University of Pittsburgh
Swanson School of Engineering
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Material Compatible Repair Evaluation

2025 NESMEA Annual Meeting

October 29th, 2025

Increase the life of partial depth repairs

Pavements

Partial Depth

Dowel Retrofit

Bridge Decks

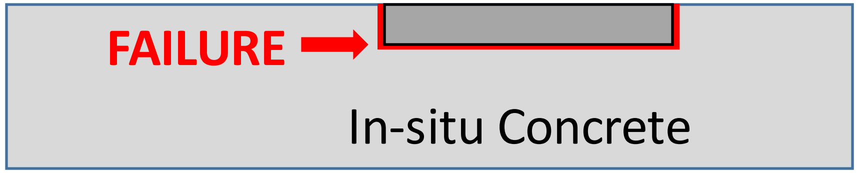
PennDOT
Type 1

Factors Contributing to Failures

- Unequal deformation under thermal loads
- Unequal deformation under traffic loads
- Excessive drying shrinkage
- Inadequate strength: Bond and compressive
- Poor construction: Insufficient consolidation or curing
- Poor durability

Factors Contributing to Failure

Conventional Repair



Elastic modulus: $E_{repair} \neq E_{existing}$

Thermal coefficient: $CTE_{repair} \neq CTE_{in\text{-}situ}$

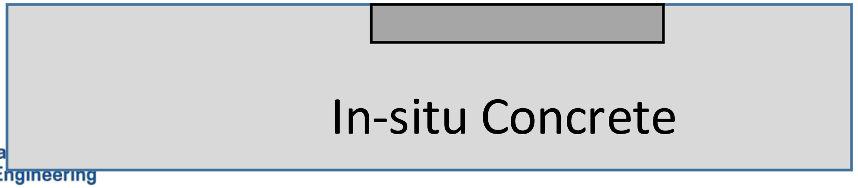
High drying shrinkage of repair patch

Mixture component	**Strength**	**Compatibility**		
		E	CTE	Shrinkage
Cement paste				
Coarse aggregate				
Internal curing agent				

GREEN: high impact
Yellow: low impact

Approach

Material Compatible Repairs (MCR)



Elastic modulus, $E_{repair} = E_{in\text{-}situ}$

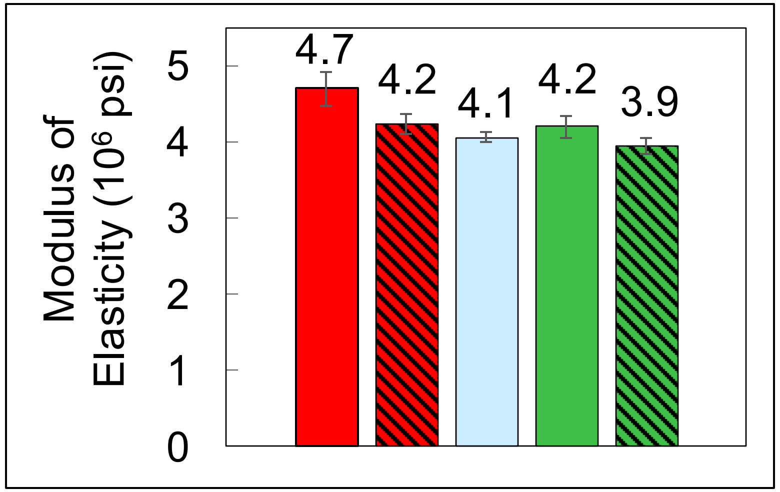
Thermal coefficient, $CTE_{repair} = CTE_{in\text{-}situ}$

