Optimum HMA Materials and Lift Thickness for Controlling Reflective Cracking

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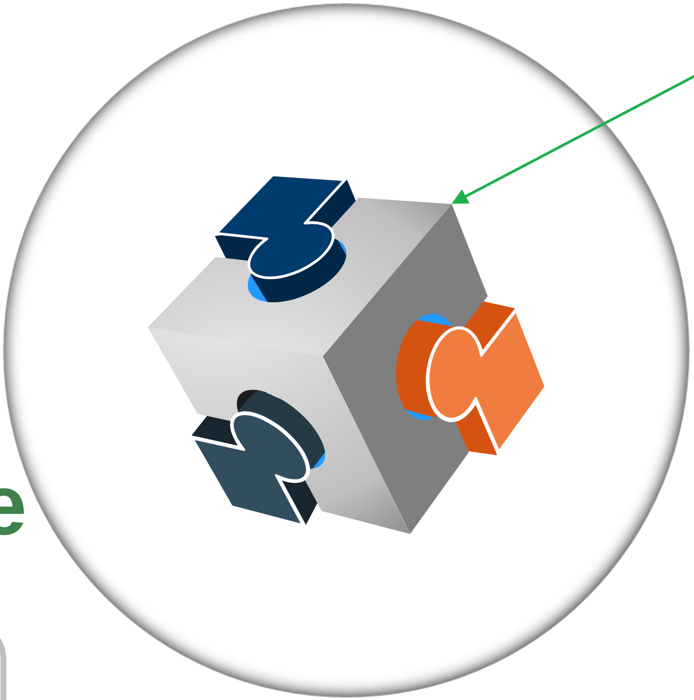
Long-lasting Flexible Pavements!

Resiliency



Safety

Cost

Climate Change

All projects must be

Safety: Predict Friction via Computer Vision & Machine Learning

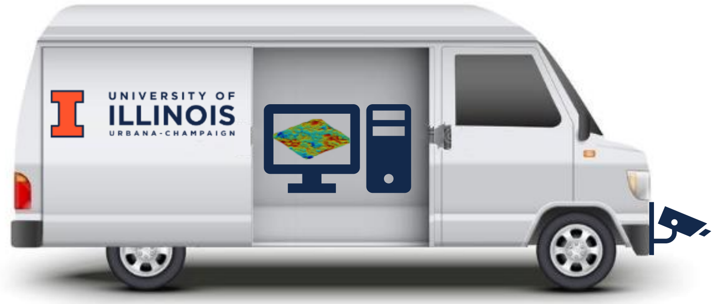
Causes of Crashes

Environment | Vehicle | Driver

Friction

Locked Wheel Skid Trailer

Expensive | Time-consuming | Variable



Actual 2D

Reconstructed 3D

Advanced Pavement Assessment (GPR)

- Investigating new possibilities for collecting data remotely, safely, and without work disruptions
- Efficient monitoring for on-time decision making

Pavement Economics and Sustainability

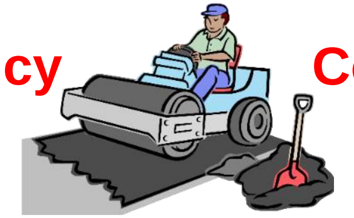
Life Cycle Cost Analysis (LCCA)

- Economic alternatives/ effectiveness
- Agency and user costs over the life of pavement

Life Cycle Assessment (LCA)

- Conserve resources, *energy use*
- Reduce health concerns to human and ecosystem, *environmental impacts*

Agency Costs



User Delay Costs

Vehicle Operating Costs

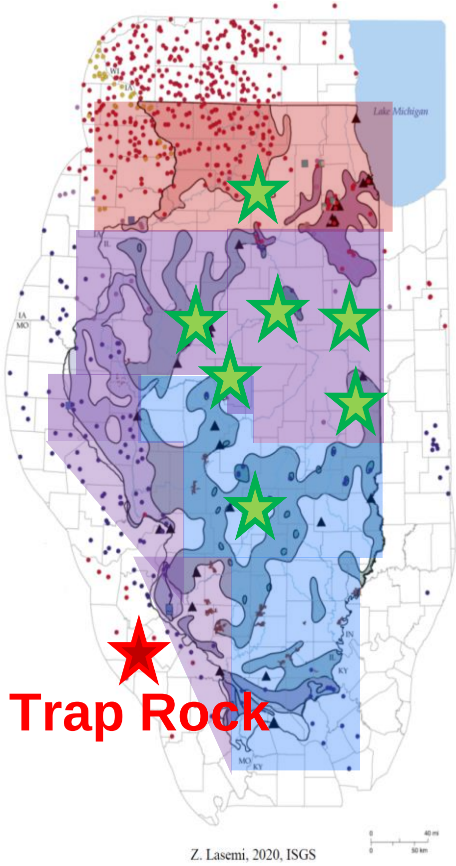
Crash Costs

Emission Costs

User Costs

Stone Matrix Asphalt Using *Local Aggregates*

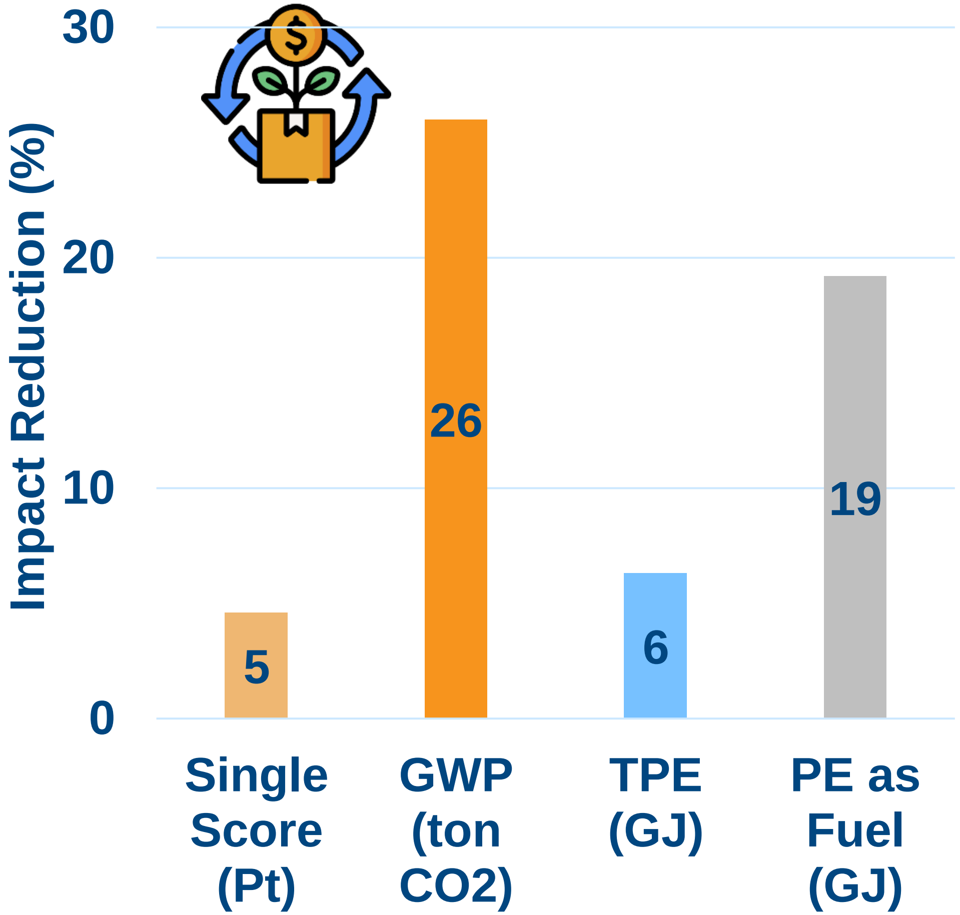
- Dolomite
- Limestone
- Both
- Crushed Gravel in Rivers



SMA cost in IL

~ $108/ton for SM

79% less in aggregate hauling cost only!

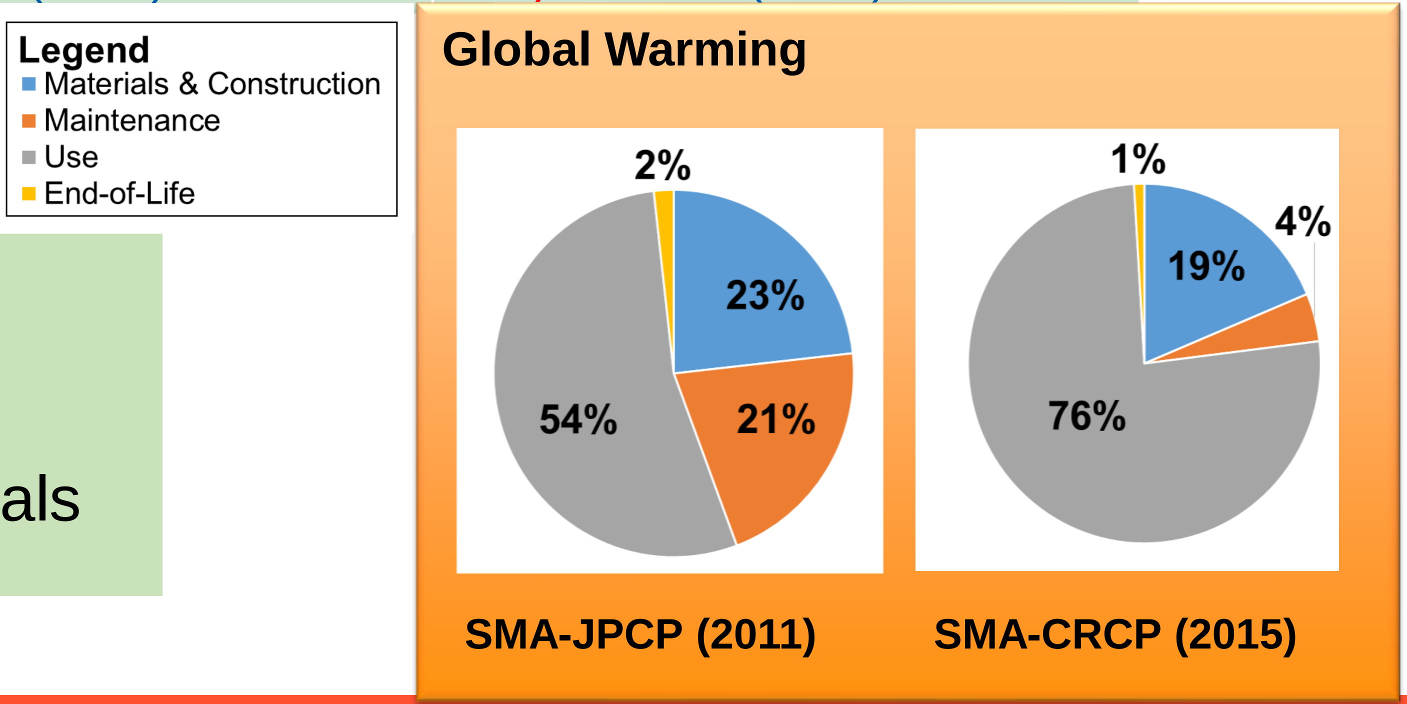


Road to Sustainability!

