USE OF SHRINKAGE REDUCING ADMIXTURES AND LIGHTWEIGHT CONCRETE IN VIRGINIA BRIDGE DECKS - 2014

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ABSTRACT

Crack surveys were performed on nine bridge decks in Virginia. Five decks were constructed with a shrinkage reducing admixture (SRA), three were constructed with lightweight concrete, and one is used as a control. Seven of the decks surveyed are supported by steel girders and two are supported by prestressed concrete. Of the seven decks supported by steel girders, four contain an SRA, two were constructed with lightweight concrete, and one was constructed with conventional concrete and serves as the control. One SRA and one lightweight deck were supported by prestressed concrete; the SRA deck is supported by a prestressed concrete box beam and the lightweight deck is supported by a prestressed concrete slab. The decks were 5 to 31 months old when the crack surveys were performed. The Virginia bridge decks are compared against low-cracking high performance concrete (LC-HPC) and conventional Kansas Department of Transportation (KDOT) decks in Kansas. The surveys performed in this trip provide a good baseline for future surveys and allow for conclusions about the early performance of the bridge decks. The decks constructed with an SRA are performing better than the decks built with lightweight concrete. Initial surveys suggest that the SRA decks are not performing as well as the LC-HPC decks and that the lightweight decks are not performing as well as either the LC-HPC or control decks in Kansas. Decks with lower paste contents are performing better than decks with higher paste contents.

Key words: bridge decks, high-performance concrete, cracking, shrinkage reducing admixture, lightweight concrete

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INTRODUCTION

Cracking in bridge decks is a serious concern because cracks provide corroding agents a direct path to the reinforcing steel, as well as reducing the overall freeze-thaw resistance of the concrete. When water or deicing chemicals have easy access to reinforcing steel, durability problems are inevitable.

Over the last several decades, the Kansas Department of Transportation (KDOT) has been working in conjunction with the University of Kansas (KU) to minimize cracking in bridge decks. Through a pooled-fund study supported by KDOT, other state and federal transportation organizations, and concrete material suppliers and organizations, the University of Kansas has developed specifications for Low-Cracking High-Performance Concrete (LC-HPC) bridge decks. These specifications address cement and water content, plastic concrete properties, construction methods, and curing requirements. In Kansas, 16 bridge decks have been constructed following the LC-HPC standards, as well as 11 bridge decks constructed following normal KDOT specifications to provide a basis of comparison. To consistently compare bridge decks, a specific crack survey procedure has been developed to minimize variations from year to year. Specifications for the procedure can be found in Appendix A. Results from the pooled-fund study show that the LC-HPC bridge decks are performing better than the decks constructed in accordance with normal KDOT specifications across the state (Lindquist et al. 2008, McLeod et al. 2009, Darwin et al. 2010, 2012, Yuan et al. 2011, Pendergrass et al. 2014).

This report describes the initial surveys of nine bridge decks in Virginia. The decks were constructed with mixtures containing different cementitious materials, aggregates, and admixtures, including shrinkage reducing admixtures (SRAs). Five decks were constructed with an SRA, three were constructed with lightweight concrete, and one was constructed with conventional normalweight concrete and served as a control. Seven of the decks surveyed are supported by steel girders and two are supported by prestressed concrete. Of the seven decks supported by steel girders, four contained an SRA, one was constructed with lightweight concrete, and one was the control. One bridge had steel girders and semi-integral abutments. One SRA and one lightweight deck were supported by prestressed concrete; the SRA deck is supported by prestressed concrete box beams and the lightweight deck is supported by a prestressed concrete slab. Of the five SRA bridge decks, two contain Sika Control 40 and three contain W. R. Grace Eclipse 4500. This report analyzes the cracking performance of the nine bridge decks to date and compares them with the LC-HPC and conventional KDOT bridge decks being analyzed in the pooled-fund study. To provide a basis for the comparisons, the LC-HPC specifications are described next.

LOW-CRACKING HIGH-PERFORMANCE CONCRETE BRIDGE DECK SPECIFICATIONS

Special provisions for LC-HPC bridge decks, covering aggregate, concrete, and construction, have been developed in Kansas. To date, 16 bridge decks have been constructed in Kansas in accordance with the standard KDOT specifications plus the special provisions covering LC-HPC; 11 control bridges for comparison have also been constructed in Kansas. Annual crack surveys are conducted on both the LC-HPC and control decks.

Low-Cracking High-Performance Concrete (LC-HPC) Specifications

LC-HPC specifications are special provisions to the standard KDOT concrete bridge deck specifications. These specifications cover mix proportions and allowable properties for plastic concrete, as well as construction and curing methods. The LC-HPC special provisions have been revised as improvements are found from field or laboratory study. The latest version of the LC-HPC specifications is included in Appendix B.

Aggregate plays an important role in the cracking performance of bridge decks because of its effects on concrete properties. LC-HPC specifications call for a maximum aggregate size of 1 in. (25 mm), and the gradation must be optimized to provide better workability in the concrete. This optimized gradation can be achieved with tools, such as described by Shilstone (1990) or provided by the KU Mix Method (Lindquist et al. 2008). These criteria provide concrete with better workability at a lower slump. High slump concrete is not used because the high slump increases settlement cracking above reinforcing bars. Coarse aggregate is limited to a maximum absorption of 0.7% to help reduce slump loss during pumping and maintain workability.

The cement content must be between 500 and 540 lb/yd^3 (296 and 320 kg/m^3), and the water-cement ratio between 0.44 and 0.45, which can be reduced to 0.43 at the construction site with approval from the Engineer. The low cement content reduces drying shrinkage. The water-cement ratio helps limit strength because of the relationship between high strength and increased cracking.

Because higher air contents are associated with reduced cracking, the air content range in fresh content must be between 6.5 and 9.5%. The required slump at the point of placement is between 1.5 and 3.0 in. (40 and 75 mm), with the goal of reducing settlement cracking above the reinforcement. To limit thermal and plastic shrinkage cracking, the temperature of fresh concrete must be between 55 and 70 ºF (13 and 21 ºC). The temperature range may be extended to 50 to 75 ºF with approval by the Engineer.

Many people assume that high strength concrete is more resistant to cracking. Stronger concrete, however, creeps less than lower strength concrete, which results in increased cracking if drying shrinkage is restrained. Therefore, the 28-day strength of concrete is limited to between 3500 and 5500 psi (24.1 and 37.9 MPa).

To reduce the amount of water lost during construction and to avoid plastic shrinkage, the evaporation rate during construction must be below 0.2 $lb/ft^2/hr$ (1.0 $kg/m^2/hr$). Air temperature, wind speed, and relative humidity 12 in. (305 mm) above the deck surface, should be monitored by the Engineer at least once per hour. If the evaporation rate exceeds 0.2 $lb/ft^2/hr$ (1.0 $kg/m^2/hr$), special actions, such as cooling the concrete or installing wind breaks, are required.

Concrete should be conveyed to the deck using conveyor belt or concrete bucket; pumping is allowed only when the contractor can demonstrate the ability to handle the approved concrete mixture with the same pump as will be used on the job site. To minimize the loss of air and avoid segregation, the maximum drop from a conveyor or concrete bucket is limited to 5 ft (1.5 m). When a pump is used, an air cuff or bladder valve must be used to limit the loss of entrained air.

Concrete consolidation should be performed using vertically-mounted internal gang vibrators. The vibrators should be held in the concrete for 3 to 15 seconds, as needed, and then removed slowly so as to not leave voids. Strike-off is performed using a vibrating or single-drum roller screed. The surface should be finished using a burlap drag, a metal pan, or both, followed by bullfloating (only if needed). Finishing aids, including water, are prohibited.

To minimize plastic shrinkage cracking caused by loss of surface water after placement, early initiation of curing is required using a layer of pre-saturated burlap placed on the deck within 10 minutes of strikeoff. A second layer of burlap must be placed within the next 5 minutes. The burlap must be soaked for at least 12 hours prior to placement.

Prior to deck construction, a qualification slab must be placed by the contractor to demonstrate the ability to place, finish, and cure the deck in accordance with LC-HPC specifications. This is to help ensure that the contractor fully understands what is expected when constructing a LC-HPC deck.

Cracking Performance of LC-HPC Bridge Decks

Crack surveys have been performed annually on both LC-HPC decks and matching control decks since the first LC-HPC deck was constructed in 2005. The results of those surveys show that the crack densities of the LC-HPC decks are consistently lower than the control decks (Lindquist et al. 2008, McLeod et al. 2009, Darwin et al. 2010, 2012, Yuan et al. 2011, Pendergrass et al. 2014). The results of the surveys described in this report will be compared with those obtained for the LC-HPC and control decks.

BRIDGES

Nine bridge decks were surveyed in Virginia during the summer of 2014. Five of the decks contained an SRA, three were constructed with lightweight concrete, and one served as a control. The bridges were located in four Virginia Department of Transportation (VDOT) districts, Staunton, Fredericksburg, Northern Virginia, and Lynchburg. Six different contractors were involved in the construction, W. C. English Inc., Lane Construction, Plecker Construction Co., Allegheny Construction Co. Inc., Shirley Contracting, and Abernathy Construction. Seven of the decks are supported by steel girders, one with the girders integrated into the abutments. Of the remaining bridges, one is supported by a prestressed concrete box beam, and the other is supported by a prestressed concrete slab. Information on the surveyed decks is summarized in Table 1.

Table 1 – Bridge properties

Bridge ID	District	Contractor*	Type of Support	Spans	Skew (deg.)	Length (ft)	(m)	Width (ft)	(m)
VA-1	Staunton	Plecker	Prestressed box beam	4	15	260.0	79.2	29.7	9.1
VA-2	Fredericksburg	English	Steel	1	11.3	128.6	39.2	44.1	13.4
VA-3	Staunton	Allegheny	Steel	3	0	340.0	103.6	26.0	7.9
VA-4	North VA	Lane	Steel	2	19	313.0	95.4	40.0	12.2
VA-5	North VA	Lane	Steel	3	0	541.8	165.2	30.0	9.1
VA-6	Lynchburg	English	Steel	4	0	264.8	80.7	36.0	11.0
VA-7	North VA	Lane	Semi-integral Abutment Steel	1	0	159.6	48.6	48.0	14.6
VA-8	Fredericksburg	Abernathy	Steel	1	12	99.0	30.2	40.0	12.2
VA-9	North VA	Shirley	Prestressed concrete slab	3	0	167.7	51.1	32.3	9.9

*English = W. C. English, Inc., Lane = Lane Construction, Abernathy = Abernathy Construction, Plecker = Plecker Construction Co., Allegheny = Allegheny Construction Co. Inc., Shirley = Shirley Contracting

CONCRETE PROPERTIES AND CONSTRUCTION PROCEDURES

The mixture proportions used for the bridge decks are shown in Table 2. Mix designs vary by water-cementitious material (w/cm) ratio (0.40 to 0.45), paste content (27.04 to 30.8%), and quantity [580 to 676 lb/yd^3 (344 to 401 kg/m^3)] and type (portland cement, and slag cement or fly ash) of cementitious material. The paste content and cementitious material content exceed the respective maximums of 27% and 540 lb/yd^3 specified for LC-HPC decks. Three bridges contained Stalite expanded slate lightweight coarse aggregate. Five bridges contained an SRA. Two of the bridges used Sika Control 40, and three used W. R. Grace Eclipse 4500. The paste content was calculated using specific gravity values of 2.93 and 2.43 for slag cement and fly ash, respectively. The exception is for VA-4 and VA-5 for which a mix design with a specific gravity of 2.94 for slag cement was provided and used in calculations. These values were obtained from mix design sheets provided for VA-2 and VA-8. Mix design sheets were not available for the other bridge decks. Therefore, the specific gravity values from these two decks were used in calculations to determine the paste content for the other decks. Based on the typical range of specific gravity for slag cement, 2.85 to 2.95, this could result in a maximum error in paste content equal to 0.2% of the total volume of concrete. Based on the typical range of specific gravities for fly ash, 1.90 to 2.80, however, the actual paste content could be as high as 1.0% greater than reported here.

The plastic concrete properties are shown in Table 3. Average slumps ranged from 3 to 6 in. (75 to 150 mm), air content ranged from 5.2 to 7.7%, and the 28-day compressive strength ranged from 3780 to 7629 psi (26 to 52.6 MPa). With the exception of one deck, the average slumps were above the maximums allowed for LC-HPC, 3 in. on the deck and a maximum of 3½ in. at the truck discharge. Approximately half of the decks had air contents within the LC-HPC recommended range of 8.0 ± 1.5 percent. Two decks had average 28-day compressive strengths above the range specified for LC-HPC decks, 3500 to 5500 psi.

The top reinforcing steel runs in the transverse direction on the decks, and the cover dimensions reported are measured to the center of the bar. According to VDOT personnel, the decks are grooved after wet curing is finished. All decks were wet cured for seven days, except for the three bridges associated with the megaproject around I-95 (VA-4, VA-5, and VA-7). Time to initiation of wet curing after finishing is not known for any of the decks. These decks are wet cured for a minimum of seven days, or until field-cured cylinders reach a minimum of 70% of the design strength. After wet curing is complete, a curing compound is applied to the surface of the deck.

Table 2 –Mixture proportions for Virginia bridge decks

Bridge ID	Date Placed	Cementitious Material**	Coarse Aggregate		Fine Aggregate		SRA Dosage (gallon/yd^3)
			(lb/yd^3)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	
VA-1[SE]	12/4/2012	50% C, 50% S	1985	1178	1022	606	1.0
VA-2	12/13/2011	50% C, 50% S	1944	1153	1096	650	N/A
VA-3[SC4]	12/19/2012	80% C, 20% FA	1832	1087	1217	722	1.0
VA-4[SE]	8/30/2013	50% C, 50% S	1986	1178	1141	677	1.5
VA-5[SE,***]	9/18/2013 9/26/2013	50% C, 50% S	1986	1178	1141	677	1.5
VA-6*	9/26/2012	50% C, 50% S	900	534	1268	752	N/A
VA-7*	2/20/2014	50% C, 50% S	850	504	1305	774	N/A
VA-8[SC4]	8/30/2013	80% C, 20% FA	1715	1017	1320	783	1.5
VA-9*,***	8/21/2013 8/27/2013 10/19/2013	80% C, 20% FA	837	497	1295	768	N/A

Bridge ID	Cementitious Material		Water Content		w/cm Ratio	Paste Content
	(lb/yd^3)	(kg/m^3)	(lb/yd^3)	(kg/m^3)		
VA-1[SE]	650	386	261	155	0.40	28.20
VA-2	676	401	273	162	0.40	29.42
VA-3[SC4]	580	344	261	155	0.45	27.07
VA-4[SE]	600	356	258	153	0.43	27.02
VA-5[SE]	600	356	258	153	0.43	27.02
VA-6*	635	377	286	170	0.45	29.39
VA-7*	660	392	292	173	0.44	30.23
VA-8[SC4]	600	356	258	153	0.43	27.29
VA-9*	675	400	292	173	0.43	30.80

*Coarse aggregate is expanded slate

[SC4] = Contains the SRA Control 40, [SE] = Contains the SRA Eclipse 4500

** C = Cement, S = Slag Cement, FA = Fly Ash

*** The data are ordered in the sequence of placements.

Table 3 – Average plastic concrete properties

Bridge ID	Slump		Air Content (%)	Average Concrete Temperature		Average Air Temperature		28 day Strength	
	(in.)	(mm)		°F	°C	°F	°C	(psi)	(MPa)
VA-1	4	100	7.6	68.0	20.0	55.5	13.1	4340	29.9
VA-2	3¾	95	5.9	63.6	17.6	45.5	7.5	5610	38.7
VA-3	3¾	95	5.7	70.0	21.1	52.6	11.4	4600	31.7
VA-4	4¼	110	5.9	76.2	24.6	65.1	18.4	4760	32.8
VA-5*	5½	140	8.6	74.6	23.7	47.4	8.6	5425	37.4
	5¼	135	6.6	73.5	23.1	51.8	11.0	5250	36.2
VA-6	6	150	7.0	68.5	20.3	58.0	14.4	5480	37.8
VA-7	5¾	145	6.0	65.2	18.4	54.9	12.7	4620	31.8
VA-8	3	75	5.2	77	25.0	71	21.7	3780	26.0
VA-9*	5	125	5.6	70	21.1	80	26.7	8580	59.2
	4¾	125	6.2	80.6	27.0	69.8	21.0	7630	52.6
	4¼	110	7.7	68.6	20.3	63.3	17.4	6990	48.2

*The data are ordered in the sequence of placements.

CRACK SURVEYS

The crack surveys described in this report were completed between July 10 and 17, 2014. Crack widths were no measured. Additional surveys are planned for 2016. Those surveys will include crack-width measurements. Scaled crack maps were completed following the procedure described in Appendix A. The scaled maps are scanned into the computer and converted into an AutoCad file using a program called Print to CAD. The AutoCad files allow the total length of the cracks to be determined.

Results

The completed crack maps for each of the crack surveys are shown. None of the decks surveyed is older than two years, with the exception of the control deck, which was 31 months old. Crack densities measured in the surveys range from 0.007 to 0.849 m/m^2. The average densities for the bridge decks made with an SRA and those made with lightweight concrete equal 0.172

m/m^2 and 0.526 m/m^2, respectively. The crack density of the control deck is 0.222 m/m^2. The crack densities are compared with those of other decks as a function of age.

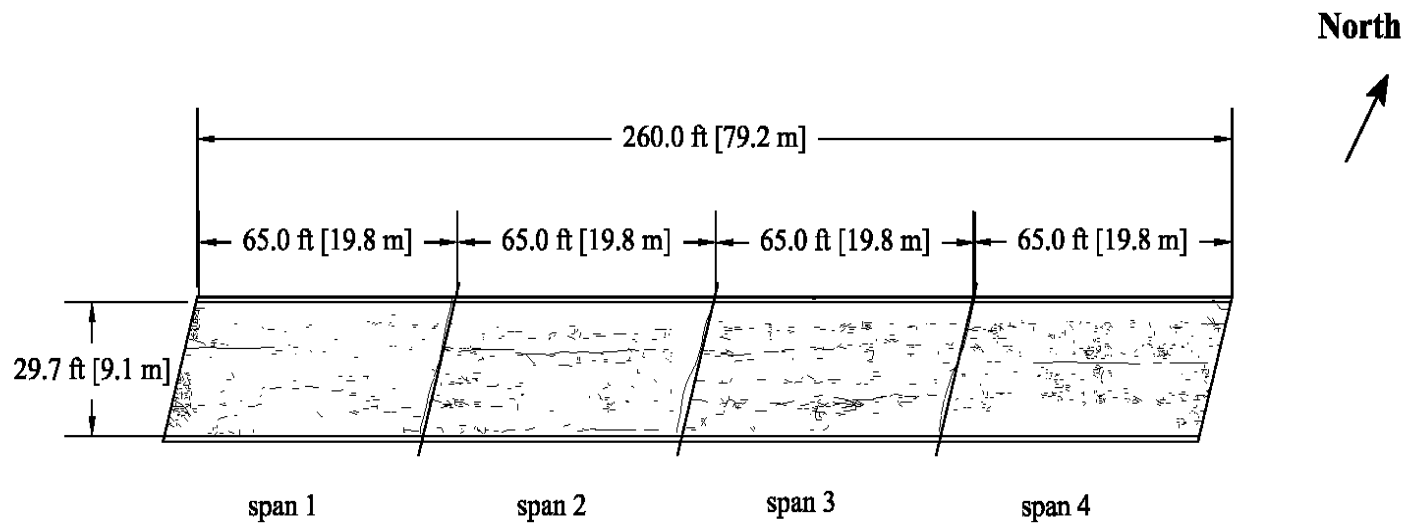
The decks are designated VA-1 through VA-9 for the purpose of this report.

VA-1

VA-1 is a four-span bridge located in the VDOT Staunton district in the town of Broadway and spans Linville Creek on Route 1421. The deck was placed on December 4, 2012. It is supported by prestressed concrete box beams and was constructed by Plecker Construction Co. The concrete contains 650 lb/yd^3 (386 kg/m^3) of cementitious material, 50 percent of which by weight is slag cement, compared to a maximum of 540 lb/yd^3 (320 kg/m^3) used for LC-HPC bridge decks. VA-1 contains the W. R. Grace SRA Eclipse 4500, added at a rate of 1.50 gal/yd^3 (200.5 L/m^3), equal to 1.78% by weight of cementitious material. The w/cm ratio on this deck is 0.40, well below the range of 0.43 to 0.45 used for LC-HPC bridge decks. The paste content was 28.2 percent, by volume, compared to a maximum of 27.00 percent for LC-HPC. Without an SRA, these parameters typically lead to concrete with high crack densities.

