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Construction of Crack-Free Bridge Decks

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The University of Kansas

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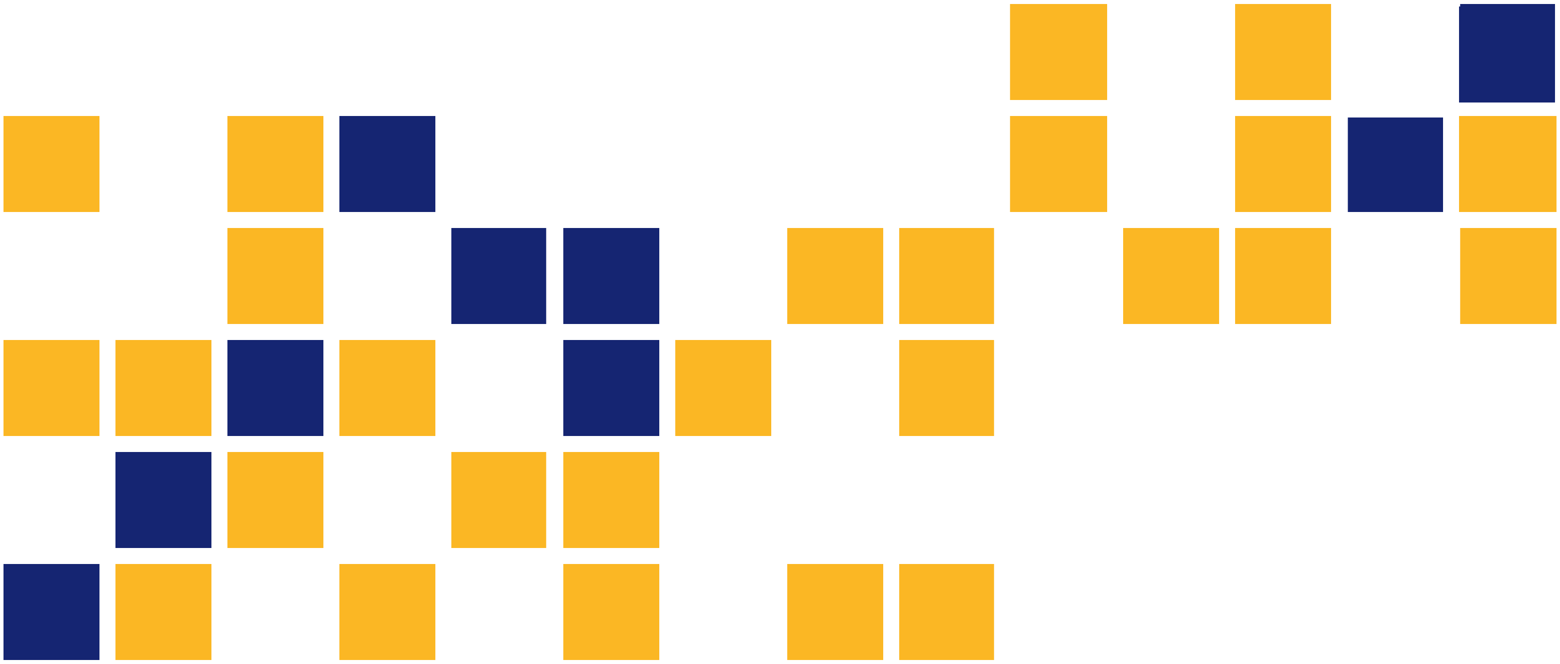

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This serves as the final report on Transportation Pooled-Fund Program Project No. TPF-5(174), "Construction of Crack-Free Bridge Decks." The goal of the study was to implement the most cost-effective techniques for improving bridge deck life through the reduction of cracking. Work was performed both in the laboratory and in the field, resulting in the construction of 17 bridge decks in Kansas that were let under Low-Cracking High-Performance Concrete (LC-HPC) specifications. The report documents the performance of the decks based on crack surveys performed on the LC-HPC decks and matching control bridge decks. The specifications for LC-HPC bridge decks, which cover aggregates, concrete, and construction procedures, as well as procedures for performing crack surveys, are summarized. The first 13 LC-HPC bridge decks are compared to control decks in terms of crack density as a function of time. Survey results are also presented for three LC-HPC decks without control decks and one deck let under LC-HPC specifications on which the specifications were not enforced. The widths of measured cracks ranged from 0.006 to 0.025 inches (0.15 to 0.64 mm). The LC-HPC bridge decks exhibit less cracking than the matching control decks in the vast majority of cases. Only bridge decks LC-HPC-2 and LC-HPC-3 have higher overall crack densities than their control decks, the two best performing control decks in the program, and the differences are small. The majority of the cracks are transverse and run parallel to the top layer of the deck reinforcement. Relatively short cracks are present near the abutments and propagate perpendicular to the abutments (longitudinally). The study demonstrates the positive effects of reduced cementitious material and cement paste contents, improved early-age and long-term curing, concrete temperature control, limitations on or de-emphasis of maximum concrete compressive strength, limitations on maximum slump, and minimizing finishing operations on minimizing cracking in bridge decks.

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Final Report

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Abstract

This serves as the final report on Transportation Pooled-Fund Program Project No. TPF-5(174), “Construction of Crack-Free Bridge Decks.” The goal of the study was to implement the most cost-effective techniques for improving bridge deck life through the reduction of cracking. Work was performed both in the laboratory and in the field, resulting in the construction of 17 bridge decks in Kansas that were let under Low-Cracking High-Performance Concrete (LC-HPC) specifications. The report documents the performance of the decks based on crack surveys performed on the LC-HPC decks and matching control bridge decks. The specifications for LC-HPC bridge decks, which cover aggregates, concrete, and construction procedures, as well as procedures for performing crack surveys, are summarized. The first 13 LC-HPC bridge decks are compared to control decks in terms of crack density as a function of time. Survey results are also presented for three LC-HPC decks without control decks and one deck let under LC-HPC specifications on which the specifications were not enforced. The widths of measured cracks ranged from 0.006 to 0.025 inches (0.15 to 0.64 mm). The LC-HPC bridge decks exhibit less cracking than the matching control decks in the vast majority of cases. Only bridge decks LC-HPC-2 and LC-HPC-3 have higher overall crack densities than their control decks, the two best performing control decks in the program, and the differences are small. The majority of the cracks are transverse and run parallel to the top layer of the deck reinforcement. Relatively short cracks are present near the abutments and propagate perpendicular to the abutments (longitudinally). The study demonstrates the positive effects of reduced cementitious material and cement paste contents, improved early-age and long-term curing, concrete temperature control, limitations on or de-emphasis of maximum concrete compressive strength, limitations on maximum slump, and minimizing finishing operations on minimizing cracking in bridge decks.

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LRM Industries, BASF Construction Chemicals, Holcim US, Fordyce Concrete, Grace Construction Products, Ash Grove Cement, and Lafarge North America provided concrete materials for laboratory studies.

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Chapter 1: Introduction

According to the American Society of Civil Engineers (ASCE, 2013), 11% of bridges in the United States are rated as structurally deficient. More than 200 million cars travel over these deficient bridges daily. Cracking of concrete bridge decks is one major factor that causes bridges to become deficient. Cracks allow chlorides and moisture to reach the decks' reinforcement, which can result in corrosion of the reinforcement steel. This can lead to spalling of the concrete and a reduction in the service life of the bridge (Lindquist, Darwin, & Browning, 2005; Lindquist, Darwin, Browning, & Miller, 2006). Moreover, bridge deck cracking increases the potential of freeze-thaw damage occurring.

In response to these crack-related problems, a 13-year, two-phase Pooled-Fund Study at the University of Kansas, entitled "Construction of Crack-Free Bridge Decks," was developed with the goal of implementing the most cost-effective techniques for improving bridge deck life through the reduction of cracking. To accomplish this goal, the researchers:

1. Developed a detailed plan to construct bridge decks with minimum cracking by incorporating "best practices" dealing with materials, construction procedures, and structural design.
2. Worked with state DOTs, designers, contractors, inspectors, and material suppliers to modify designs, specifications, contracting procedures, construction techniques, and materials to obtain decks exhibiting minimal cracking.
3. Selected and scheduled bridges to be constructed using "best practices," and pre-qualify designers and contractors in application of the techniques.
4. Performed detailed crack surveys on the bridge decks.
5. Correlated the cracking measured in Task 4 with environmental and site conditions, construction techniques, design specifications, and material properties, and compared results with earlier data.

6. Documented the results of the study. Those results have been documented during the 13-year term of the study through a series of reports and papers describing the development of crack reduction technologies and the performance of the bridges constructed in the program. These are listed in the Bibliography of this report.

The approach taken to minimize cracking involved concrete mixtures with low cement paste contents, low slump, and moderate rather than high strength. Construction procedures included concrete temperature control, minimum finishing, and an early start coupled with extended curing. The result was a reduction in plastic, settlement, thermal, and drying shrinkage cracking, all of which contribute to cracking in bridge decks.

The study involved cooperation between state Departments of Transportation, cement companies and other material suppliers, contractors, and designers. Work was performed both in the laboratory and in the field, resulting in the construction of 17 bridge decks (in 22 placements) in Kansas that were let under Low-Cracking High-Performance Concrete (LC-HPC) specifications. The study was performed in two phases, concluding in 2016. In addition, two bridge decks were constructed in Minnesota under LC-HPC specifications, along with control decks, the performance of which was reported by Pendergrass, Shrestha, Riedel, Polley, and Darwin (2013).

This is the final report for the program. The key goal of this report is to provide final documentation of the performance of the 17 bridge decks constructed in Kansas using the Low-Cracking High-Performance Concrete specifications.

In 2005, the Kansas Department of Transportation (KDOT), with participation by the University of Kansas as part of this study, started constructing bridge decks following LC-HPC specifications for aggregate, concrete, and construction practices. Thirteen of these decks were paired with control decks that have similar traffic volume, age, and environmental conditions.

Every year, crack surveys were performed to compare the cracking performance of the LC-HPC decks with that of the control decks. Seventeen LC-HPC bridges were planned for construction. The specifications were followed on 16 of the 17 bridges; all 17, however, remained in the study. Bridges that were constructed in accordance with the LC-HPC specifications are labeled as LC-HPC-1 through 13, 15, 16, and 17. The single bridge that was not constructed in accordance with LC-HPC specifications is labeled as OP-14 (Overland Park 14) and is the only one of the 17 bridges not constructed under the supervision of the Kansas Department of Transportation. Control bridges are labeled Control-1/2 through 13. LC-HPC-1 and LC-HPC-2 were paired to one control deck, designated Control-1/2, and LC-HPC-8 and LC-HPC-10 were paired to one control deck, designated Control-8/10. The bridge number reflects the order in which the bridges were let, not the order in which they were constructed. Most of the bridge decks in this study are supported by steel girders. LC-HPC-8, LC-HPC-10, and Control-8/10, however, are supported by precast-prestressed concrete girders.

In this report, crack survey data for the years 2014, 2015, and 2016 are summarized. Four prior reports have been published with the specific goal of summarizing the crack survey results for 2006 through 2015. Gruman, Darwin, and Browning (2009) summarized the crack survey results for 2006, 2007, and 2008. Pendergrass, Darwin, and Browning (2011) summarized the crack survey results for 2009 and 2010. Kaul, Darwin, and Browning (2012) and Bohaty, Riedel, and Darwin (2013) summarized the crack survey results for 2011, 2012, and 2013, and Alhmood, Darwin, and O'Reilly (2015) summarized the crack survey results for 2014 and 2015. This report extends the work of Alhmood et al. (2015) to include surveys performed in 2016. In addition to the summaries of the crack survey results, four in-depth reports by Lindquist, Darwin, and Browning (2008), McLeod, Darwin, and Browning (2009), Yuan, Darwin, and Browning (2011), and Pendergrass and Darwin (2014) have been issued that address the evaluation of crack reduction technologies for both effectiveness and their impact on the durability of the resulting concrete (some of the findings are being implemented in follow-on studies and by programs outside of this Pooled-Fund study), the key parameters that control cracking in bridge decks, and the experiences involved in the construction of the LC-HPC decks, the performance of the bridge decks constructed under this program, and the lessons learned from the construction and evaluation of those decks.

It is with some level of pride that, at the conclusion of this study, the investigators can point to the adoption of many of the recommendations developed in this study that have been adopted by state Departments of Transportation within their regular bridge deck specifications (sometimes with and sometimes without attribution), including reduced cementitious material and cement paste contents, improved early-age and long-term curing, limitations on or de-emphasis of maximum concrete compressive strength, limitations on maximum slump, and minimizing finishing operations.

In addition to a summary of the cracking performance of the bridge-decks constructed in Kansas (the decks that have received the greatest scrutiny in the study), this report includes a bibliography of the papers and reports that have resulted from the study. Additional papers from this research are in preparation.

Chapter 2: Specifications

Three special provisions of the Kansas Department of Transportation (KDOT) standard specifications have been developed for LC-HPC bridge decks. These special provisions cover the requirements for aggregate, concrete, and construction practices with the goal of reducing cracking of concrete bridge decks (KDOT, 2007a, 2007b, 2007c). The latest versions of the special provisions are shown in Appendix A. The special provisions are written to minimize the potential for plastic shrinkage and settlement cracking in plastic concrete and drying shrinkage and thermal cracking in hardened concrete. The background for the approach taken to achieve these goals is presented by Schmitt and Darwin (1995, 1999), Darwin, Browning, and Lindquist (2004), Darwin et al. (2010), Browning, Darwin, and Hurst (2007, 2009), and Darwin (2014).

2.1 Aggregate

LC-HPC specifications cover the requirements for coarse and fine aggregate. The coarse aggregate must be gravel, chat, or crushed stone. The minimum soundness and the maximum absorption should be 0.9 and 0.7, respectively. Table 2.1 lists the maximum allowable percentages of deleterious substance.

Table 2.1: Deleterious Substance Requirements for Coarse Aggregate

Substance	**Maximum % Allowable by Weight**
Material passing No. 200 sieve	2.5%
Shale or shale-like material	0.5%
Clay lumps and friable particles	1.0%
Sticks (including absorbed water)	0.1%
Coal	0.5%

For the fine aggregate, natural sand (Type FA-A) or chat (Type FA-B) are the two acceptable types. Moreover, these aggregate types must meet both the KDOT and the AASHTO requirements for mortar strength and organic impurities, respectively. Table 2.2 and Table 2.3 show the provisions on deleterious substances for natural sand and chat, respectively.

Table 2.2: Deleterious Substance Requirements for Type FA-A (Natural Sand)

Substance	Maximum % Allowable by Weight
Material passing No. 200 sieve	2.0%
Shale or shale-like material	0.5%
Clay lumps and friable particles	1.0%
Sticks (including absorbed water)	0.1%

Table 2.3: Deleterious Substance Requirements for Type FA-B (Chat)

Substance	Maximum % Allowable by Weight
Material passing No. 200 sieve	2.0%
Clay lumps and friable particles	0.25%

The combined aggregate gradation must be obtained by implementing a proven optimization method such as the KU Mix (Lindquist et al., 2008) or Shilstone (1990) Methods.

2.2 Concrete

According to the Kansas Department of Transportation (2007b), the minimum and maximum cement content that meets LC-HPC requirements are values between 500 and 540 lb/yd^3 of concrete (297 and 320 kg/m^3), respectively. Furthermore, the water-cement ratio (by weight) should range from 0.44 to 0.45. The combined requirements for cement content and water-cement ratio ensures that the cement paste content will be below 26 percent by volume. The engineer in charge can approve a reduction in the water-cement ratio to 0.43 at the bridge construction site. For LC-HPC bridge decks 1 through 7, the LC-HPC specifications permitted a cement content between 522 and 563 lb/yd^3 of concrete (310 to 334 kg/m^3), with a maximum water-cement ratio of 0.45. For LC-HPC bridge decks 8 through 13, the LC-HPC specifications permitted a cement content between 500 and 535 lb/yd^3 of concrete (297 to 317 kg/m^3) with a maximum water-cement ratio of 0.42. For LC-HPC bridge decks 15, 16, and 17, LC-HPC specifications permitted a cement content between 500 and 540 lb/yd^3 of concrete (297 to 320 kg/m^3) with minimum and maximum water-cement ratios of 0.44 and 0.45, respectively. All of the LC-HPC bridge decks discussed in this report, with the exception of LC-HPC 15 and 16, were constructed using 535 or 540 lb/yd^3 of concrete (317 and 320 kg/m^3). Bridge decks for

LC-HPC 15 and 16 contained concrete with cement contents of 500 lb/yd^3 (297 kg/m^3) and 520–540 lb/yd^3 (308 to 320 kg/m^3), respectively.

Concrete must be sampled at the discharge of the pump, conveyor, or bucket. The allowable air content (by volume) ranges from 6.5 to 9.5%. To limit settlement cracking over the reinforcing bars, current specifications state that the concrete slump should range from 1½ to 3 inches (38 to 76 mm); the maximum allowable slump at the truck is 3½ inches (90 mm). When LC-HPC 1 through 13 were constructed, the specifications had a maximum limit on slump of 4 inches (100 mm). The concrete temperature at the time of placement should not exceed 70°F (21°C) and should not be lower than 55°F (13°C). The construction engineer in charge can approve adjusting the range 5°F (3°C) higher or lower depending on the construction situation. After the construction of LC-HPC 1 through 13, the LC-HPC specifications were modified to set a lower and upper limit for the compressive strength of concrete. The 28-day compressive strength of concrete must be between 3500 and 5500 psi (24.1 and 37.0 MPa).

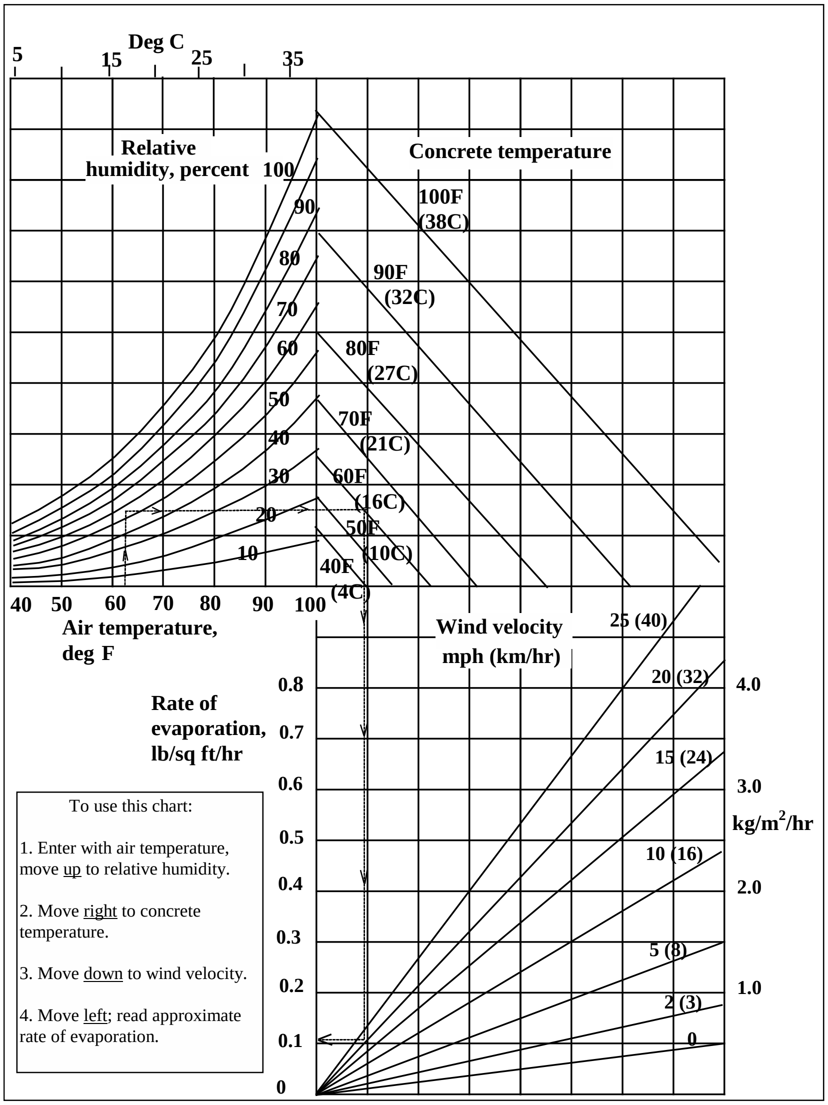
The use of vinsol resin or tall oil-based air-entraining admixtures is permitted per the LC-HPC specifications. The use of mineral, set-accelerating, or set-retarding admixtures is prohibited. At the time of construction for LC-HPC 1 through 11, the specifications permitted the use of water-reducing, set-retarding, and Type C or E set-accelerating admixtures only if approved by the engineer in charge. Nevertheless, only water-reducing admixtures were used in these decks. The current specification allows for a Type A water-reducer or dual-rated Type A-F water-reducer. A Type F high-range water-reducer can be used if concrete made with it complies with the plastic and hardened concrete properties specifications. If slump on site needs to be adjusted, only adding water-reducing or high-range water-reducing admixtures is allowed. Withholding a portion of water during batching is not allowed.

The concrete supplier and contractor must demonstrate the ability to meet all the specifications by preparing both a qualification batch and a qualification concrete slab using LC-HPC concrete before the bridge deck is constructed (KDOT, 2007c). Before the qualification batch is verified, the actual jobsite haul time must be simulated. All admixtures must be included in the qualification batch. The same personnel and equipment must place both the qualification slab and the LC-HPC bridge deck. If the concrete meets the LC-HPC specifications during the construction of the qualification slab, then those mixture proportions can be used in the LC-HPC deck.

2.3 Construction

Ambient temperature, wind speed, relative humidity 12 inches (30 cm) above the deck, and the plastic temperature of concrete must be measured at least once per hour by KDOT personnel. This information can be used to estimate the evaporation rate by using an evaporation rate chart (Figure 2.1). At all times during the construction process, the evaporation rate must remain under 0.2 lb/ft^2/hr (1 kg/m^2/hr). If the evaporation rate upper limit is exceeded, concrete cooling, wind break installation, or other methods must be implemented to reduce the evaporation rate. Reducing the evaporation rate by concrete fogging is prohibited.

LC-HPC specifications allow contractors to use buckets or conveyors to place concrete. A concrete pump may be used if the contractor demonstrated the ability to pump the LC-HPC concrete during the construction of the qualification slab. To avoid loss of entrained air in concrete, it is not acceptable to drop concrete from a height greater than 5 ft (1.5 m), and concrete pumps must have an air cuff or bladder valve to limit the free fall of concrete that may cause a loss in air.



To use this chart:

1. Enter with air temperature, move up to relative humidity.

2. Move right to concrete temperature.

3. Move down to wind velocity.

4. Move left; read approximate rate of evaporation.

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.

Figure 2.1: Evaporation Rate Chart

Source: ACI Committee 308 (1997)

Chapter 3: Crack Survey Procedure

Crack surveys for both LC-HPC and control bridge decks are performed annually. The surveys are performed in accordance with the specifications presented in Appendix B and summarized next.

3.1 Procedure

To provide accurate and comparable results, a standard procedure is followed for crack surveys. Crack surveys should be performed only on a day that is at least mostly sunny. The air temperature should not be less than 60°F (16°C) at the time of survey. Moreover, the bridge deck should be completely dry. The crack survey is invalid if it rains during the time of survey or if the sky becomes overcast.

A scaled plan (map) for the bridge deck should be developed and printed before the survey. These plans serve as the template to indicate the location and length of the cracks on the actual bridge deck, and they should include a compass indicating north. Plans should be developed at a scale of 1 inch = 10 ft (25.4 mm = 3.048 m). Furthermore, a 5 ft × 5 ft (1.524 m × 1.524 m) grid should be printed on a separate paper and placed underneath the deck plan; this grid should match the bridge grid that will be discussed later in this section. The grid helps the surveyor keep track of crack location and length. Some human error is involved when drawing the cracks.

Traffic control is provided to ensure the safety of the surveyors during the bridge survey. After closing at least one lane of the bridge to traffic, two surveyors draw a 5 ft × 5 ft (1.524 m × 1.524 m) grid on the bridge deck using sidewalk chalk or lumber crayons. This grid is called the bridge grid and should match the grid drawn on the plans. Surveyors mark any cracks they can see while bending at waist height. Surveyors should not mark any crack that cannot be seen from waist height. When surveyors see a crack, they may bend closer and trace the crack to its end, even tracing portions of the same crack that cannot be seen from waist height. If the surveyors see another crack while tracing a crack (not attached to the crack being traced), they should not mark it unless it can also be seen when bending from waist height. After marking a crack, the surveyors should return to the location where they started marking the crack and continue surveying. At least two surveyors should inspect each section of the bridge. This method results in consistent crack survey results between bridges (Lindquist et al., 2005, 2008). After cracks are marked on the bridge, another surveyor draws the marked cracks on the scaled bridge plan.

To determine crack density, the bridge plans with the marked cracks are scanned into a computer and converted to AutoCAD files. In AutoCAD, any lines on the bridge plan not representing cracks (such as bridge abutments or boundaries) are erased. The total length of the cracks can then be measured using AutoCAD. Crack density is calculated by dividing the total length of the cracks by the area of the bridge deck. Crack densities are reported in m/m^2 for the whole bridge, each placement, and each span.

3.2 Crack Widths

Starting in the summer of 2015, crack widths were measured for most of the bridges that were surveyed. Crack widths were measured using a wallet-sized crack comparator. The accuracy of the comparator was verified with multiple devices. Most of the crack widths for cracks that can be seen from waist height have widths between 0.006 and 0.025 inches (0.150 mm to 0.635 mm).

Chapter 4: Results

Tables 4.1, 4.2, and 4.3 summarize the crack densities for the bridge decks surveyed in 2014, 2015, and 2016, respectively. Decks listed as "did not survey" were surveyed either the year before or the year after, except for four decks that had exhibited high cracking prior to 2014: Surveys on Control-5 ended in 2010 and surveys on Control-7, LC-HPC-12, and Control-12 ended in 2014. As will be explained in Sections 4.21 and 4.22, the high cracking in LC-HPC-12 and Control-12 resulted largely from the loads applied during construction. Four decks were surveyed in 2016 (LC-HPC-3, Control-3, LC-HPC-11, and Control-11) to obtain final data for those projects (Table 4.3). The survey results for OP-14 are not included in the tables but are covered in Section 4.25. The crack maps for the 2014, 2015, and 2016 surveys are included in this report. The results of the surveys performed in 2006, 2007, and 2008 were reported by Gruman et al. (2009); those performed in 2009 and 2010 were reported by Pendergrass et al. (2011); and those performed in 2011, 2012, and 2013 were reported by Kaul et al. (2012) and Bohaty et al. (2013); the earlier results are summarized in Appendix C.

Figure 4.1 shows crack density versus time for the bridge decks included in this study, including OP-14. The south lane of LC-HPC-11 and decks LC-HPC-12 and Control-12 have been excluded because the south lane of LC-HPC-11 has been subjected to exceptionally high loading conditions and, as a result, undergone structural damage, and LC-HPC-12 and Control-12 were subjected to unusual torsional loading during construction that has affected the cracking performance of both decks.

As shown in Figure 4.1, the LC-HPC decks have exhibited lower overall cracking than the control decks. There is, however, some overlap, with some of the LC-HPC decks exhibiting higher crack densities than some of the control decks because they were constructed by different contractors (Yuan et al., 2011; Pendergrass & Darwin, 2014) and have experienced different conditions. This report includes individual comparisons for 13 LC-HPC and control deck pairs. In those comparisons, the LC-HPC decks have performed better than their controls in 11 of 13 cases based on cracking in the total deck and 14 of 16 cases based on cracking in individual placements. The better control decks are the two best performing control decks in the program, and as will be demonstrated, the differences are small.

Table 4.1: 2014 Crack Density Comparison of LC-HPC versus Control Decks

Bridge Name	Bridge Location	Deck Age (months)	2014 Crack Density (m/m^2)	Bridge Girder Type
LC-HPC-1	EB Parallel Pkwy over I-635	102.5/103.1[Y]	0.043/0.024[Y]	Steel
Control-1/2	WB Parallel Pkwy over I-635	103.3/102.7	0.106/0.217	
LC-HPC-2	34th St. over I-635	92.2	0.116	Steel
Control-1/2	WB Parallel Pkwy over I-635	103.3/102.7	0.106/0.217	
LC-HPC-3	WB 103rd over US-69	79.4	0.759	Steel
Control-3	EB 103rd St. over US-69	83.2	0.376	
LC-HPC-4	SB US-69 to I-435 Rp over 103rd St	80.4/80.3	0.371/0.173	Steel
Control-4	Antioch to WB I-435 & NB US-69/Rp/WB I-435 to NB US-69 Rp	80.7	0.667	
LC-HPC-5	SB US-69 to WB I-435 Rp over Quivera Rp	79.4	0.229	Steel
Control-5	SB US-69 to EB I-435 Rp over US-69 Hwy and I-435	-	Did not survey	
LC-HPC-6	SB US-69 to WB I-435 Rp over WB I-435 to Quivera Rp	79.7	0.356	Steel
Control-6	SB US-69 to EB I-435 Rp over US-69 Hwy and I-435	68.2	0.646	
LC-HPC-7	Co Rd 150 over US-75	95.7	0.087	Steel
Control-7	NB Antioch over I-435	-	Did not survey	
LC-HPC-8	E 1350 Rd over US-69	81.6	0.425	Prestressed Concrete
Control-8/10	K-52 over US-69	87.2	0.566	
LC-HPC-9	NB US-69 over Marais Des Cygnes River	62	0.454	Steel
Control-9	SB US-69 over Marais Des Cygnes River	73.8/74.1	0.733	
LC-HPC-10	E 1800 Rd over US-69	86.2	0.117	Prestressed Concrete
Control-8/10	K-52 over US-69	87.2	0.566	
LC-HPC-11	EB US-50 over K&O RR	84.8	0.842	Steel
Control-11	US-50 over BNSF RR	98	0.922	
LC-HPC-12	Unit 2 K-130 over Neosho River	64.9/76.3	0.657	Steel
Control-12	Unit 1 K-130 over Neosho River	64.0/76.4	1.152	
LC-HPC-13	NB US-69 over BNSF RR	75.2	0.471	Steel
Control-13	SB US-69 over BNSF RR	72.5	0.711	
LC-HPC-15	NB K-7 over Johnson Dr./55th St	43	0.317	Steel
LC-HPC-16	SB K-7 over Johnson Dr./55th St	43.5	0.311	Steel
LC-HPC-17	Clear Creek Parkway over K-7	32.5	0.274	Steel

[Y] Slash separates age and density for different placements.