Reduced drying shrinkage

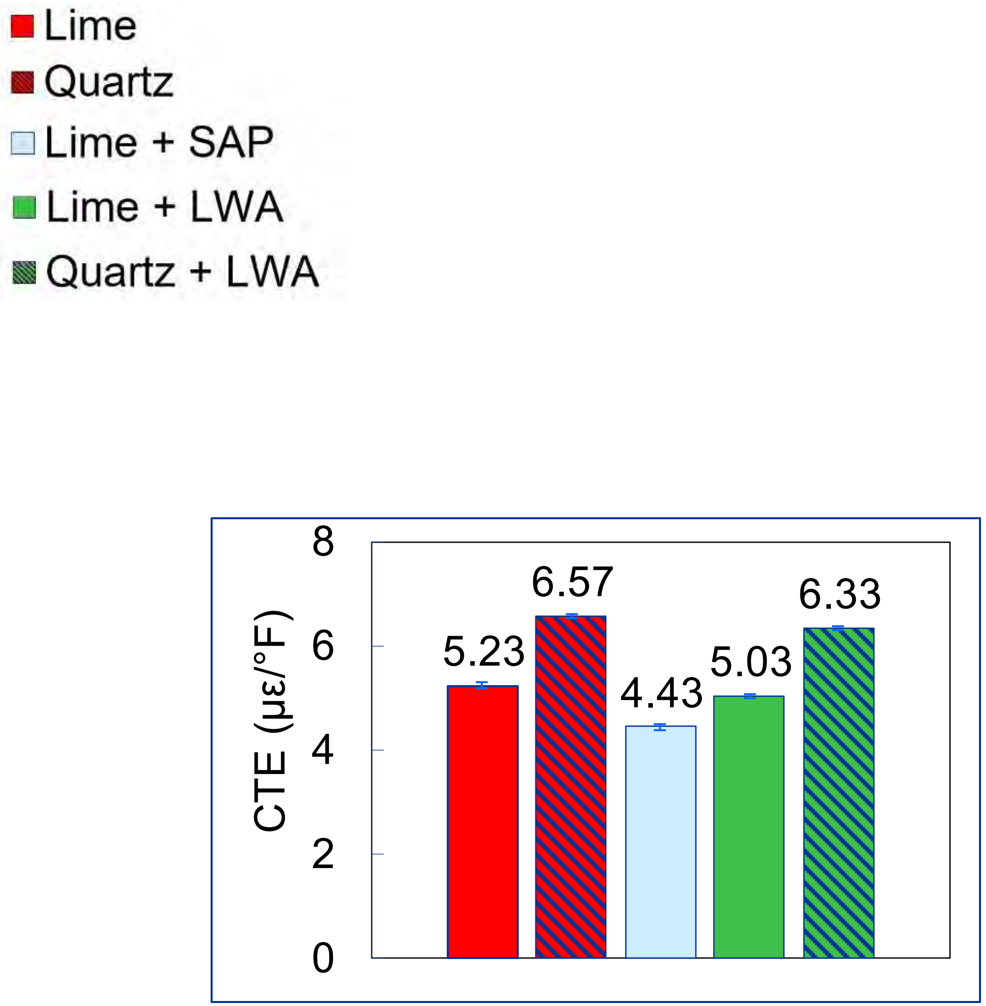
Laboratory Experimental Results

Mixture description	Coarse Agg.	Internal curing
L-NIC	Limestone	-
Q-NIC	Quartz	-
L-SAP	Limestone	SAP
L-LWA	Limestone	LWA
Q-LWA	Quartz	LWA