The average slump was 4 in. (100 mm), and the average air content was 7.6 percent. The average 28-day strength of lab-cured cylinders was 4340 psi (29.9 MPa), which is in the suggested range of 3500-5500 psi for LC-HPC. The strength, however, is low considering the 0.40 w/cm ratio used for the deck. The average plastic concrete and air temperatures during the deck placement were 68.0 °F (20.0 °C) and 55.5 °F (13.1 °C), respectively. The average evaporation rate during construction was 0.034 lb/ft^2/hr. All of the values are within the allowable range for LC-HPC, with the exception of slump. The *average* slump exceeds the 3½-in. *maximum* slump allowed out of the truck for LC-HPC.

VA-1 was surveyed at an age of 19.1 months. The crack map is shown in Figure 1. The crack density was 0.455 m/m^2 (Figure 1). The majority of cracks in this deck are relatively small, running in the longitudinal direction. This suggests some restraint across the prestressed box beams. There are a few large longitudinal cracks that run along the deck. There is also a large transverse crack over each of the piers. This type of crack pattern is highly unusual; most cracks in bridge decks typically run in the transverse direction.



Bridge Number: B682
Bridge Location: Rte. 1421 over Linville Creek
Construction Date: 12/4/2012
Crack Survey Date: 7/11/2014

Bridge Length: 260.0 ft (79.2 m)
Bridge Width: 29.7 ft (9.1 m)
Skew: 15 °
Number of Spans: 4
- **Span 1:** 65.0 ft (19.8 m)
- **Span 2:** 65.0 ft (19.8 m)
- **Span 3:** 65.0 ft (19.8 m)
- **Span 4:** 65.0 ft (19.8 m)

Number of Placements: 1

Bridge Age: 19.1 months
Crack Density: 0.455 m/m^2
- **Span 1:** 0.492 m/m^2
- **Span 2:** 0.503 m/m^2
- **Span 3:** 0.443 m/m^2
- **Span 4:** 0.383 m/m^2

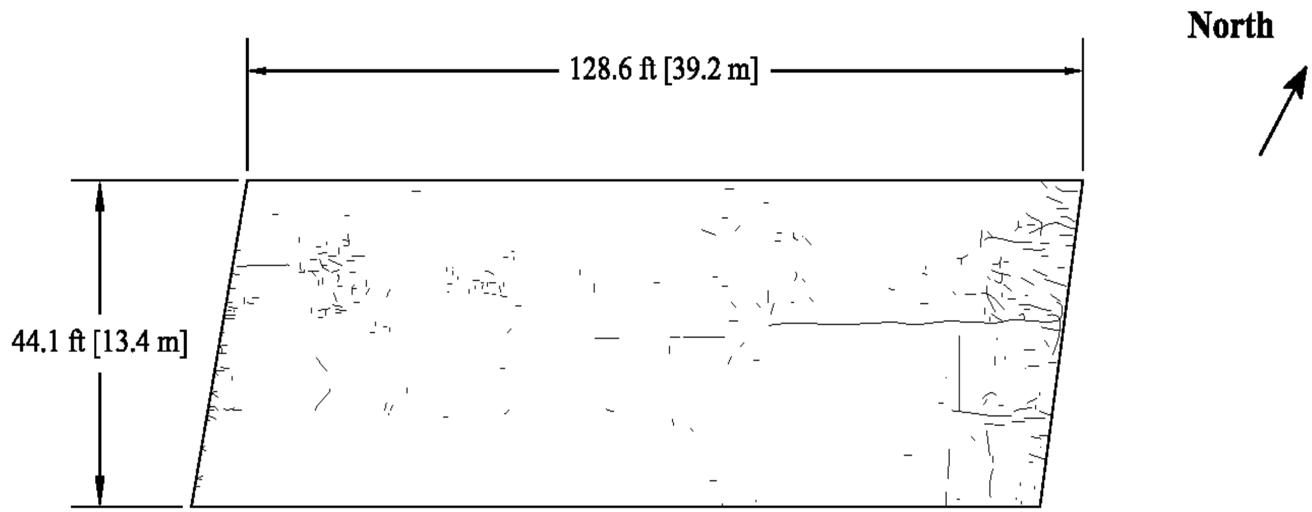
Figure 1: VA-1 (Survey 1)

VA-2

VA-2 is a single-span bridge located about five miles southwest of Spotsylvania on Route 208 and crosses over the Ta River in VDOT's Fredericksburg district. It is supported by steel girders and was constructed by W. C. English, Inc. The deck was constructed on December 13, 2011 in a single placement that began in the morning and continued until early evening. The reinforcing steel on this deck has a top cover to the center of the bar of 2.75 in. (70 mm) and a bottom cover to the center of the bar of 1.50 in. (40 mm). The concrete contains 676 lb/yd^3 (401 kg/m^3) of cementitious material, 50% of which is slag cement. The w/cm ratio used on this deck was 0.40, which is below the LC-HPC range. The paste content was 29.42 percent. It serves as the control deck.

The average slump was 3¾ in. (95 mm), and the average air content was 5.9 percent. The average 28-day strength of the cylinders was 5610 psi (38.7 MPa). The average plastic concrete and air temperatures were 63.6 °F (17.6 °C) and 45.5 °F (7.5 °C), respectively. The average slump and 28-day strength both exceeded the values for LC-HPC, and the air content was below the value for LC-HPC. The concrete temperature and air temperature were all within the acceptable ranges for LC-HPC. Two trucks were rejected for excessive time between batching and placement.

VA-2 was surveyed at an age of 31.0 months. The crack density was found to be 0.222 m/m^2 (Figure 2). The majority of the cracking on this deck is located on the east end of the bridge. There is one large longitudinal crack that extends approximately a third of the way across the deck for the east end. All other cracks are small; most run in the longitudinal direction and are spread out across the middle of the span or at the west end of the bridge. Again, it is unusual to see most cracks running in the longitudinal direction.



Bridge Number: B601
Bridge Location: Rte. 208 over TA River
Construction Date: 12/13/2011
Crack Survey Date: 07/16/2014

Bridge Length: 128.6 ft (39.2 m)
Bridge Width: 44.1 ft (13.4 m)
Skew: 11 °
Number of Spans: 1
Number of Placements: 1

Bridge Age: 31.0 months
Crack Density: 0.222 m/m^2

Figure 2: VA-2 (Survey 1)

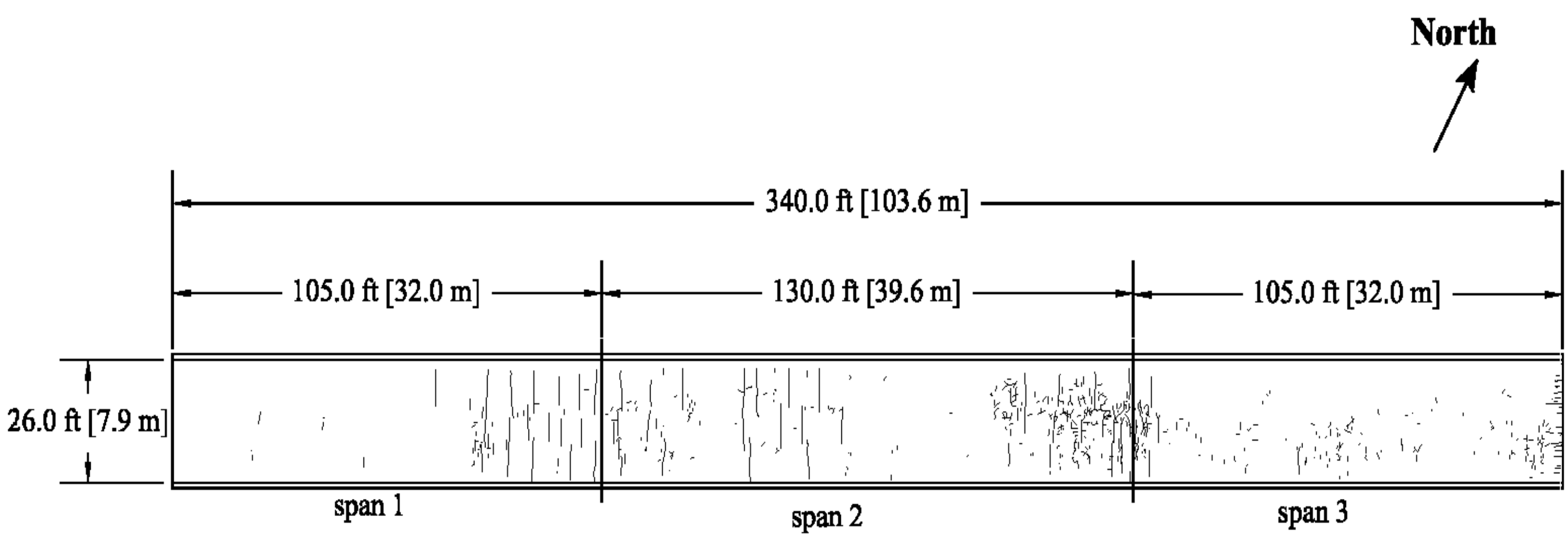
VA-3

VA-3 is a three-span bridge constructed on December 19, 2012. It is located about halfway between Covington and Lexington south of I-64 on McKinney Hollow Road in the Stauton district, and spans the Cowpasture River. The deck is supported by steel girders and was constructed by Allegheny Construction Co. The concrete contains 580 lb/yd^3 (344 kg/m^3) of cementitious material, 20 percent of which is fly ash. The concrete contained the Sika SRA Control 40, at a dosage rate of 1.0 gal/yd^3 (133.7 L/m^3), equal to 1.44% by weight of cementitious material. The w/cm ratio was 0.45, which is within the range used in LC-HPC decks. The paste content was 27.07 percent, just outside the range for LC-HPC.

The average slump was 3¾ in. (110 mm), and the average air content was 5.7 percent. The average 28-day strength was 4600 psi (31.7 MPa). The average plastic concrete and air temperatures were 70.0 °F (21.1 °C) and 52.6 °F (11.4 °C), respectively. The average evaporation rate during construction was 0.138 lb/ft^2/hr. The average slump slightly exceeded the LC-HPC maximum slump of 3½ in. The average air content, however, was significantly lower than the range recommended by the LC-HPC specifications. Strength, temperatures, and the evaporation rate were all within those required for LC-HPC.

VA-3 was surveyed at an age of 18.6 months. The crack density was found to be 0.344 m/m^2 (Figure 3). The cracking on this deck was a combination of long transverse cracks and pockets of smaller transverse and longitudinal cracks. The first span has very little cracking for the first 60% of the span, measured form the south end. A VDOT representative mentioned that construction had gone very well at that end of the deck. No mention was made of what problems arose at other sections of the deck or what made construction on that end that much better. The other portions of Spans 1 and 2 are in far worse condition. Span 2 has a crack density of 0.502

m/m^2 compared to the 0.263 m/m^2 and 0.228 m/m^2 for spans 1 and 3, respectively. Throughout span 2 large transverse cracks can be found. In addition to the large transverse cracks, several small transverse cracks are located closer to the support between spans 2 and 3. Span 3 has mostly small transverse cracks with small longitudinal cracks at the north abutment.



Bridge Number: B626
Bridge Location: RTE. 633 over Cowpasture River
Construction Date: 12/19/2012
Crack Survey Date: 7/10/2014

Bridge Length: 340.0 ft (103.6 m)
Bridge Width: 26.0 ft (7.9 m)
Skew: 0°
Number of Spans: 3
- **Span 1:** 105.0 ft (32.0 m)
- **Span 2:** 130.0 ft (39.6 m)
- **Span 2:** 105.0 ft (32.0 m)

Number of Placements: 1

Bridge Age: 18.6 months
Crack Density: 0.344 m/m^2
- **Span 1:** 0.263 m/m^2
- **Span 2:** 0.502 m/m^2
- **Span 3:** 0.228 m/m^2

Figure 3: VA-3 (Survey 1)

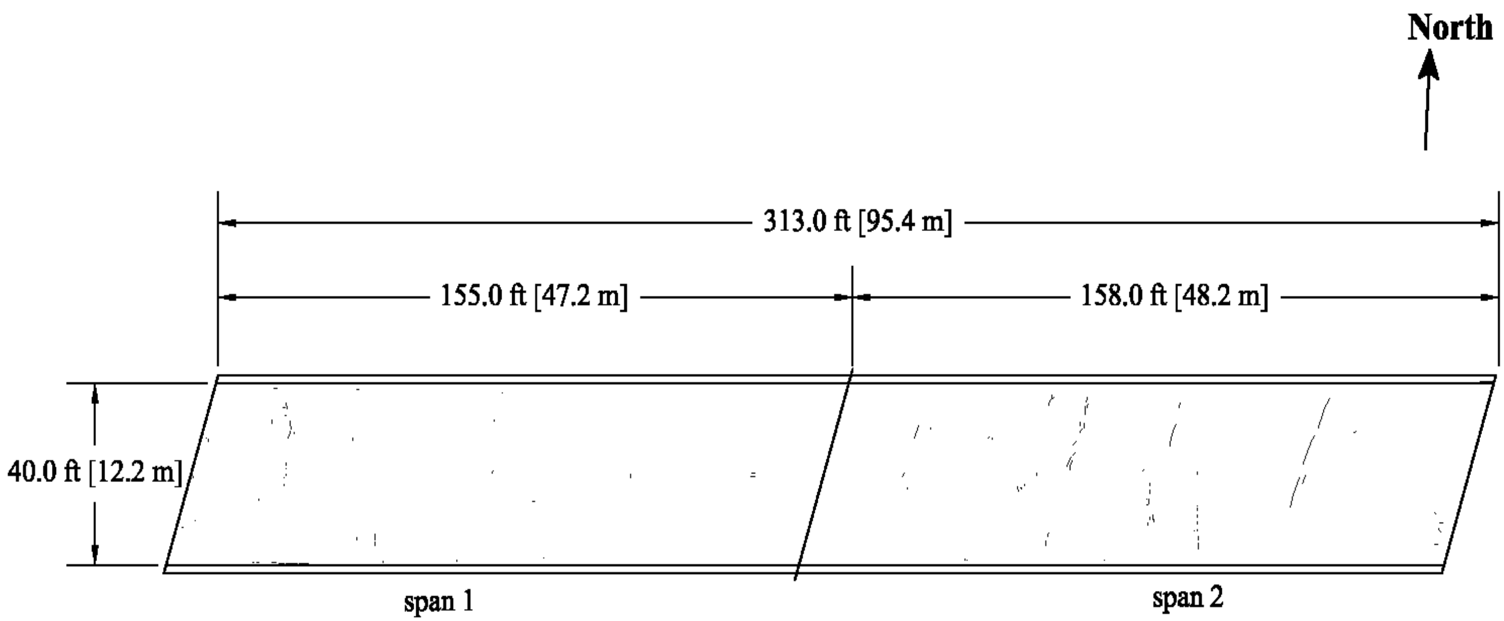
VA-4

VA-4 is located south of the town of Triangle on Telegraph Road spanning I-95. This bridge is part of the I-95 megaproject that is improving I-95 in the Northern Virginia district. It is a two-span bridge supported by steel girders and was built by Lane Construction. The deck was cast with a single placement at night on August 30, 2013. The concrete contains 600 lb/yd^3 (356 kg/m^3) of cementitious material, 50 percent of which is slag cement, and contains the SRA Eclipse 4500 at a dosage rate of 1.50 gal/yd^3 (200.5 L/m^3), or 1.93% by weight of cementitious material. The w/cm ratio used on this deck was 0.43, which is lower than the 0.44-0.45 range used in LC-HPC decks. The paste content was 27.02 percent.

The average slump was 5½ in. (140 mm), and the average air content was 6.0 percent. The average 28-day strength was 4760 psi (32.8 MPa). The average plastic concrete and air temperatures were 76.2 °F (24.6 °C) and 65.1 °F (18.4 °C), respectively. The slump, air content, and concrete temperature were outside of the ranges specified for LC-HPC.

The average evaporation rate during placement was calculated to be 0.018 lb/ft^2/hr, which is well below the maximum of 0.2 lb/ft^2/hr prescribed in the LC-HPC specifications. The deck was cured for seven days. Soaked burlap was placed on the deck and moisture was maintained with an automated system. The system runs for fifteen minutes and rests for thirty minutes for the entirety of the seven days. Plastic was used to reduce evaporation. At seven days the compressive strength of the concrete was found to be 80 percent of the design strength, which is above the 70 percent of strength necessary for curing to cease.

VA-4 was surveyed at an age of 10.5 months. The crack density was 0.027 m/m^2 (Figure 4). Span 1 has a few small transverse and longitudinal cracks scattered throughout. In addition to these small cracks, one longitudinal crack with an approximate length of 9.3 ft (2.8 m) has formed on the south side of the span. There is more cracking on span 2 than on span 1, with varying size cracks that run almost exclusively in the transverse direction. The crack density, however, is very low throughout the deck.



Bridge Number: B607
Bridge Location: Telegraph Road over I-95
Construction Date: 8/30/2013
Crack Survey Date: 7/15//2014

Bridge Length: 313.0 ft (95.4 m)
Bridge Width: 40.0 ft (12.2 m)
Skew: 19°
Number of Spans: 2
Span 1: 155.0 ft (47.2 m)
Span 2: 158.0 ft (48.2 m)
Number of Placements: 1

Bridge Age: 10.5 months
Crack Density: 0.027 m/m^2
Span 1: 0.037 m/m^2
Span 2: 0.016 m/m^2

Figure 4: VA-4 (Survey 1)

VA-5

VA-5 is located in the town of Triangle and is a flyover for Joplin Road on I-95. Like VA-4, it is also part of the megaproject currently improving I-95. It is supported by steel girders and was built by Lane Construction. It was cast in two night placements on September 18 and 26, 2013. The reinforcing steel has a top cover to the center of the bar of 2¾ in. (70 mm) and a bottom cover to the center of the bar of 1½ in. (40 mm). The concrete mixture proportions were the same as those used for VA-4, including the SRA dosage. VA-5 is a curved bridge. However, because the total area of the crack map does not change, a straight crack map is used for simplicity. The procedures in Appendix A outline how curved bridges are handled during a survey.

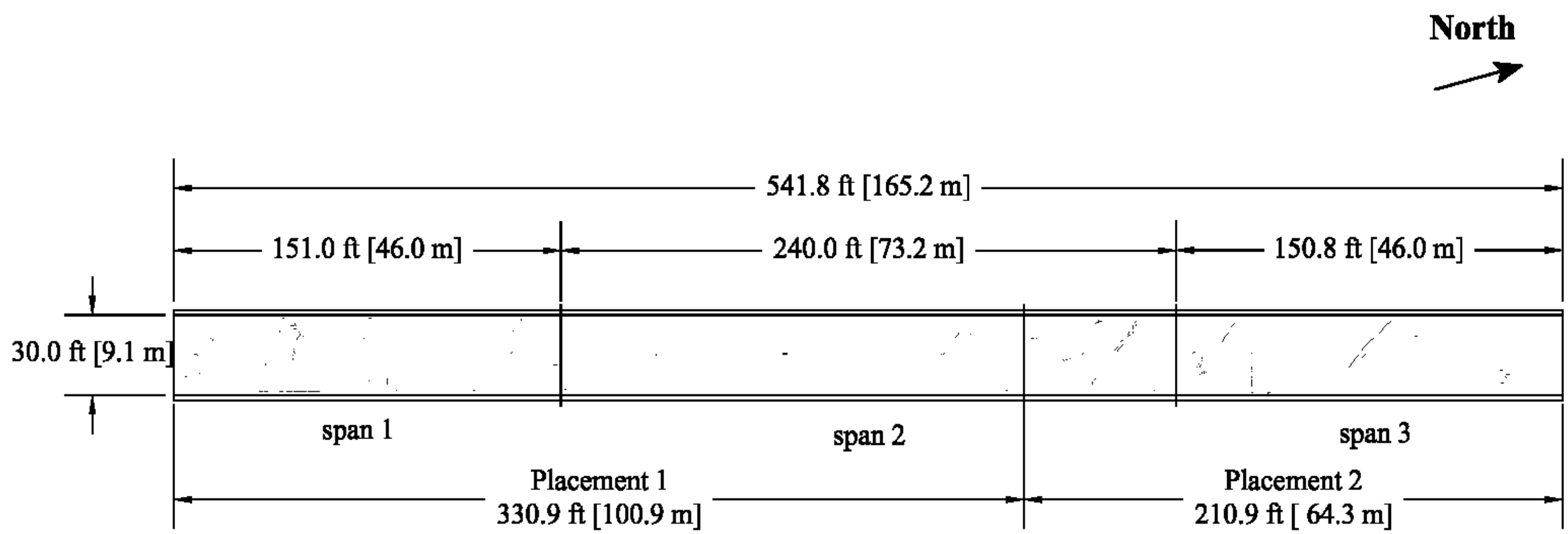
For the first placement, the average slump was 5½ in. (140 mm), and the average air content was 7.0 percent. The average 28-day strength of the cylinders taken for this deck was 5425 psi (37.4 MPa). The average plastic concrete and air temperatures were 74.6 °F (23.7 °C) and 47.4 °F (8.6 °C), respectively. The average evaporation rate during construction was 0.066 lb/ft^2/hr. Slump, concrete temperature, and the difference between air temperature and concrete temperature exceeded LC-HPC limits. Air content, strength, and evaporation all met the requirements.

