Effects of Concrete Cure Time on Epoxy Overlay and Sealant Performance

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MDOT Michigan Department of Transportation
Center for Technology & Training

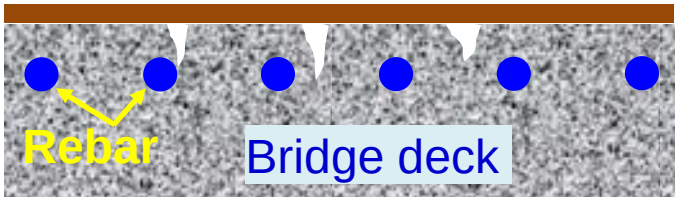
OUTLINE

- Introduction
- Objectives
- Minimum concrete age to receive a thin epoxy overlay
- Experimental program
- Performance evaluation over deck repairs
- Conclusions and recommendations

INTRODUCTION

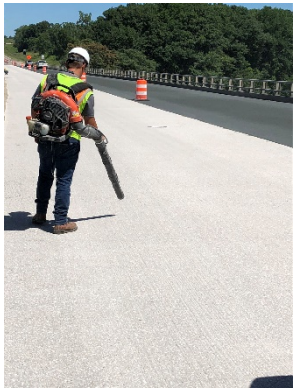
- Flood coatings are used to protect bridge decks.

Epoxy overlay



Healer sealer

Shotblasting



Cleaning

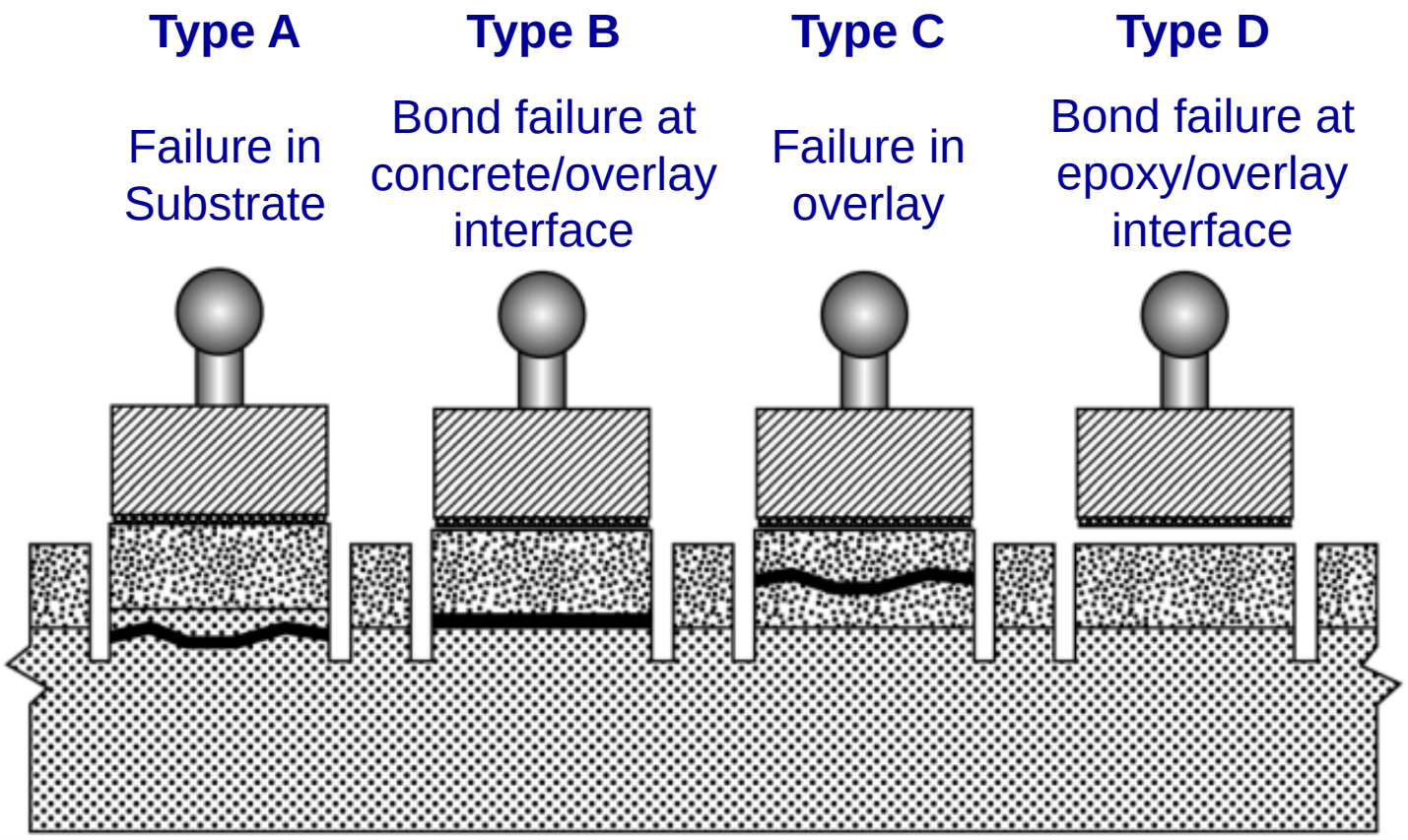
Near-surface moisture assessment

Flood coat application

Aggregate broadcasting

INTRODUCTION

Tensile bond pull-off strength test failure modes (ASTM C1583)



- Bond strength > 250 psi with Type D failure was considered for further analysis.

INTRODUCTION

- The current specifications and special provision (12SP-710B-03[1]) *do not permit the application of flood coating on new concrete in partial- or full-depth deck repairs and/or joint repairs before completing the 28-day curing period*.

- Waiting for a longer period to apply flood coating increases project completion time, and cost of construction and mobility.

- Due to conflicts with traffic and weather limitations, there is an interest to evaluate the possibility of reducing the 28-day waiting period for flood coat application.

1. MDOT (2018). *"Special Provision for Penetrating Healer Sealer on Bridge Decks: 12SP-710B-03,"* Michigan Department of Transportation (MDOT), 425 W. Ottawa St., Lansing, MI 48909, USA.

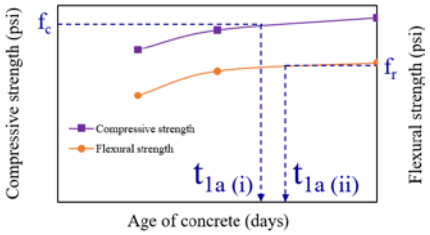
OBJECTIVE

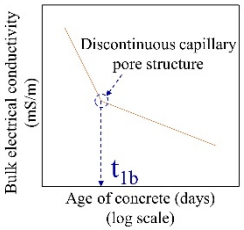
To determine if a procedure or a set time is better for deciding when to place **an overlay** or a sealer on MDOT standard materials and special/patching material.

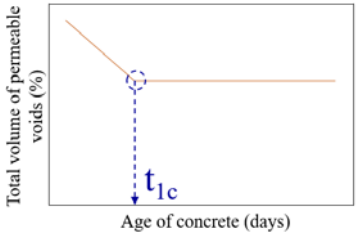
MIN. CONCRETE AGE TO RECEIVE AN EPOXY OVERLAY

t = Max

t_1

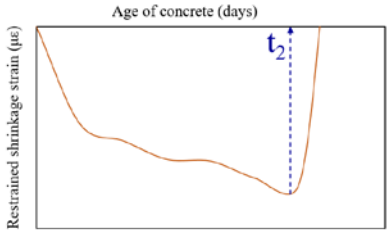




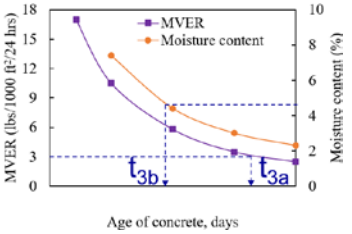


t_1 = max (t_{1a}, t_{1b}, and t_{1c})

t_2



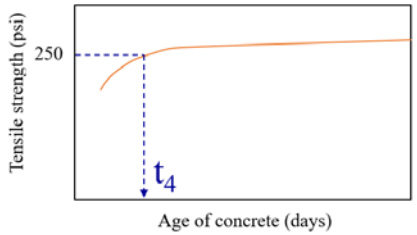
t_3



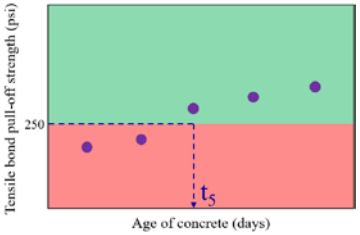
Concrete Mixes: Grade DM and BDJR

Epoxy overlay	Viscosity (cps)	Label
526 Lo-Mod	1500-3000	E1
Pro-Poxy Type III DOT	1500	E2

t_4



t_5



Applied at 14, 21, and 28-day old concrete, exposed to elements, and evaluated bond strength under different exposure conditions.