Modulus of Elasticity & CTE



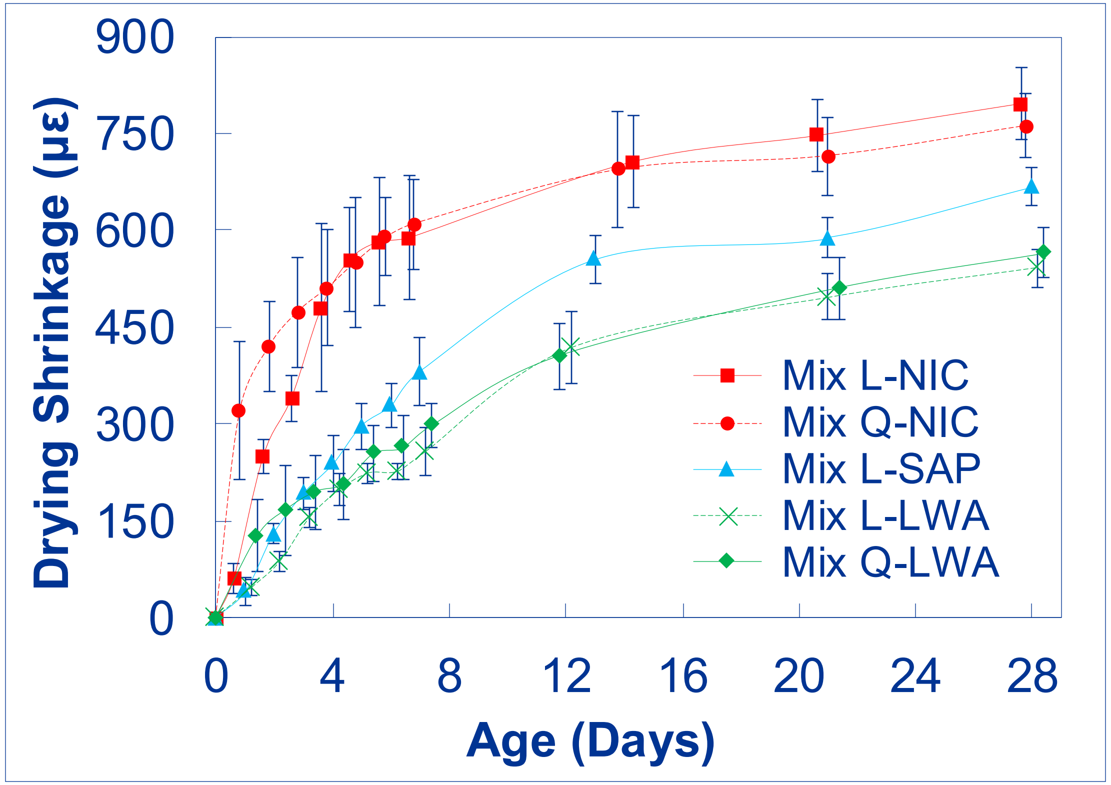
AASHTO T336



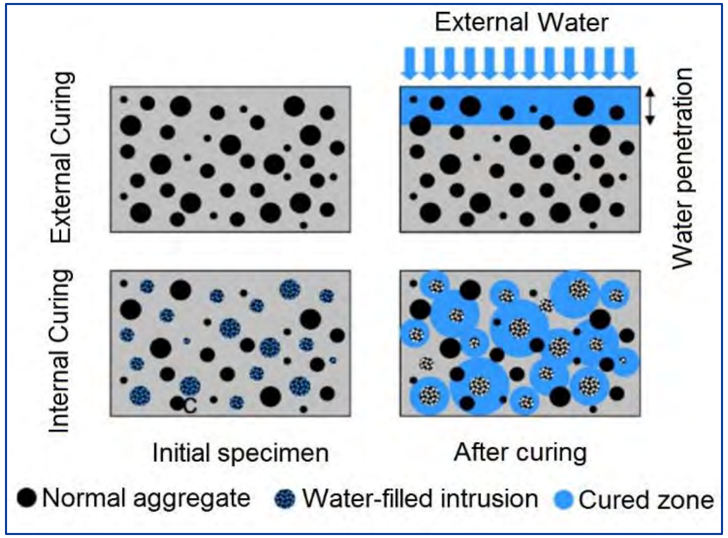
ASTM C469

Laboratory Experimental Results

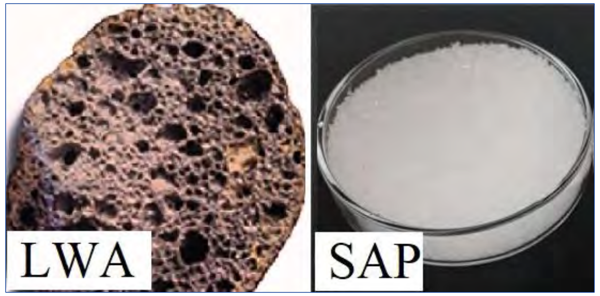
Drying Shrinkage



ASTM C596



Bentz, Dale P., and W. Jason Weiss. Internal curing: a 2010 state-of-the-art review