Table 4.2: 2015 Crack Density Comparison of LC-HPC versus Control Decks

Bridge Name	Bridge Location	Deck Age (months)	2015 Crack Density (m/m^2)	Bridge Girder Type
LC-HPC-1	EB Parallel Pkwy over I-635	15.1/114.5	0.045	Steel
Control-1/2	WB Parallel Pkwy over I-635	115.6/115.3	0.189	
LC-HPC-2	34th St. over I-635	104.2	0.222	Steel
Control-1/2	WB Parallel Pkwy over I-635	115.6/115.3	0.189	
LC-HPC-3	WB 103rd over US-69	91.5	0.487	Steel
Control-3	EB 103rd St. over US-69	96.9	0.391	
LC-HPC-4	SB US-69 to I-435 Rp over 103rd St	93.3/93.2	0.217	Steel
Control-4	Antioch to WB I-435 & NB US-69/Rp/WB I-435 to NB US-69 Rp	92.9	0.775	
LC-HPC-5	SB US-69 to WB I-435 Rp over Quivera Rp	91.8	0.247	Steel
Control-5	SB US-69 to EB I-435 Rp over US-69 Hwy and I-435	-	Did not survey	
LC-HPC-6	SB US-69 to WB I-435 Rp over WB I-435 to Quivera Rp	92.2	0.386	Steel
Control-6	SB US-69 to EB I-435 Rp over US-69 Hwy and I-435	81.9	0.628	
LC-HPC-7	Co Rd 150 over US-75	106.9	0.036	Steel
Control-7	NB Antioch over I-435	-	Did not survey	
LC-HPC-8	E 1350 Rd over US-69	92.0	0.462	Prestressed Concrete
Control-8/10	K-52 over US-69	98.1	0.680	
LC-HPC-9	NB US-69 over Marais Des Cygnes River	73.6	0.430	Steel
Control-9	SB US-69 over Marais Des Cygnes River	84.4/84.1	0.779	
LC-HPC-10	E 1800 Rd over US-69	96.8	0.125	Prestressed Concrete
Control-8/10	K-52 over US-69	98.1	0.680	
LC-HPC-11	EB US-50 over K&O RR	-	Did not survey	Steel
Control-11	US-50 over BNSF RR	-	Did not survey	
LC-HPC-12	Unit 2 K-130 over Neosho River	-	Did not survey	Steel
Control-12	Unit 1 K-130 over Neosho River	-	Did not survey	
LC-HPC-13	NB US-69 over BNSF RR	85.9	0.486	Steel
Control-13	SB US-69 over BNSF RR	84.1	0.718	
LC-HPC-15	NB K-7 over Johnson Dr./55th St	56.2	0.299	Steel
LC-HPC-16	SB K-7 over Johnson Dr./55th St	55.0	0.397	Steel
LC-HPC-17	Clear Creek Parkway over K-7	45.5	0.308	Steel

Table 4.3: 2016 Crack Density Comparison of LC-HPC versus Control Decks

Bridge Name	Bridge Location	Deck Age (months)	2016 Crack Density (m/m^2)	Bridge Girder Type
LC-HPC-3	WB 103rd over US-69	105	0.453	Steel
Control-3	EB 103rd St. over US-69	115.3	0.416	
LC-HPC-11	EB US-50 over K&O RR	110.7	0.883	Steel
Control-11	US-50 over BNSF RR	124.9	1.16	

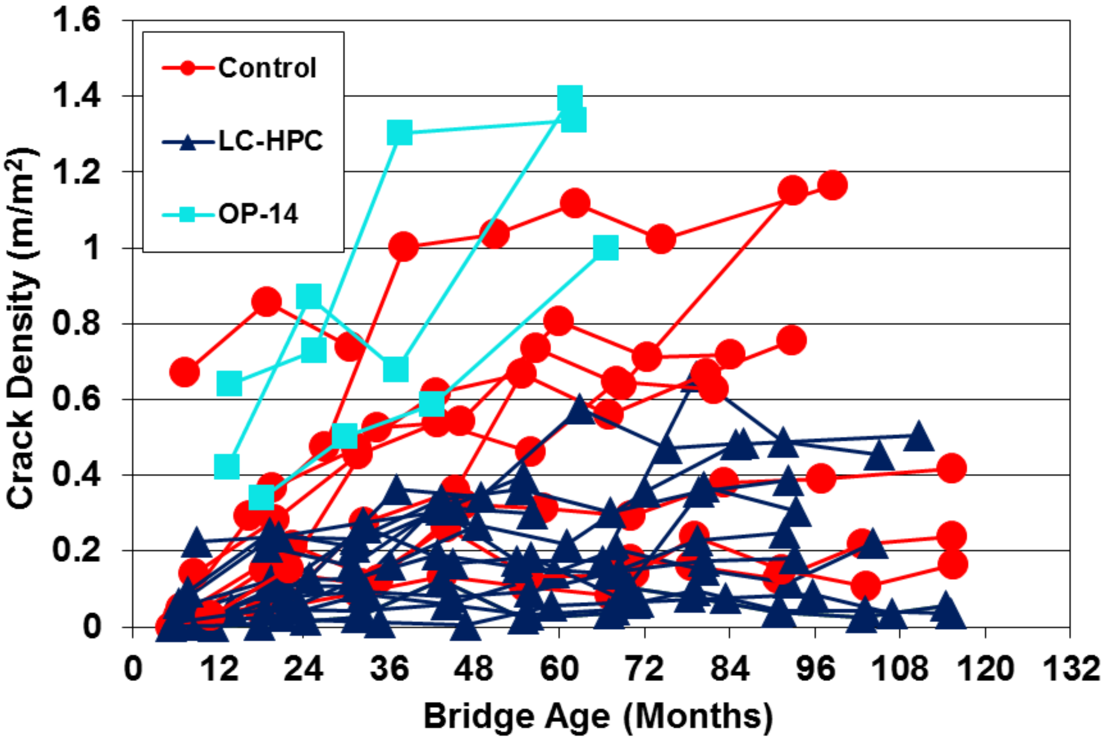
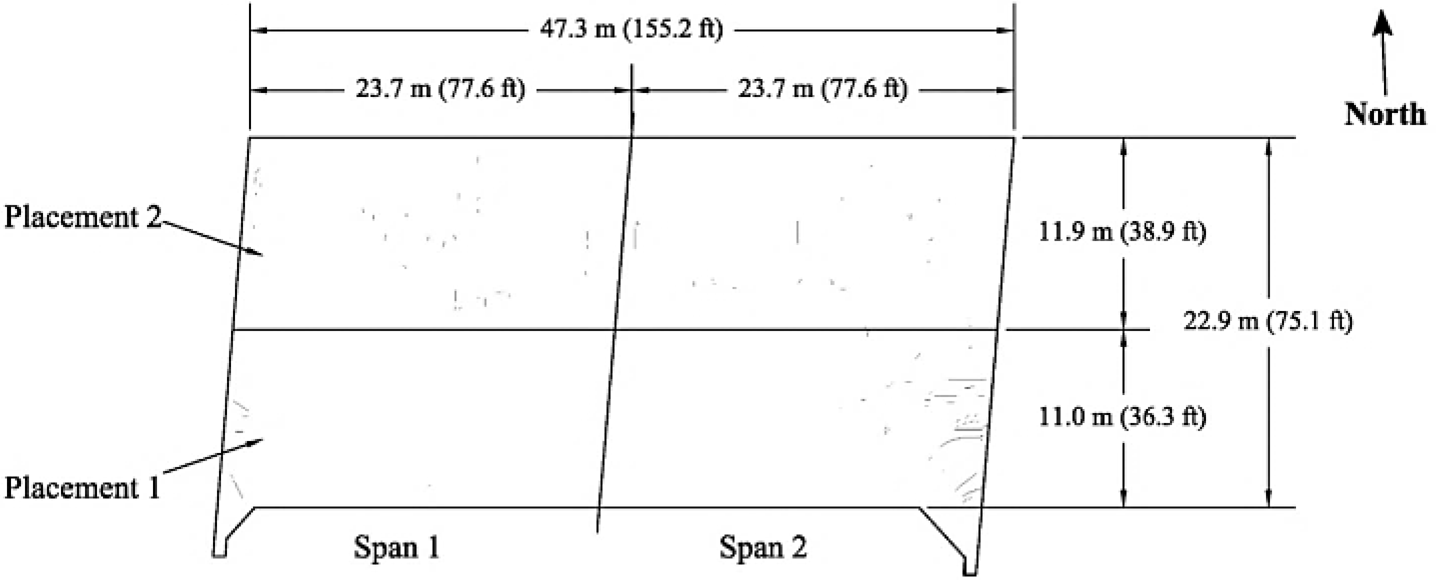


Figure 4.1: LC-HPC and Control Decks Crack Densities versus Deck Age

4.1 LC-HPC-1

The bridge deck of LC-HPC-1 was constructed in two placements; Placement 1 was constructed on 10/14/2005 and Placement 2 was constructed on 11/2/2005. This bridge has been surveyed 10 times; the results of Surveys 9 and 10 of LC-HPC-1 are included in this report. Survey 9 was performed at a deck age of 103.1 months for Placement 1 and 102.5 months for Placement 2; the crack map from this survey is shown in Figure 4.2. Survey 10 was performed at a deck age of 115.1 months for Placement 1 and 114.5 months for Placement 2; the crack map from this survey is shown in Figure 4.3. Crack densities of 0.050 and 0.027 m/m^2 were observed in Survey 9 (Figure 4.2) for Placements 1 and 2, respectively. These values are similar to the crack densities from Survey 8, reported by Bohaty et al. (2013). Crack densities of 0.037 and 0.055 m/m^2 were observed in Survey 10 (Figure 4.3) for Placements 1 and 2, respectively. Survey 10 for Placement 1 showed that the bridge deck had a slightly lower crack density compared to Survey 9. The surveys showed that the deck has experienced some scaling, making it harder to identify cracks during the survey. As shown in Figure 4.2 and Figure 4.3, most of the cracks that were marked for both placements are relatively small transverse cracks, parallel to the deck's top reinforcement, with longitudinal cracks near the abutments.

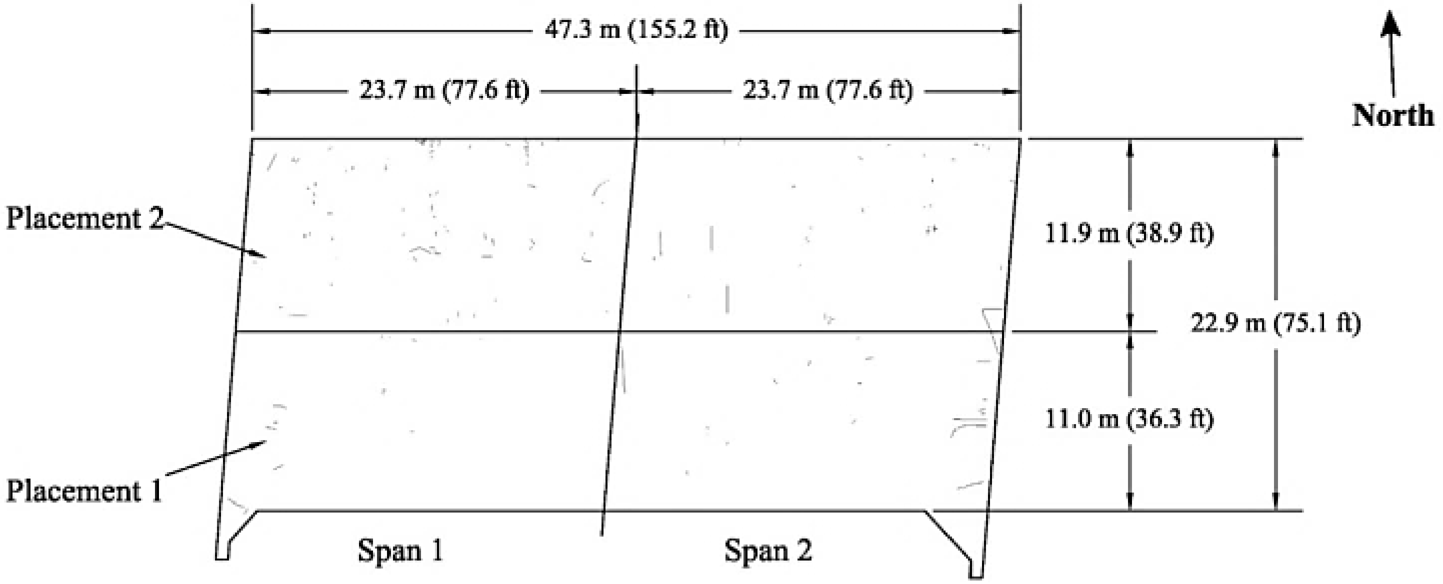


Bridge Number: 105-304 (KU #1)
Bridge Location: EB Parallel Pkwy over I-635
Construction Date:
  Placement 1 (South): 10/14/2005
  Placement 2 (North): 11/2/2005
Crack Survey Date: 5/19/2014

Bridge Length: 47.3 m (155.2 ft)
Bridge Width: 22.9 m (75.1 ft)
Skew: -5°
Number of Spans: 2
  Span 1 (West): 23.7 m (77.6 ft)
  Span 2 (East): 23.7 m (77.6 ft)
Number of Placements: 2

Bridge Age:
  Placement 1: 103.1 months
  Placement 2: 102.5 months
Crack Density: 0.038 m/m^2
  Placement 1: 0.050 m/m^2
  Placement 2: 0.027 m/m^2
  Span 1: 0.022 m/m^2
  Span 2: 0.051 m/m^2

Figure 4.2: LC-HPC-1 (Survey 9)



Bridge Number: 105-304 (KU #1)
Bridge Location: EB Parallel Pkwy over I-635
Construction Date:
  Placement 1 (South): 10/14/2005
  Placement 2 (North): 11/2/2005
Crack Survey Date: 5/18/2015

Bridge Length: 47.3 m (155.2 ft)
Bridge Width: 22.9 m (75.1 ft)
Skew: -5°
Number of Spans: 2
  Span 1 (West): 23.7 m (77.6 ft)
  Span 2 (East): 23.7 m (77.6 ft)
Number of Placements: 2

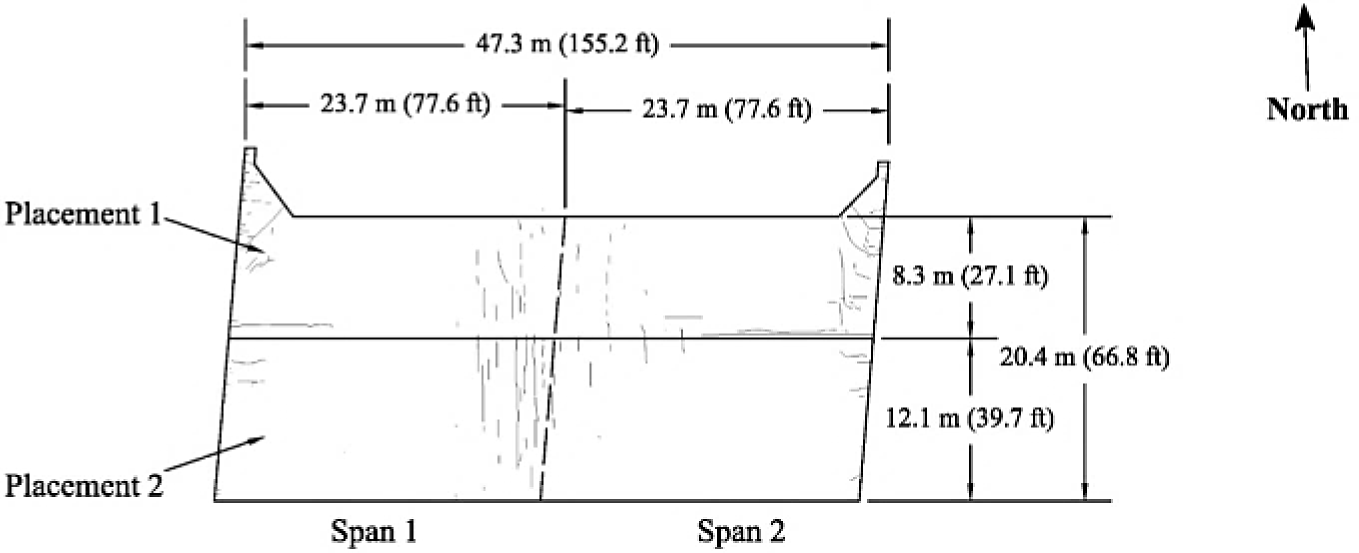
Bridge Age:
  Placement 1: 115.1 months
  Placement 2: 114.5 months
Crack Density: 0.045 m/m^2
  Placement 1: 0.037 m/m^2
  Placement 2: 0.055 m/m^2
  Span 1: 0.043 m/m^2
  Span 2: 0.053 m/m^2

Figure 4.3: LC-HPC-1 (Survey 10)

4.2 Control-1/2

Control-1/2 is paired with both LC-HPC-1 and LC-HPC-2, which have similar environmental conditions, age, and traffic volume. Control-1/2 has been surveyed 10 times. The deck was constructed in two placements; Placement 1 was constructed on 9/30/2005 and Placement 2 was constructed on 10/10/2005. The results of Surveys 9 and 10 of Control-1/2 are included in this report. Survey 9 was performed at a deck age of 103.3 months for Placement 1 and 102.7 months for Placement 2; the crack map from this survey is shown in Figure 4.4. Survey 10 was completed at a deck age of 115.6 months for Placement 1 and 115.3 months for Placement 2; the crack map from this survey is shown in Figure 4.5. Crack densities of 0.106 and 0.217 m/m^2 were observed in Survey 9 for Placements 1 and 2, respectively (Figure 4.4). Crack densities of 0.164 and 0.239 m/m^2 were observed in Survey 10 for Placements 1 and 2, respectively (Figure 4.5). These crack densities are greater than the densities from Survey 8 reported by Bohaty et al. (2013). Most of the cracking is transverse and took place above the pier. These cracks are parallel to the top reinforcement. Cracks have propagated longitudinally near the abutments. A limited amount of map cracking has occurred since Survey 9.

The crack densities for LC-HPC-1 and Control-1/2 are compared in Figure 4.6. The crack densities for both placements of Control-1/2 have been greater than the crack densities for LC-HPC-1.

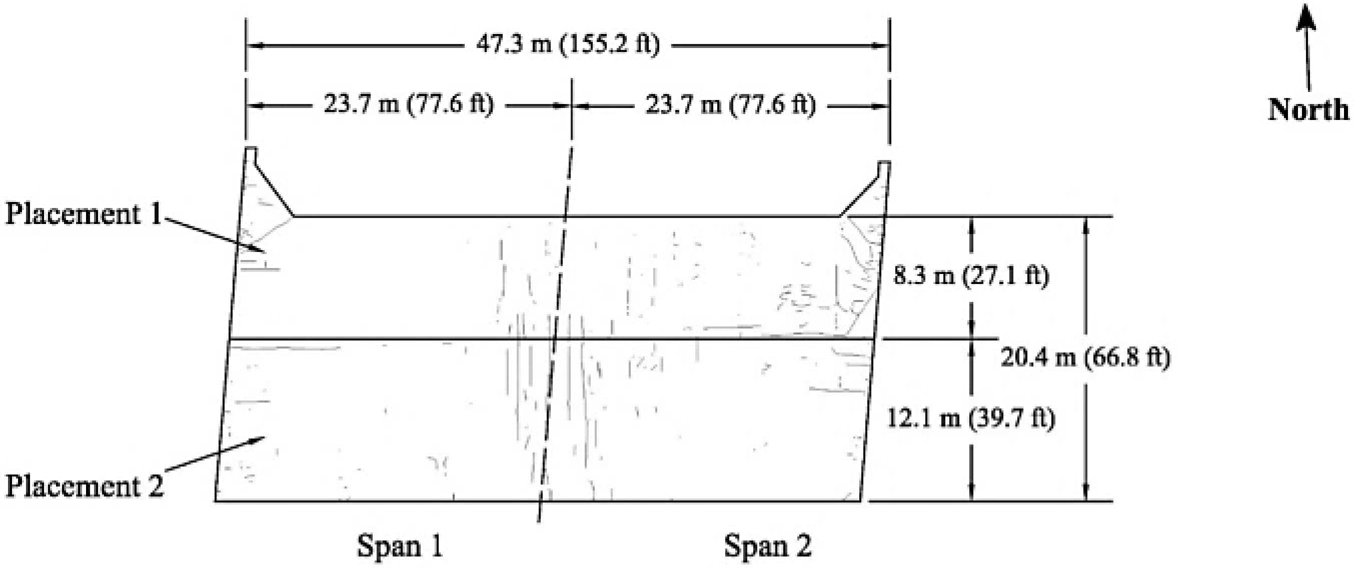


Bridge Number: 105-311 (KU #1/2 Control)
Bridge Location: WB Parallel Pkwy over I-635
Construction Dates:
  North Subdeck: 9/30/2005
  North Overlay: 10/10/2005
  South Subdeck: 10/18/2005
  South Overlay: 10/28/2005
Crack Survey Date: 5/19/2014

Bridge Length: 47.3 m (155.2 ft)
Bridge Width: 20.7 m (67.8 ft)
Skew: -5°
Number of Spans: 2
  Span 1 (West): 23.7 m (77.6 ft)
  Span 2 (East): 23.7 m (77.6 ft)
Number of Placements: 2

Bridge Age:
  Placement 1 (N): 103.3 months
  Placement 2 (S): 102.7 months
Crack Density: 0.151 m/m²
  Placement 1: 0.106 m/m²
  Placement 2: 0.217 m/m²
  Span 1: 0.184 m/m²
  Span 2: 0.118 m/m²

Figure 4.4: Control-1/2 (Survey 9)



Bridge Number: 105-311 (KU #1/2 Control)
Bridge Location: WB Parallel Pkwy over I-635
Construction Dates:
- **North Subdeck:** 9/30/2005
- **North Overlay:** 10/10/2005
- **South Subdeck:** 10/18/2005
- **South Overlay:** 10/28/2005

Crack Survey Date: 5/18/2015

Bridge Length: 47.3 m (155.2 ft)
Bridge Width: 20.7 m (67.8 ft)
Skew: -5°
Number of Spans: 2
- **Span 1 (West):** 23.7 m (77.6 ft)
- **Span 2 (East):** 23.7 m (77.6 ft)

Number of Placements: 2

Bridge Age:
- **Placement 1 (N):** 115.6 months
- **Placement 2 (S):** 115.3 months

Crack Density: 0.189 m/m²
- **Placement 1:** 0.239 m/m²
- **Placement 2:** 0.164 m/m²
- **Span 1:** 0.139 m/m²
- **Span 2:** 0.242 m/m²

Figure 4.5: Control-1/2 (Survey 10)

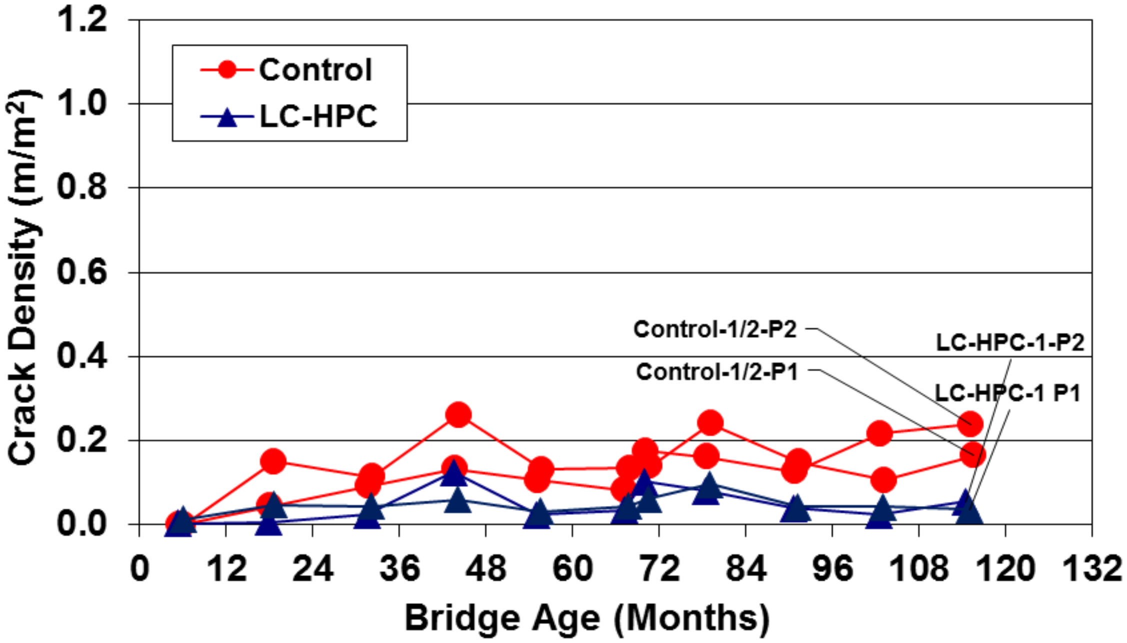
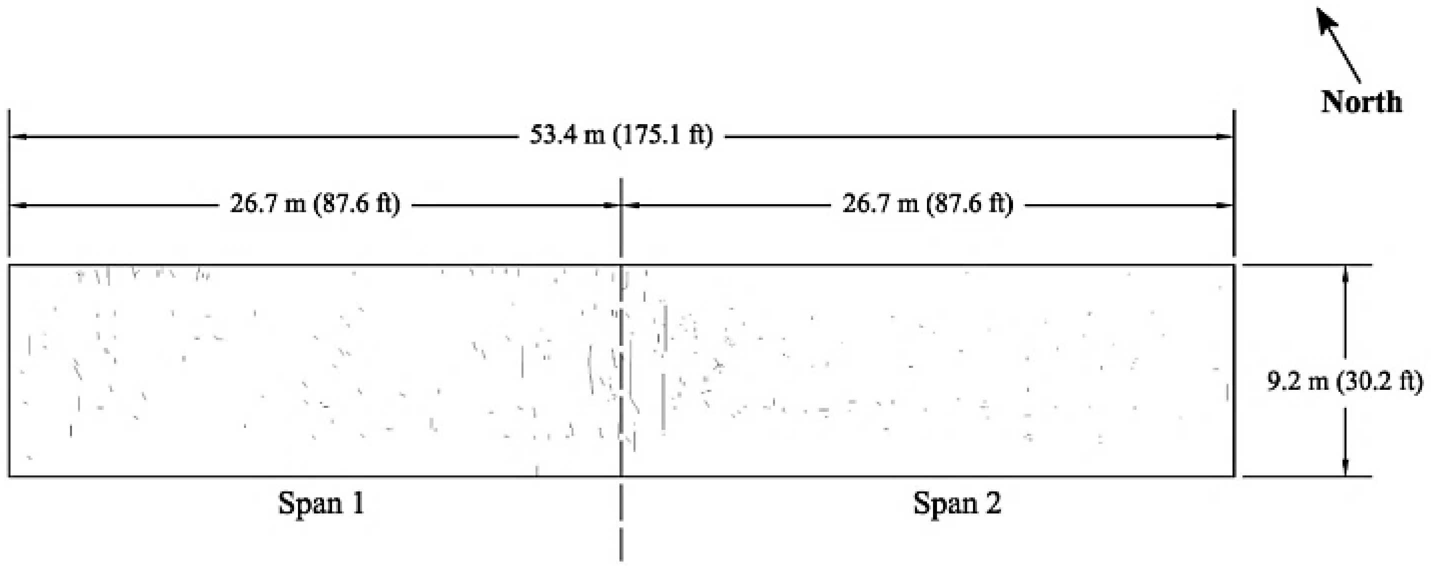


Figure 4.6: LC-HPC-1 and Control-1/2 Crack Densities versus Deck Age

4.3 LC-HPC-2

Bridge deck LC-HPC-2 was constructed on 9/13/2006 and has been surveyed nine times. Survey 8 was performed at a deck age of 92.2 months; the crack map from this survey is displayed in Figure 4.7. Survey 9 was completed at a deck age of 104.2 months; the crack map from this survey is shown in Figure 4.8. A crack density of 0.116 m/m^2 was observed in Survey 8 (Figure 4.7). This value is noticeably lower than observed in Survey 7, 0.141 m/m^2, as reported by Bohaty et al. (2013) at an age of 80.3 months. A crack density of 0.220 m/m^2 was observed in Survey 9 (Figure 4.8), which is higher than all previously reported crack densities. Map cracking is the dominant type of crack that has been surveyed. Some transverse cracks appear in the middle of the bridge above the pier.

As shown in Figure 4.9, the two decks are exhibiting similar cracking behavior. Placement 2 of Control-1/2 has a higher crack density than LC-HPC-2 and Placement 1 of Control-1/2. Placement 1 of Control-1/2 has a lower crack density than LC-HPC-2. Control-1/2 is the best performing control deck in the study.

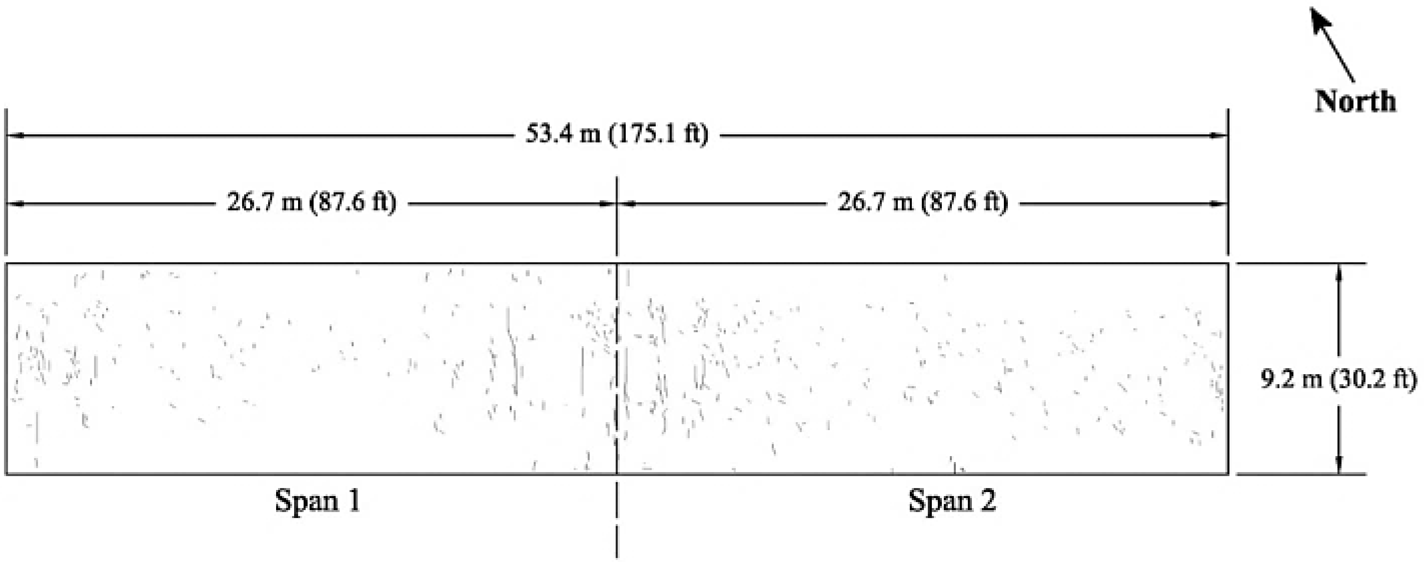


Bridge Number: 105-310 (KU #2)
Bridge Location: 34th St over I-635
Construction Date: 9/13/2006
Crack survey Date: 5/20/2014

Bridge Length: 53.4 m (175.2 ft)
Bridge Width: 9.2 m (30.2 ft)
Skew: 0°
Number of Spans: 2
Span 1 (West): 26.7 m (87.6 ft)
Span 2 (East): 26.7 m (87.6 ft)
Number of Placements: 1

Bridge Age: 92.2 months
Crack density: 0.116 m/m^2
Span 1 (West): 0.131 m/m^2
Span 2 (East): 0.101 m/m^2

Figure 4.7: LC-HPC-2 (Survey 8)



Bridge Number: 105-310 (KU #2)
Bridge Location: 34th St over I-635
Construction Date: 9/13/2006
Crack survey Date: 5/19/2015

Bridge Length: 53.4 m (175.2 ft)
Bridge Width: 9.2 m (30.2 ft)
Skew: 0°
Number of Spans: 2
Span 1 (West): 26.7 m (87.6 ft)
Span 2 (East): 26.7 m (87.6 ft)
Number of Placements: 1

Bridge Age: 104.2 months
Crack density: 0.222 m/m ^{2}
Span 1 (West): 0.220 m/m ^{2}
Span 2 (East): 0.223 m/m ^{2}

Figure 4.8: LC-HPC-2 (Survey 9)

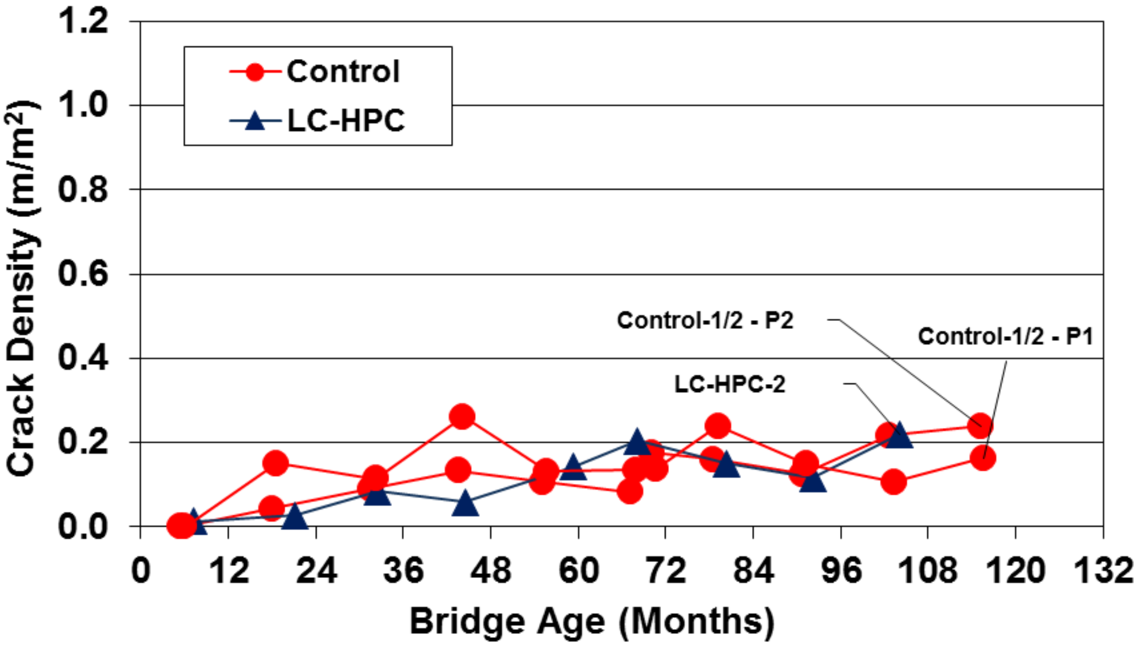
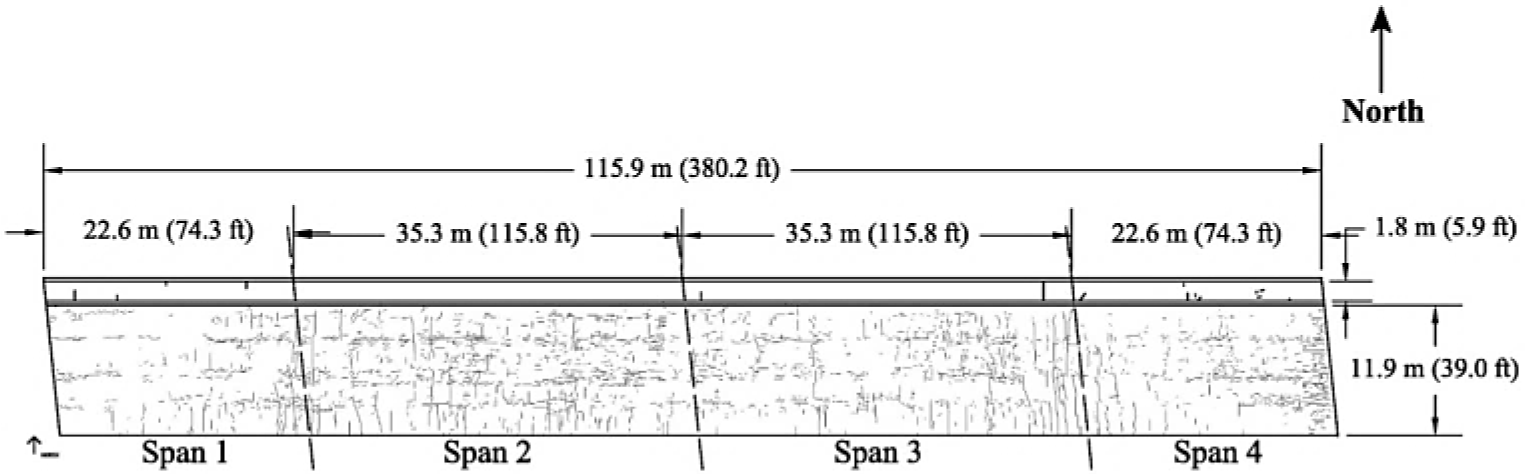


Figure 4.9: LC-HPC-2 and Control-1/2 Crack Densities versus Deck Age

4.4 LC-HPC-3

Bridge deck LC-HPC-3 was constructed on 11/13/2007 and has been surveyed nine times. The results from Surveys 7, 8, and 9 are included in this report. Survey 7 of LC-HPC-3 was completed at deck age of 83.2 months; the crack map is shown in Figure 4.10. Survey 8 of LC-HPC-3 was performed at a deck age of 91.5 months; the crack map is shown in Figure 4.11. Survey 9 was performed at a deck age of 105 months; the crack map is shown in Figure 4.12. A crack density of 0.663 m/m^2 was observed in Survey 7 (Figure 4.10), which is significantly higher than that obtained in Survey 6 at 0.174 m/m^2 reported by Bohaty et al. (2013). A crack density of 0.487 m/m^2 was observed in Survey 8 (Figure 4.11). A crack density of 0.453 was obtained in Survey 9. The significant increase in crack density from Survey 6 to Survey 7 may have resulted from surveyors mistakenly misidentifying the outlines of coarse aggregate particles as cracks. According to the results obtained from Survey 8 and 9, Survey 7 could be considered as an outlier since the crack densities in both Survey 8 and 9 results are significantly lower (at least 0.173 m/m^2 or 27%) than the value obtained in Survey 7. The vast majority of the cracks are relatively short in length. A few medium-length transverse cracks run parallel to the reinforcing steel in the top layer, primarily over the two outer piers.