EXPERIMENTAL PROGRAM

Mix Design

Material	Quantity (per yd^3)	
	Grade DM	BDJR
Coarse aggregate (lbs)	1,644	1,488
Fine aggregate (lbs)	1,356	1,557
Cement – Type I (lbs)	397	656
Ground granulated blast furnace slag (lbs)[1]	214	
Water added (lbs)	186	182
Air entraining admixture (fl oz)	10.78	5.07
Hydration controlling admixture (fl oz)	18.56	
Water reducing admixture (fl oz)	54.44	58.67
Total water in the mix (lbs)	238	246
w/cm ratio	0.39	0.38

[1] 35% Slag is used (12SP-706C-03)

EXPERIMENTAL PROGRAM

Evaluation parameter (a)	Measurand (b)	ASTM standard (c)	Size of the specimen (in.) (d)	Concrete age at the time of overlay application (e)	Curing and exposure condition (f)[c]	Concrete age at the time of testing (days) (g)
Concrete wet curing duration (t_1)	Compressive strength	C39	4 × 8	NA	ASTM	7, 14, 21, and 28
	Flexural strength[a]	C78	6 × 6 × 20 4 × 4 × 14	NA	ASTM	7, 14, 21, and 28
	Bulk electrical conductivity[b]	C1760	4 × 8	NA	ASTM	1, 3, 7, 14, 21, and 28
	Porosity	C642	4 × 2	NA	ASTM	3, 7, 14, 21, and 28
Concrete age at the time of cracking (t_2)	Restrained shrinkage	C1581	As per the ASTM	NA	RT	Until cracking
Concrete age to achieve acceptable substrate moisture (t_3)	Moisture vapor emission rate (MVER)	F1869	40 × 40 × 9	NA	RT	14, 21, and 28
	Moisture content	F2659	40 × 40 × 9	NA	RT	7, 14, 21, and 28
Concrete age to develop the specified minimum tensile strength (t_4)	Flexural strength[a]	C78	6 × 6 × 20	NA	ASTM	7, 14, 21, and 28
Concrete age at the time of epoxy application to develop the specified bond strength (t_5)	Tensile bond pull-off strength	C1583	40 × 40 × 9	14	RT–RT	17, 21, 28, 42, 105, and outdoor[d]
					RT–HS[e]	17, 21, 28, 42, 105, and outdoor
					RT–WD[f]	17, 28, 42, 105, and outdoor
			40 × 40 × 9	21	RT–RT	24, 28, 35, 49, 112, and outdoor
					RT–HS	24, 28, 35, 49, 112, and outdoor
					RT–WD	24, 35, 49, 112, and outdoor
			40 × 40 × 9	28	RT–RT	31, 35, 42, 56, 119, and outdoor
					RT–HS	31, 35, 42, 56, 119, and outdoor
					RT–WD	31, 42, 56, 119, and outdoor

Note: ASTM = American Society for Testing and Materials; NA = not applicable

[a]Beam specimens of 6 × 6 × 20 in. and 4 × 4 × 14 in. were used for BDJR and Grade DM, respectively.

[b]One-day data was recorded only for the BDJR concrete mix.

[c]ASTM, RT, HS, and WD represent curing conditions. ASTM – continuous submerged wet curing until testing, RT – room temperature, HS – elevated temperature, and WD – one-week alternate wet and dry cycles. RT, HS, and WD in RT–** represent the overlay exposure conditions before or during testing.

[d]The overlay performance under outdoor conditions was evaluated at specific concrete ages as described later in the report.

[e]The performance under winter conditions was evaluated in February 2020 on BDJR and Grade DM slabs at 337 and 385 days of concrete age, respectively.

[f]Grade DM slabs with 14, 21, and 28-day application ages and BDJR slabs with 28-day application age were used.

EXPERIMENTAL PROGRAM









MDOT staff
Sealant/overlay manufacturer representative
TCG technical staff
14 student employees
On-site training for student employees.

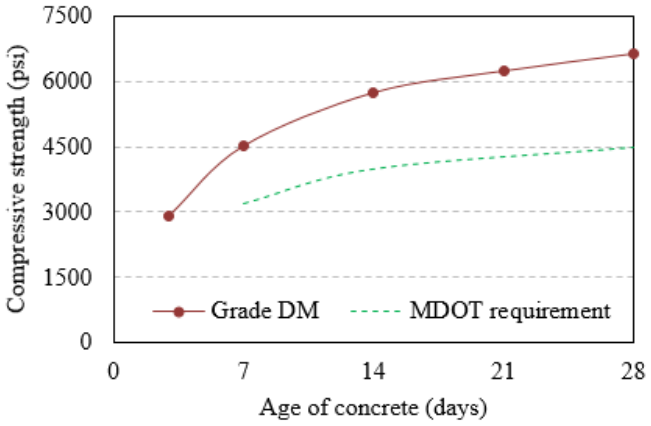
56 – 40 x 40 x 9 in. slabs **36 – 6 x 6 x 20 in. beams**

CONCRETE WET CURING DURATION

Grade DM

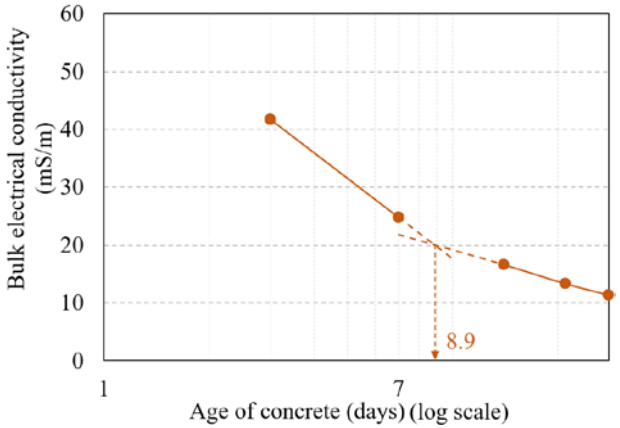
Strength requirement

t_{1a} = 7 days



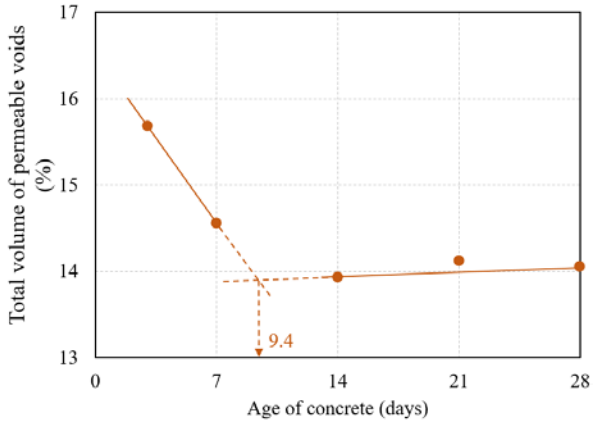
Discontinuous capillary pore structure

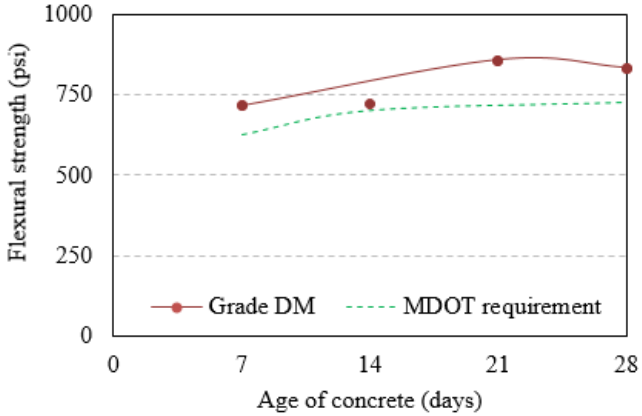
t_{1b} = 9 days



Porosity

t_{1c} = 10 days





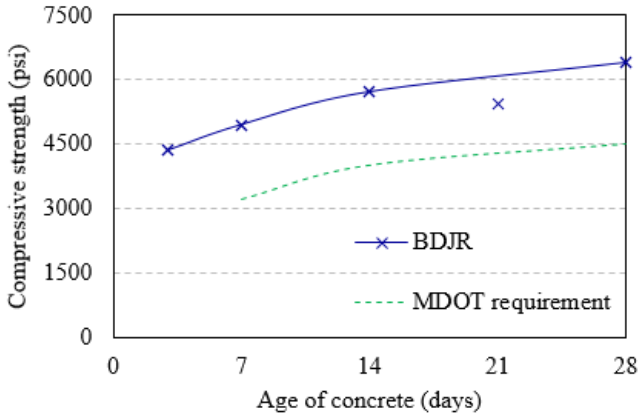
t_1 = max (t_{1a}, t_{1b}, and t_{1c}) = max (7, 9, and 10) = **10 days**