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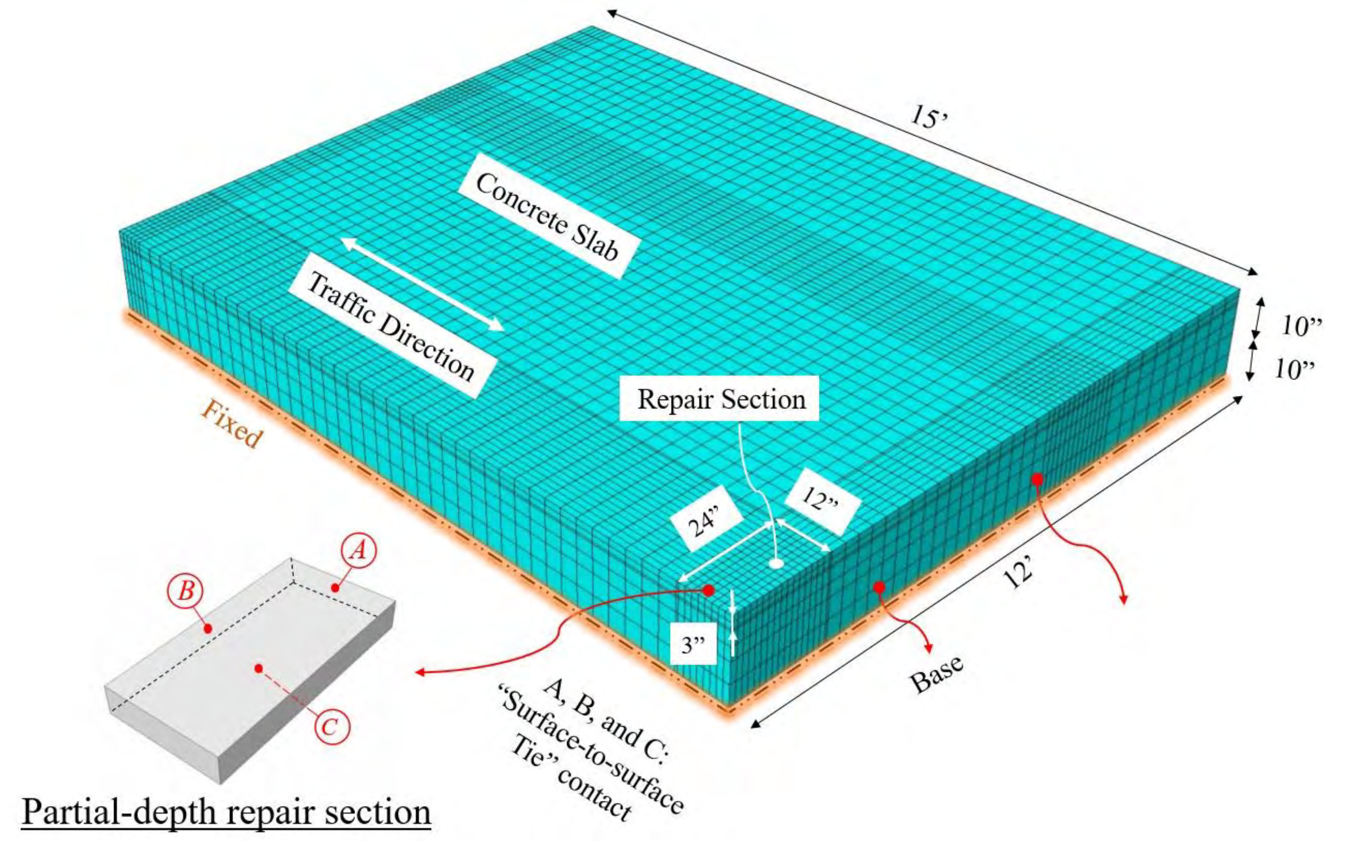
ABAQUS Model



