INTERNAL CURING AND SUPPLEMENTARY CEMENTITIOUS MATERIALS IN BRIDGE DECKS

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SL Report 18-2
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THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
2385 Irving Hill Road, Lawrence, Kansas 66045-7563

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ABSTRACT

Supplementary cementitious materials (SCMs) are used in conjunction with pre-wetted fine lightweight aggregate to provide internal curing, producing high-performance, low-shrinking concrete to mitigate bridge deck cracking. This study examines the density of cracks in bridge decks in Indiana and Utah that incorporated internal curing with various combinations of portland cement and SCMs, specifically, slag cement, Class C and Class F fly ash, and silica fume, in concrete mixtures with water-cementitious material ratios ranging from 0.39 to 0.44. When compared with crack densities in low-cracking high-performance concrete (LC-HPC) and control bridge decks in Kansas, concrete mixtures with a paste content higher than 27% exhibited more cracking, regardless of the use of internal curing or SCMs. Bridge decks with paste contents below 26% that incorporate internal curing and SCMs exhibited low cracking at early ages, although additional surveys will be needed before conclusions on long-term behavior can be made.

Key words: bridge decks, internal curing high-performance concrete, cracking, lightweight aggregate, paste content, supplementary cementitious materials

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INTRODUCTION

Cracking in bridge decks is a serious concern because cracks provide corrosive agents a direct path to reinforcing steel and reduce the freeze-thaw resistance of the concrete. Over the past two decades, the Kansas Department of Transportation (KDOT) has been working 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.

The LC-HPC specifications address cement and water content, plastic concrete properties, construction methods, and curing requirements. The constituent that undergoes shrinkage in concrete is cement paste (cementitious materials plus water in a concrete mixture). As a measure to reduce shrinkage compared to conventional bridge deck concrete, LC-HPC specifications limit cement content and dictate a tight range of water-cement (*w/c*) ratios. Cement contents are limited to 500 to 540 lb/yd^3 (296 to 320 kg/m^3). Because of a lack of consensus on the effect of supplementary cementitious materials (SCMs) on drying shrinkage at the time LC-HPC specifications were first written, only portland cement has been permitted in LC-HPC decks. A *w/c* ratio of 0.43 to 0.45 is specified to help limit strength because of the relationship between high strength and increased cracking due to reduced creep, which can result in increased cracking if drying shrinkage is restrained. For portland cement mixtures following LC-HPC specifications for *w/c* ratio and cement content, the paste content is inherently limited to 24.6% by volume. The 28-day strength of concrete is limited to values between 3500 and 5500 psi (24.1 and 37.9 MPa), and the air content of fresh concrete must be 8.0 ± 1.5% to improve durability and reduce cracking. An optimized aggregate gradation is used in LC-HPC mixtures. This can be achieved with tools such as described by Shilstone (1990) or provided by the KU Mix Method (Lindquist et al. 2008, 2015).

These criteria provide concrete with better workability at a lower slump. LC-HPC specifications limit slump to values between 1½ and 3 in. (40 and 75 mm) at the point of placement and 3½ in. (90 mm) at the truck because high slump increases settlement cracking above reinforcing bars. 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.

To reduce the amount of water lost during construction and to avoid plastic shrinkage cracking, the evaporation rate during bridge deck placement is limited to 0.2 lb/ft^2/hr (1.0 kg/m^2/hr). If the evaporation rate exceeds this limit, special actions, such as cooling the concrete or installing wind breaks, are required. Procedures for ensuring proper consolidation of concrete through the use of vertically mounted internal gang vibrators are also specified. The surface must 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 after final strike-off. 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.

In Kansas, 16 bridge decks have been constructed following the LC-HPC specifications (Kansas Department of Transportation 2011, 2014a, 2014b), with 11 bridge decks constructed following conventional KDOT specifications to provide a basis of comparison. The LC-HPC specifications are included in Appendix A. To provide a consistent method to compare bridge decks, a specific crack survey procedure has been developed to minimize variations from year to year (Lindquist et al. 2008, Yuan et al. 2011, Pendergrass et al. 2014). This procedure is presented in Appendix B. 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, 2016, 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. Crack width measurements are also taken during surveys. 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, 2016, Yuan et al. 2011, Pendergrass et al. 2014, Alhmood et al. 2015).

There are other approaches available in addition to LC-HPC to reduce cracking in bridge decks. These include the use of internal curing (IC) through partial replacement of aggregate with pre-wetted fine lightweight aggregate (LWA). For concrete with water-cementitious material (*w/cm*) ratios below about 0.42, the cement paste can experience self-desiccation during early hydration, resulting in autogenous shrinkage of the concrete. In cases where the concrete is restrained from shrinking, tensile stresses develop and crack the concrete. Proper distribution of IC water has been shown to improve performance of concrete due to the reduction of autogenous shrinkage by providing additional water for hydration throughout the entire cement paste matrix (Bentz and Weiss 2011). IC water is also available to reduce drying shrinkage for concrete made with *w/cm* ratios both above and below 0.42. Applicability of this technology for bridge deck cracking and durability is discussed in this report.

The initial survey results of six bridge decks in Indiana are the primary focus of this report. The first deck (IN-IC) was placed with IC concrete that contained 100% portland cement with internal curing obtained by replacing a portion of aggregate with pre-wetted fine LWA. The control deck for IN-IC, designated IN-Control, incorporated mixture proportions similar to the IN-IC deck but with no IC water provided (no LWA replacement). The other four bridges were constructed with internally cured high-performance concrete (IN-IC-HPC) containing SCMs, either Class C fly ash or slag cement along with silica fume. The IN-IC-HPC decks contained higher quantities of IC water than IN-IC.

In addition to the six bridges in Indiana, the results of crack surveys conducted by Brigham Young University (BYU) on two internally cured decks in Utah (UT-IC-1 and UT-IC-2) are also included in this paper for comparison. UT-IC-1 and UT-IC-2 were constructed in spring 2012 and are similar in structure type (including precast panels to support an internally cured deck topping) and mixture proportions. The concrete used in both UT-IC decks incorporated a partial replacement of cement with Class F fly ash. The age of both Utah bridges was 24 months at the time of most recent surveys and followed a procedure similar to that used by KU for visually inspecting bridge decks for cracks. This report analyzes the cracking performance of the eight bridge decks and compares them with that of the LC-HPC and conventional KDOT bridge decks being analyzed in the pooled-fund study.

BRIDGES

The Indiana bridges are located in two Indiana Department of Transportation (INDOT) districts, Seymour and Vincennes. The four IN-IC-HPC decks are supported by steel girders and have steel stay-in-place forms; the other two (IN-Control and IN-IC) are supported by prestressed box beams. The two Utah IC decks, surveyed by Brigham Young University researchers (included as an additional reference for comparison) consist of toppings supported by precast half-deck concrete panels that are, in turn, supported by precast prestressed concrete girders. Information on the decks is summarized in Table 1. In this report, the IC and control decks in Indiana are designated IN-IC and IN-Control, respectively, and the internally cured high-performance concrete decks are designated IN-IC-HPC-1 through IN-IC-HPC-4. The internally cured Utah deck toppings are designated UT-IC-1 and UT-IC-2.

Table 1: Bridge decks

Bridge ID	District	Type of Support	Spans	Skew (deg.)	Length (ft)	Length (m)	Width (ft)	Width (m)
IN-IC	Seymour	Prestressed box beams	1	10.6	40.3	12.3	29	8.8
IN-Control	Seymour	Prestressed box beams	1	0	50	15.2	29	8.8
IN-IC-HPC-1	Vincennes	Steel beams	3	0	224	68.3	34.5	10.5
IN-IC-HPC-2	Seymour	Steel beams	1	0	55	16.8	43.5	13.3
IN-IC-HPC-3	Seymour	Steel beams	4	34.8	256	78.0	33	10.1
IN-IC-HPC-4	Vincennes	Steel beams	2	6.7	230	70.1	43.8	13.4
UT-IC-1	-	Deck panels on prestressed girders	1	34	127.5	38.9	50.8	15.5
UT-IC-2	-	Deck panels on prestressed girders	1	4	119.8	36.5	50.8	15.5

CONCRETE PROPERTIES AND CONSTRUCTION PROCEDURES

The mixture proportions used for the bridge decks are shown in Table 2. The plastic concrete properties along with 28-day compressive strengths are listed in Table 3. Two concrete mix designs were used for internally cured bridge decks in Indiana, IN-IC and IN-IC-HPC. The IN-IC concrete contained 657 lb/yd^3 (390 kg/m^3) of portland cement, the only binder, and had a *w/c* ratio of 0.39, which resulted in a paste volume of 27.6%, exceeding the paste content range in the Kansas LC-HPC specifications. For the IC concrete mixtures, current literature typically reports the amount of IC water in lb per 100 lb (kg per 100 kg) of cementitious material. For this paper, the amount of IC water is reported as a percentage by weight of cementitious material. The

IC water for the IN-IC deck was provided through replacement of 24% of total aggregate (by volume) with pre-wetted fine LWA that provided 7.2% of IC water by weight of cement in the mixture (Di Bella et al. 2012). Determination of absorption in the laboratory was based on soaking the material for 24 hours before placing it in a pre-wetted surface dry (PSD) condition. For fine LWA, absorption tends to increase with longer soak times, so properties are described in terms of the PSD condition rather than the SSD condition since the material is not fully saturated. A commercially available fine LWA with a 24-hour absorption of 10.4% and a PSD specific gravity of 1.56 was used. All LWA referenced in this paper is expanded shale. The mixture proportions conformed to INDOT specifications and determination of LWA properties followed procedures outlined by the New York State DOT (NYSDOT) for construction of a series of internally cured bridge decks (Streeter et al 2012). A modified paper towel test method (NY 703-19E Test Method) that includes instructions for determining LWA properties in the field as well as in the lab was used in lieu of ASTM C128.

Table 2: Mixture proportions (SSD/PSD basis)

Bridge ID	**Date Placed**	**Cementitious Material Percentages**[b]	**Coarse Aggregate**	**Fine Aggregate**	**Fine LWA (PSD)**
			lb/yd^3 (kg/m^3)	**lb/yd^3 (kg/m^3)**	**lb/yd^3 (kg/m^3)**
IN-IC	9/24/2010	100% C	1764 (1046)	528 (313)	455 (270)
IN-Control	9/23/2010	100% C	1764 (1046)	1224 (726)	-
IN-IC-HPC-1[a]	7/19/2013	78% C, 18% S, 4% SF	1805 (1071)	795 (472)	375 (222)
	10/18/2013		1800 (1068)	801 (475)	348 (206)
IN-IC-HPC-2	10/1/2013	71% C, 25% C-FA, 4% SF	1726 (1024)	819 (486)	334 (198)
IN-IC-HPC-3	11/1/2014	72% C, 24% C-FA, 4% SF	1758 (1043)	644 (382)	446 (265)
IN-IC-HPC-4[a]	7/14/2015	76% C, 20% S, 4% SF	1763 (1046)	665 (395)	447 (265)
	10/3/2015		1768 (1049)	663 (393)	448 (266)
UT-IC-1	Spring 2012	79% C, 21% F-FA	1721 (1021)	706 (419)	324 (192)
UT-IC-2	Spring 2012	79% C, 21% F-FA	1721 (1021)	706 (419)	324 (192)

[a] The first row is for placement 1 and the second row is for placement 2.