CONCRETE WET CURING DURATION

- **BDJR**

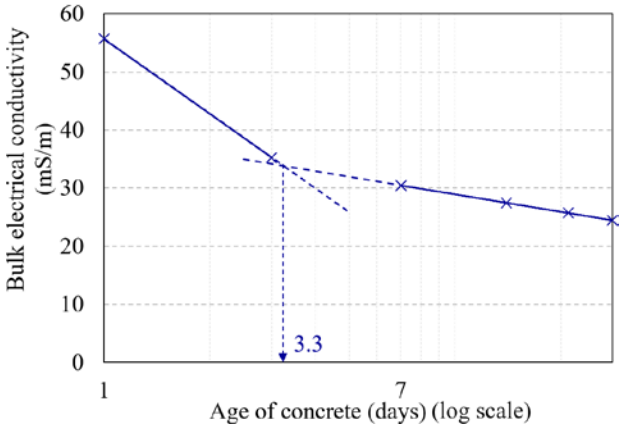
Strength requirement

t_{1a} = 7 days



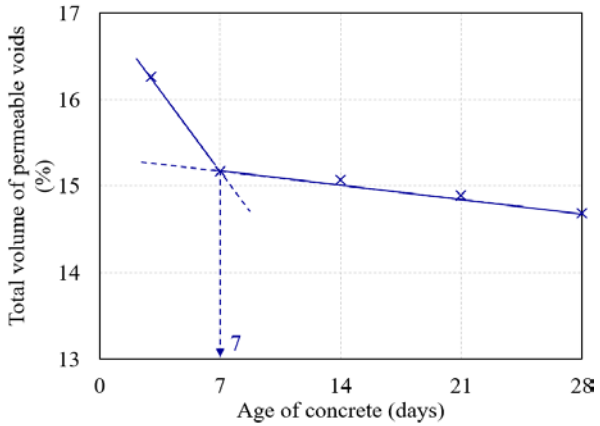
Discontinuous capillary pore structure

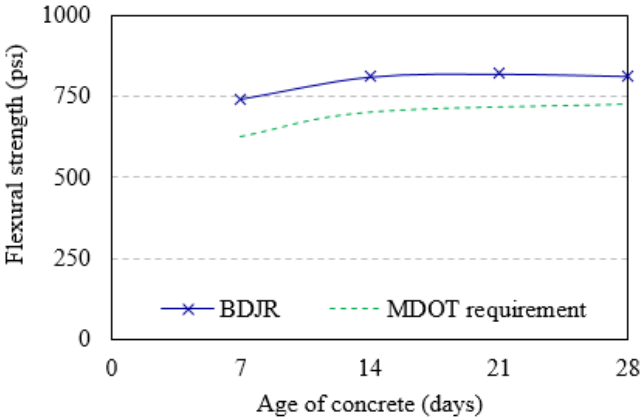
t_{1b} = 4 days



Porosity

t_{1c} = 7 days





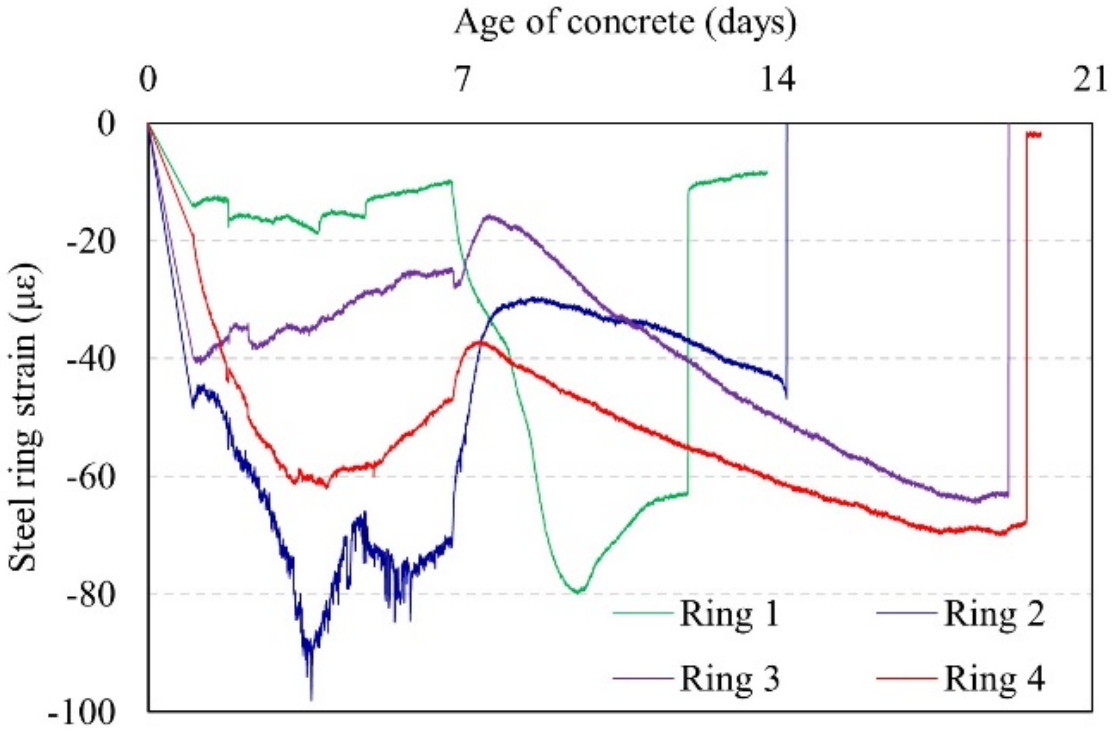
t_1 = max (t_{1a}, t_{1b}, and t_{1c}) = max (7, 4, and 7) = **7 days**

CONCRETE AGE AT THE TIME OF CRACKING

- **Grade DM**

Restrained shrinkage crack ring test setup

Cracked concrete ring



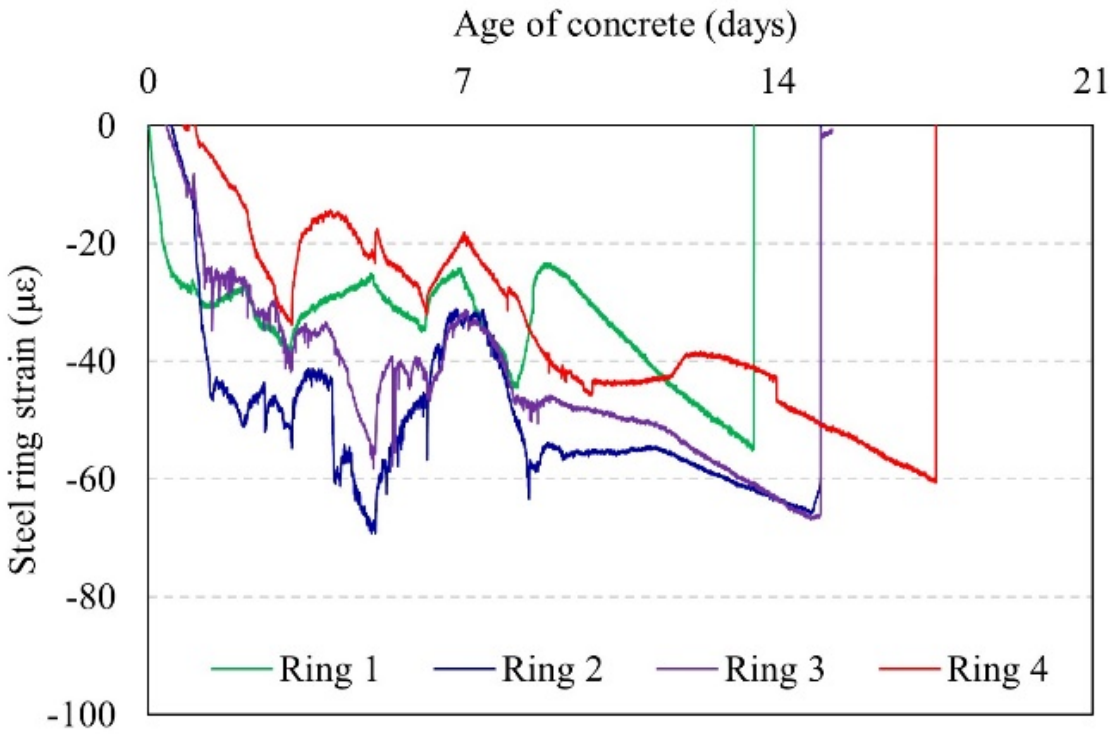
t_2 = max (13, 15, and 20) = **20 days**

CONCRETE AGE AT THE TIME OF CRACKING

- **BDJR**

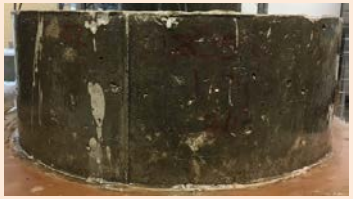
Restrained shrinkage crack ring test setup

Cracked concrete ring



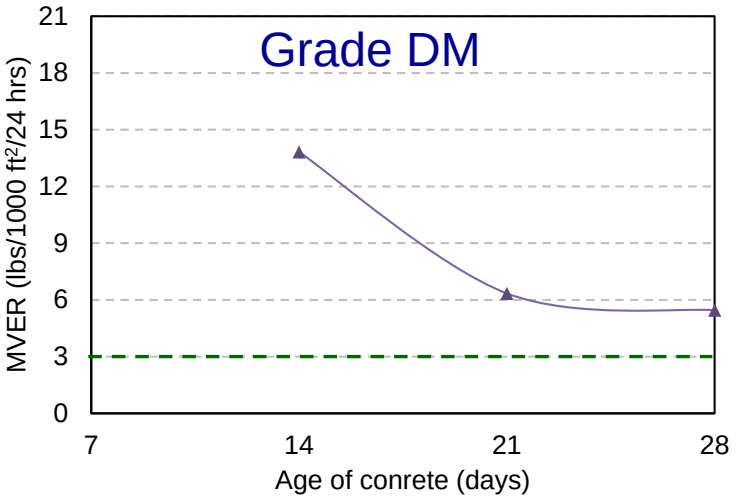
t_2 = max (14, 15, and 18) = **18 days**

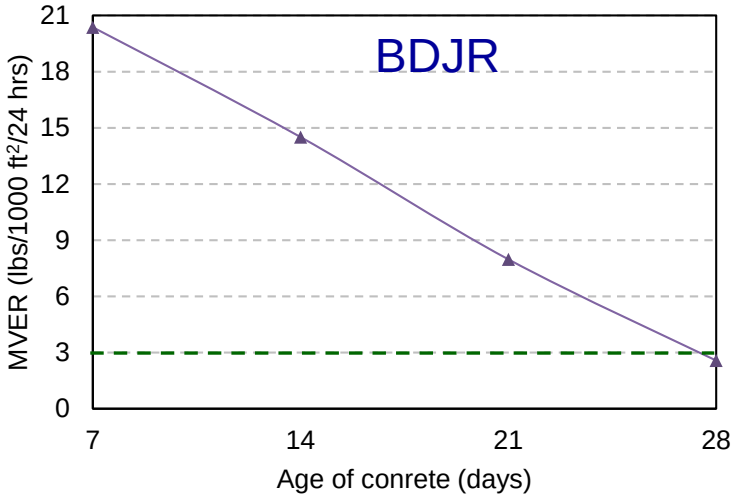
CONCRETE AGE AT THE TIME OF CRACKING

Grade DM		BDJR	
Untreated rings			
			
13 ~ **20 days** (4 specimens)		14 ~ **18 days** (4 specimens)	
Treated rings			
E-bond	**Unitex**	**E-bond**	**Unitex**
			