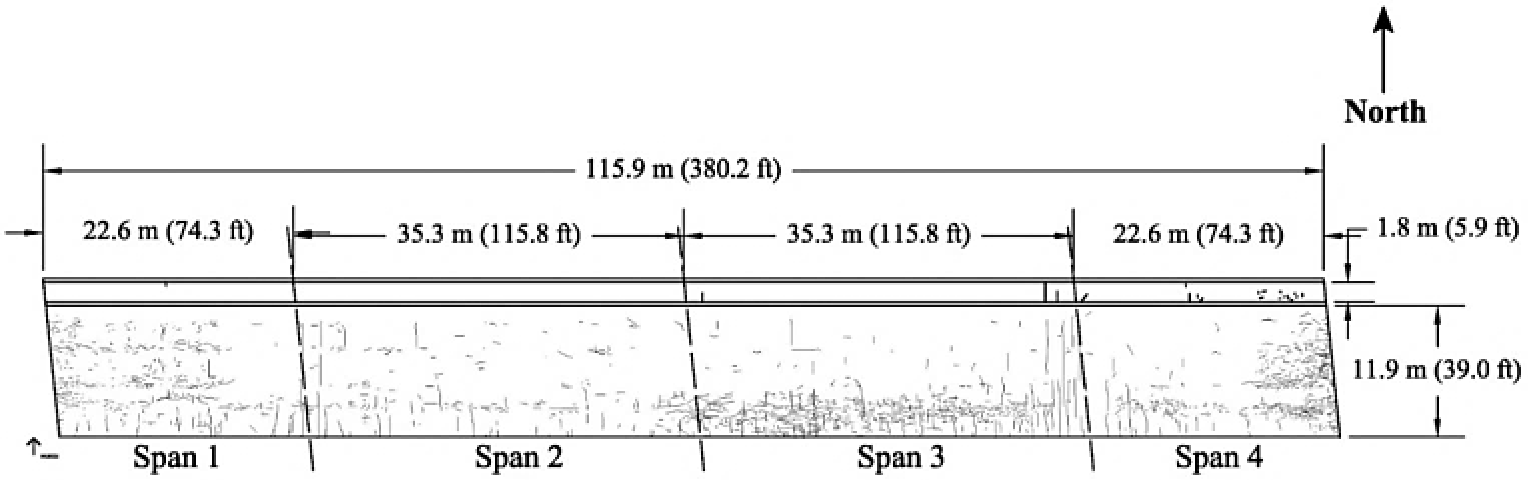


Bridge Number: 46-338 (KU #3)
Bridge Location: WB 103rd St over US 69
Construction Date: 11/13/2007
Crack survey Date: 6/24/2014

Bridge Length: 115.9 m (380.2 ft)
Bridge Width: 11.9 m (39.0 ft)
Skew: 6°
Number of Spans: 4
Span 1 : 22.6 m (74.3 ft)
Span 2 : 35.3 m (115.8 ft)
Span 3 : 35.3 m (115.8 ft)
Span 4 : 22.6 m (74.3 ft)
Number of Placements: 1

Bridge Age: 79.3 months
Crack density: 0.660 m/m^2
Span 1 : 0.488 m/m^2
Span 2 : 0.843 m/m^2
Span 3 : 0.640 m/m^2
Span 4 : 0.576 m/m^2

Figure 4.10: LC-HPC-3 (Survey 7)

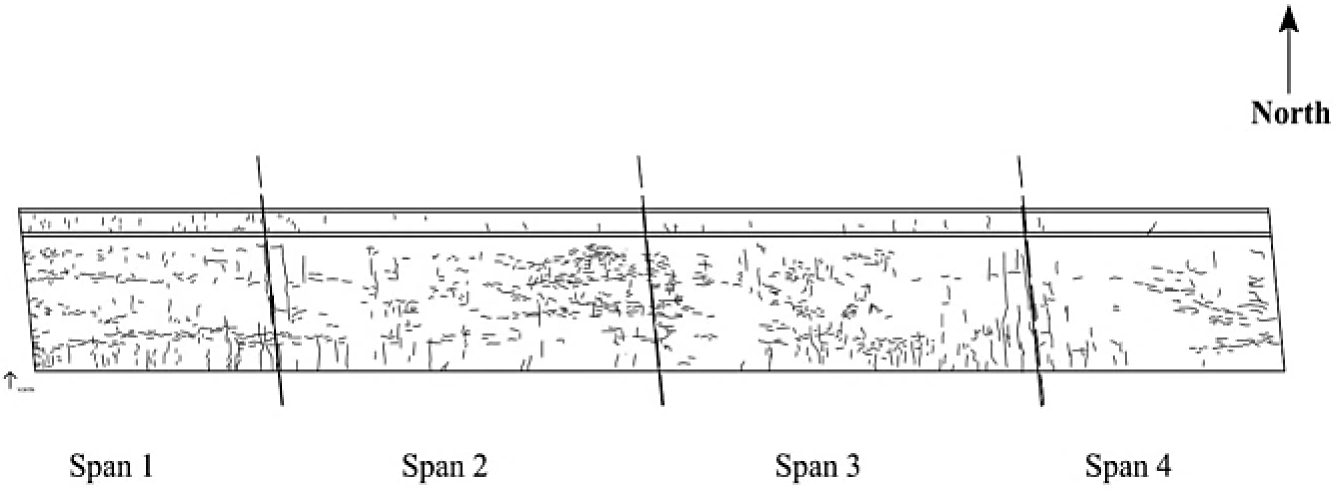


Bridge Number: 46-338 (KU #3)
Bridge Location: WB 103rd St over US 69
Construction Date: 11/13/2007
Crack survey Date: 6/29/2015

Bridge Length: 115.9 m (380.2 ft)
Bridge Width: 11.9 m (39.0 ft)
Skew: 6°
Number of Spans: 4
Span 1 : 22.6 m (74.3 ft)
Span 2 : 35.3 m (115.8 ft)
Span 3 : 35.3 m (115.8 ft)
Span 4 : 22.6 m (74.3 ft)
Number of Placements: 1

Bridge Age: 91.5 months
Crack density: 0.487 m/m²
Span 1 : 0.488 m/m²
Span 2 : 0.294 m/m²
Span 3 : 0.645 m/m²
Span 4 : 0.542 m/m²

Figure 4.11: LC-HPC-3 (Survey 8)



Bridge Number: 46-338 (KU #3)
Bridge Location: WB 103rd St over US 69
Construction Date: 11/13/2007
Crack survey Date: 6/2/2016

Bridge Length: 115.9 m (380.2 ft)
Bridge Width: 11.9 m (39.0 ft)
Skew: 6°
Number of Spans: 4
Span 1 : 22.6 m (74.3 ft)
Span 2 : 35.3 m (115.8 ft)
Span 3 : 35.3 m (115.8 ft)
Span 4 : 22.6 m (74.3 ft)
Number of Placements: 1

Bridge Age: 105 months
Crack density: 0.453 m/m^2
Span 1 : 0.540 m/m^2
Span 2 : 0.472 m/m^2
Span 3 : 0.470 m/m^2
Span 4 : 0.308 m/m^2

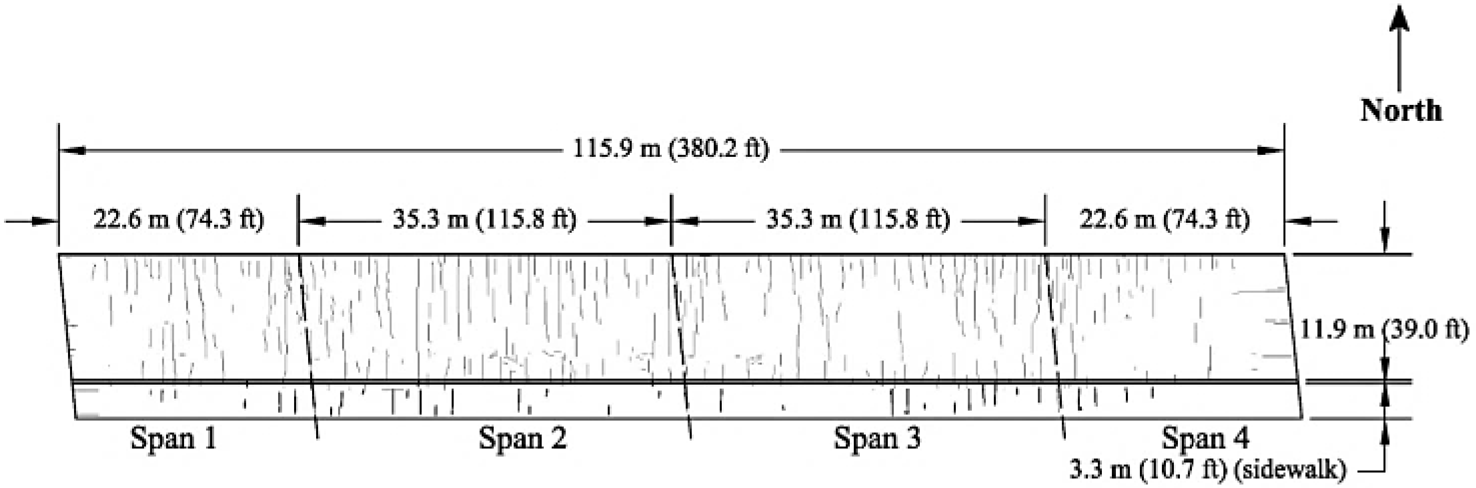
Figure 4.12: LC-HPC-3 (Survey 9)

4.5 Control 3

Bridge deck Control-3 was constructed on 7/17/2007 and has been surveyed nine times. The results of Surveys 7, 8, and 9 are included in this report. Survey 7 was completed at a deck age of 83.2 months; the crack map appears in Figure 4.13. Survey 8 was completed at a deck age of 96.9 months; the crack map appears in Figure 4.14. Survey 9 was completed at a deck age of 115.3 months; the crack map appears in Figure 4.15. A crack density of 0.382 m/m^2 was observed in Survey 7 (Figure 4.13), which is higher than obtained in Survey 6, 0.294 m/m^2, reported by Bohaty et al. (2013). A crack density of 0.391 m/m^2 was observed in Survey 8 (Figure 4.14), slightly higher than the recorded crack density for Survey 7. A crack density of 0.416 m/m^2 was observed in Survey 9 which is slightly higher than that of Survey 8 (Figure 4.15).

Figure 4.16 compares crack densities of LC-HPC-3 and Control-3 as a function of age. With the exception of Survey 7, which is likely an outlier, the two decks have exhibited comparable cracking performance since construction, with Control-3 having a crack density of 0.416 m/m^2 versus LC-HPC-3 having a crack density of 0.453 m/m^2 at Survey 9. Control-3 is the second best performing control deck in the study.

The majority of cracks marked on Control-3 are transverse cracks that may have occurred due to settlement cracking. Some cracks propagate longitudinally from both ends of the deck near the abutments.

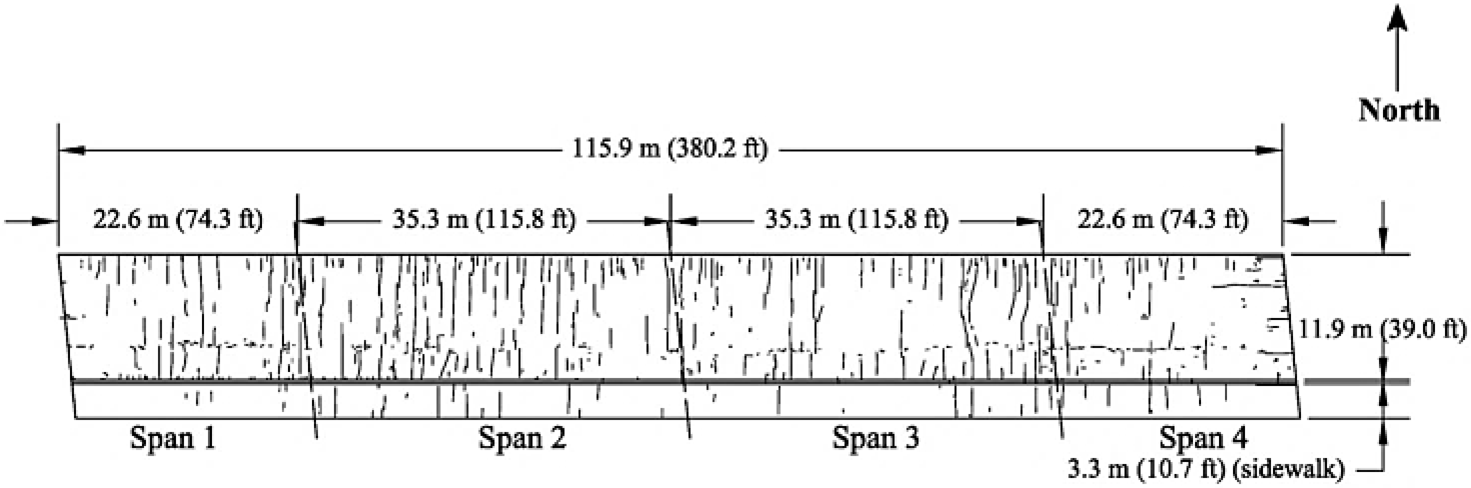


Bridge Number: 46-337 (Control 3)
Bridge Location: EB 103rd St. over US-69
Construction Date: 7/17/2007
Crack survey Date: 6/24/2014

Bridge Length: 115.9 m (380.2 ft)
Bridge Width: 11.9 m (39.0 ft)
Skew: 6°
Number of Spans: 4
Span 1: 22.6 m (74.3 ft)
Span 2: 35.3 m (115.8 ft)
Span 3: 35.3 m (115.8 ft)
Span 4: 22.6 m (74.3 ft)
Number of Placements: 1

Bridge Age: 83.2 months
Crack density: 0.382 m/m^2
Span 1: 0.366m/m^2
Span 2: 0.445 m/m^2
Span 3: 0.388 m/m^2
Span 4: 0.291 m/m^2

Figure 4.13: Control-3 (Survey 7)



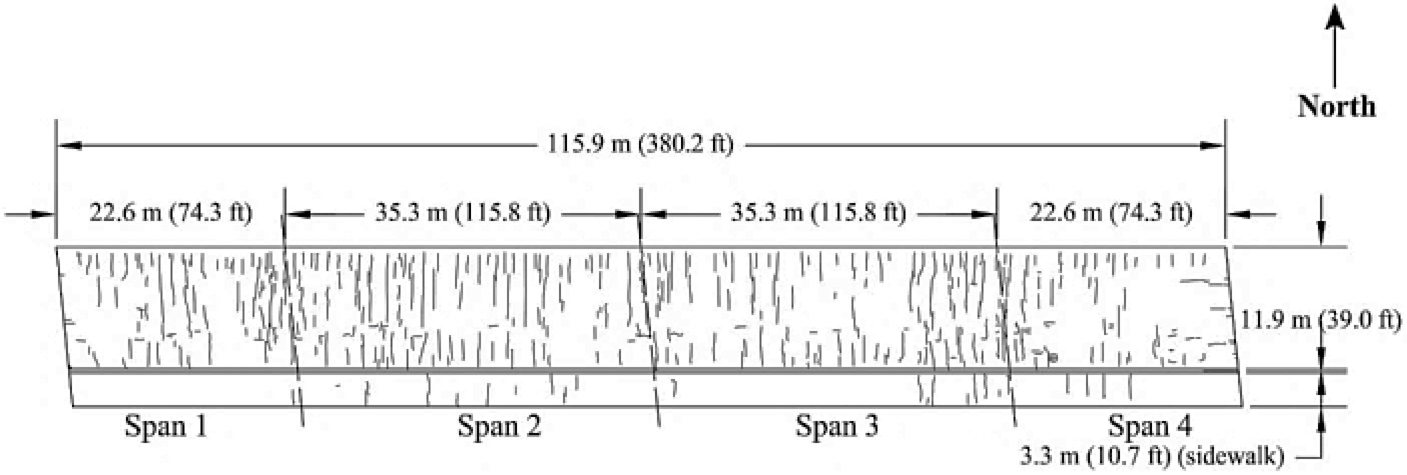
Bridge Number: 46-337 (Control 3)
Bridge Location: EB 103rd St. over US-69
Construction Date: 7/17/2007
Crack survey Date: 6/30/2015

Bridge Length: 115.9 m (380.2 ft)
Bridge Width: 11.9 m (39.0 ft)
Skew: 6°
Number of Spans: 4
- **Span 1:** 22.6 m (74.3 ft)
- **Span 2:** 35.3 m (115.8 ft)
- **Span 3:** 35.3 m (115.8 ft)
- **Span 4:** 22.6 m (74.3 ft)

Number of Placements: 1

Bridge Age: 96.9 months
Crack density: 0.391 m/m^2
- **Span 1:** 0.340m/m^2
- **Span 2:** 0.461 m/m^2
- **Span 3:** 0.383 m/m^2
- **Span 4:** 0.347 m/m^2

Figure 4.14: Control-3 (Survey 8)



Bridge Number: 46-337 (Control 3)
Bridge Location: EB 103rd St. over US-69
Construction Date: 7/17/2007
Crack survey Date: 7/8/2016

Bridge Length: 115.9 m (380.2 ft)
Bridge Width: 11.9 m (39.0 ft)
Skew: 6°
Number of Spans: 4
- **Span 1:** 22.6 m (74.3 ft)
- **Span 2:** 35.3 m (115.8 ft)
- **Span 3:** 35.3 m (115.8 ft)
- **Span 4:** 22.6 m (74.3 ft)

Number of Placements: 1

Bridge Age: 115.3 months
Crack density: 0.416 m/m^2
- **Span 1:** 0.403 m/m^2
- **Span 2:** 0.459 m/m^2
- **Span 3:** 0.434 m/m^2
- **Span 4:** 0.333 m/m^2

Figure 4.15: Control -3 (Survey 9)

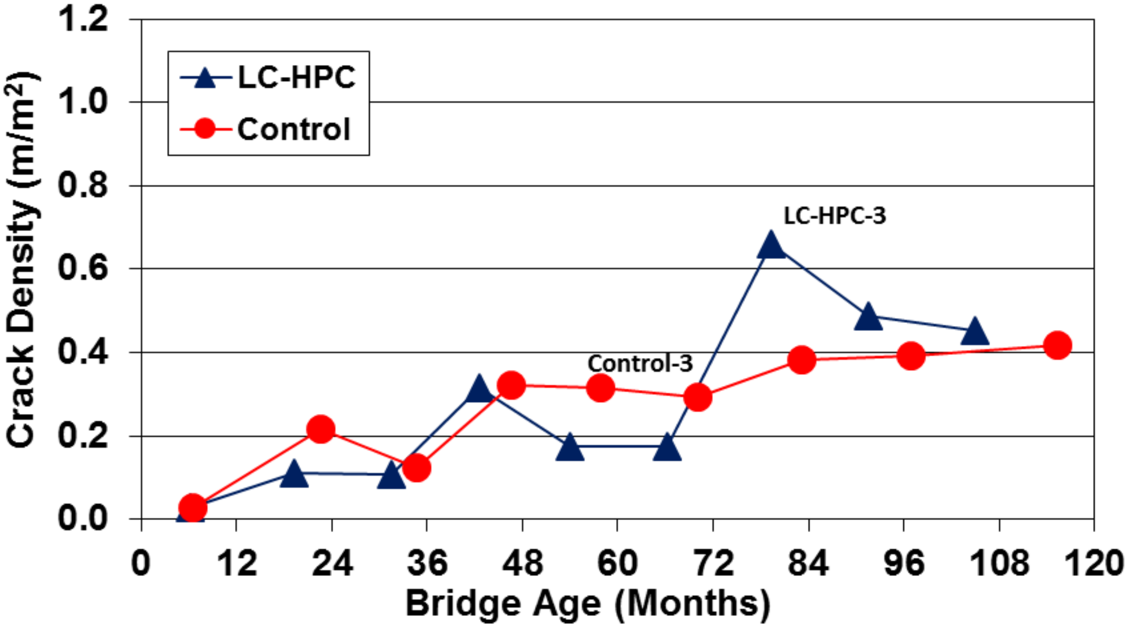
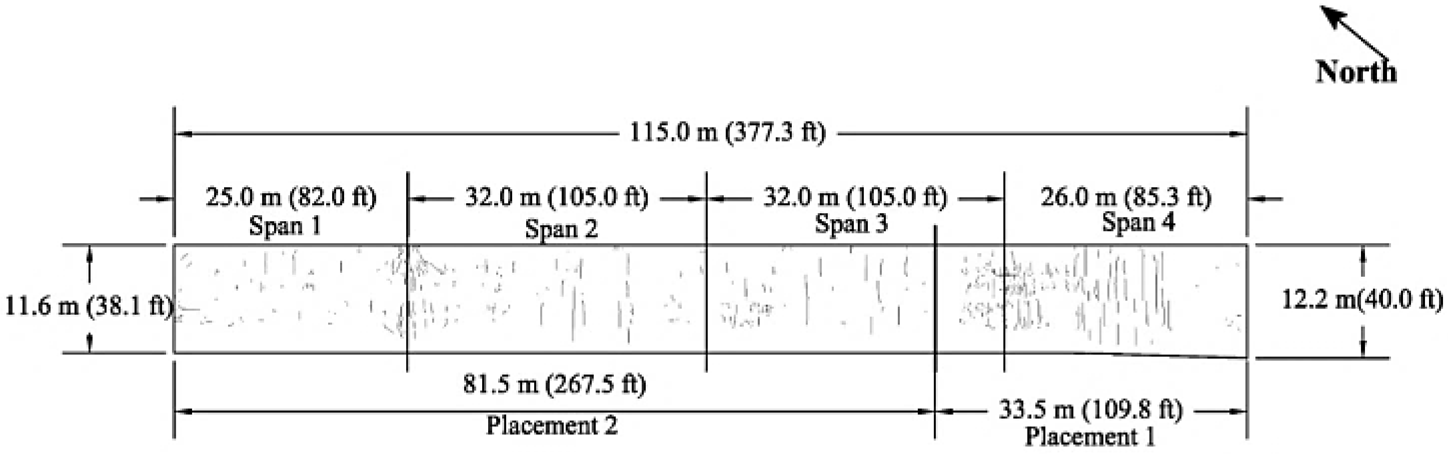


Figure 4.16: LC-HPC-3 and Control-3 Crack Densities versus Deck Age

4.6 LC-HPC-4

Bridge deck LC-HPC-4 was constructed in two placements. Placement 1 was cast on 9/29/2007 and Placement 2 was cast on 10/2/2007. This deck has been surveyed eight times, and the results of Surveys 7 and 8 of LC-HPC-4 are discussed in this report. Survey 7 (Figure 4.17) was completed at deck ages of 80.4 and 80.3 months for Placements 1 and 2, respectively; the crack map appears in Figure 4.17. Survey 8 (Figure 4.18) was completed at a deck age of 93.3 and 93.2 months for Placements 1 and 2, respectively. Crack densities of 0.371 and 0.173 m/m^2 for Placements 1 and 2, 0.225 m/m^2 overall, were observed in Survey 7. The crack density for Placement 1 was about twice that for Placement 2, with both noticeably higher than observed in Survey 6, reported by Bohaty et al. (2013), for which the respective crack densities were 0.147, 0.077, and 0.105 m/m^2. Crack densities of 0.305 and 0.181 m/m^2 for Placements 1 and 2 and 0.217 m/m^2 overall were observed in Survey 8. These values are nearly the same to those recorded during Survey 7. Medium-length transverse cracks are present and distributed over the area of the deck. Near the deck's north western abutment, some cracks propagate longitudinally.

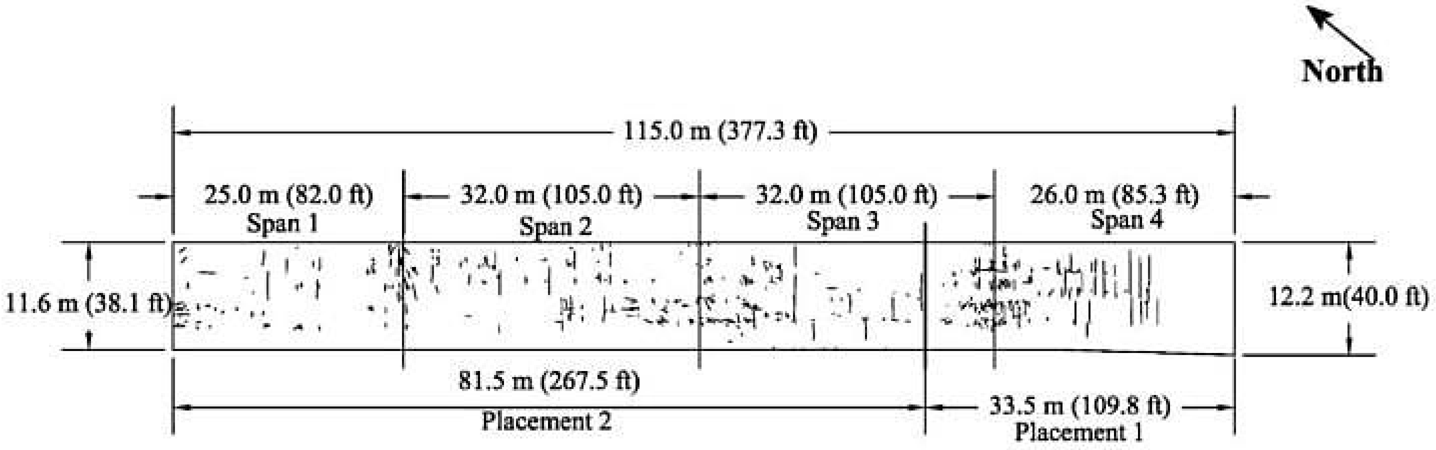


Bridge Number: 46-339 Unit 1
(KU #4)
Bridge Location: Flyover Ramp
US-69S to I-435W
Construction Date:
Placement 1 (South): 9/29/2007
Placement 2 (North): 10/2/2007
Crack Survey Date: 6/27/2014

Bridge Length: 115.0 m (377.3 ft)
Bridge Width: 11.6 m (38.1 ft)
Skew: 0°
Number of Spans: 4
Span 1: 25.0 m (82.0 ft)
Span 2: 32.0 m (105.0 ft)
Span 3: 32.0 m (105.0 ft)
Span 4: 26.0 m (85.3 ft)
Number of Placements: 2

Bridge Age:
Placement 1: 80.4 months
Placement 2: 80.3 months
Crack Density: 0.225 m/m^2
Placement 1: 0.371 m/m^2
Placement 2: 0.173 m/m^2
Span 1: 0.159 m/m^2
Span 2: 0.202 m/m^2
Span 3: 0.168 m/m^2
Span 4: 0.412 m/m^2

Figure 4.17: LC-HPC-4 (Survey 7)



Bridge Number: 46-339 Unit 1
(KU #4)
Bridge Location: Flyover Ramp
US-69S to I-435W
Construction Date:
Placement 1 (South): 9/29/2007
Placement 2 (North): 10/2/2007
Crack Survey Date: 7/9/2015

Bridge Length: 115.0 m (377.3 ft)
Bridge Width: 11.6 m (38.1 ft)
Skew: 0°
Number of Spans: 4
Span 1: 25.0 m (82.0 ft)
Span 2: 32.0 m (105.0 ft)
Span 3: 32.0 m (105.0 ft)
Span 4: 26.0 m (85.3 ft)
Number of Placements: 2

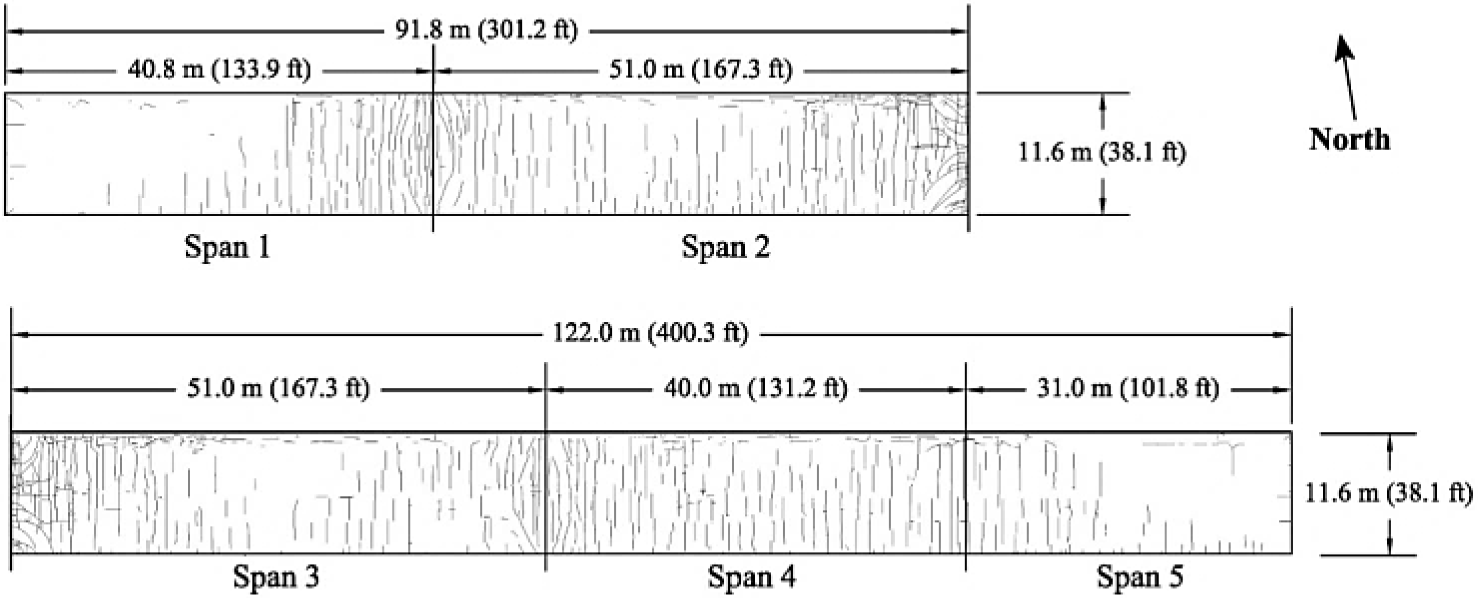
Bridge Age:
Placement 1: 93.3 months
Placement 2: 93.2 months
Crack Density: 0.217 m/m^2
Placement 1: 0.305 m/m^2
Placement 2: 0.181 m/m^2
Span 1: 0.163 m/m^2
Span 2: 0.175 m/m^2
Span 3: 0.245 m/m^2
Span 4: 0.289 m/m^2

Figure 4.18: LC-HPC-4 (Survey 8)

4.7 Control-4

Bridge deck Control-4 was constructed on 8/5/2014. This deck has been surveyed eight times. Surveys 7 and 8 are discussed in this report. Survey 7 was completed at a deck age of 80.7 months, and the crack map for this survey is shown in Figure 4.19. Survey 8 was completed at a deck age of 92.2 months, and the crack map for this survey is shown in Figure 4.20. A crack density of 0.667 m/m^2 was observed in Survey 7 (Figure 4.19), an increase from the value recorded in Survey 6 at 0.561 m/m^2 (Bohaty et al., 2013). A crack density of 0.755 m/m^2 was observed in Survey 8 (Figure 4.20). Cracking in Control-4 is significant in the outer portions of the end spans. The majority of the cracks are transverse and appear to run parallel to the top layer of reinforcement. Cracks propagate from both abutments. Longitudinal cracks are present near the northern side of the deck parallel to the parapet, and might be a result of the 3.2-ft (0.975-m) overhang at the exterior steel girder.

Figure 4.21 compares crack densities of LC-HPC 4 and Control-4 over time. As shown in Figure 4.22, both LC-HPC-4 placements are exhibiting much less cracking than Control-4.