[b] C = portland cement; S = slag cement; SF = silica fume; C-FA = Class C fly ash; F-FA = Class F fly ash

Table 2 (cont.): Mixture proportions (SSD/PSD basis)

Bridge ID	Cementitious Material Content	Water Content	Design IC Water	Actual IC Water	*w/cm* Ratio	Paste Content
	lb/yd^3 (kg/m^3)	lb/yd^3 (kg/m^3)	Percent of Binder by Weight	Percent of Binder by Weight		Percent
IN-IC	657 (390)	256 (152)	7	7.2	0.39	27.6
IN-Control	657 (390)	256 (152)	-	-	0.39	27.6
IN-IC-HPC-1*	568 (337)	228 (135)	8	9.1	0.401	24.6
	567 (336)	238 (141)	8	8.5	0.426	25.2
IN-IC-HPC-2	567 (336)	237 (141)	8	9.2	0.418	25.3
IN-IC-HPC-3	600 (356)	250 (148)	8	11.6	0.417	25.9
IN-IC-HPC-4*	582 (345)	241 (143)	8	12	0.414	25.7
	585 (348)	246 (146)	8	11.2	0.42	26
UT-IC-1	605 (359)	266 (158)	7	7	0.44	28
UT-IC-2	605 (359)	266 (158)	7	7	0.44	28

* = The first row is for placement 1 and the second row is for placement 2.

Table 3: Average plastic properties and compressive strengths

Bridge ID	Slump	Air Content	28-day Strength
	in. (mm)	(%)	psi (MPa)
IN-IC	-	-	4900 (33.8)
IN-Control	-	-	4380 (30.2)
IN- IC-HPC-1*	4¾ (120)	5.1	7680 (53.0)
	5¾ (145)	5.5	6640 (45.8)
IN-IC-HPC-2	5 (125)	6.4	6720 (46.3)
IN-IC-HPC-3	5½ (140)	7.0	5500 (37.9)
IN-IC-HPC-4*	4¾ (120)	6.2	6120 (42.2)[a]
	5¼ (135)	5.5	
UT-IC-1	3½ (90)	6.4	5710 (39.4)
UT-IC-2	3¼ (85)	6.0	5370 (37.0)

* = The first row is for placement 1 and the second row is for placement 2

[a] = Data on separate placements not available

- = Data not available

The IN-IC-HPC mixtures were designed to improve cracking and ionic transport properties of concrete (Barrett et al. 2015a). First, to reduce ion transport and have a denser microstructure, a ternary binder system with cement, silica fume (3 to 7% by mass), and slag cement (15 to 20% by mass) or Class C fly ash (20 to 25% by mass) was used to produce a refined pore system and greater calcium hydroxide consumption. During construction, absorption of the pre-wetted LWA obtained before batching exceeded the values determined in the laboratory. As batched, the IN-IC-HPC mixtures had between 8.8 and 12% of IC water by weight of binder. The fine LWA used for the IN-IC-HPC decks had a 24-hour absorption capacity (based on dry weight) and a PSD specific gravity of approximately 13% and 1.70, respectively, based on preliminary laboratory testing. These values varied slightly for each of the IN-IC-HPC decks and were used to develop mixture proportions. Laboratory testing used 24-hour values to ensure that 72-hour values in the field would easily meet or exceed the initial design, but no upper limit on the amount of IC water was designated. Second, the IN-IC-HPC specifications placed a 25% (±1.0%) limit on the paste content of the mixtures to improve the shrinkage and cracking performance of the concrete. The actual paste contents of the four IN-IC-HPC decks ranged from 24.6% to 26.0% by volume. As explained by Barrett et al. (2015a), this limitation was applied based on the recommendations by Schmitt and Darwin (1995) as a result of their study of 33 bridge deck placements in Kansas that showed a clear relationship between paste content and bridge deck cracking. Schmitt and Darwin (1995) concluded that when volume of the paste exceeded 27%, cracking significantly increases. A 7-day wet burlap curing regime was used for all Indiana bridges. INDOT removed the requirement for bridge decks to be covered by a commercial sealant for the internally cured decks and left them unsealed.

For the IC bridge decks in Indiana, the *w/cm* ratio was permitted to be between 0.39 and

0.42 to achieve high compressive strength and maintain durability, notably lower than the *w/cm* ratios used in the LC-HPC bridge decks in Kansas (0.44 to 0.45). IC water for these bridges was used to eliminate chemical shrinkage, defined as the change in volume due to the chemical reaction between cement and water (Barrett et al. 2015b), and autogenous shrinkage, defined as the change in volume due to self-desiccation, particularly in mixtures with low *w/cm* ratios (Di Bella et al. 2012, Barrett et al. 2015b). For mixtures without SCMs, the amount of IC water was specified to be 7% of the cement weight, based on work by Bentz and Weiss (2011), which indicated that chemical and autogenous shrinkage of portland cement can be mitigated by providing 7% internal curing water by weight of cement. For the IN-IC-HPC mixtures, which had a ternary binder system, the amount of IC water was specified to be 8% of the binder weight. The shrinkage behavior and rate of hydration for SCMs requires a higher amount of internal curing water to counteract the effects of chemical and autogenous shrinkage (Bentz and Weiss 2011). For the Indiana bridges, the 24-hour absorption (based on dry weight) and the PSD specific gravity of pre-wetted fine LWA, determined before construction, were used to design and batch the internally cured concrete mixtures. At the batching plant, the LWA stockpile was sprinkled for at least 48 hours and drained for 12 hours prior to batching. Prior to batching, the absorption, surface moisture, and specific gravity of the LWA were determined using the centrifuge method developed by Miller et al. (2014). Surface moisture and specific gravity values obtained before batching were used to adjust the mixture proportions to achieve a proper yield and *w/cm* ratio. The amount of fine LWA and subsequent amount of IC water in the mixtures, however, were adjusted only if the absorption was lower than that of the 24-hour absorption obtained in laboratory testing (Barrett et al. 2015a). The four IN-IC-HPC decks had a total of six placements. The placements were 10.5 to 37.2 months old when the first crack surveys were performed. The IN-IC deck concrete was placed using buckets, but the IN-Control concrete was pumped. Concrete in the four IN-IC-HPC decks was also pumped. All Indiana decks were tined shortly after concrete placement. The internally cured deck toppings in Utah were placed on precast half-deck concrete panels supported by five precast prestressed single span concrete girders. The topping concrete had a *w/cm* of 0.44 and a paste content of 28% by volume. This paste content exceeds Kansas LC-HPC concrete. The deck topping concrete incorporated Class F fly ash (21% by mass) as a partial replacement for portland cement; 16.7% of the total aggregate (by volume) was replaced with pre-wetted fine LWA with an absorption capacity of 15% and PSD specific gravity of 1.56 to provide IC water equal to 7% of the weight of binder (Guthrie et al. 2014). The 24-hour absorption of the pre-wetted fine LWA was used to proportion the aggregates. The LWA stockpile was sprinkled for a minimum of two days prior to mixing. The absorption was measured periodically, and when an absorption of 15% was achieved, the stockpile was drained. A curing compound was sprayed on the deck after finishing, followed by a 14-day period of curing under plastic. The two Utah IC deck toppings were constructed by the same contactor and utilized conventional wooden formwork. The deck surfaces were tined shortly after placement.

RESULTS

The crack surveys for the Indiana decks were completed between August 8 and 11, 2016. Additional surveys are planned for summer 2018. Placement ages range between 10.5 and 71.6 months. The two-year survey results presented for the Utah decks were completed in by 2012 Brigham Young University researchers (Guthrie et al. 2014). Crack densities for the Indiana and Utah decks ranged from 0 to 0.784 m/m^2 and are listed in Table 4. Based on previous work at KU, surveys should be conducted one and three years after placement and the survey at three years has proven to be a good predictor of long-term performance. Thus, ideally, the surveys conducted on the IC-HPC and Utah decks should be repeated. The results presented here for bridge decks younger than three years, however, do serve as a baseline for future surveys.

Table 4: Summary of LWA information and crack densities

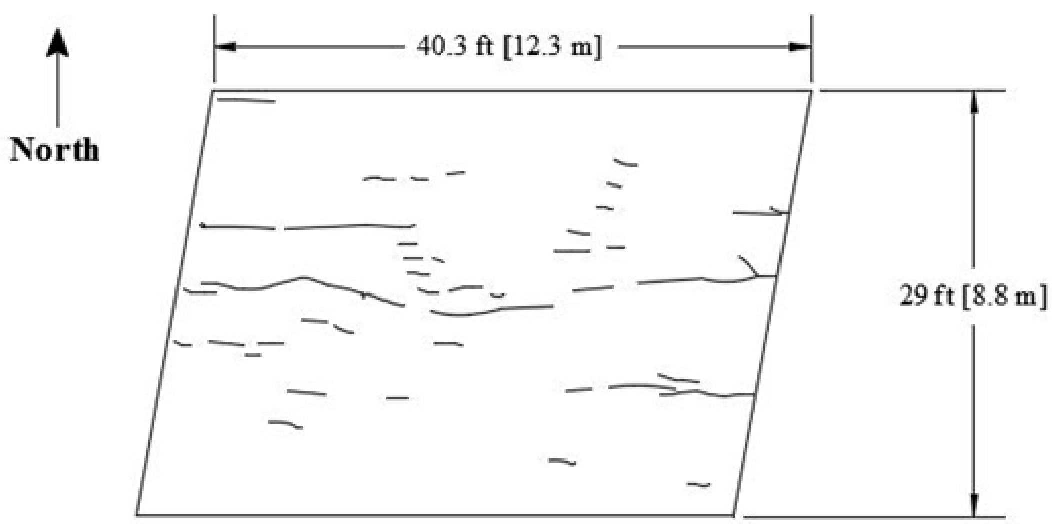
Bridge ID	LWA Used	IC Water (percent of binder)	Age at Survey (months)	Crack Density (m/m^2)
IN-IC	Expanded Shale	7.2	71.6	0.347
IN-Control	-	-	71.6	0.507
IN-IC-HPC-1*	Expanded Shale	9.1	34.7	0
		8.5	37.2	0.020
IN-IC-HPC-2	Expanded Shale	9.2	34.8	0.003
IN-IC-HPC-3	Expanded Shale	11.6	21.6	0.016
IN-IC-HPC-4*	Expanded Shale	12	10.5	0.021
		11.2	15.6	0.005
UT-IC-1	Expanded Shale	7	24	0.784
UT-IC-2	Expanded Shale	7	24	0.427

* = The first row is for Placement 1 and the second row is for Placement 2.

