


SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

DEVELOPMENT OF A SPECIFICATION FOR LOW CRACKING BRIDGE DECK CONCRETE IN VIRGINIA

Virginia DOT Workshop – Charlottesville, VA

Harikrishnan Nair, Ph.D., P.E, VTRC
Senior Research Scientist

October 4, 2017

U.S. Department of Transportation
Federal Highway Administration

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS
AASHTO

Presentation Outline

- INTRODUCTION
- RESEARCH
- SPECIFICATION DEVELOPMENT
- IMPLEMENTATION

INTRODUCTION

Deck Cracking Problem

- Cracks can result from excessive loading, environmental conditions, chemical reactions, construction or design errors.

- Cracks act as a pathway for water and aggressive chemical ions to penetrate concrete and enable its deterioration.

INTRODUCTION

Classification of Cracks (TRB Circular,E-C107)

Type of Cracking	Time of Appearance
Plastic Shrinkage	30 min to 6 h
Plastic settlement	10 min to 3 h
Thermal expansion and contraction	1 day to 2–3 weeks
Drying shrinkage	Weeks to months

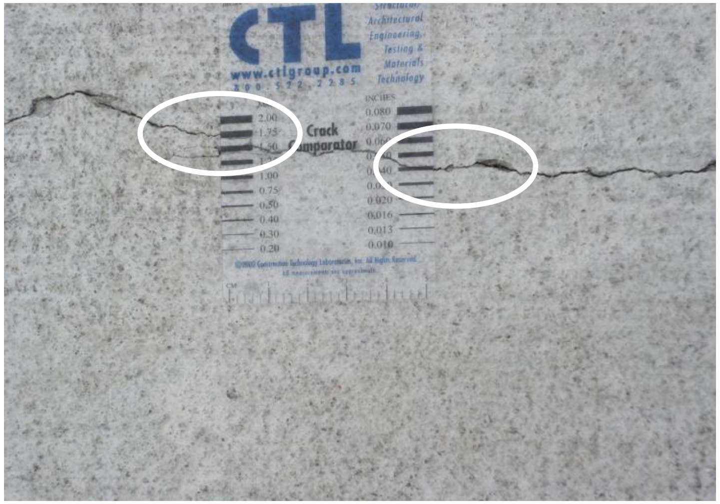
Deck Cracking Problem

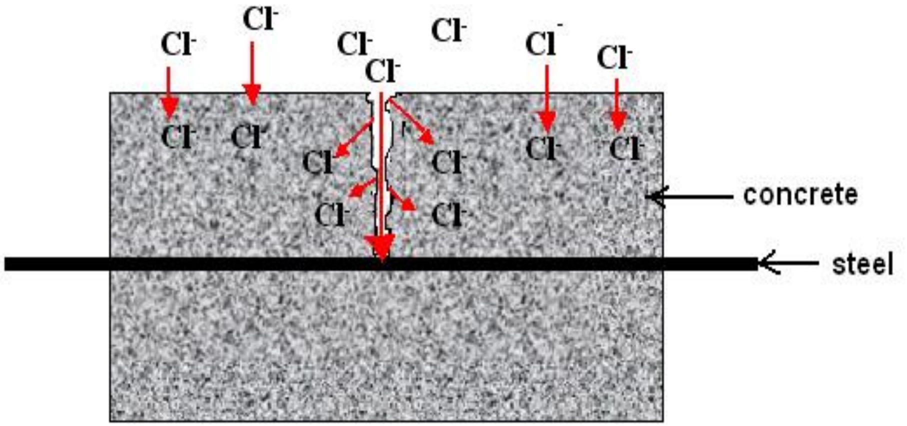
Drying shrinkage cracks – may occur weeks to months after pour.

Deck Cracking Problem

Difficult to penetrate cracks < 0.1 mm wide.

Cracks with a width over 0.20 mm can be and should be sealed





Chloride diffusion in cracked concrete

Corrosion Resistant Rebars

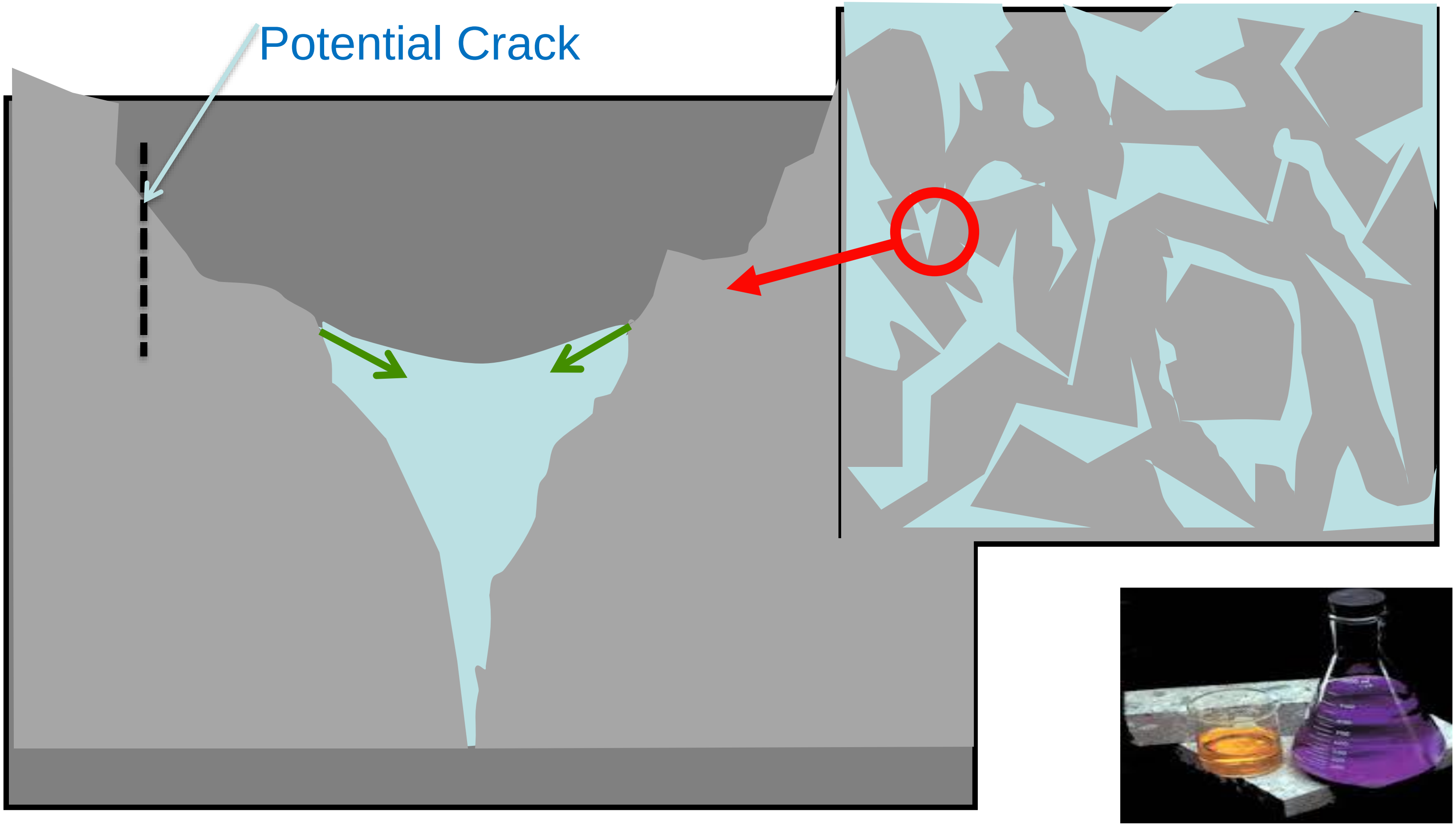
RESEARCH

To investigate the effectiveness of reducing drying shrinkage in VDOT concrete mixes using the following:

- Normal weight concrete with Shrinkage Reducing Admixture (SRA)
- Lightweight (LW) concrete with LW coarse aggregate
- Shrinkage compensating concrete

SRA: How it works

Typically shrinkage reduction achieved is between 35–45%

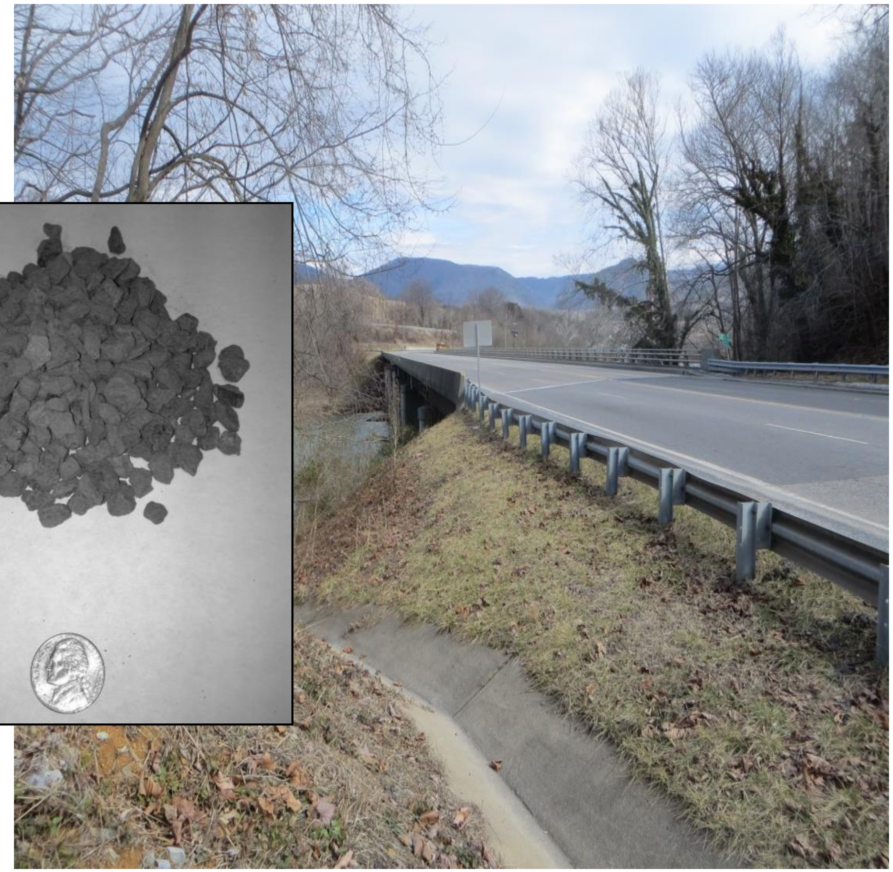


SRAs function by reducing capillary tension of pore water

VDOT Use of Lightweight Concrete Bridge Deck

Route 629 over Cowpasture River

Route 60 over Maury River



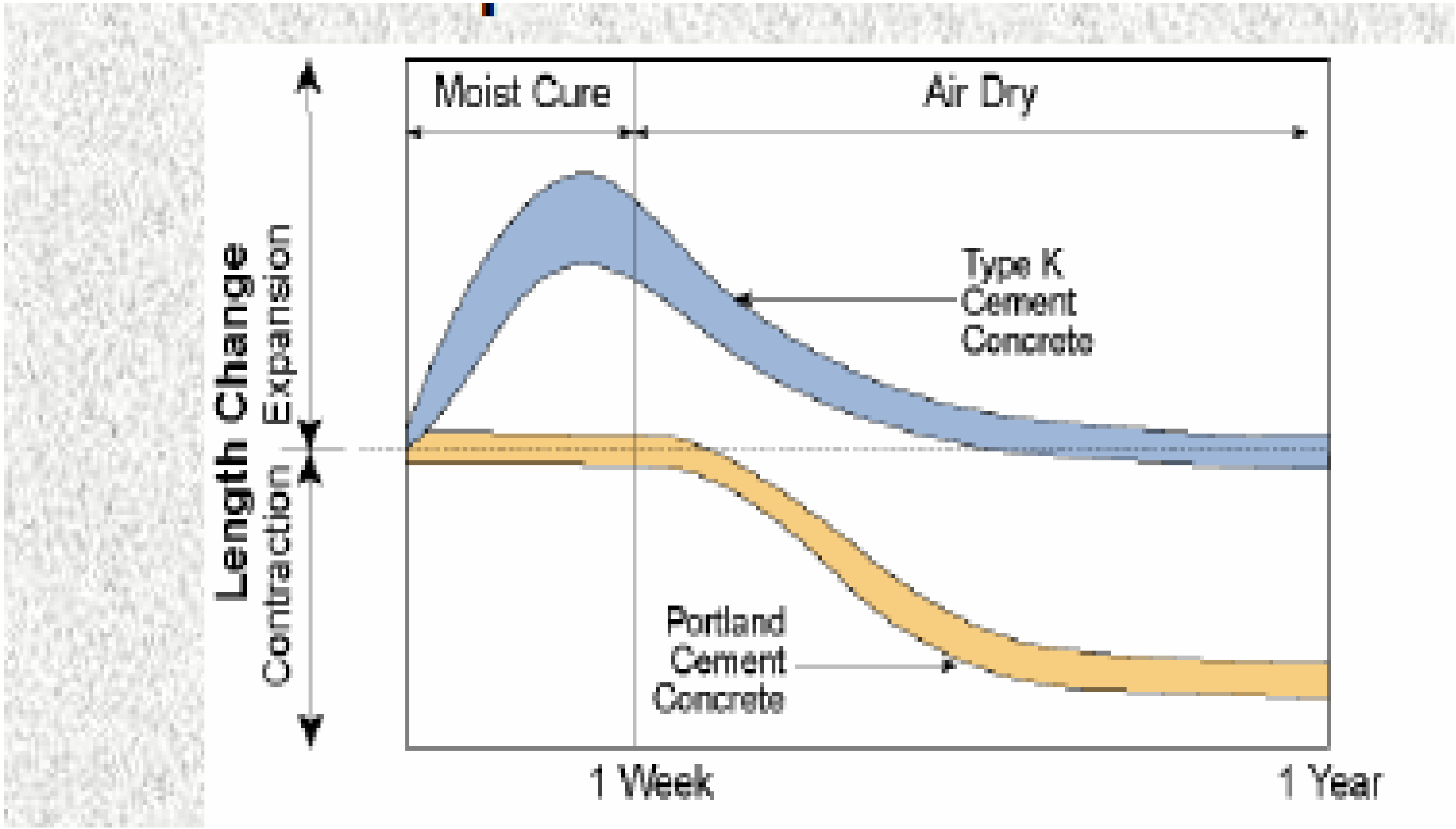
After 33 Years

No Transverse Crack (Continuous two span bridge on Steel Beams)

After 30 Years

Skew, no cracks

Shrinkage Compensating Concrete



Ref: P.K. Mehta and P.J.M. Monteiro, Concrete: Microstructure, Properties, and Materials

METHODS

Details of Bridges That Used SRA, LWC, and SC

No.	Route or Bridge No./Name	Length (ft)	Width (ft)	No. of Spans	Type of Beam Support	Skew Angle (Degrees)
NWC with SRA						
Northern Virginia District (I-95 Express Lanes)						
1	B607 (Telegraph Road)	313	40	2	Steel	19
2	B609 (GHS Ramp)	448.3	30	2	Steel	0 (curved)
3	B603 (JHS Ramp)	541	30	3	Steel	0 (curved)
4	B602 (Ramp)	558	30	3	Steel	0 (curved)
5	B601 (Ramp)	964	30	9	Concrete (1 span)/Steel	0 (curved)
Staunton District						
6	Route 633 Covington	340	26	3	Steel	0
7	Route 1421 Linville Creek	260	29.67	4	Prestressed concrete box beams	15
8	Route 250 Ramseys Draft	65	40	1	Prestressed concrete box beams	30
Fredericksburg District						
9	Route 600 Herring Creek	99	40	1	Steel	17
LWC						
10	Route 657, Senseny Road, Winchester/ Staunton	249	32	4	Steel	0
11	Route 128, Chandlers Mountain Road, Lynchburg/Lynchburg	264	36	4	Steel	0
12	Route 15, Opal/Culpeper	256	28	2	Lightweight concrete beams	27
13	Route 49, The Falls Road, Crewe/ Richmond	175	42	3	Steel	0
14	Route 646, Aden Road, Nokesville/Northern Virginia	167	32	3	Prestressed concrete slab	0
15	Route 3, Piankatank River, Mathews County/Fredericksburg	4186	28	30	Steel	0
16	I-95 HOV Lane, Stafford/Northern Virginia	159	48	1	Steel	0
SC						