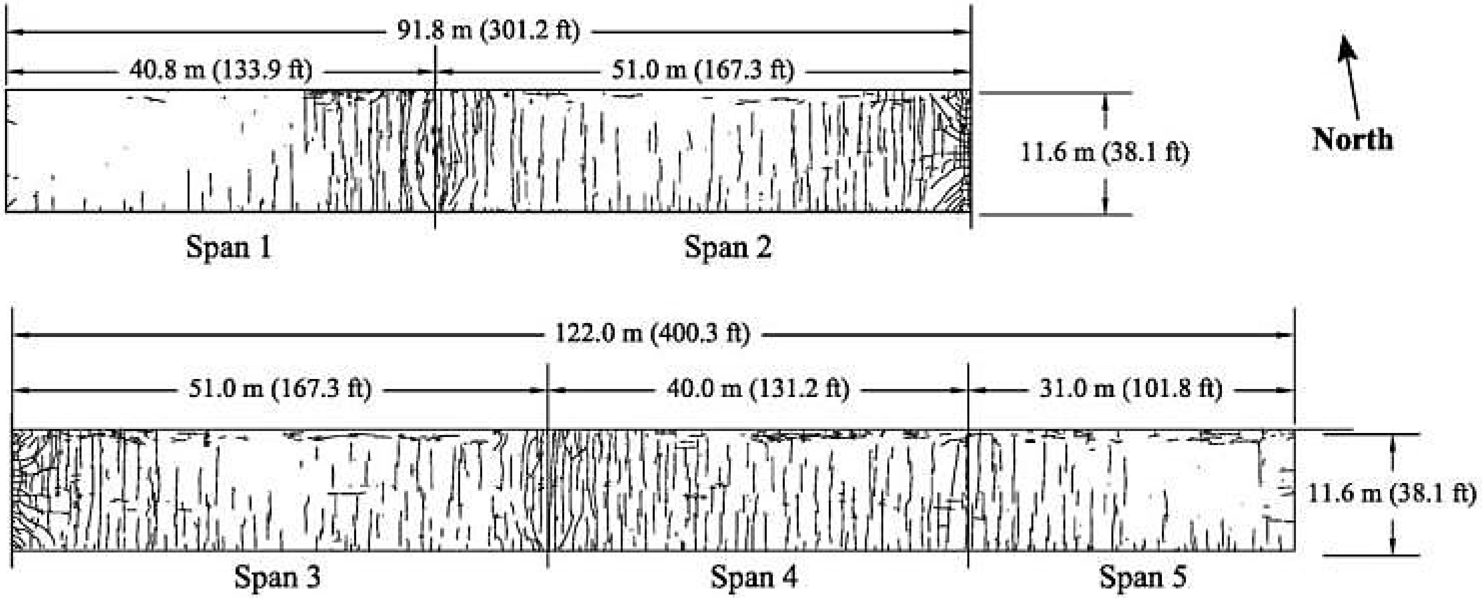
Bridge Number: 46-347 (KU #4 Control)
Bridge Location: NB US-69 Rd
Construction Date: 11/16/2007
Crack survey Date: 8/5/2014

Bridge Length: 213.8 m (701.5 ft)
Bridge Width: 11.6 m (38.1 ft)
Skew: 0°
Number of Spans: 5
- **Span 1:** 40.8 m (133.9 ft)
- **Span 2:** 51.0 m (167.3 ft)
- **Span 3:** 51.0 m (167.3 ft)
- **Span 4:** 40.0 m (131.2 ft)
- **Span 5:** 31.0 m (101.8 ft)

Number of Placements: 1

Bridge Age: 80.7 months
Crack density: 0.667 m/m²
- **Span 1:** 0.476 m/m²
- **Span 2:** 0.815 m/m²
- **Span 3:** 0.782 m/m²
- **Span 4:** 0.759 m/m²
- **Span 5:** 0.367 m/m²

Figure 4.19: Control-4 (Survey 7)



Bridge Number: 46-347 (KU #4 Control)
Bridge Location: NB US-69 Rd
Construction Date: 11/16/2007
Crack survey Date: 7/17/2015

Bridge Length: 213.8 m (701.5 ft)
Bridge Width: 11.6 m (38.1 ft)
Skew: 0°
Number of Spans: 5
  Span 1: 40.8 m (133.9 ft)
  Span 2: 51.0 m (167.3 ft)
  Span 3: 51.0 m (167.3 ft)
  Span 4: 40.0 m (131.2 ft)
  Span 5: 31.0 m (101.8 ft)
Number of Placements: 1

Bridge Age: 92.9 months
Crack density: 0.755 m/m^2
  Span 1: 0.458 m/m^2
  Span 2: 0.774 m/m^2
  Span 3: 0.920 m/m^2
  Span 4: 0.972 m/m^2
  Span 5: 0.568 m/m^2

Figure 4.20: Control-4 (Survey 8)

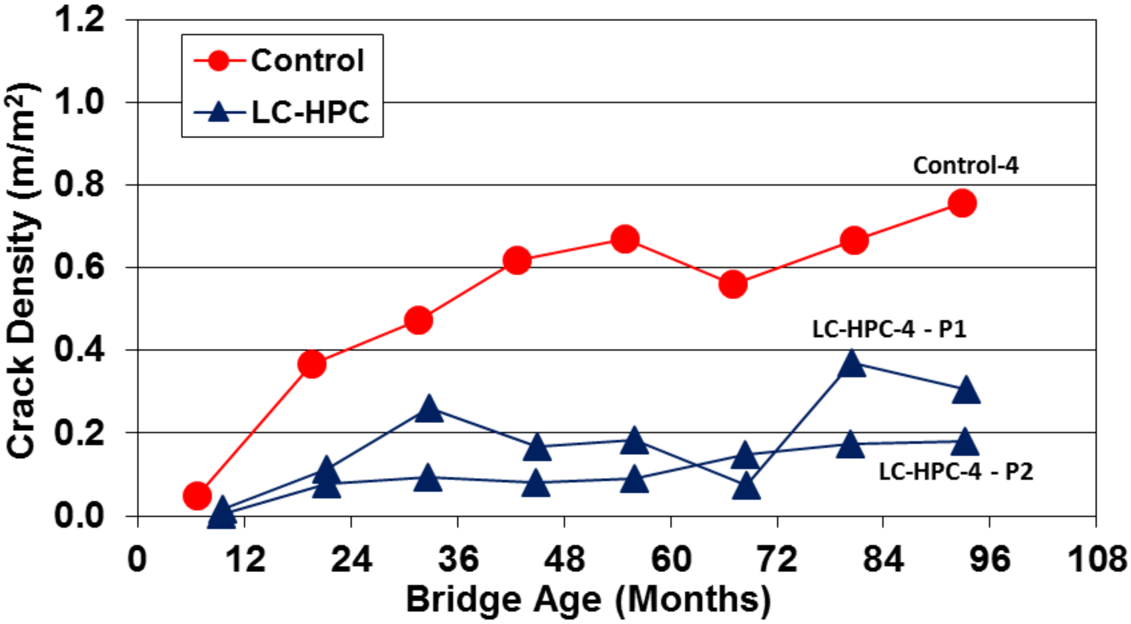


Figure 4.21: LC-HPC-4 and Control-4 Crack Densities versus Deck Age

4.8 LC-HPC-5

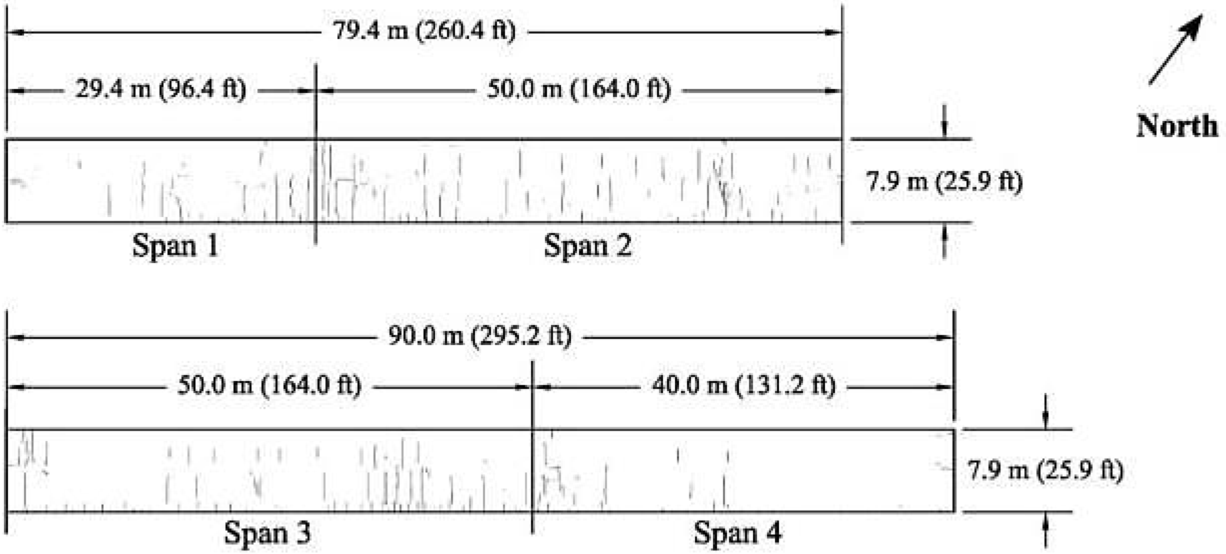
Bridge deck LC-HPC-5 was constructed on 11/14/2007 and has been surveyed eight times. The results for Surveys 7 and 8 are included in this report. Survey 7 was completed at 79.4 months; the results are shown in Figure 4.22. Survey 8 was completed at 91.8 months; the results are shown in Figure 4.23. A crack density of 0.229 m/m^2 was observed in Survey 7 (Figure 4.22). This value indicates a nearly 70% increase in crack density compared to Survey 6 reported by Bohaty et al. (2013), which was 0.140 m/m^2. A crack density of 0.247 m/m^2 was observed in Survey 8 (Figure 4.23). The majority of the cracks marked are medium-length transverse cracks. Also, some cracks have propagated longitudinally from both bridge ends near the abutments. It can be noted that most of the cracking has occurred on the southern side of the bridge. This may be related to the bridge being superelevated and the soaker hoses being placed at the centerline of the bridge at the time of construction, resulting a lack of water for curing at the more elevated side of the deck.

It was noted during the surveys that surface voids were present on the deck, likely due to incomplete finishing. These voids were noted in the construction report for LC-HPC-5 as being present immediately after bullfloating. Figure 4.24 shows a photo of a portion of the deck taken during Survey 8 illustrating these voids.

4.9 Control-5

In 2012, an overlay was placed on Control-5 due to its high crack density; thus, Survey 3 was the last survey performed for Control-5, which is reported by Bohaty et al. (2013). A crack density of 0.738 m/m^2 was observed in Survey 3.

Figure 4.25 compares the crack densities of LC-HPC-5 and Control-5 over time. LC-HPC-5 has exhibited much better performance than the Control 5 deck.

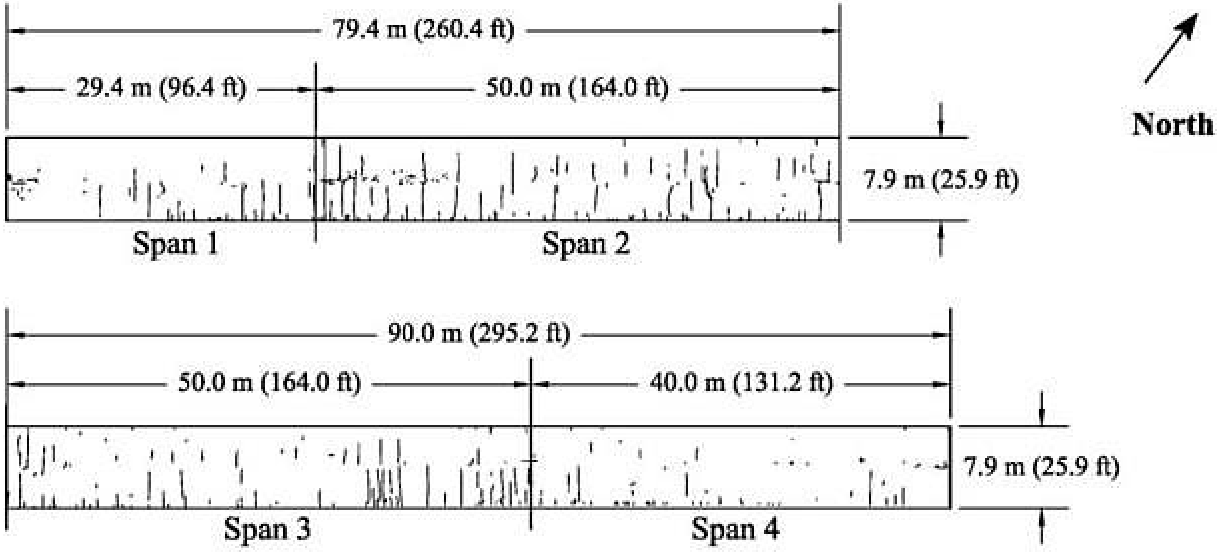


Bridge Number: 46-340 Unit 1 (KU #5)
Bridge Location: Flyover Ramp US-69 to I-435 W
Construction Date: 11/14/2007
Crack survey Date: 6/25/2014

Bridge Length: 169.4 m (555.7 ft)
Bridge Width: 7.9 m (25.9 ft)
Skew: 0°
Number of Spans: 4
Span 1: 29.4 m (96.4 ft)
Span 2: 50.0 m (164.0 ft)
Span 3: 50.0 m (164.0 ft)
Span 4: 40.0 m (131.2 ft)
Number of Placements: 1

Bridge Age: 79.4 months
Crack density: 0.229 m/m²
Span 1: 0.195 m/m²
Span 2: 0.321 m/m²
Span 3: 0.257 m/m²
Span 4: 0.106 m/m²

Figure 4.22: LC-HPC-5 (Survey 7)



Bridge Number: 46-340 Unit 1 (KU #5)
Bridge Location: Flyover Ramp US-69 to I-435 W
Construction Date: 11/14/2007
Crack survey Date: 7/9/2015

Bridge Length: 169.4 m (555.7 ft)
Bridge Width: 7.9 m (25.9 ft)
Skew: 0°
Number of Spans: 4
Span 1: 29.4 m (96.4 ft)
Span 2: 50.0 m (164.0 ft)
Span 3: 50.0 m (164.0 ft)
Span 4: 40.0 m (131.2 ft)
Number of Placements: 1

Bridge Age: 91.8 months
Crack density: 0.247 m/m^2
Span 1: 0.192 m/m^2
Span 2: 0.351 m/m^2
Span 3: 0.293 m/m^2
Span 4: 0.102 m/m^2

Figure 4.23: LC-HPC-5 (Survey 8)

Figure 4.24: Surface Voids in LC-HPC-5 Bridge Deck

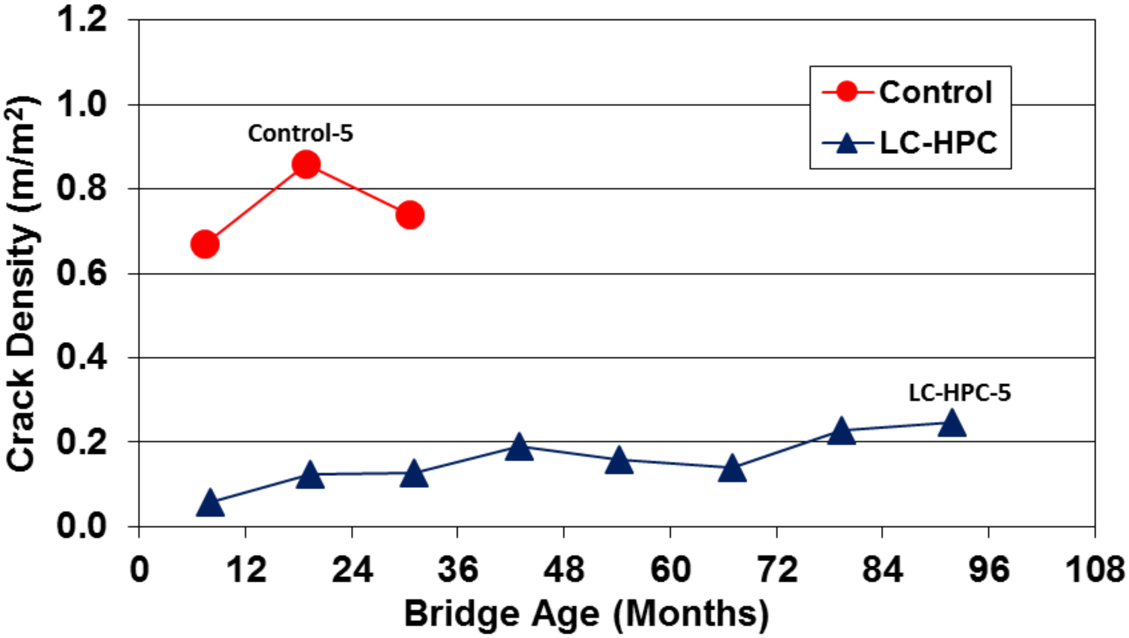


Figure 4.25: LC-HPC-5 and Control-5 Crack Densities versus Deck Age

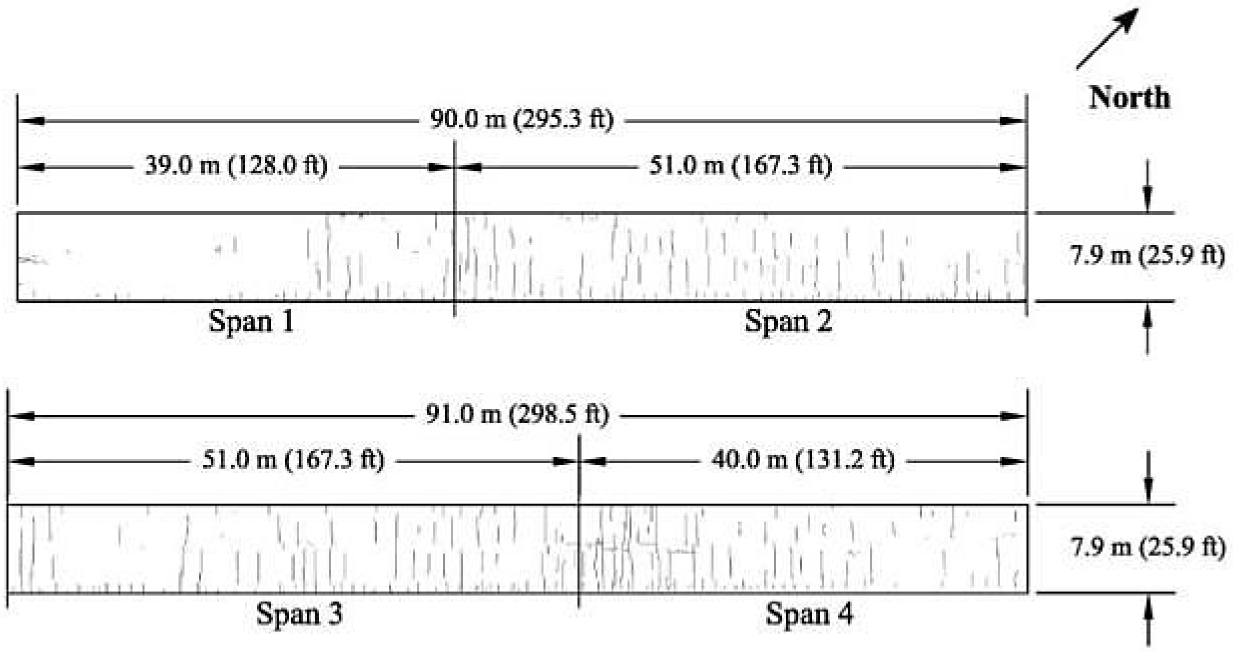
4.10 LC-HPC-6

Bridge deck LC-HPC-6 was constructed on 11/3/2007 and has been surveyed eight times. The results of Surveys 7 and 8 are included in this report. Survey 7 was performed at a deck age of 79.7 months; the crack map appears in Figure 4.26. Survey 8 was performed at a deck age of 92.2 months; the crack map appears in Figure 4.27. An overall crack density of 0.356 m/m^2 was observed in Survey 7 (Figure 4.26). This value represents an increase in crack density when compared to Survey 6, 0.303 m/m^2, reported by Bohaty et al. (2013). An overall crack density of 0.386 m/m^2 was observed in Survey 8 (Figure 4.27). Similar to LC-HPC-5, surface voids were observed during construction and during the surveys. Most of the cracks are transverse.

4.11 Control-6

Bridge deck Control-6 was constructed on 10/20/2008 and has been surveyed seven times. The results for Surveys 6 and 7 are included in this report. Survey 6 was completed at 68.2 months; the crack map is shown in Figure 4.28. Survey 7 was completed at 81.9 months; the crack map is shown in Figure 4.29. A crack density of 0.646 m/m^2 was observed in Survey 6 (Figure 4.28), which is considerably higher than Survey 5 at 0.461 m/m^2 (Bohaty et al., 2013). A crack density of 0.628 m/m^2 was observed in Survey 7 (Figure 4.29), slightly lower than Survey 6. The majority of the cracks are transverse and run across the full width of the deck. The cracks are closer to each other over the piers than at other locations. Cracks propagate longitudinally adjacent the abutments. Some longitudinal cracks are present in the middle of the deck.

Figure 4.30 compares the crack densities between LC-HPC-6 and Control-6 over time. LC-HPC-6 has performed better than Control-6 over the lifetime of the decks.

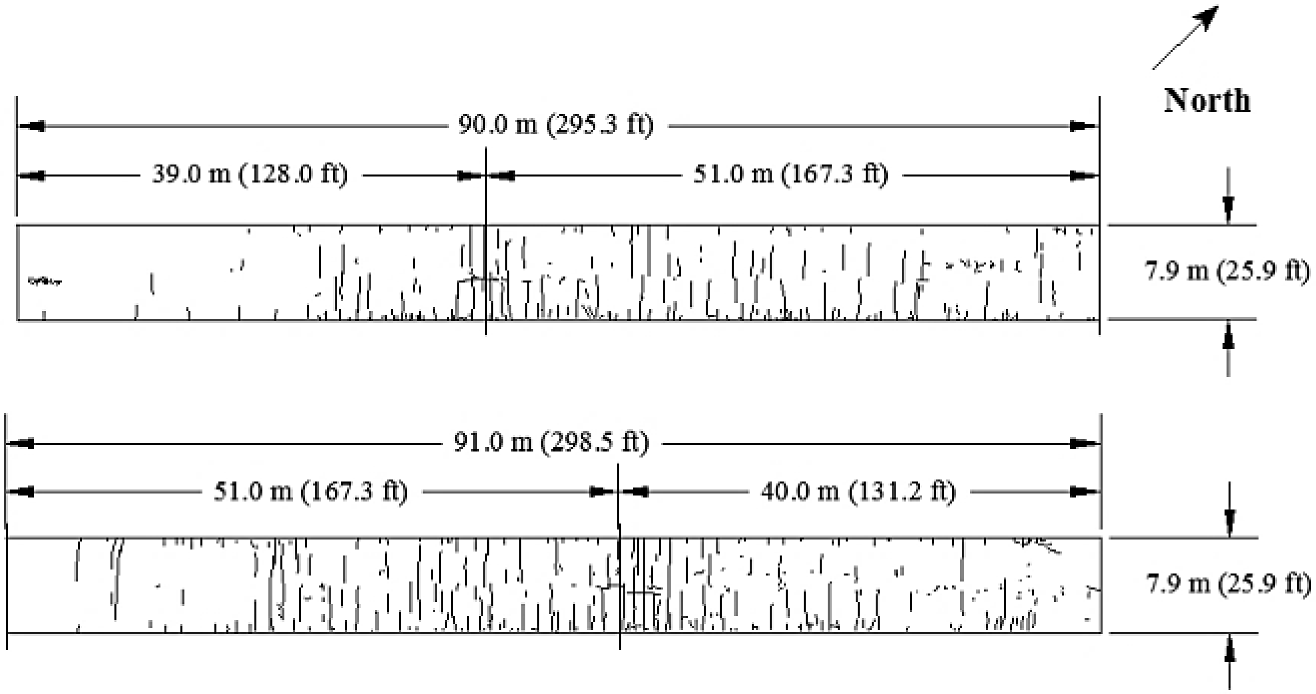


Bridge Number: 46-340 Unit 2 (KU #6)
Bridge Location: SB US-69 to WB I-435
Construction Date: 11/3/2007
Crack survey Date: 6/25/2014

Bridge Length: 181.0 m (593.8 ft)
Bridge Width: 7.9 m (25.9 ft)
Skew: 0°
Number of Spans: 4
  Span 1: 39.0 m (128.0 ft)
  Span 2: 51.0 m (167.3 ft)
  Span 3: 51.0 m (167.3 ft)
  Span 4: 40.0 m (131.2 ft)
Number of Placements: 1

Bridge Age: 79.7 months
Crack density: 0.356 m/m²
  Span 1: 0.182 m/m²
  Span 2: 0.396 m/m²
  Span 3: 0.389 m/m²
  Span 4: 0.439 m/m²

Figure 4.26: LC-HPC-6 (Survey 7)

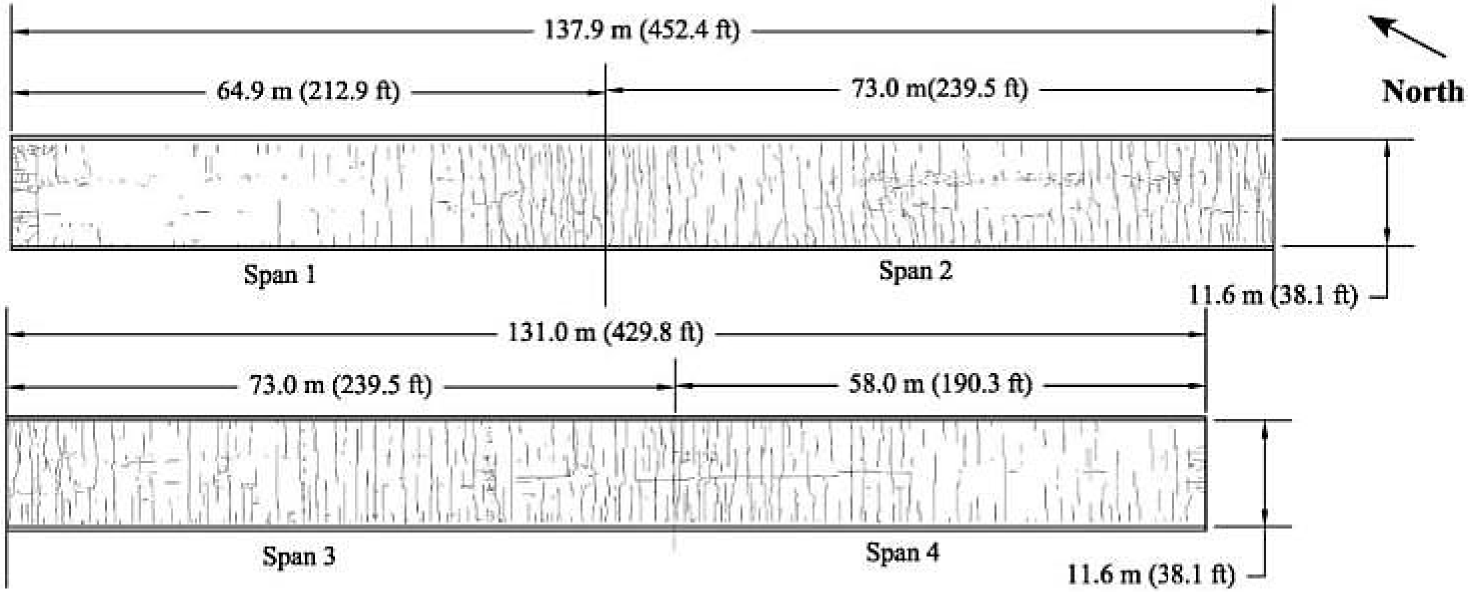


Bridge Number: 46-340 Unit 2 (KU #6)
Bridge Location: SB US-69 to WB I-435
Construction Date: 11/3/2007
Crack survey Date: 7/9/2015

Bridge Length: 181.0 m (593.8 ft)
Bridge Width: 7.9 m (25.9 ft)
Skew: 0°
Number of Spans: 4
Span 1: 39.0 m (128.0 ft)
Span 2: 51.0 m (167.3 ft)
Span 3: 51.0 m (167.3 ft)
Span 4: 40.0 m (131.2 ft)
Number of Placements: 1

Bridge Age: 92.2 months
Crack density: 0.386 m/m^2
Span 1: 0.192 m/m^2
Span 2: 0.439 m/m^2
Span 3: 0.374 m/m^2
Span 4: 0.439 m/m^2

Figure 4.27: LC-HPC-6 (Survey 8)

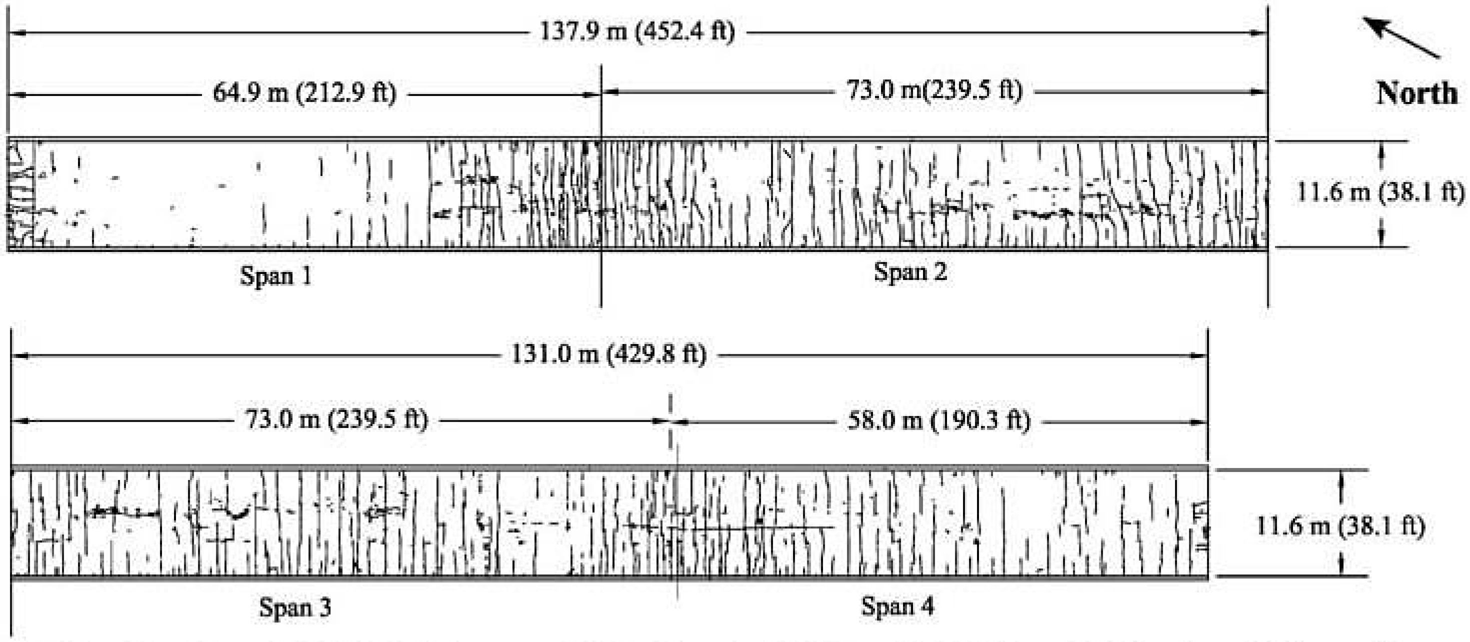


Bridge Number: 46-341 Unit 4 (Control #6)
Bridge Location: Flyover Ramp S-69 to I-435 E, Overland Park, KS
Construction Date: 10/20/2008
Crack survey Date: 6/27/2014

Bridge Length: 268.9 m (882.2 ft)
Bridge Width: 11.6 m (38.1 ft)
Skew: 0°
Number of Spans: 4
Span 1: 64.9 m (212.9 ft)
Span 2: 73.0 m (239.5 ft)
Span 3: 73.0 m (239.5 ft)
Span 4: 58.0 m (190.3 ft)
Number of Placements: 1

Bridge Age: 68.2 months
Crack density: 0.646 m/m^2
Span 1: 0.374 m/m^2
Span 2: 0.786 m/m^2
Span 3: 0.760 m/m^2
Span 4: 0.632 m/m^2

Figure 4.28: Control-6 (Survey 6)



Bridge Number: 46-341 Unit 4
(Control #6)
Bridge Location: Flyover Ramp
S-69 to I-435 E, Kansas City, KS
Construction Date: 10/20/2008
Crack survey Date: 7/14/2015

Bridge Length: 268.9 m (882.2 ft)
Bridge Width: 11.6 m (38.1 ft)
Skew: 0°
Number of Spans: 4
- **Span 1:** 64.9 m (212.9 ft)
- **Span 2:** 73.0 m (239.5 ft)
- **Span 3:** 73.0 m (239.5 ft)
- **Span 4:** 58.0 m (190.3 ft)

Number of Placements: 1

Bridge Age: 81.9 months
Crack density: 0.628 m/m^2
- **Span 1:** 0.395 m/m^2
- **Span 2:** 0.782 m/m^2
- **Span 3:** 0.688 m/m^2
- **Span 4:** 0.621 m/m^2

Figure 4.29: Control-6 (Survey 7)

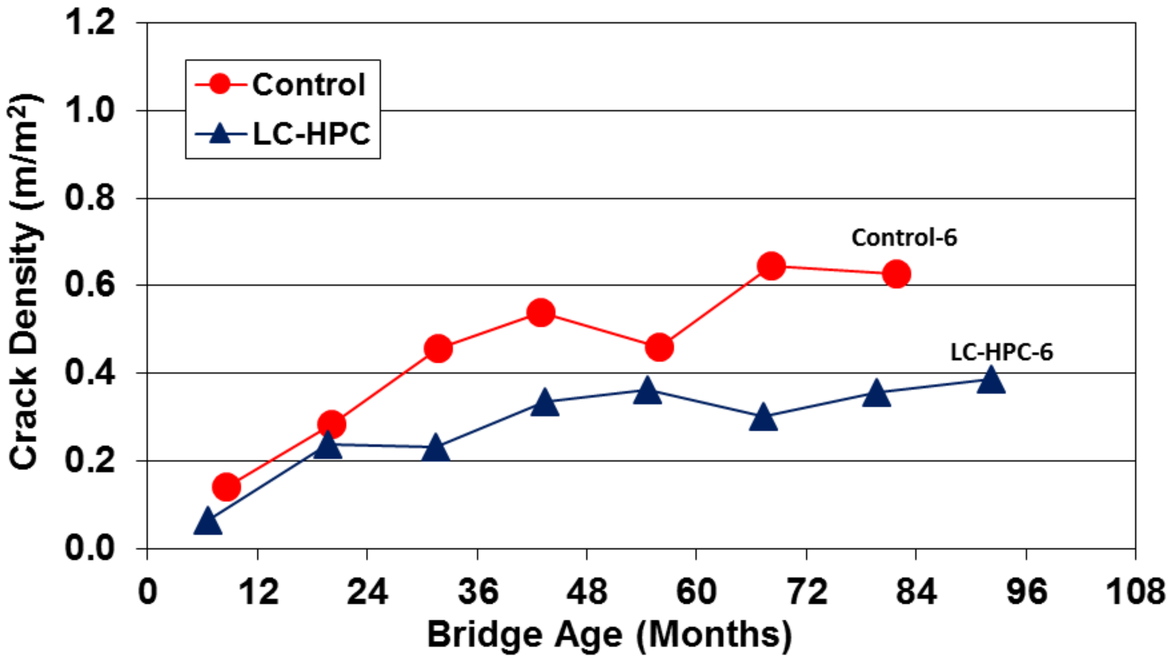


Figure 4.30: LC-HPC-6 and Control-6 Crack Densities versus Deck Age

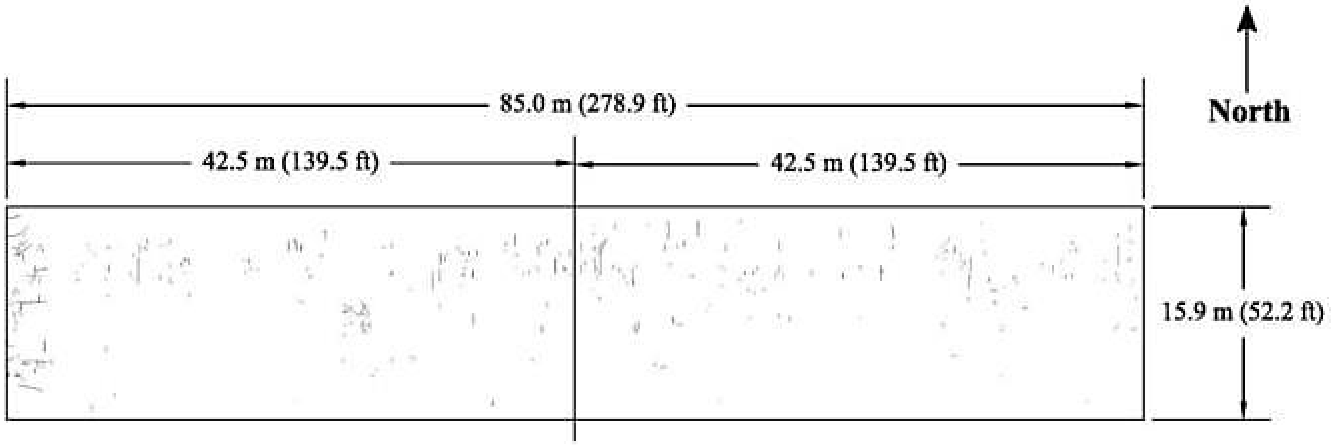
4.12 LC-HPC-7

Bridge deck LC-HPC-7 was constructed on 6/24/2006. The deck has been surveyed nine times. The results of Surveys 8 and 9 of LC-HPC-7 are presented in this report. Survey 8 was completed at a deck age of 95.7 months; the crack map is shown in Figure 4.31. Survey 9 was completed at a deck age of 106.9 months; the crack map for this survey is shown in Figure 4.32. A crack density of 0.087 m/m^2 was observed in Survey 8 (Figure 4.31). This value is greater than the crack density reported by Bohaty et al. (2013) for Survey 7, 0.074 m/m^2. In Survey 9, however, a crack density of only 0.036 m/m^2 was observed (Figure 4.32). The measured crack density might have dropped due to dirt present on some portions of the bridge deck at the time of Survey 9. As shown in Figure 4.31 and Figure 4.32 most of the cracks are relatively short and are distributed over the whole area of the bridge. There are some cracks near the west abutment that have propagated perpendicular to the abutment of the bridge. This deck has consistently exhibited the lowest crack density in this study.