For the second placement, the average slump was 5¼ in. (130 mm), and the average air content was 6.6 percent. The average 28-day strength of the cylinders taken for this deck was 5250 psi (36.2 MPa). The average plastic concrete and air temperatures were 73.5 °F (23.1 °C) and 51.8 °F (11.0 °C), respectively. Only the strength and difference between concrete and air temperatures met LC-HPC.

The first placement was cured for 15 days with soaked burlap lined on one side with plastic. The contractor utilized an automated system placed underneath the burlap, directly on the concrete, that would operate for fifteen minutes and rest for thirty. Curing was stopped after seven days. At

15 days, the field cured cylinders had reached at least 70 percent of the design strength. The second placement was cured for ten days using the same procedure.

VA-5 was surveyed with the first and second placements at 9.8 and 9.5 months, respectively. The overall crack density was found to be 0.007 m/m^2 (Figure 5). From span to span there is very little difference in crack density. There is very minimal cracking at the north abutment, and zero cracking at the south abutment. All of the cracks on this deck are relatively small. The larger cracks run in the transverse direction and the smaller cracks run in the longitudinal direction. Placement 2, with a crack density of 0.012 m/m^2, has more than double the crack density of placement 1 (0.005 m/m^2). Both placements, however, have very little cracking. It should be noted that this bridge had not been opened to traffic at the time of the crack survey. With the deck being as young as it is, very little cracking was to be expected.



Bridge Number: B603
Bridge Location: JHS Flyover over I-95
Construction Date:
Placement 1: 9/18/2013
Placement 2: 9/26/2013
Crack Survey Date: 7/14/2014

Bridge Length: 541.8 ft (165.2 m)
Bridge Width: 30.0 ft (9.1 m)
Skew: 0°
Number of Spans: 3
Span 1: 151.0 ft (46.0 m)
Span 2: 240.0 ft (73.2 m)
Span 3: 150.8 ft (46.0 m)
Number of Placements: 2

Bridge Age:
Placement 1: 9.8 months
Placement 2: 9.5 months
Crack Density: 0.007 m/m^2
Span 1: 0.008 m/m^2
Span 2: 0.007 m/m^2
Span 3: 0.006 m/m^2
Placement 1: 0.005 m/m^2
Placement 2: 0.012 m/m^2

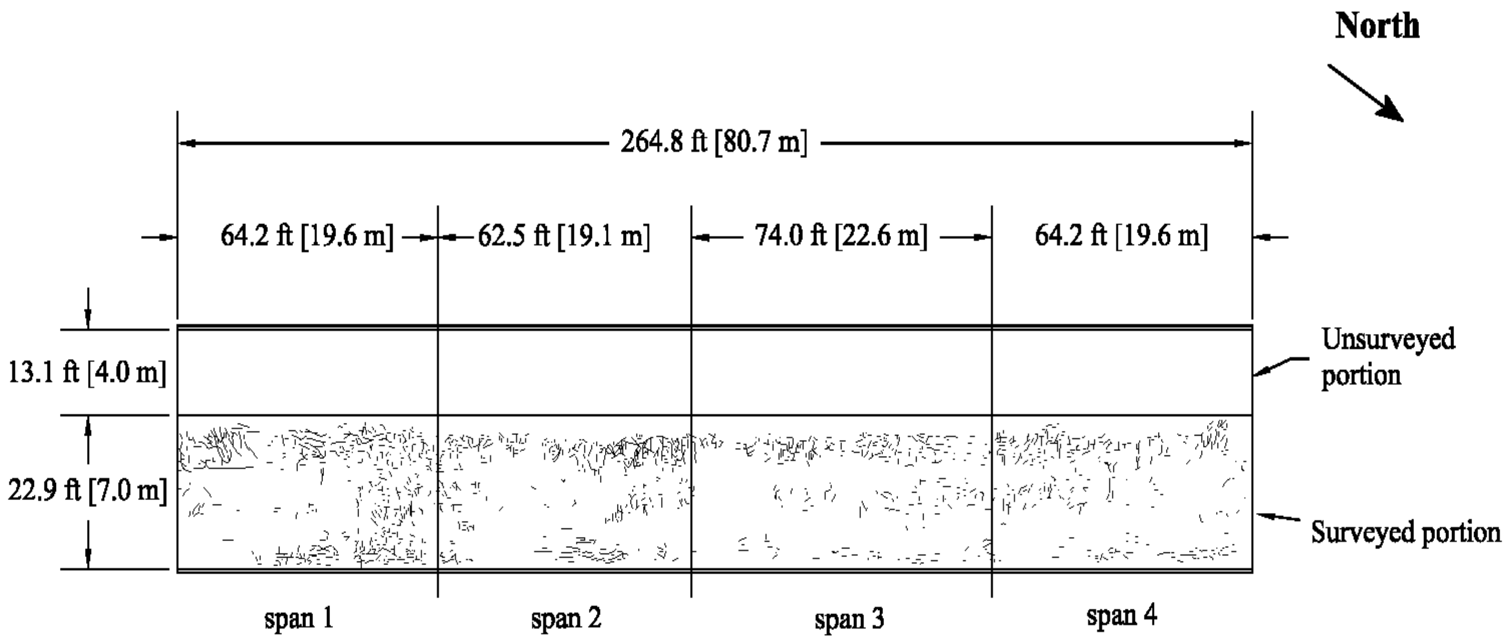
Figure 5: VA-5 (Survey 1)

VA-6

VA-6 carries the westbound lanes of Chandlers Mountain Road over the Norfolk Southern Railway in the city of Lynchburg and Lynchburg district. The four-span deck is supported by steel girders and was constructed by W. C. English, Inc. with a single placement on September 26, 2012. The concrete contains 635 lb/yd^3 (377 kg/m^3) of cementitious material, 50 percent of which is slag cement. The deck was cast with lightweight concrete that contains expanded slate for 100 percent of the coarse aggregate. The w/cm ratio on this deck was 0.45, which is within the range suggested in the LC-HPC specifications. The paste content was 29.39 percent. Both the paste content and cementitious material content exceeded the maximum values for LC-HPC decks.

The average slump was 6.0 in. (150 mm), and the average air content was 7.0 percent. The average 28-day strength of the concrete was 5480 psi (28.8 MPa). The average plastic concrete and air temperatures were 68.5 °F (20.3 °C) and 58.0 °F (14.4 °C), respectively. The average evaporation rate during construction was 0.0335 lb/ft^2/hr. The only plastic concrete property that did not meet LC-HPC was slump.

VA-6 was surveyed at an age of 21.4 months. The crack density was 0.719 m/m^2 (Figure 6). Due to the high crack density of the bridge and time constraints placed on the survey crew, only half of the bridge was surveyed. Crew members were able to check various areas of the unsurveyed portion of the deck to ensure that the half surveyed was representative of the entire bridge deck. Span 1 is in the worst condition of the four spans, with a crack density of 1.02 m/m^2. Most of the cracks on this span run in the longitudinal direction. While most of these cracks are small, there are several larger longitudinal cracks near the centerline of the bridge. Most of the cracks on span 2 are also small longitudinal cracks. There is also a small area of map cracking closer to the support between span 2 and span 3. The majority of the cracks in span 3 and span 4 also run in the longitudinal direction. As with the first two spans, the cracks are predominately small. For a bridge that is less than two years old, this deck is in very poor condition. As with VA-1 and VA-2, the fact that most of the cracking is in the longitudinal direction is highly unusual.



Bridge Number: B623
Bridge Location: WB RTE. 128 over Norfolk Southern Railway
Construction Date: 09/26/2012
Crack Survey Date: 07/10/2014

Bridge Length: 264.8 ft (80.7 m)
Bridge Width: 36.0 ft (11.0 m)
Skew: 0°
Number of Spans: 4
Span 1: 64.2 ft (19.6 m)
Span 2: 62.5 ft (19.1 m)
Span 3: 74.0 ft (22.6 m)
Span 4: 64.2 ft (19.6 m)
Number of Placements: 1

Bridge Age: 21.4 months
Crack Density: 0.719m/m^2
Span 1: 1.020 m/m^2
Span 2: 0.830 m/m^2
Span 3: 0.494 m/m^2
Span 4: 0.570 m/m^2

Figure 6: VA-6 (Survey 1)

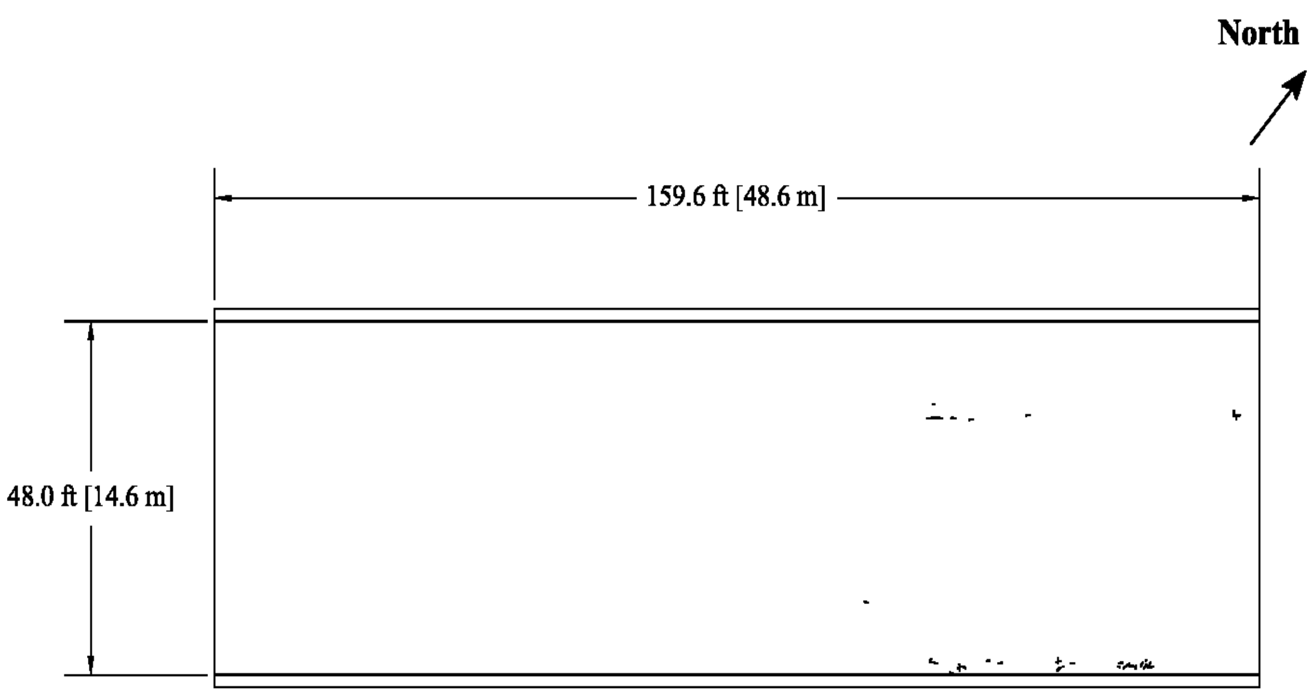
VA-7

VA-7 is the new I-95 HOV lane over Aquia Creek near Aquia Harbour. It is part of the same megaproject as VA-4 and VA-5. It is a single-span bridge supported by steel girders that are semi-integral with the abutments, and, like VA-4 and VA-5, was built by Lane Construction. It was cast on February 20, 2014 with a single placement starting in the morning and continuing on into midafternoon. The reinforcing steel has a top cover to the center of the bar of 2½ in. (65 mm) and a bottom cover to the center of the bar of 1¼ in. (30 mm). The concrete contains 660 lb/yd^3 (392 kg/m^3) of cementitious material, 50 percent of which is slag cement. The concrete for this deck is lightweight concrete that uses expanded slate for 100 percent of the coarse aggregate. The w/cm ratio is 0.44, which is within the range for LC-HPC. The paste content was 30.23 percent.

The average slump on the placement was 5½ in. (140 mm), and the average air content was 6.0 percent. The average 28-day compressive strength was 4620 psi (31.8 MPa). The average concrete temperature during the placement was 65.2 °F (18.4 °C), and the average air temperature was 54.9 °F (12.7 °C). The average evaporation rate during construction was 0.0315 lb/ft^2/hr. The slump and air content was outside LC-HPC, while all other plastic concrete properties were within LC-HPC ranges. It should be noted that the first load of concrete was placed when the air temperature was below 40 °F (4 °C), which is not permitted for LC-HPC. Additionally, two trucks, the first and twenty third, were rejected due to high slump. The fact that two trucks were rejected suggests that good quality control practices were in place.

The average evaporation rate was calculated to be 0.06 lb/ft^2/hr, well below the maximum of 0.2 lb/ft^2/hr. The deck was cured for twelve days with soaked burlap and an automated system. The system would run for fifteen minutes and rest for thirty. Plastic was used to help reduce evaporation. Curing time was considered to be sufficient at 12 days, when the field cured cylinders reached at least 70% of the design strength.

VA-7 was surveyed at 4.8 months, too early to learn much about the cracking tendency of the deck. The crack density was just 0.009 m/m^2 (Figure 7). Only a few very small longitudinal cracks were found during the survey, which is not surprising considering the age of the deck. The deck had not been opened to traffic at the time of the survey.



Bridge Number: B608
Bridge Location: I-95 over Aquia Creek
Construction Date: 02/20/2014
Crack Survey Date: 07/17/2014

Bridge Length: 159.6 ft (48.6 m)
Bridge Width: 48.0 ft (14.6 m)
Skew: 0°
Number of Spans: 1
Number of Placements: 1

Bridge Age: 4.8 months
Crack Density: 0.009 m/m^2

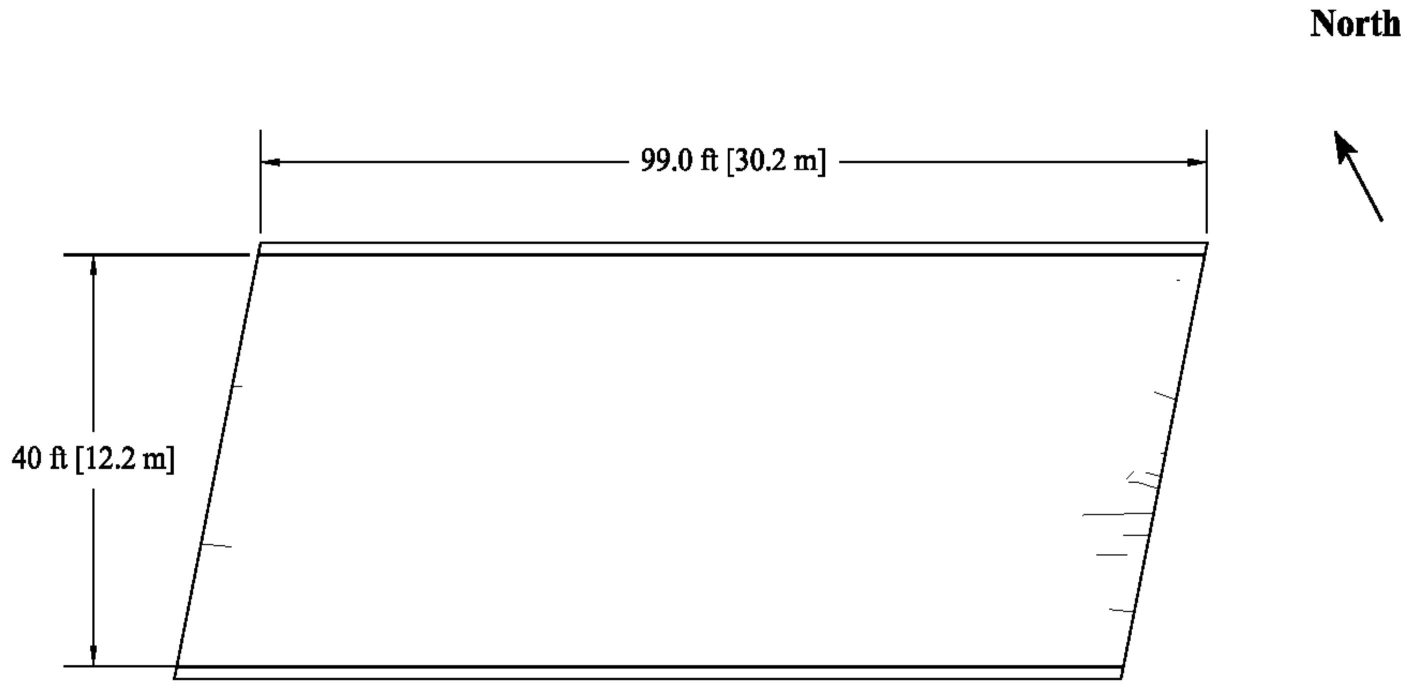
Figure 7: VA-7 (Survey 1)

VA-8

VA-8 is a single-span bridge located in the Fredericksburg district, about 30 miles northeast of Richmond on Route 600 over Herring Creek. The deck is supported by steel girders and was built by Abernathy Construction. The deck was cast with a single placement on August 30, 2013. The reinforcing steel has a top cover to the center of the bar of 2¾ in. (70 mm) and a bottom cover to the center of the bar of 1½ in. (40 mm). The concrete contains 600 lb/yd^3 (356 kg/m^3) of cementitious material, 20 percent of which is fly ash, and the Sika SRA Control 40, which was used at a dosage rate of 1.50 gal/yd^3 (200.5 L/m^3), or 2.09% by weight of cementitious material. The w/cm ratio for this deck was 0.43, which is lower than used for LC-HPC decks. The paste content was 27.29 percent.

The average slump was 3 in. (75 mm), and the average air content was 5.2 percent. The average 28-day strength was 3780 psi (26.0 MPa). The average concrete temperature during placement was 77.0 °F (25.0 °C), and the average ambient temperature was 71.0 °F (21.7 °C). The average evaporation rate during construction was 0.017 lb/ft^2/hr. All plastic concrete properties were within LC-HPC range with the exception of concrete temperature, which exceeded the maximum temperature allowed.

VA-8 was surveyed at 10.5 months, and crack density was 0.025 m/m^2 (Figure 8). The only cracks on the deck are short longitudinal cracks originating at the abutments.



Bridge Number: B615
Bridge Location: Rte. 600 over Herring Creek
Construction Date: 08/30/2013
Crack Survey Date: 07/16/2014

Bridge Length: 99.0 ft (30.2 m)
Bridge Width: 40.0 ft (12.2 m)
Skew: 12 °
Number of Spans: 1
Number of Placements: 1

Bridge Age: 10.5 months
Crack Density: 0.025 m/m^2

Figure 8: VA-8 (Survey 1)

VA-9

VA-9 is approximately 5 miles southeast of Nokesville on Route 646 over Cedar Run in the Northern Virginia district. This deck is supported by a prestressed concrete slab and was constructed by Shirley Contracting. The deck was cast in three placements on August 21, 27 and October 19, 2013. All placements uses the same mix design that contains 675 lb/yd^3 (400 kg/m^3) of cementitious material, 20 percent of which is fly ash. The concrete for this deck is lightweight, using expanded slate as 100 percent of the coarse aggregate. The w/cm ratio is 0.43, which is lower than a LC-HPC deck. The paste content is 30.80 percent.