Concrete slab/repair: 20-node thermally coupled brick elements.

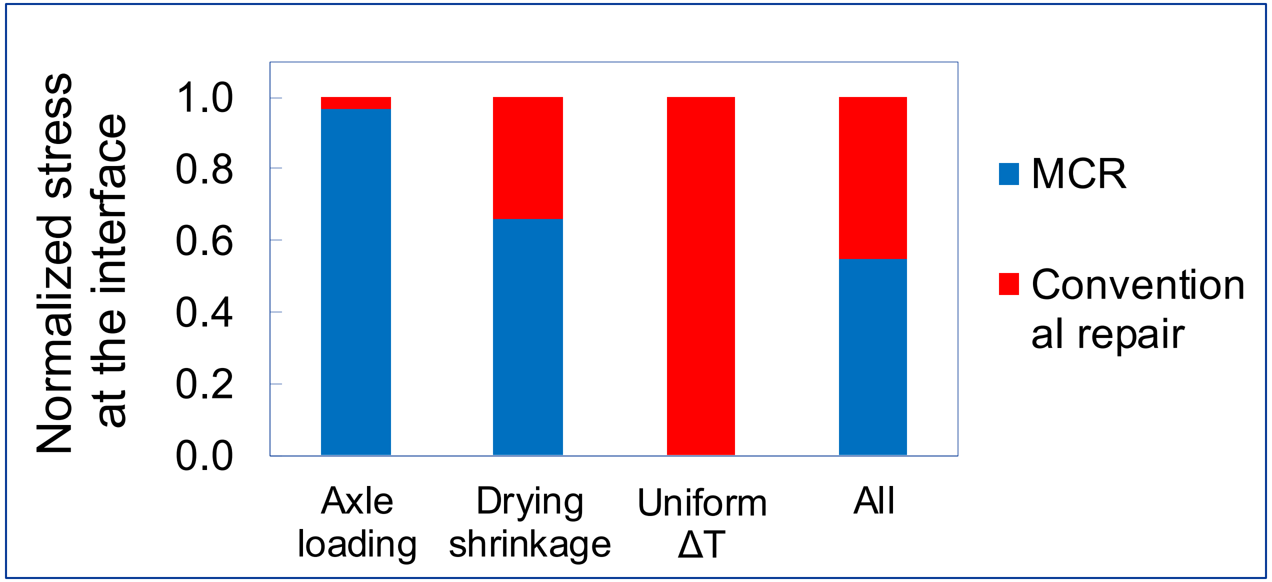
Base layer: 8-node thermally coupled brick elements

Friction factor between the granular base and the slab = 1.5

Material compatible repair (MCR)					Conventional repair				
E_1	E_2	CTE_1	CTE_2	ε	E_1	E_2	CTE_1	CTE_2	ε
4.7	4.7	5.2	5.2	540	4.7	4.2	5.2	6.6	790

Loading Cases and Stress Analysis

Load Description	Load	Material Compatible Repair			Incompatible Repair		
		E	CTE	Shrinkage	E	CTE	Shrinkage
Traffic load	18 kips single axle	Same	Same	-	Different	Different	-
Drying shrinkage	ΔT = ε / CTE			w/ IC			w/o IC
Temperature change	ΔT = -70 F			-			-
Combination of all	All			w/ IC			w/o IC



Developing a Performance Engineered Repair Material (PERM)