(68 ~ 73 days) (3 specimens)	(68 ~ 74 days) (3 specimens)	(57 ~ 60 days) (2 specimens)	(48 ~ 61 days) (2 specimens)

CONCRETE AGE TO ACHIEVE AN ACCEPTABLE SUBSTRATE MOISTURE

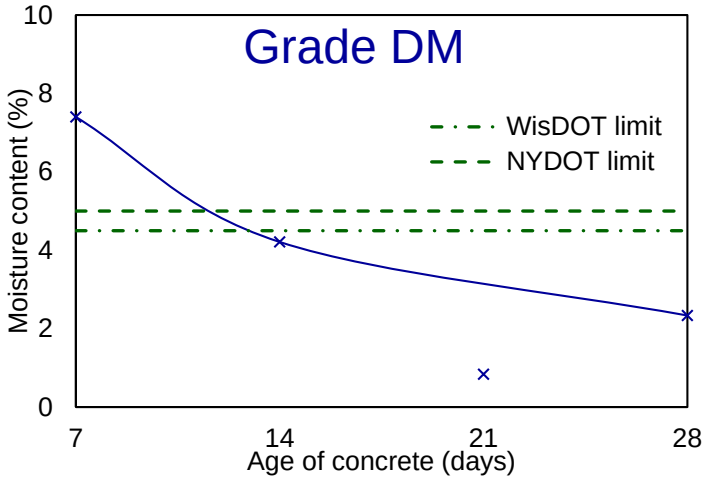
MVER (< 3 lbs/1000 ft^2/24 hrs) and Moisture content (< 4.5 ~ 5%)
(under standard laboratory conditions)

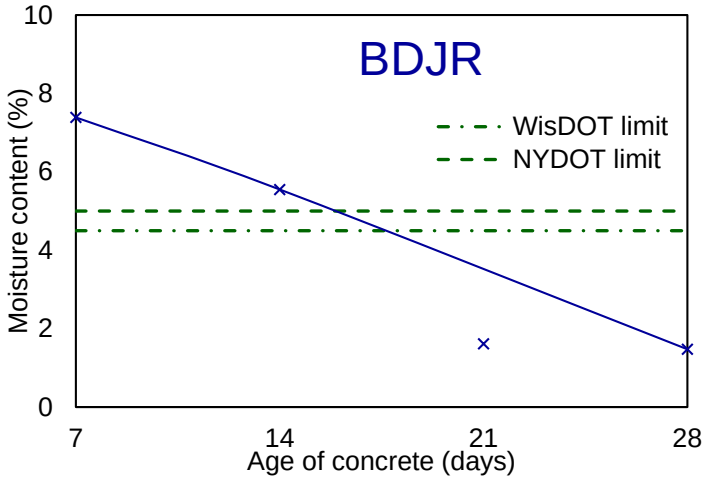




Electrical impedance meter

PCE-WP21



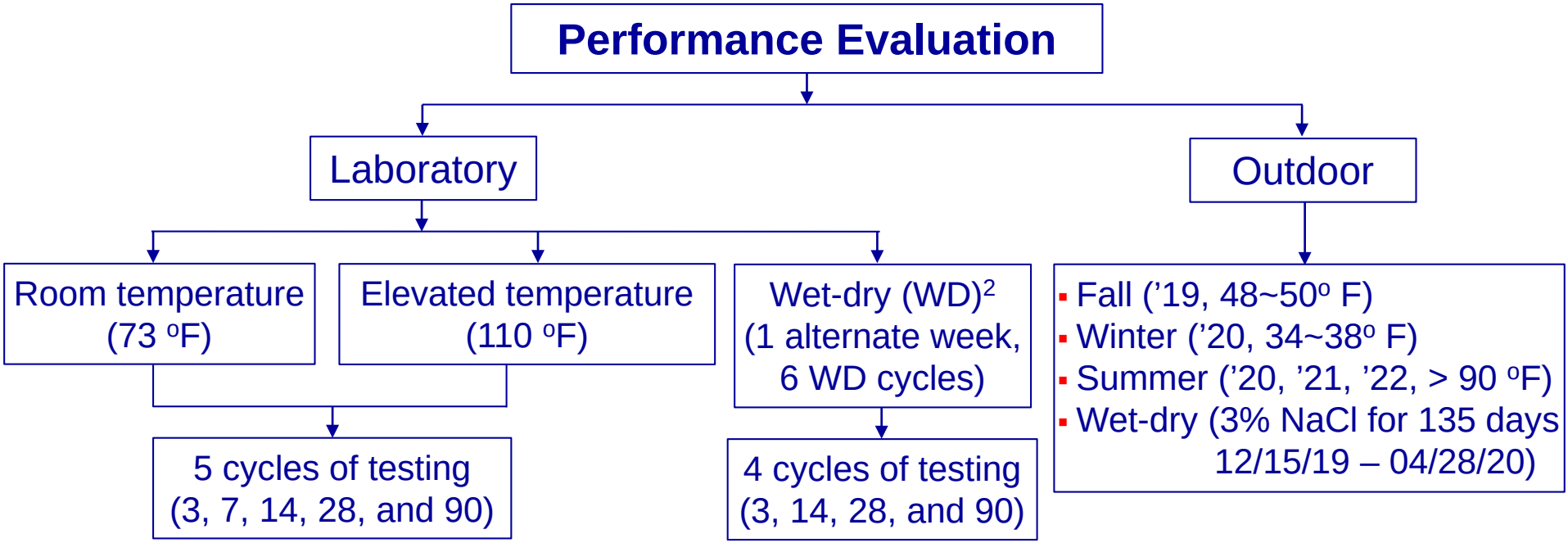


t_{3a} > 28 days, t_{3b} ≅ 14 days

t_{3a} ≅ 28 days, t_{3b} ≅ 17 days

EPOXY OVERLAY PERFORMANCE

The minimum required bond strength[1] ≥ 250 psi



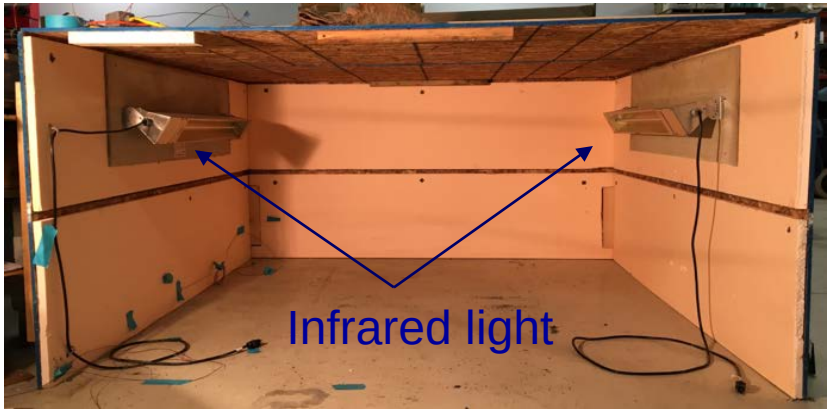
- Epoxy overlays were applied at 14, 21, and 28 days of concrete age.
- Wet-dry (WD) specimens were used at 14, 21, and 28-day application ages for Grade DM and only at 28-day application age for BDJR.

[1] Special Provision 12SP-712C-03

[2]The wet-dry specimens were exposed to 3% NaCl solution under room temperature. One-week wet and one-week dry cycles were performed for 12 weeks.

EPOXY OVERLAY PERFORMANCE

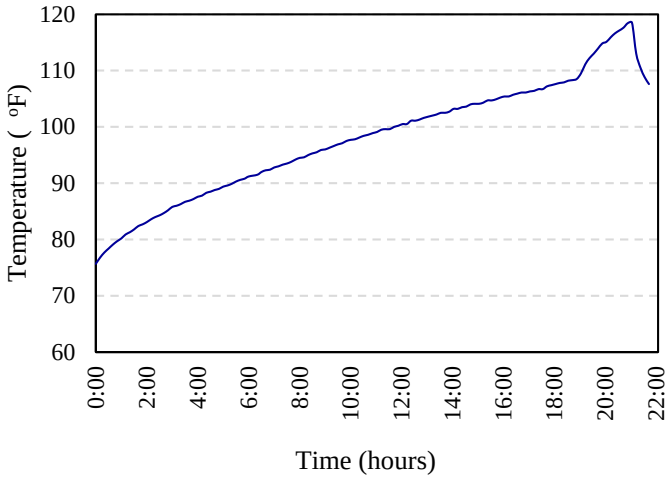
Elevated temperature exposure setup in the laboratory



Insulated chamber with infrared heaters

Temperature controller

Temperature recorder



Temperature profile

EPOXY OVERLAY PERFORMANCE

Outdoor exposure

Summer

Winter

Continuous exposure to 3% NaCl
for 135 days
(12/15/2019 to 04/28/2020)