VA-9 was constructed in two stages and four placements. Stage one was the construction of the eastbound lane. For this stage, Span 2 and Span 3 (labeled 1 in Figure 9A), excluding the closure strip (labelled 2 in Figure 9A) between them, were constructed on August 21, 2013; Span 1 and both closure stripes of east bound lane (labelled 2 in Figure 9A) were placed on August 27,. Stage two was the construction of the westbound lane of the bridge, all three spans (labeled 3 in Figure 9A), excluding the two closure stripes (labeled 4 in Figure 9A), were placed on October 19, 2013; the closure stripes were placed on October 22. All closures are four feet wide centered at the piers. Figure 9A illustrates the construction sequence of VA-9, the numbers indicate construction stages and placements. Since the closure stripes-having the same mix design properties but different placement dates compared to the adjacent slabs- appeared to have not a significant cracking pattern, the crack density was calculated with assumption that there were only three placements on the bridge (instead of four), as shown in Figure 9B.

For the first placement, the average slump was 5 in. (125 mm), the average air content was 5.6 percent. These are above and below, respectively, the LC-HPC values. The average 28-day strength was 8580 psi (59.2 MPa), which exceeded the LC-HPC maximum. The average concrete and air temperature during construction was 70 °F (21.1 °C) and 80 °F (26.7 °C), respectively. No specific curing information was found for this placement; according to VDOT personnel, immediately after concrete placement the deck was covered with wet burlap, soaker hoses, and polyethylene sheets, curing lasted for 7 days.

For the second placement, the average slump was 4¾ in. (125 mm), and the average air content was 6.2 percent. The average 28-day strength was 7630 psi (52.6 MPa), which is above the LC-HPC maximum. The average plastic concrete and air temperatures were 80.6 °F (27.0 °C) and 69.8 °F (21.0 °C), respectively. Placement 2 was cured with soaked burlap and polyethylene for seven days, until field cured cylinders exhibited strengths higher than required strength of 4000 psi. Concrete was checked daily by the contractor during curing.

For the third placement, the average slump was 4¼ in. (110 mm), and the average air content was 7.7 percent. The average 28-day strength of the cylinders taken for this deck was 6990 psi (48.2 MPa). The average plastic concrete and air temperatures were 68.6 °F (20.3 °C) and 63.3 °F (17.4 °C), respectively. Placement 3 was also cured with wet burlap and polyethylene; five days after placement, field cured cylinders was tested and did not satisfy the required strength. According to VDOT personnel, curing lasted for a total of 7 days.

VDOT personnel indicated that the lightweight aggregate was not properly pre-wetted prior to mixing, which may have played a role in variations in compressive strength and degree of cracking.

VA-9 was surveyed with the three placements at 10.8, 10.6 and 8.8 months, respectively. The overall crack density was 0.849 m/m^2 (Figure 9). This deck has a severe cracking problem for a deck of any age and is less than one year old. Placement 1 has serious cracking issues, with a crack density of 1.145 m/m^2, not only with the frequency of the cracks, but the size of them as well. Two cracks on placement 1 had grown large enough to warrant patching. Span 2 has a mixture of large and small transverse and longitudinal cracks on placement 1. On placement 1 in span 3, there is a high number of large transverse cracks connected with smaller longitudinal cracks. Placement 2 has similar cracking with Placement 1, and the crack density is 1.475 m/m^2. There is a large amount of small longitudinal cracks, as well as some larger transverse and longitudinal cracks. Placement 3 is in significantly better condition than placements 1 and 2, with a crack density of 0.531 m/m^2. On placement 3 in span 1, cracking consists of very small longitudinal cracks. Placement 3 in span 2 has mostly small longitudinal cracks. There is, however, one large transverse crack near the pier between spans 2 and 3. On placement 3 in span 3 there are several larger longitudinal cracks above the support between spans 2 and 3, with one large transverse crack, also above the support. The rest of the span has only smaller longitudinal cracks. The size and frequency of the longitudinal cracks, as was mentioned earlier, is atypical.

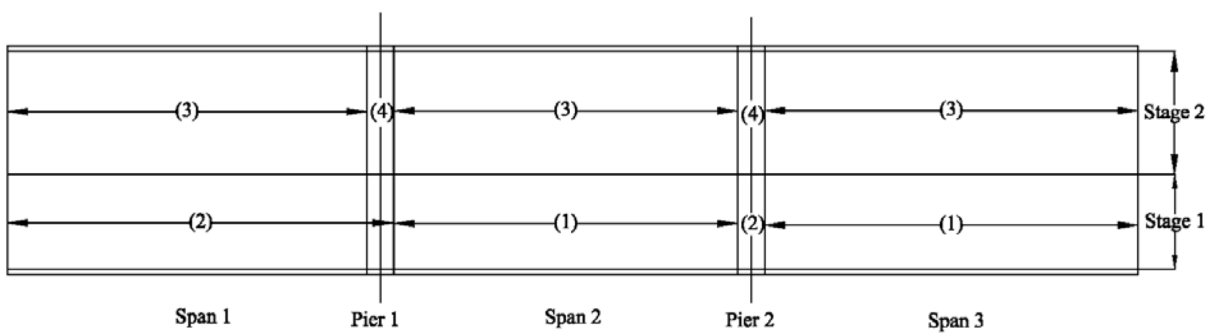
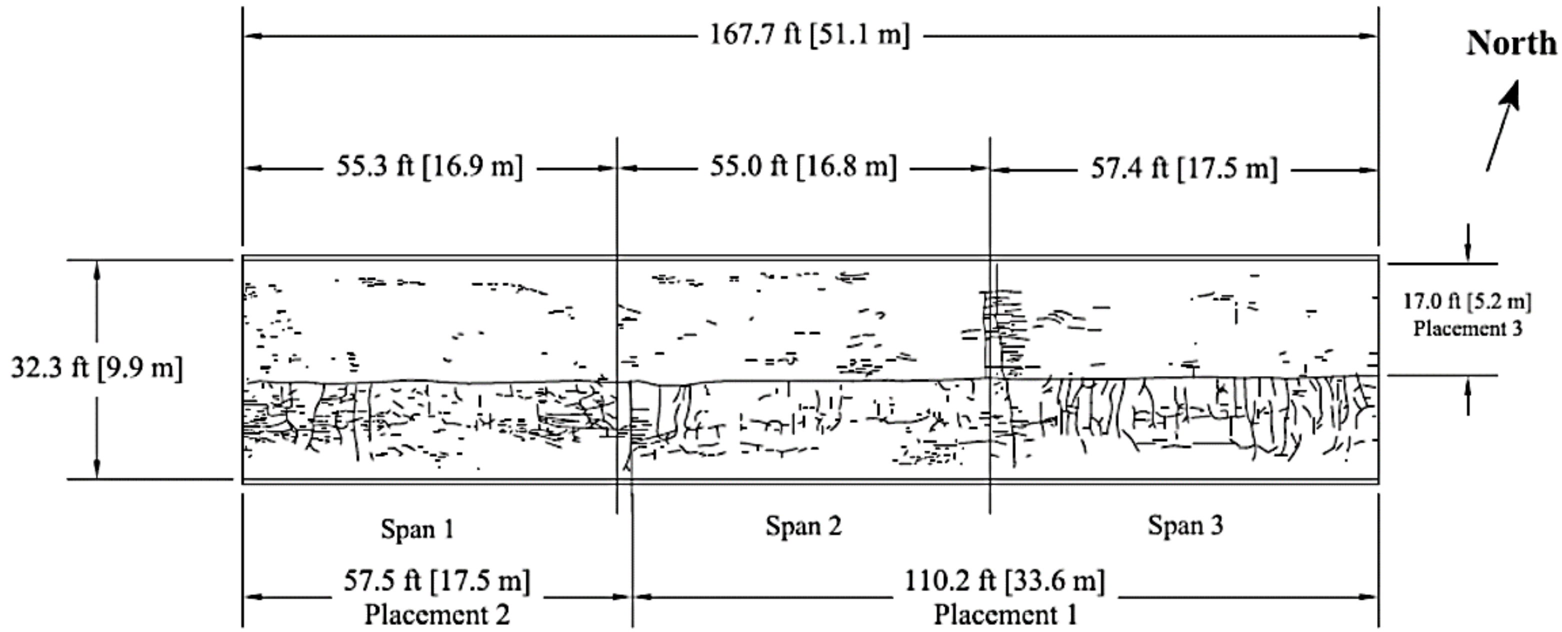


Figure 9A: Construction Sequence of VA-9



Bridge Number: B617
Bridge Location: Rte. 646 Aden Rd over Cedar Run
Construction Date:
- **Placement 1:** 8/21/2013
- **Placement 2:** 8/27/2013
- **Placement 3:** 19/10/2013

Crack Survey Date: 7/15 /2014

Bridge Length: 167.7 ft (51.1 m)
Bridge Width: 32.3 ft (9.9 m)
Skew: 0°
Number of Spans: 3
- **Span 1:** 55.3 ft (16.9 m)
- **Span 2:** 55.0 ft (16.8 m)
- **Span 3:** 57.4 ft (17.5 m)

Number of Placements: 3

Bridge Age:
- **Placement 1:** 10.8 months
- **Placement 2:** 10.6 Months
- **Placement 3:** 8.9 months

Crack Density: 0.849 m/m^2
- **Span 1:** 0.844 m/m^2
- **Span 2:** 0.709 m/m^2
- **Span 3:** 0.988 m/m^2
- **Placement 1:** 1.145 m/m^2
- **Placement 2:** 1.475 m/m^2
- **Placement 3:** 0.531 m/m^2

Figure 9B: VA-9 (Survey 1)

COMPARISON WITH LC-HPC BRIDGE DECKS

Table 4 provides an overview of the survey data. Table 5 provides an overview of the average crack density of each type of deck, although the comparisons shown in Table 5 are, at this time, preliminary at best. It should be noted that the control deck surveyed in Virginia is performing well relative to control decks in Kansas at a similar age. As pointed out earlier, the lightweight aggregate used in the three placements of VA-9 was not properly pre-wetted, which likely affected both strength and density, and weighted the average values for LWA decks for both.

Table 4 – Summary of crack densities for Virginia bridge decks

#	Date Cast	Type of Support	Age at Survey (month)	Type of Deck	Crack Density (m/m^2)
VA-1	12/4/2012	Prestressed box beam	19.1	SRA	0.455
VA-2	5/15/2013	Steel	31.0	Control	0.222
VA-3	12/19/2012	Steel	18.6	SRA	0.344
VA-4	8/30/2013	Steel	10.5	SRA	0.027
VA-5[1]	9/18/2013	Steel	9.8	SRA	0.005
	9/26/2013		9.5		0.012
VA-6	9/26/2012	Steel	21.4	LWC	0.719
VA-7	2/20/2014	Semi-integral abutment steel	4.8	LWC	0.009
VA-8	8/30/2013	Steel	10.5	SRA	0.025
VA- 9[1]	8/21/2013	Prestressed slab	10.8	LWC	1.145
	8/27/2013		10.6		1.475
	10/19/2013		8.9		0.531

[1] = First row is for placement 1 and the second row is for placement 2.

Table 5 – Summary of average crack densities for each type of bridge deck

Type of Deck	Number of Decks	Average Age (month)	Average Paste Content (%)	Average 28-Day Compressive Strength (psi)	Average Crack Density (m/m^2)
SRA	5	13.7	27.32	4892	0.172
Lightweight	3	11.3	30.14	6660	0.526
Control	1	31.0	29.42	5610	0.222

Shrinkage Reducing Admixture

The addition of shrinkage reducing admixtures has proven effective in reducing the drying shrinkage of concrete (Pendergrass et al. 2014). Therefore, when used in bridge decks, SRAs can potentially reduce cracking caused by restrained shrinkage. To study the effectiveness of shrinkage reducing admixtures in alleviating cracking in bridge decks, the crack densities of the five Virginia bridge decks are compared with the control and LC-HPC decks in Kansas and the control deck in Virginia, which contain no SRAs. The information on the five decks is summarized in Table 6. As shown in the table, the decks were constructed with concrete containing Control 40 or Eclipse 4500. Crack densities for the control decks in Kansas are used because only a single data point is available for Virginia.

Table 6 – Summary of SRA information and crack densities of five Virginia decks

#	SRA Used	Producer	Dosage (gallon/yd^3)	Age at Survey (month)	Crack Density (m/m^2)
VA-1	Eclipse 4500	W. R. Grace	1.5	19.1	0.455
VA-3	Control 40	Sika Corp.	1.0	18.6	0.344
VA-4	Eclipse 4500	W. R. Grace.	1.5	10.5	0.027
VA-5 Placement 1	Eclipse 4500	W. R. Grace	1.5	9.8	0.005
VA-5 Placement 2				9.5	0.012
VA-8	Control 40	Sika Corp.	1.5	10.5	0.025

Figures 10 and 11 compare the crack densities of the decks in Virginia with, respectively, those of control decks and LC-HPC decks in Kansas as a function of age. Data is plotted by placement when more than one placement is used. As shown in Figure 10, three of the decks containing an SRA exhibit low crack densities at early ages, 10 to 11 months, when compared to control decks, but the two bridges with ages near 19 months exhibit higher crack densities than the average for the control decks at that age. The VA control deck is performing well when compared with the Kansas control decks. Figure 11 also shows that the decks containing an SRA had low crack densities in their early ages (first 12 months in use) when compared to LC-HPC decks. The two decks surveyed at 19 months, however, exhibit higher crack densities than the LC-HPC decks. In fact, the crack densities of these two decks are higher than most of LC-HPC decks, independent of age. Since the five data points for decks containing an SRA were collected from different decks, no conclusion can yet be made in terms of the long-term performance of SRAs in reducing deck cracking. Further surveys are planned.

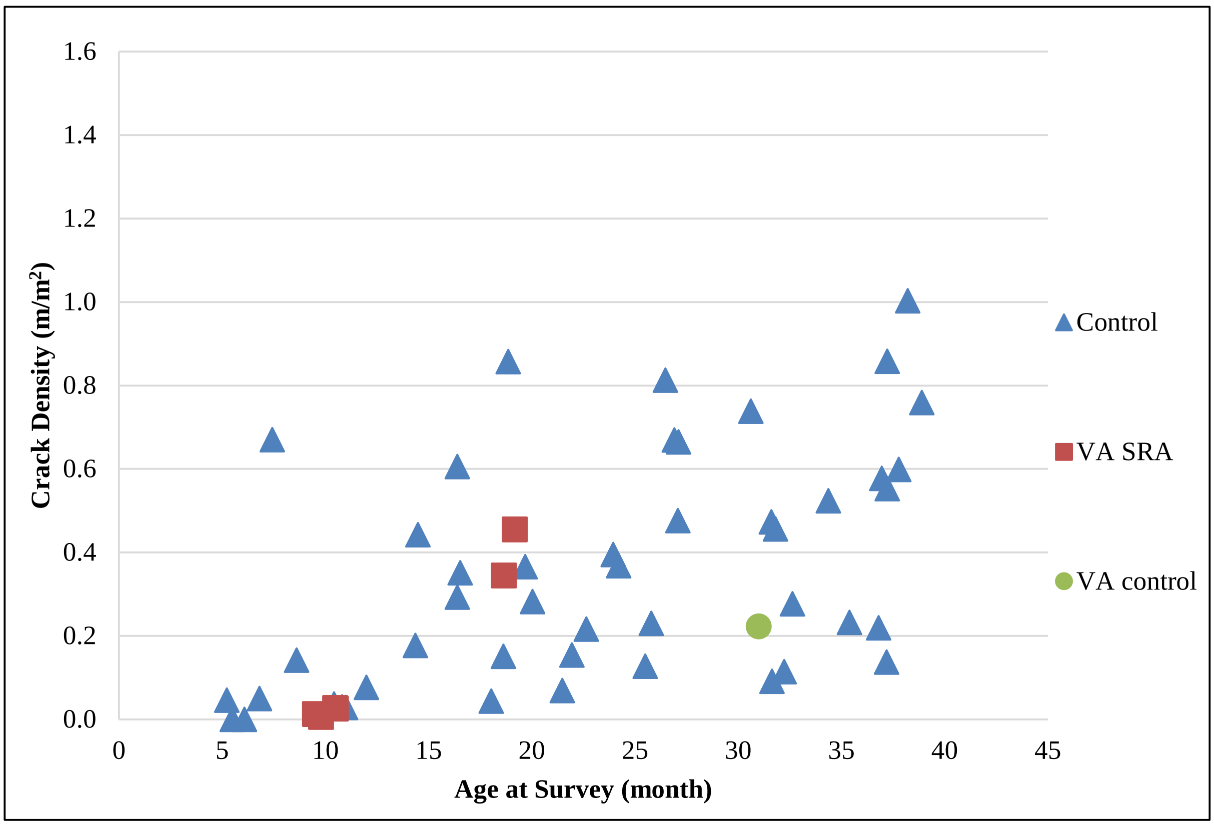


Figure 10: Crack densities of control decks and SRA decks versus bridge age

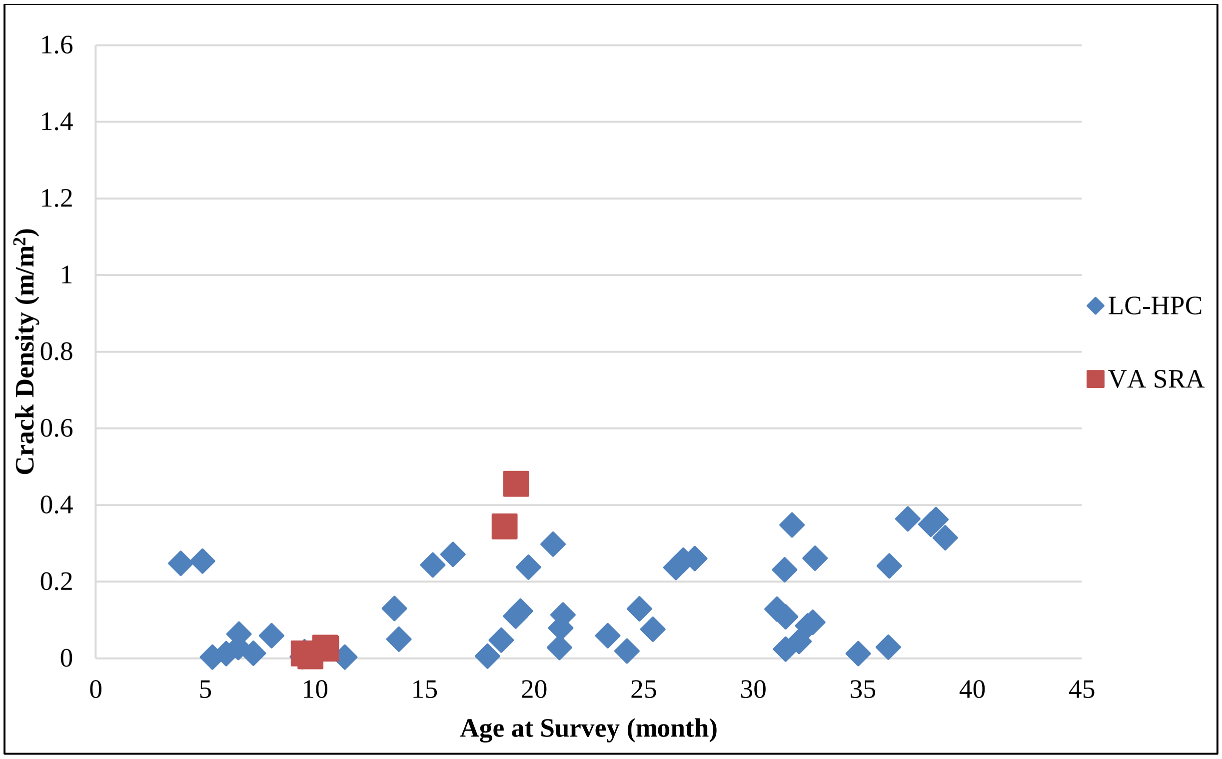


Figure 11: Crack densities of LC-HPC decks and SRA decks versus bridge age

Lightweight Aggregate

Studies performed at the University of Kansas show that the use of pre-wetted *fine* lightweight aggregate (LWA) reduces the shrinkage of concrete by providing internal curing (Reynolds et al. 2009, Browning et al. 2011). Three Virginia decks (VA-6, VA-7, and VA-9) contained concrete in which all of the *coarse* aggregate was replaced by LWA. The degree of saturation of the LWA is not known. The crack-reducing effects of LWA are studied by comparing the crack densities of LWA decks with control and LC-HPC decks.