IN-IC

IN-IC is a single-span bridge located in the INDOT Seymour district near the city of Bloomington and spans over Stephens Creek on North Gettys Creek Rd. The deck was placed in September 2010 in a single placement. It is supported by prestressed concrete box beams. IN-IC is 29 ft (8.4 m) wide, and the deck varies in depth from 4½ in. (114 mm) at edge gutters to 8 in. (205 mm) at the roadway centerline. A single layer of reinforcing steel was placed at the mid-depth of the deck. The IN-IC bridge spans approximately 40.3 ft (12.3 m). The concrete contained 657 lb/yd^3 (390 kg/m^3) of Type I/II portland cement, compared to a maximum of 540 lb/yd^3 (320 kg/m^3) used for LC-HPC bridge decks. IN-IC contained pre-wetted fine LWA for providing IC water. The *w/cm* ratio was 0.39, well below the range of 0.43 to 0.45 used for LC-HPC bridge decks. The paste content was 27.6%, by volume, which is higher than the 22.8-24.6% used in LC-HPC bridge decks and the threshold of 27% based on the work by Schmitt and Darwin (1995, 1999). Without internal curing, these parameters typically lead to concrete with high crack densities. The lightweight aggregate used in this bridge provided an average IC water content of 7.2% by weight of cement. The average 28-day strength of the lab-cured cylinders was 4900 psi (33.8 MPa), which is within the suggested range of 3500-5500 psi (24.1-37.9 MPa) for LC-HPC. The strength, however, was low considering the *w/cm* ratio of 0.39. Fresh concrete properties including slump, temperature, and air content are not available for this deck.

IN-IC was surveyed at an age of 71.6 months with a resultant crack density of 0.347 m/m^2. Figure 1 shows the crack survey results for IN-IC. The majority of the cracks in this deck are oriented in the longitudinal direction, with the longest cracks appearing to occur at the prestressed box girder boundaries. The average crack width for this bridge was 0.006 in. (0.15 mm).



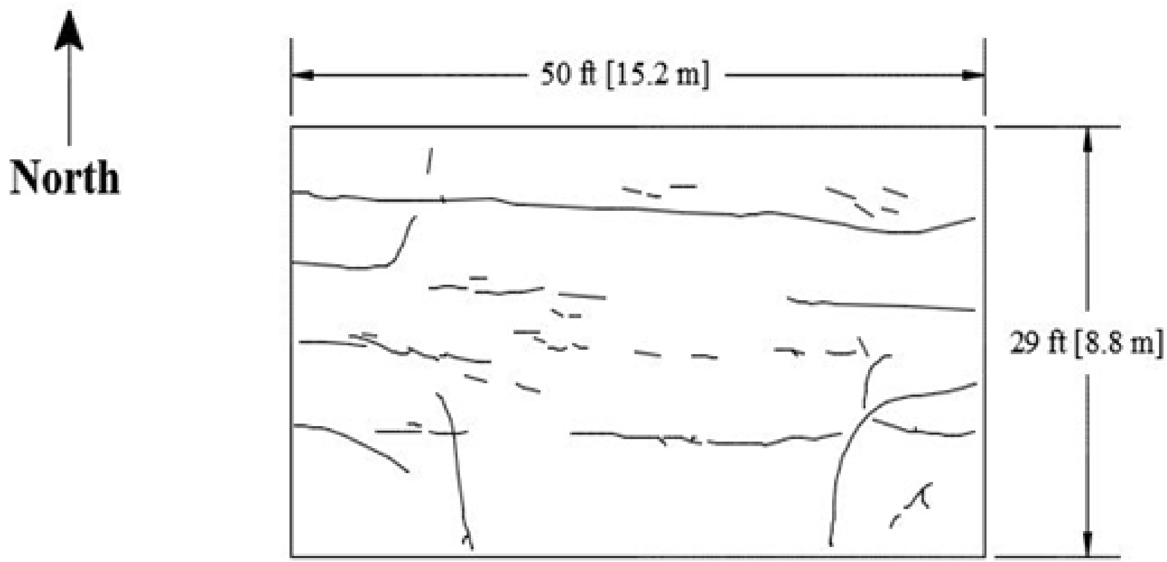
Average crack density = 0.347 m/m^2

Figure 1: IN-Control (Survey 1 – 71.6 months)

IN-Control

IN-Control is a single-span bridge also located on North Gettys Creek Rd., spanning over Stephens Creek near IN-IC. It serves as the control deck for IN-IC and did not utilize internal curing. Like IN-IC, IN-Control is supported by prestressed concrete box girders. The deck was, like IN-IC, constructed in September 2010 in a single placement. Deck geometry and reinforcement layout are similar to IN-IC. IN-Control spans approximately 50 ft (15.2 m). This bridge deck used the same type and amount of cement and *w/cm* ratio as the IN-IC deck. The average 28-day strength of the cylinders was 4380 psi (30.2 MPa), which is again low, considering the low *w/cm* ratio. Fresh concrete properties including slump, temperature, and air content are not available for this deck.

IN-Control was surveyed at an age of 71.6 months. The crack survey results are shown in Figure 2. The crack density was 0.507 m/m^2. Like IN-IC, most of the cracks are oriented in the longitudinal direction, with the longest cracks occurring at or near the prestressed box girder boundaries. There are more transverse cracks in IN-Control than IN-IC. The average crack width in this bridge was 0.010 in. (0.25 mm). In some cases, the box girders experienced differential settlement with respect to each other of as much as 3/8 in. (10 mm), as shown in Figure 3. This uneven settlement of adjacent girders may have contributed to the high number of longitudinal cracks on the deck.



Average crack density = 0.507 m/m^2

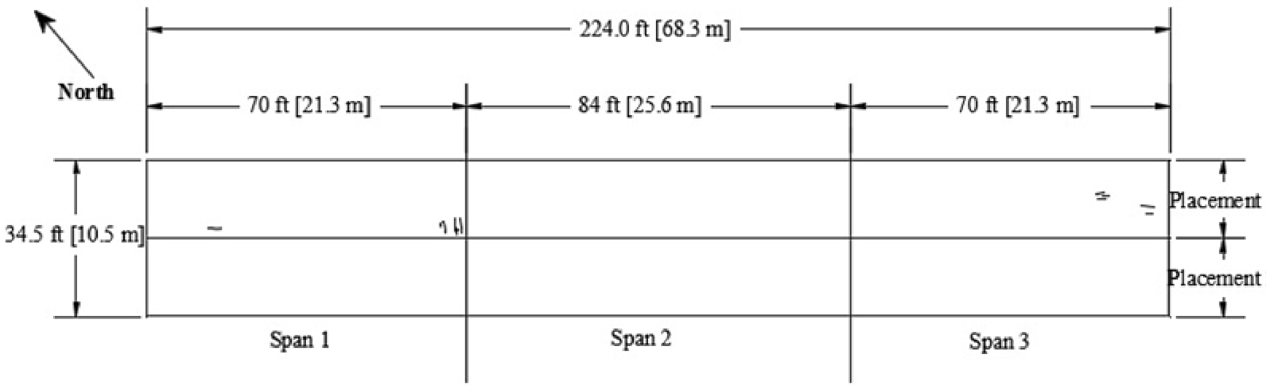
Figure 2: IN-Control (Survey 1 – 71.6 months)

Figure 3: Differential settlement of girders in IN-Control

IN-IC-HPC-1

IN-IC-HPC-1 is located north of West Baden Springs on US 150 crossing the Lost River. It is a three-span bridge with a length and width of 224 ft (68.3 m) and 34.5 ft (10.5 m), respectively. The deck is supported by steel girders and was constructed in two placements, in July and October 2013. The deck has a depth of 8 in. (205 mm), with 2.5 in. (64 mm) of top cover over reinforcing bars. The concrete contained 568 and 567 lb/yd^3 (324 kg/m^3) of cementitious material for Placements 1 and 2, respectively, 18% of which was slag cement and 4% of which was silica fume (by weight). For IC, the concrete also contained pre-wetted fine LWA, accounting for approximately 15% of total aggregate volume. The actual absorption of the LWA, determined prior to casting, was 18.7% for both placements (versus 14.9% used in design). This resulted in average IC water contents of 9.1 and 8.5% by weight of binder for Placements 1 and 2, respectively. The *w/cm* ratios for Placements 1 and 2 were 0.401 and 0.426, respectively, which are below the range for LC-HPC decks. The paste contents for Placements 1 and 2 were 24.6 and 25.2% of total volume, respectively. The paste content for Placement 2 was slightly outside of the range used in LC-HPC decks (22.8-24.6%). The average slumps for Placements 1 and 2 were 4¾ in. (120 mm) and 5¾ in. (145 mm) as measured at the point of placement, respectively, which exceed the maximum slump of 3½ in. (90 mm) specified for LC-HPC decks. The average air contents for Placements 1 and 2 were 5.1 and 5.5%, respectively, which are below the range (8.0 ± 1.5%) in the LC-HPC specifications. The average 28-day strengths for Placements 1 and 2 were 7680 and 6640 psi (53.0 and 45.8 MPa), respectively, which exceed the upper limit for compressive strength under LC-HPC specifications.

The two placements of IN-IC-HPC-1 were surveyed at ages of 34.7 and 37.2 months and have crack densities of 0 and 0.02 m/m^2, respectively, as shown in Figure 4. Both placements showed noticeable coarse aggregate pop-outs throughout the deck, more so on Placement 2 than Placement 1. Moderate scaling damage was observed near the north end. Figure 5 shows photos of scaling and freeze-thaw damage on IN-IC-HPC-1. Placement 2 had a few short longitudinal cracks on an end span, close to the abutment, and a few longer transverse cracks over the pier between the other two spans. The average crack width was 0.006 in. (0.15 mm).