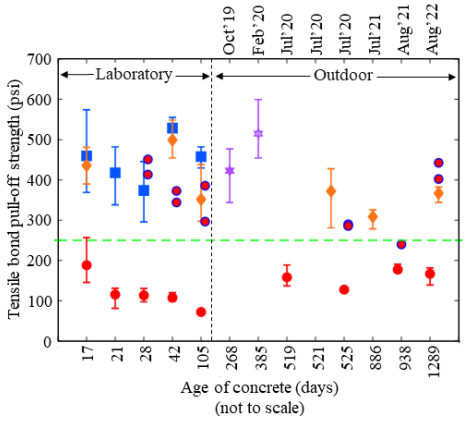
EPOXY OVERLAY PERFORMANCE

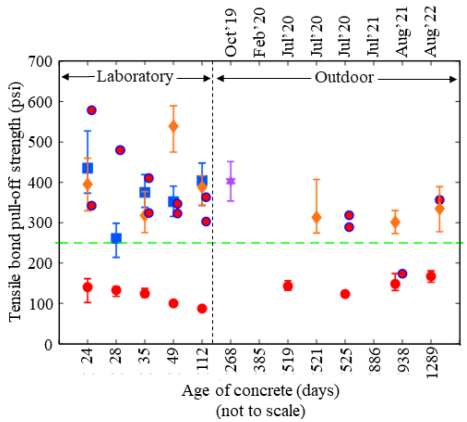
- Outdoor testing was performed on all slabs in October 2019 (ambient temp. 48~50^0 F), 14-day slabs in February 2020 (ambient temp. 34~38^0 F), and all slabs in summer 2020, ’21, and ’22 (ambient temp. > 90^0 F).
- 14-day slabs had the lowest strength and the highest moisture.

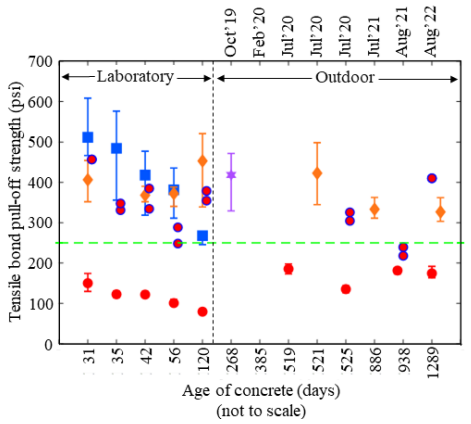
14-day | **21-day** | **28-day**

Grade DM concrete

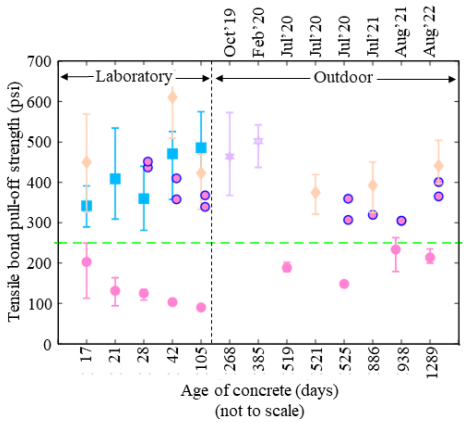
E1

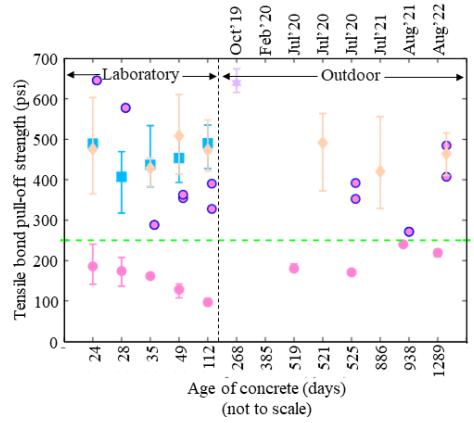


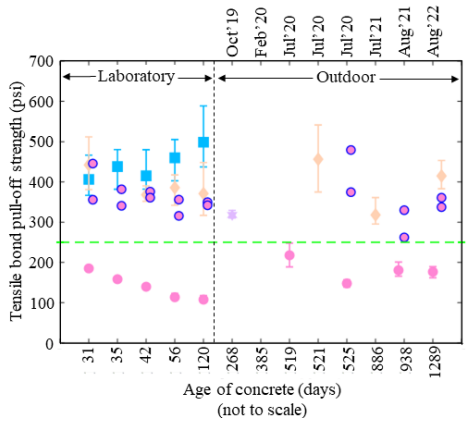




E2







E1 – RT | E1 – HS/Summer (Hot) | E1 – HS/Summer (cool) | E1 – WD | E1 – Fall | E1 – Winter

E2 – RT | E2 – HS/Summer (Hot) | E2 – HS/Summer (cool) | E2 – WD | E2 – Fall | E2 – Winter

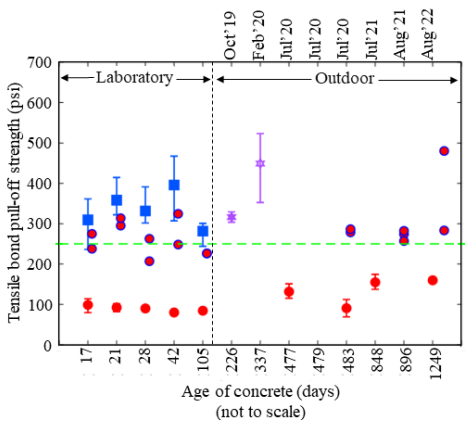
EPOXY OVERLAY PERFORMANCE

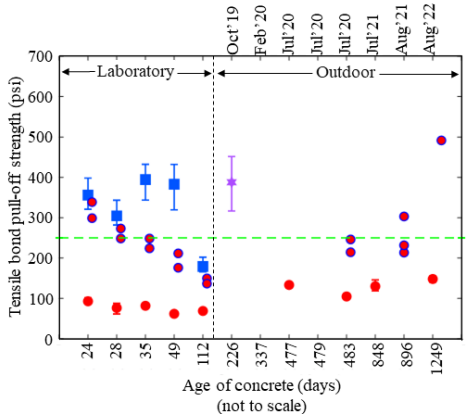
- Outdoor testing was performed on all slabs in October 2019 (ambient temp. 48~50^0 F), 14-day slabs in February 2020 (ambient temp. 34~38^0 F), and all slabs in summer 2020, ’21, and ’22 (ambient temp. > 90^0 F).
- 14-day slabs had the lowest strength and the highest moisture.