Figures 12 and 13 compare the crack densities of bridge decks containing LWA with those for the control decks and LC-HPC decks, respectively. Like Figures 10 and 11, data is plotted by placement when more than one placement is used. As shown in the figures, the crack densities of LWA decks are not lower than those of control or LC-HPC decks of similar age. In fact, two of the LWA decks had significantly higher crack densities than the average crack densities for control decks at a similar age. It is clear that the replacement of coarse aggregate *as applied in two of the three decks* did not help the crack performance.

As noted earlier, the lightweight aggregate used in VA-9 was not properly pre-wetted before mixing, likely resulting an increase in strength, which, along with a high paste content, may have contributed to the high crack density. The three LWA data points at approximately 10 months of age in Figures 12 and 13 represent the three placements of VA-9. Specific crack densities are shown in Table 4.

Due to the relatively low age of the decks containing LWA, additional surveys will be needed to determine the effectiveness of the coarse aggregate replacement in that case.

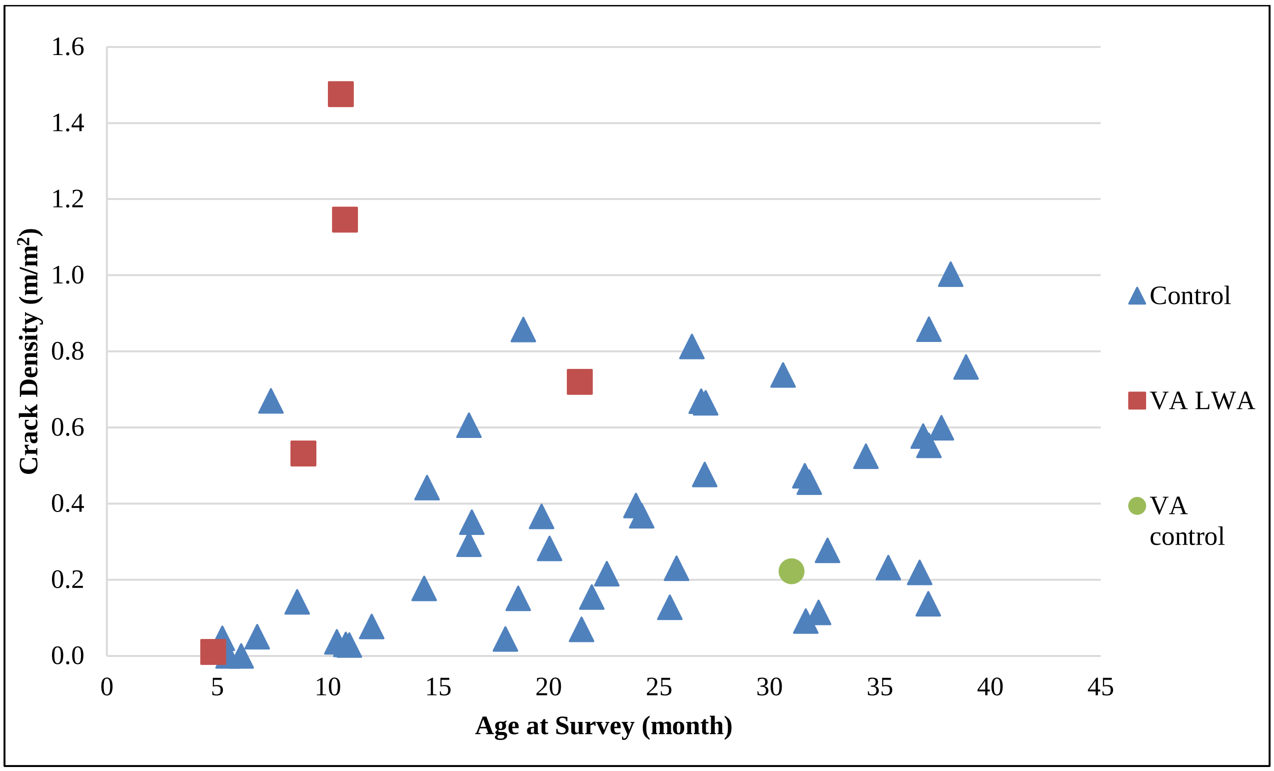


Figure 12: Crack densities of Virginia bridge decks using lightweight aggregate and control decks versus deck age

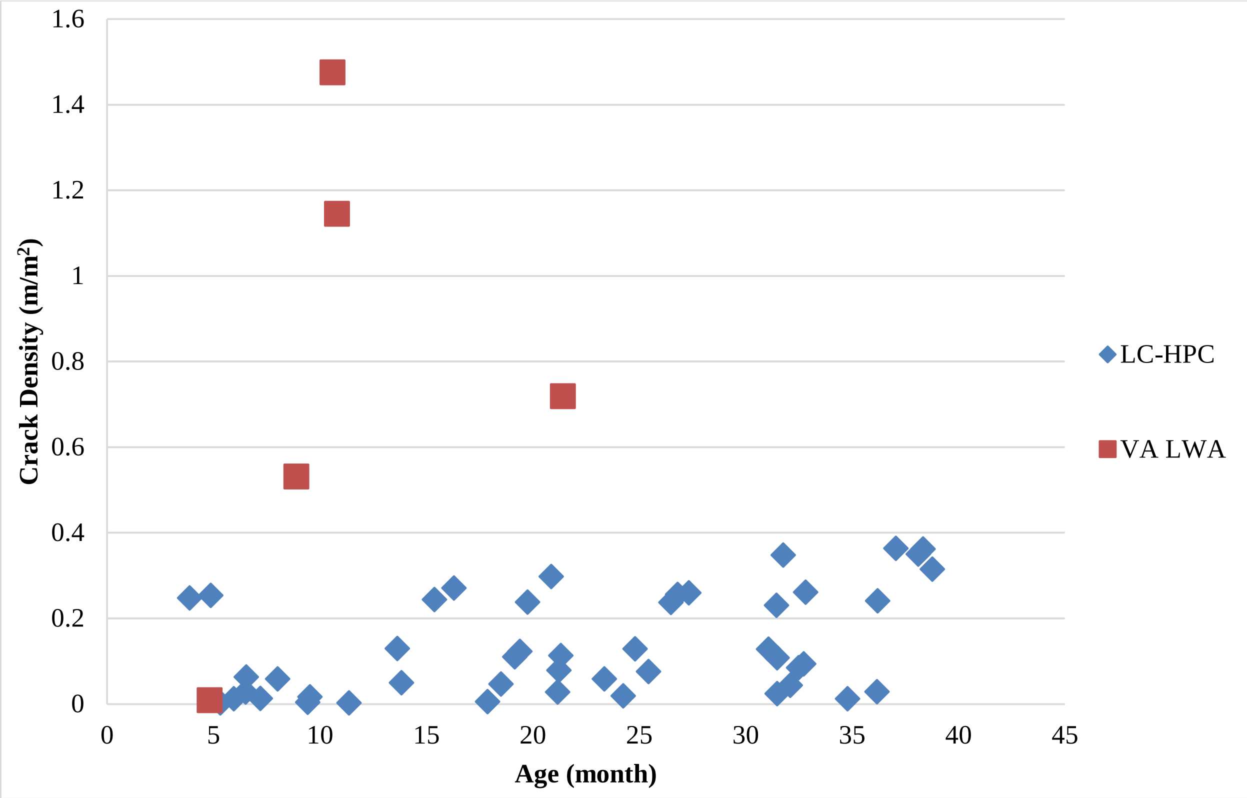


Figure 13: Crack densities of Virginia bridge decks using lightweight aggregate and LC-HPC decks versus deck age

Paste Content

Paste content consists of the cementitious materials and water. The remaining volume of concrete is comprised of aggregate and air. Aggregate has a high stiffness, making it dimensionally stable, regardless of moisture loss. Paste has the highest potential for shrinkage due to the fact that, as water is lost during drying, the paste loses volume. Studies have shown that increased paste content leads to increased cracking in bridge decks. Specifically, Schmitt and Darwin (1995), Miller and Darwin (2000), and Lindquist et al. (2008) showed that bridge decks with mixtures containing 28% paste or more exhibited significantly more cracking than mixtures containing 27% paste or less. Figure 14 *trends* toward this conclusion for the Virginia decks. Cracking is generally greater for the decks as the paste content increases. It should be noted that the data point with over 30% paste content and a crack density well below 0.100 m/m^2 represents a bridge that is less than

5.0 months old. At such a young age, it understandably has a very low crack density. As would be expected, the younger decks have less cracking than the older decks. The exception to this is the deck with the highest crack density; this deck is less than a year old, but has both the highest paste content and the highest crack density in the study. Additional surveys are needed to draw firm conclusions from these decks.

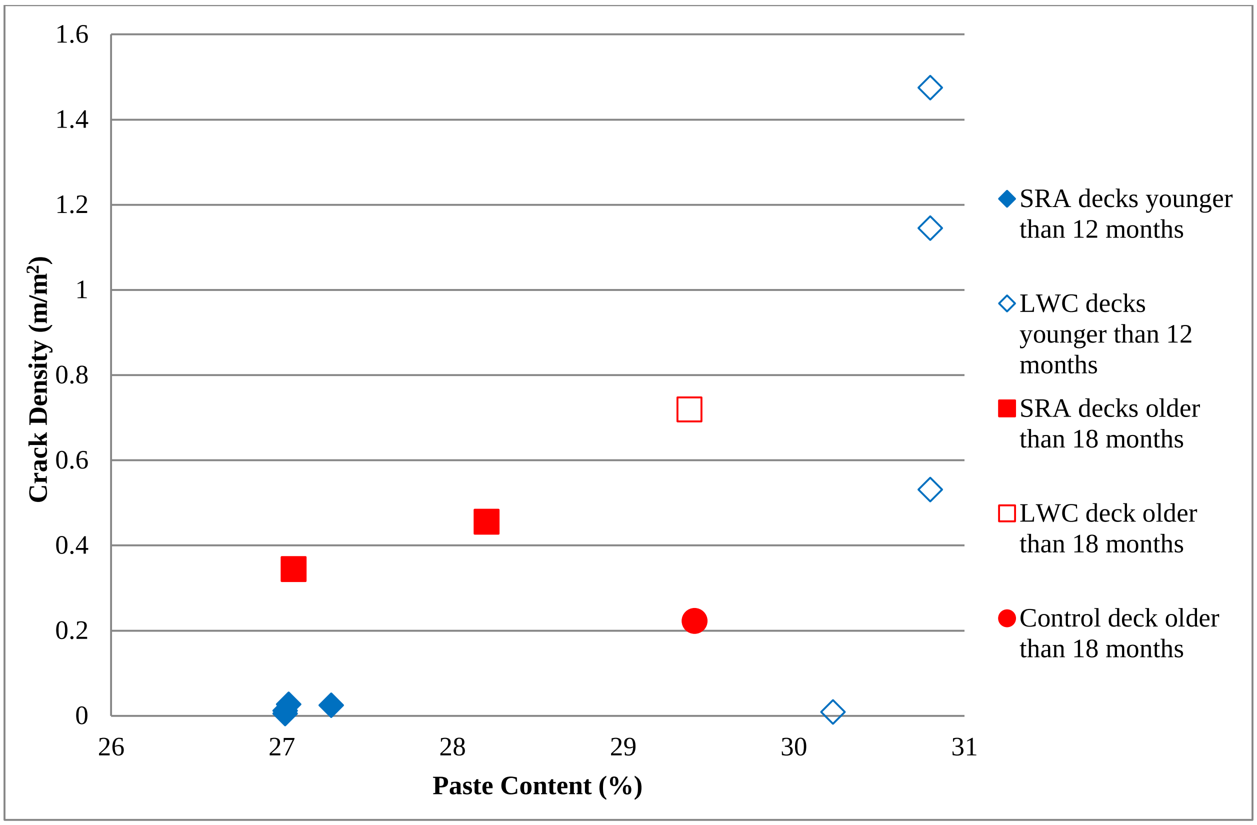


Figure 14: Crack density versus paste content

28-Day Strength

The strength of concrete also has an effect on the amount of cracking in a bridge deck. As concrete strength increases, it exhibits decreased creep compared to lower-strength concrete. Creep reduces stresses caused by restrained shrinkage and, thus, reduces the potential for cracking.

Schmitt and Darwin (1995), Miller and Darwin (2008), and Lindquist et al. (2008), in addition to showing the benefits of decreased paste content, also showed the benefits of having decks constructed with lower-strength concrete. The data for the Virginia decks also trends toward this conclusion. Concrete with compressive strengths near 4500 psi generally performed well, with mostly decreasing performance as the compressive strength increased.

No conclusions about the strength of the concrete as it relates to crack density can be made at this point. The bridge decks need to age more before any conclusions can be made.

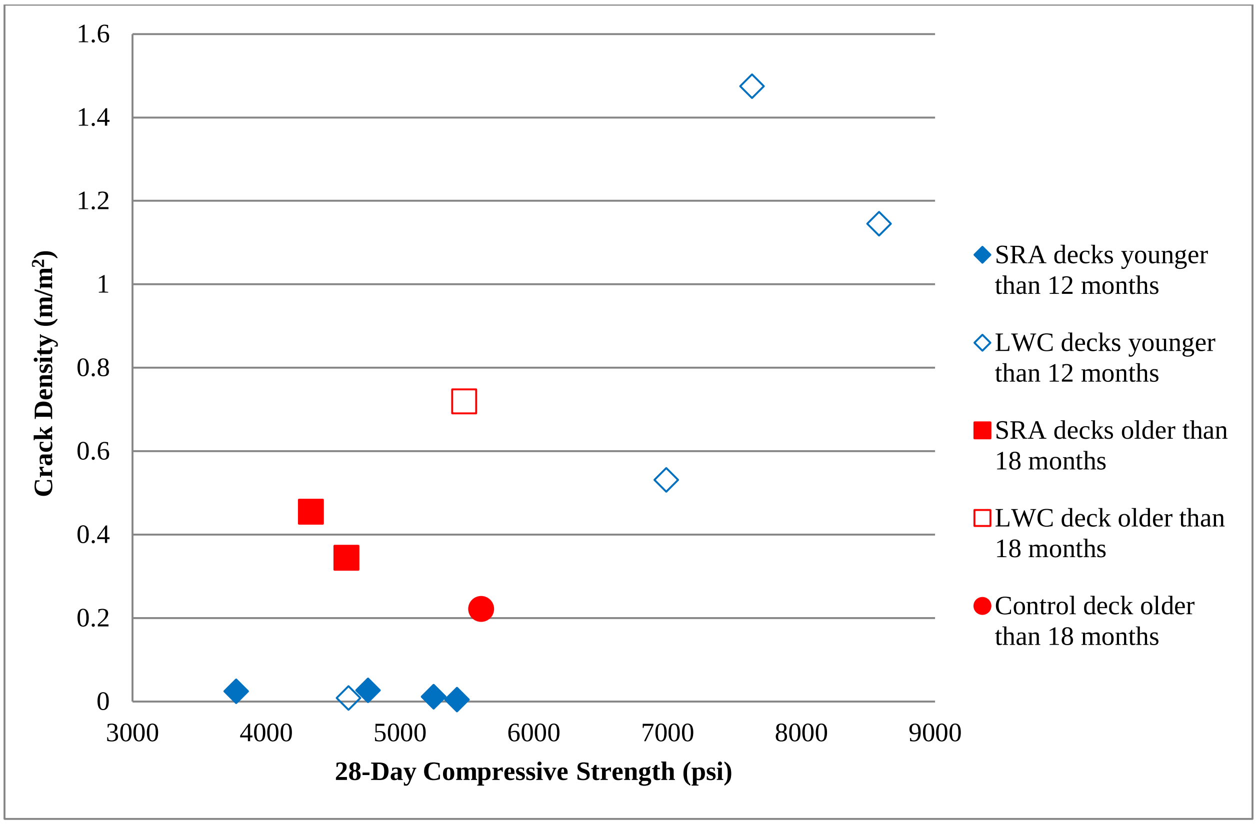


Figure 15: Crack density versus the 28-day compressive strength of the concrete

Contractors

It has been shown that the contractor plays just as important of a role in establishing the performance of a bridge deck as the plastic concrete properties (Lindquist et al. 2008, Yuan et al. 2011 and Pendergrass et al. 2014). All three bridge decks (VA-4, VA-5, and VA-7) built by Lane

Construction as part of the HOV lane additions to I-95 are performing very well. During the crack surveys, a representative from Lane was on site along with VDOT representatives. It was apparent to the authors that excellent quality control was being provided by both the contractor and VDOT personnel for these bridges. All three of the decks are still very young, however. Future surveys will determine the long-term performance of the bridge decks

Not enough information is available to make any comments, positive or negative, about the remaining five contractors.

SUMMARY AND CONCLUSIONS

Crack surveys were performed on nine bridge decks in Virginia. Five decks were constructed with a shrinkage reducing admixture (SRA), three were constructed with lightweight concrete, and the final deck was constructed with normalweight concrete and is used as a control. Seven of the decks surveyed are supported by steel girders and two are supported by prestressed concrete. Of the seven decks supported by steel girders, four contain an SRA, two were constructed with lightweight concrete, and one served as a control. One SRA and one lightweight concrete deck are supported by prestressed concrete; the SRA deck is supported by a prestressed concrete box beam and the lightweight deck is supported by a prestressed concrete slab. The decks were compared for cracking performance with low-cracking high-performance (LC-HPC) and control bridge decks in Kansas.

These surveys will serve as a baseline for future surveys and provide the data for some conclusions concerning the early performance of the decks. Future surveys will enable conclusions on the long-term performance of the bridge decks. The following conclusions can be drawn from the surveys as well as previous studies:

1. The bridge decks containing an SRA are performing better than the decks constructed with lightweight concrete.
2. The initial surveys suggest that some of the decks constructed with an SRA are not performing as well as the LC-HPC decks in Kansas. A future survey in which crack widths are measured may provide a clearer picture of the effectiveness of the SRAs.
3. The initial surveys suggest that the bridges constructed with lightweight concrete are not performing as well as either the LC-HPC or control decks in Kansas.

4. The bridge decks constructed with lightweight concrete had higher paste contents than the decks containing an SRA.
5. The bridge decks constructed with lightweight concrete had higher 28-day compressive strengths than decks containing an SRA.
6. The bridge decks with lower paste contents are performing better than the bridge decks with higher paste contents.

REFERENCES

Browning, J., Darwin, D., Reynolds, D., and Pendergrass, B., "Lightweight Aggregate as Internal Curing Agent to Limit Concrete Shrinkage," *ACI Materials Journal*, Vol. 108, No. 6, Nov.-Dec. 2011.

Darwin, D., Browning, J., Lindquist, W., McLeod, H. A. K., Yuan, J., Toledo, M., Reynolds, D., 2010, "Low-Cracking, High-Performance Concrete Bridge Decks: Case Studies Over First 6 Years," *Transportation Research Record* 2202, December.

Darwin, D., Browning, J., McLeod, H. A. K., Lindquist, W., Yuan, J., 2012, "Implementing Lessons Learned From Twenty Years of Bridge-Deck Crack Surveys," *Andy Scanlon Symposium on Serviceability and Safety of Concrete Structures: From Research to Practice*, SP-284, American Concrete Institute, Farmington Hills, MI.

Kansas Department of Transportation (2014a). "Low-Cracking High-Performance Concrete - Aggregates," *Standard Specifications for State Road and Bridge Construction*, Topeka, KS.

Kansas Department of Transportation (2014b). "Low-Cracking High-Performance Concrete," *Standard Specifications for State Road and Bridge Construction*, Topeka, KS.

Kansas Department of Transportation (2011c). "Low-Cracking High-Performance Concrete - Construction," *Standard Specifications for State Road and Bridge Construction*, Topeka, KS.

Lindquist, W., Darwin D., and Browning J., 2008, "Development of Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks: Free Shrinkage, Mixture Optimization, and Concrete Production" *SM Report* No. 92, University of Kansas Center for Research, KS, November.

McLeod, H. A. K., Darwin, D., and Browning, J., 2009, "Development and Construction of Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks: Construction Methods, Specifications, and Resistance to Chloride Ion Penetration" *SM Report* No. 94, University of Kansas Center for Research, Lawrence, KS, September.

Miller, G. G. and Darwin, D., 2000, "Performance and Constructability of Silica Fume Bridge Deck Overlays," *SM Report* No. 57, University of Kansas Center for Research, Lawrence, KS, January.