Average crack density = 0.010 m/m^2

Placement 1 crack density = 0.02 m/m^2 Placement 2 crack density = 0 m/m^2

Span 1 crack density = 0.025 m/m^2 Span 2 crack density = 0.0 m/m^2

Span 3 crack density = 0.011 m/m^2

Figure 4: IN-IC-HPC-1 (Survey 1 – 34.7 months [Placement 1], 37.2 months [Placement 2])

(a) Scaling near the north end of IN-IC-HPC-1

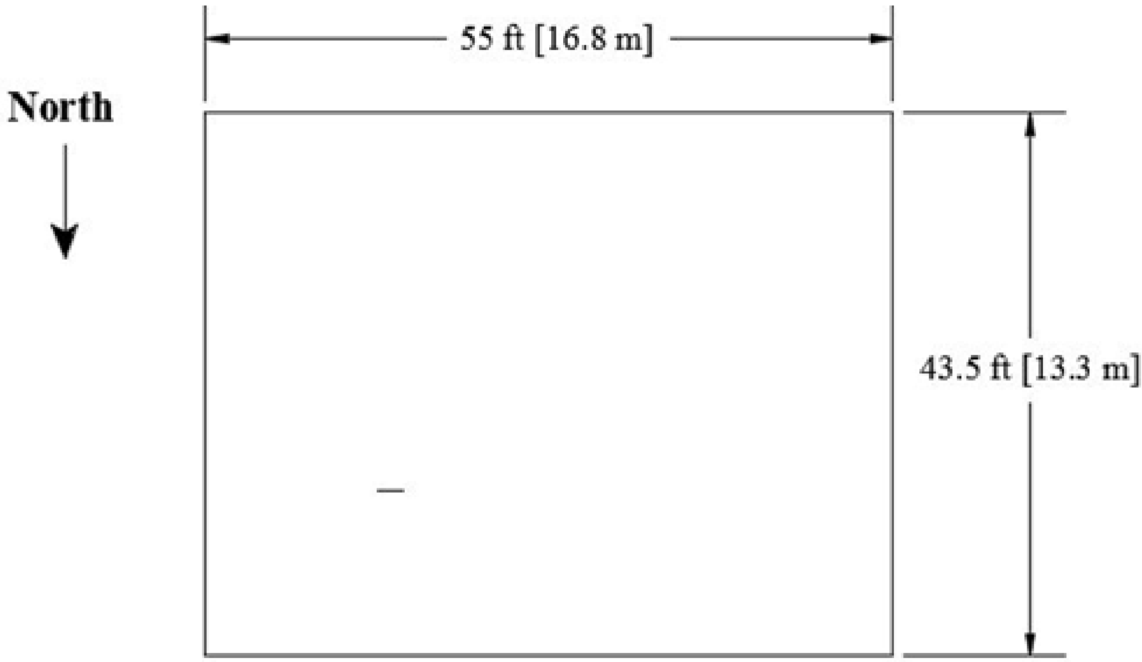
(b) Aggregate popouts (the crack width comparator has a width of approximately 2 in. [50 mm])

Figure 5: Scaling and freeze-thaw damage on IN-IC-HPC-1

IN-IC-HPC-2

IN-IC-HPC-2 is located in the town of Austin on US 31 over Hutto Creek. It is a single-span bridge with a length and width of 55 ft (16.8 m) and 43.5 ft (13.3 m), respectively, and is supported by steel girders. The deck was placed in October 2013. The deck is 8 in. (205 mm) thick. The concrete contained 575 lb/yd^3 (340 kg/m^3) of cementitious material, 25% of which was Class C fly ash, and 4% of which was silica fume. For internal curing, the concrete contained pre-wetted fine LWA, accounting for 15% of total aggregate volume. The actual absorption of LWA determined prior to casting for this deck was 20% (versus a design absorption of 13.75%). This resulted in an average IC water content of 9.2% by weight of binder. The *w/cm* ratio for this deck was 0.418, which is lower than the 0.43-0.45 range used in LC-HPC specifications. The paste content was 25.3% which is slightly outside of the range used in LC-HPC decks (22.8-24.6%). The average slump was 5 in. (125 mm), and the average air content was 6.4%. The average 28-day strength was 6720 psi (46.3 MPa). The concrete slump, air content, and compressive strength were outside of the ranges specified by LC-HPC specifications.

IN-IC-HPC-2 was surveyed at an age of 34.8 months. The crack density was 0.003 m/m^2. As shown in Figure 6, there was only one short longitudinal crack on the deck, with a width of 0.006 in. (0.15 mm). Figure 7 shows coarse aggregate pop-outs and deterioration on the walls of tined surface grooves that may have been caused by a combination of freeze-thaw damage and poor tining.



Average crack density = 0.003 m/m^2

Figure 6: IN-IC-HPC-2 (Survey 1 – 34.8 months)

(a) Freeze-thaw damage

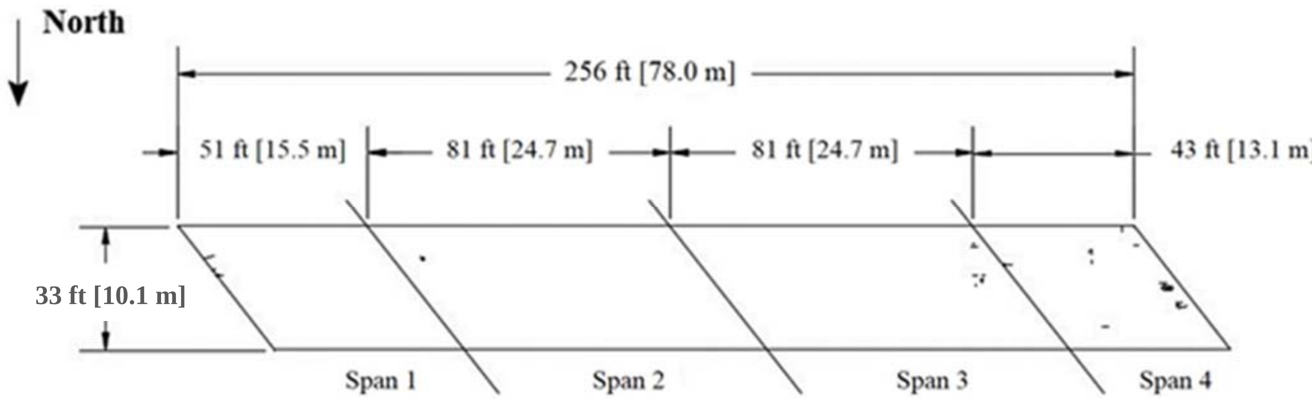
(b) Aggregate pop-out

Figure 7: Freeze-thaw damage and aggregate pop-out on IN-IC-HPC-2

IN-IC-HPC-3

IN-IC-HPC-3 is located on SR 46 over interstate highway I-74 in the town of West Harrison. This four-span bridge has a length and width of 256 ft (78 m) and 33 ft (10.1 m), respectively, and is supported by steel girders. The deck was constructed in a single placement in November 2014. The concrete contained 600 lb/yd^3 (355 kg/m^3) of cementitious material, 24% of which was Class C fly ash and 4% of which was silica fume. The pre-wetted fine LWA accounted for 21% of the total aggregate volume to provide an IC water content of 11.6% by weight of binder. The average *w/cm* ratio was 0.417 for this deck, outside the range suggested in the LC-HPC specifications (0.43-0.45). The paste content was 25.9%, which is outside of the range used in LC-HPC decks (22.8-24.6%). The average slump was 5½ in. (140 mm), and the average air content was 7.0%. The average 28-day strength was 5500 psi (37.9 MPa). Air content and strength met the LC-HPC requirements, but slump was higher than the limit specified within LC-HPC specifications.

IN-IC-HPC-3 was surveyed at 21.6 months. The overall crack density was found to be 0.016 m/m^2, as shown in Figure 8. The highest concentration of cracking on this deck was observed on one of the end spans. Most of the cracks were short, longitudinal, and narrow, located at the two abutments. The average crack width of all cracks recorded was 0.006 in. (0.15 mm). There were no transverse cracks, even over the piers. The surface of the deck did not show any indication of freeze-thaw damage or aggregate pop-outs. With the deck being relatively young, little cracking was expected.



Average crack density = 0.016 m/m^2
Span 1 crack density = 0.014 m/m^2 Span 2 crack density = 0.002 m/m^2
Span 3 crack density = 0.007 m/m^2 Span 4 crack density = 0.063 m/m^2

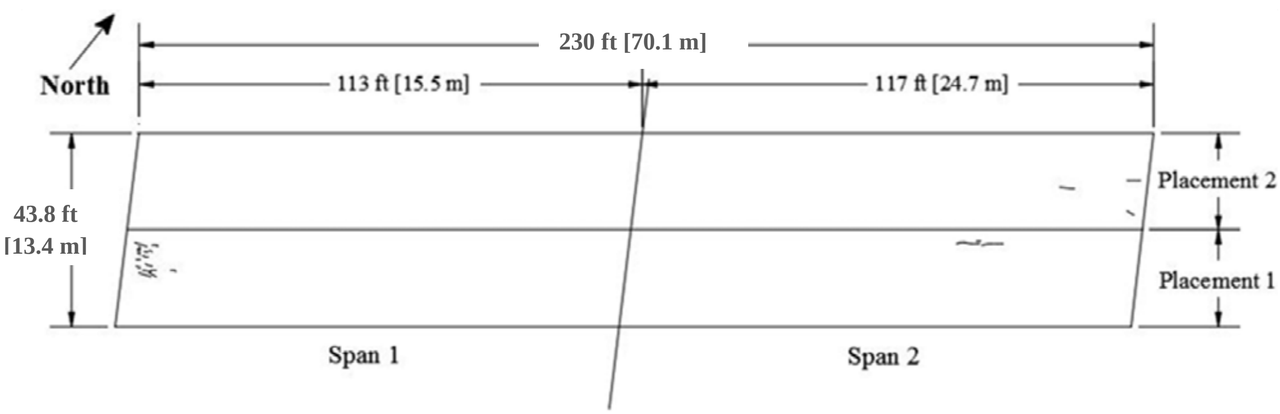
Figure 8: IN-IC-HPC-3 (Survey 1 – 21.6 months)

IN-IC-HPC-4

IN-IC-HPC-4 is located on SR 61 crossing over I-64. The two-span bridge has a length and width of 230 ft (70.1 m) and 43.8 ft (13.4 m), respectively, and is supported by steel girders. The deck was constructed in two placements, in July and October of 2015. The concrete contained 582 and 585 lb/yd^3 (345 and 347 kg/m^3) of cementitious material for Placements 1 and 2, respectively, 20% of which was slag and 4% of which was silica fume (by weight). The pre-wetted fine LWA for internal curing accounted for 21% of the total aggregate by volume. The actual absorptions of the LWA determined prior to casting were 20.1% and 18.9% for Placements 1 and 2, respectively (versus a design absorption of 13.3%). This resulted in average IC water contents of 12.0 and 11.2% by weight of binder for Placements 1 and 2, respectively. The average *w/cm* ratios for Placements 1 and 2 were 0.414 and 0.420, respectively, lower than those used in the LC-HPC decks. The actual paste contents for Placements 1 and 2 were 25.7% and 26%, respectively, slightly outside of the range used in LC-HPC decks (22.8-24.6%). The average slumps for Placements 1 and 2 were 4¾ in. (120 mm) and 5¼ in. (130 mm), respectively. The average air content was 6.2%

for the first placement and 5.5% for the second placement. Strength data were not provided for separate placements. The average 28-day compressive strength was given as 6120 psi (42.2 MPa). Slump, air content, and strength are outside the ranges given in the LC-HPC specifications.