Year of Rehab	2011	2015
Type	SMA-JPCP, FD-HMA widening	SMA-CRCP, FD-HMA widening
Design Life	22 years	30 years
Length/Lanes	3.5 mi (4)	1.1 mi (3)
Traffic	**70,000** ADT (2013)	**105,000** ADT (2010)

Differences in projects

- Thicknesses of SMA overlay
- Width of lanes
- Maintenance schedule
- Existing JPCP/CRCP condition
- Increased use of recycled materials and WMA

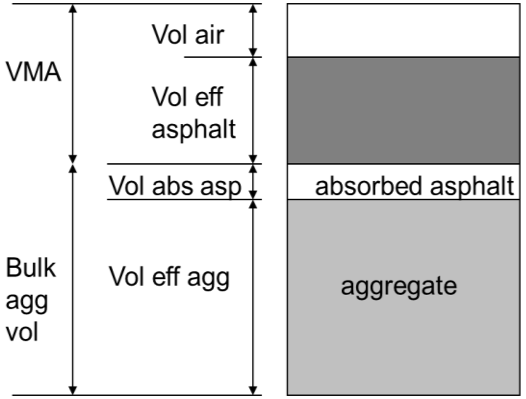


Balancing Properties to Control Main Distresses!

Courtesy D. Lippert

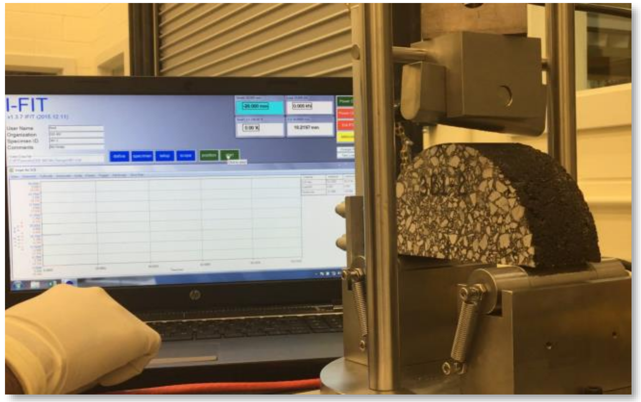
-40°C | 20°C | 40°C

Low in-service temp



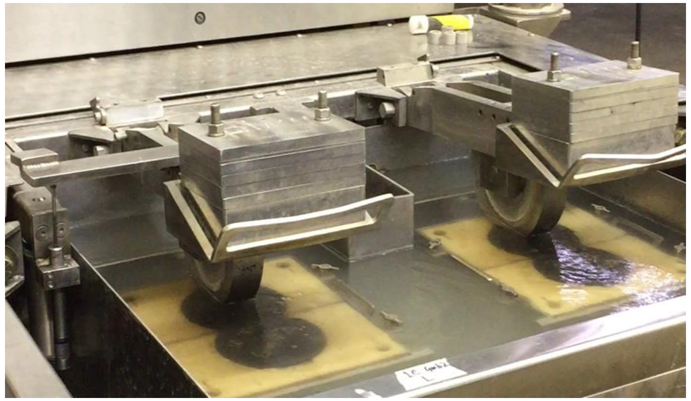
Volumetrics

Intermediate in-service temp



I-FIT

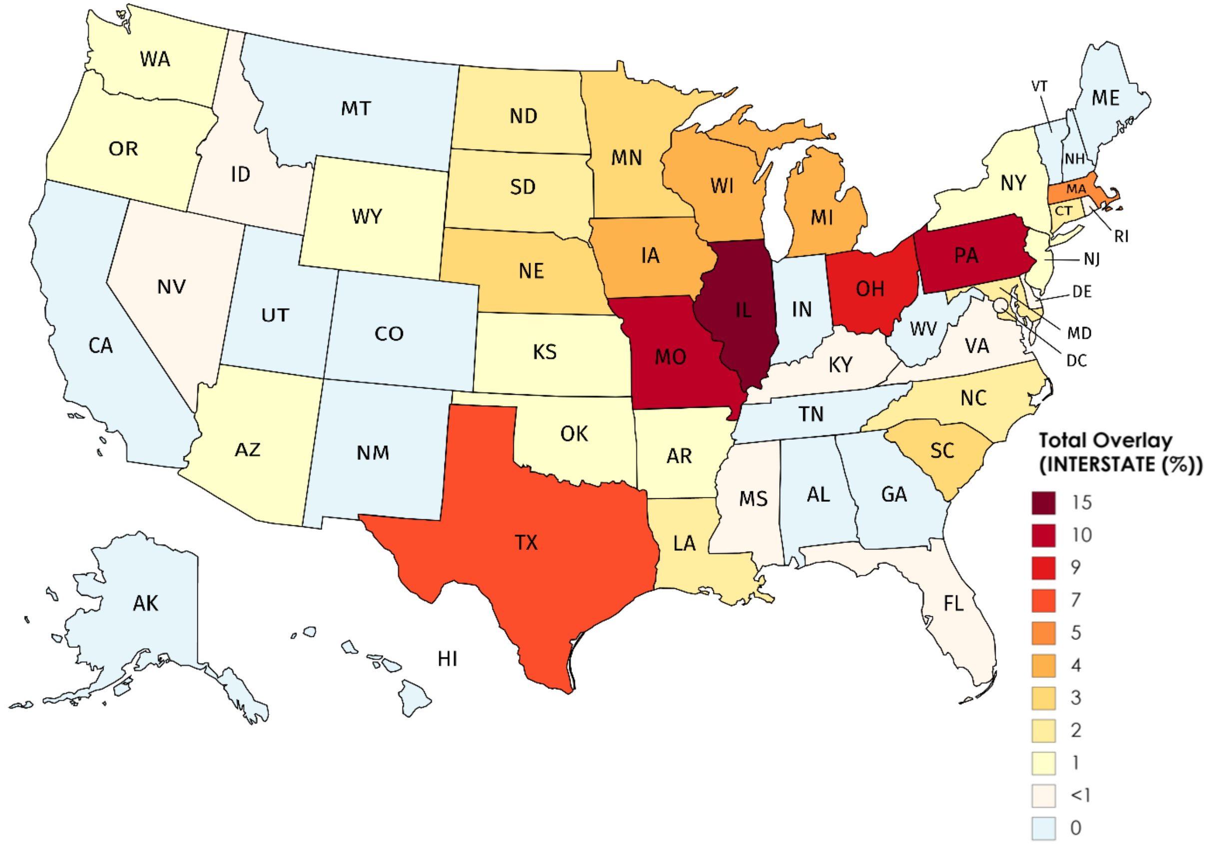
High temp

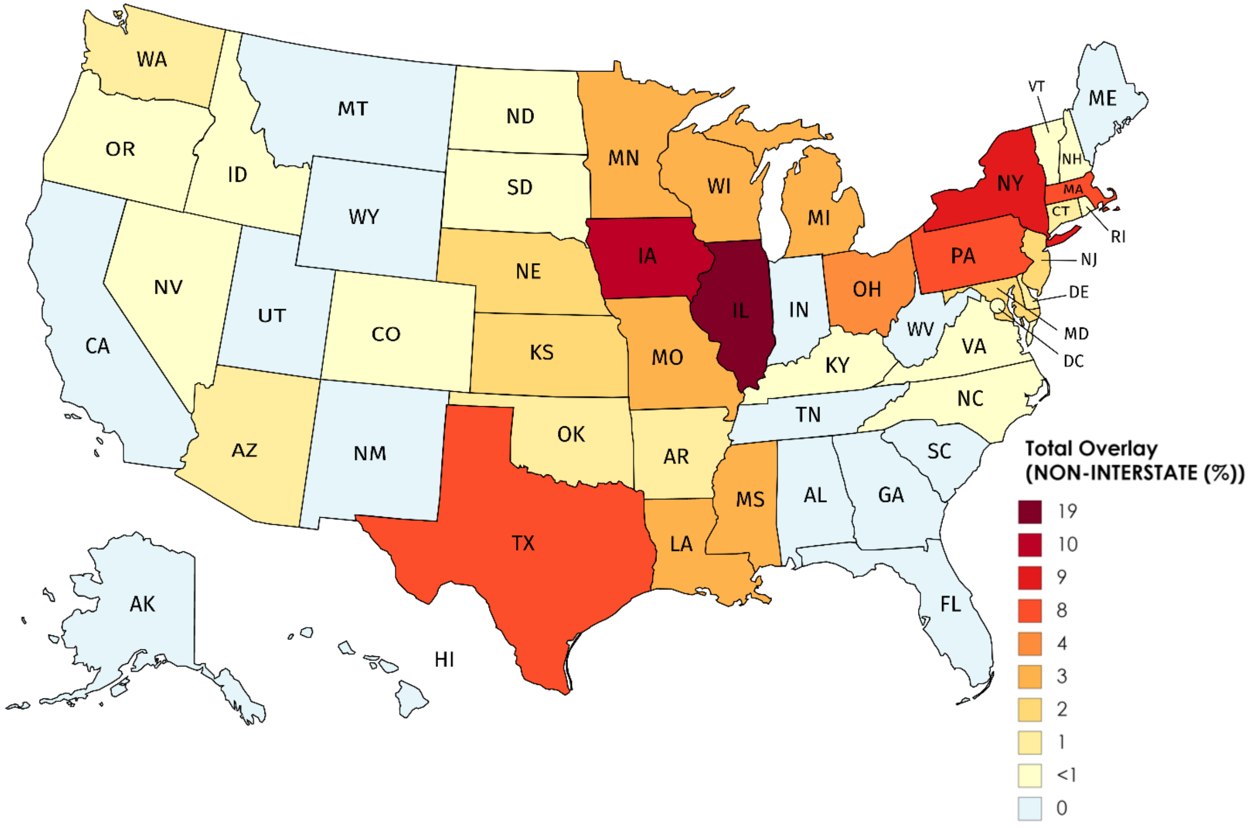


Hamburg Wheel Track

Reflective Cracking Is Common in Overlays