Pendergrass, B., Darwin, D., and Browning, J., 2014, "Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks: Shrinkage Reducing Admixtures, Internal Curing, and Cracking

Performance,” *SM Report* No. 107, University of Kansas Center for Research, Lawrence, KS, February.

Reynolds, D., Darwin, D., and Browning, J., 2009, "Lightweight Aggregates as an Internal Curing Agent for Low-Cracking High-Performance Concrete" *SM Report* 97, University of Kansas Center for Research, Lawrence, KS, December.

Schmitt, T.R. and Darwin, D., 1995, “Cracking in Concrete Bridge Decks,” *SM Report* No. 39, University of Kansas Center for Research, Lawrence, KS, April.

Shilstone, J. M., Sr. (1990). “Concrete Mixture Optimization,” *Concrete International*, Vol. 12, No. 6, June, pp. 33-39.

Yuan, J., Darwin D., and Browning, J., 2011, “Development and Construction of Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks: Free Shrinkage Tests, Restrained Ring Tests, Construction Experience, and Crack Survey Results,” *SM Report* No. 103, University of Kansas Center for Research, Lawrence, KS, September.

APPENDIX A

BRIDGE DECK SURVEY SPECIFICATION*

*From Lindquist et al. (2005)

BRIDGE DECK SURVEY SPECIFICATION

1.0 DESCRIPTION.

This specification covers the procedures and requirements to perform bridge deck surveys of reinforced concrete bridge decks.

2.0 SURVEY REQUIREMENTS.

a. Pre-Survey Preparation.

(1) Prior to performing the crack survey, related construction documents need to be gathered to produce a scaled drawing of the bridge deck. The scale must be exactly 1 in. = 10 ft (for use with the scanning software), and the drawing only needs to include the boundaries of the deck surface.

NOTE 1 – In the event that it is not possible to produce a scaled drawing prior to arriving at the bridge deck, a hand-drawn crack map (1 in.= 10 ft) created on engineering paper using measurements taken in the field is acceptable.

(2) The scaled drawing should also include compass and traffic directions in addition to deck stationing. A scaled 5 ft by 5 ft grid is also required to aid in transferring the cracks observed on the bridge deck to the scaled drawing. The grid shall be drawn separately and attached to the underside of the crack map such that the grid can easily be seen through the crack map.

NOTE 2 – Maps created in the field on engineering paper need not include an additional grid.

(3) For curved bridges, the scaled drawing need not be curved, i.e., the curve may be approximated using straight lines.

(4) Coordinate with traffic control so that at least one side (or one lane) of the bridge can be closed during the time that the crack survey is being performed.

b. Preparation of Surface.

(1) After traffic has been closed, station the bridge in the longitudinal direction at ten feet intervals. The stationing shall be done as close to the centerline as possible. For curved bridges, the stationing shall follow the curve.

(2) Prior to beginning the crack survey, mark a 5 ft by 5 ft grid using lumber crayons or chalk on the portion of the bridge closed to traffic corresponding to the grid on the scaled drawing. Measure and document any drains, repaired areas, unusual cracking, or any other items of interest.

(3) Starting with one end of the closed portion of the deck, using a lumber crayon or chalk, begin tracing cracks that can be seen while bending at the waist. After beginning to trace cracks, continue to the end of the crack, even if this includes portions of the crack that were not initially seen while bending at the waist. Areas covered by sand or other debris need not be surveyed. Trace the cracks using a different color crayon than was used to mark the grid and stationing.

(4) At least one person shall recheck the marked portion of the deck for any additional cracks. The goal is not to mark every crack on the deck, only those cracks that can initially be seen while bending at the waist.

NOTE 3 – An adequate supply of lumber crayons or chalk should be on hand for the survey. Crayon or chalk colors should be selected to be readily visible when used to mark the concrete.

c. Weather Limitations.

(1) Surveys are limited to days when the expected temperature during the survey will not be below 60°F.

(2) Surveys are further limited to days that are forecasted to be at least mostly sunny for a majority of the day.

(3) Regardless of the weather conditions, the bridge deck must be <u>completely</u> dry before the survey can begin.

3.0 BRIDGE SURVEY.

a. Crack Surveys.

Using the grid as a guide, transfer the cracks from the deck to the scaled drawing. Areas that are not surveyed should be marked on the scaled drawing. Spalls, regions of scaling, and other areas of special interest need not be included on the scale drawings but should be noted.

b. Delamination Survey.

At any time during or after the crack survey, bridge decks shall be checked for delamination. Any areas of delamination shall be noted and drawn on a separate drawing of the bridge. This second drawing need not be to scale.

c. Under Deck Survey.

Following the crack and delamination survey, the underside of the deck shall be examined and any unusual or excessive cracking noted.

APPENDIX B

LC-HPC SPECIFICATIONS

KANSAS DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION TO THE
STANDARD SPECIFICATIONS, 2007 EDITION

Add a new SECTION to DIVISION 1100:

LOW-CRACKING HIGH-PERFORMANCE CONCRETE – AGGREGATES

1.0 DESCRIPTION

This specification is for coarse aggregates, fine aggregates, and mixed aggregates (both coarse and fine material) for use in bridge deck construction.

2.0 REQUIREMENTS

a. Coarse Aggregates for Concrete.

(1) Composition. Provide coarse aggregate that is crushed or uncrushed gravel, chat, or crushed stone. (Consider calcite cemented sandstone, rhyolite, basalt and granite as crushed stone

(2) Quality. The quality requirements for coarse aggregate for bridge decks are in **TABLE 1-1**:

TABLE 1-1: QUALITY REQUIREMENTS FOR COARSE AGGREGATES FOR BRIDGE DECK				
Concrete Classification	**Soundness (min.)**	**Wear (max.)**	**Absorption (max.)**	**Acid Insol. (min.)**
Grade 3.5 (AE) (LC-HPC) [1]	0.90	40	0.7	55

[1] Grade 3.5 (AE) (LC-HPC) – Bridge Deck concrete with select coarse aggregate for wear and acid insolubility.

(3) Product Control.

(a) Deleterious Substances. Maximum allowed deleterious substances by weight are:

- Material passing the No. 200 sieve (KT-2).. 2.5%
- Shale or Shale-like material (KT-8)... 0.5%
- Clay lumps and friable particles (KT-7) 1.0%
- Sticks (wet) (KT-35).. 0.1%
- Coal (AASHTO T 113)... 0.5%

(b) Uniformity of Supply. Designate or determine the fineness modulus (grading factor) according to the procedure listed in the Construction Manual Part V, Section 17 before delivery, or from the first 10 samples tested and accepted. Provide aggregate that is within ±0.20 of the average fineness modulus.

(4) Do not combine siliceous fine aggregate with siliceous coarse aggregate if neither meet the requirements of **subsection 2.0c.(2)(a)**. Consider such fine material, regardless of proportioning, as a Basic Aggregate that must conform to **subsection 2.0c**.

(5) Handling Coarse Aggregates.

(a) Segregation. Before acceptance testing, remix all aggregate segregated by transportation or stockpiling operations.

(b) Stockpiling.

- Stockpile accepted aggregates in layers 3 to 5 feet thick. Berm each layer so that aggregates do not "cone" down into lower layers.
- Keep aggregates from different sources, with different gradings, or with a significantly different specific gravity separated.
- Transport aggregate in a manner that insures uniform gradation.
- Do not use aggregates that have become mixed with earth or foreign material.

- Stockpile or bin all washed aggregate produced or handled by hydraulic methods for 12 hours (minimum) before batching. Rail shipment exceeding 12 hours is acceptable for binning provided the car bodies permit free drainage.
- Provide additional stockpiling or binning in cases of high or non-uniform moisture.

b. Fine Aggregates for Basic Aggregate in MA for Concrete.

(1) Composition.

(a) Type FA-A. Provide either singly or in combination natural occurring sand resulting from the disintegration of siliceous or calcareous rock, or manufactured sand produced by crushing predominately siliceous materials.

(b) Type FA-B. Provide fine granular particles resulting from the crushing of zinc and lead ores (Chat).

(2) Quality.

(a) Mortar strength and Organic Impurities. If the District Materials Engineer determines it is necessary, because of unknown characteristics of new sources or changes in existing sources, provide fine aggregates that comply with these requirements:

- Mortar Strength (Mortar Strength Test, KTMR-26). Compressive strength when combined with Type III (high early strength) cement:
  - At age 24 hours, minimum…………..100%*
  - At age 72 hours, minimum…………..100%*

  *Compared to strengths of specimens of the same proportions, consistency, cement and standard 20-30 Ottawa sand.
- Organic Impurities (Organic Impurities in Fine Aggregate for Concrete Test, AASHTO T 21). The color of the supernatant liquid is equal to or lighter than the reference standard solution.

(b) Hardening characteristics. Specimens made of a mixture of 3 parts FA-B and 1 part cement with sufficient water for molding will harden within 24 hours. There is no hardening requirement for FA-A.

(3) Product Control.

(a) Deleterious Substances.

- Type FA-A: Maximum allowed deleterious substances by weight are:
  - Material passing the No. 200 sieve (KT-2)………..……………. 2.0%
  - Shale or Shale-like material (KT-8) ……………………………. 0.5%
  - Clay lumps and friable particles (KT-7)………..………………. 1.0%
  - Sticks (wet) (KT-35)…………………………...……………..…… 0.1%
- Type FA-B: Provide materials that are free of organic impurities, sulfates, carbonates, or alkali. Maximum allowed deleterious substances by weight are:
  - Material passing the No. 200 sieve (KT-2)……………….…........ 2.0%
  - Clay lumps & friable particles (KT-7)…………………………. 0.25%

(c) Uniformity of Supply. Designate or determine the fineness modulus (grading factor) according to the procedure listed in the Construction Manual Part V, Section 17 before delivery, or from the first 10 samples tested and accepted. Provide aggregate that is within ±0.20 of the average fineness modulus.

(4) Proportioning of Coarse and Fine Aggregate. Use a proven optimization method such as the Shilstone Method or the KU Mix Method.

Do not combine siliceous fine aggregate with siliceous coarse aggregate if neither meet the requirements of **subsection 2.0c.(2)(a)**. Consider such fine material, regardless of proportioning, as a Basic Aggregate and must conform to the requirements in **subsection 2.0c**.

(5) Handling and Stockpiling Fine Aggregates.

- Keep aggregates from different sources, with different gradings or with a significantly different specific gravity separated.
- Transport aggregate in a manner that insures uniform grading.
- Do not use aggregates that have become mixed with earth or foreign material.

- Stockpile or bin all washed aggregate produced or handled by hydraulic methods for 12 hours (minimum) before batching. Rail shipment exceeding 12 hours is acceptable for binning provided the car bodies permit free drainage.
- Provide additional stockpiling or binning in cases of high or non-uniform moisture.

c. Mixed Aggregates for Concrete.

(1) Composition.

(a) Total Mixed Aggregate (TMA). A natural occurring, predominately siliceous aggregate from a single source that meets the Wetting & Drying Test (KTMR-23) and grading requirements.

(b) Mixed Aggregate. A combination of basic and coarse aggregates that meet **TABLE 1-2**.

- Basic Aggregate (BA). Singly or in combination, a natural occurring, predominately siliceous aggregate that does not meet the grading requirements of Total Mixed Aggregate.

(c) Coarse Aggregate. Granite, crushed sandstone, chat, and gravel. Gravel that is not approved under **subsection 2.0c.(2)** may be used, but only with basic aggregate that meets the wetting and drying requirements of TMA.

(2) Quality.

(a) Total Mixed Aggregate.

- Soundness, minimum (KTMR-21) ……..…………0.90
- Wear, maximum (KTMR-25) …………………..……50%
- Wetting and Drying Test (KTMR-23) for Total Mixed Aggregate
  Concrete Modulus of Rupture:
  - At 60 days, minimum………………………….550 psi
  - At 365 days, minimum…..…………………..……550 psi

  Expansion:
  - At 180 days, maximum…………….………….0.050%
  - At 365 days, maximum……………………..…….0.070%

  Aggregates produced from the following general areas are exempt from the Wetting and Drying Test:
  - Blue River Drainage Area.
  - The Arkansas River from Sterling, west to the Colorado state line.
  - The Neosho River from Emporia to the Oklahoma state line.

(b) Basic Aggregate.

- Retain 10% or more of the BA on the No. 8 sieve before adding the Coarse Aggregate. Aggregate with less than 10% retained on the No. 8 sieve is to be considered a Fine Aggregate described in **subsection 2.0b**. Provide material with less than 5% calcareous material retained on the ⅜" sieve.
- Soundness, minimum (KTMR-21)……………….0.90
- Wear, maximum (KTMR-25)…………………..……50%
- Mortar strength and Organic Impurities. If the District Materials Engineer determines it is necessary, because of unknown characteristics of new sources or changes in existing sources, provide mixed aggregates that comply with these requirements:
  - Mortar Strength (Mortar Strength Test, KTMR-26). Compressive strength when combined with Type III (high early strength) cement:
    - At age 24 hours, minimum…………..100%*
    - At age 72 hours, minimum…………..100%*

    *Compared to strengths of specimens of the same proportions, consistency, cement and standard 20-30 Ottawa sand.
  - Organic Impurities (Organic Impurities in Fine Aggregate for Concrete Test, AASHTO T 21). The color of the supernatant liquid is equal to or lighter than the reference standard solution.

(3) Product Control.

(a) Size Requirement. Provide mixed aggregates that comply with the grading requirements in **TABLE 1-2**.

TABLE 1-2: GRADING REQUIREMENTS FOR MIXED AGGREGATES FOR CONCRETE BRIDGE DECKS												
Type	Usage	Percent Retained on Individual Sieves - Square Mesh Sieves										
		1½"	1"	3/4"	1/2"	3/8"	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100
MA-4	Optimized for LC-HPC Bridge Decks*	0	2-6	5-18	8-18	8-18	8-18	8-18	8-18	8-15	5-15	0-10

*Use a proven optimization method, such as the Shilstone Method or the KU Mix Method.
Note: Manufactured sands used to obtain optimum gradations have caused difficulties in pumping, placing or finishing. Natural coarse sands and pea gravels used to obtain optimum gradations have worked well in concretes that were pumped.

(b) Deleterious Substances. Maximum allowed deleterious substances by weight are:

- Material passing the No. 200 sieve (KT-2)……………..….. 2.5%
- Shale or Shale-like material (KT-8)…………………..……. 0.5%
- Clay lumps and friable particles (KT-7)…………………… 1.0%
- Sticks (wet) (KT-35)………………………..…………… 0.1%
- Coal (AASHTO T 113)…..……………………..………. 0.5%

(c) Uniformity of Supply. Designate or determine the fineness modulus (grading factor) according to the procedure listed in the Construction Manual Part V, Section 17 before delivery, or from the first 10 samples tested and accepted. Provide aggregate that is within ±0.20 of the average fineness modulus.

(4) Handling Mixed Aggregates.

(a) Segregation. Before acceptance testing, remix all aggregate segregated by transit or stockpiling.

(b) Stockpiling.

- Keep aggregates from different sources, with different gradings or with a significantly different specific gravity separated.
- Transport aggregate in a manner that insures uniform grading.
- Do not use aggregates that have become mixed with earth or foreign material.
- Stockpile or bin all washed aggregate produced or handled by hydraulic methods for 12 hours (minimum) before batching. Rail shipment exceeding 12 hours is acceptable for binning provided the car bodies permit free drainage.
- Provide additional stockpiling or binning in cases of high or non-uniform moisture.

d. Lightweight Aggregates for Concrete.

Fine lightweight aggregate is permitted as a means to provide internal curing water for concrete. The requirements of ASTM C1761 and C330 shall apply, except as modified in this specification.

(1) Product Control

- Size Requirement: All lightweight aggregate shall pass 3/8 in. sieve.

(2) Proportioning.

- Volume of lightweight aggregate added to a mixture shall not exceed 10 percent of total aggregate volume. If lightweight aggregate is used as a replacement for normalweight aggregate, the replacement shall be made on a volume basis.

(3) Pre-wetting.

- Lightweight aggregate shall be pre-wetted prior to adding at the time of batching. Recommendations for pre-wetting made by the lightweight aggregate supplier shall be followed to ensure that the lightweight aggregate has achieved an acceptable absorbed moisture content at the time of batching. Mixture proportions shall not be adjusted based on the absorbed water in the lightweight aggregate.

(4) Handling and Stockpiling Lightweight Aggregates.

- Lightweight aggregates shall be handled and stockpiled in accordance with the requirements for fine aggregates in subsection 2.0b.(5)

3.0 TEST METHODS

Test aggregates according to the applicable provisions of **SECTION 1117**.

4.0 PREQUALIFICATION

Aggregates for concrete must be prequalified according to **subsection 1101.2**.

5.0 BASIS OF ACCEPTANCE

The Engineer will accept aggregates for concrete base on the prequalification required by this specification, and **subsection 1101.4**.

07-29-09 LAL
04-18-11 DD
01-27-14 BP DD
07-16-14 DD

SPECIAL PROVISION TO THE
STANDARD SPECIFICATIONS 2007 EDITION

Add a new SECTION to DIVISION 400:

LOW-CRACKING HIGH-PERFORMANCE CONCRETE

1.0 DESCRIPTION

Provide the grades of low-cracking high-performance concrete (LC-HPC) specified in the Contract Documents.

2.0 MATERIALS

Coarse, Fine & Mixed Aggregate..**07-PS0165, latest version**
Admixtures...**DIVISION 1400**
Cement ....**DIVISION 2000**
Water ....**DIVISION 2400**

3.0 CONCRETE MIX DESIGN

a. General. Design the concrete mixes specified in the Contract Documents.

Provide aggregate gradations that comply with **07-PS0165, latest version** and Contract Documents.

If desired, contact the DME for available information to help determine approximate proportions to produce concrete having the required characteristics on the project.

Take full responsibility for the actual proportions of the concrete mix, even if the Engineer assists in the design of the concrete mix.

Submit all concrete mix designs to the Engineer for review and approval. Submit completed volumetric mix designs on KDOT Form No. 694 (or other forms approved by the DME).

Do not place any concrete on the project until the Engineer approves the concrete mix designs. Once the Engineer approves the concrete mix design, do not make changes without the Engineer's approval.

Design concrete mixes that comply with these requirements:

b. Air-Entrained Concrete for Bridge Decks. Design air-entrained concrete for structures according to **TABLE 1-1**.

TABLE 1-1: AIR ENTRAINED CONCRETE FOR BRIDGE DECKS

Grade of Concrete Type of Aggregate (SECTION 1100)	lb of Cementitious per cu yd of Concrete, min/max	lb of Water per lb of Cementitious*	Designated Air Content Percent by Volume**	Specified 28-day Compressive Strength Range, psi
Grade 3.5 (AE) (LC-HPC)				
MA-4	500 / 540	0.44 – 0.45	8.0 ± 1.0	3500 – 5500

*Limits of lb. of water per lb. of cementitious. Includes free water in aggregates, but excludes water of absorption of the aggregates. With approval of the Engineer, may be decreased to 0.43 on-site.

**Concrete with an air content less than 6.5% or greater than 9.5% shall be rejected. The Engineer will sample concrete for tests at the discharge end of the conveyor, bucket or if pumped, the piping.

c. Portland Cement. Select the type of portland cement specified in the Contract Documents. <u>Portions of portland cement may be replaced with slag cement or slag cement and silica fume if used in conjunction with internal curing using pre-wetted lightweight aggregate (see 07-PS0165 subsection 2.0d.). The replacements of portland cement are limited to 30% by volume with slag cement and 3% by volume with silica fume..</u>

d. Design Air Content. Use the middle of the specified air content range for the design of air-entrained concrete.

e. Admixtures for Air-Entrainment and Water Reduction. Verify that the admixtures used are compatible and will work as intended without detrimental effects. Use the dosages recommended by the admixture manufacturers to determine the quantity of each admixture for the concrete mix design. Incorporate and mix the admixtures into the concrete mixtures according to the manufacturer's recommendations.

Set retarding or accelerating admixtures are prohibited for use in Grade 3.5 (AE) (LC-HPC) concrete. These include Type B, C, D, E, and G chemical admixtures as defined by ASTM C 494/C 494M – 08. Do not use admixtures containing chloride ion (CL) in excess of 0.1 percent by mass of the admixture in Grade 3.5 (AE) (LC-HPC) concrete.

(1) Air-Entraining Admixture. If specified, use an air-entraining admixture in the concrete mixture. If another admixture is added to an air-entrained concrete mixture, determine if it is necessary to adjust the air-entraining admixture dosage to maintain the specified air content. Use only a vinsol resin or tall oil based air-entraining admixture.