4.13 Control-7

Control-7 was constructed in two placements. Placement 1 was cast on 3/29/2006 and Placement 2 was cast on 9/15/2006. This deck has been surveyed seven times, and the crack survey results of Survey 7 are included in this report. Survey 7 was performed at a deck age of 98.5 months for Placement 1 and 93.0 months for Placement 2; the crack map for this survey is shown in Figure 4.33. In Survey 7, crack densities of 1.165 m/m^2 for Placement 1 and 1.15 m/m^2 for Placement 2 were observed. These values are higher than the crack densities last reported by Bohaty et al. (2013), 1.022 m/m^2 for Placement 1 and 0.638 m/m^2 for Placement 2. Due to high cracking of Control-7, Survey 7 was the last survey of this bridge deck. The majority of the cracks present in Placement 1 are transverse. Relatively long longitudinal cracks cross the transverse cracks. Above the pier, cracks are much closer to each other compared to other areas of the deck. Placement 2 has a longitudinal crack running next to the construction joint. In both placements, cracks propagate longitudinally near the abutments.

Figure 4.34 compares the crack densities over time for LC-HPC-7 and Control-7 over time. It can be concluded that LC-HPC-7 has maintained a much lower crack density than Control 7. Noticeably, Control-7 experienced a significant increase in crack density after the second year.

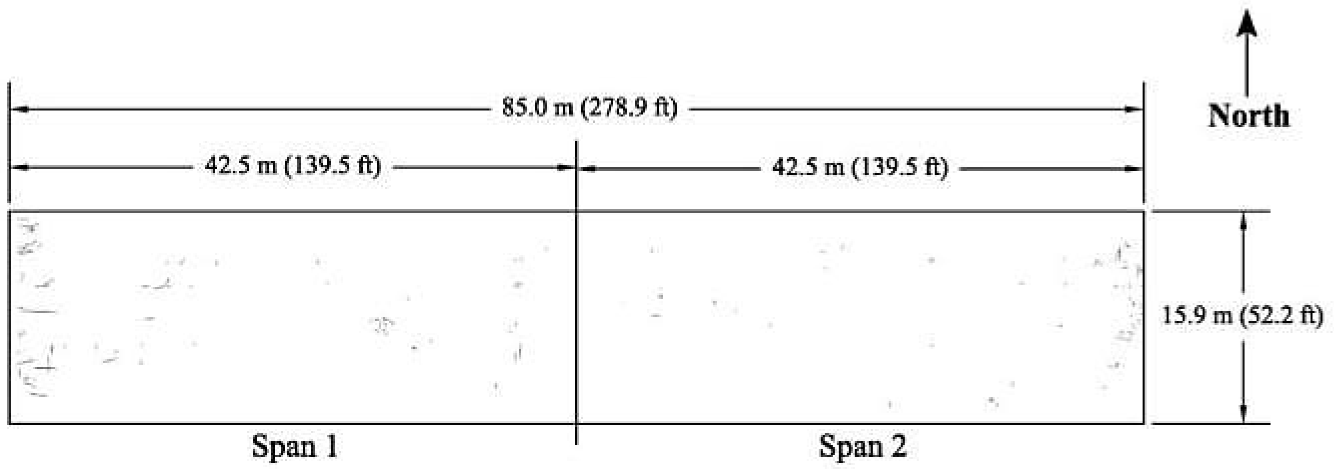


Bridge Number: 43-33 (KU #7)
Bridge Location: Co. Rd. 150 over US-75
Construction Date: 6/24/2006
Crack survey Date: 6/13/2014

Bridge Length: 85.0 m (278.9 ft)
Bridge Width: 15.9 m (52.2 ft)
Skew: 0°
Number of Spans: 2
Span 1 (West): 42.5 m (139.5 ft)
Span 2 (East): 42.5 m (139.5 ft)
Number of Placements: 1

Bridge Age: 95.7 months
Crack density: 0.087 m/m^2
Span 1: 0.106 m/m^2
Span 2: 0.067 m/m^2

Figure 4.31: LC-HPC-7 (Survey 8)

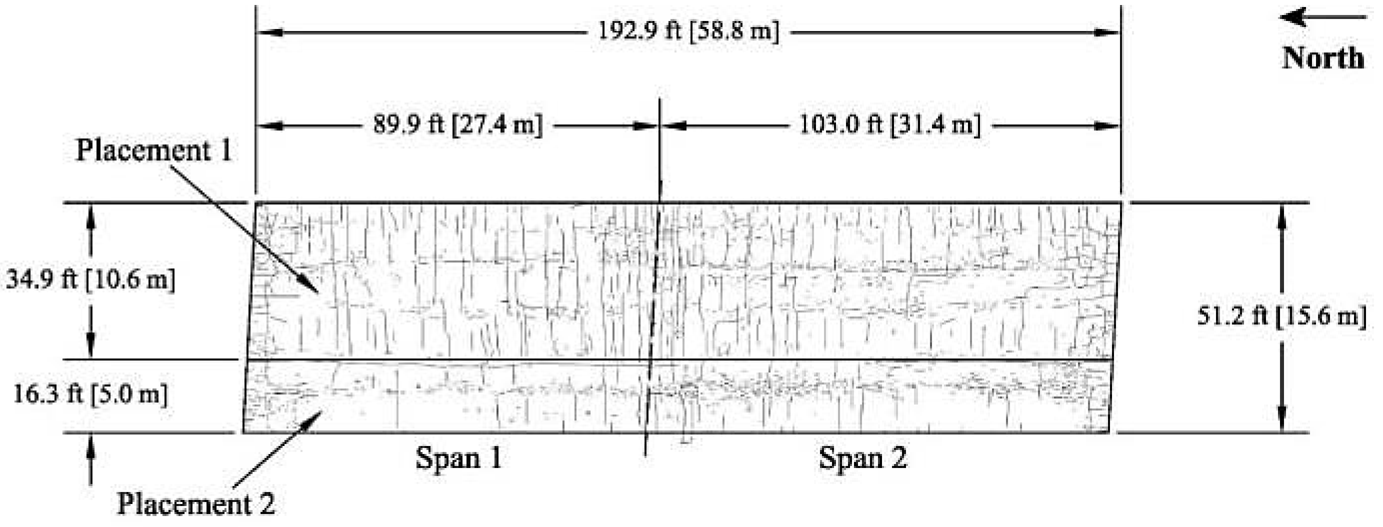


Bridge Number: 43-33 (KU #7)
Bridge Location: Co. Rd. 150 over US-75
Construction Date: 6/24/2006
Crack survey Date: 5/21/2015

Bridge Length: 85.0 m (278.9 ft)
Bridge Width: 15.9 m (52.2 ft)
Skew: 0°
Number of Spans: 2
Span 1 (West): 42.5 m (139.5 ft)
Span 2 (East): 42.5 m (139.5 ft)
Number of Placements: 1

Bridge Age: 106.9 months
Crack density: 0.036 m/m²
Span 1: 0.053 m/m²
Span 2: 0.022 m/m²

Figure 4.32: LC-HPC-7 (Survey 9)



Bridge Number: 46-334(Control #7)
Bridge Location: NB Antioch over I-435
Construction Date:
Placement 1 (East): 3/29/2006
Placement 2 (West): 9/15/2006
Crack survey Date: 6/12/2014

Bridge Length: 58.8 m (192.9 ft)
Bridge Width: 15.6 m (51.2 ft)
Skew: -3.3°
Number of Spans: 2
Span 1 (North): 27.4 m (89.9 ft)
Span 2 (South): 31.4 m (103.0 ft)
Number of Placements: 2

Bridge Age:
Placement 1: 98.5 months
Placement 2: 93 months
Crack density: 1.160 m/m^2
Span 1: 1.068 m/m^2
Span 2: 1.240 m/m^2
Placement 1: 1.165 m/m^2
Placement 2: 1.150 m/m^2

Figure 4.33: Control-7 (Survey 7)

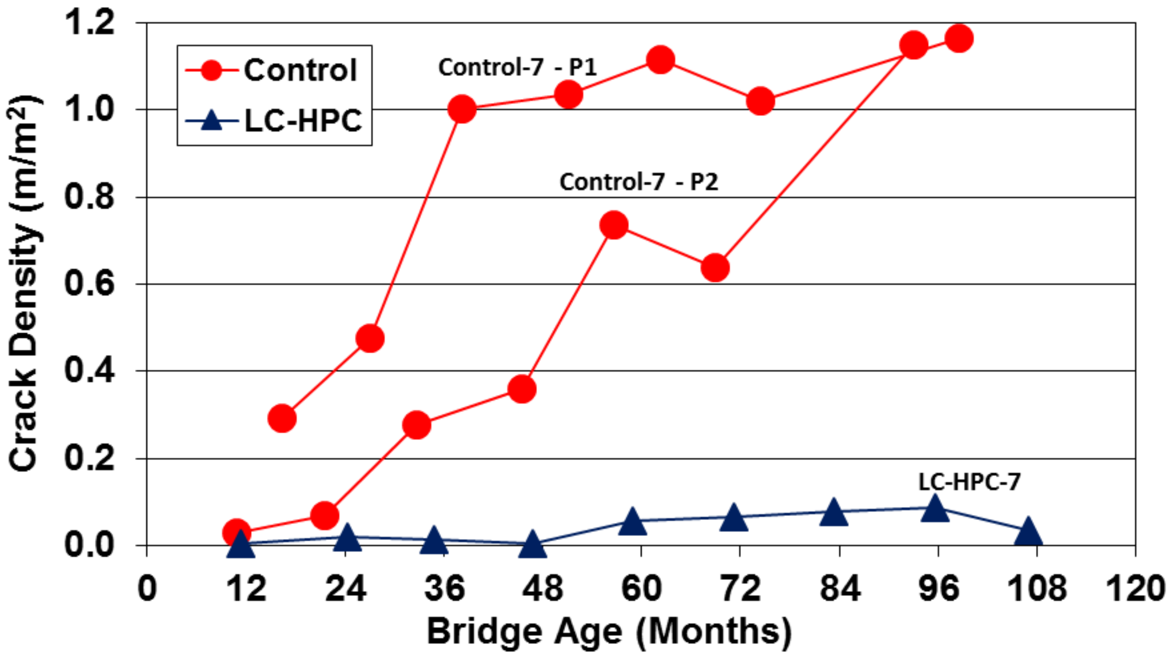
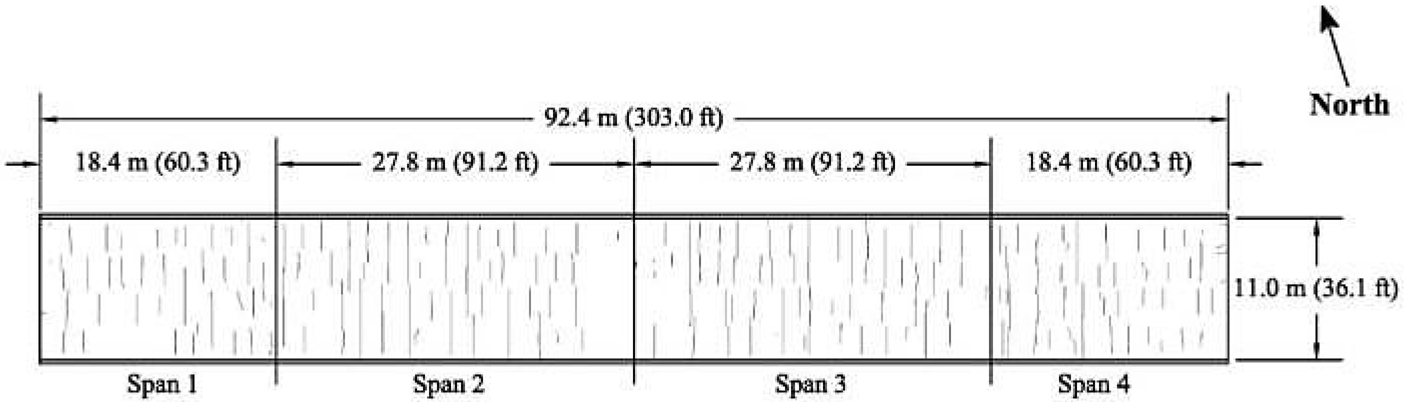


Figure 4.34: LC-HPC-7 and Control-7 Crack Densities versus Deck Age

4.14 LC-HPC-8

Bridge deck LC-HPC-8 is supported by precast-prestressed girders and was constructed on 10/3/2007. LC-HPC-8 has been surveyed seven times, and the results of Surveys 6 and 7 are presented in this report. Survey 6 was completed at a deck age of 81.6 months; the crack map appears in Figure 4.35. Survey 7 was performed at a deck age of 92.0 months; the crack map appears in Figure 4.36. A crack density of 0.425 m/m^2 was observed in Survey 6 (Figure 4.35). In Survey 7, a crack density of 0.462 m/m^2 was observed (Figure 4.36). Both values exceed the crack densities observed in previous surveys. Figure 4.35 and Figure 4.36 show that almost all of the cracks are transverse. Additionally, cracks are minor above the center pier, suggesting that cracking may be a result from increased girder camber. Small longitudinal cracks are present near the abutments.

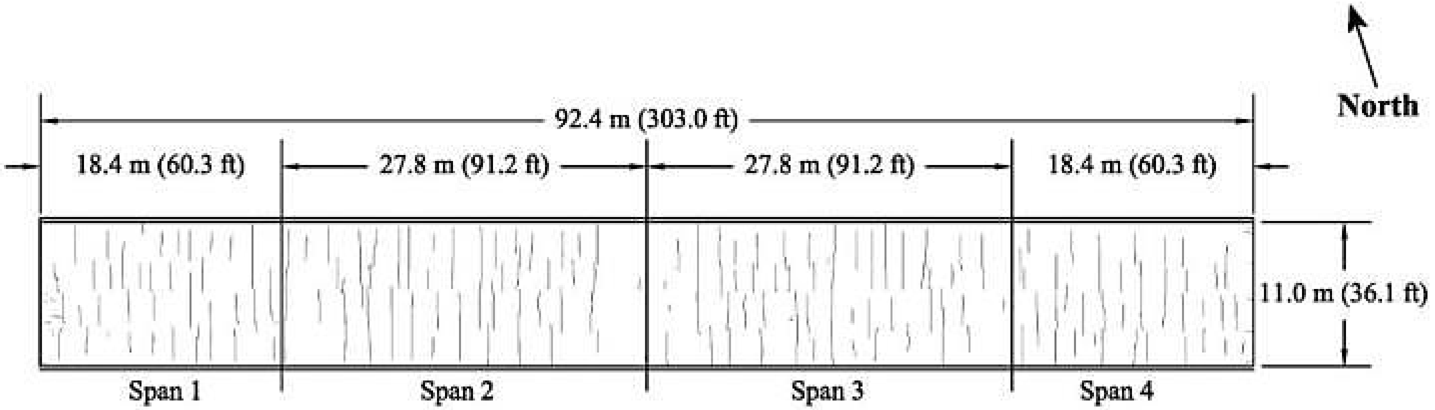


Bridge Number: 54-53 (KU 8)
Bridge Location: E 1350 Rd over US-69
Construction Date: 10/3/2007
Crack survey Date: 7/21/2014

Bridge Length: 92.4 m (303.0 ft)
Bridge Width: 11.0 m (36.1 ft)
Skew: 0°
Number of Spans: 4
Span 1 (West): 18.4 m (60.3 ft)
Span 2 (West): 27.8 m (91.2 ft)
Span 3 (East): 27.8 m (91.2 ft)
Span 4 (East): 18.4 m (60.3 ft)
Number of Placements: 1

Bridge Age: 81.6 months
Crack density: 0.425 m/m²
Span 1 (West): 0.276 m/m²
Span 2 (West): 0.335 m/m²
Span 3 (East): 0.471 m/m²
Span 4 (East): 0.321 m/m²

Figure 4.35: LC-HPC-8 (Survey 6)



Bridge Number: 54-53 (KU 8)
Bridge Location: E 1350 Rd over US-69
Construction Date: 10/3/2007
Crack survey Date: 6/10/2015

Bridge Length: 92.4 m (303.0 ft)
Bridge Width: 11.0 m (36.1 ft)
Skew: 0°
Number of Spans: 4
- **Span 1 (West):** 18.4 m (60.3 ft)
- **Span 2 (West):** 27.8 m (91.2 ft)
- **Span 3 (East):** 27.8 m (91.2 ft)
- **Span 4 (East):** 18.4 m (60.3 ft)

Number of Placements: 1

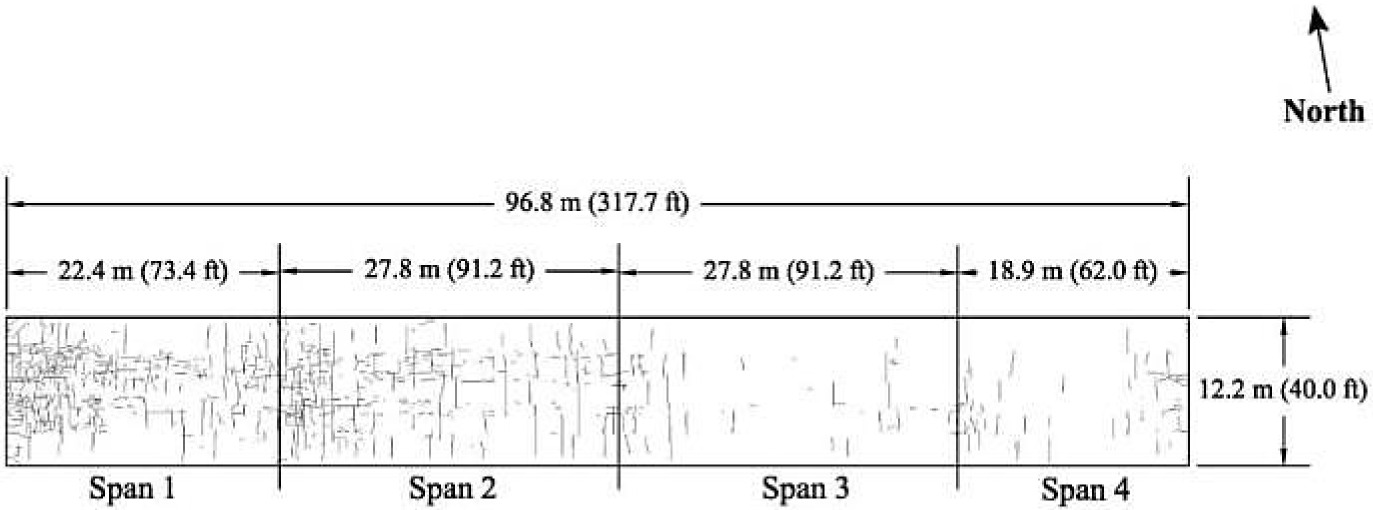
Bridge Age: 92 months
Crack density: 0.462 m/m²
- **Span 1 (West):** 0.496 m/m²
- **Span 2 (West):** 0.442 m/m²
- **Span 3 (East):** 0.456 m/m²
- **Span 4 (East):** 0.473 m/m²

Figure 4.36: LC-HPC-8 (Survey 7)

4.15 Control-8/10

Bridge deck Control-8/10 serves as the control for both LC-HPC-8 and LC-HPC-10. It is a monolithic deck supported by precast-prestressed girders. Control-8/10 was constructed on 4/16/2007 and has been surveyed eight times. This report includes the results for Surveys 7 and 8. Survey 7 was completed at a deck age of 87.2 months; the crack map is shown in Figure 4.37. Survey 8 was completed at a deck age of 98.1 months; the crack map is shown in Figure 4.38. A crack density of 0.566 m/m^2 was observed in Survey 7 (Figure 4.37). Survey 7 shows a crack density similar to that recorded in Survey 6 by Bohaty et al. (2013), which was 0.581 m/m^2. In Survey 8, a crack density of 0.680 m/m^2 was observed (Figure 4.38). Span 1 of the bridge has a higher crack density than the other spans, with a significant portion of these cracks due to map cracking. Also, there are moderately-sized transverse cracks distributed over the whole area of the bridge, but there are fewer in Spans 3 and 4 than in Spans 1 and 2.

Figure 4.39 compares the crack densities for LC-HPC-8 and Control-8/10 over time. LC-HPC-8 showed higher cracking than Control-8/10 during the early ages of the deck, but has exhibited lower densities since the third survey.



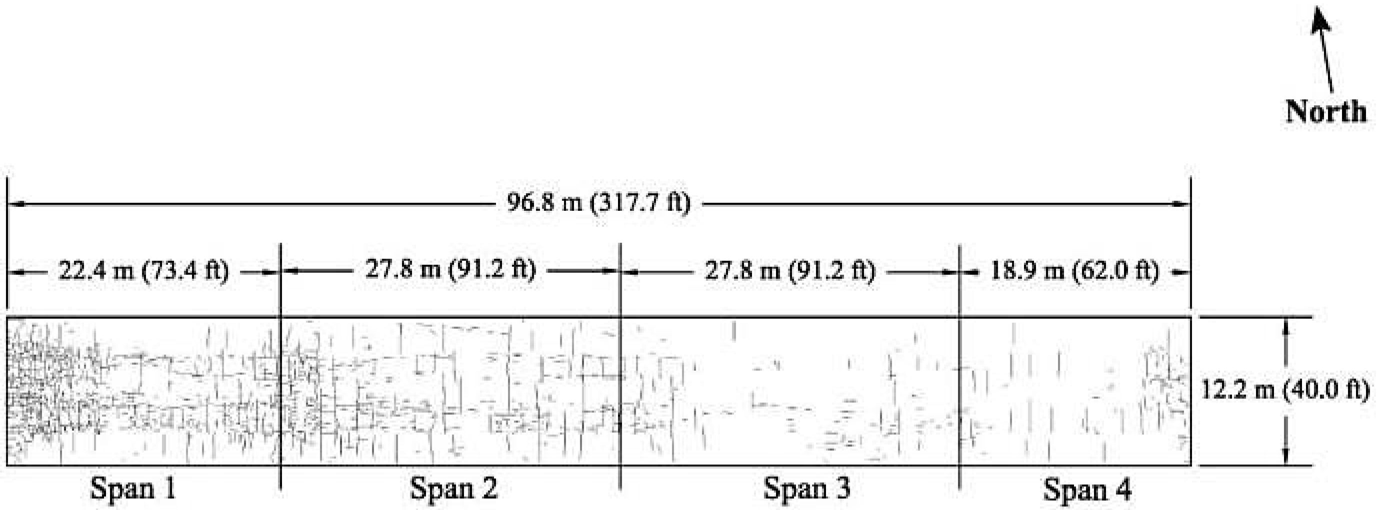
Bridge Number: 54-59 (KU #8-#10 Control)
Bridge Location: K-52 over US-69
Construction Date: 4/16/2007
Crack survey Date: 7/23/2014

Bridge Length: 96.8 m (317.7 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: 0°
Number of Spans: 4
- **Span 1:** 22.4 m (73.4 ft)
- **Span 2:** 27.8 m (91.2 ft)
- **Span 3:** 27.8 m (91.2 ft)
- **Span 4:** 18.9 m (62.0 ft)

Number of Placements: 1

Bridge Age: 87.2 months
Crack density: 0.566 m/m²
- **Span 1:** 1.121 m/m²
- **Span 2:** 0.734 m/m²
- **Span 3:** 0.173 m/m²
- **Span 4:** 0.247 m/m²

Figure 4.37: Control-8/10 (Survey 7)



Bridge Number: 54-59 (KU #8-#10 Control)
Bridge Location: K-52 over US-69
Construction Date: 4/16/2007
Crack survey Date: 6/19/2015

Bridge Length: 96.8 m (317.7 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: 0°
Number of Spans: 4
  Span 1: 22.4 m (73.4 ft)
  Span 2: 27.8 m (91.2 ft)
  Span 3: 27.8 m (91.2 ft)
  Span 4: 18.9 m (62.0 ft)
Number of Placements: 1

Bridge Age: 98.1 months
Crack density: 0.680 m/m²
  Span 1: 1.465 m/m²
  Span 2: 0.788 m/m²
  Span 3: 0.239 m/m²
  Span 4: 0.327 m/m²

Figure 4.38: Control-8/10 (Survey 8)

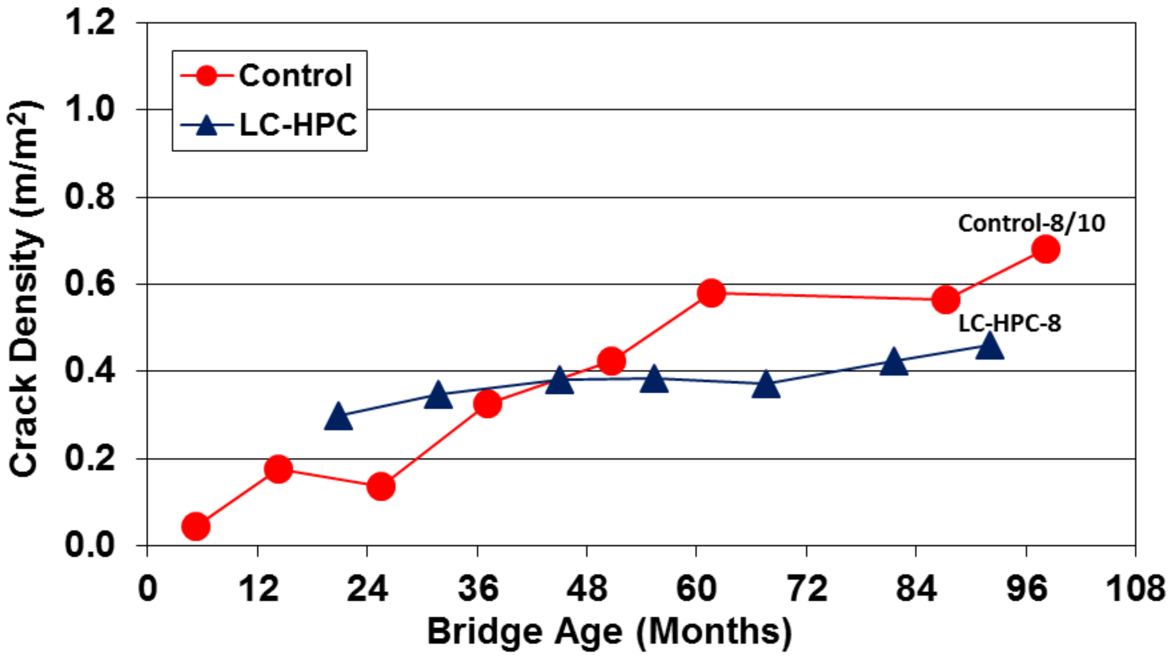
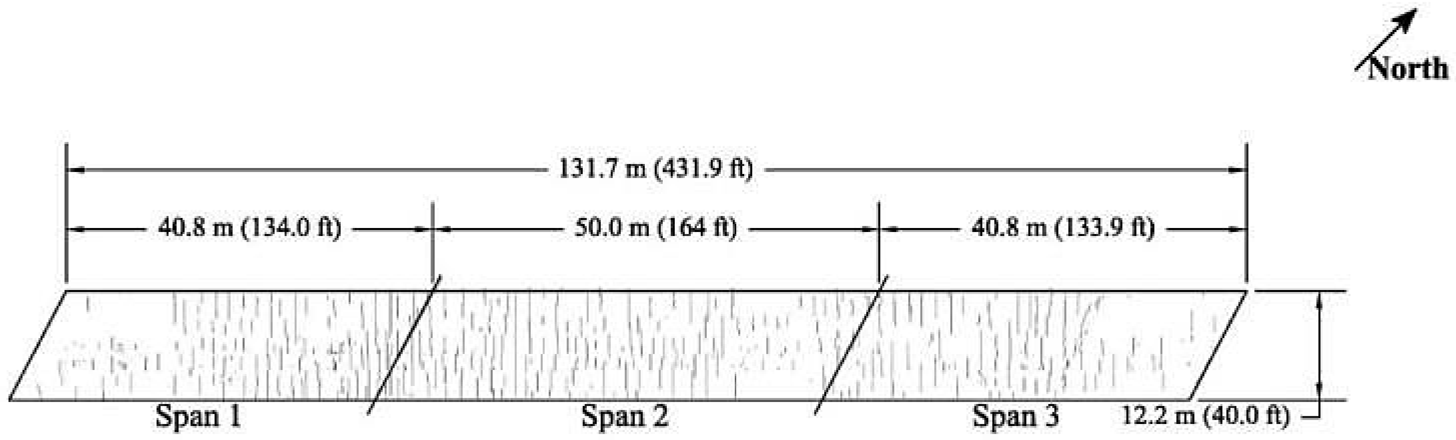


Figure 4.39: LC-HPC-8 and Control-8/10 Crack Densities versus Deck Age

4.16 LC-HPC-9

Bridge deck LC-HPC-9 was constructed on 4/15/2009 and has been surveyed six times. This report includes the results of Surveys 5 and 6. Survey 5 was performed at a deck age of 62.0 months; the crack map is shown in Figure 4.40. Survey 6 was performed at a deck age of 73.6 months; the crack map is shown in Figure 4.41. In Survey 5, a crack density of 0.454 m/m^2 was observed (Figure 4.40). This value is significantly greater than that reported for Survey 4 by Bohaty et al. (2013), 0.299 m/m^2. A crack density of 0.430 m/m^2 was observed in Survey 6 (Figure 4.41), slightly lower than Survey 5. The cracks are uniformly distributed over much of the deck with the exception of the end spans, which exhibit a lower crack density.

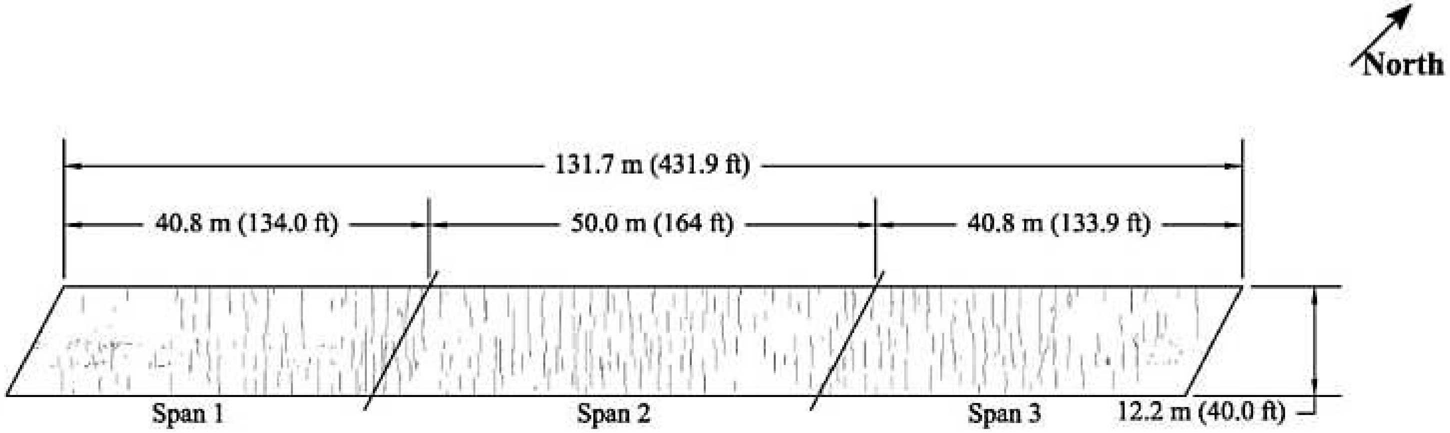


Bridge Number: 54-57 (KU 9)
Bridge Location: NB US-69 over
Marair Des Cygnes Rv
Construction Date: 4/15/2009
Crack survey Date: 8/6/2014

Bridge Length: 131.7 m (431.9 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -27.7°
Number of Spans: 3
Span 1 (South): 40.8 m (134.0 ft)
Span 2 (Middle): 50.0 m (164.0 ft)
Span 3 (North): 40.8 m (133.9 ft)
Number of Placements: 1

Bridge Age: 62 months
Crack density: 0.454 m/m^2
Span 1 (South): 0.453 m/m^2
Span 2 (Middle): 0.503 m/m^2
Span 3 (North): 0.401 m/m^2

Figure 4.40: LC-HPC-9 (Survey 5)



Bridge Number: 54-57 (KU 9)
Bridge Location: NB US-69 over Marair Des Cygnes Rv
Construction Date: 4/15/2009
Crack survey Date: 6/2/2015

Bridge Length: 131.7 m (431.9 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -27.7°
Number of Spans: 3
Span 1 (South): 40.8 m (134.0 ft)
Span 2 (Middle): 50.0 m (164.0 ft)
Span 3 (North): 40.8 m (133.9 ft)
Number of Placements: 1

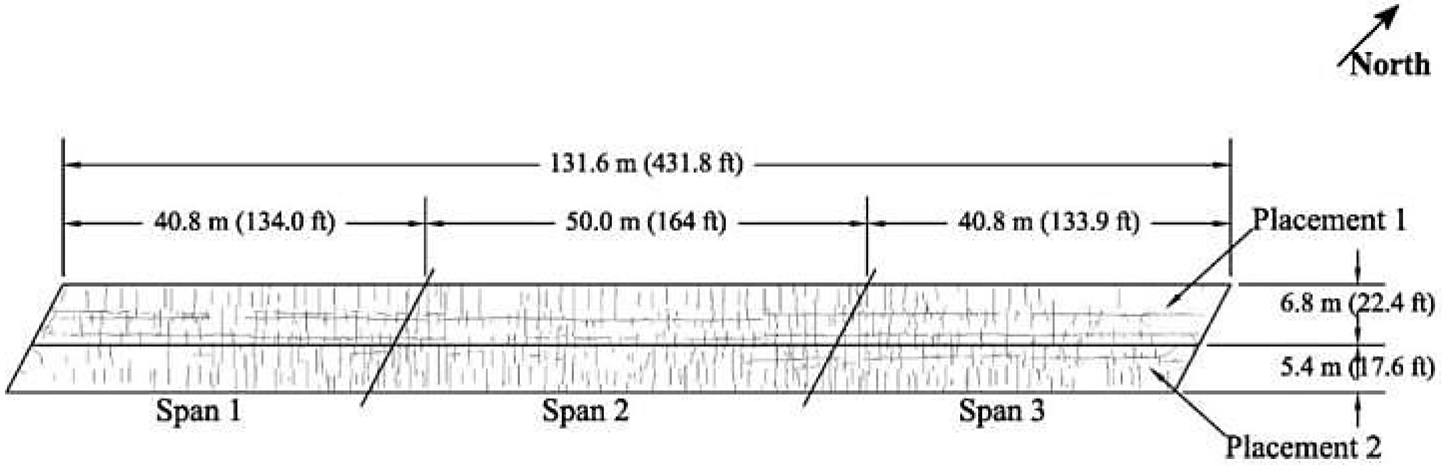
Bridge Age: 73.6 months
Crack density: 0.430 m/m²
Span 1 (South): 0.386 m/m²
Span 2 (Middle): 0.485 m/m²
Span 3 (North): 0.431 m/m²

Figure 4.41: LC-HPC-9 (Survey 6)

4.17 Control-9

Bridge deck Control-9 was constructed in two placements. Placement 1 was constructed on 5/21/2008 and Placement 2 was constructed on 5/29/2008. Control-9 deck has been surveyed six times. The results of Surveys 5 and 6 are included in this report. Survey 5 was completed at deck 74.1 and 73.8 months; the crack map is shown in Figure 4.42. Survey 6 was performed at deck age of 84.4 and 84.1 months; the crack map is shown in Figure 4.43. In Survey 5, crack densities of 0.732 and 0.755 m/m^2 were observed for Placements 1 and 2, respectively. Both of these values are higher than Survey 4, which recorded crack densities of 0.561 and 0.635 m/m^2 for Placements 1 and 2, respectively (Bohaty et al., 2013). In Survey 6, crack densities of 0.722 and 0.845 m/m^2 were observed for Placements 1 and 2, respectively. For Survey 6, Placement 1 exhibited a slight decrease in crack density compared to Survey 5, while the crack density for Placement 2 increased compared to the previous survey. As shown in Figure 4.42 and Figure 4.43, the majority of the cracks are transverse, parallel to the top layer of reinforcement. In Placement 1, there are two longitudinal cracks that run almost over the entire length of the deck. In Placement 2 some relatively short cracks run longitudinally. Some cracks are present near the abutments, where they have propagated longitudinally.