15% of the US interstate and 19% of non-interstate overlays are in Illinois*

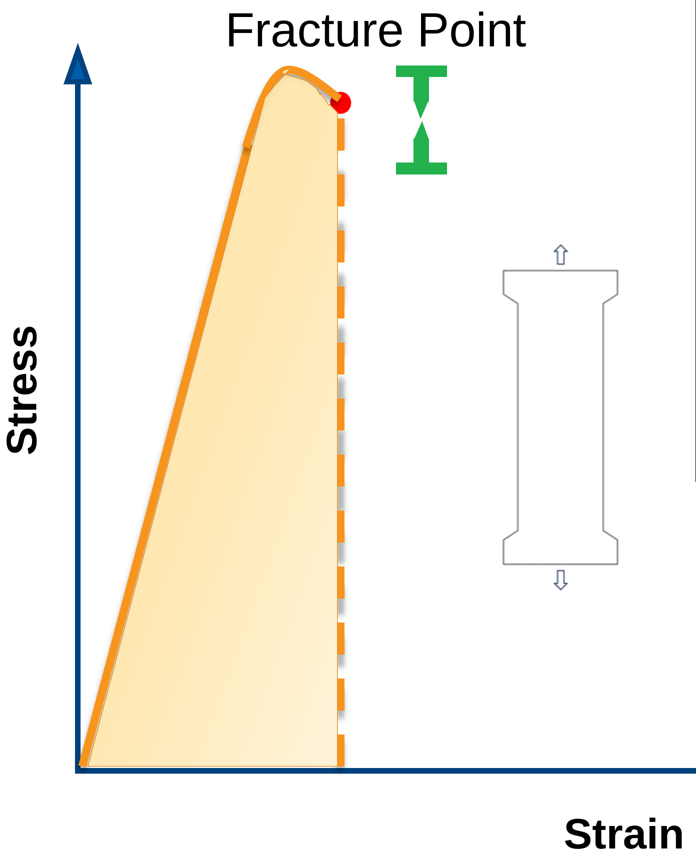


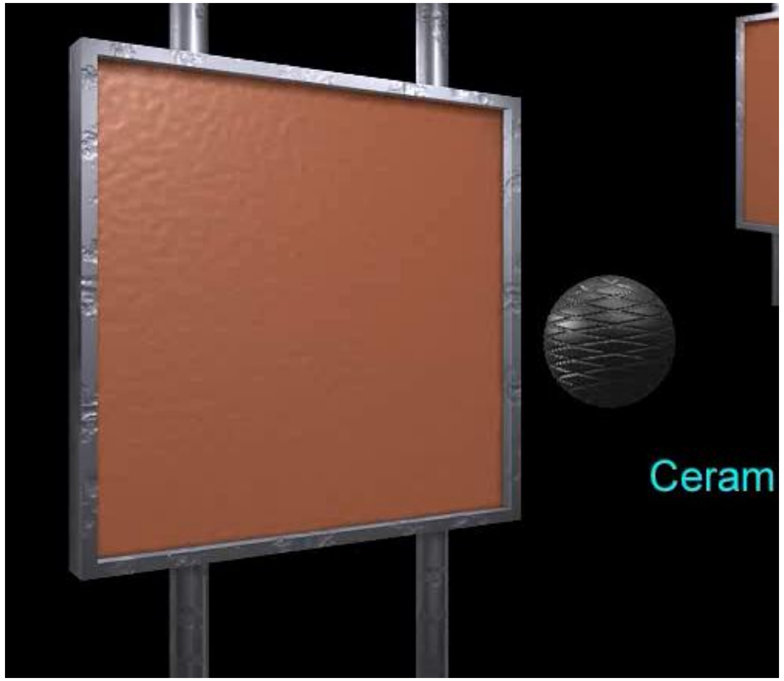


Reflective cracking is common in AC overlays

*Data Source: FHWA 2017

Illustration – Brittle Material

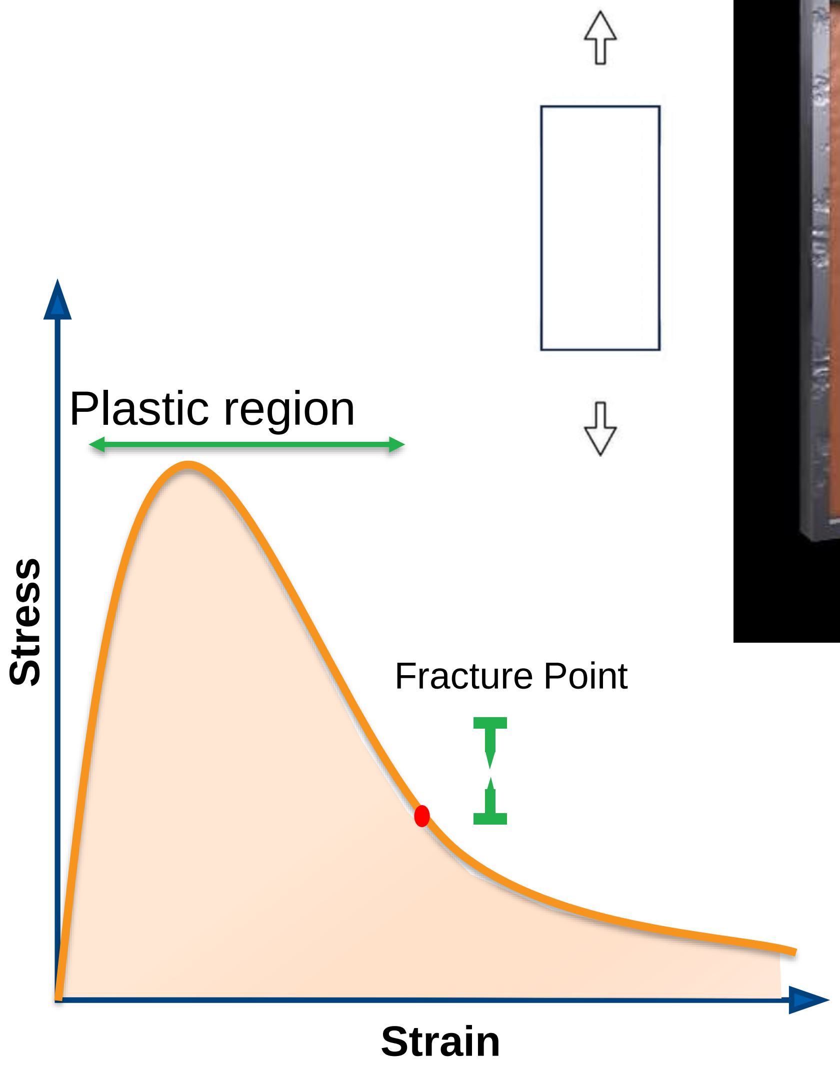


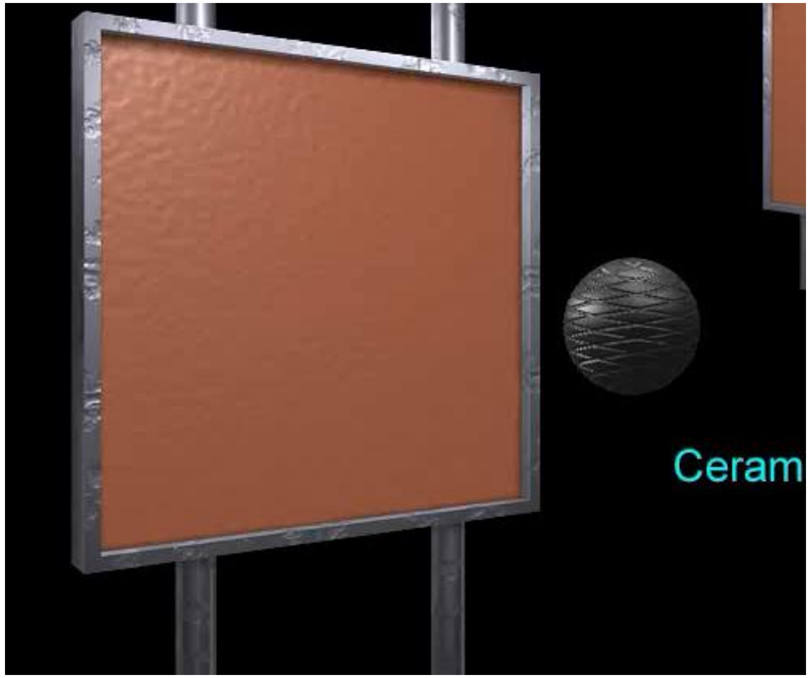


- Fracture occurs immediately after yield point and is catastrophic
- Most of energy absorbed is used for crack propagation

$$Energy_{plastic} \approx 0$$

Illustration – Ductile Material





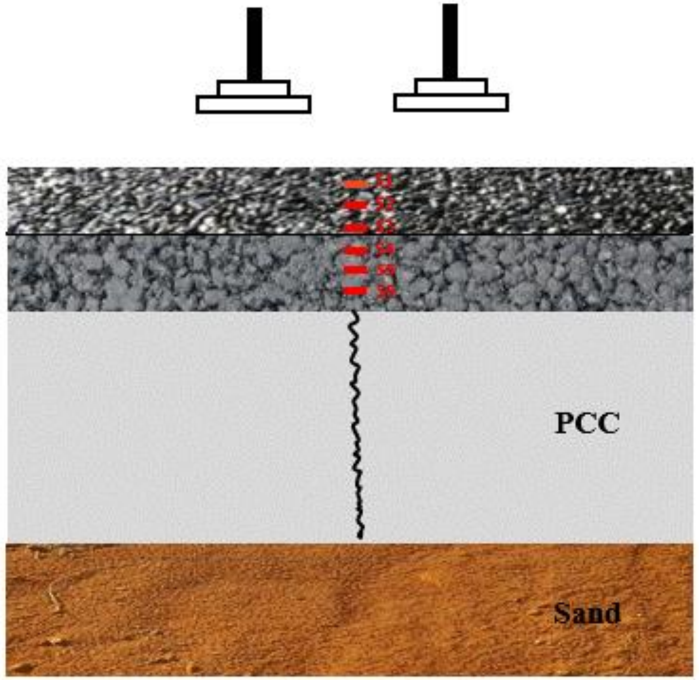
- Fracture occurs slowly after yield point and is stable
- Energy absorbed is used for 1) **plastic deformation** and ii) **crack propagation**

$$Energy_{plastic} > 0$$

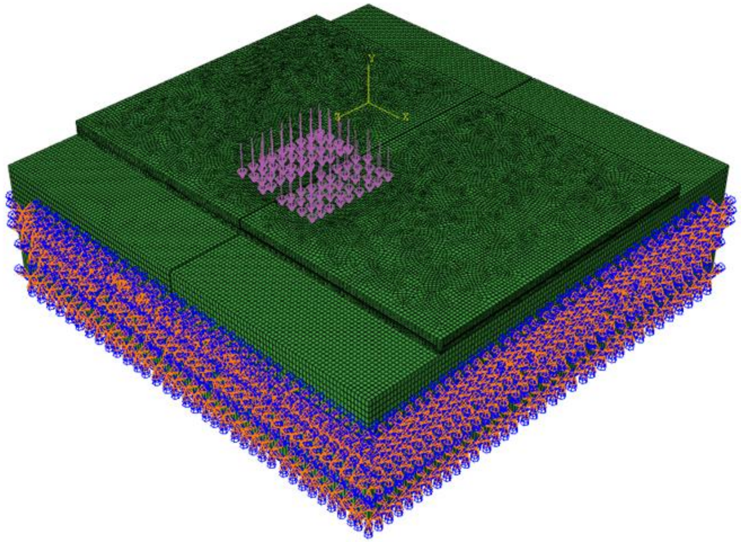
$$Energy_{absorbed} = Energy_{Cracks} + Energy_{plastic}$$