- Material incompatibility between repair and existing concretes lead to high stresses at the interface
- Coarse aggregate selection is key for stiffness and thermal compatibility
- Use historic construction data and cores to evaluate CTE (AASHTO T336), E (ASTM C469), and f'c (ASTM C39) of in-situ concrete
- Use appropriate materials and proportioning so:
  - CTE of the PERM and the in-situ concrete are comparable,
  - Drying shrinkage of the PERM is minimized
  - Strength and durability requirements are met

Performance Engineered Repair Material (PERM)

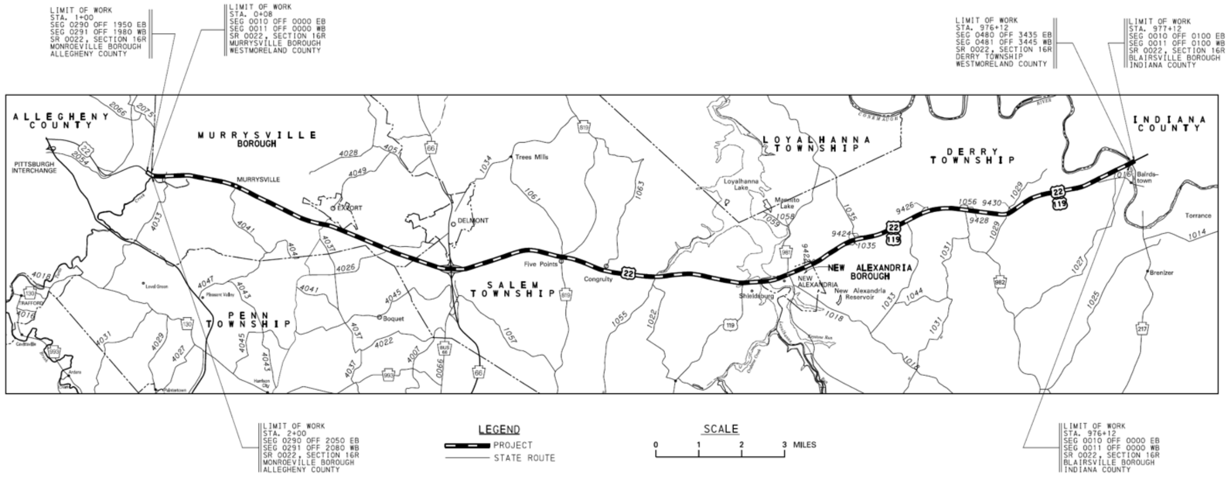
Mix Parameter	Property	Specified test(s)	Acceptance
Cement	-	-	ASTM C150
Aggregate properties	Coarse aggregate	-	ASTM C33
	Fine aggregate	-	ASTM C136 / ASTM C778
	Lightweight aggregate	-	ASTM C330
Mixture design specifications	w/c	-	Pub 408-Section 704
	Cement factor	-	Pub 408-Section 704
	Coarse aggregate content	-	Pub 408-Section 704
Fresh concrete	Slump	ASTM C143	ASTM C928
	Air content	ASTM C231/ASTM C173	ASTM C928
	Setting time	ASTM C191	ASTM C928
	Mixing room condition	-	ASTM C511
Hardened concrete	Compressive strength	ASTM C39	Pub 408-Section 704/ASTM C928
	Flexural strength	ASTM C78	-
	Rapid chloride permeability	AASHTO T277	-
Bond strength	Slant shear	ASTM C882	ASTM C928
	Splitting tensile	ASTM C496	-
Compatibility	Coefficient of thermal expansion	AASHTO T 336	Material compatible repairs
	Internal curing	ASTM C1761	Material compatible repairs
	Shrinkage	ASTM C596	Material compatible repairs