Figure 4.44 compares the crack densities for LC-HPC-9 and Control-9 over time. LC-HPC-9 has a significantly lower crack density than either placement of Control-9.



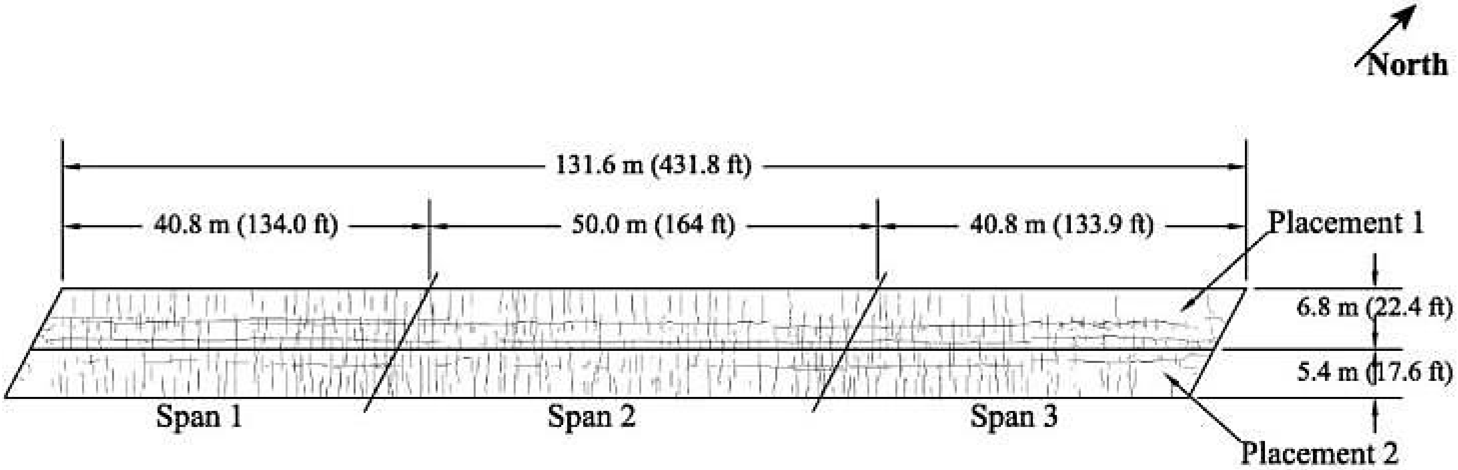
Bridge Number: 54-58 (Control #9)
Bridge Location: NB US-69 over Marair Des Cygnes Rv
Construction Date:
Placement 1 (West)**:** 5/21/2008
Placement 2 (East): 5/29/2008

Crack survey Date: 7/24/2014

Bridge Length: 131.6 m (431.8 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -27.2°
Number of Spans: 3
Span 1 (South): 40.8 m (134.0 ft)
Span 2 (Middle): 50.0 m (164.0 ft)
Span 3 (North): 40.8 m (133.8 ft)
Number of Placements: 2
Placement1(West): 6.8 m (22.4 ft)
Placement2 (East): 5.4 m (17.6 ft)

Bridge Age:
Placement 1: 74.1 months
Placement 2: 73.8 months
Crack density: 0.733 m/m²
Placement 1: 0.732 m/m²
Placement 2: 0.755 m/m²
Span 1 (South): 0.707 m/m²
Span 2 (Middle): 0.769 m/m²
Span 3 (North): 0.715 m/m²

Figure 4.42: Control-9 (Survey 5)



Bridge Number: 54-58 (Control #9)
Bridge Location: NB US-69 over
Marair Des Cygnes Rv
Construction Date:
Placement 1 (West): 5/21/2008
Placement 2 (East): 5/29/2008

Crack survey Date: 6/1/2015

Bridge Length: 131.6 m (431.8 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -27.2°
Number of Spans: 3
Span 1 (South): 40.8 m (134.0 ft)
Span 2 (Middle): 50.0 m (164.0 ft)
Span 3 (North): 40.8 m (133.8 ft)
Number of Placements: 2
Placement1(West): 6.8 m (22.4 ft)
Placement2 (East): 5.4 m (17.6 ft)

Bridge Age:
Placement 1: 84.4 months
Placement 2: 84.1 months
Crack density: 0.779 m/m²
Placement 1: 0.722 m/m²
Placement 2: 0.845 m/m²
Span 1 (South): 0.840 m/m²
Span 2 (Middle): 0.819 m/m²
Span 3 (North): 0.728 m/m²

Figure 4.43: Control-9 (Survey 6)

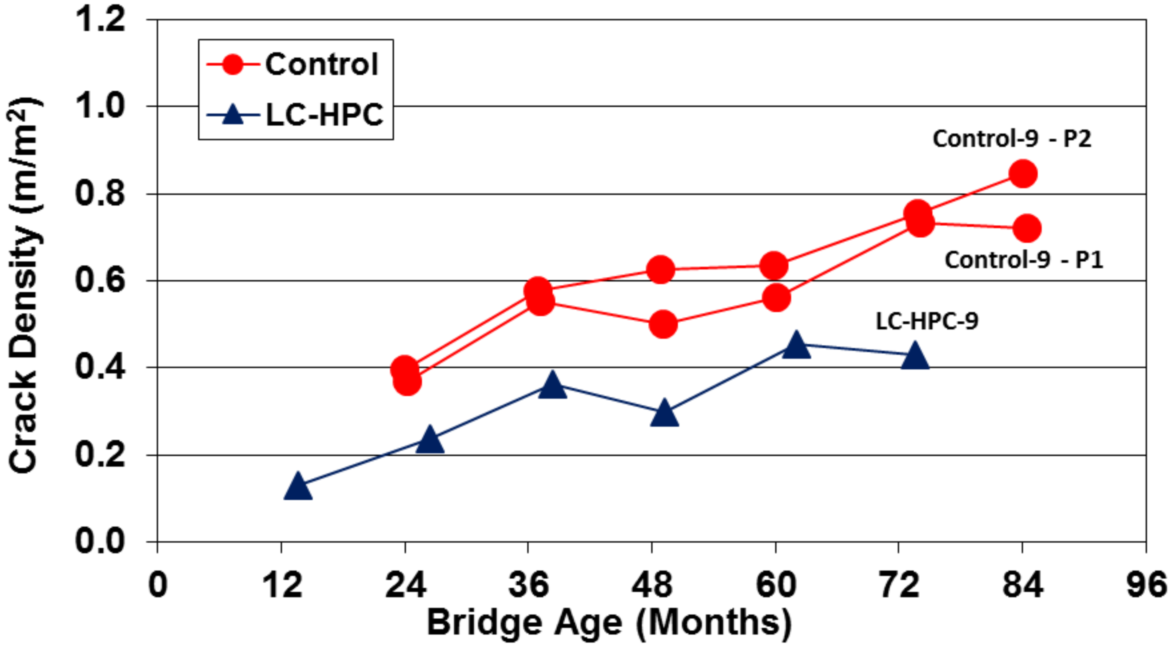
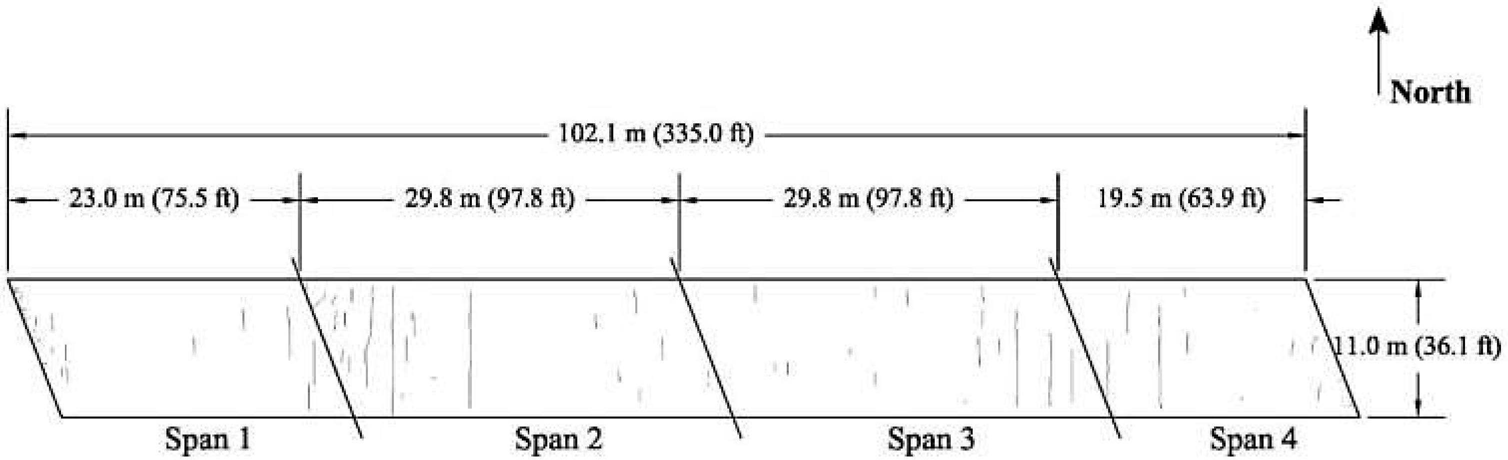


Figure 4.44: LC-HPC-9 and Control-9 Crack Densities versus Deck Age

4.18 LC-HPC-10

Bridge deck LC-HPC-10 is supported by precast-prestressed girders and was constructed on 05/17/2007. LC-HPC-10 deck has been surveyed eight times. The results of Surveys 7 and 8 of LC-HPC-10 are included in this report. Survey 7 was performed at a deck age of 86.2 months; the crack map is displayed in Figure 4.45. Survey 8 was performed at a deck age of 96.8 months; the crack map is displayed in Figure 4.46. A crack density of 0.117 m/m^2 was observed in Survey 7 (Figure 4.45). The crack density for the survey completed in 2013, 0.125 m/m^2, as reported by Bohaty et al. (2013), is higher than recorded in Survey 7. In Survey 8, a crack density of 0.125 m/m^2 was observed (Figure 4.46). The first survey of this deck, exhibiting a higher crack density when compared to Control-8/10, was considered as an outlier in previous reports. However, the crack density dropped for the next two surveys, perhaps because of force transferred to the deck from the precast-prestressed girders. Therefore, it cannot be considered as an outlier and must be included in the study to provide a full understanding of the deck behavior. Most of the cracks that are present on LC-HPC-10 are transverse.

Figure 4.47 compares the crack densities of LC-HPC-10 and Control-8/10 over time. With the exception of the first survey, LC-HPC-10 has exhibited less cracking than Control-8/10.

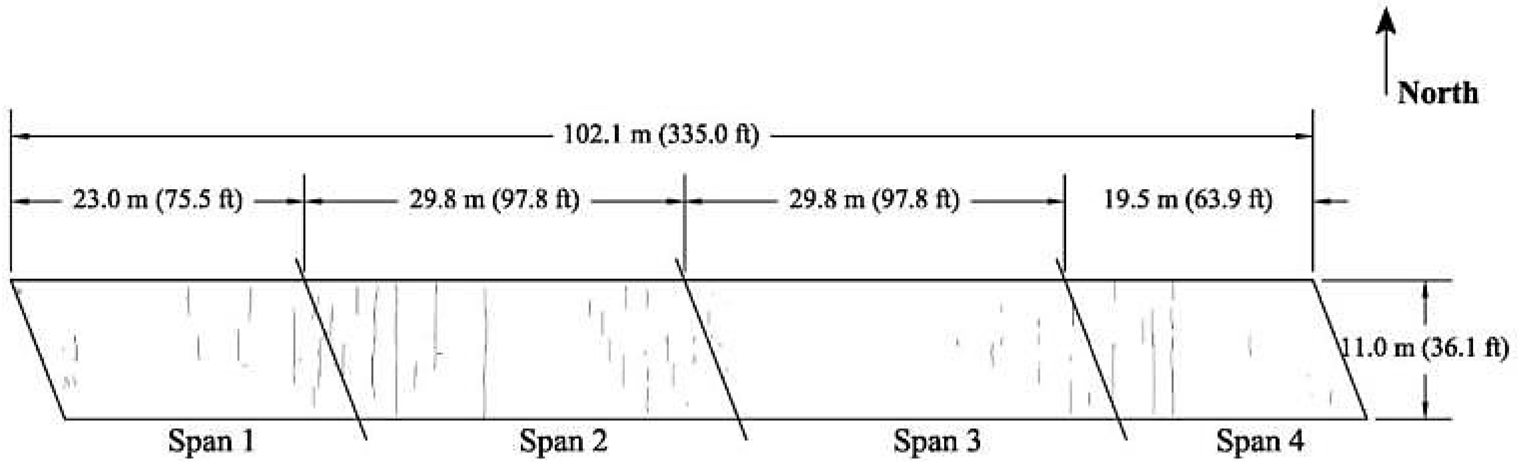


Bridge Number: 54-60 (KU 10)
Bridge Location: E1800Rd over US-69
Construction Date: 5/17/2007
Crack survey Date: 7/22/2014

Bridge Length: 102.1 m (335.0 ft)
Bridge Width: 11.0 m (36.1 ft)
Skew: 21.3°
Number of Spans: 4
  Span 1 (West): 23.0 m (75.5 ft)
  Span 2 (West): 29.8 m (97.8 ft)
  Span 3 (East): 29.8 m (97.8 ft)
  Span 4 (East) : 19.5 m (63.9 ft)
Number of Placements: 1

Bridge Age: 86.2 months
Crack density: 0.117 m/m^2
  Span 1 (West): 0.105 m/m^2
  Span 2 (West): 0.153 m/m^2
  Span 3 (East): 0.095 m/m^2
  Span 4 (East): 0.109 m/m^2

Figure 4.45: LC-HPC-10 (Survey 7)



Bridge Number: 54-60 (KU 10)
Bridge Location: E1800Rd over US-69
Construction Date: 5/17/2007
Crack survey Date: 6/11/2015

Bridge Length: 102.1 m (335.0 ft)
Bridge Width: 11.0 m (36.1 ft)
Skew: 21.3°
Number of Spans: 4
  Span 1 (West): 23.0 m (75.5 ft)
  Span 2 (West): 29.8 m (97.8 ft)
  Span 3 (East): 29.8 m (97.8 ft)
  Span 4 (East) : 19.5 m (63.9 ft)
Number of Placements: 1

Bridge Age: 96.8 months
Crack density: 0.125 m/m^2
  Span 1 (West): 0.119 m/m^2
  Span 2 (West): 0.205 m/m^2
  Span 3 (East): 0.042 m/m^2
  Span 4 (East): 0.138 m/m^2

Figure 4.46: LC-HPC-10 (Survey 8)

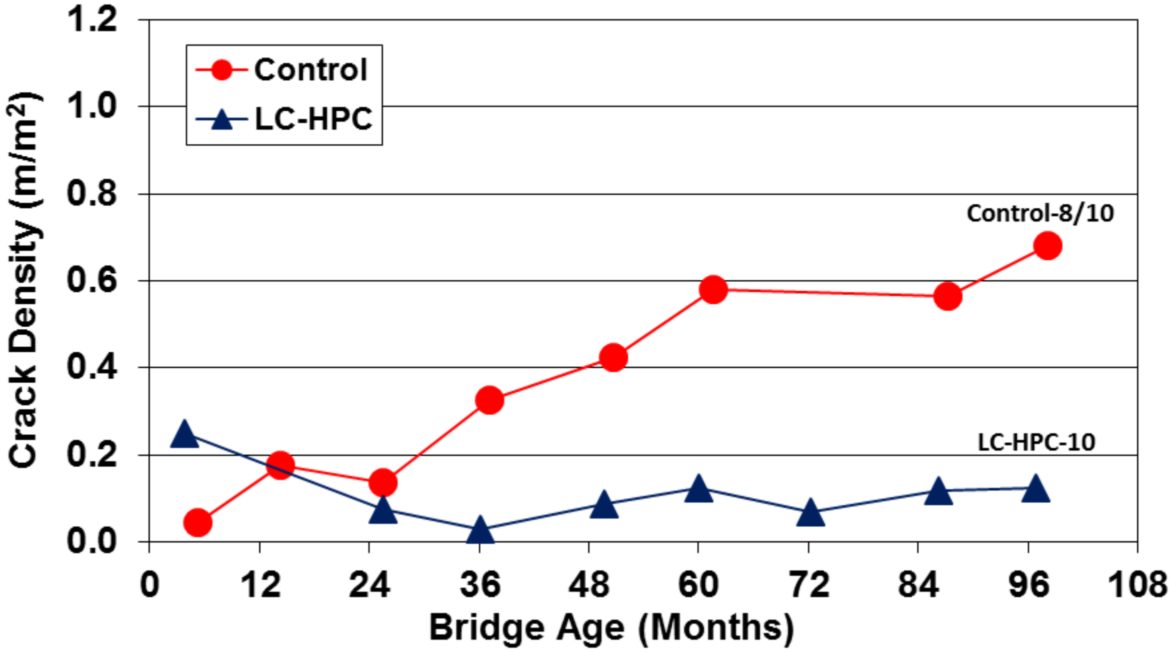


Figure 4.47: LC-HPC-10 and Control-8/10 Crack Densities versus Deck Age

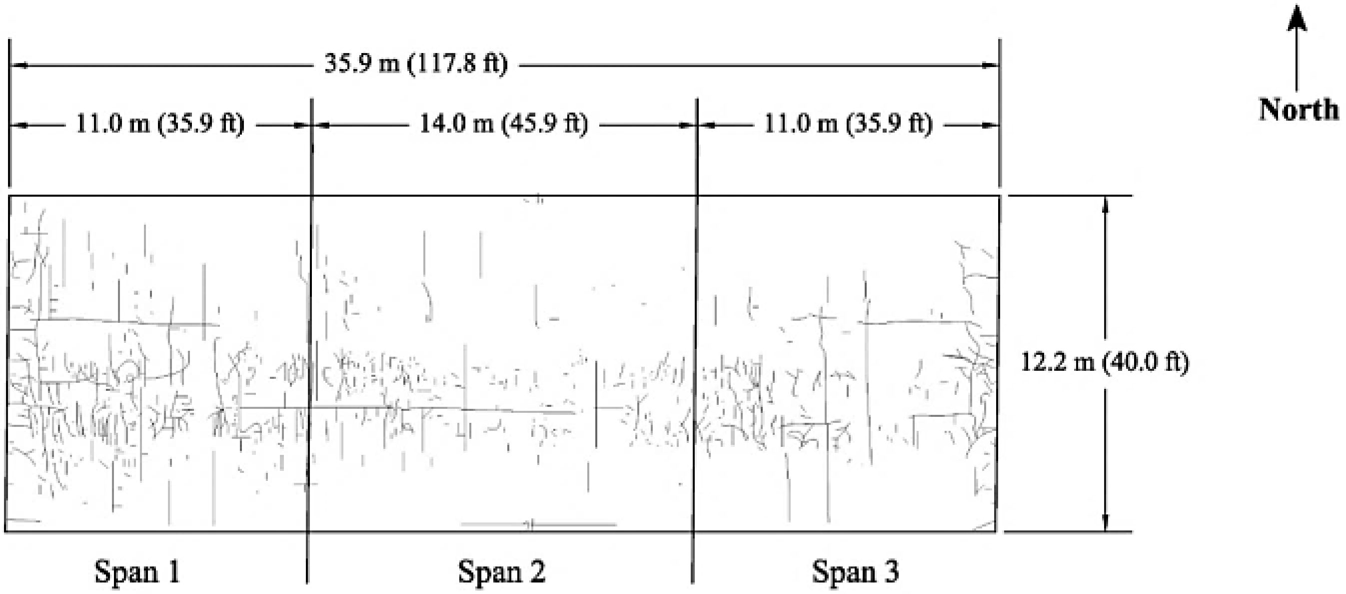
4.19 LC-HPC-11

Bridge deck LC-HPC-11 was constructed on 6/9/2007 and has been surveyed seven times. This report includes the results of Surveys 6 and 7. Survey 6 was completed at a deck age of 84.8 months; the crack map for this survey is shown in Figure 4.48. Survey 7 was completed at a deck age of 110.7 months; the crack map for this survey is shown in Figure 4.49. The results indicate that about 70% of the total length of cracks on this deck are located in the south lane of this deck—a phenomenon that has not been observed on any other LC-HPC deck (where cracks are distributed evenly on both lanes). The majority of the cracks in the south lane are located directly above and on either side of the girder that is centered on the driving lane. Figure 4.50 shows the crack density calculated separately for the south and north lanes of the deck. As shown in the Figure 4.50, the north side of the deck exhibits cracking behavior similar to the majority of LC-HPC bridges, while the south side of the deck exhibits significantly higher cracking, particularly after 60 months. The south lane also exhibits significant discoloration not observed on the north lane (Figure 4.51). It is likely that this unusual crack distribution and discoloration is due to heavy truck traffic in the south (right) lane, as LC-HPC-11 is located close to an area with four major salt mines. As a result, only the north lane is considered representative of an LC-HPC deck.

4.20 Control-11

Bridge deck Control-11 was constructed on 3/28/2006 and has been surveyed nine times. The results of Surveys 8 and 9 are included in this report. Survey 8 was completed at a deck age of 98.0 months; the crack map is shown in Figure 4.52. Survey 9 was completed at a deck age of 124.9 months; the crack map is shown in Figure 4.53. In Survey 8, a crack density of 0.922 m/m^2 was observed. In Survey 9, a crack density of 1.16 m/m^2 was observed. In both Surveys 8 and 9, the crack densities are considerably higher than the recorded values during Survey 7, 0.657 m/m^2 (Bohaty et al., 2013). Most of the cracks are transverse and spaced uniformly. A longitudinal crack runs the full length of the deck. Cracks have propagated perpendicular to the abutments.

Figure 4.54 compares crack densities for LC-HPC-11 and Control-11 over time. Although both bridge decks show high crack densities, LC-HPC-11 has consistently exhibited lower crack densities.

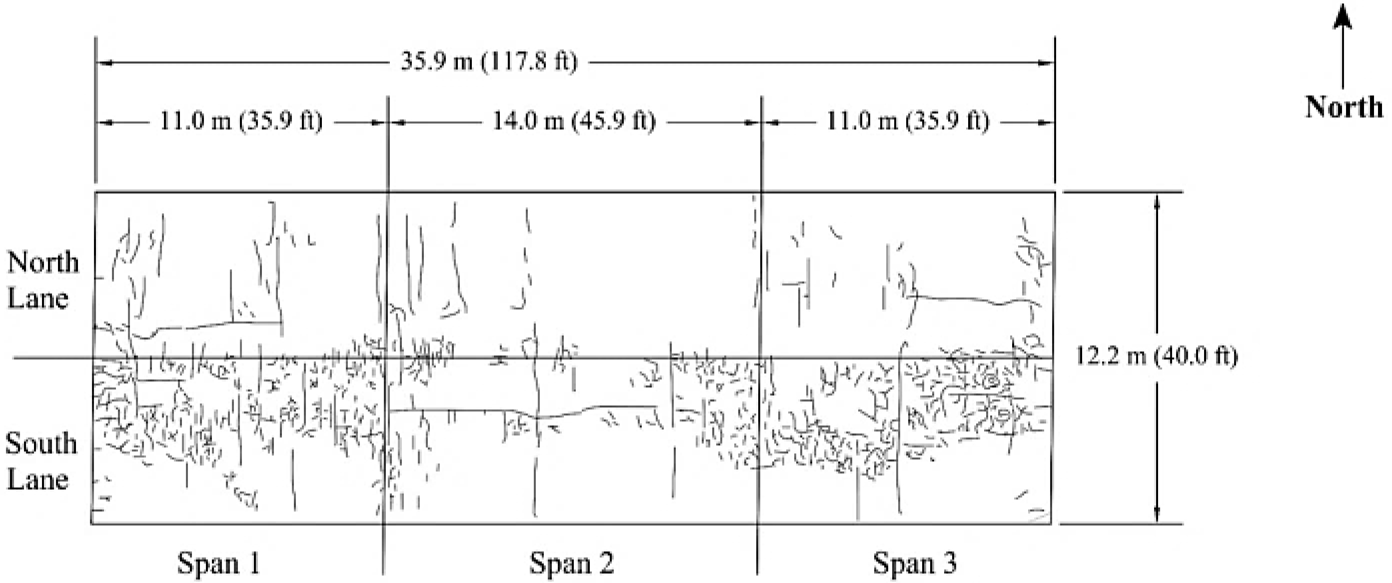


Bridge Number: 78-119 (KU #11)
Bridge Location: EB US-50 over
K &ORR, Hutchinson, KS
Construction Date: 6/9/2007
Crack Survey Date: 7/3/2014

Bridge Length: 35.9 m (117.8 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -0.7°
Number of Spans: 3
Span 1: 11.0 m (35.9 ft)
Span 2: 14.0 m (45.9 ft)
Span 3: 11.0 m (35.9 ft)
Number of Placements: 1

Bridge Age: 84.8 months
Crack Density: 0.842 m/m^2
Span 1: 1.305 m/m^2
Span 2: 0.511 m/m^2
Span 3: 0.803 m/m^2

Figure 4.48: LC-HPC-11 (Survey 6)



Bridge Number: 78-119 (KU #11)
Bridge Location: EB US-50 over
K &ORR, Hutchinson, KS
Construction Date: 6/9/2007
Crack Survey Date:7/3/2014

Bridge Length: 35.9 m (117.8 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -0.7°
Number of Spans: 3
Span 1: 11.0 m (35.9 ft)
Span 2: 14.0 m (45.9 ft)
Span 3: 11.0 m (35.9 ft)
Number of Placements: 1

Bridge Age: 110.7 months
Crack Density: 0.883 m/m^2
Span 1: 1.11 m/m ^{2}
Span 2: 0.610 m/m^2
Span 3: 1.01 m/m ^{2}

Figure 4.49: LC-HPC-11 (Survey 7)

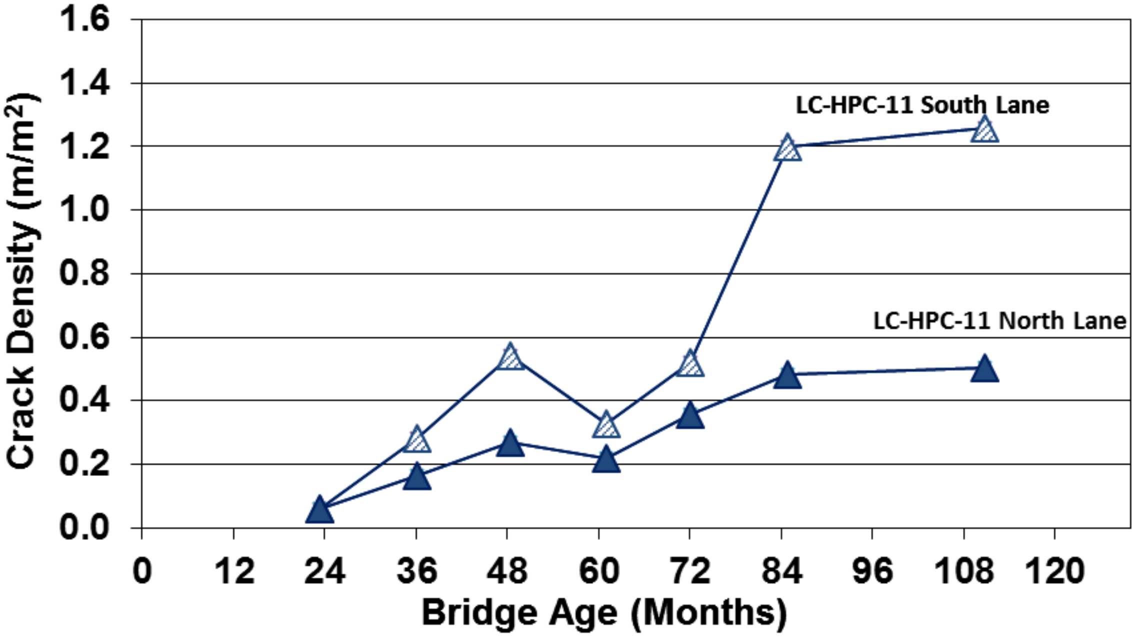
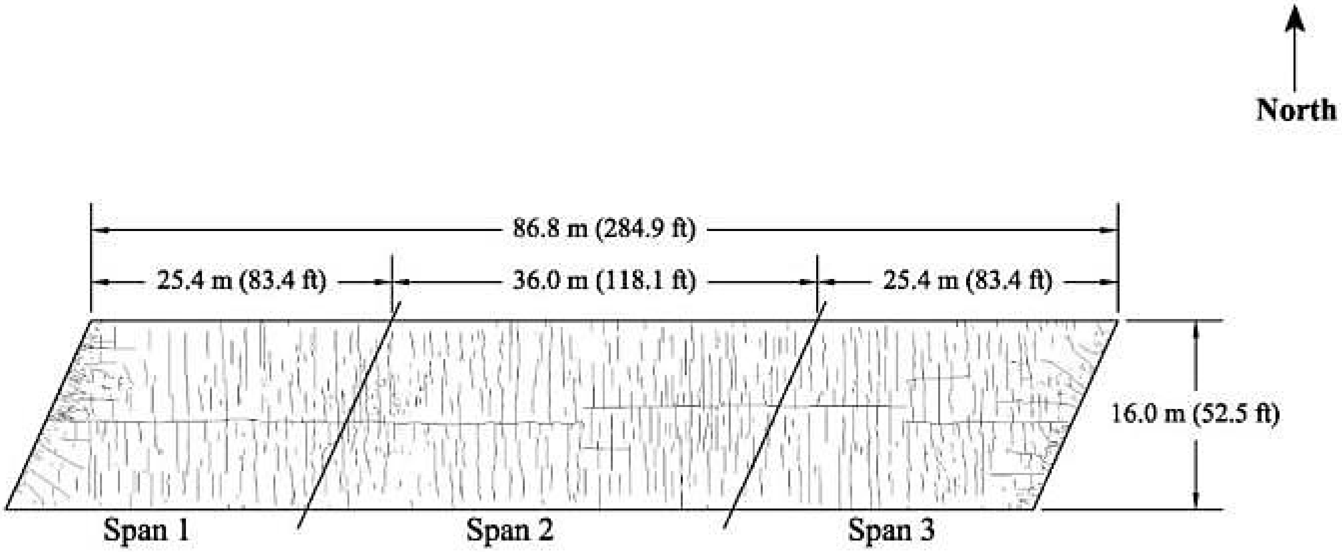


Figure 4.50: LC-HPC 11 Lane-Separated Crack Densities versus Deck Age

Figure 4.51: Short Map Cracks and Discolored Surface on South Lane

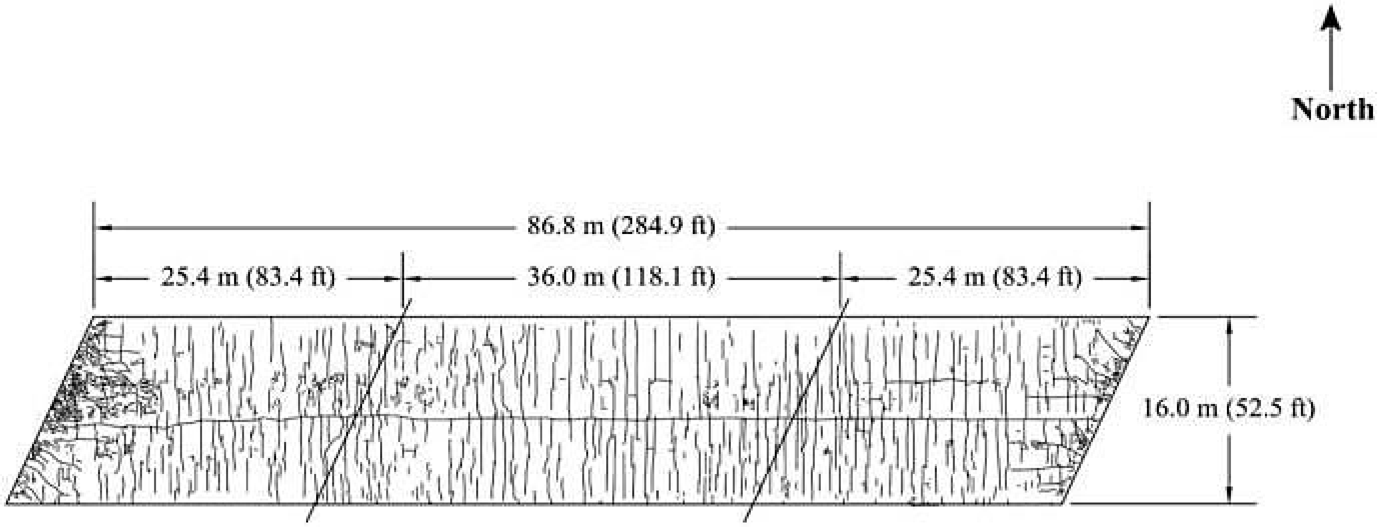


Bridge Number: 56-155 (KU #11 Control)
Bridge Location: US-50 over BNSF Railroad, Emporia, KS
Construction Date: 3/28/2006
Crack Survey Date: 5/27/2014

Bridge Length: 86.8 m (284.9 ft)
Bridge Width: 16.0 m (52.5 ft)
Skew: -24.3°
Number of Spans: 3
  Span 1: 25.4 m (83.4 ft)
  Span 2: 36.0 m (118.1 ft)
  Span 3: 25.4 m (83.4 ft)
Number of Placements: 1

Bridge Age: 98 months
Crack Density: 0.680 m/m^2
  Span 1: 0.494 m/m^2
  Span 2: 0.659 m/m^2
  Span 3: 0.681 m/m^2

Figure 4.52: Control-11 (Survey 8)



Bridge Number: 56-155 (KU #11 Control)
Bridge Location: US-50 over BNSF Railroad, Emporia, KS
Construction Date: 3/28/2006
Crack Survey Date: 6/29/2016