17	Route 613/South Fork/ Staunton	320	28	4	Prestressed concrete box beams	0

METHODS

- Trial batches were conducted for the proposed mix designs.
- Bridge deck placement details (Concrete temperature, air temperature, relative humidity and wind speed) were documented.
- Concretes were tested for fresh and hardened properties.
- Decks were wet cured for 7 days followed by curing compound.
- Crack survey's (length, width, location) were conducted at different intervals.

Concrete Mix Designs for All Bridges (per cubic yard)

Bridge	Cement (lb)	Fly Ash (lb)	Slag (lb)	Total Cementitious Content (lb)	Water (lb)	w/c
NWC with SRA						
I-95 Express Lanes	300	-	300	**600 (SRA 1)**	271	0.45
Route 633	464	116	-	**580 (SRA 2)**	262	0.45
Route 1421	325	-	325	**650 (SRA 2)**	260	0.40
Route 250	480	120	-	**600 (SRA 3)**	262	0.44
Route 600	480	120	-	**600 (SRA 2)**	258	0.43
LWC						
Route 657	529	176	-	**705**	267	0.38
Route 128	318	-	317	**635**	286	0.45
Route 15	330	-	330	**660**	292	0.44
Route 49	525	171	-	**696**	313	0.45
Route 646	540	135	-	**675**	292	0.43
Route 3	508	127	-	**635**	286	0.45
I-95 HOV Lane	330	-	330	**660**	292	0.44
SC Concrete						
Route 613	572	143	-	**715**	349	0.48

Trial Batch Results

- Acceptable Compressive strength (VDOT Spec: 28 day min 4000 psi)

- Very low permeability – Below 1000 coulombs

(VDOT Spec: 28 day max 2500 Coulombs)

- Excellent Freeze Thaw Durability

SRA (producer 3) reduced the air content

-Higher dosage of air entraining agent was required

Reduction in shrinkage with use of SRA ranged from 10 – 58%

Placement and Fresh Concrete properties

VDOT spec: Range of slump: 2-4 in, Air content: 5-8%
With high-range water–reducing admixture: slump: 2-7 in, Air content: 5-9%

NWC with SRA

- In most cases concrete mixture was placed by pumping.
- Slump ranged from 2.6 to 6 in and Air content 5.0 to 7.8%
- Paste content (total volume of cementitious material and water) close to 27%
- The concrete evaporation rates were very low (less than 0.1 $lb/ft^2/hr$) in all projects