Project Overview

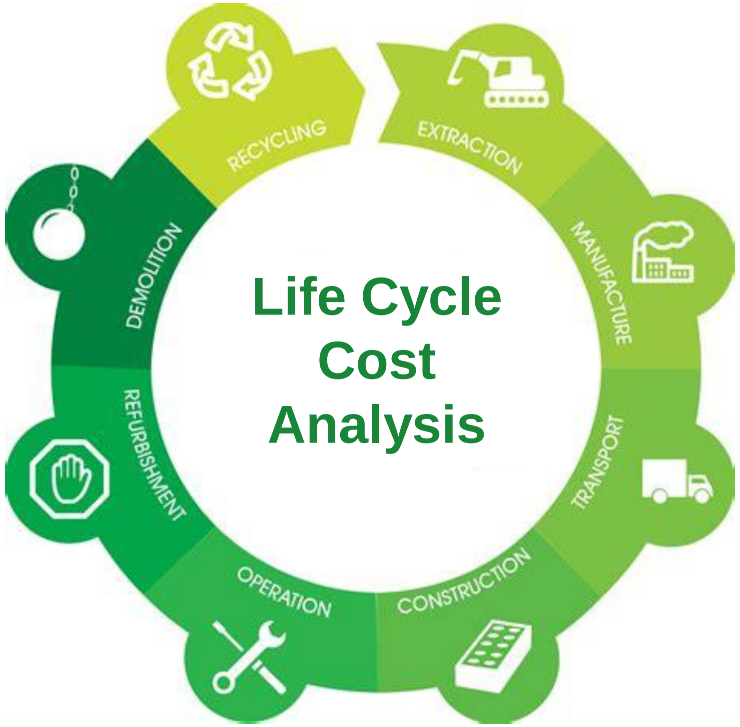
Lab Testing



Mechanistic Analysis



Cost Analysis

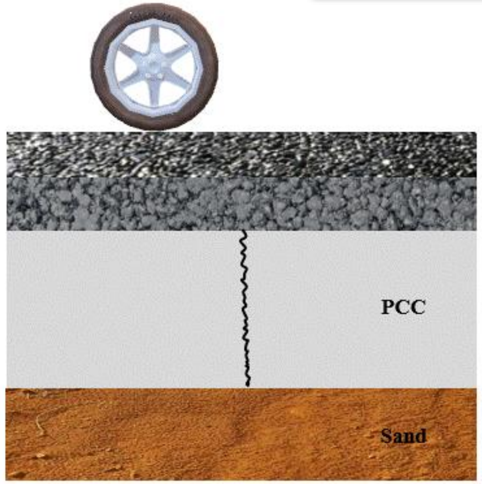


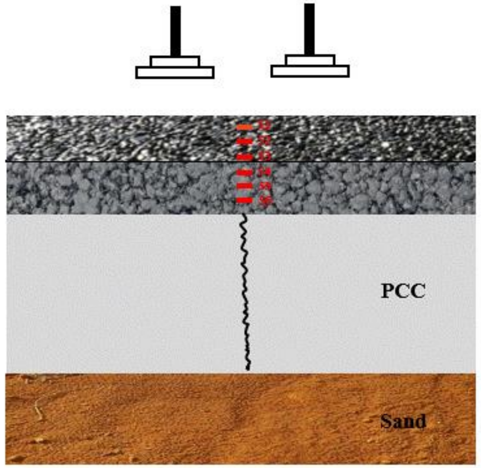
Testing Program

Small-Scale

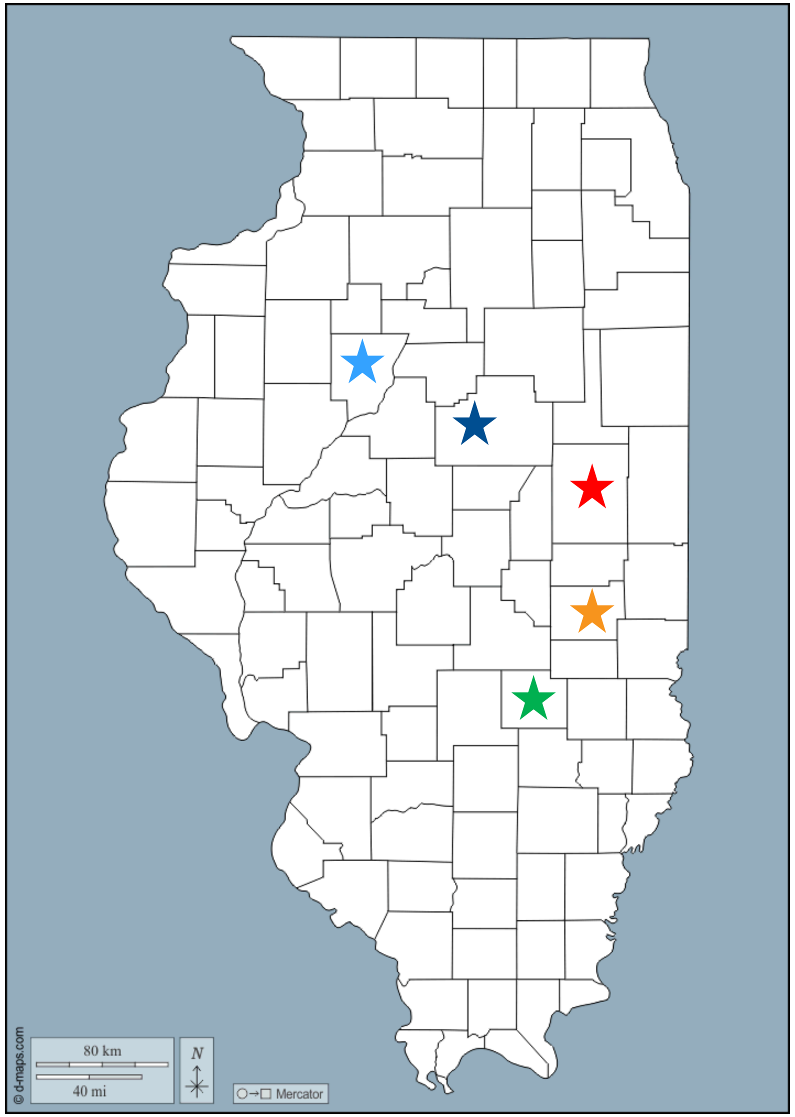
Tests		*Objectives*
I-FIT		❑ Evaluate cracking potential
HWTT		❑ Assess rutting susceptibility
E*		❑ Examine stiffness ❑ Derive viscoelastic properties

Large-Scale



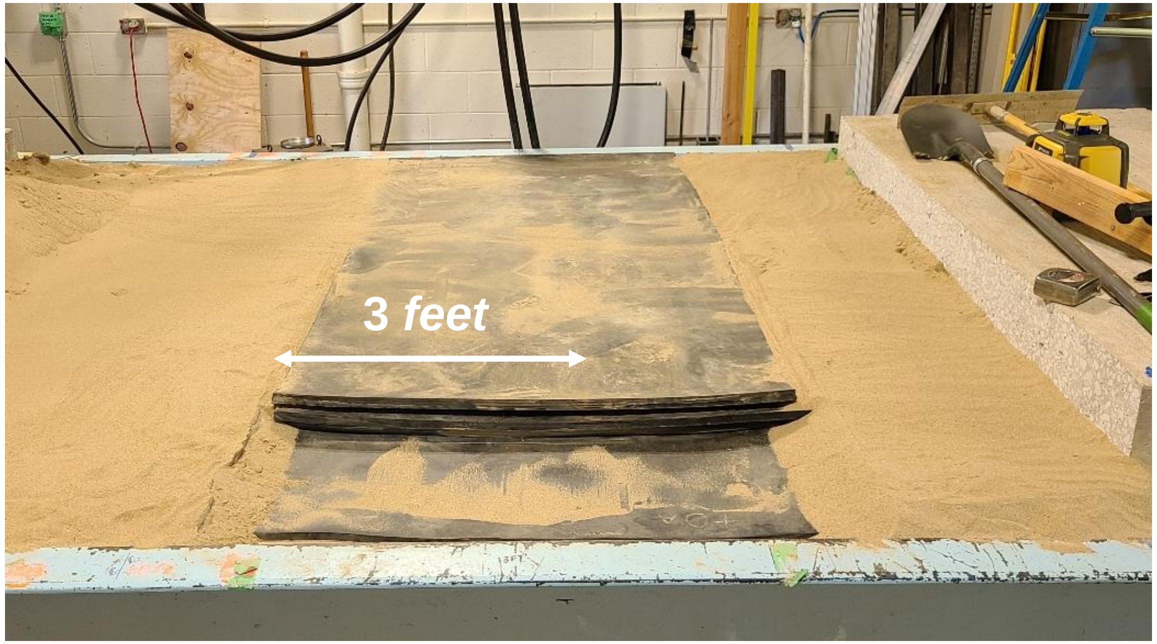


Plant Mixtures



Id	N-Design	AC (%)	Binder Grade	ABR (%)
IL-4.75	50	8.2	SBS PG 70-22	10.0
IL-9.5	70	6.1	PG 58-28	29.3
IL-9.5FG	90	5.9	SBS PG 70-22	0.0
IL-19	70	5.3	PG 58-28	20.0
SMA-9.5	80	6.6	SBS PG 76-22	9.8
SMA-12.5	80	6.3	SBS PG 76-28	14.7

Subgrade Preparation

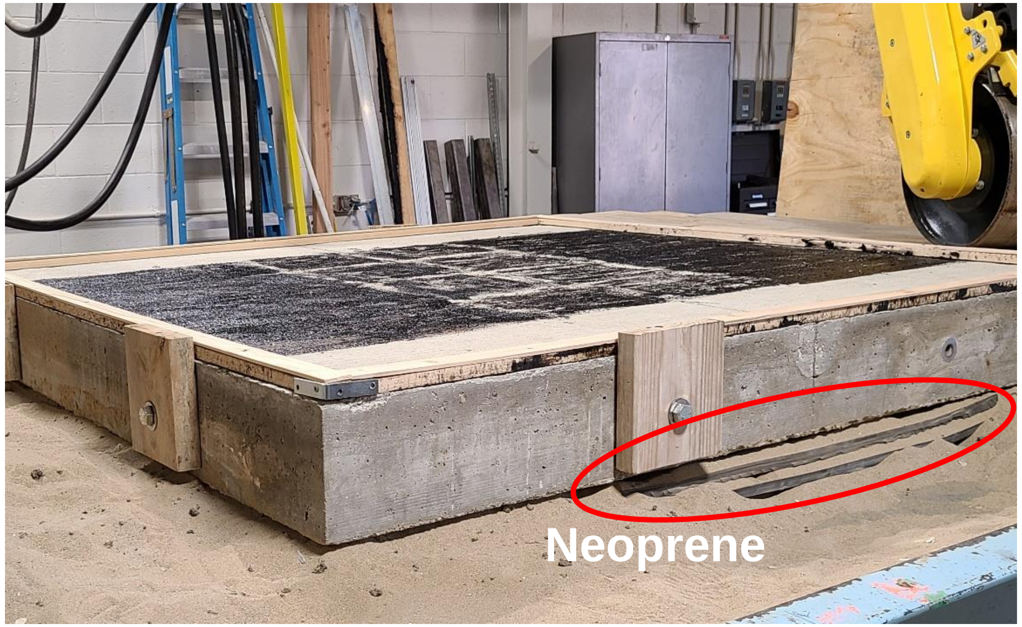


Compaction

3.75” Neoprene Sheet

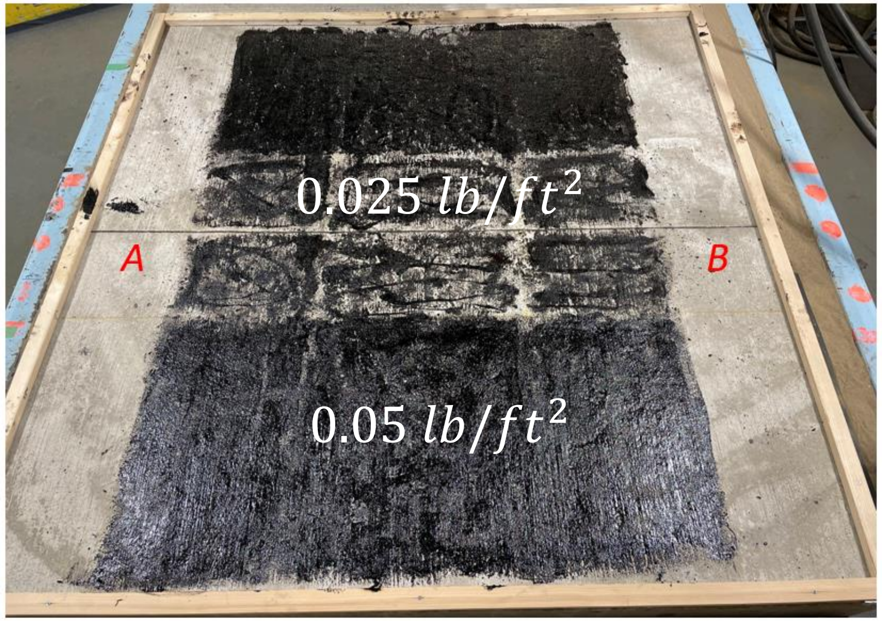
- ***Amplify Deflection***
- ***Accelerate Testing***