Bridge Length: 86.8 m (284.9 ft)
Bridge Width: 16.0 m (52.5 ft)
Skew: 24.3°
Number of Spans: 3
- **Span 1:** 25.4 m (83.4 ft)
- **Span 2:** 36.0 m (118.1 ft)
- **Span 3:** 25.4 m (83.4 ft)

Number of Placements: 1

Bridge Age: 124.9 months
Crack Density: 1.160 m/m²
- **Span 1:** 1.40 m/m²
- **Span 2:** 0.951 m/m²
- **Span 3:** 1.217 m/m²

Figure 4.53: Control-11 (Survey 9)

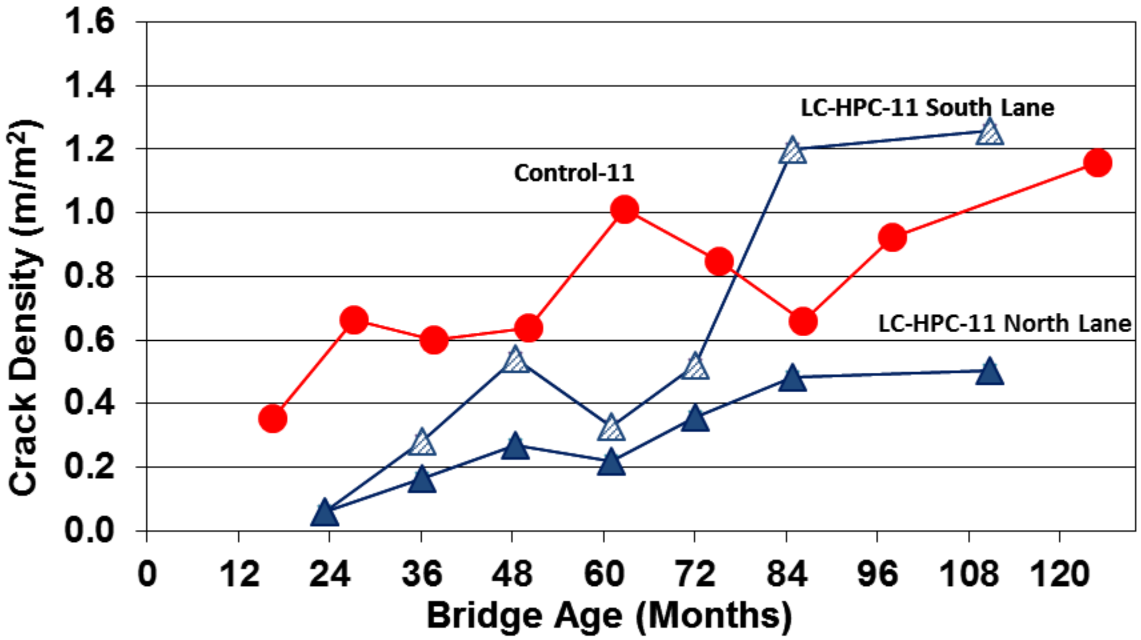


Figure 4.54: LC-HPC-11 and Control-11 Crack Densities versus Deck Age

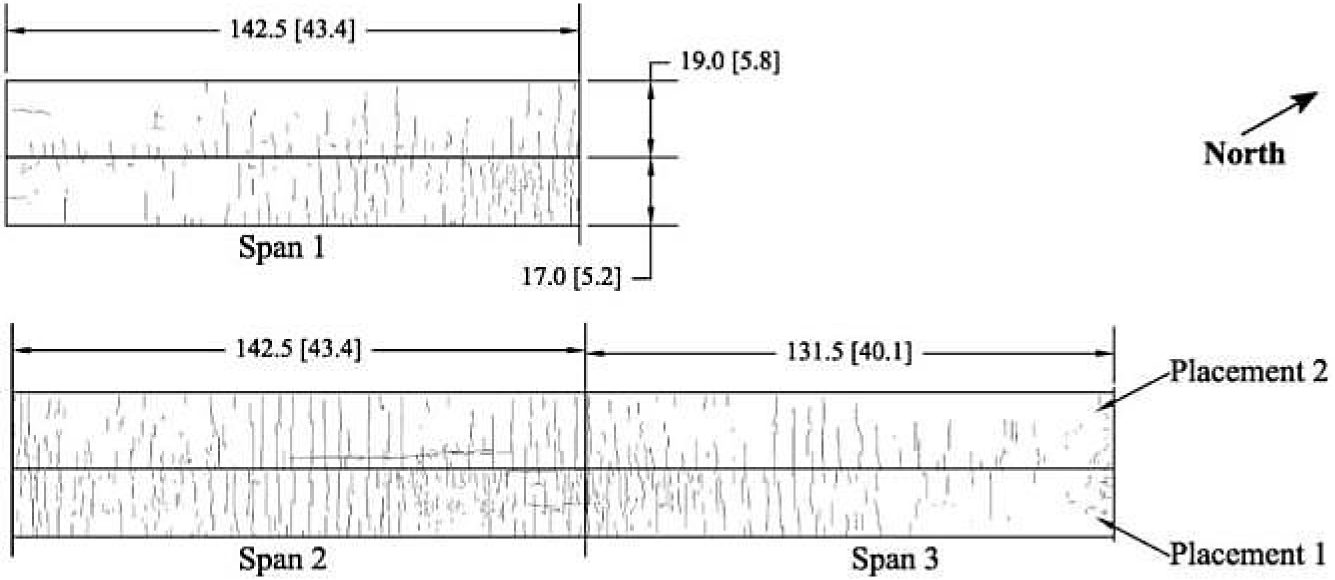
4.21 LC-HPC-12

Bridge deck LC-HPC-12 was constructed in two placements; Placement 1 was constructed on 4/4/2008, and Placement 2 was constructed on 3/18/2009. Six surveys have been performed on this bridge deck. The results of Survey 6 of LC-HPC-12 are included in this report. Survey 6 was completed at deck ages of 76.3 and 64.9 months for Placements 1 and 2, respectively; the crack map is displayed in Figure 4.55. In Survey 6, crack densities of 0.657 m/m^2 overall, and 0.789 and 0.540 m/m^2 for Placements 1 and 2, respectively, were measured (Figure 4.55). These values are considerably higher than recorded during Survey 5, 0.431, 0.478, and 0.381 m/m^2 (Bohaty et al., 2013). Most of the cracks are transverse and run through the full width of the deck. Shorter cracks are also present and propagate from the construction joint between the two placements. Cracks are closer to each other above the piers than in other areas of the deck. During the construction of Placement 2, heavy equipment was placed on Placement 1 (McLeod et al., 2009; Yuan et al., 2011; Pendergrass & Darwin, 2014). This resulted in torsional stresses applied to Placement 1 and may explain the fact that Placement 1 has a higher crack density compared to Placement 2. In addition, because loads were applied during construction, the portion of the deck being cast was subjected to relatively large torsional deflections. This extraordinary loading rarely occurs during construction, suggesting that the absolute value of crack density in LC-HPC-12 is not representative of the crack performance of LC-HPC bridge decks.

4.22 Control-12

Like LC-HPC-12, Control-12 was constructed in two placements; Placement 1 was cast on 4/1/2008 and Placement 2 was cast on 4/14/2009. LC-HPC-12 and Control-12 are one bridge spanning over the Neosho River, and Control-12 is the southern portion of this bridge. This deck has been surveyed six times, and the results of Survey 6 are included in this report. Survey 6 was performed at 76.4 and 64.0 months for Placements 1 and 2, respectively; the crack map is displayed in Figure 4.56. In Survey 6, crack densities of 1.152 m/m^2 overall, and 1.141 and 1.163 m/m^2 for Placements 1 and 2 were observed (Figure 4.56). These values are higher than recorded for Survey 5, 0.858, 0.838, and 0.880 m/m^2 (Bohaty et al., 2013). The majority of the cracks are long transverse cracks. They are very closely spaced compared to the transverse cracks present on LC-HPC-12. Some longitudinal cracks are also present. The middle span exhibits the greatest amount of cracking. Control-12 was subjected to the same type of loading during construction as LC-HPC-12. Like LC-HPC-12, Control-12 was subjected to heavy loads during construction.

Figure 4.57 compares the crack densities for LC-HPC-12 and Control-12 over time. Although cracking has been high in LC-HPC-12, its performance has consistently exceeded that of Control-12.



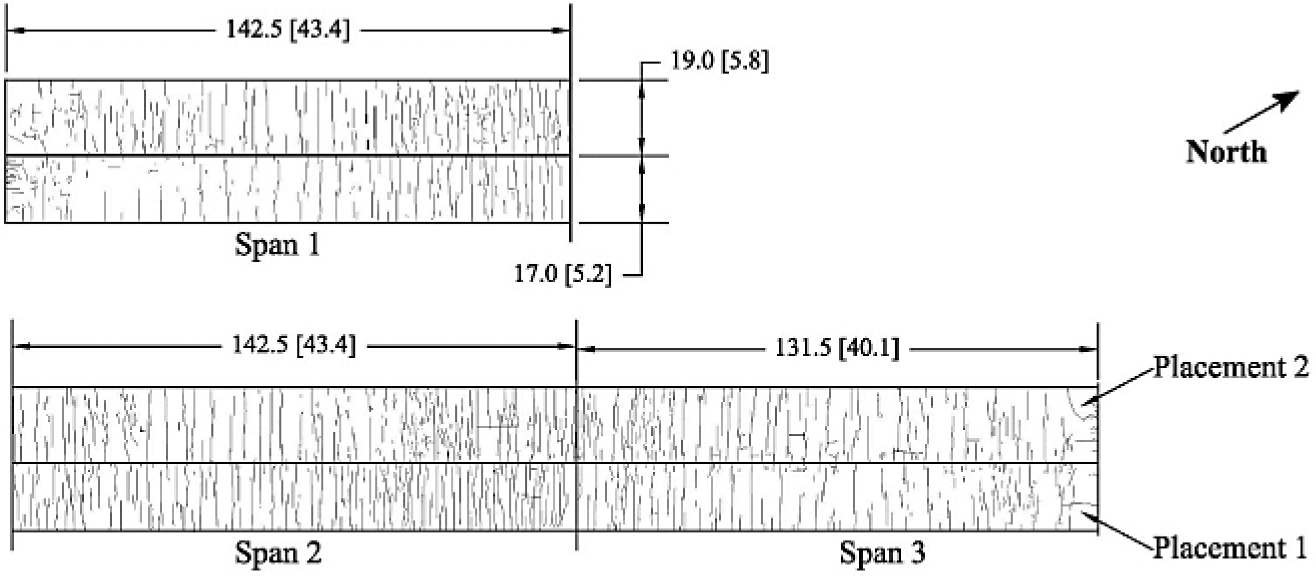
Bridge Number: 56-057 (KU 12)
Bridge Location: K-130 over Neosho Rv Unit 2
Construction Date:
Placement 1(East): 4/4/2008
Placement 2(West): 3/18/2009

Crack Survey Date: 8/13/2014

Bridge Length: 416.5' (126.95m)
Bridge Width: 36' (10.97m)
Skew: 0°
Number of Spans: 3
Span 1 (West): 142.5' (43.43m)
Span 2 (Mid): 142.5' (43.43m)
Span 3 (East): 131.5' (40.08m)
Number of Placements: 2

Bridge Age:
Placement 1: 76.3 months
Placement 2: 64.9 months
Crack Density: 0.657 m/m²
Placement 1: 0.789 m/m²
Placement 2: 0.540 m/m²
Span 1: 0.475 m/m²
Span 2: 0.929 m/m²
Span 3: 0.556 m/m

Figure 4.55: LC-HPC-12 (Survey 6)



Bridge Number: 56-057 (Control 12)
Bridge Location: K-130 over Neosho Rv Unit 1
Construction Date:
Placement 1 (East): 4/1/2008
Placement 2 (West): 4/14/2009
Crack Survey Date: 8/13/2014

Bridge Length: 416.5' (126.95m)
Bridge Width: 36' (10.97m)
Skew: 0°
Number of Spans: 3
Span 1 (West): 142.5' (43.43m)
Span 2 (Mid): 142.5' (43.43m)
Span 3 (East): 131.5' (40.08m)
Number of Placements: 2

Bridge Age:
Placement 1: 76.4 months
Placement 2: 64 months
Crack Density: 1.152 m/m²
Placement 1: 1.141 m/m²
Placement 2: 1.163 m/m²
Span 1: 0.967 m/m²
Span 2: 1.420 m/m²
Span 3: 1.063 m/m²

Figure 4.56: Control-12 (Survey 6)

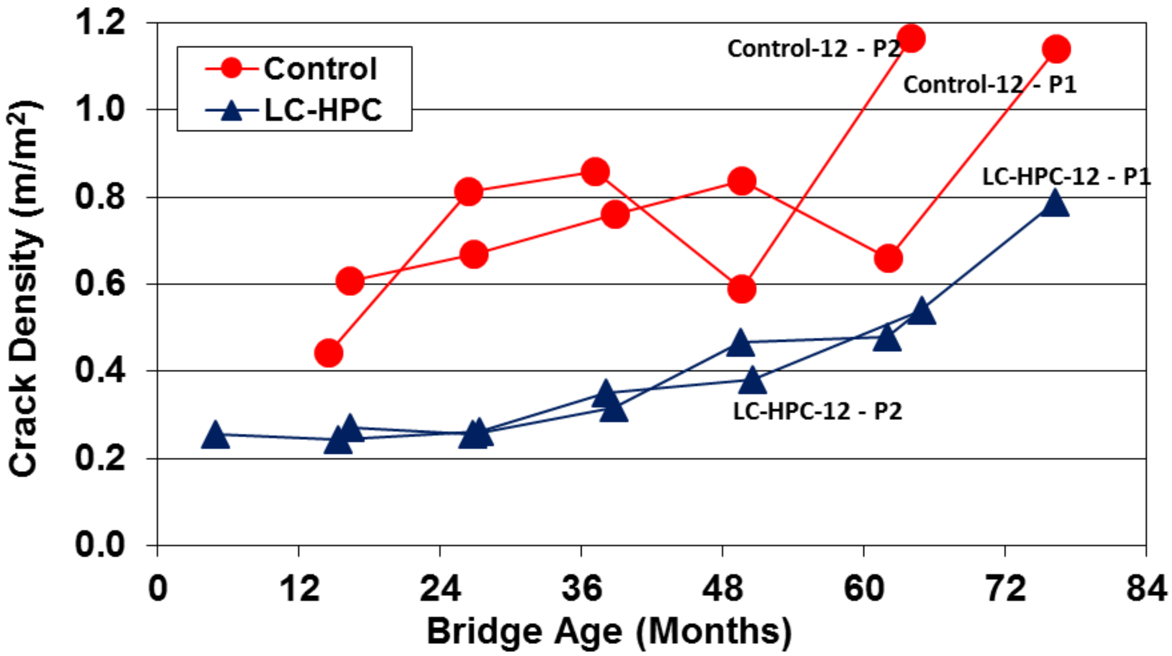
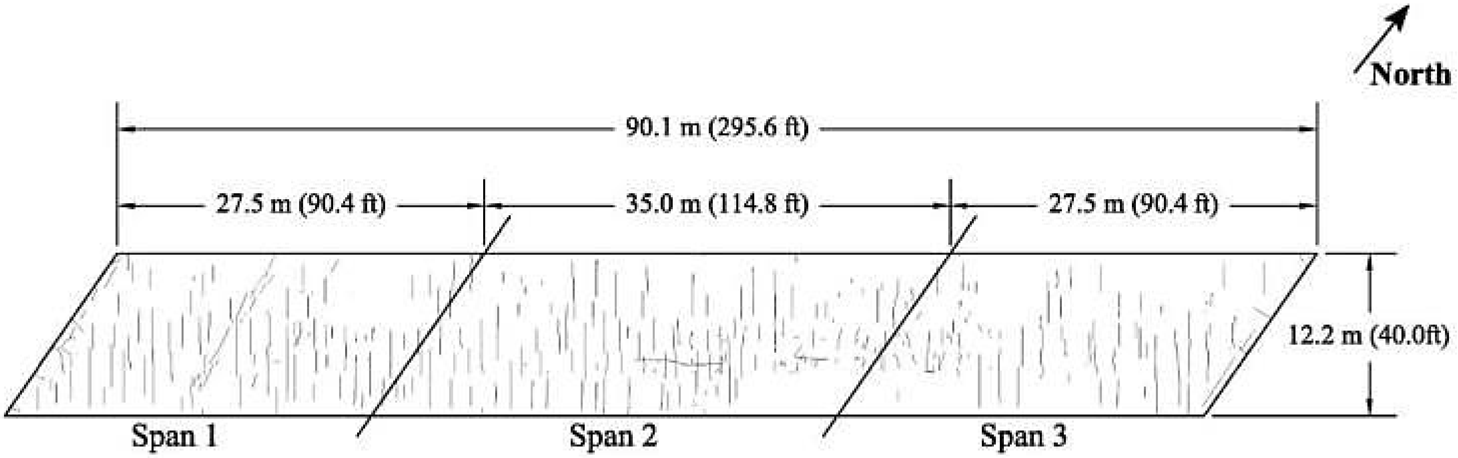


Figure 4.57: LC-HPC-12 and Control-12 Crack Densities versus Deck Age

4.23 LC-HPC-13

Bridge deck LC-HPC-13 was constructed on 4/29/2008 and has been surveyed seven times. The results of Surveys 6 and 7 of LC-HPC-13 are included in this report. Survey 6 was completed at a deck age of 75.2 months; the crack map is shown in Figure 4.58. Survey 7 was completed at a deck age of 85.9 months; the crack map is shown in Figure 4.59. A crack density of 0.471 m/m^2 was observed in Survey 6 (Figure 4.58). This value is lower than recorded during Survey 5 at 0.576 m/m^2 (Bohaty et al., 2013). Based on surveys before and since, it appears that Survey 5 is an outlier. In Survey 7, a crack density of 0.486 m/m^2 was observed (Figure 4.59). Moderate-sized cracks were marked during both surveys. Short cracks are present above the eastern pier.



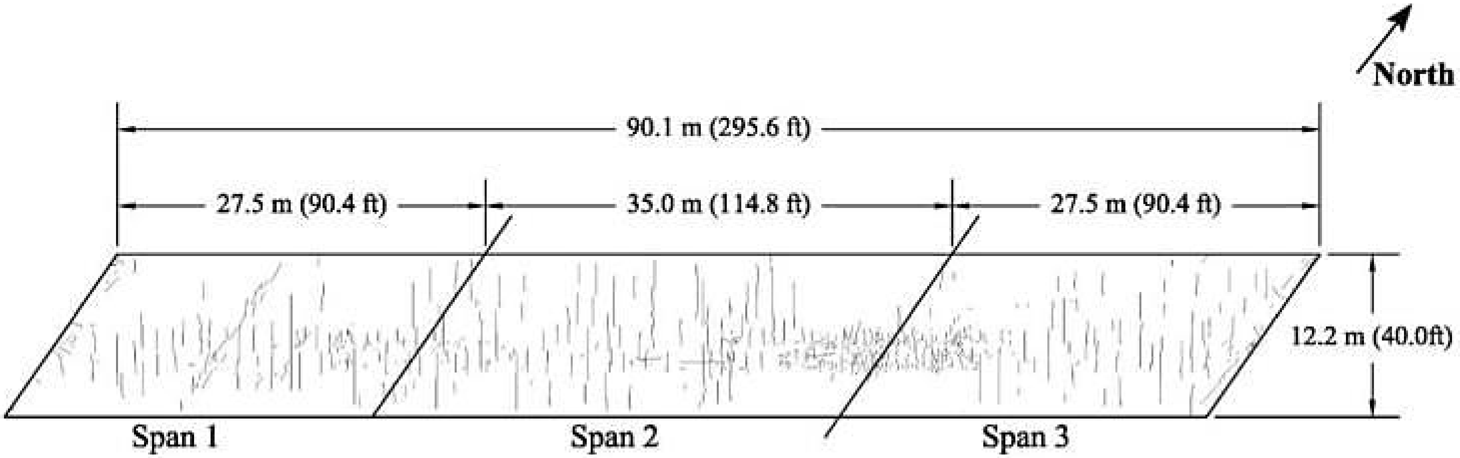
Bridge Number: 54-66 (KU 13)
Bridge Location: NB US-69 over
BNSF RR, Linn County, KS
Construction Date: 4/29/2008
Crack survey Date: 8/4/2014

Bridge Length: 90.1 m (295.6 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -34.8
Number of Spans: 3
- **Span 1 (West):** 27.5 m (90.4 ft)
- **Span 2 (Middle):** 35.0 m (114.8 ft)
- **Span 3 (East):** 27.5 m (90.4 ft)

Number of Placements: 1

Bridge Age: 75.2 months
Crack density: 0.471 m/m²
- **Span 1 (West):** 0.544 m/m²
- **Span 2 (middle):** 0.491 m/m²
- **Span 3 (East):** 0.373 m/m²

Figure 4.58: LC-HPC-13 (Survey 6)



Bridge Number: 54-66 (KU 13)
Bridge Location: NB US-69 over
BNSF RR, Linn County, KS
Construction Date: 4/29/2008
Crack survey Date: 6/24/2015

Bridge Length: 90.1 m (295.6 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -34.8
Number of Spans: 3
Span 1 (West): 27.5 m (90.4 ft)
Span 2 (Middle): 35.0 m (114.8 ft)
Span 3 (East): 27.5 m (90.4 ft)
Number of Placements: 1

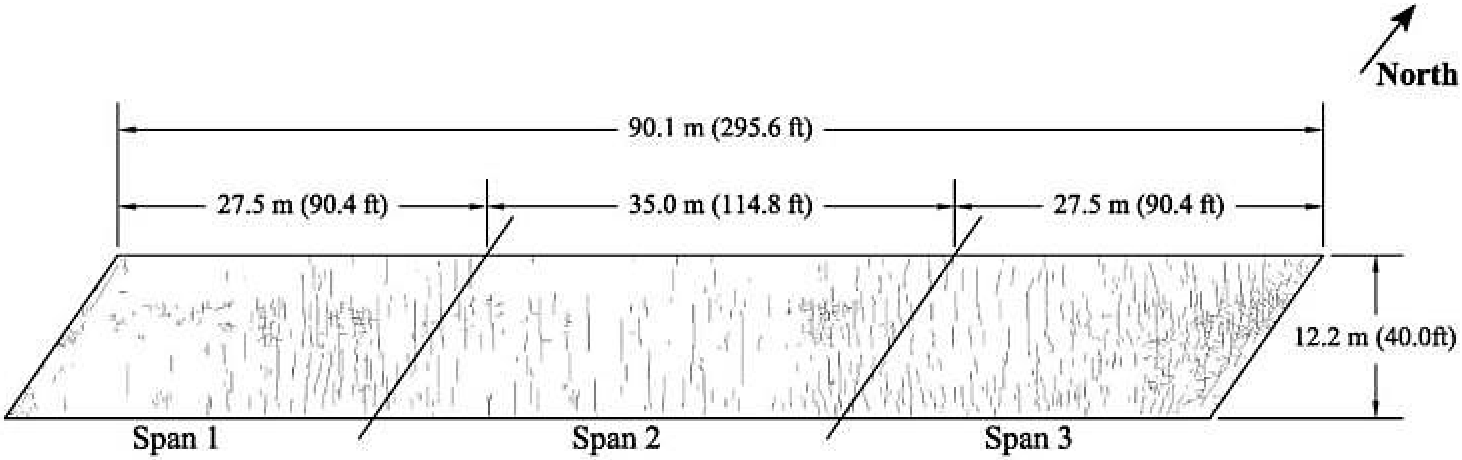
Bridge Age: 85.9 months
Crack density: 0.486 m/m^2
Span 1 (West): 0.438 m/m^2
Span 2 (middle): 0.534 m/m^2
Span 3 (East): 0.474 m/m^2

Figure 4.59: LC-HPC-13 (Survey 7)

4.24 Control-13

Bridge deck Control-13 was constructed on 7/25/2008 and has been surveyed seven times. The results of Surveys 6 and 7 are included in this report. Survey 6 was completed at a deck age of 72.5 months; the crack map is shown in Figure 4.60. Survey 7 was completed at a deck age of 84.1 months; the crack map is shown in Figure 4.61. In Survey 6, a crack density of 0.711 m/m^2 was observed (Figure 4.60). Survey 6 has a lower crack density than Survey 5, 0.807 m/m^2 (Bohaty et al., 2013). In Survey 7, a crack density of 0.718 m/m^2 was observed (Figure 4.61), which is slightly higher than Survey 6. Similar to LC-HPC-13, Survey 5 can be considered as an outlier. As shown in Figure 4.60 and Figure 4.61, it can be seen that there are moderate-length transverse cracks distributed over the whole area of the bridge. Map cracking is present at some locations on the deck. Short cracks have propagated perpendicular to both abutments.

Figure 4.62 compares the crack densities for LC-HPC-13 and Control-13 over time. LC-HPC-13 has consistently exhibited less cracking density than Control-13 over the life of the decks.

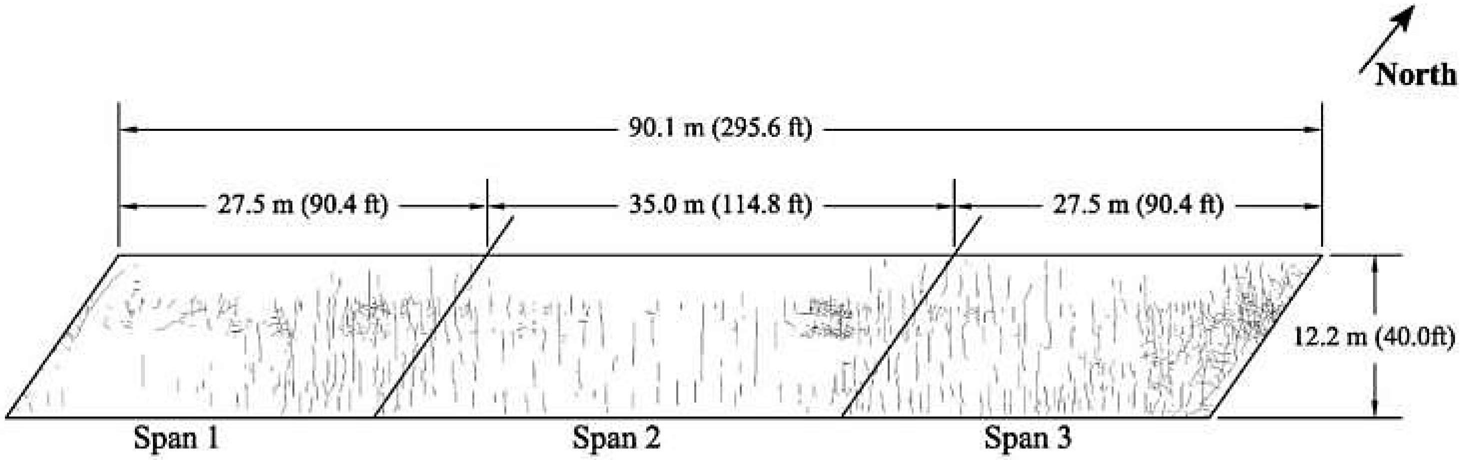


Bridge Number: 54-67
(KU 13 Control)
Bridge Location: SB US-69 over
BNSF RR, Linn County, KS
Construction Date: 7/25/2008
Crack survey Date: 8/8/2014

Bridge Length: 90.1 m (295.6 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -34.8
Number of Spans: 3
Span 1 (West): 27.5 m (90.4 ft)
Span 2 (Middle): 35.0 m (114.8 ft)
Span 3 (East): 27.5 m (90.4 ft)
Number of Placements: 1

Bridge Age: 72.5 months
Crack density: 0.711 m/m²
Span 1 (West): 0.624 m/m²
Span 2 (middle): 0.530 m/m²
Span 3 (East): 1.029 m/m²

Figure 4.60: Control-13 (Survey 6)



Bridge Number: 54-67
(KU 13 Control)
Bridge Location: SB US-69 over
BNSF RR, Linn County, KS
Construction Date: 7/25/2008
Crack survey Date: 6/22/2015

Bridge Length: 90.1 m (295.6 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -34.8
Number of Spans: 3
Span 1 (West): 27.5 m (90.4 ft)
Span 2 (Middle): 35.0 m (114.8 ft)
Span 3 (East): 27.5 m (90.4 ft)
Number of Placements: 1

Bridge Age: 84.1 months
Crack density: 0.718 m/m²
Span 1 (West): 0.647 m/m²
Span 2 (middle): 0.508 m/m²
Span 3 (East): 1.094 m/m²

Figure 4.61: Control-13 (Survey 7)

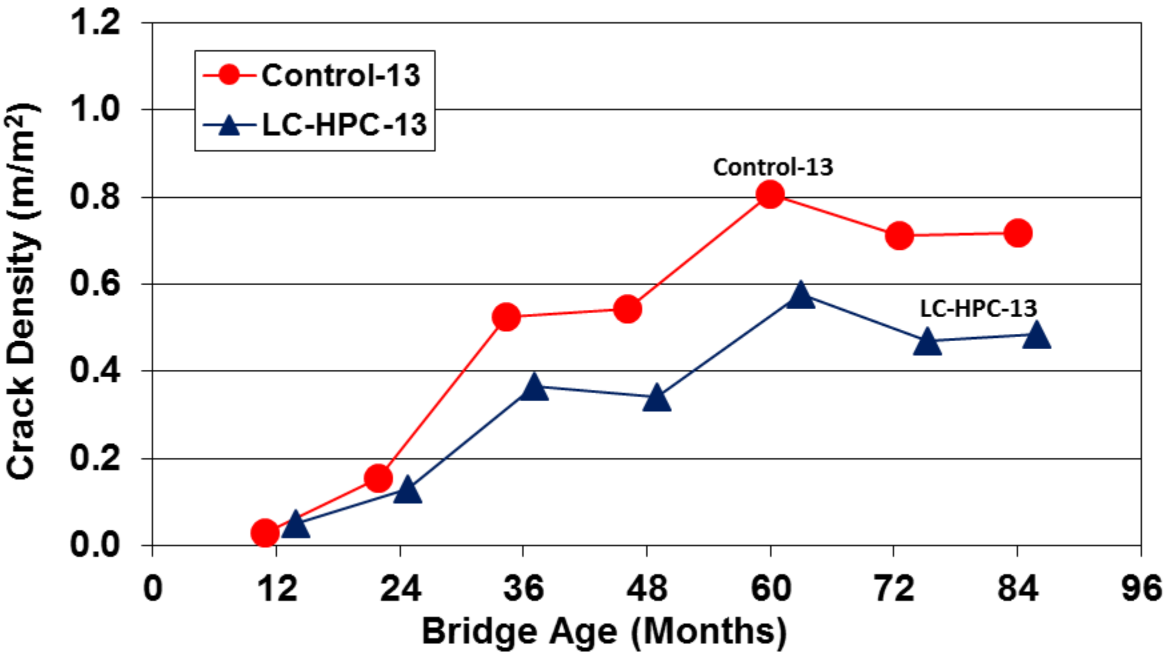


Figure 4.62: LC-HPC-13 and Control-13 Crack Densities versus Deck Age

4.25 OP-14

Bridge deck OP-14 was constructed in three placements; Placements 1, 2, and 3 were cast on 12/19/2007, 5/2/2008, and 5/21/2008, respectively. OP-14 has been surveyed four times. Survey 4 was the last for OP-14 due to excessive deck cracking. Survey 4 recorded crack densities of 1.083, 1.331, and 1.387 m/m^2 for Placements 1, 2, and 3, respectively (Bohaty et al., 2013). Placements 2 and 3 of this deck recorded the highest crack densities among any of the decks included in this study (LC-HPC and control decks). Figure 4.63 shows the crack densities for the three placements of OP-14 over time (Bohaty et al., 2013). OP-14 was bid as an LC-HPC bridge deck. However, the contractor did not follow important aspects of the LC-HPC specifications, and the owner, the City of Overland Park, did not enforce the specifications (McLeod et al., 2009).

Placement 1 of OP-14 was constructed on two separate dates because the concrete pump clogged after placing the first 30 ft (9 m) of the deck. This portion of the deck was demolished before the second construction attempt. For some concrete batches during the second attempt, the measured slump was much higher than the maximum slump specified for LC-HPC decks.

Inadequate consolidation was observed during the construction: the gang vibrators were removed too quickly, leaving visible holes at the deck surface. Excessive bullfloating was used on the deck surface, which resulted in excessive cement paste on the surface. The specified 10-minute time between finishing and placing burlap was exceeded throughout the deck construction. Furthermore, water was used as a finishing aid. Placements 2 and 3 of OP-14 had the same construction issues as Placement 1, resulting in high deck cracking. During the construction of Placement 2, concrete trucks were delayed and the contractor removed concrete from a previously placed wingwall and used it to complete a portion of the deck. During the construction of Placement 3, the deck reinforcement was not fully supported, resulting in reinforcement vibration. This issue may have increased the potential for settlement cracking (Lindquist et al., 2008; Gruman et al., 2009; McLeod et al., 2009).