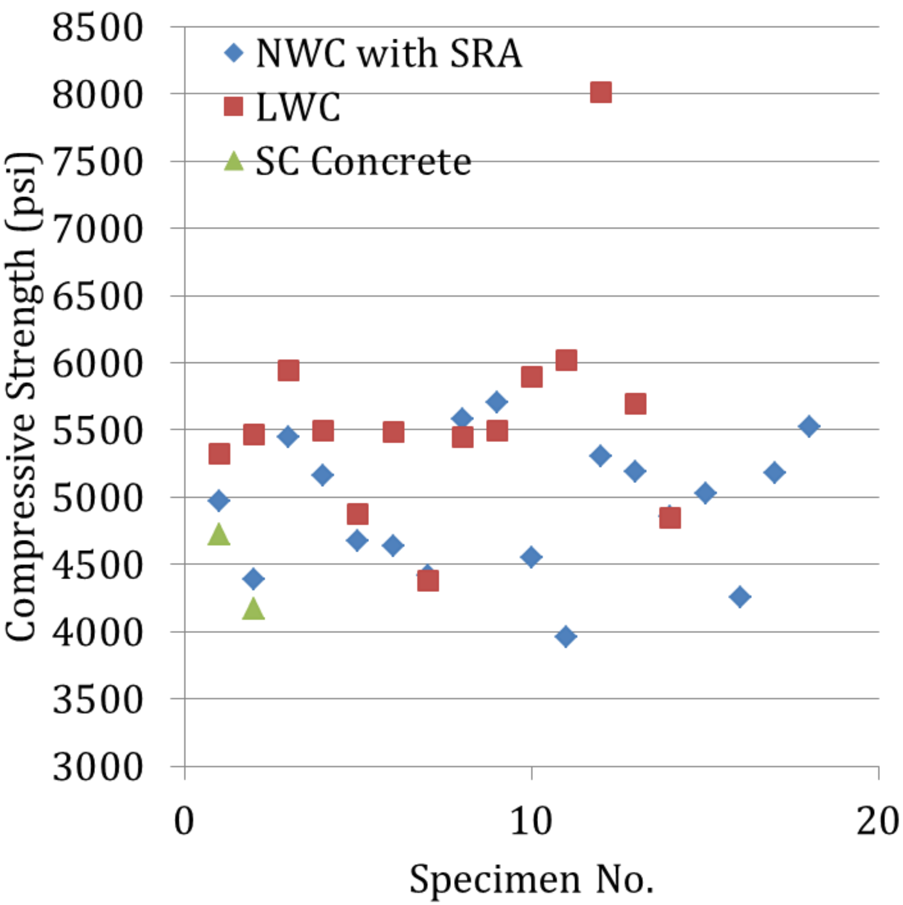
Placement and Fresh Concrete properties

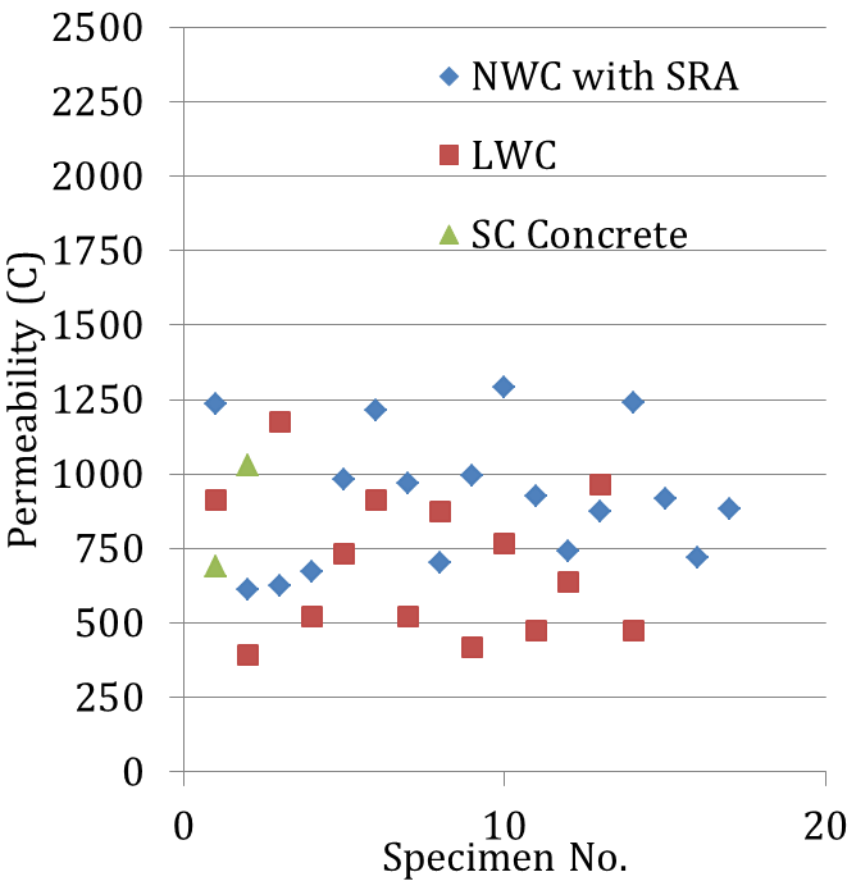
Lightweight Concrete
- unit weight of the LWC ranged from 114.2 to 120.9 lb/ft^3
- In most cases concrete mixture was placed by pumping.
- Average slumps ranged from 4 to 8 inches, and air content ranged from 5.5% to 8.0%.
- The concrete evaporation rates were very low

Shrinkage compensating concrete
- Hydration stabilizer was used to control the slump loss
- All fresh concrete properties and the evaporation rate met the VDOT specification