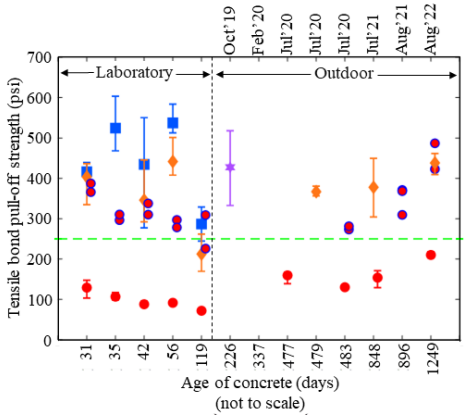
BDJR concrete

14-day | **21-day** | **28-day**

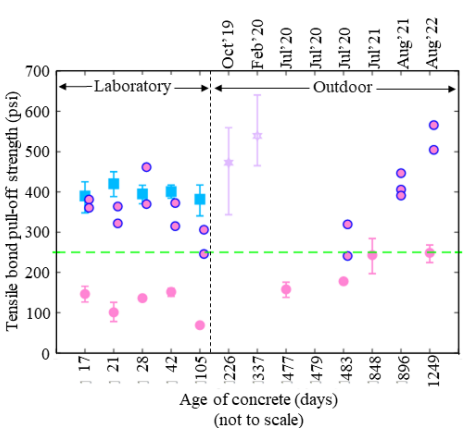
E1

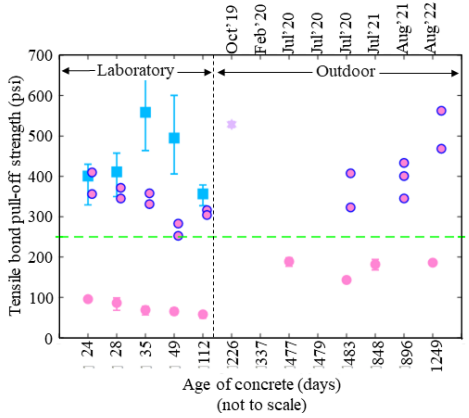


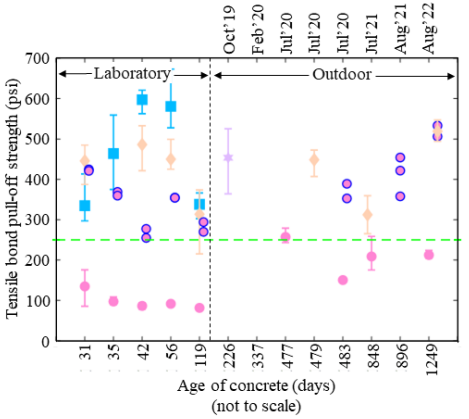




E2



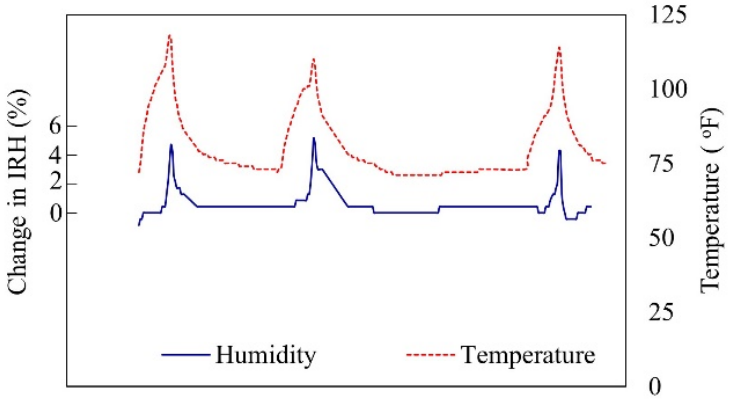




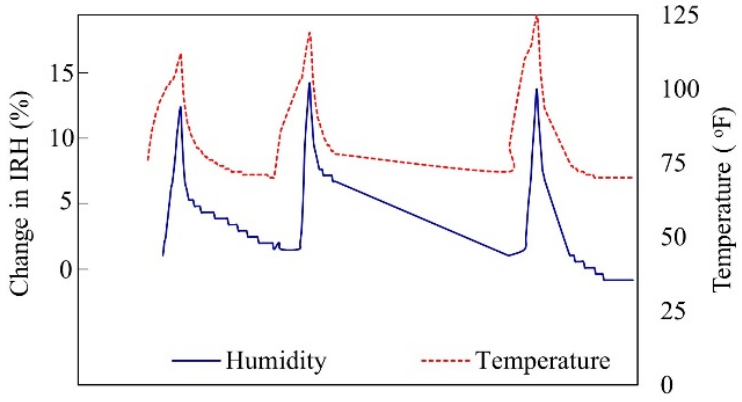
E1 – RT
E2 – RT
E1 – HS/Summer (Hot)
E2 – HS/Summer (Hot)
E1 – HS/Summer (cool)
E2 – HS/Summer (cool)
E1 – WD
E2 – WD
E1 – Fall
E2 – Fall
E1 – Winter
E2 – Winter

EPOXY OVERLAY PERFORMANCE

Elevated temperature and moisture profile at 1.0 in. (laboratory)

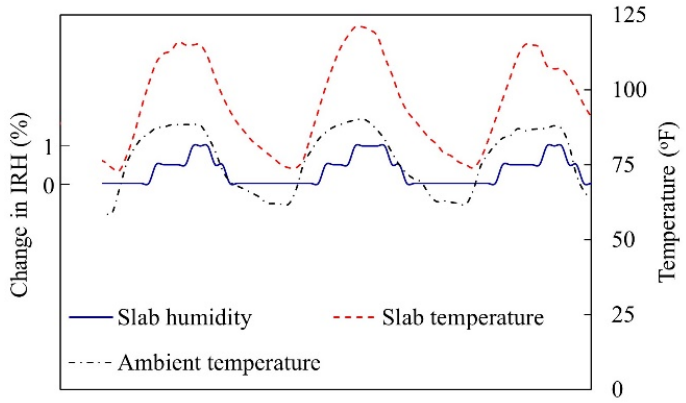


Grade DM

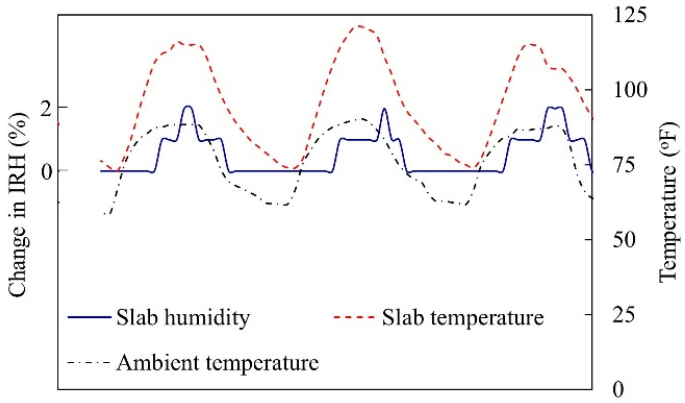


BDJR

Temperature and moisture profile at 1.0 in. (outdoor)



Grade DM



BDJR

- Several manufacturers and DOTs limit substrate temperature to 90, 95, or 100^0 F for overlay application.
- Grade DM and BDJR slabs shows an increase in RH when the concrete temperature is about 100 ^{0}F.

CONCRETE DURABILITY

- All wet-dry (WD) slabs fabricated with Grade DM concrete mix and used for bond strength were exposed to 3% NaCl solution for 42 days in laboratory and 135 days in outdoor.
- On the 544th day, two 2.13 × 2 in. deep cores were extracted from each WD slabs and chloride content was evaluated following ASTM C1152.

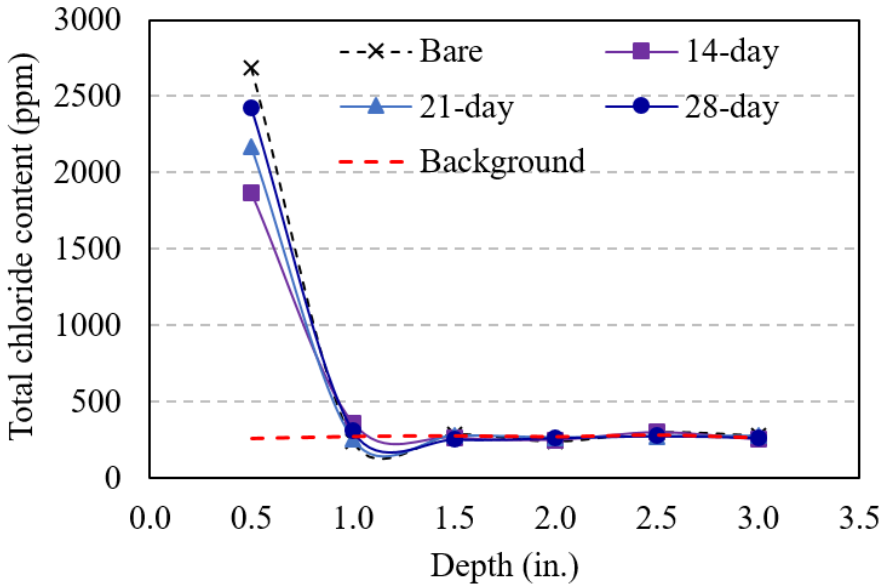
Total Chloride Content Along the Depth of Wet-dry (WD) Slabs at 544-day

Depth (in.)	Total chloride content (ppm)						
	Background	14-day		21-day		28-day	
		E1	E2	E1	E2	E1	E2
0.5	262	270	244	242	245	277	264
1.0	271	261	228	260	139	235	238
1.5	275	274	232	236	247	259	240

- Overlays have prevented chloride ingress

CONCRETE DURABILITY

- On the 406th day, cores were extracted from bare and epoxy coated slabs, fabricated with Grade DM concrete mix, of all application ages and top 0.5 in. was discarded.
- Porosity test was performed.
- Few cores were ponded with 3% NaCl solution for 137 days and the chloride content was evaluated on the 544th day following ASTM C1152.



Total chloride content along the depth at 544th day

Total volume of permeable voids of the slabs at 406-day

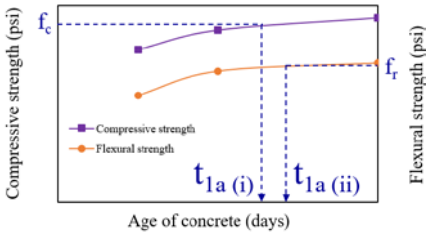
Specimen	Total volume of permeable voids (%)
Bare	14.83
14-day	14.31
21-day	14.68
28-day	14.85

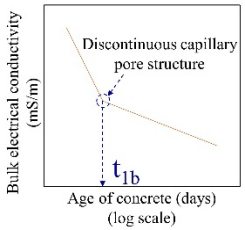
- Overlay application on young concrete did not impact concrete durability performance.

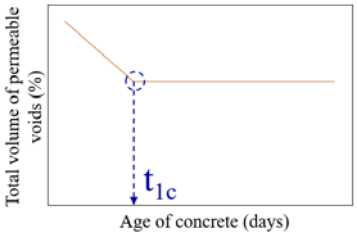
CONCRETE AGE TO RECEIVE AN EPOXY OVERLAY

t = Max

t_1

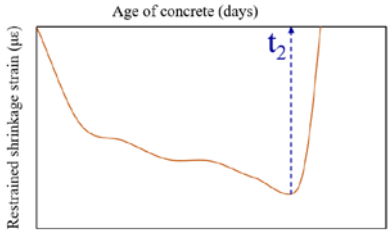




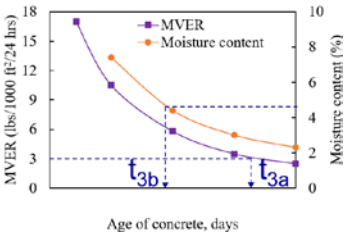


t_1 = max (t_{1a}, t_{1b}, and t_{1c})

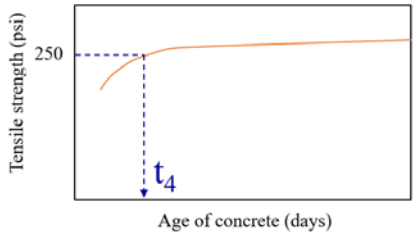
t_2



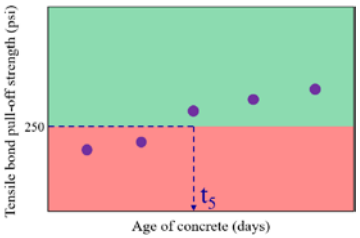
t_3



t_4



t_5



Grade DM	BDJR
$t_1 = 9$	$t_1 = 7$
$t_2 = 20$	**$t_2 = 18$**
$t_{3a} > 28$ $t_{3b} \cong 14$	$t_{3a} \cong 28$ $t_{3b} \cong 17$
$t_4 < 7$	$t_4 < 7$
$t_5 = 14$	$t_5 = 14$

