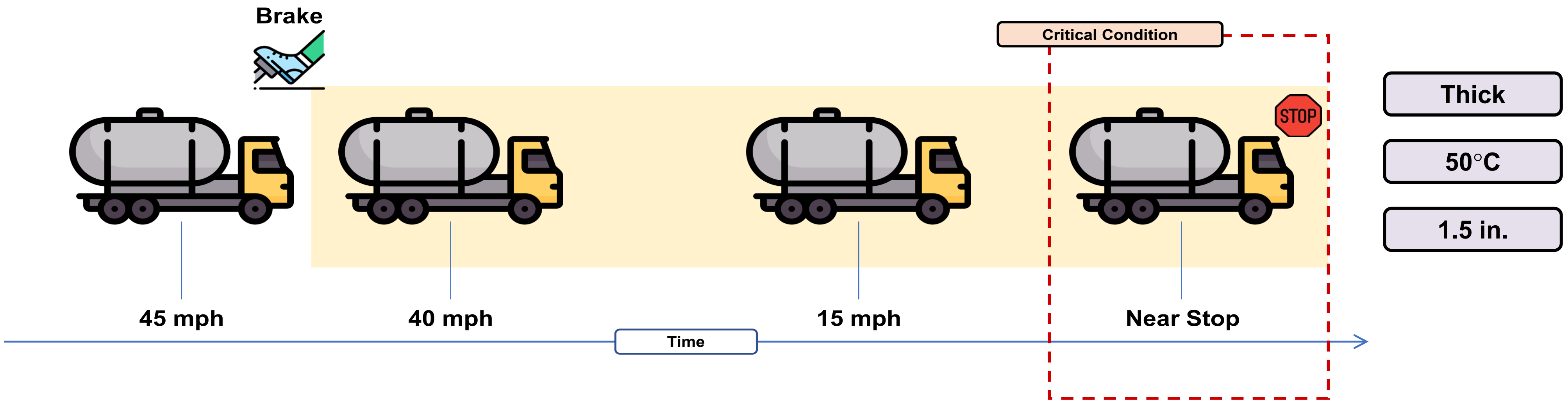


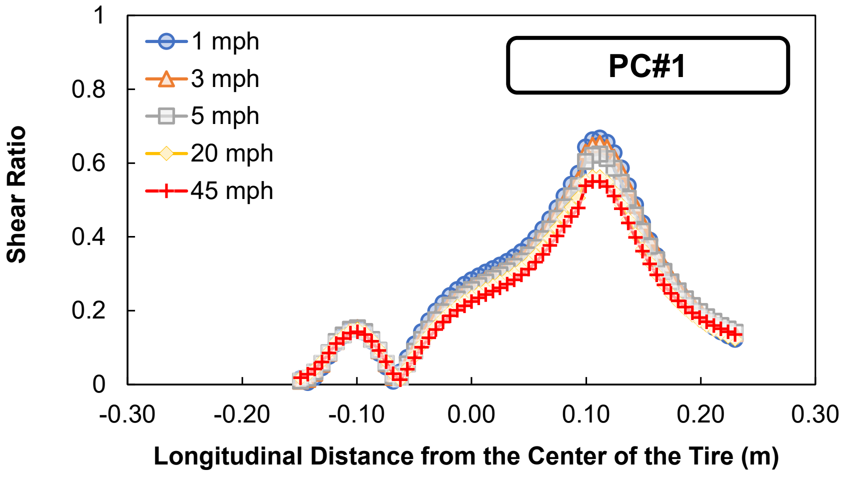
PC#1

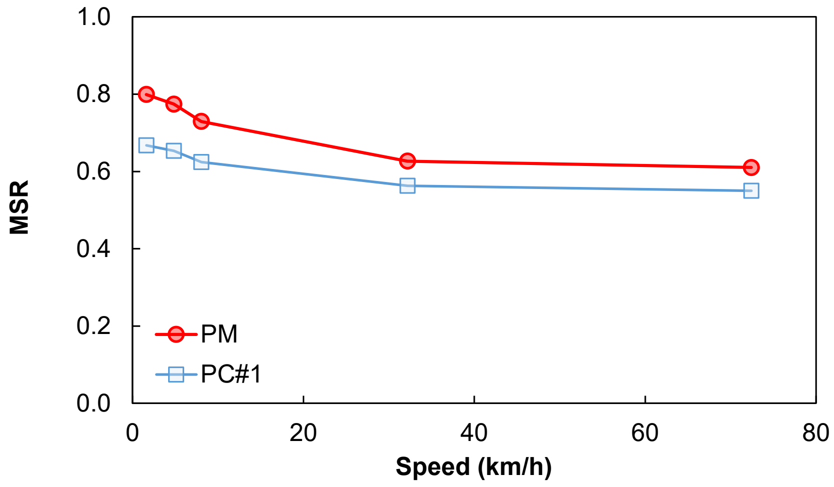


PM

- ❑ MSR occurs in front of the tire along the center-line of the tire.
- ❑ PM shows a higher MSR than PC#1 reinforced pavements.

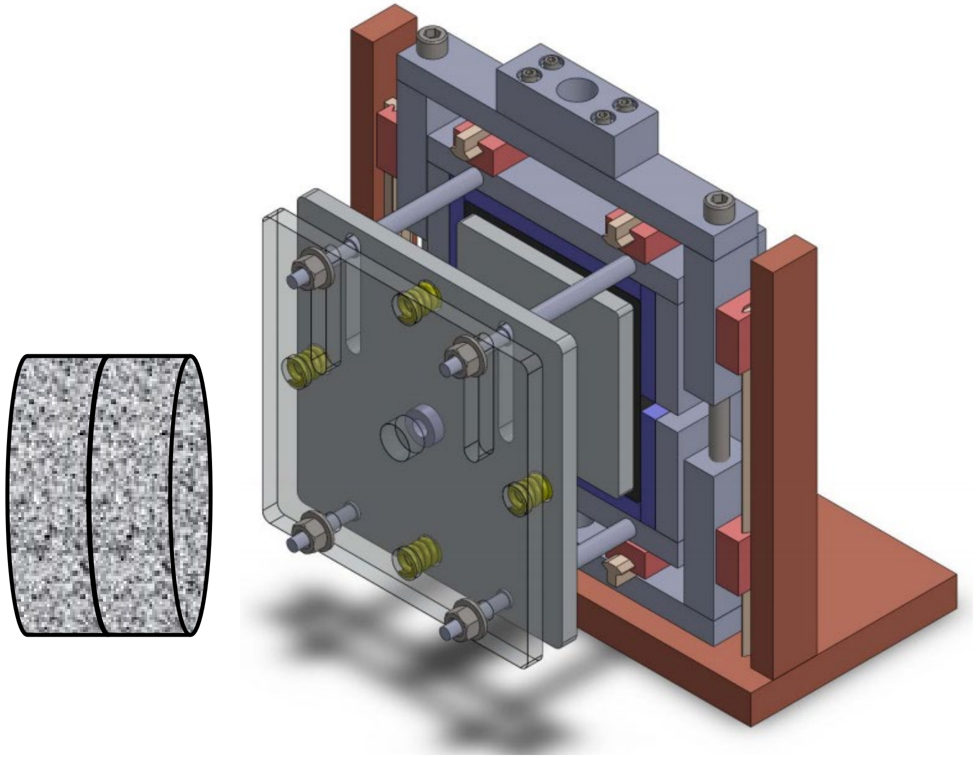






- The interlayer shear resistance is poorer when the vehicle speed is lower.

Acceptance Criterion



Confining Pressure	40 psi
Temperature	122°F (50°C)
Actuator Displacement Rate	0.2 in./min
Minimum Required ISS	44 psi (305 kPa)

Conclusions

- The presence of any geosynthetic product at any testing condition reduced the ISS in comparison to the control specimen.
- Paving composite #1 (PC#1) and paving grid (PaG) display the higher shear strength among the geosynthetic-reinforced specimens, while paving mat (PM), paving fabric (PF), and paving composite #2 (PC#2) show lower shear strength.
- Higher temperature, lower speed, and thinner overlay condition yield higher MSR values. This phenomenon indicates that the interlayer shear resistant ability is the weakest while the vehicle is about to stop during hot days.
- The MAST test condition for the acceptance of geosynthetic interlayer materials includes **50°C (122°F)**, **5.08 mm/min (0.2 in./min)** displacement rate, and **275.8 kPa (40 psi)** confining pressure. The minimum required shear strength for geosynthetic-reinforced specimens at this condition is **305 kPa (44 psi)**. This threshold value may need to be adjusted for different machines due to different machine compliance.

NC STATE

Thank You!