Concrete Slab Preparation and Placement



Saw Cut 6-in-deep → **Place PCC** → **Place HMA**

Slab Construction – Mix Preparation



Apply Tack Coat (SS-1h)

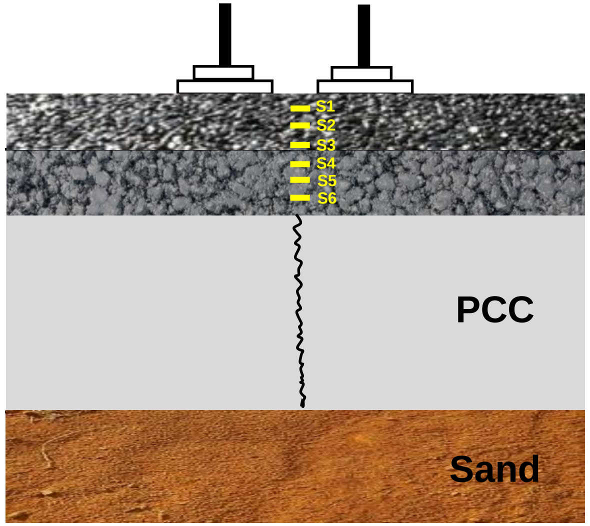
Pre-heat AC to loose-state in oven

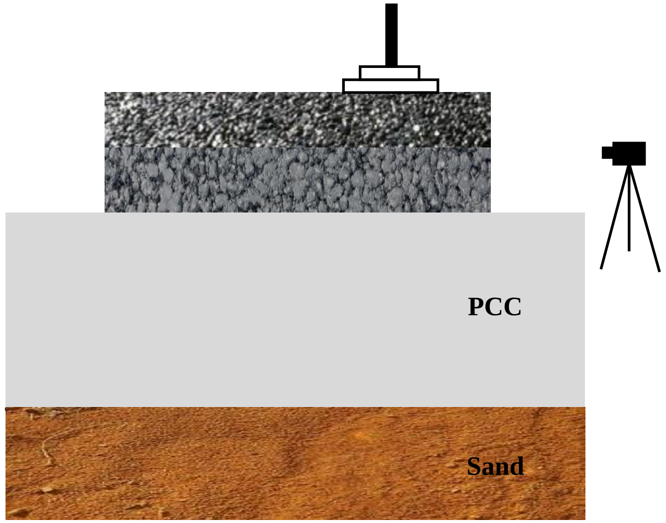
Heat to compaction temperature in mixer

Slab Construction – Compaction

Discharge Materials → **Spread & Level Materials** → **Lift Compaction** → **Saw Cut Overlay Edge**

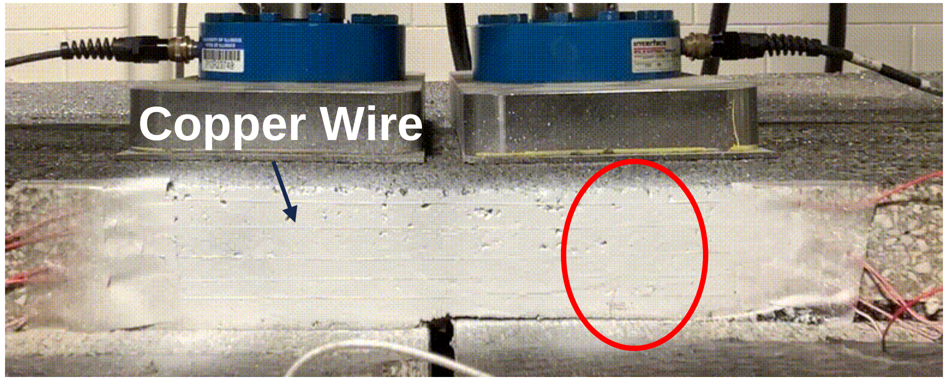
Instrumentation





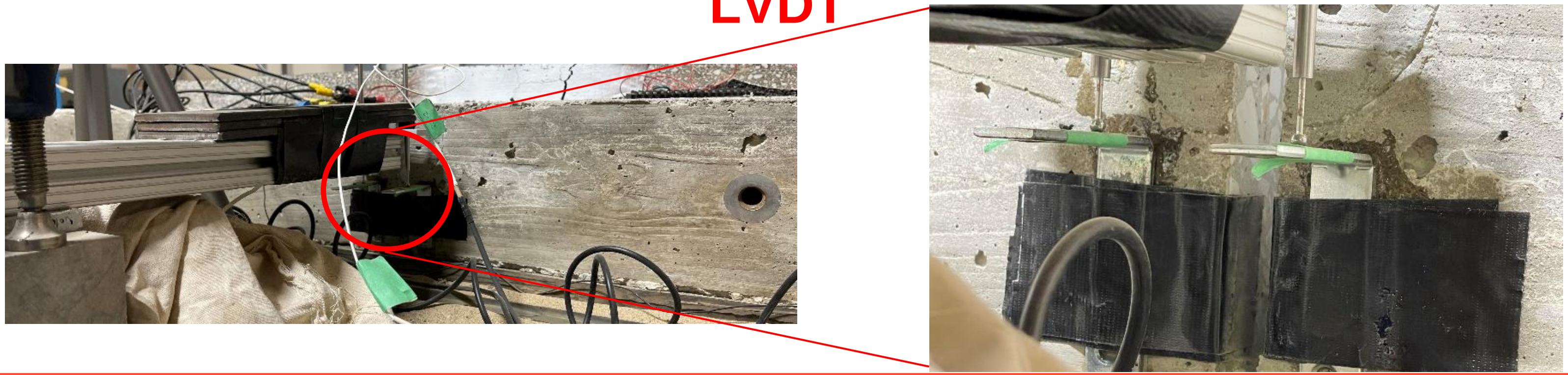
Goal 1: Measure Crack Propagation Speed

Camera & Copper Wires



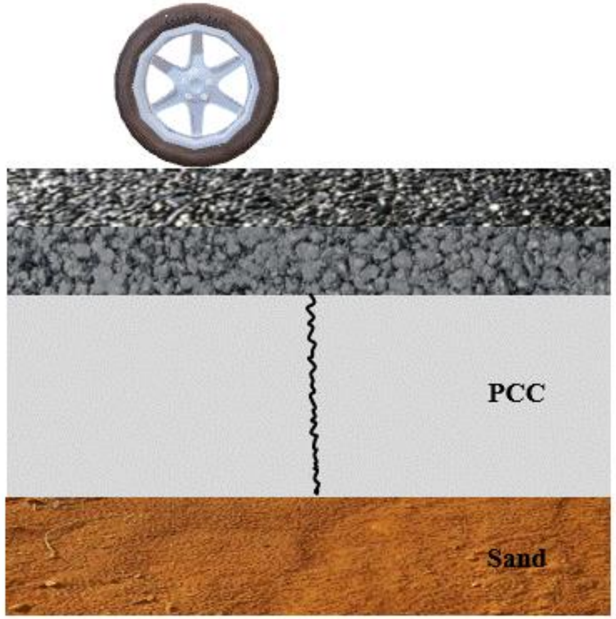
Goal 2: Measure PCC Deflection

LVDT

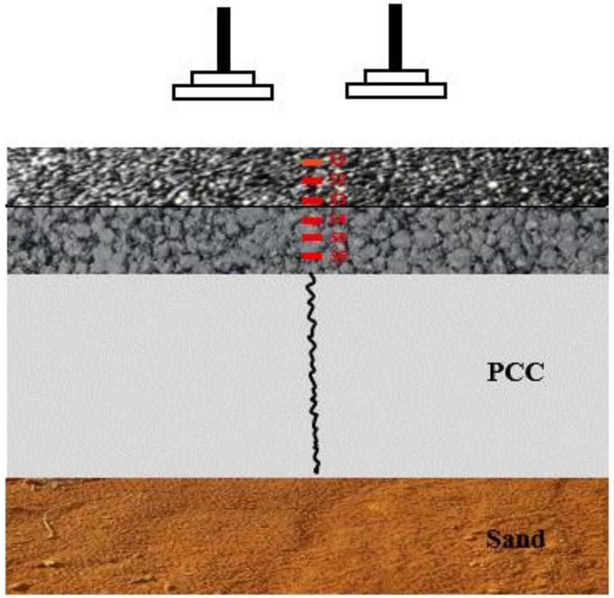


Loading Mechanism

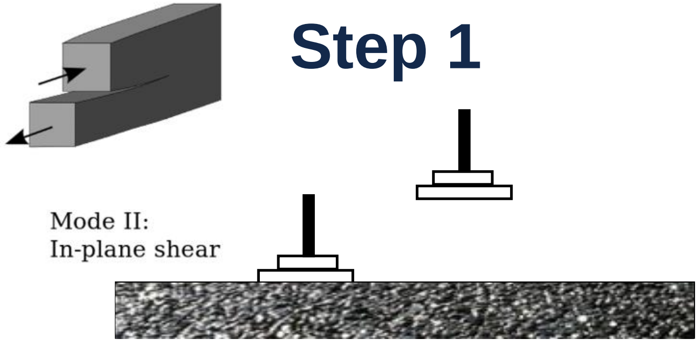
Real



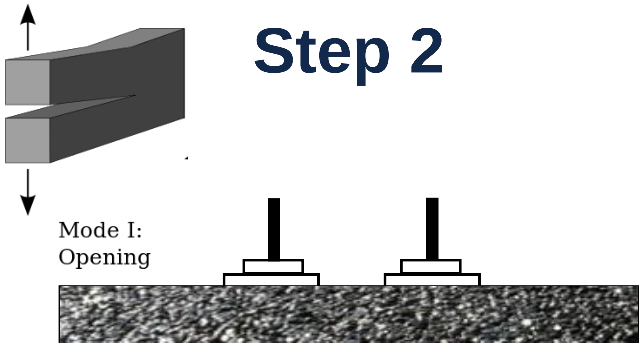
Simulated



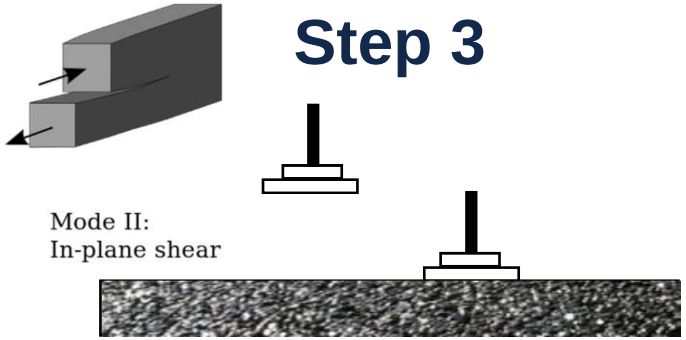
Step 1



Step 2



Step 3



Overlay Scenarios

Non-Interstate

Control

IL-9.5 Surface Course @ 1.50 in
IL-4.75 Binder Course @ 0.75 in
PCC @ 7 in

Alternatives

1	IL-9.5 @ 1.50 in IL-9.5 FG @ 1.25 in
2	SMA 9.5 @ 1.50 in IL-4.75 @ 0.75 in
3	IL 9.5 FG @ 1.25 in IL-4.75 @ 0.75 in

Interstate

Control

IL-9.5 Surface Course @ 1.50 in
IL-19.0 Binder Course @ 2.25 in
PCC @ 7 in

Alternatives

1	SMA 9.5 @ 1.50 in SMA 12.5 @ 2.00 in
2	SMA 12.5 @ 2.00 in IL-19.0 @ 2.25 in
3	SMA 9.5 @ 1.50 in IL-9.5 @ 1.50 in

Interstate

Ctrl	
	IL-9.5 @ 1.50 in
	IL-19.0 @ 2.25 in

	Alt1
SMA-9.5 @ 1.50 in	
SMA-12.5 @ 2.00 in	

- Excessive joint opening → tension cracks (paths not well-defined)
- Mild PCC-binder debonding
- Low FI & modulus surface + low FI binder → poor performance