(2) Water-Reducing Admixture. Use a Type A water reducer or a dual rated Type A water reducer – Type F high-range water reducer, when necessary to obtain compliance with the specified fresh and hardened concrete properties.

Include a batching sequence in the concrete mix design. Consider the location of the concrete plant in relation to the job site, and identify the approximate quantity, when and at what location the water-reducing admixture is added to the concrete mixture.

The manufacturer may recommend mixing revolutions beyond the limits specified in **subsection 5.0**. If necessary and with the approval of the Engineer, address the additional mixing revolutions (the Engineer will allow up to 60 additional revolutions) in the concrete mix design.

Slump control may be accomplished in the field only by redosing with a water-reducing admixture. If time and temperature limits are not exceeded, and if at least 30 mixing revolutions remain, the Engineer will allow redosing with up to 50% of the original dose. The redosed concrete shall be retested for slump prior to deposit on the bridge deck.

(3) Adjust the mix designs during the course of the work when necessary to achieve compliance with the specified fresh and hardened concrete properties. Only permit such modifications after trial batches to demonstrate that the adjusted mix design will result in concrete that complies with the specified concrete properties.

The Engineer will allow adjustments to the dose rate of air entraining and water-reducing chemical admixtures to compensate for environmental changes during placement without a new concrete mix design or qualification batch.

f. Designated Slump. Designate a slump for each concrete mix design within the limits in **TABLE 1-2**.

TABLE 1-2: DESIGNATED SLUMP*

Type of Work	Designated Slump (inches)
Grade 3.5 (AE) (LC-HPC)	1 ½ - 3

* The Engineer will obtain sample concrete at the discharge end of the conveyor, bucket or if pumped, the piping.

If potential problems are apparent at the discharge of any truck, and the concrete is tested at the truck discharge (according to **subsection 6.0**), the Engineer will reject concrete with a slump greater than 3 ½ inches at the truck discharge, 3 inches if being placed by a bucket.

4.0 REQUIREMENTS FOR COMBINED MATERIALS

a. Measurements for Proportioning Materials.

(1) Cement. Measure cement as packed by the manufacturer. A sack of cement is considered as 0.04 cubic yards weighing 94 pounds net. Measure bulk cement by weight. In either case, the measurement must be accurate to within 0.5% throughout the range of use.

(2) Water. Measure the mixing water by weight or volume. In either case, the measurement must be accurate to within 1% throughout the range of use.

(3) Aggregates. Measure the aggregates by weight. The measurement must be accurate to within 0.5% throughout the range of use.

(4) Admixtures. Measure liquid admixtures by weight or volume. If liquid admixtures are used in small quantities in proportion to the cement as in the case of air-entraining agents, use readily adjustable mechanical dispensing equipment capable of being set to deliver the required quantity and to cut off the flow automatically when this quantity is discharged. The measurement must be accurate to within 3% of the quantity required.

b. Testing of Aggregates. Testing Aggregates at the Batch Site. Provide the Engineer with reasonable facilities at the batch site for obtaining samples of the aggregates. Provide adequate and safe laboratory facilities at the batch site allowing the Engineer to test the aggregates for compliance with the specified requirements.

KDOT will sample and test aggregates from each source to determine their compliance with specifications. Do not batch the concrete mixture until the Engineer has determined that the aggregates comply with the specifications. KDOT will conduct sampling at the batching site, and test samples according to the Sampling and Testing Frequency Chart in Part V. For QC/QA Contracts, establish testing intervals within the specified minimum frequency.

After initial testing is complete and the Engineer has determined that the aggregate process control is satisfactory, use the aggregates concurrently with sampling and testing as long as tests indicate compliance with specifications. When batching, sample the aggregates as near the point of batching as feasible. Sample from the stream as the storage bins or weigh hoppers are loaded. If samples can not be taken from the stream, take them from approved stockpiles, or use a template and sample from the conveyor belt. If test results indicate an aggregate does not comply with specifications, cease concrete production using that aggregate. Unless a tested and approved stockpile for that aggregate is available at the batch plant, do not use any additional aggregate from that source and specified grading until subsequent sampling and testing of that aggregate indicate compliance with specifications. When tests are completed and the Engineer is satisfied that process control is again adequate, production of concrete using aggregates tested concurrently with production may resume.

c. Handling of Materials.

(1) Aggregate Stockpiles. Approved stockpiles are permitted only at the batch plant and only for small concrete placements or for the purpose of maintaining concrete production. Mark the approved stockpile with an "Approved Materials" sign. Provide a suitable stockpile area at the batch plant so that aggregates are stored without detrimental segregation or contamination. At the plant, limit stockpiles of tested and approved coarse aggregate and fine aggregate to 250 tons each, unless approved for more by the Engineer. If mixed aggregate is used, limit the approved stockpile to 500 tons, the size of each being proportional to the amount of each aggregate to be used in the mix.

Load aggregates into the mixer so no material foreign to the concrete or material capable of changing the desired proportions is included. When 2 or more sizes or types of coarse or fine aggregates are used on the same project, only 1 size or type of each aggregate may be used for any one continuous concrete placement.

(2) Segregation. Do not use segregated aggregates. Previously segregated materials may be thoroughly re-mixed and used when representative samples taken anywhere in the stockpile indicated a uniform gradation exists.

(3) Cement. Protect cement in storage or stockpiled on the site from any damage by climatic conditions which would change the characteristics or usability of the material.

(4) Moisture. Provide aggregate with a moisture content of ± 0.5% from the average of that day. If the moisture content in the aggregate varies by more than the above tolerance, take whatever corrective measures are necessary to bring the moisture to a constant and uniform consistency before placing concrete. This may be accomplished by handling or manipulating the stockpiles to reduce the moisture content, or by adding moisture to the stockpiles in a manner producing uniform moisture content through all portions of the stockpile.

For plants equipped with an approved accurate moisture-determining device capable of determining the free moisture in the aggregates, and provisions made for batch to batch correction of the amount of water and the weight of aggregates added, the requirements relative to manipulating the stockpiles for moisture control will be waived. Any procedure used will not relieve the producer of the responsibility for delivery of concrete meeting the specified water-cement ratio and slump requirements.

Do not use aggregate in the form of frozen lumps in the manufacture of concrete.

(5) Separation of Materials in Tested and Approved Stockpiles. Only use KDOT Approved Materials. Provide separate means for storing materials approved by KDOT. If the producer elects to use KDOT Approved Materials for non-KDOT work, during the progress of a project requiring KDOT Approved Materials, inform the Engineer and agree to pay all costs for additional materials testing.

Clean all conveyors, bins and hoppers of unapproved materials before beginning the manufacture of concrete for KDOT work.

5.0 MIXING, DELIVERY, AND PLACEMENT LIMITATIONS

a. Concrete Batching, Mixing, and Delivery. Batch and mix the concrete in a central-mix plant, in a truck mixer, or in a drum mixer at the work site. Provide plant capacity and delivery capacity sufficient to maintain continuous delivery at the rate required. The delivery rate of concrete during concreting operations must provide for the proper handling, placing and finishing of the concrete.

Seek the Engineer's approval of the concrete plant/batch site before any concrete is produced for the project. The Engineer will inspect the equipment, the method of storing and handling of materials, the production procedures, and the transportation and rate of delivery of concrete from the plant to the point of use. The Engineer will grant approval of the concrete plant/batch site based on compliance with the specified requirements. The Engineer may, at any time, rescind permission to use concrete from a previously approved concrete plant/batch site upon failure to comply with the specified requirements.

Clean the mixing drum before it is charged with the concrete mixture. Charge the batch into the mixing drum so that a portion of the water is in the drum before the aggregates and cementitious. Uniformly flow materials into the drum throughout the batching operation. Add all mixing water in the drum by the end of the first 15 seconds of the mixing cycle. Keep the throat of the drum free of accumulations that restrict the flow of materials into the drum.

Do not exceed the rated capacity (cubic yards shown on the manufacturer's plate on the mixer) of the mixer when batching the concrete. The Engineer will allow an overload of up to 10% above the rated capacity for central-mix plants and drum mixers at the work site, provided the concrete test data for strength, segregation and uniform consistency are satisfactory, and no concrete is spilled during the mixing cycle.

Operate the mixing drum at the speed specified by the mixer's manufacturer (shown on the manufacturer's plate on the mixer).

Mixing time is measured from the time all materials, except water, are in the drum. If it is necessary to increase the mixing time to obtain the specified percent of air in air-entrained concrete, the Engineer will determine the mixing time.

If the concrete is mixed in a central-mix plant or a drum mixer at the work site, mix the batch between 1 to 5 minutes at mixing speed. Do not exceed the maximum total 60 mixing revolutions. Mixing time begins after all materials, except water, are in the drum, and ends when the discharge chute opens. Transfer time in multiple drum mixers is included in mixing time. Mix time may be reduced for plants utilizing high performance mixing drums provided thoroughly mixed and uniform concrete is being produced with the proposed mix time. Performance of the plant must comply with Table A1.1, of ASTM C 94, Standard Specification for Ready Mixed Concrete. Five of the six tests listed in Table A1.1 must be within the limits of the specification to indicate that uniform concrete is being produced.

If the concrete is mixed in a truck mixer, mix the batch between 70 and 100 revolutions of the drum or blades at mixing speed. After the mixing is completed, set the truck mixer drum at agitating speed. Unless the mixing unit is equipped with an accurate device indicating and controlling the number of revolutions at mixing speed, perform the mixing at the batch plant and operate the mixing unit at agitating speed while traveling from the plant to the work site. Do not exceed 350 total revolutions (mixing and agitating).

If a truck mixer or truck agitator is used to transport concrete that was completely mixed in a stationary central mixer, agitate the concrete while transporting at the agitating speed specified by the manufacturer of the equipment (shown on the manufacturer's plate on the equipment). Do not exceed 250 total revolutions (additional re-mixing and agitating).

Provide a batch slip including batch weights of every constituent of the concrete and time for each batch of concrete delivered at the work site, issued at the batching plant that bears the time of charging of the mixer drum with cementitious and aggregates. Include quantities, type, product name and manufacturer of all admixtures on the batch ticket.

If non-agitating equipment is used for transportation of concrete, provide approved covers for protection against the weather when required by the Engineer.

Place non-agitated concrete within 30 minutes of adding the cement to the water.

Do not use concrete that has developed its initial set. Regardless of the speed of delivery and placement, the Engineer will suspend the concreting operations until corrective measures are taken if there is evidence that the concrete can not be adequately consolidated.

Adding water to concrete after the initial mixing is prohibited. Add all water at the plant. If needed, adjust slump through the addition of a water reducer according to **subsection 3.0e.(2)**.

b. Placement Limitations.

(1) Concrete Temperature. Unless otherwise authorized by the Engineer, the temperature of the mixed concrete immediately before placement is a minimum of 55°F, and a maximum of 70°F. With approval by the Engineer, the temperature of the concrete may be adjusted 5°F above or below this range.

(2) Qualification Batch. For Grade 3.5 (AE) (LC-HPC) concrete, qualify a field batch (one truckload or at least 6 cubic yards) at least 35 days prior to commencement of placement of the bridge decks. Produce the qualification batch

from the same plant that will supply the job concrete. Simulate haul time to the jobsite prior to discharge of the concrete for testing. Prior to placing concrete in the qualification slab and on the job, submit documentation to the Engineer verifying that the qualification batch concrete meets the requirements for air content, slump, temperature of plastic concrete, compressive strength, unit weight and other testing as required by the Engineer.

Before the concrete mixture with plasticizing admixture is used on the project, determine the air content of the qualification batch. Monitor the slump, air content, temperature and workability at initial batching and estimated time of concrete placement. If these properties are not adequate, repeat the qualification batch until it can be demonstrated that the mix is within acceptable limits as specified in this specification.

(3) Placing Concrete at Night. Do not mix, place or finish concrete without sufficient natural light, unless an adequate and artificial lighting system approved by the Engineer is provided.

(4) Placing Concrete in Cold Weather. Unless authorized otherwise by the Engineer, mixing and concreting operations shall not proceed once the descending ambient air temperature reaches 40°F, and may not be initiated until an ascending ambient air temperature reaches 40°F. The ascending ambient air temperature for initiating concreting operations shall increase to 45°F if the maximum ambient air temperature is expected to be between 55°F and 60°F during or within 24 hours of placement and to 50°F if the ambient air temperature is expected to equal or exceed 60°F during or within 24 hours of placement.

If the Engineer permits placing concrete during cold weather, aggregates may be heated by either steam or dry heat before placing them in the mixer. Use an apparatus that heats the weight uniformly and is so arranged as to preclude the possible occurrence of overheated areas which might injure the materials. Do not heat aggregates directly by gas or oil flame or on sheet metal over fire. Aggregates that are heated in bins, by steam-coil or water-coil heating, or by other methods not detrimental to the aggregates may be used. The use of live steam on or through binned aggregates is prohibited. Unless otherwise authorized, maintain the temperature of the mixed concrete between 55°F to 70°F at the time of placing it in the forms. With approval by the Engineer, the temperature of the concrete may be adjusted up to 5°F above or below this range. Do not place concrete when there is a probability of air temperatures being more than 25°F below the temperature of the concrete during the first 24 hours after placement unless insulation is provided for both the deck and the girders. Do not, under any circumstances, continue concrete operations if the ambient air temperature is less than 20°F.

If the ambient air temperature is 40°F or less at the time the concrete is placed, the Engineer may permit the water and the aggregates be heated to at least 70°F, but not more than 120°F.

Do not place concrete on frozen subgrade or use frozen aggregates in the concrete.

(5) Placing Concrete in Hot Weather. When the ambient temperature is above 90ºF, cool the forms, reinforcing steel, steel beam flanges, and other surfaces which will come in contact with the mix to below 90ºF by means of a water spray or other approved methods. For Grade 3.5 (AE) (LC-HPC) concrete, cool the concrete mixture to maintain the temperature immediately before placement between 55°F and 70°F. With approval by the Engineer, the temperature of the concrete may be up to 5°F below or above this range.

Maintain the temperature of the concrete at time of placement within the specified temperature range by any combination of the following:

Shading the materials storage areas or the production equipment.

Cooling the aggregates by sprinkling with potable water.

Cooling the aggregates or water by refrigeration or replacing a portion or all of the mix water with ice that is flaked or crushed to the extent that the ice will completely melt during mixing of the concrete.

- Liquid nitrogen injection.

6.0 INSPECTION AND TESTING

The Engineer will test the first truckload of concrete by obtaining a sample of fresh concrete at truck discharge and by obtaining a sample of fresh concrete at the discharge end of the conveyor, bucket or if pumped, the piping. The Engineer will obtain subsequent sample concrete for tests at the discharge end of the conveyor, bucket or if pumped, the discharge end of the piping. If potential problems are apparent at the discharge of any truck, the Engineer will test the concrete at truck discharge prior to deposit on the bridge deck. If a truckload is redosed with an admixture on-site or set aside to allow for concrete properties to meet the required specifications, the truckload shall be retested prior to deposit on the bridge deck. All retesting shall be performed by the Contractor or Concrete Supplier under the supervision of the Engineer.

The Engineer will cast, store, and test strength test specimens in sets of 5. See **TABLE 1-3**.

KDOT will conduct the sampling and test the samples according to **SECTION 2500** and **TABLE 1-3**. The Contractor may be directed by the Engineer to assist KDOT in obtaining the fresh concrete samples during the placement operation.

A plan will be finalized prior to the construction date as to how out-of-specification concrete will be handled.

TABLE 1-3: SAMPLING AND TESTING FREQUENCY CHART

Tests Required (Record to)	Test Method	CMS	Verification Samples and Tests	Acceptance Samples and Tests
Slump (0.25 inch)	KT-21	a	Each of first 3 truckloads for any individual placement, then 1 of every 3 truckloads	
Temperature (1°F)	KT-17	a	Every truckload, measured at the truck discharge, and from each sample made for slump determination.	
Mass (0.1 lb)	KT-20	a	One of every 6 truckloads	
Air Content (0.25%)	KT-18 or KT-19	a	Each of first 3 truckloads for any individual placement, then 1 of every 6 truckloads	
Cylinders (1 lbf; 0.1 in; 1 psi)	KT-22 and AASHTO T 22	VER	Make at least 2 groups of 5 cylinders per pour or major mix design change with concrete sampled from at least 2 different truckloads evenly spaced throughout the pour, with a minimum of 1 set for every 100 cu yd. Include in each group 3 test cylinders to be cured according to KT-22 and 2 test cylinders to be field-cured. Store the field-cured cylinders on or adjacent to the bridge. Protect all surfaces of the cylinders from the elements in as near as possible the same way as the deck concrete. Test the field-cured cylinders at the same age as the standard-cured cylinders.	
Density of Fresh Concrete (0.1 lb/cu ft or 0.1% of optimum density)	KT-36	ACI		b,c: 1 per 100 cu yd for thin overlays and bridge deck surfacing.

Note a: "Type Insp" must = "ACC" when the assignment of a pay quantity is being made. "ACI" when recording test values for additional acceptance information.
Note b: Normal operation. Minimum frequency for exceptional conditions may be reduced by the DME on a project basis, written justification shall be made to the Chief of the Bureau of Materials and Research and placed in the project documents. (Multi-Level Frequency Chart (see page 17, Appendix A of Construction Manual, Part V).
Note c: Applicable only when specifications contain those requirements.

The Engineer will reject concrete that does not comply with specified requirements. If a truckload is found not to comply with the specified requirements, successive truckloads shall be tested until the requirements are met.

The Engineer will permit occasional deviations below the specified cementitious content, if it is due to the air content of the concrete exceeding the designated air content, but only up to the maximum tolerance in the air content. Continuous operation below the specified cement content for any reason is prohibited.

As the work progresses, the Engineer reserves the right to require the Contractor to change the proportions if conditions warrant such changes to produce a satisfactory mix. Any such changes may be made within the limits of the Specifications at no additional compensation to the Contractor.

07-29-09 LAL, 04-18-11
01-27-14 BP DD
07-16-14 DD

KANSAS DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION TO THE
STANDARD SPECIFICATIONS, 2007 EDITION

Add a new SECTION to DIVISION 700:

LOW-CRACKING HIGH-PERFORMANCE CONCRETE – CONSTRUCTION

1.0 DESCRIPTION

Construct the low-cracking high-performance concrete (LC-HPC) structures according to the Contract Documents and this specification.

BID ITEMS	UNITS
Qualification Slab	Cubic Yard
Concrete (*) (AE) (LC-HPC)	Cubic Yard
*Grade of Concrete	

2.0 MATERIALS

Provide materials that comply with the applicable requirements.

LC-HPC .... **07-PS0166, latest version**

Concrete Curing Materials .... **DIVISION 1400**

3.0 CONSTRUCTION REQUIREMENTS

a. Qualification Batch and Slab. For each LC-HPC bridge deck, produce a qualification batch of LC-HPC that is to be placed in the deck and complies with **07-PS0166, latest version**, and construct a qualification slab that complies with this specification to demonstrate the ability to handle, place, finish and cure the LC-HPC bridge deck.

After the qualification batch of LC-HPC complies with **07-PS0166, latest version**, construct a qualification slab 15 to 45 days prior to placing LC-HPC in the bridge deck. Construct the qualification slab to comply with the Contract Documents, using the same LC-HPC that is to be placed in the deck and that was approved in the qualification batch. Submit the location of the qualification slab for approval by the Engineer. Place, finish and cure the qualification slab according to the Contract Documents, using the same personnel, methods and equipment (including the concrete pump, if used) that will be used on the bridge deck.

A minimum of 1 day after construction of the qualification slab, core 4 full-depth 4 inch diameter cores, one from each quadrant of the qualification slab, and forward them to the Engineer for visual inspection of degree of consolidation.

Do not commence placement of LC-HPC in the deck until approval is given by the Engineer. Approval to place concrete on the deck will be based on satisfactory placement, consolidation, finishing and curing of the qualification slab and cores, and will be given or denied within 24 hours of receiving the cores from the Contractor. If an additional qualification slab is deemed necessary by the Engineer, it will be paid for at the contract unit price for Qualification Slab.

b. Falsework and Forms. Construct falsework and forms according to **SECTION 708**.

c. Handling and Placing LC-HPC.