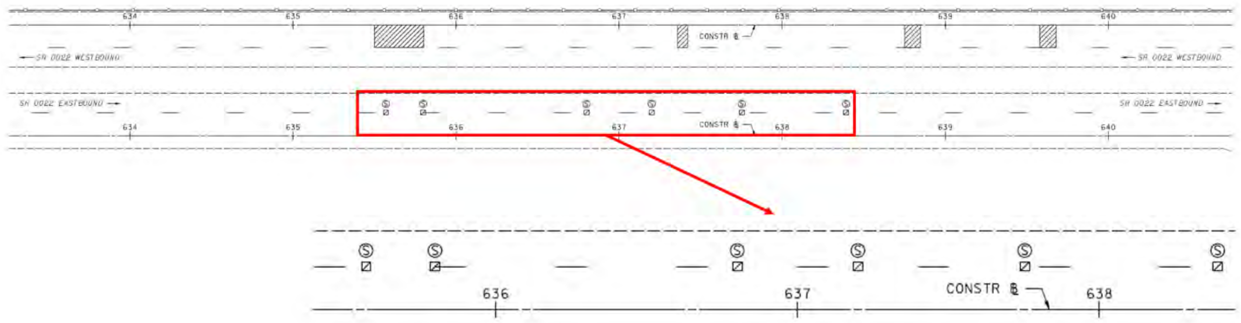
Implement Field Study of PERM Procedure

Follow on research project to assess recommendations of PERM procedure

PCC repair project on SR 22 Westmoreland County in District 12

Test section EB between SR 819 & Hannastown Rd (SR 1055) - 635+57 to 638+39





Project Evaluation

- 12-in thick w/ 14-ft travel lane; 20-ft skewed joints
- Six 4-in dia cores – test for f'c (ASTM C39), E (ASTM C469), and CTE (AASHTO T336)
- Coarse aggregate established to be limestone

Existing Roadway	Average	Standard Deviation
Compressive Strength (psi)	6220	132
Elastic Modulus (psi)	$5.28*10^6$	$2.84*10^5$
Coefficient of Thermal Expansion (10^{-6} in/in/°F)	5.1	0.1

Mixture Design

- Repair material met compressive strength requirements for class AA cement concrete repair materials specified by Pub 408
- #8 Greer limestone as coarse aggregate

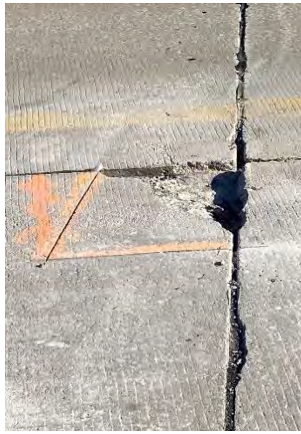
Proportion	Unit	Acceptable Range		Used value
w/c	by mass	Pub 408 specifications	< 0.42	0.32
Cement factor	lb/yd^3		588 - 800	750
C. Agg. / Concrete	ft^3/yd^3		9.93 - 13.1	10.0
C. Agg. / F. Agg.	by mass		-	1.24 - 1.42
Air Entraining Admixture	oz. / 100 lb cement	Product data sheet recommendation	0.1 - 6	5.5
Superplasticizer	oz. / 100 lb cement		2 - 12	9.0
				Targeted value
Slump	Inches	ASTM C928	≥ 3"	3″
Air Content	by volume	Pub 408	6%	6%