IMPACT OF PENETRATING SEALANTS ON OVERLAY PERFORMANCE

IMPACT OF PENETRATING SEALANTS ON OVERLAY PERFORMANCE

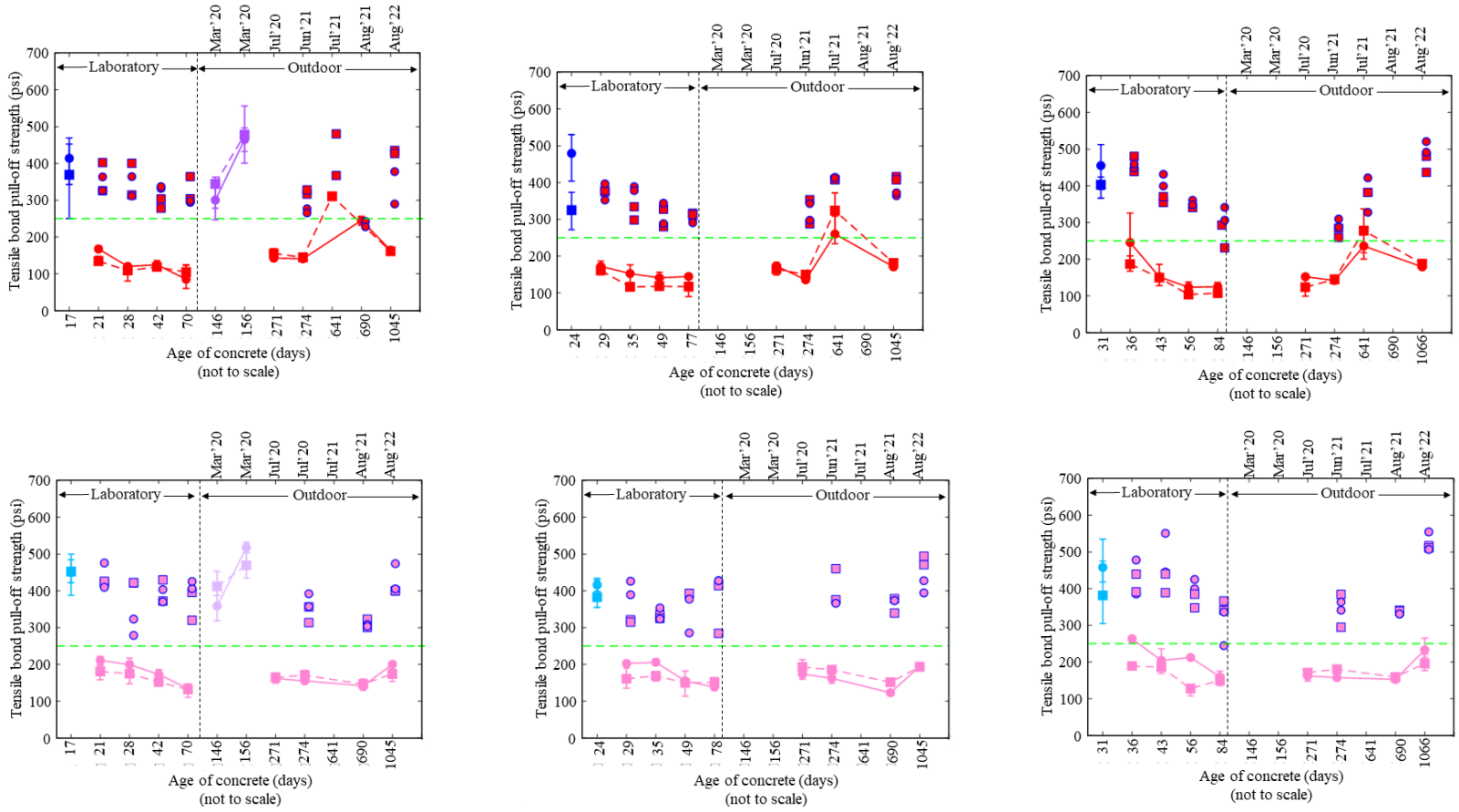
14-day

21-day

28-day

E1

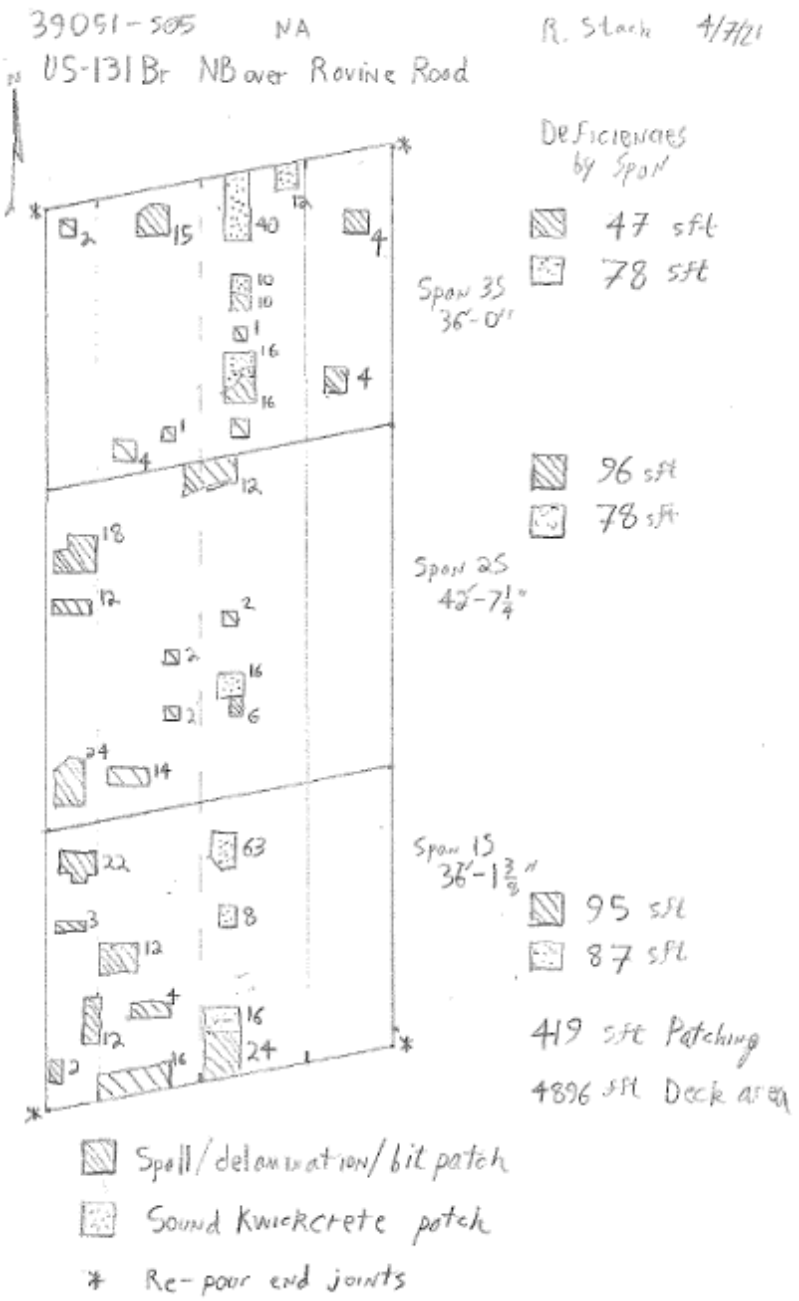
E2



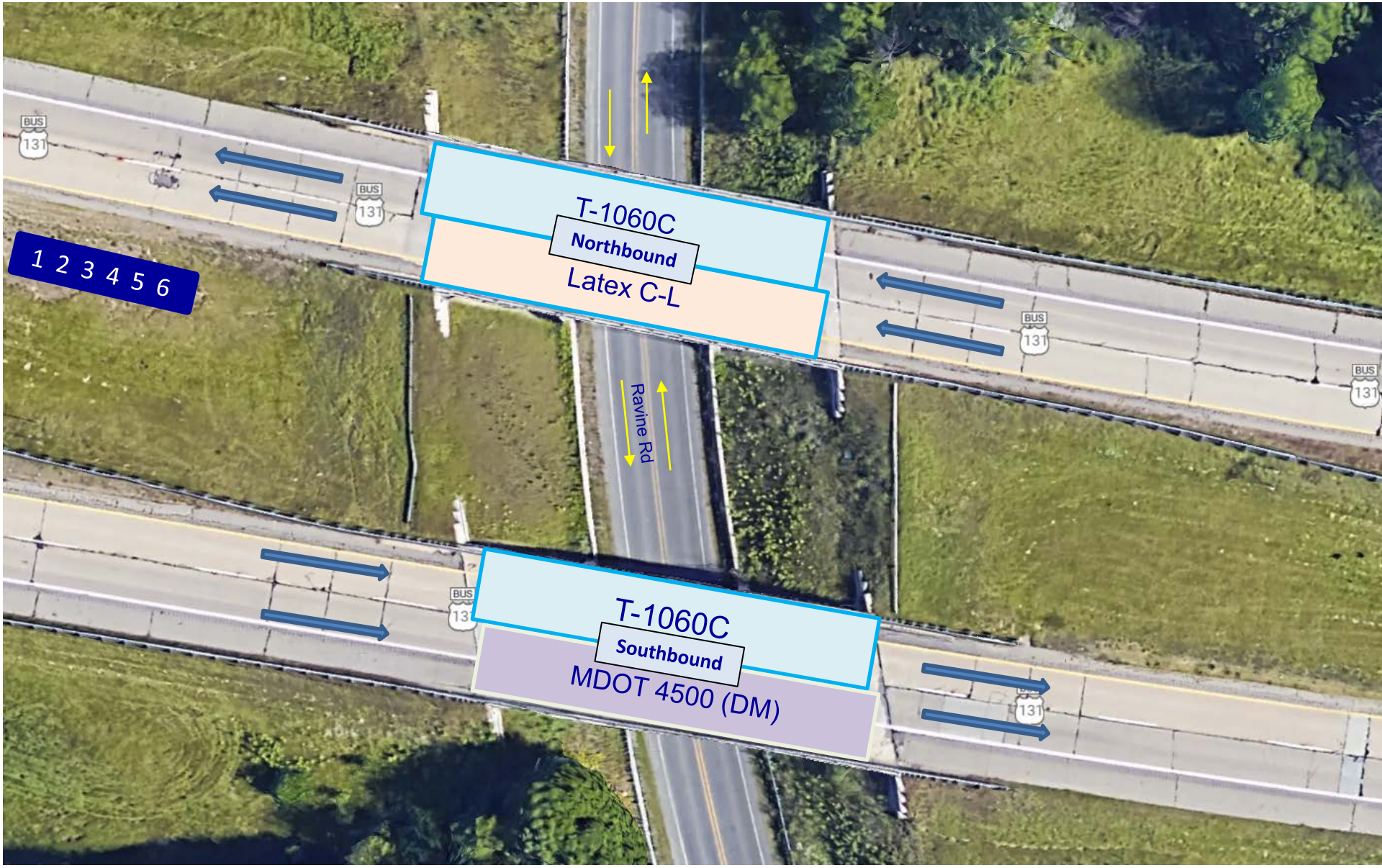
E1 – RS – RT
E1 – ST – RT
E2 – RS – RT
E2 – ST – RT
E1 – RS – HS/Summer (Hot)
E1 – ST – HS/Summer (Hot)
E2 – RS – HS/Summer (Hot)
E2 – ST – HS/Summer (Hot)
E1 – RS – HS/Summer (Cool)
E1 – ST – HS/Summer (Cool)
E2 – RS – HS/Summer (Cool)
E2 – ST – HS/Summer (Cool)
E1 – RS – Winter
E1 – ST – Winter
E2 – RS – Winter
E2 – ST – Winter

PERFORMANCE EVALUATION OVER DECK REPAIRS

US -131 BR Over Ravine Rd



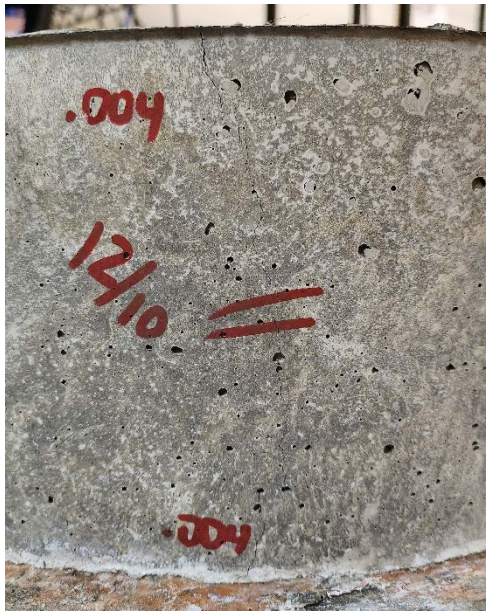
US -131 BR Over Ravine Rd



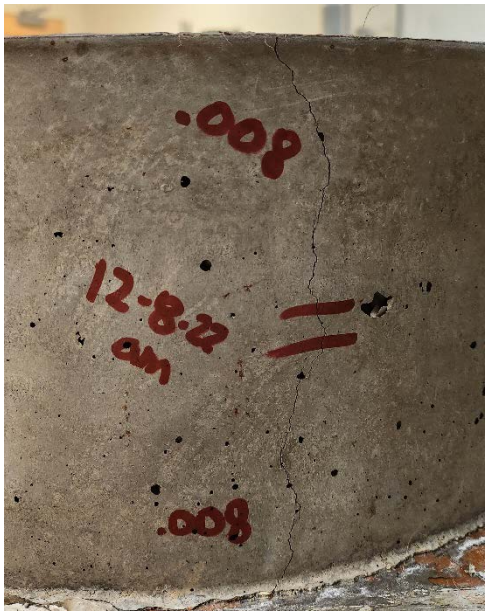
T 1060C - Very rapid-setting cement-based concrete repair mortar

T-1060C REPAIR MATERIAL -TIME OF CRACKING

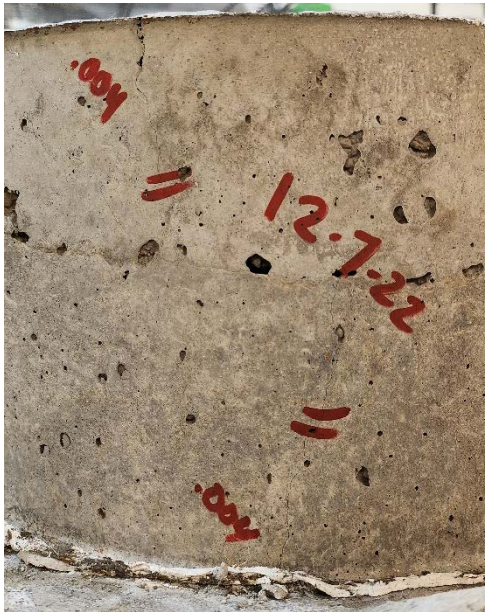
	Log-1	Log-2	Log-3
Crack width	0.004 in.	0.008 in.	0.004 in.
Casting date	**12/1/2022**		
7-Day	**12/07/2022**		
28-Day	**12/28/2022**		
Age at cracking	10 days	08 days	07 days



Log-1



Log-2



Log-3

T-1060C mix

Deck Repair

Elevated Temperature > 98º F

1

2

3

4

Temperature	100.2 ºF	98.7 ºF	100.4 ºF	101.2 ºF
Bond strength	361.58 psi	394.9 psi	202.2 psi	207.7 psi

Typical Temperature < 80º F

5

6

- Bond strength test was performed after 24 days of patching the repairs and 3 days after epoxy application.
- Nonuniform aggregate distribution

Temperature	64.2 ºF	64.4 ºF
Bond strength	413.42 psi	282.97 psi

T-1060C mix

Slab Specimens

Elevated Temperature > 100º F

1

2

3

4

Temperature	107.6 ºF	106.4 ºF	111.2 ºF	113.4 ºF
Bond strength	269.5 psi	195.12 psi	236.3 psi	221.38 psi

Typical Temperature < 80º F

5

6

Temperature	65.4º F	65.8º F
Bond strength	334.6 psi	322.7 psi

- Nonuniform aggregate distribution
- Poor surface profile

DM mix

Deck Repair

Elevated Temperature ≥ 100º F

1

2

3

4

Temperature	103 ºF	105.2 ºF	102.3 ºF	99.8 ºF
Bond strength	284.6 psi	174.7 psi	240.8 psi	394.9 psi

Typical Temperature < 80º F

5

6

Temperature	64.3 ºF	64.2 ºF