- Excessive joint opening → tension cracks (paths not well-defined)
- Mild PCC-binder debonding
- SMA surface + binder → good performance

Interstate

Alt2

SMA-12.5 @ 2.00 in
IL-19.0 @ 2.25 in

- Bottom-up reflective crack
- Mild PCC-binder debonding, binder-surface debonding
- Thickest structure + SMA surface → good performance

Alt3

SMA-9.5 @ 1.50 in
IL-9.5 @ 1.50 in

- Excessive joint opening → tension cracks (paths not well-defined)
- Moderate PCC-binder debonding, binder-surface debonding
- Thinnest structure + low FI binder → poor performance

Non-Interstate

Ctrl

IL-9.5 @ 1.50 in
IL-4.75 @ 0.75 in

- Bottom-up reflective crack
- Significant PCC-binder debonding, slab faulting
- Low FI & modulus surface → poor performance

Alt1

IL-9.5 @ 1.50 in
IL-9.5FG @ 1.25 in

- Bi-directional reflective cracks
- Significant PCC-binder debonding, slab faulting, binder-surface debonding
- Low FI & modulus surface → poor performance

Non-Interstate

Alt2

SMA-9.5 @ 1.50 in
IL-4.75 @ 0.75 in

- Top-down reflective crack
- Significant PCC-binder debonding
- High FI & modulus surface + stress-absorbing binder → good performance

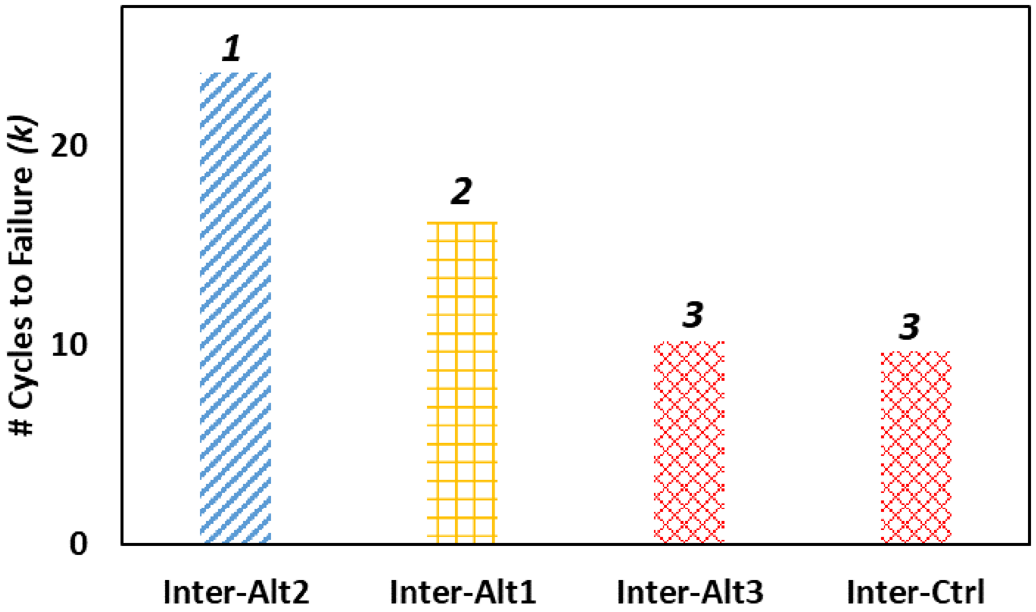
Alt3

IL-9.5FG @ 1.50 in
IL-4.75 @ 0.75 in

- Bottom-up reflective crack
- Significant PCC-binder debonding, slab faulting
- Small PCC deflections (delayed debonding)
- High modulus surface + stress-absorbing binder → good performance

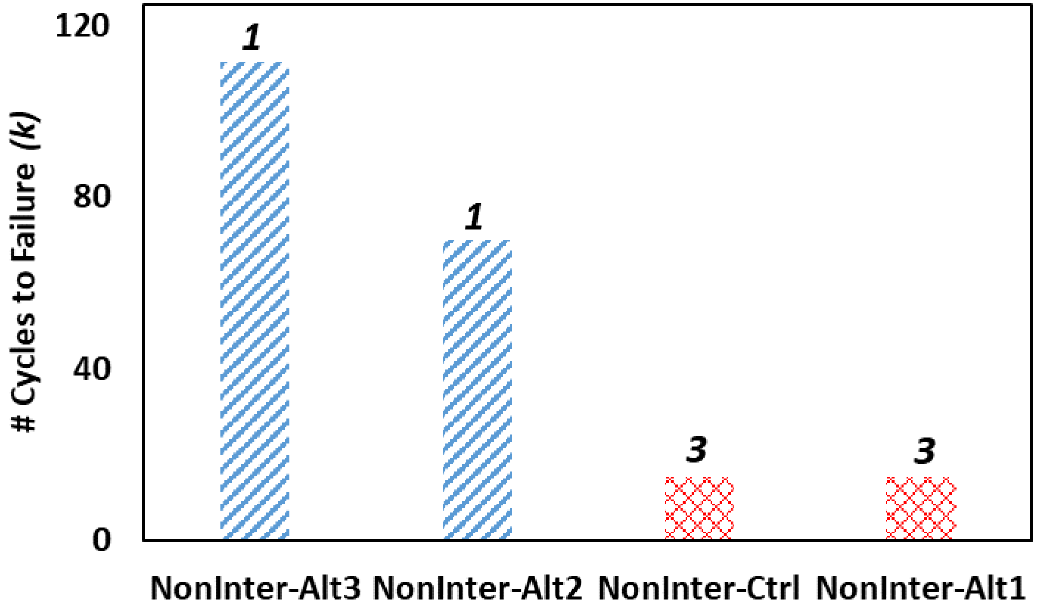
Overall Performance!

Interstate



Ctrl	IL-9.5 @ 1.50 in	IL-19 @ 2.25 in
Alt2	SMA-12.5 @ 2.00 in	IL-19 @ 2.25 in
Alt1	SMA-9.5 @ 1.50 in	SMA-12.5 @ 2.00 in
Alt3	SMA-9.5 @ 1.50 in	IL-9.5 @ 1.50 in

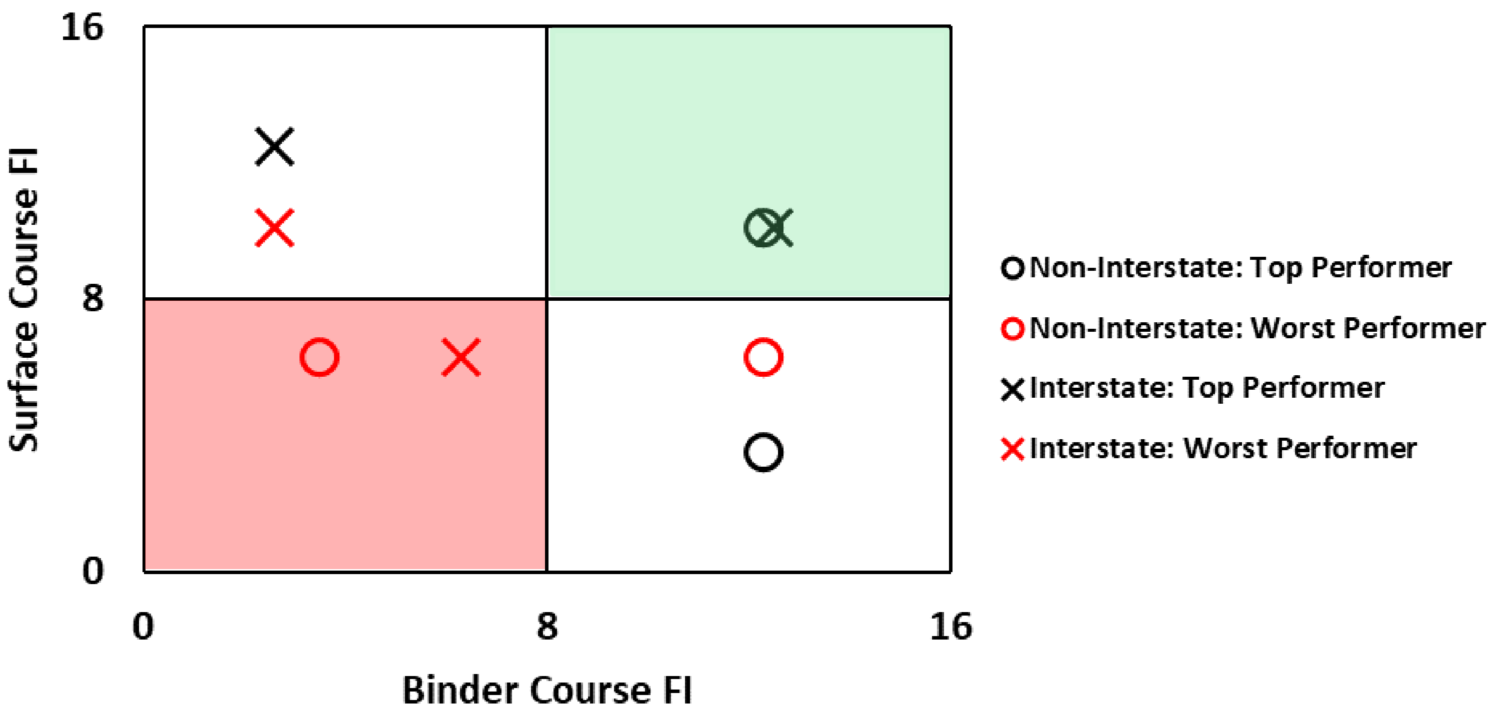
Non-Interstate

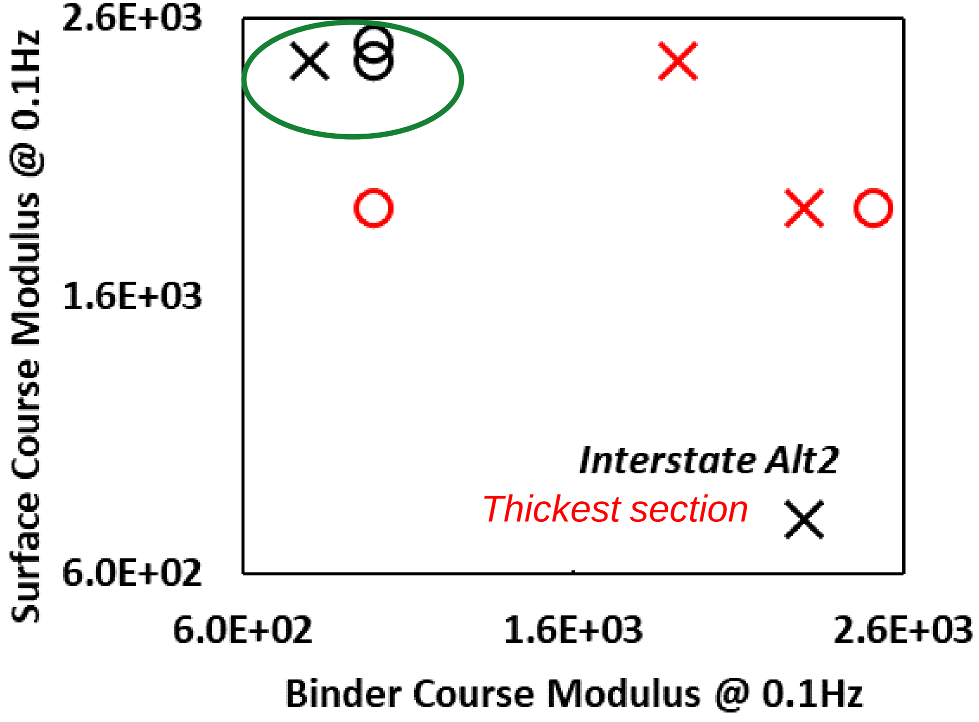


Ctrl	IL-9.5 @ 1.50 in	IL-4.75 @ 0.75 in
Alt2	SMA-9.5 @ 1.50 in	IL-4.75 @ 0.75 in
Alt1	IL-9.5 @ 1.50 in	IL-9.5FG @ 1.25 in
Alt3	IL-9.5FG @ 1.25 in	IL-4.75 @ 0.75 in