The two placements of IN-IC-HPC-4 were surveyed at ages of 10.5 and 15.6 months, respectively, and have the lowest ages of the decks in this study. The crack densities for Placements 1 and 2 were 0.021 and 0.005 m/m^2, respectively, as shown in Figure 9. Span 1 of Placement 1 had some plastic shrinkage cracking close to the abutment. Short longitudinal cracks were also present on both placements for Span 2; the cracks in Placement 2 were closer to the abutment. No transverse cracks were observed, even over the piers. The average crack width was 0.006 in. (0.15 mm) for this bridge. The cracks located in Span 1 were significantly wider (average width of 0.014 in. [0.36 mm]) than those located in Span 2 (average width of 0.004 in. [0.10 mm]). As shown in Figure 10, freeze-thaw damage and poor surface finishing (poor tining/grooving) were observed on the surface of the deck; more so on Placement 1 than Placement 2. No aggregate pop-outs were observed.



Average crack density = 0.013 m/m^2

Placement 1 crack density = 0.021 m/m^2 Placement 2 crack density = 0.005 m/m^2

Span 1 crack density = 0.014 m/m^2 Span 2 crack density = 0.012 m/m^2

Figure 9: IN-IC-HPC-4 (Survey 1 – 10.5 months [Placement 1], 15.6 months [Placement 2])

Figure 10: Freeze-thaw damage on IN-IC-HPC-4

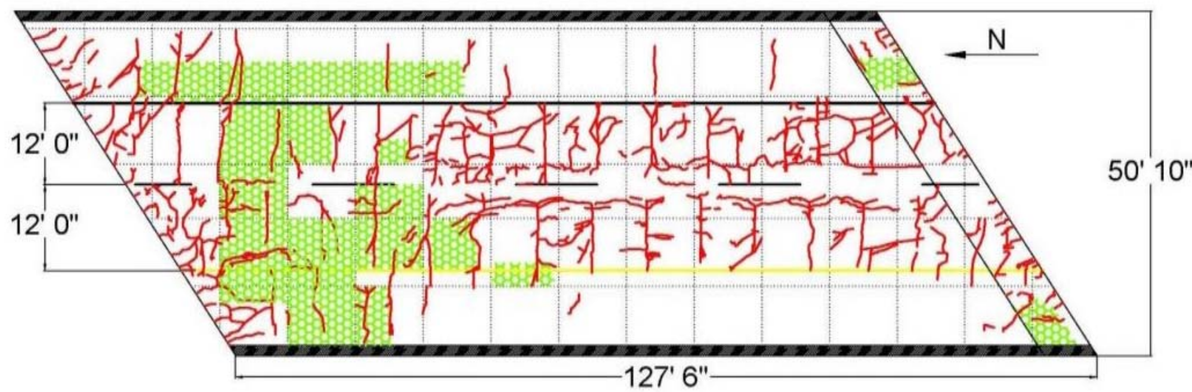
UT-IC-1 and UT-IC-2

UT-IC-1 and 2 are located in the city of West Jordan. UT-IC-1 is on Dannon Way Road, and UT-IC-2 is on 8200 South Road. Both are single span bridges supported by prestressed concrete girders and were placed in the spring of 2012. The length and width of UT-IC-1 are 127.5 ft (38.9 m) and 50.8 ft (15.5 m), respectively. The length and width of UT-IC-2 are 119.8 ft (36.5 m) and 50.8 ft (15.5 m), respectively. Precast half-deck concrete panels support the IC deck topping for both bridges and are 8 ft (2.4 m) wide, bearing only at the edges of the girders. The deck topping was specified to have 2½ in. (75 mm) of cover over top reinforcing bars and varies in thickness from 3½ in. to over 9 in.

The mix design for the IC deck toppings contained 605 lb/yd^3 (347 kg/m^3) of cementitious material, of which 21% (by weight) was Class F fly ash. The concrete also contained 16% pre-wetted fine LWA of total aggregate volume to provide an IC water content of 7% by weight of binder. The *w/cm* ratio was 0.44, which is within the range suggested in LC-HPC specifications. The paste content was 28% of concrete volume, above of the range used in LC-HPC decks (22.8-24.6%) and above the 27% maximum recommended by Schmitt and Darwin (1995, 1999).

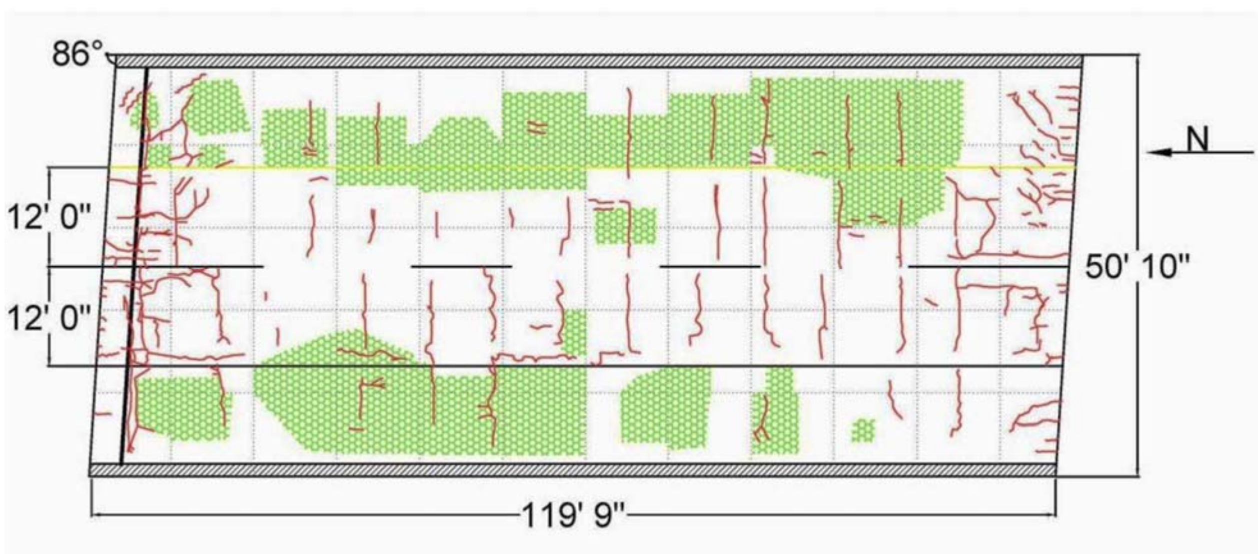
The average slumps for UT-IC-1 and UT-IC-2 were 3½ in. (90 mm) and 3¼ in. (85 mm), respectively. The average air contents for UT-IC-1 and UT-IC-2 were 6.4% and 6%, respectively. The average 28-day strengths of the concrete for UT-IC-1 and UT-IC-2 were 5710 psi (39.4 MPa) and 5370 psi (37.0 MPa), respectively. The air contents for both decks were below the requirements in the LC-HPC specifications and strength for UT-IC-1 exceeded the maximum for LC-HPC decks.

UT-IC-1 and UT-IC-2 were surveyed by a Brigham Young University research team at the ages of 2, 5, 8, 12, and 24 months (Guthrie et al. 2014). At 24 months, the crack densities for UT-IC-1 and UT-IC-2 were, respectively, 0.784 and 0.427 m/m^2, as shown in Figures 11 and 12. In addition to the cracks, the figures also show grid lines spaced at 10 ft (3.05 m). For UT-IC-1, longitudinal, transverse, and map cracks were spread along the driving lanes of the deck with less cracking observed along the shoulders. Short longitudinal cracks formed adjacent to the north abutment across the entire width of the deck. The south abutment displayed a similar cracking pattern but with somewhat fewer cracks than the north abutment. For UT-IC-2, most of the cracks were transverse, with longitudinal cracks adjacent to the abutments. UT-IC-2 had less map cracking than UT-IC-1. The majority of transverse and longitudinal cracks were at the precast half deck panel joints in both decks. The spacing of a majority of transverse cracks away from the abutments were approximately 8 ft (2.4 m), matching the width of the precast half deck panels. The longitudinal cracking that occurred away from the abutments appeared to be at the edges of the precast panels (Guthrie et al. 2014). For both decks, the crack widths ranged from 0.008 to 0.050 in. (0.20 to 1.27 mm); the majority of cracks had widths between 0.01 and 0.02 in. (0.25 to 0.51 mm).



Average crack density = 0.784 m/m^2

Figure 11: UT-IC-1 (Survey by BYU – 24 months, Guthrie et al. 2014). Note: 1 ft = 0.305 m



Average crack density = 0.427 m/m^2

Figure 12: UT-IC-2 (Survey by BYU – 24 months, Guthrie et al. 2014) Note: 1 ft = 0.305 m

Comparing Performance

To evaluate the effectiveness of internal curing in reducing cracking in bridge decks, the crack densities of the five Indiana IC bridge decks and two Utah IC deck toppings are compared with Kansas control and LC-HPC decks and the control deck in Indiana. Crack densities are plotted for individual placements when more than one placement was used, which is the case for IN-IC-HPC-1 and IN-IC-HPC-4.

As shown in Figure 13, the IN-IC-HPC decks have exhibited significantly less cracking than the IN-IC and UT-IC deck toppings. It appears that having a low paste content (at or below 26% for IN-IC-HPC decks) is a dominant factor. Based on previous work examining bridge decks in Kansas, crack surveys are needed at or beyond three years after construction in order to establish long-term cracking performance. In many cases, surveys conducted prior to three years after construction have not shown future trends for cracking. Previous work in Kansas has also shown that decks supported by steel girders have typically exhibited higher crack densities than prestressed concrete or box girders due to higher restraint in steel than concrete (Darwin et al. 2016, Harley et al. 2011, Shrestha et al. 2013). The reduction in shrinkage when combining SCMs with internal curing has been shown previously (De la Varga et al. 2012, Pendergrass and Darwin 2014). A greater amount of IC water and inclusion of a ternary binder system in IN-IC-HPC decks may have also contributed to low crack densities, but these decks were all placed close to or within three years at the time of the most recent survey. Additional surveys at later dates are needed to monitor cracking and durability issues, establish a better estimate of long-term behavior, and compare with older bridge decks in this study.