Hardened Concrete Properties

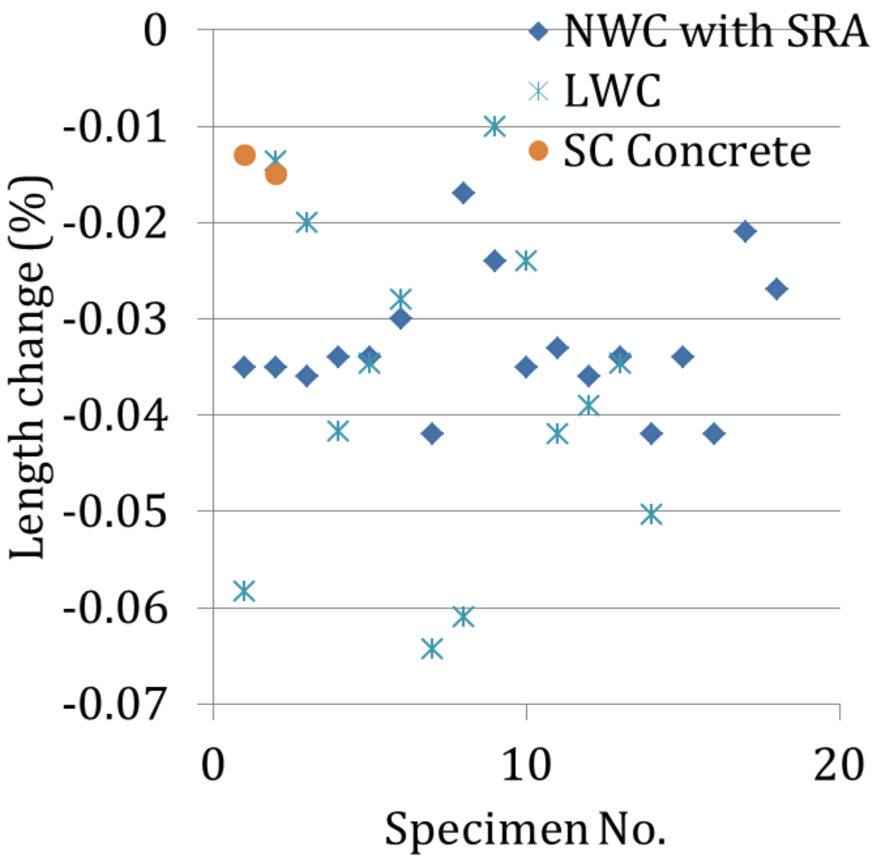
Compressive Strength and Permeability

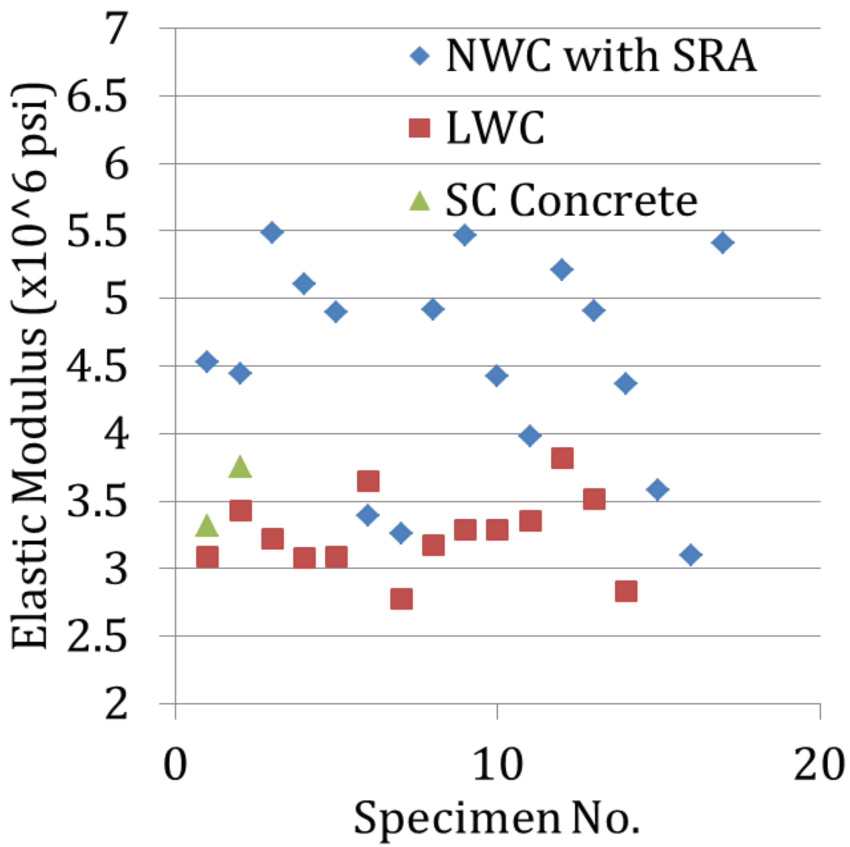




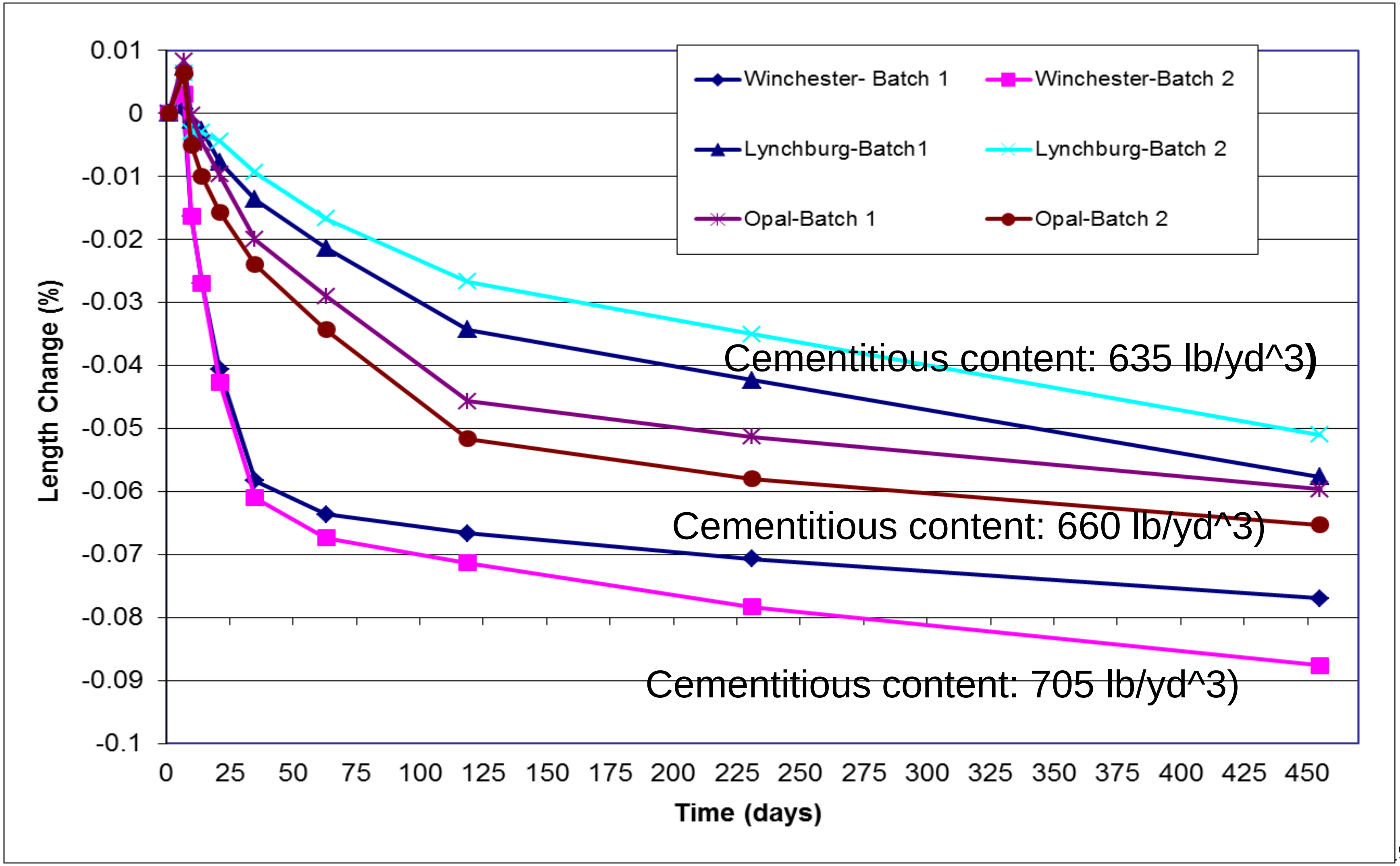
Hardened Concrete Properties

28-day Length Change and Elastic Modulus





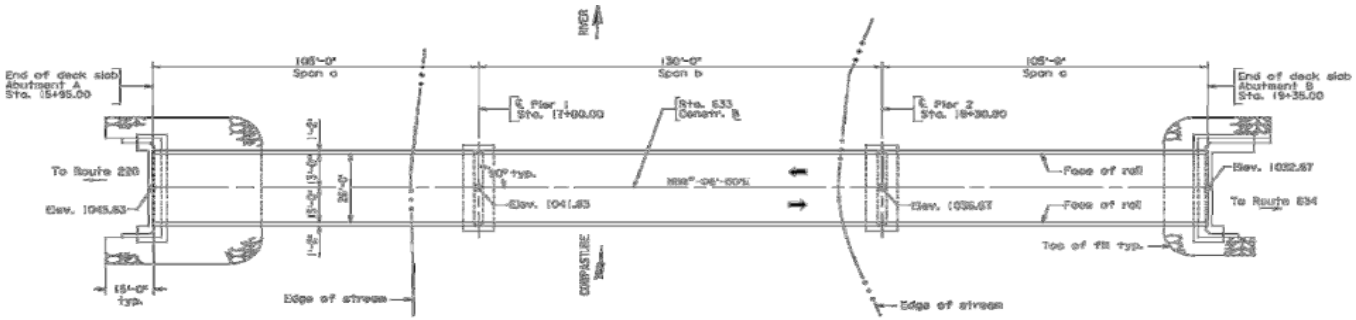
Shrinkage Results –Lightweight Concrete (2012 Projects)