(1) Quality Control Plan (QCP). At a project progress meeting prior to placing LC-HPC, discuss with the Engineer the method and equipment used for deck placement. Submit an acceptable QCP according to the Contractor's Concrete Structures Quality Control Plan, Part V. Detail the equipment (for both determining and controlling the evaporation rate and LC-HPC temperature), procedures used to minimize the evaporation rate, plans for maintaining a continuous rate of finishing the deck without delaying the application of curing materials within the time specified in **subsection 3.0f.**, including maintaining a continuous supply of LC-HPC throughout the placement with an adequate quantity of LC-HPC to complete the deck and filling diaphragms and end walls in advance of deck placement, and plans for placing the curing materials within the time specified in **subsection 3.0f**. In the plan, also include input from the LC-

HPC supplier as to how variations in the moisture content of the aggregate will be handled, should they occur during construction.

(2) Use a method and sequence of placing LC-HPC approved by the Engineer. Do not place LC-HPC until the forms and reinforcing steel have been checked and approved. Before placing LC-HPC, clean all forms of debris.

(3) Finishing Machine Setup. On bridges skewed greater than 10º, place LC-HPC on the deck forms across the deck on the same skew as the bridge, unless approved otherwise by State Bridge Office (SBO). Operate the bridge deck finishing machine on the same skew as the bridge, unless approved otherwise by the SBO. Before placing LP-HPC, position the finish machine throughout the proposed placement area to allow the Engineer to verify the reinforcing steel positioning.

(4) Environmental Conditions. Maintain environmental conditions on the entire bridge deck so the evaporation rate is less than 0.2 lb/sq ft/hr. The temperature of the mixed LC-HPC immediately before placement must be a minimum of 55°F and a maximum of 70°F. With approval by the Engineer, the temperature of the LC-HPC may be adjusted 5°F above or below this range. This may require placing the deck at night, in the early morning or on another day. The evaporation rate (as determined in the American Concrete Institute Manual of Concrete Practice 305R, Chapter 2) is a function of air temperature, LC-HPC temperature, wind speed and relative humidity. The effects of any fogging required by the Engineer will not be considered in the estimation of the evaporation rate (**subsection 3.0c.(5)**).

Just prior to and at least once per hour during placement of the LC-HPC, the Engineer will measure and record the air temperature, LC-HPC temperature, wind speed, and relative humidity on the bridge deck. The Engineer will take the air temperature, wind, and relative humidity measurements approximately 12 inches above the surface of the deck. With this information, the Engineer will determine the evaporation rate using KDOT software or **FIGURE 710-1**.

When the evaporation rate is equal to or above 0.2 lb/ft^2/hr, take actions (such as cooling the LC-HPC, installing wind breaks, sun screens etc.) to create and maintain an evaporation rate less than 0.2 lb/ft^2/hr on the entire bridge deck.

(5) Fogging of Deck Placements. Fogging using hand-held equipment may be required by the Engineer during unanticipated delays in the placing, finishing or curing operations. If fogging is required by the Engineer, do not allow water to drip, flow or puddle on the concrete surface during fogging, placement of absorptive material, or at any time before the concrete has achieved final set.

(6) Placement and Equipment. Place LC-HPC by conveyor belt or concrete bucket. Pumping of LC-HPC will be allowed if the Contractor can show proficiency when placing the approved mix during construction of the qualification slab using the same pump as will be used on the job. Placement by pump will also be allowed with prior approval of the Engineer contingent upon successful placement by pump of the approved mix, using the same pump as will be used for the deck placement, at least 15 days prior to placing LC-HPC in the bridge deck. To limit the loss of air, the maximum drop from the end of a conveyor belt or from a concrete bucket is 5 feet and pumps must be fitted with an air cuff/bladder valve. Do not use chutes, troughs or pipes made of aluminum.

Place LC-HPC to avoid segregation of the materials and displacement of the reinforcement. Do not deposit LC-HPC in large quantities at any point in the forms, and then run or work the LC-HPC along the forms.

Fill each part of the form by depositing the LC-HPC as near to the final position as possible.

The Engineer will obtain sample LC-HPC for tests and cylinders at the discharge end of the conveyor, bucket, or if pumped, the piping.

(7) Consolidation.

- Accomplish consolidation of the LC-HPC on all span bridges that require finishing machines by means of a mechanical device on which internal (spud or tube type) concrete vibrators of the same type and size are mounted (**subsection 154.2**).
- Observe special requirements for vibrators in contact with epoxy coated reinforcing steel as specified in **subsection 154.2**.
- Provide stand-by vibrators for emergency use to avoid delays in case of failure.
- Operate the mechanical device so vibrator insertions are made on a maximum spacing of 12 inch centers over the entire deck surface.
- Provide a uniform time per insertion of all vibrators of 3 to 15 seconds, unless otherwise designated by the Engineer.
- Provide positive control of vibrators using a timed light, buzzer, automatic control or other approved method.
- Extract the vibrators from the LC-HPC at a rate to avoid leaving any large voids or holes in the LC-HPC.
- Do not drag the vibrators horizontally through the LC-HPC.
- Use hand held vibrators (**subsection 154.2**) in inaccessible and confined areas such as along bridge rail or curb.

- When required, supplement vibrating by hand spading with suitable tools to provide required consolidation.
- Reconsolidate any voids left by workers.

Continuously place LC-HPC in any floor slab until complete, unless shown otherwise in the Contract Documents.

d. Construction Joints, Expansion Joints and End of Wearing Surface (EWS) Treatment. Locate the construction joints as shown in the Contract Documents. If construction joints are not shown in the Contract Documents, submit proposed locations for approval by the Engineer.

If the work of placing LC-HPC is delayed and the LC-HPC has taken its initial set, stop the placement, saw the nearest construction joint approved by the Engineer, and remove all LC-HPC beyond the construction joint.

Construct keyed joints by embedding water-soaked beveled timbers of a size shown on the Contract Documents, into the soft LC-HPC. Remove the timber when the LC-HPC has set. When resuming work, thoroughly clean the surface of the LC-HPC previously placed, and when required by the Engineer, roughen the key with a steel tool. Before placing LC-HPC against the keyed construction joint, thoroughly wash the surface of the keyed joint with clean water.

e. Finishing. Strike off bridge decks with a vibrating screed or single-drum roller screed, either self-propelled or manually operated by winches and approved by the Engineer. Use a self-oscillating screed on the finish machine, and operate or finish from a position either on the skew or transverse to the bridge roadway centerline. See **subsection 3.0c.(3)**. Do not mount tamping devices or fixtures to drum roller screeds; augers are allowed.

Irregular sections may be finished by other methods approved by the Engineer and detailed in the required QCP. See **subsection 3.0c.(1)**.

Finish the surface by a burlap drag, metal pan or both, mounted to the finishing equipment. Use a float or other approved device behind the burlap drag or metal pan, as necessary, to remove any local irregularities. Do not add water to the surface of LC-HPC. Do not use a finishing aid.

Tining of plastic LC-HPC is prohibited. All LC-HPC surfaces must be reasonably true and even, free from stone pockets, excessive depressions or projections beyond the surface.

Finish all top surfaces, such as the top of retaining walls, curbs, abutments and rails, with a wooden float by tamping and floating, flushing the mortar to the surface and provide a uniform surface, free from pits or porous places. Trowel the surface producing a smooth surface, and brush lightly with a damp brush to remove the glazed surface.

f. Curing and Protection.

(1) General. Cure all newly placed LC-HPC immediately after finishing, and continue uninterrupted for a minimum of 14 days. Cure all pedestrian walkway surfaces in the same manner as the bridge deck. Curing compounds are prohibited during the 14 day curing period.

(2) Cover With Wet Burlap. Soak the burlap a minimum of 12 hours prior to placement on the deck. Rewet the burlap if it has dried more one hour before it is applied to the surface of bridge deck. Apply 1 layer of wet burlap within 10 minutes of LC-HPC strike-off from the screed, followed by a second layer of wet burlap within 5 minutes. Do not allow the surface to dry after the strike-off, or at any time during the cure period. In the required QCP, address the rate of LC-HPC placement and finishing methods that will affect the period between strike-off and burlap placement. See **subsection 3.0c.(1)**. During times of delay expected to exceed 10 minutes, cover all concrete that has been placed, but not finished, with wet burlap.

Maintain the wet burlap in a fully wet condition using misting hoses, self-propelled, machine-mounted fogging equipment with effective fogging area spanning the deck width moving continuously across the entire burlap-covered surface, or other approved devices until the LC-HPC has set sufficiently to allow foot traffic. At that time, place soaker hoses on the burlap, and supply running water continuously to maintain continuous saturation of all burlap material to the entire LC-HPC surface. For bridge decks with superelevation, place a minimum of 1 soaker hose along the high edge of the deck to keep the entire deck wet during the curing period.

(3) Waterproof Cover. Place white polyethylene film on top of the soaker hoses, covering the entire LC-HPC surface after soaker hoses have been placed, a maximum of 12 hours after the placement of the LC-HPC. Use as wide of sheets as practicable, and overlap 2 feet on all edges to form a complete waterproof cover of the entire LC-HPC surface. Secure the polyethylene film so that wind will not displace it. Should any portion of the sheets be broken or damaged before expiration of the curing period, immediately repair the broken or damaged portions. Replace sections that have lost their waterproof qualities.

If burlap and/or polyethylene film is temporarily removed for any reason during the curing period, use soaker hoses to keep the entire exposed area continuously wet. Replace saturated burlap and polyethylene film, resuming the specified curing conditions, as soon as possible.

Inspect the LC-HPC surface once every 6 hours for the entirety of the 14 day curing period, so that all areas remain wet for the entire curing period and all curing requirements are satisfied.

(4) Documentation. Provide the Engineer with a daily inspection set that includes:

- documentation that identifies any deficiencies found (including location of deficiency);
- documentation of corrective measures taken;
- a statement of certification that the entire bridge deck is wet and all curing material is in place;
- documentation showing the time and date of all inspections and the inspector's signature.
- documentation of any temporary removal of curing materials including location, date and time, length of time curing was removed, and means taken to keep the exposed area continuously wet.

(5) Cold Weather Curing. When LC-HPC is being placed in cold weather, also adhere to **07-PS0166, latest version**.

When LC-HPC is being placed and the ambient air temperature may be expected to drop below 40ºF during the curing period or when the ambient air temperature is expected to drop more than 25°F below the temperature of the LC-HPC during the first 24 hours after placement, provide suitable measures such as straw, additional burlap, or other suitable blanketing materials, and/or housing and artificial heat to maintain the LC-HPC and girder temperatures between 40ºF and 75ºF as measured on the upper and lower surfaces of the LC-HPC. Enclose the area underneath the deck and heat so that the temperature of the surrounding air is as close as possible to the temperature of LC-HPC and between 40ºF and 75ºF. When artificial heating is used to maintain the LC-HPC and girder temperatures, provide adequate ventilation to limit exposure to carbon dioxide if necessary. Maintain wet burlap and polyethylene cover during the entire 14 day curing period. Heating may be stopped after the first 72 hours if the time of curing is lengthened to account for periods when the ambient air temperature is below 40ºF. For every day the ambient air temperature is below 40ºF, an additional day of curing with a minimum ambient air temperature of 50ºF will be required. After completion of the required curing period, remove the curing and protection so that the temperature of the LC-HPC during the first 24 hours does not fall more than 25°F.

(6) Curing Membrane. At the end of the 14-day curing period remove the wet burlap and polyethylene and within 30 minutes, apply 2 coats of an opaque curing membrane to the LC-HPC. Apply the curing membrane when no free water remains on the surface but while the surface is still wet. Apply each coat of curing membrane according to the manufacturer's instructions with a minimum spreading rate per coat of 1 gallon per 80 square yards of LC-HPC surface. If the LC-HPC is dry or becomes dry, thoroughly wet it with water applied as a fog spray by means of approved equipment. Spray the second coat immediately after and at right angles to the first application.
Protect the curing membrane against marring for a minimum of 7 days. Give any marred or disturbed membrane an additional coating. Should the curing membrane be subjected to continuous injury, the Engineer may limit work on the deck until the 7-day period is complete. Because the purpose of the curing membrane is to allow for slow drying of the bridge deck, extension of the initial curing period beyond 14 days, while permitted, shall not be used to reduce the 7-day period during which the curing membrane is applied and protected.

(7) Construction Loads. Adhere to **TABLE 710-2**.

If the Contractor needs to drive on the bridge before the approach slabs can be placed and cured, construct a temporary bridge from the approach over the EWS capable of supporting the anticipated loads. Do not bend the reinforcing steel which will tie the approach slab to the EWS or damage the LC-HPC at the EWS. The method of bridging must be approved by the Engineer.

TABLE 710-2: CONCRETE LOAD LIMITATIONS ON BRIDGE DECKS		
Days after concrete is placed	**Element**	**Allowable Loads**
1*	Subdeck, one-course deck or concrete overlay	Foot traffic only.

3*	One-course deck or concrete overlay	Work to place reinforcing steel or forms for the bridge rail or barrier.
7*	Concrete overlays	Legal Loads; Heavy stationary loads with the Engineer's approval.***
10 (15)**	Subdeck, one-course deck or post-tensioned haunched slab bridges**	Light truck traffic (gross vehicle weight less than 5 tons).****
14 (21)**	Subdeck, one-course deck or post-tensioned haunched slab bridges**	Legal Loads; Heavy stationary loads with the Engineer's approval.***Overlays on new decks.
28	Bridge decks	Overloads, only with the State Bridge Engineer's approval.***

*Maintain a 7 day wet cure at all times (14-day wet cure for decks with LC-HPC).
** Conventional haunched slabs.
*** Submit the load information to the appropriate Engineer. Required information: the weight of the material and the footprint of the load, or the axle (or truck) spacing and the width, the size of each tire (or track length and width) and their weight.
****An overlay may be placed using pumps or conveyors until legal loads are allowed on the bridge.

g. Grinding and Grooving. Correct surface variations exceeding 1/8 inch in 10 feet by use of an approved profiling device, or other methods approved by the Engineer after the curing period. Perform grinding on hardened LC-HPC after the 7 day curing membrane period to achieve a plane surface and grooving of the final wearing surface as shown in the Contract Documents.

Use a self-propelled grinding machine with diamond blades mounted on a multi-blade arbor. Avoid using equipment that causes excessive ravels, aggregate fractures or spalls. Use vacuum equipment or other continuous methods to remove grinding slurry and residue.

After any required grinding is complete, give the surface a suitable texture by transverse grooving. Use diamond blades mounted on a self-propelled machine that is designed for texturing pavement. Transverse grooving of the finished surface may be done with equipment that is not self-propelled providing that the Contractor can show proficiency with the equipment. Use equipment that does not cause strain, excessive raveling, aggregate fracture, spalls, disturbance of the transverse or longitudinal joint, or damage to the existing LC-HPC surface. Make the grooving approximately 3/16 inch in width at 3/4 inch centers and the groove depth approximately 1/8 inch. For bridges with drains, terminate the transverse grooving approximately 2 feet in from the gutter line at the base of the curb. Continuously remove all slurry residues resulting from the texturing operation.

h. Post Construction Conference. At the completion of the deck placement, curing, grinding and grooving for a bridge using LC-HPC, a post-construction conference will be held with all parties that participated in the planning and construction present. The Engineer will record the discussion of all problems and successes for the project.

i. Removal of Forms and Falsework. Do not remove forms and falsework without the Engineer's approval. Remove deck forms approximately 2 weeks (a maximum of 4 weeks) after the end of the curing period (removal of burlap), unless approved by the Engineer. The purpose of 4 week maximum is to limit the moisture gradient between the bottom and the top of the deck.

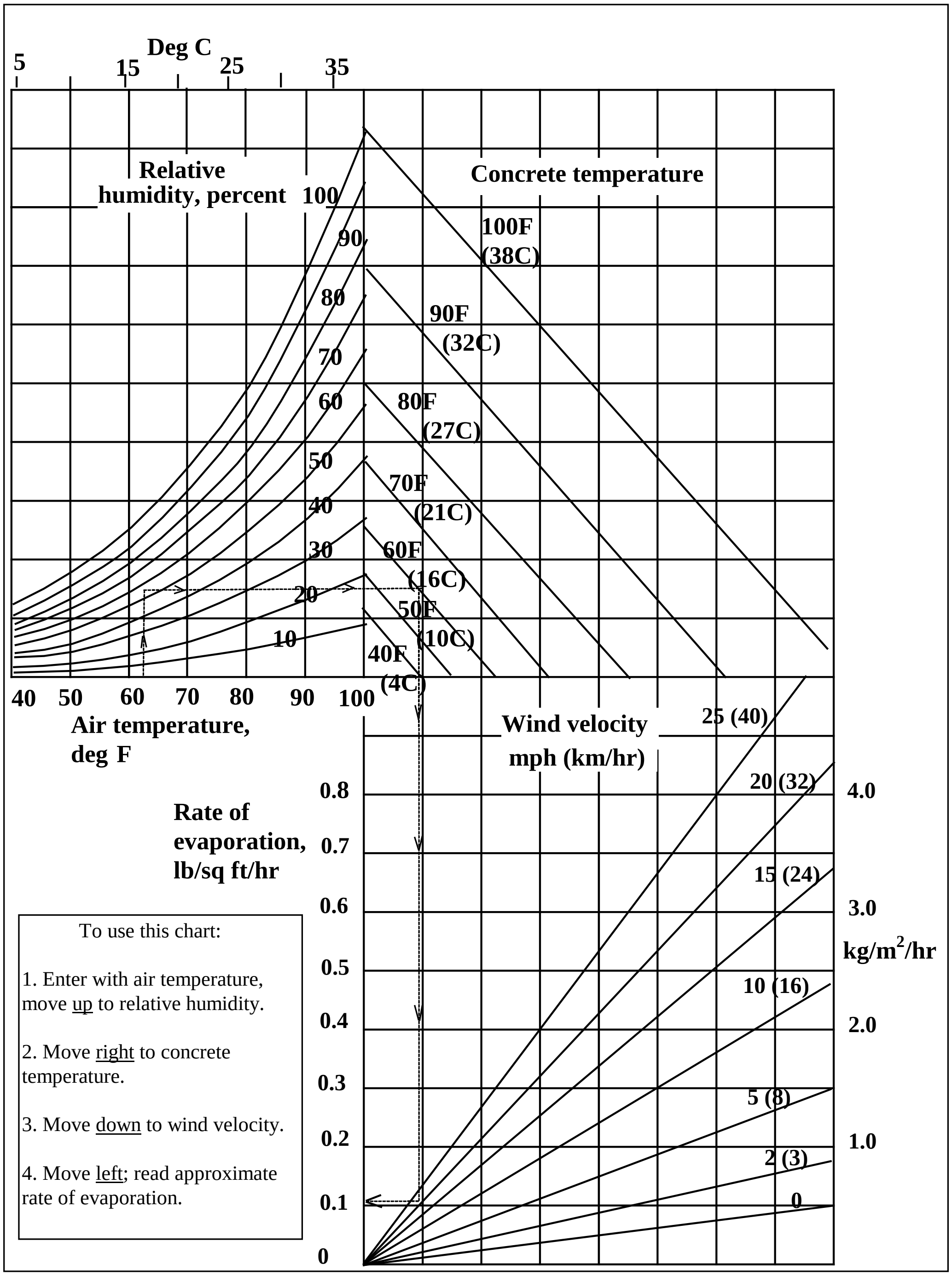
For additional requirements regarding forms and falsework, see **SECTION 708**.

4.0 MEASUREMENT AND PAYMENT

The Engineer will measure the qualification slab and the various grades of (AE) (LC-HPC) concrete placed in the structure by the cubic yard. No deductions are made for reinforcing steel and pile heads extending into the LP-HPC. The Engineer will not separately measure reinforcing steel in the qualification slab.

Payment for the "Qualification Slab" and the various grades of "(AE) (LC-HPC) Concrete" at the contract unit prices is full compensation for the specified work.

FIGURE 710-1: STANDARD PRACTICE FOR CURING CONCRETE



Effect of concrete and air temperatures, relative humidity, and wind velocity on the rate of evaporation of surface moisture from concrete. This chart provides a graphic method of estimating the loss of surface moisture for various weather conditions. To use the chart, follow the four steps outlined above. When the evaporation rate exceeds 0.2 lb/ft^2/hr (1.0 kg/ m^2/hr), measures shall be taken to prevent excessive moisture loss from the surface of unhardened concrete; when the rate is less than 0.2 lb/ft^2/hr (1.0 kg/m^2/hr) such measures may be needed. When excessive moisture loss is not prevented, plastic cracking is likely to occur.

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