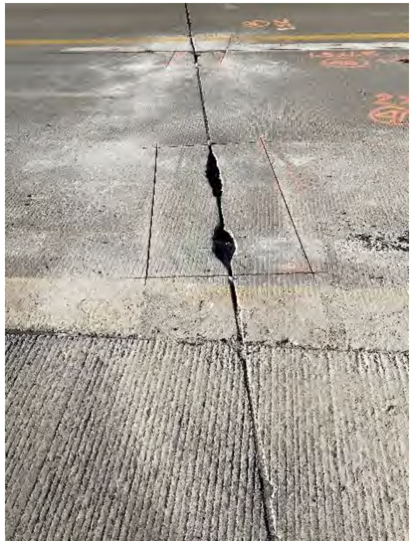
Partial Depth Repair Locations

Station	Approximate Size and Location
635 + 80	1-ft x 3-ft (center line passing)
636 + 43	1.5-ft x 2-ft (center line passing)
636 + 53	1-ft x 4.5-ft (center line passing)
636 + 63	1.5-ft x 2-ft (center line passing)
637 + 02	1-ft x 7-ft (center line passing)
637 + 42	0.75-ft x 2.25-ft (center line passing)
637 + 85	2-ft x 3-ft (center line both lanes)
638 + 02	2-ft x 4-ft (passing lane left wheelpath)
638 + 02	1.5-ft x 1.5-ft (center line passing)








Section Construction

- PERM repair material placed using same labor and construction practices as traditional repair used by contractor (Commercial Grade QUIKRETE FastSet mix) 5/22
- Wax based curing compound used for all locations
- Companion specimens cast and kept in field conditions to measure CTE (AASHTO T336), elastic modulus (ASTM C469), compressive strength (ASTM C39), and drying shrinkage (ASTM C157)

Existing Roadway	Existing Road	PERM
f'c (psi)	6220	5910
E (10^6 psi)	5.28	4.95
CTE (10^{-6} in/in/°F)	5.1	5.2

Project Monitoring

- Perform visual distress survey each year since partial depth repairs placed
- 3 years since construction and both MCR and conventional repair material holding up well with no visible distress
- Conduct nondestructive ultrasonic tomography testing at final year of study to monitor repair condition

Cost / Benefit

- MCR repair method estimated to increase repair costs by 7%
- Analysis based on current PennDOT costs over 15 year cycle of repairs
  - Avg service life of 2-3 years of existing repair method vs 15 yrs with MCR repair method
- Estimated $7.7 million in potential savings over 15 year cycle

Pavement Repair Research Results Benefit Analysis Summary					
Repair Method and PennDOT Costs per Year	Total Repairs Cost	Adjustment for Increased Repair Costs (7%)	Average 2-Year Life Cycle Annual Replacements Costs – Current Method	Average 15-Year Annual Life Cycle Replacement Costs – New Method	Potential Savings Over 15-Year Cycle of Repairs
Partial Depth Repairs (Material Comptable Repairs)					
2018	$1,049,049.65	$1,122,483.13	$600,339	$85,648	$7,720,360
2019	$3,045,572.50	$3,258,762.58			
2020	$383,670.00	$410,526.90			
2021	$324,420.00	$347,129.40			

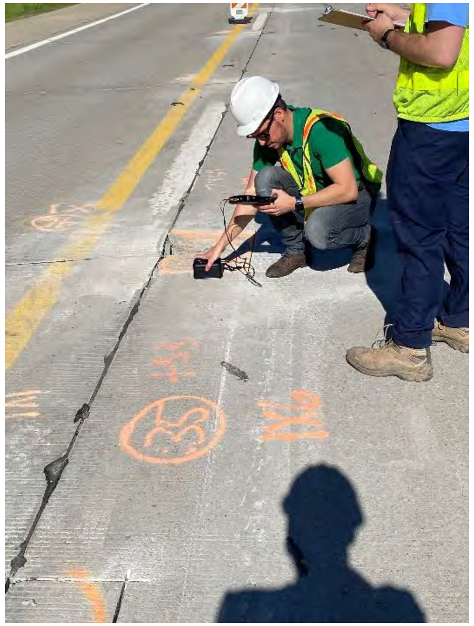
Conclusions

- Material incompatibility between repair and existing concretes lead to high stresses at the interface

- Coarse aggregate selection is key for stiffness and thermal compatibility

- IC agents show promise in reduce of drying shrinkage in repair materials

- Use of a MCR shown through modeling to significantly decrease interface stresses



Acknowledgements

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Thank you!

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