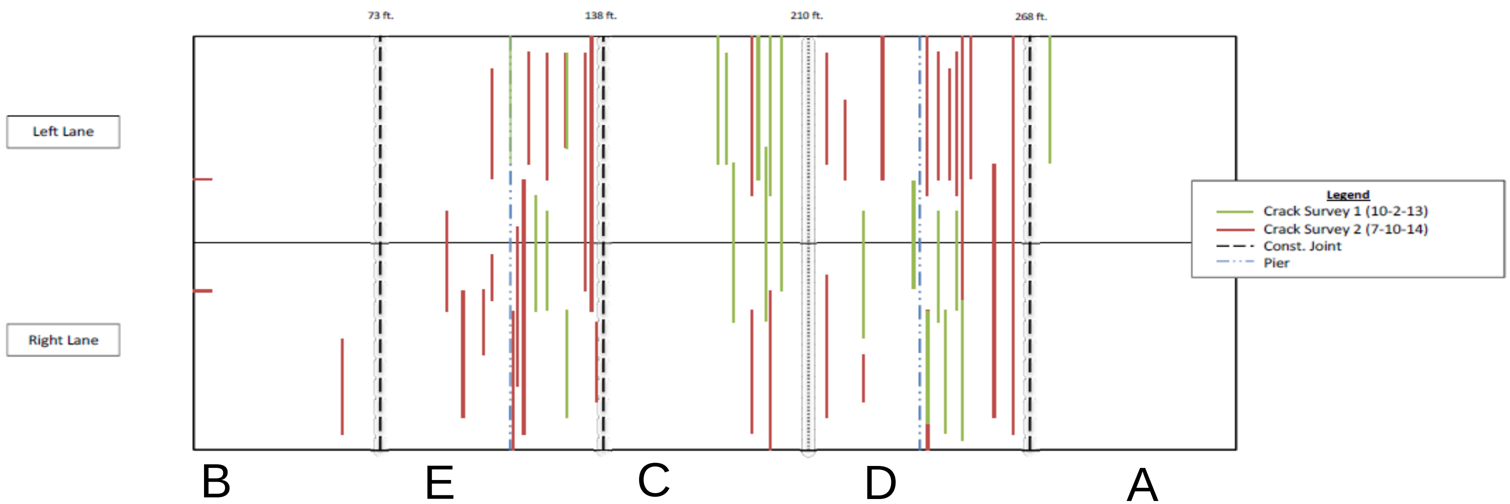


Crack Survey: NWC with SRA

Route or Bridge No.	Length of Bridge	No. of Cracks: Length (ft) and Width (mm)	Age at Time of Survey (months)	Crack Density (ft/ft^2)
B607 (Telegraph Road)	313 ft	1 crack: 36 ft (0.2 mm)	15	0.0028
B609 (GHS Ramp)	448 ft	4 cracks: 3 ft (0.25 mm),15 ft (0.2 mm), 9 ft (0.3 mm),1 ft (0.25 mm)	7	0.0020
B603 (JHS Ramp)	542 ft	No cracks	14	0.0
B602 (Ramp)	558 ft	1 crack: 7 ft (0.2 mm)	13	0.0004
B601 (Ramp)	964 ft	20 short cracks: Average length: 4-5 ft	5	0.0049
Route 1421	260 ft	3 transverse cracks over the piers	14	0.0115
Route 250	65 ft	No cracks	9	0.0
Route 600	99 ft	5 short longitudinal cracks at abutments	9	0.0062
Route 633	340 ft	Several cracks	19	0.1853

Crack Survey: NWC with SRA
Rte. 633 Staunton District (19 months)