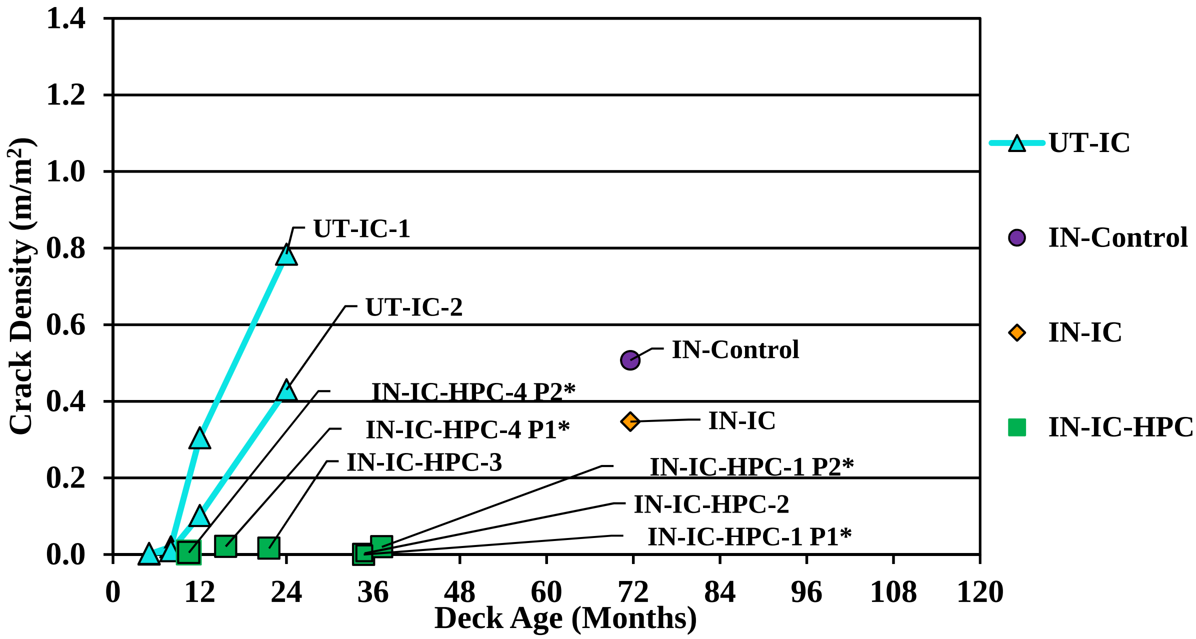


Figure 13: Crack densities of Indiana and Utah IC bridge decks and Indiana control deck vs. deck age

*P1 and P2 denotes the first and second placement of the bridge, respectively.

Figure 14 compares the crack densities of the IC decks in Indiana and IC deck toppings in Utah with the crack densities of the control decks in Kansas (denoted as KS-Control) as a function of age. As shown in the figure, the six IN-IC-HPC placements (IN-IC-HPC-1 through IN-IC-HPC-4) exhibited lower crack densities than the Kansas control decks at similar ages. The IN-IC deck, performing better than the IN-Control deck at the same age, falls within the spread of Kansas control deck data. The internally cured Utah deck toppings (UT-IC-1 and UT-IC-2), despite their relatively young ages, exhibit the highest cracking density among all IC decks in this study. The crack density of UT-IC-1 was higher at 24 months than all but one of the Kansas control decks. The crack density for UT-IC-2 was also greater than most Kansas control decks surveyed at a similar age.

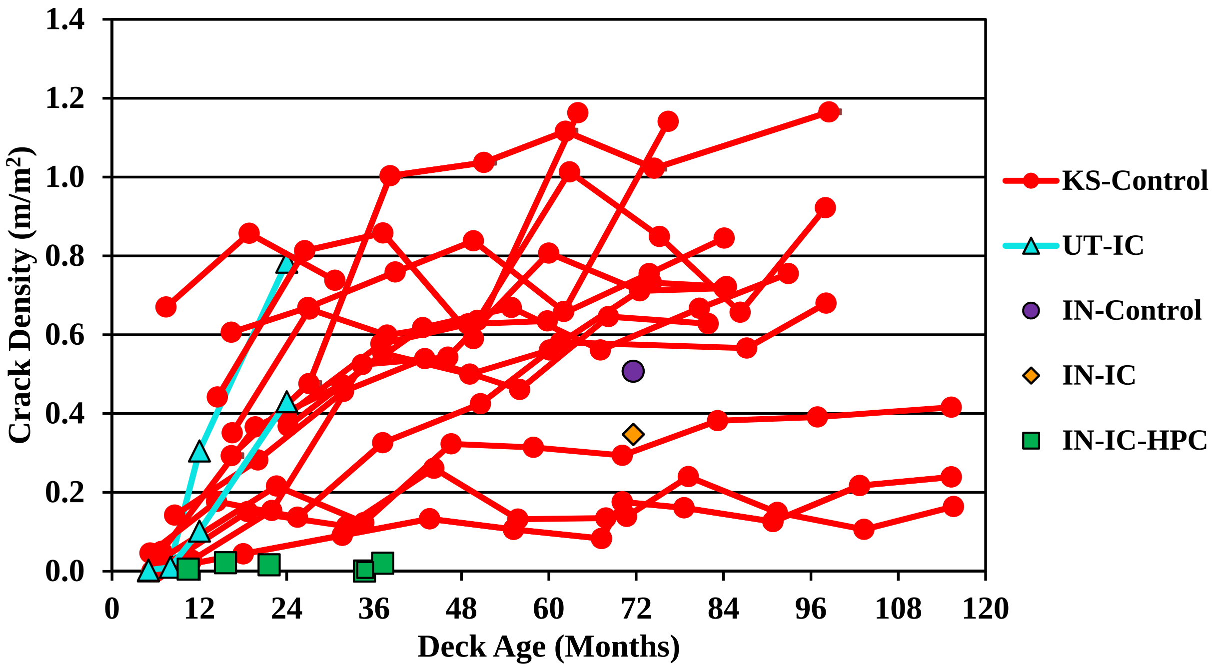


Figure 14: Crack densities of Kansas control decks and IC decks vs. deck age

Figure 15 compares the crack densities as a function of age for the IC decks in Indiana and IC deck toppings in Utah with the LC-HPC decks in Kansas. As shown in the figure, the IN-IC-HPC decks had lower crack densities than most of the LC-HPC decks at similar ages. IN-IC and IN-Control exhibited greater crack densities than most LC-HPC decks; at 24 months, the Utah IC deck toppings had higher crack densities than all LC-HPC decks at similar ages. It appears that internal curing and SCMs contributed greatly to reducing the cracking of IN-IC-HPC bridges. Internal curing and SCMs or internal curing alone, however, provided no advantage for the Utah IC deck toppings (UT-IC-1 and UT-IC-2) or the Indiana IC deck (IN-IC), which had paste contents above 27% by volume and, thus, greater than both the IN-IC-HPC and LC-HPC decks.

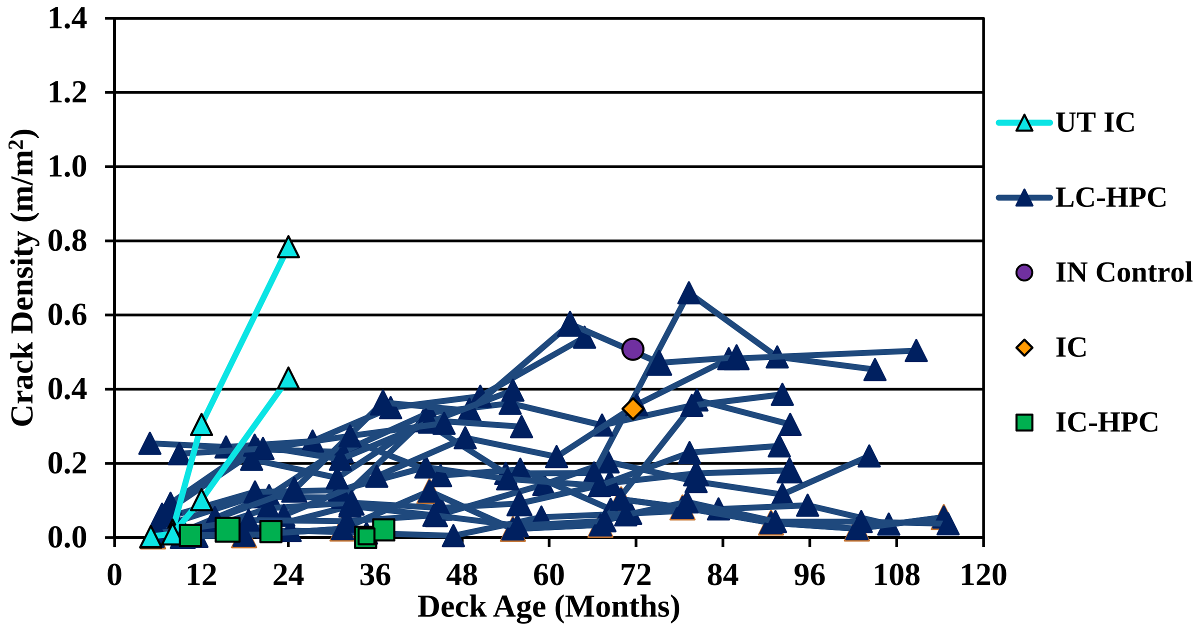


Figure 15: Crack densities of LC-HPC decks and IC decks vs. deck age

Figure 16 shows the crack density of the bridge decks in this study as a function of paste content. Aggregate has a high stiffness, making it dimensionally stable, regardless of moisture loss. Paste in the constituent of concrete that undergoes shrinkage. Studies conducted by University of Kansas dating back to over twenty years ago (Schmitt and Darwin 1995; Miller and Darwin 2000; Darwin et al. 2004; Lindquist et al. 2008) have shown that increased paste content, independent of other factors, leads to increased cracking in bridge decks. Paste contents less than 27% by volume consistently result in reduced cracking. Figure 16 clearly supports this finding. The Utah deck toppings, with paste contents of 28%, and the IN-Control and IN-IC decks, with paste contents of 27.6%, exhibited significantly greater cracking than the IN-IC-HPC decks, with paste contents lower than 26%. Both Utah deck toppings had higher crack densities than all Kansas LC-HPC decks and most of the Kansas Control decks at two years after construction. The IN-Control and IN-IC decks also had higher crack densities than a majority of Kansas LC-HPC decks, and fell within the spread of Kansas control decks at similar survey ages. The internally cured Utah deck toppings had the highest cracking densities in spite of having the required amount of IC water and being supported by prestressed concrete girders, which are also believed to be more helpful in improving cracking performance of the deck than steel girders (Portland Cement Association 1970). Although the UT-IC deck toppings were the only bridges in this study that included precast half-deck concrete panels, this variable is believed to not significantly affect resultant crack densities. Based on previous studies by KU researchers, a series of bridge decks supported by precast panels have also exhibited cracking at panel joints; however, the crack densities of these decks was not negatively affected compared to those without deck panels for similar concrete mixture proportions with SCMs and paste contents below 26% (Harley et al. 2011, Shrestha et al. 2013). These findings demonstrate that a high paste volume can significantly increase bridge deck cracking, even when a crack reduction technology or different structure type is used.