Effect of HMA Flexibility, Modulus, and Thickness

Overlays with high FI layers and high modulus surface are resistant to reflective cracking



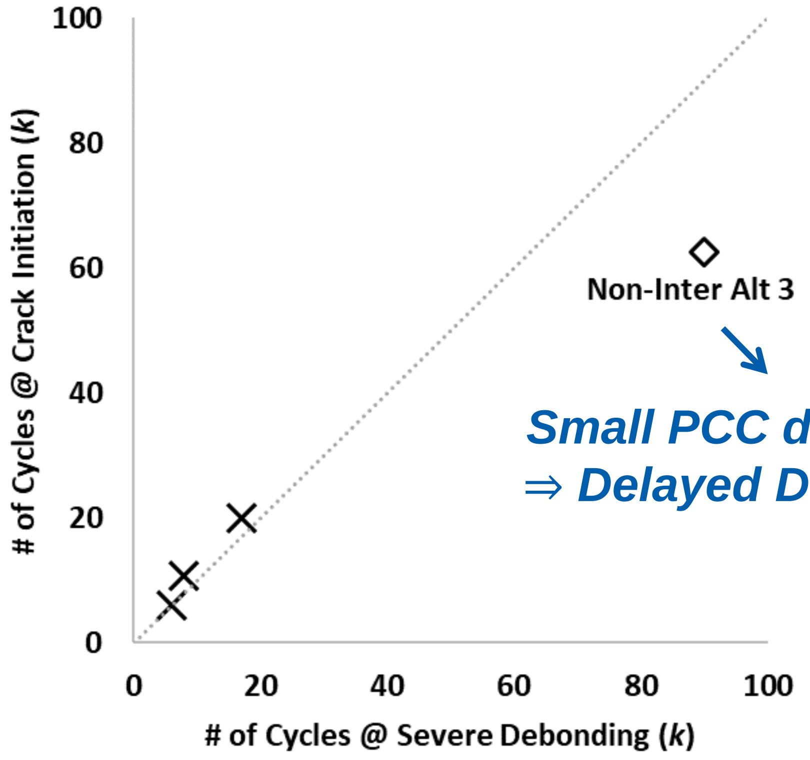


Thicker structure could enhance overlays' reflective cracking resistance

Effect of Debonding

Binder-PCC Interface

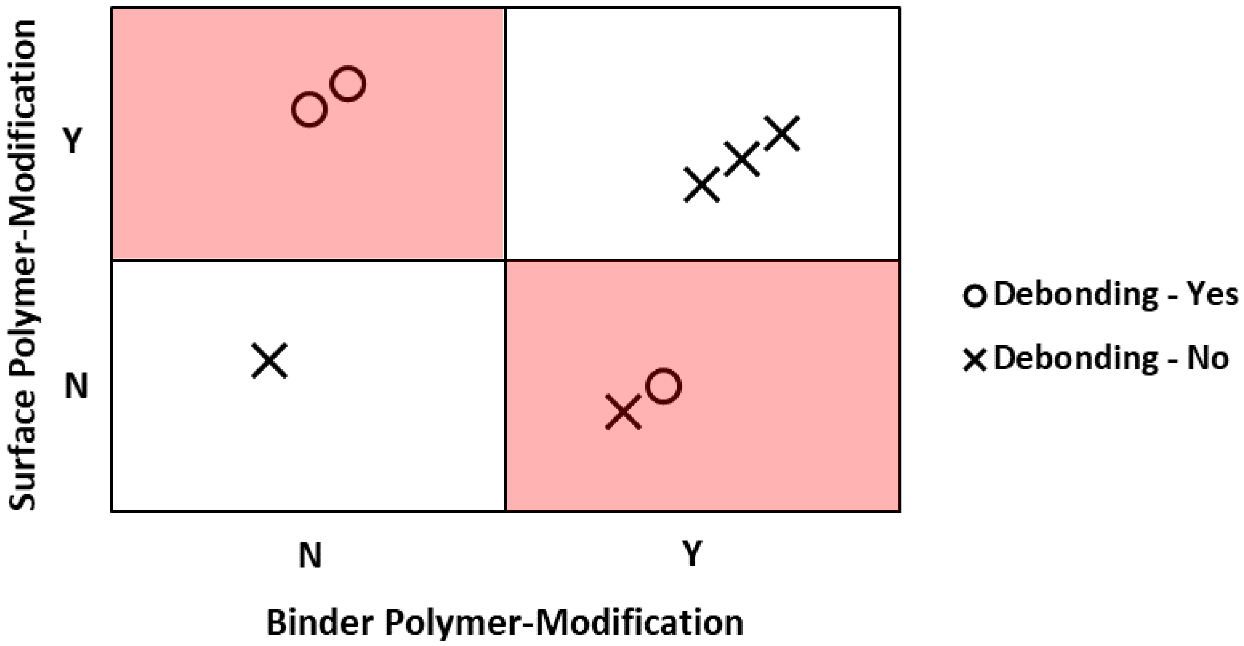
Reflective crack initiation is strongly tied to binder-PCC debonding



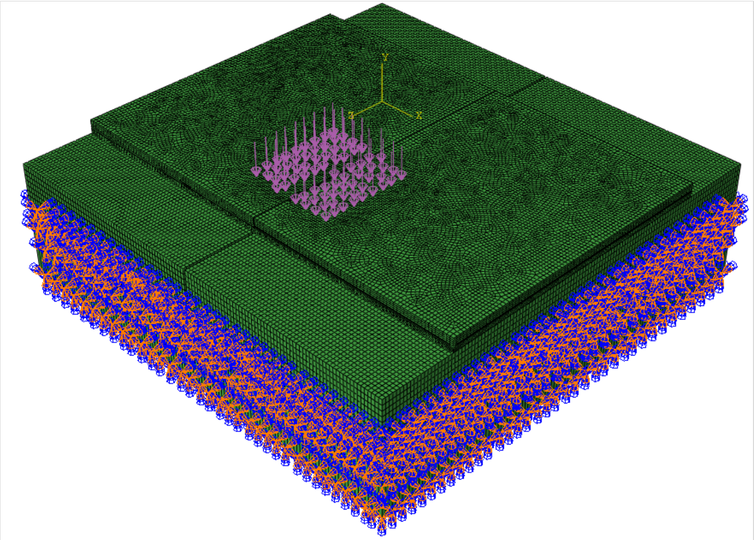
Small PCC deflection
⇒ Delayed Debonding

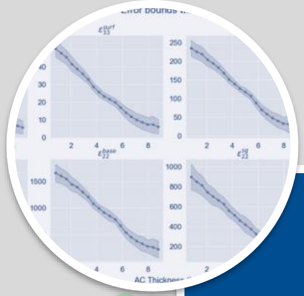
Surface-Binder Interface

Debonding at surface-binder interface creates stress intensity, affecting crack propagation



Mechanistic Analysis - Overview



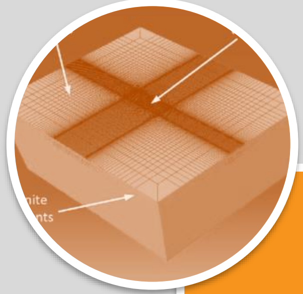


Prediction Model

- Simulation matrix
- Simple model

Model Validation

- Experimental results
- Correlation of fracture properties



Model Development

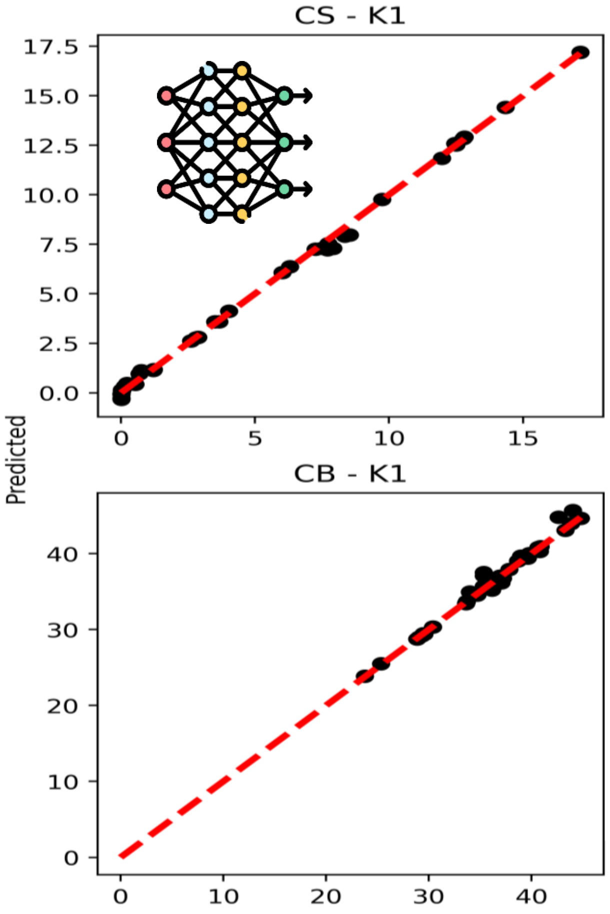
- Test slab emulation
- Fracture modeling
- Analysis of fracture properties

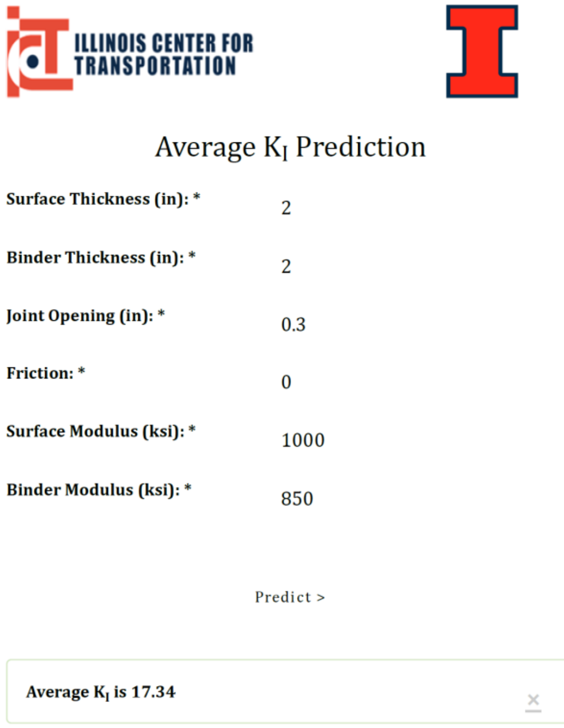
Model Validation and Surrogate Model

Average K_1 ($MPa.mm^{-0.5}$)	Rank
30.28	NIS Alt-3
31.32	NIS Alt-2
31.90	NIS CTRL
33.23	NIS Alt-1
26.14	IS Alt-2
29.61	IS Alt-1
31.32	IS CTRL
32.31	IS Alt-3