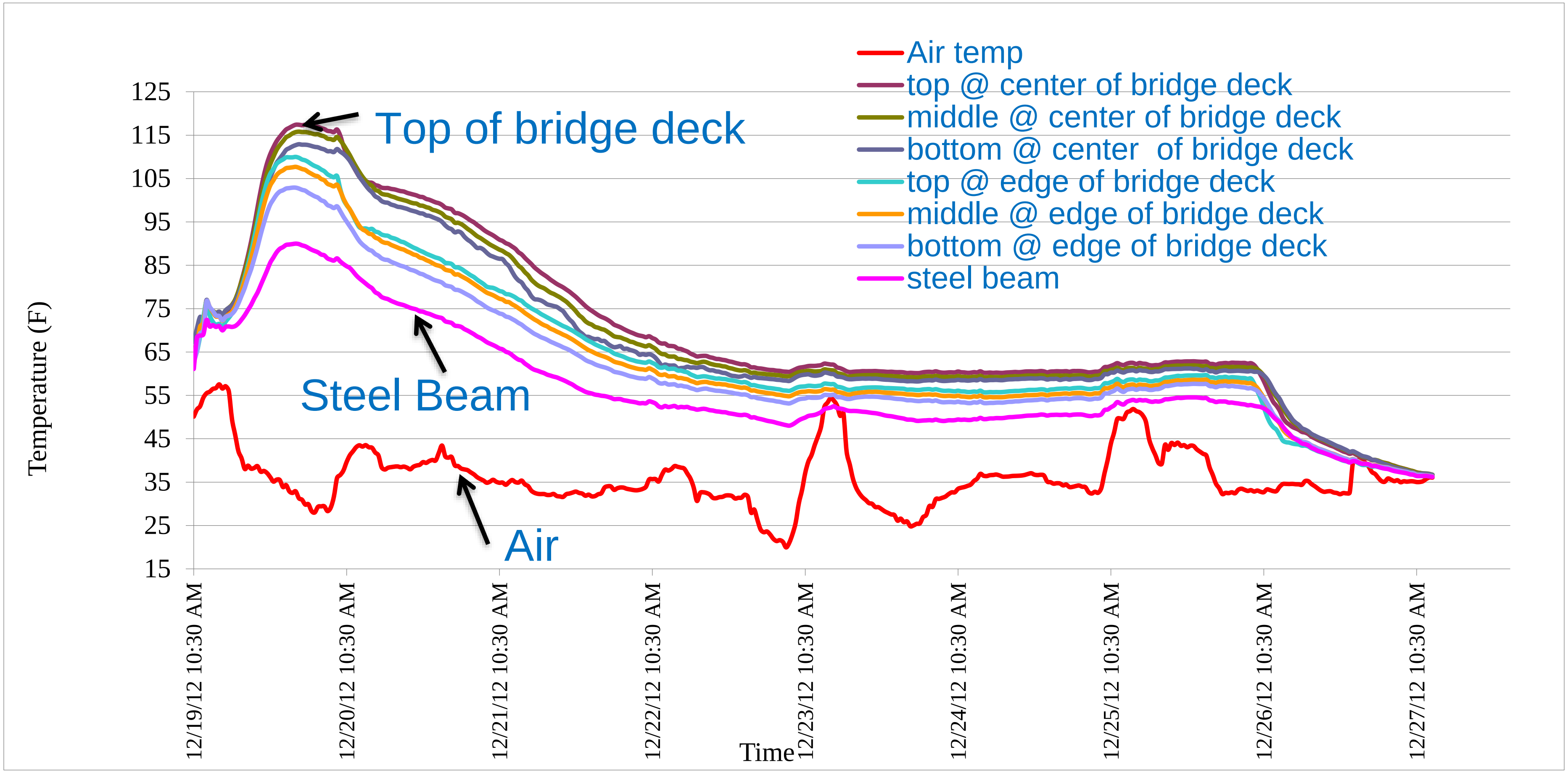




Crack survey plots (Rte. 633 Bridge) (not in scale)

Did not follow placement sequence (C&D combined)

Crack Survey: NWC with SRA
Temperature data for Rte.633 bridge (Pour E)



Crack Survey –Lightweight concrete

Winchester (2 Years)

Opal (1 ½ Years)

Lynchburg (1 ½ Years)

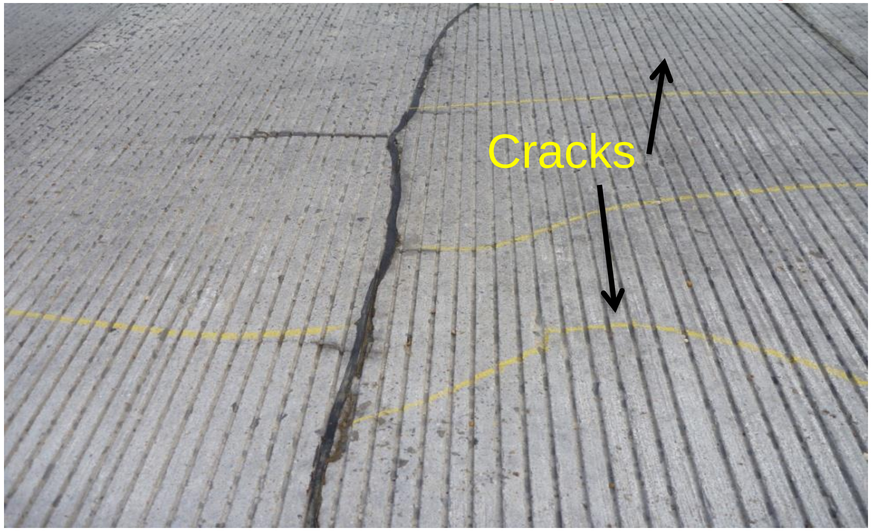
I-95 Expressway, Stafford (6 months)

Crack Survey –Lightweight concrete

Mathews County, Fredericksburg (6 Months)

Crewe, Richmond (7 Months)

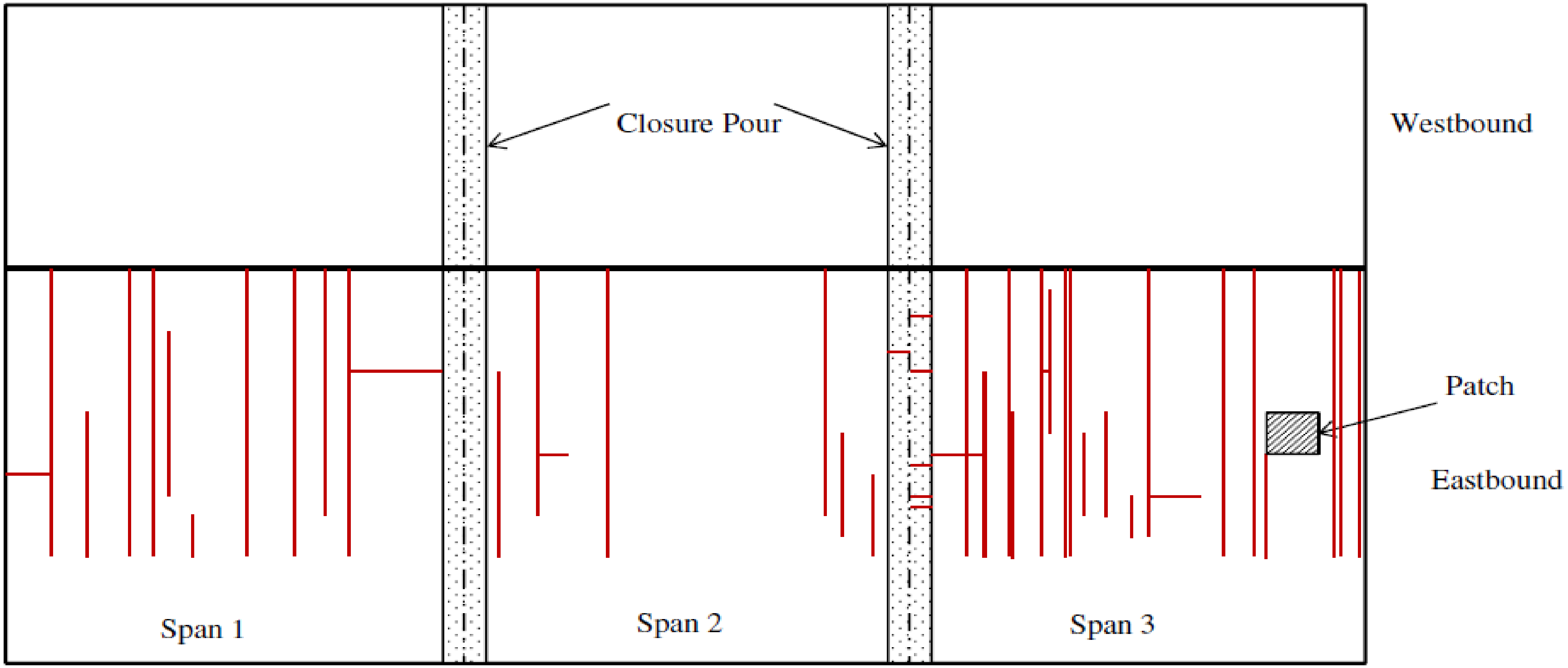
Nokesville, NOVA (10 Months)