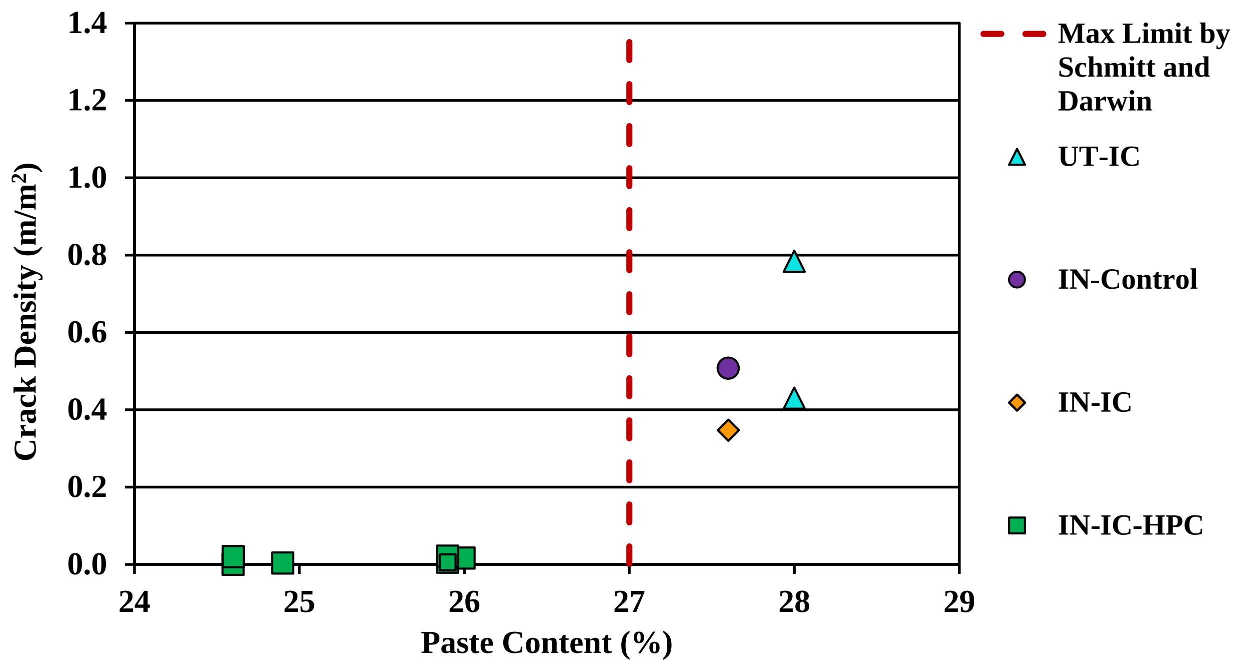


Figure 16: Crack densities of Indiana and Utah IC bridge decks and Indiana control deck vs. paste content

Figure 17 shows the crack density of bridge decks in this study as a function of 28-day compressive strength. 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. As concrete compressive strength increases, creep decreases. Creep reduces stresses caused by restrained shrinkage and, thus, reduces the potential for cracking. As shown in Figure 17, the IN-IC and IN-Control decks have 28-day compressive strengths of 4900 and 4380 psi (33.8 and 30.2 MPa), respectively, which are within the recommended range in the LC-HPC specifications, exhibited crack density values of 0.347 and 0.507 m/m^2, respectively – greater than all IN-IC-HPC decks and also greater than most of LC-HPC decks at a similar age. It appears that the higher paste contents of IN-IC, IN-Control and UT-IC deck toppings were more influential in increasing cracking than their lower compressive strengths in reducing cracking. However, it must be mentioned that two oldest IN-IC-HPC decks (37.2 month old IN-IC-HPC-1 and 34.8 month old IN-IC-HPC-2) exhibited the lowest crack densities among all IC decks and better than almost all LC-HPC decks despite having the highest 28-day compressive strength (6640 and 6720 psi [45.8 and 46.3 MPa], respectively) among the decks investigated in this study. Recent studies have suggested that the use of internal curing and one SCM, fly ash, reduce the modulus of elasticity and increase creep (De la Varga et al. 2012). Menkulasi et al. (2015) showed that IC mixtures exhibited lower shrinkage and higher creep coefficients than mixtures that did not contain any lightweight aggregate.

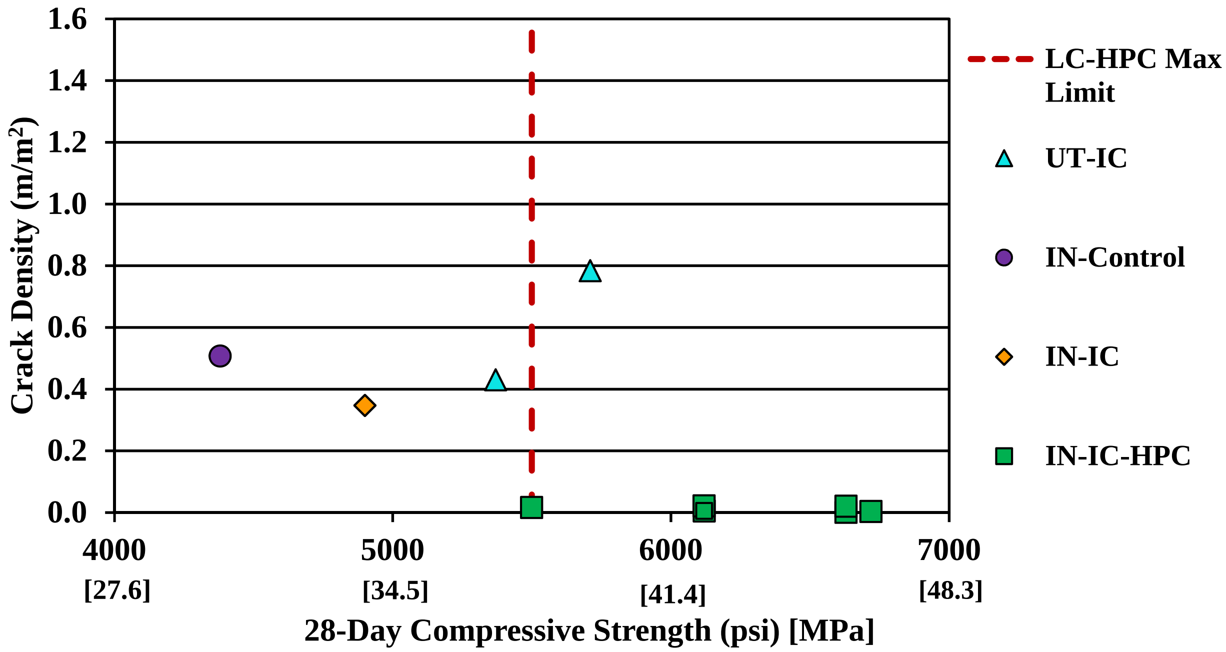


Figure 17: Crack density vs. 28-day compressive strength of concrete for Indiana and Utah IC and Indiana control bridge decks

Figure 18 compares the crack density for Utah and Indiana IC bridge decks with the actual amount of IC water. The amount of IC water is also listed in Tables 2 and 4. The results indicate that decks that had more than 8% IC water by weight of binder exhibited lower cracking. Pendergrass and Darwin (2014) showed that mixtures containing pre-wetted LWA, slag, and silica fume exhibit a reduction in both early-age (0 to 90 days) and long-term (90 to 360 days) drying shrinkage. They concluded that drying shrinkage was reduced as slag was added in conjunction with lightweight aggregate. An additional reduction in shrinkage was observed as silica fume was added in conjunction with the lightweight aggregate and slag. A possible explanation for the lower crack densities in the IN-IC-HPC decks is that in addition to including SCMs, providing more IC water than required for eliminating chemical and autogenous shrinkage can also help reduce drying shrinkage.

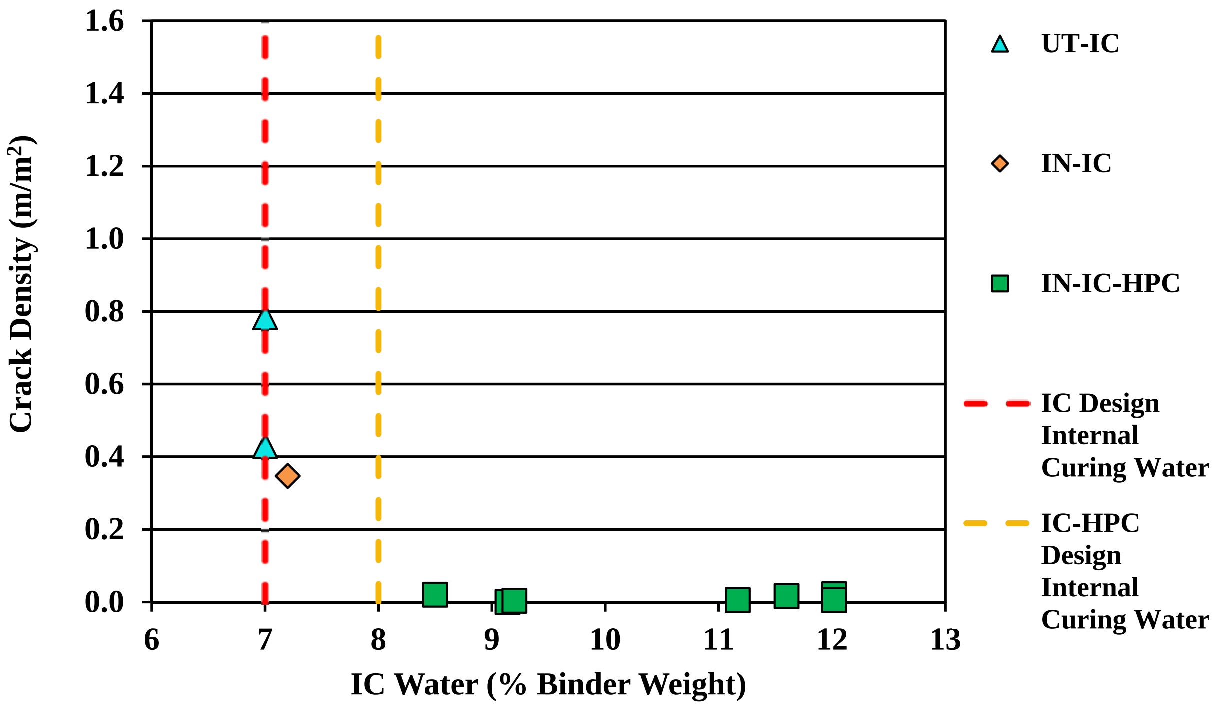


Figure 18: Crack density vs. actual IC water for Indiana and Utah IC bridge decks

Figure 19 compares crack density with slump for the UT-IC and IN-IC-HPC bridge decks. The average slump for these decks ranged from 3¼ in. (85 mm) for UT-IC-2 to 5¾ in. (145 mm) for Placement 2 of IN-IC-HPC-1. The minimum average slump for the IN-IC-HPC decks was 4¾ in. (120 mm), which exceeds the 3½-in. (90-mm) limit in the Kansas LC-HPC specifications. Fresh concrete properties were not available for IN-IC and IN-Control. Although the average slumps for UT-IC deck toppings fell within LC-HPC specifications, the resultant crack densities were higher than all of the IN-IC-HPC decks. Based on work in Kansas that documented cracking of Kansas LC-HPC and Control decks, achieving good consolidation and early application of curing after final strike-off during construction have had more influence on cracking than slump (Darwin et al. 2016).