Actual Rank (from tests)
NIS Alt-3
NIS Alt-2
NIS CTRL
NIS Alt-1
IS Alt-2
IS Alt-1
IS Alt-3
IS CNTRL

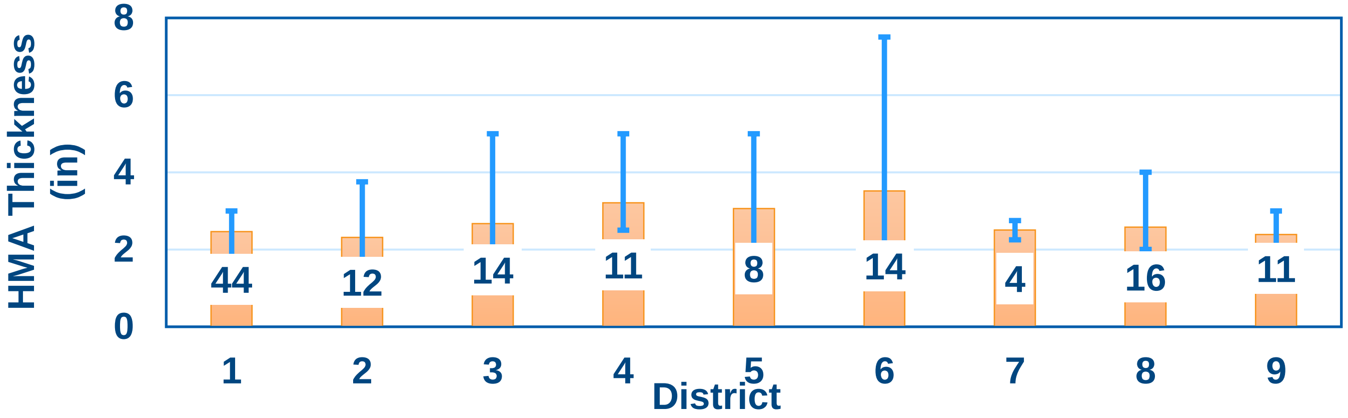
Neural Network



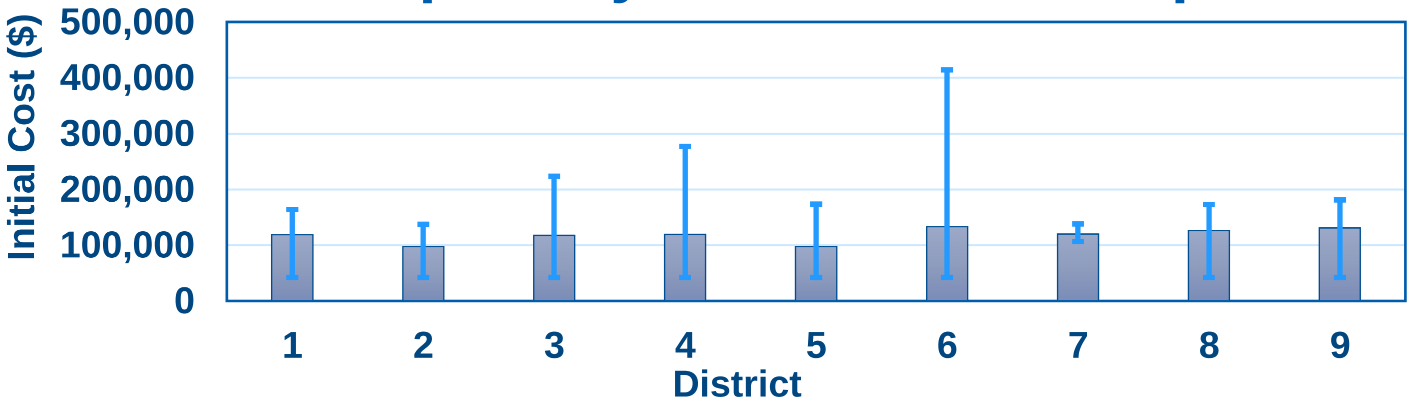


LCCA: Overlay Projects and Costs 2018-2019

- 130 projects (> 30% in District 1)
- Average total thickness (2.5-3.5 in)



One lane-mile based on total quantity of HMA and unit price

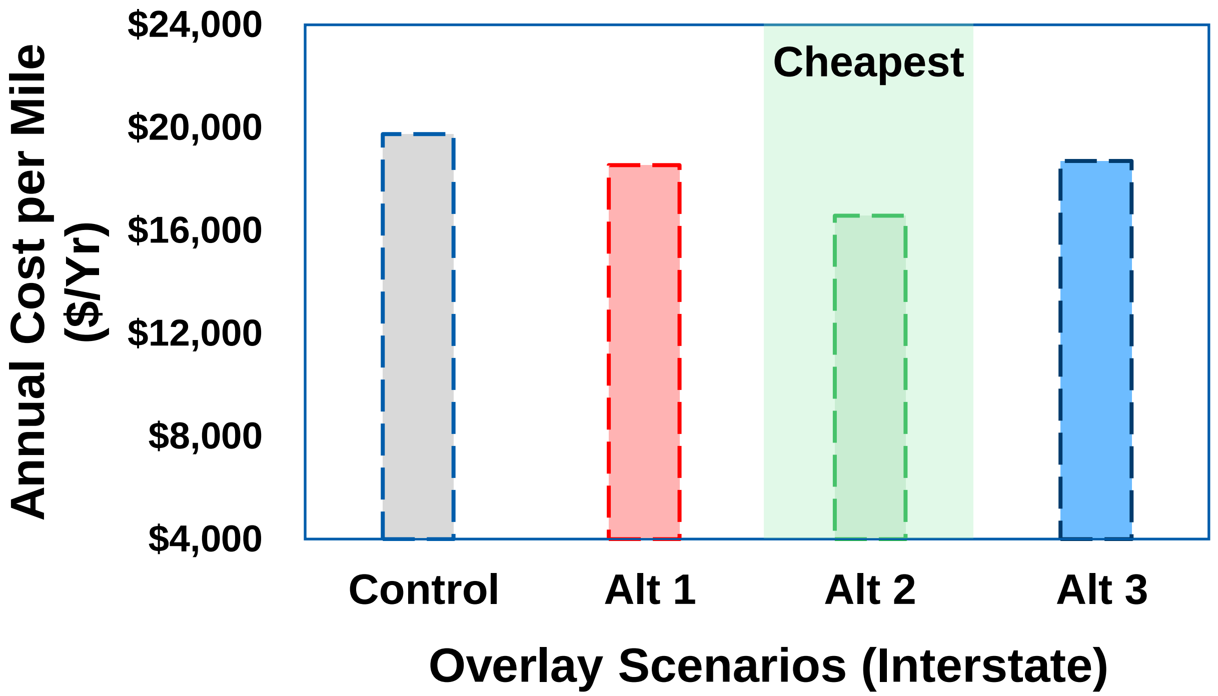


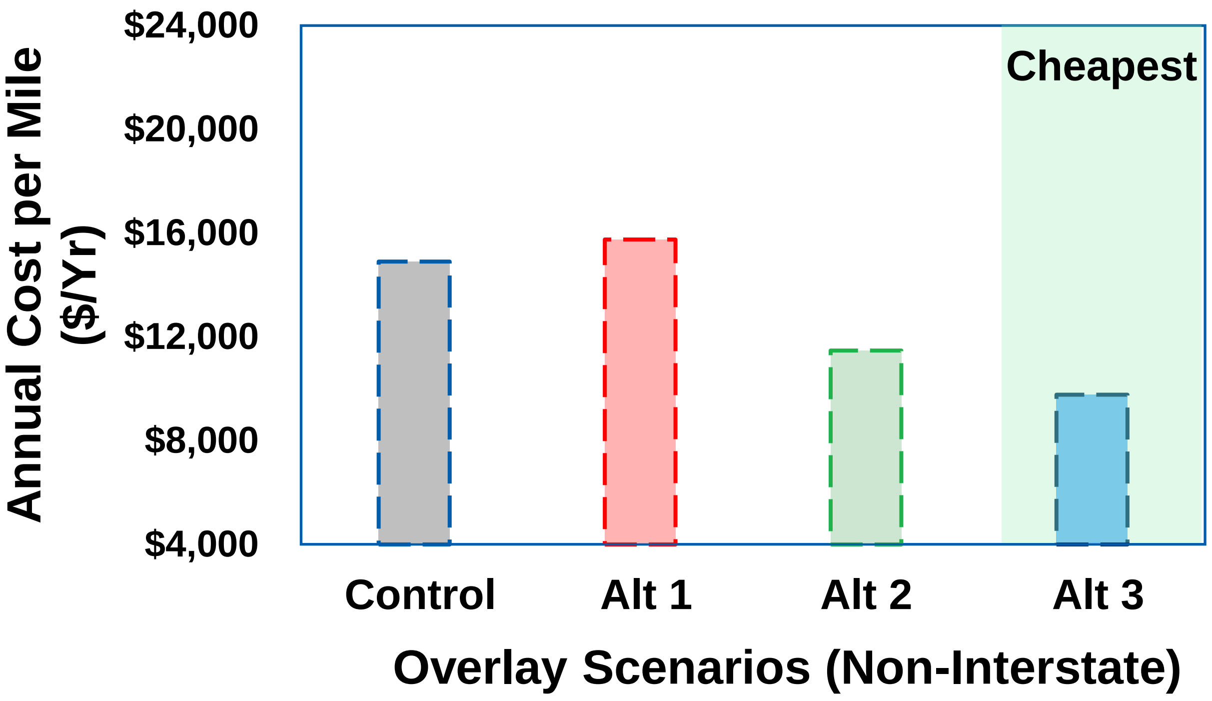
LCCA Assumptions

- Project length = 1 mile
- Number of lanes = 1
- Average Lane width =12 ft
- No centerlines or edge lanes
- Standard surface & binder layer weights ==> 112.0 $lb/yd^2.in$

Criterion	Poor (yrs)	Moderate (yrs)	Good (yrs)
Overlay Service Life	10-11	12-13	14-15
1st Maintenance	3	4	5
2nd Maintenance	6	8	10

Annual Cost per Mile





Alt1: SMA-9.5 @ 1.50 in / SMA-12.5 @ 2.00 in

Alt2: SMA-12.5 @ 2.00 in / IL-19 @ 2.25 in

Alt2: SMA-9.5 @ 1.50 in / IL-4.75 @ 0.75 in

Alt3: IL-9.5FG @ 1.25 in / IL-4.75 @ 0.75 in

Final Remarks

- **An optimum and cost-effective overlay to control reflective cracks comprises a high modulus and flexible surface, and a flexible binder**
- **The thicker the HMA overlay, the greater reflective cracks control**
- **Layer bonding is important:**
  - Low at binder-PCC may cause joint opening, inducing rapid failure of overlay
  - Low at surface-binder would impact crack propagation (*polymer-modified doesn't bond well with non-polymer lift*)

Non-Interstate

SMA-9.5 @ 1.50 in	**IL-9.5FG @ 1.25 in**
IL-4.75 @ 0.75 in	**IL-4.75 @ 0.75 in**
SMA-9.5 with local Illinois gravels may be considered to reduce cost	Low-volume low-speed roads

Interstate

SMA-12.5 @ 2.00 in	**SMA-9.5 @ 1.50 in**
IL-19 @ 2.25 in	**SMA-12.5 @ 2.00 in**
	When thin structure is required

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THANK YOU

Any Questions?

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