Nokesville, NOVA (10 Months)

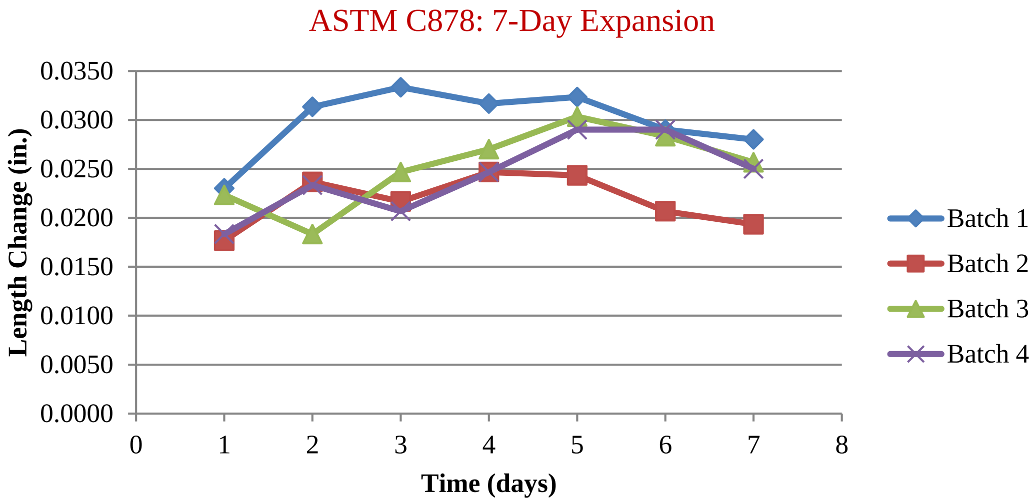
Crack Survey –Lightweight concrete

Crack Survey Plots for Route 646 Nokesville (not to scale)



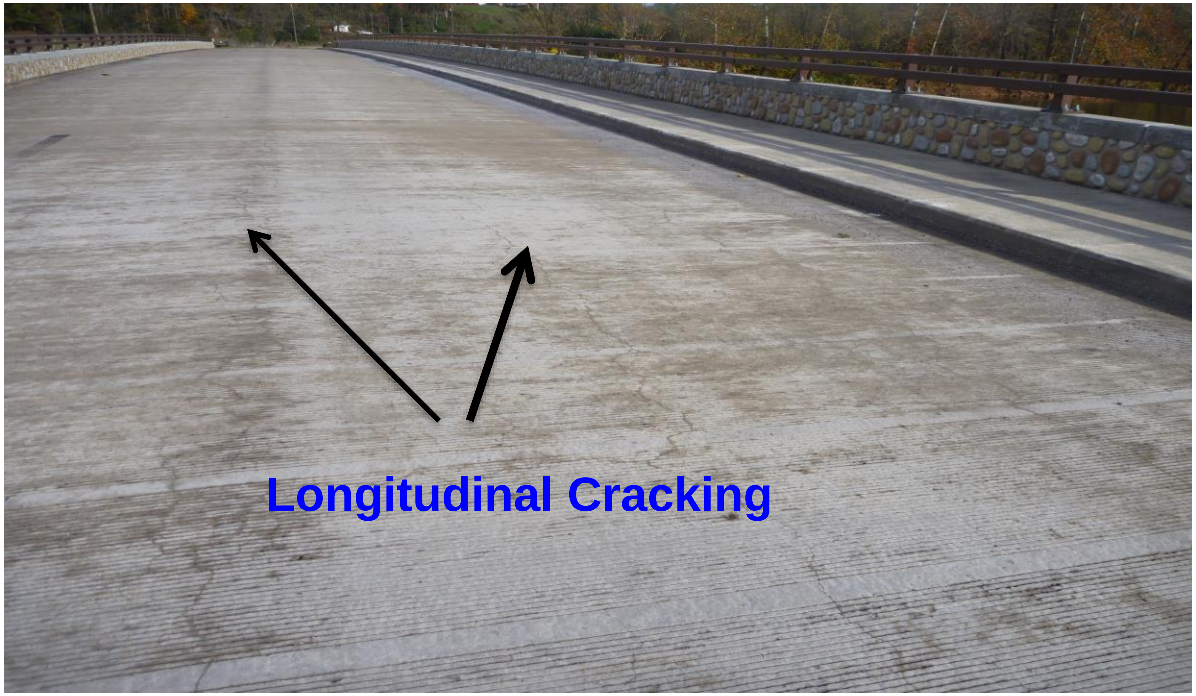
Shrinkage compensating concrete

Route 613 Bentonville – Staunton District



CRACK SURVEY: Shrinkage compensating concrete

Route 613 Bentonville – Staunton District



Reflective cracking caused by the differential movement of the box beams at the keyway

Transverse cracks over the piers were observed

CONCLUSIONS

- Bridge decks with fewer cracks can be constructed.

- The use of SRA along with low cementitious contents (600 lb/yd^3 maximum) was found to be very effective in reducing cracks in bridge decks.

- For low cracking decks, the 28-day drying shrinkage (ASTM C157) should be kept below 350 microstrains.

- Decks with reduced cracks or no cracks can be successfully placed using LWC with a cementitious content below 650 lb/yd^3 while meeting strength and permeability requirements.

CONCLUSIONS

- The LWCs used in this study had shrinkage values as high as 0.060% and did not crack. This shows the benefits of the lower elastic modulus, internal curing, and lower coefficient of thermal expansion of LWC.

- Proper concrete placement, consolidation, and curing are important factors in achieving crack-free bridge decks.

- Following a proper construction sequence and maintaining a low temperature differential between concrete and air are important for reducing cracks in bridge decks.

- A low permeability value for concrete can be achieved by using fly ash or slag.

SPECIFICATION FOR LOW CRACKING BRIDGE DECK CONCRETE

1. The cementitious materials content shall be less than or equal to 600 pounds per cubic yard for NWC. The 28-day drying shrinkage shall be less than or equal to 0.035% (based on the average of three specimens) when tested in accordance with ASTM C157.

Specimens shall be moist cured for 7 days prior to testing for drying shrinkage. A shrinkage reducing admixture shall be used unless the 28-day drying shrinkage is less than or equal to 0.035% without the admixture.

2. The cementitious materials content shall be less than or equal to 650 pounds per cubic yard for LWC and the maximum fresh density shall be 120 lb/ft^3.

Implementation

Included in 2016 Road and Bridge specification

http://www.virginiadot.org/business/resources/const/VDOT_2016_RB_Specs.pdf

SECTION 217—HYDRAULIC CEMENT CONCRETE

217.12—Low Shrinkage Class A4 Modified Concrete

ACKNOWLEDGEMENT

VTRC

VDOT Central Office and Districts

FHWA

Industry

Questions?

Contact Information:

Harikrishnan.Nair@VDOT.Virginia.gov