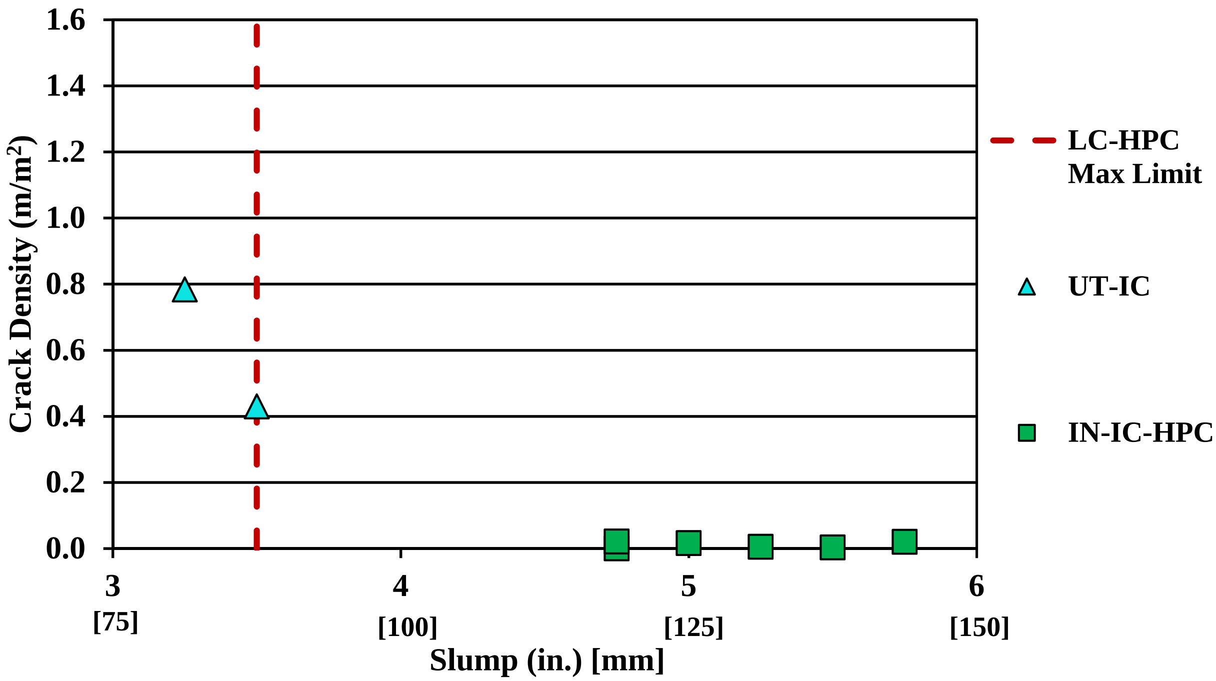


Figure 19: Crack density vs. slump for IN-IC-HPC and Utah IC bridge decks

The effectiveness of internal curing in reducing drying and autogenous shrinkage of concrete has been shown by many researchers (for example Henkensiefken et al. 2009; Browning et al. 2011). When used in bridge decks, pre-wetted LWA can potentially reduce cracking caused by restrained shrinkage. One area of concern for internally cured bridge decks is with freeze-thaw durability. For concrete with excess IC water, trapped water can remain in the pores of the LWA (Jones et al. 2014). Depending on the degree of saturation, on freezing, this water can cause local failures, such as scaling damage and pop-outs, or general freeze-thaw damage (Powers 1975). For concrete placed later in the construction season and prone to freezing prior to the system drying out, excess IC water would tend to compromise durability. The freeze-thaw performance of IC concrete has also been shown to depend on the type and proportions of the fine LWA (Jones et al. 2014). Scaling resistance of concrete, including internally cured mixtures, depends heavily on finishing procedures. Providing additional curing time for concrete mixtures with SCMs has also been shown to be beneficial in increasing strength and reducing shrinkage (Tazawa et al. 1989).

Based on results described by Jones et al. (2014), scaling resistance does not appear to be negatively affected by providing internal curing to concrete mixtures. For the noted freeze-thaw and scaling damage on the affected IN-IC-HPC decks, it is possible that a combination of early curing application, specifying a longer curing time, and including a lower amount of IC water would have helped mitigate these issues. Future surveys of the IN-IC-HPC decks are needed to evaluate long-term durability of concrete with excess IC water. Ongoing research at KU will examine the effects of varying the amount of IC water on shrinkage and durability for a series of concrete mixtures.

SUMMARY AND CONCLUSIONS

To determine the effect of internal curing and supplementary cementitious materials on bridge deck cracking, crack surveys were performed on six decks in Indiana; crack surveys by Brigham Young University researchers of two Utah bridges with deck toppings (UT-IC) were also used for comparison. Five of the decks in Indiana had internally cured concrete obtained by replacing a portion of aggregate with pre-wetted fine LWA. One deck, IN-Control, was constructed with plain concrete (no LWA) and is used as a control. Four of the decks surveyed in Indiana are supported by steel girders and two are supported by prestressed concrete box beams. The four decks supported by steel girders had a ternary concrete mixture containing SCMs, slag or Class C fly ash, with silica fume and internal curing (IN-IC-HPC). The two decks supported by prestressed box beams contained 100% portland cement mixtures, including IN-Control and one with internally cured concrete (IN-IC). The two internally cured deck toppings in Utah that were surveyed by BYU are both supported by prestressed concrete girders and precast deck panels. The internally cured decks are 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 data for some conclusions concerning the early performance of the decks. Future surveys will aid in better understanding the long-term performance of bridge decks that utilize SCMs and/or IC.

The following conclusions can be drawn from the surveys as well as previous studies:

1. The IN-IC-HPC bridge decks are exhibiting less cracking than the IN-IC and IN-Control decks, the UT-IC toppings, and the Kansas LC-HPC and control decks within the first three years after placement.
2. The Kansas LC-HPC decks exhibit less cracking than the IN-IC and IN-Control decks and the UT-IC deck toppings.
3. Paste content appears to be a dominant factor affecting cracking, with the IN-IC-HPC and LC-HPC decks, with paste contents of 26% or less performing significantly better than the IC decks with paste contents greater than 27% by volume.
4. Further research is needed to establish the long-term cracking and durability performance of concrete bridge decks that incorporate internal curing or internal curing and SCMs.

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APPENDIX A

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

KANSAS DEPARTMENT OF TRANSPORTATION
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.	

TABLE 1-3: SAMPLING AND TESTING FREQUENCY CHART				
Tests Required (Record to)	**Test Method**	**CMS**	**Verification Samples and Tests**	**Acceptance Samples and Tests**
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.

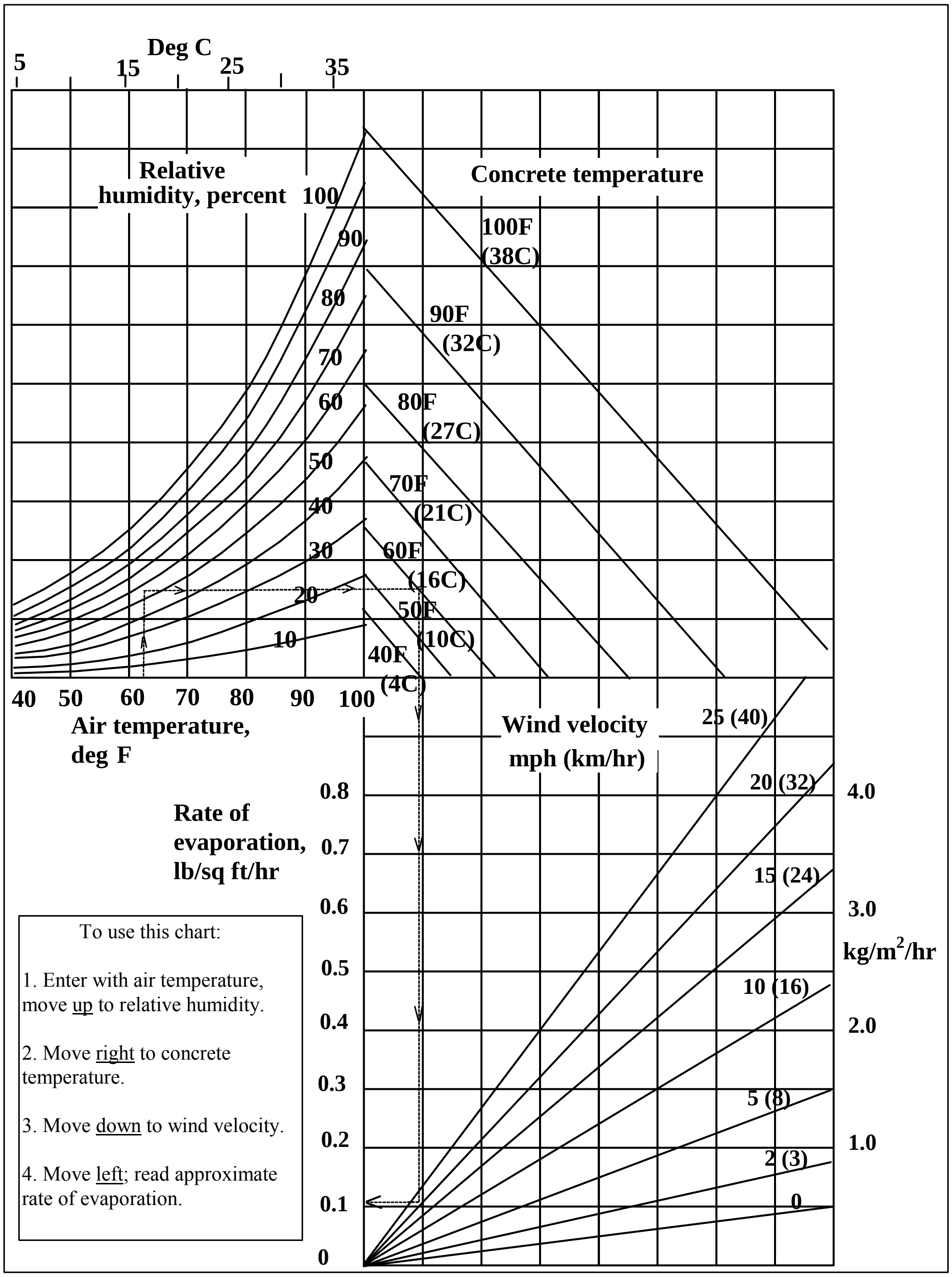
For additional requirements regarding forms and falsework, see **SECTION 708**.

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.

07-29-09 LAL, 04-18-11 DD

*From Kansas Department of Transportation (2014a, 2014b, 2011)

APPENDIX B

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.

*From Lindquist et al. (2008)