Bond strength	422.9 psi	456.5 psi

DM mix

Slab Specimens

Elevated Temperature > 100º F

1

2

3

4

Temperature	106.2ºF	108 ºF	113 ºF	113.3 ºF
Bond strength	212.9 psi	224.0 psi	252.2 psi	204.4 psi

Typical Temperature < 80º F

5

6

Temperature	65.3 ºF	64.2 ºF
Bond strength	447.5 psi	463.2 psi

Latex mix

Deck Repair

Elevated Temperature > 100º F

1

2

3

4

Temperature	103.4 ºF	102.2 ºF	102.3 ºF	100.5ºF
Bond strength	275.5 psi	281.5 psi	229.8 psi	262.6 psi

Typical Temperature < 80º F

5

6

Temperature	64.3 ºF	64.2 ºF
Bond strength	489.2 psi	439.6 psi

Latex mix

Slab Specimens

Elevated Temperature > 100º F

1

2

3

4

Temperature	103.4 ºF	102.3 ºF	102.5 ºF	100.5ºF
Bond strength	265.6 psi	251.1 psi	255.5 psi	262.6 psi

Typical Temperature < 80º F

5

6

Temperature	72.4 ºF	72.2 ºF
Bond strength	577.1 psi	502.5 psi

- Performance is great.
- The impact of poor surface preparation is evident.

CONCLUSIONS AND RECOMMENDATIONS

- A set time is identified to place an overlay on Grade DM and DBJR mixes.
- Epoxy overlays can be applied on bridge decks when Grade DM concrete age is 20 days (based on cracking).
- Epoxy overlays can be applied on bridge decks when BDJR concrete age is 18 days (based on cracking).
- Concrete durability is not compromised with the early application of thin epoxy overlays.
- Epoxy overlay performance over repair materials is satisfactory.
- Surface preparation is critical for overlay performance.
- Uniformly mixed material is critical for overlay performance.

RECOMMENDATIONS

- Use the procedure (framework) presented in this study to decide on the concrete age to receive a thin epoxy overlay.
- Consider concrete with slag over Type I cement for improving epoxy overlay bond strength.
- Consider using low viscous epoxy overlays that are more stable under elevated temperature.
- Update the special provision 12SP-712B-04 and 12SP-712C-03 with the following statement:

Do not perform surface preparation or installation of epoxy overlay on patches with Grade DM, BDJR concrete, T 1060C, or Latex mix less than 21 days of age.

THANK YOU!