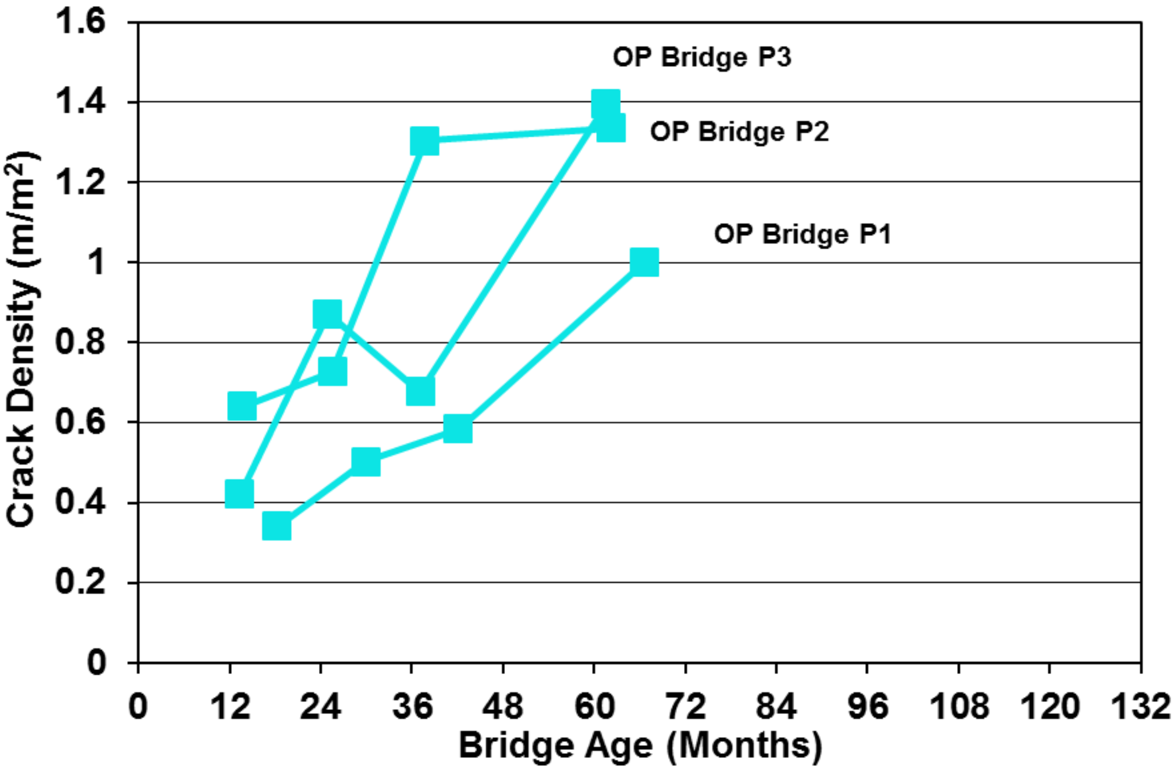
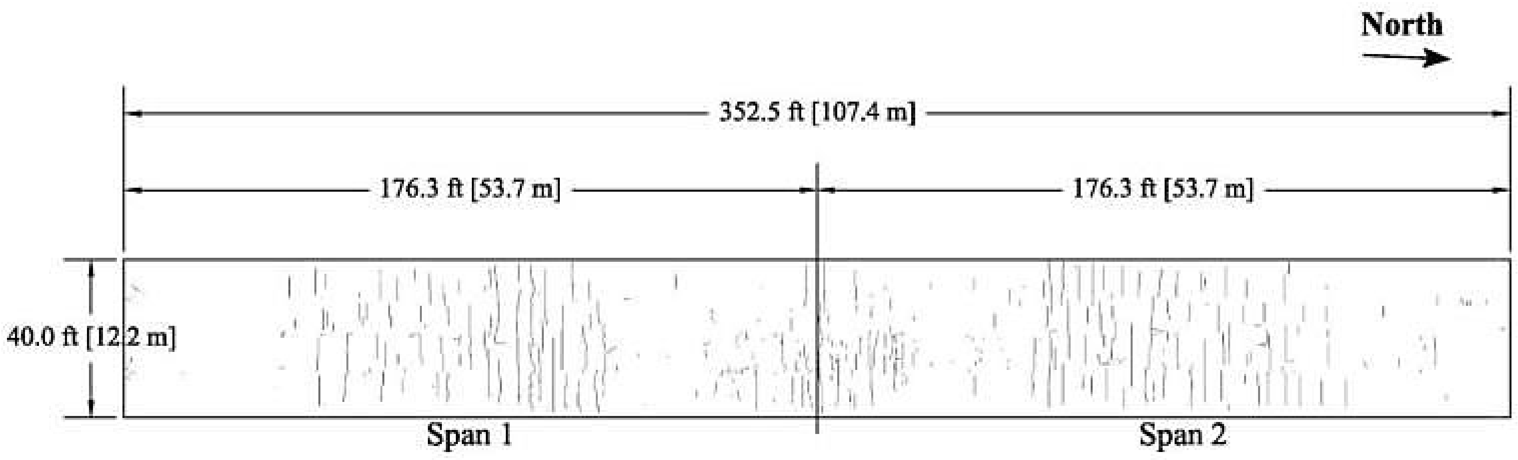


Figure 4.63: OP-14 Crack Densities versus Deck Age
Source: Bohaty et al. (2013)

4.26 LC-HPC-15

Bridge deck LC-HPC-15 was constructed on 11/10/2010. This deck does not have a control deck for comparison. LC-HPC-15 has been surveyed four times and this report includes the results of Surveys 3 and 4. Survey 3 was performed at a deck age of 43.0 months; the crack map is shown in Figure 4.64. Survey 4 was performed at a deck age of 56.2 months; the crack map is shown in Figure 4.65. A crack density of 0.316 m/m^2 was observed in Survey 3 (Figure 4.64), a significant increase in crack density from Survey 2, 0.161 m/m^2 (Bohaty et al., 2013). In Survey 4, a crack density of 0.299 m/m^2 was observed (Figure 4.65), slightly lower than in Survey 3. As shown in Figure 4.64 and Figure 4.65, the majority of the cracks in LC-HPC-15 are transverse, and appear to run parallel to the top reinforcement layer. A few short cracks appear near the abutments. Figure 4.66 displays the crack density versus deck age for LC-HPC-15.

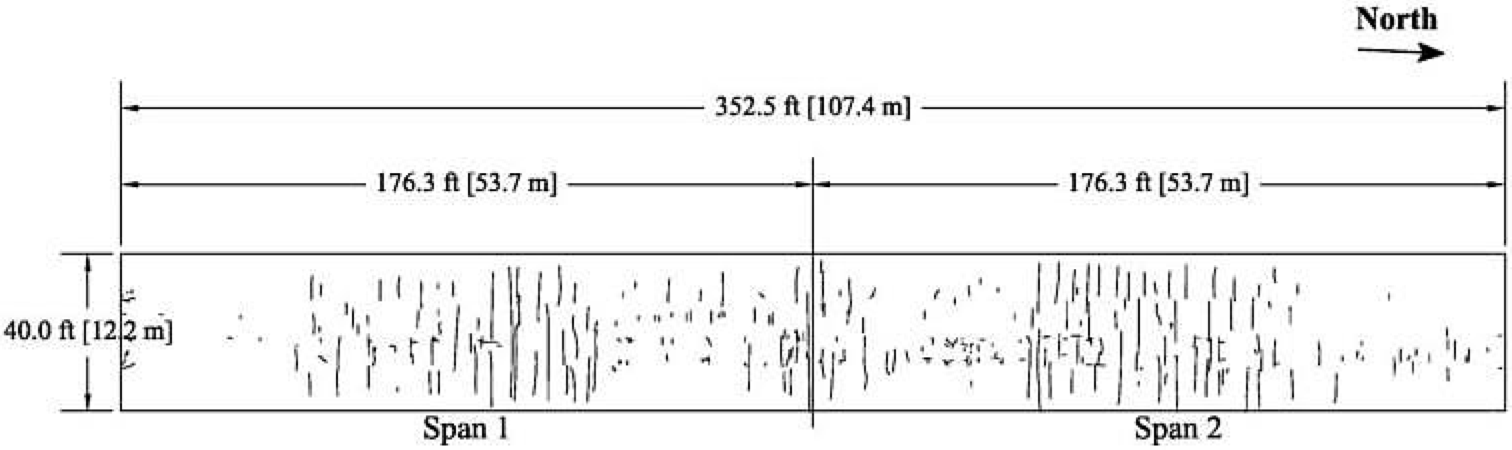


Bridge Number: 46-351 (KU 15)
Bridge Location: NB K-7 over Johnson Dr./55th St.
Construction Date: 11-10-10
Crack Survey Date: 6-9-2014

Bridge Length: 352.5 ft (118.2 m)
Bridge Width: 40.0 ft(12.2 m)
Skew: 0°
Number of Spans: 3
Span 1: 176.25 ft (36.7 m)
Span 2: 176.25 ft (44.8 m)
Number of Placements: 1

Bridge Age: 43 months
Crack Density: 0.317 m/m^2
Span 1: 0.290 m/m^2
Span 2: 0.344 m/m^2

Figure 4.64: LC-HPC-15 (Survey 3)



Bridge Number: 46-351 (KU 15)
Bridge Location: NB K-7 over
Johnson Dr./55th St.
Construction Date: 11-10-10
Crack Survey Date: 6-23-2015

Bridge Length: 352.5 ft (118.2 m)
Bridge Width: 40.0 ft(12.2 m)
Skew: 0°
Number of Spans: 3
Span 1: 176.25 ft (36.7 m)
Span 2: 176.25 ft (44.8 m)
Number of Placements: 1

Bridge Age: 56.2 months
Crack Density: 0.299 m/m²
Span 1: 0.288 m/m²
Span 2: 0.311 m/m²

Figure 4.65: LC-HPC-15 (Survey 4)

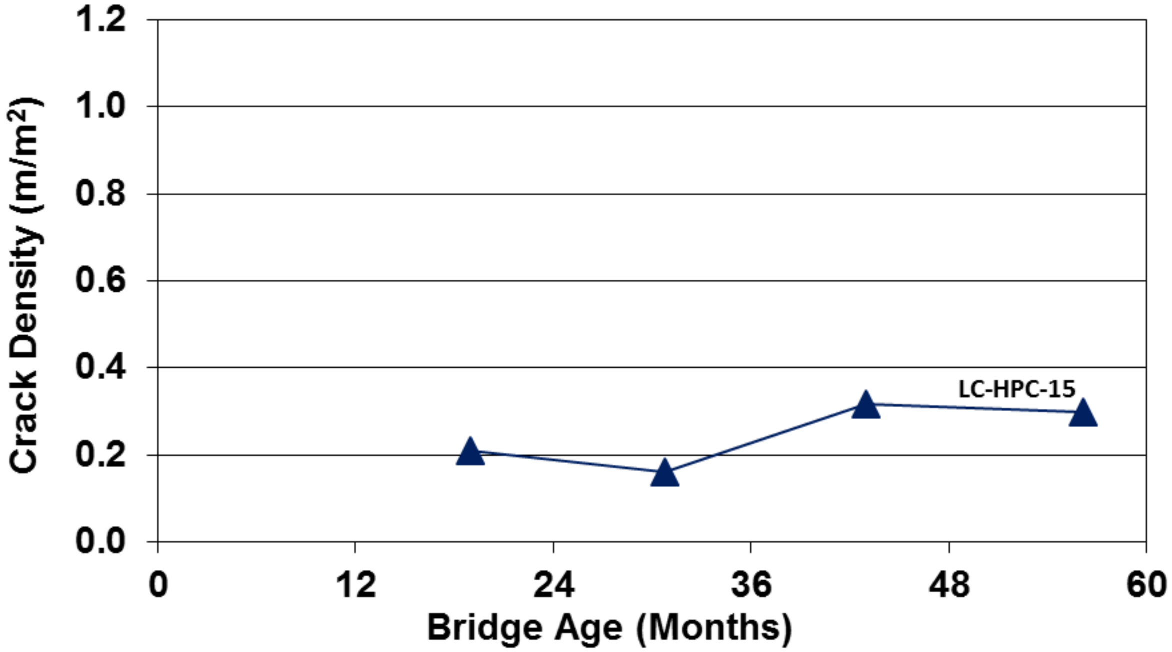
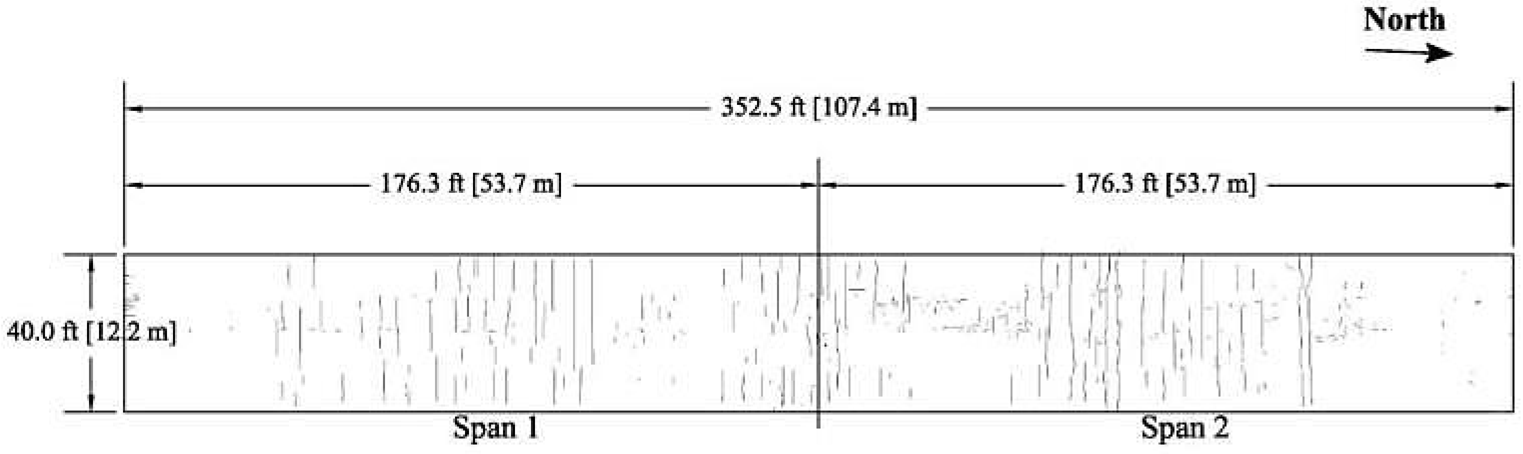


Figure 4.66: LC-HPC-15 Crack Densities versus Deck Age

4.27 LC-HPC-16

Bridge deck LC-HPC-16 was constructed on 6/11/2014. This bridge does not have a control deck for comparison. The deck has been surveyed five times. The results of Surveys 4 and 5 of LC-HPC-16 are discussed in this report. Survey 4 was completed at a deck age of 43.5 months; the crack map is displayed in Figure 4.67. Survey 5 was completed at a deck age of 55.0 months; the crack map is displayed in Figure 4.68. A crack density of 0.311 m/m^2 was observed in Survey 4 (Figure 4.67) compared to a crack density in Survey 3 of 0.211 m/m^2 (Bohaty et al., 2013). In Survey 5, a crack density of 0.397 m/m^2 was observed (Figure 4.68). Most of the cracks are transverse (Figure 4.67 and Figure 4.68). Map cracking is also present on some portions of the deck. Near the abutments, some cracks have propagated longitudinally. Figure 4.69 shows the crack density as a function of age for LC-HPC-16.

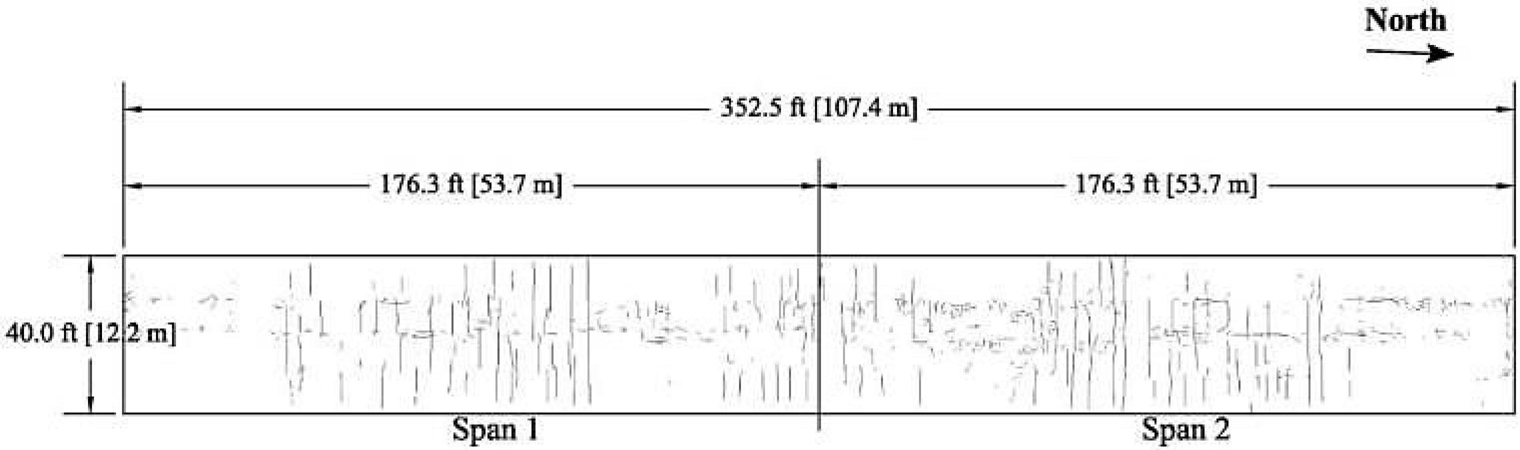


Bridge Number: 46-352 (KU 16)
Bridge Location: SB K-7 over Johnson Dr./55th St.
Construction Date: 10-28-2010
Crack Survey Date: 6-11-2014

Bridge Length: 352.5 ft (107.4 m)
Bridge Width: 40.0 ft(12.2 m)
Skew: 0°
Number of Spans: 2
 Span 1: 176.25 ft (53.7 m)
 Span 2: 176.25 ft (53.7 m)
 Number of Placements: 1

Bridge Age: 43.5 months
Crack Density: 0.311 m/m^2
 Span 1: 0.267 m/m^2
 Span 2: 0.354 m/m^2

Figure 4.67: LC-HPC-16 (Survey 4)



Bridge Number: 46-352 (KU 16)
Bridge Location: SB K-7 over
Johnson Dr./55th St.
Construction Date: 10-28-2010
Crack Survey Date: 5-27-2015

Bridge Length: 352.5 ft (107.4 m)
Bridge Width: 40.0 ft(12.2 m)
Skew: 0°
Number of Spans: 2
Span 1: 176.25 ft (53.7 m)
Span 2: 176.25 ft (53.7 m)
Number of Placements: 1

Bridge Age: 55 months
Crack Density: 0.397 m/m²
Span 1: 0.361 m/m²
Span 2: 0.447 m/m²

Figure 4.68: LC-HPC-16 (Survey 5)

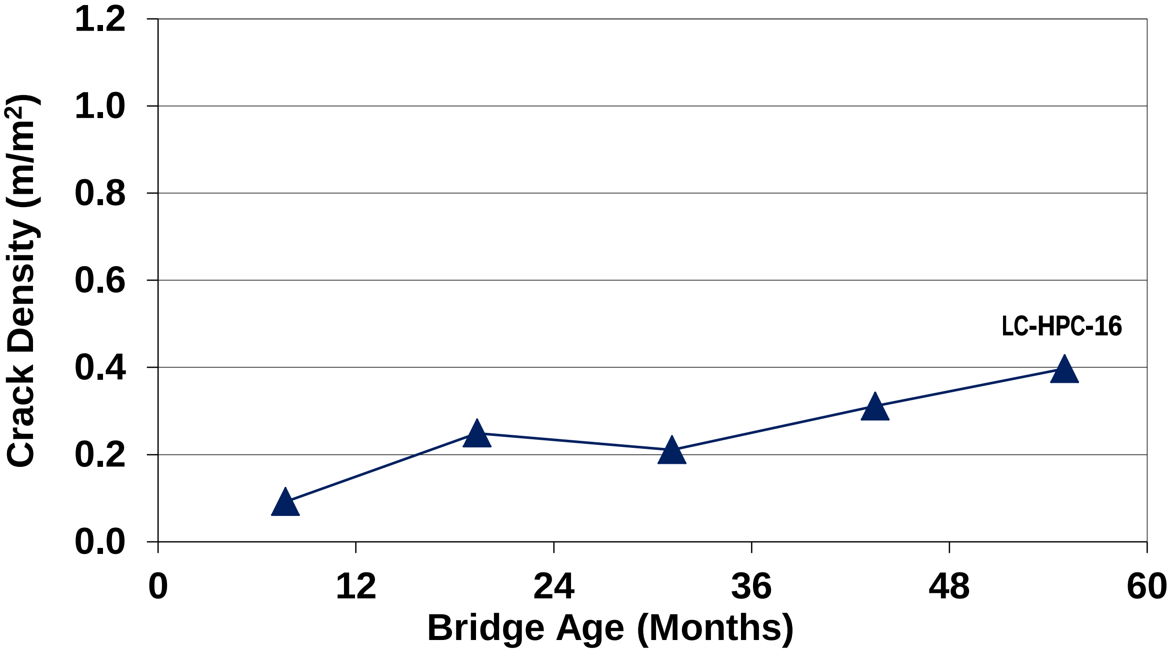
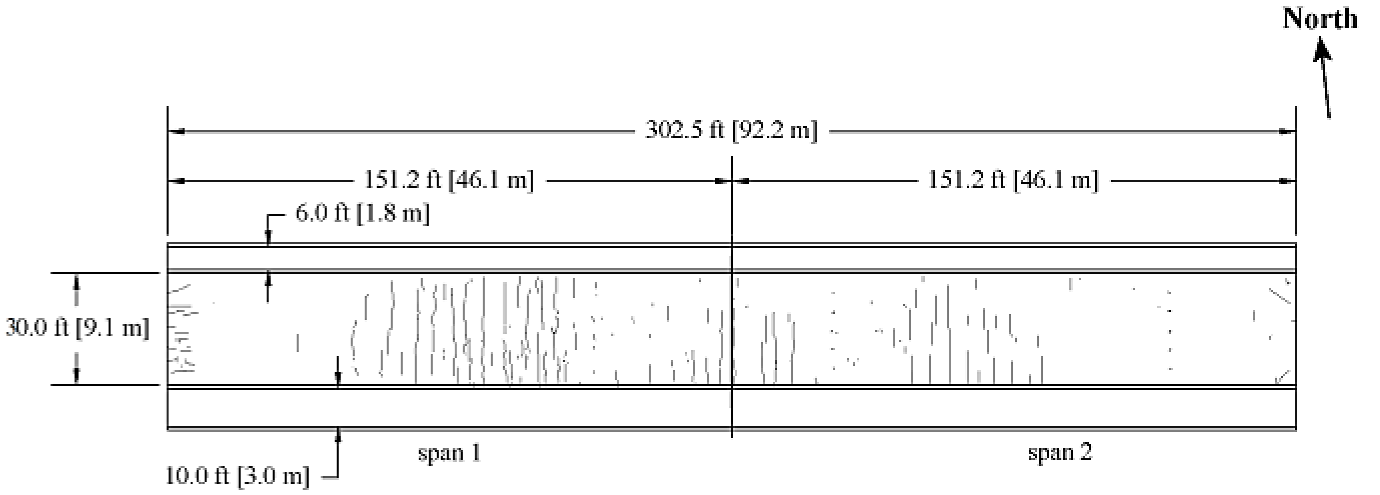


Figure 4.69: LC-HPC-16 Crack Densities versus Deck Age

4.28 LC-HPC-17

Bridge deck LC-HPC-17 was placed on 9/28/2011. The bridge was constructed with a sidewalk on each side. There is no control deck for this bridge. The deck has been surveyed four times, and the results of Surveys 3 and 4 are included in this report. Survey 3 was performed at a deck age of 32.5 months; the crack map is shown in Figure 4.70. Survey 4 was performed at a deck age of 45.5 months; the crack map is shown in Figure 4.71. In Survey 3, an overall crack density of 0.274 m/m^2 was observed (Figure 4.70), slightly higher than the value reported by Bohaty et al. (2013) for Survey 2, 0.240 m/m^2. An overall crack density of 0.308 m/m^2 was observed in Survey 4 (Figure 4.71). The surveys do not include the sidewalks. As shown in Figure 4.70 and Figure 4.71, the majority of the cracks are transverse and located near the mid-span. There are also some transverse cracks above the pier. Survey 4 recorded some small areas of map cracking near the east abutment. Cracks also propagate longitudinally near the west abutment. Figure 4.72 shows the crack density for LC-HPC-17 over time.

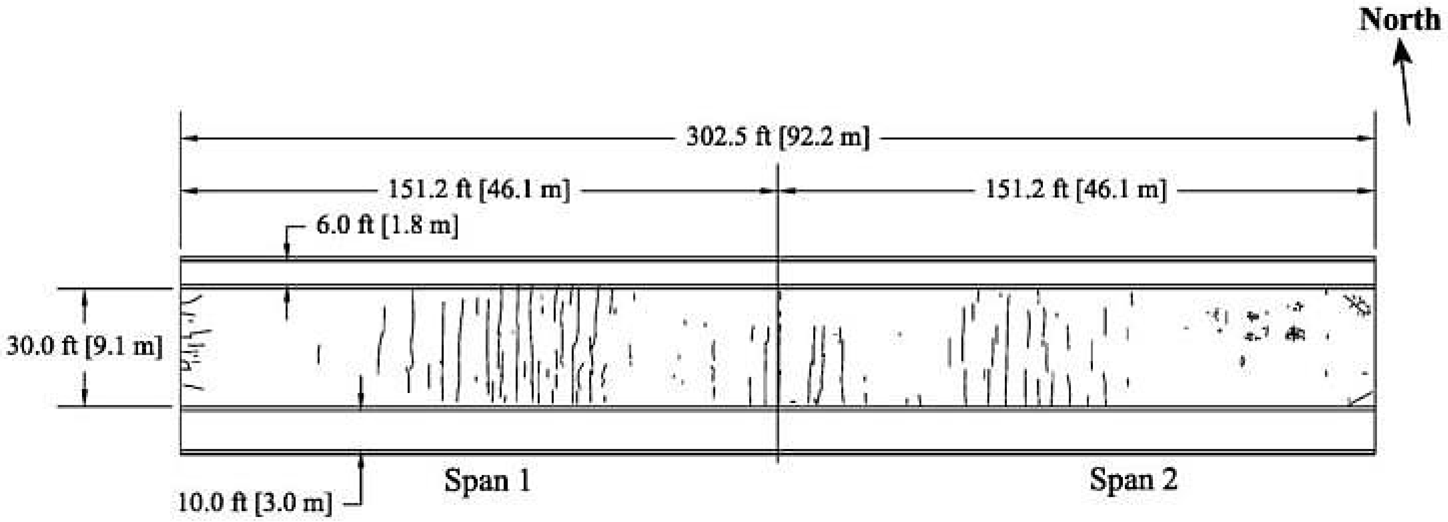


Bridge Number: 46-373 (KU 17)
Bridge Location: Clear Creek Parkway over K-7
Construction Date: 09-28-11
Crack Survey Date: 6/11/2014

Bridge Length: 302.5 ft (92.2 m)
Bridge Width: 48.0 ft(14.6 m)
Skew: 0°
Number of Spans: 2
  Span 1: 151.25 ft (46.1 m)
  Span 2: 151.25 ft (46.1 m)
  Number of Placements: 1

Bridge Age: 32.5 months
Crack Density: 0.274 m/m^2
  Span 1: 0.359 m/m^2
  Span 2: 0.189 m/m^2

Figure 4.70: LC-HPC-17 (Survey 3)



Bridge Number: 46-373 (KU 17)
Bridge Location: Clear Creek Parkway over K-7
Construction Date: 09-28-11
Crack Survey Date: 6-25-2015

Bridge Length: 302.5 ft (92.2 m)
Bridge Width: 48.0 ft(14.6 m)
Skew: 0°
Number of Spans: 2
  Span 1: 151.25 ft (46.1 m)
  Span 2: 151.25 ft (46.1 m)
  Number of Placements: 1

Bridge Age: 45.5 months
Crack Density: 0.308 m/m^2
  Span 1: 0.349 m/m^2
  Span 2: 0.268 m/m^2

Figure 4.71: LC-HPC-17 (Survey 4)

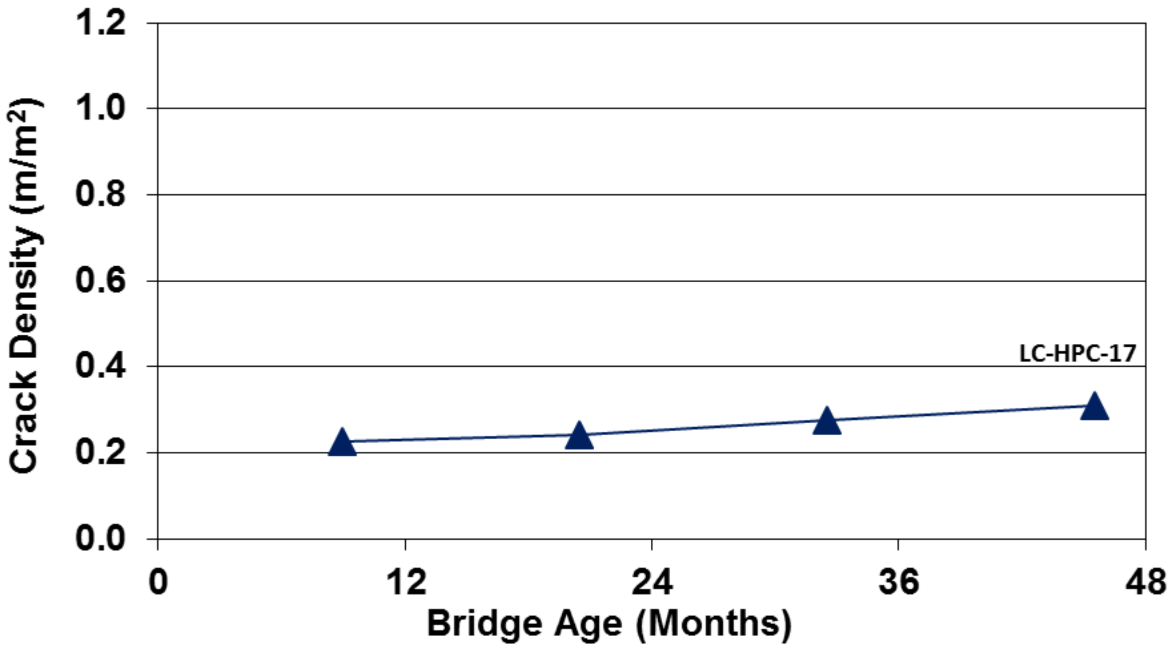


Figure 4.72: LC-HPC-17 Crack Densities versus Deck Age

4.29 Comparison of LC-HPC Decks without Matching Control Decks with LC-HPC Decks with Control Decks

Figure 4.73 compares the crack densities of LC-HPC 15, 16, and 17, all constructed by the same contractor, with those of the first 13 LC-HPC decks (which have control decks) as a function of age. The crack densities for LC-HPC 15, 16, and 17 fall just under the upper boundary of the first 13 LC-HPC decks. LC-HPC-16 started with a crack density similar to most of the earlier LC-HPC-decks. The crack density, however, jumped in the second and subsequent surveys. LC-HPC-15 and LC-HPC-17 exhibited higher crack densities during their initial surveys. The majority of the earlier LC-HPC decks have exhibited lower crack densities during the first 60 months after construction.

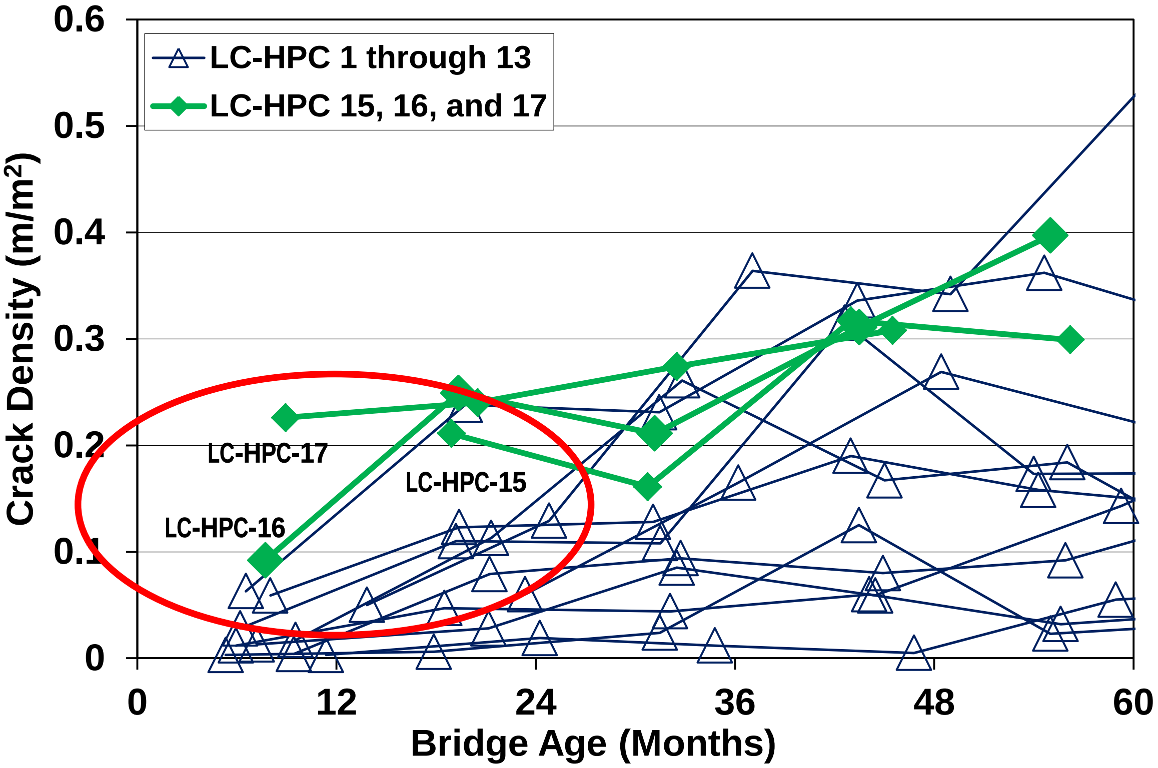


Figure 4.73: LC-HPC 1 through 13 and LC-HPC 15, 16, and 17 Crack Densities versus Deck Age

4.30 Summary

Table 4.1, Table 4.2, and Table 4.3 list crack survey results for bridge decks included in this study for the surveys completed in 2014, 2015, and 2016. The highest recorded crack density on an LC-HPC deck was 0.66 m/m^2 (LC-HPC-3 at 79.3 months) and the highest density on a control deck was 1.165 m/m^2 (Placement 1 of Control-7 at 98.5 months).

Eleven of the 13 LC-HPC decks exhibited lower overall crack densities than their controls. As shown in Figure 4.10, Control-1/2 exhibited slightly lower overall cracking than LC-HPC-2. Placement 2 of Control-1/2 has a higher crack density than LC-HPC-2 and Placement 1 of Control-1/2, while Placement 1 of Control-1/2 has a lower crack density than LC-HPC-2. Control-1/2 is the best performing control deck in the study. LC-HPC-3 has a crack density that is about 8% higher than Control-3, the second best control deck in the study. Both LC-HPC decks supported by precast-prestressed girders (LC-HPC-8 and LC-HPC-10) performed better than the control deck (Control-8/10).

The majority of the cracks present in the bridge decks are transverse, although longitudinal cracks form, especially adjacent to abutments.

Bridge deck OP-14 was not constructed in accordance with LC-HPC specifications and has exhibited excessive cracking throughout its life. Two of the three placements of OP-14 exhibit the highest crack densities among all decks included in this study (1.331 m/m^2 for Placement 2 and 1.387 m/m^2 for Placement 3).

Chapter 5: Summary and Conclusions

Low-Cracking High-Performance Concrete (LC-HPC) specifications have been developed by KDOT and the University of Kansas for the purpose of increasing the expected service life of concrete bridge decks by the reduction of cracking. Surveys of LC-HPC and control bridge decks were performed and crack densities compared to examine the benefits of implementing LC-HPC specifications. Comparisons between 13 LC-HPC and matching control bridge decks are made based on the crack density and changes in crack density over time.

Based on the results of this study, the following conclusions can be drawn:

1. The LC-HPC bridge decks exhibit less cracking than the matching control decks in the vast majority of cases. Only bridge decks LC-HPC-2 and LC-HPC-3 have higher overall crack densities higher than their control decks, the two best performing control decks in the program, and the differences are small.
2. Transverse cracking is the most common. Cracks of this type appear to run directly over and parallel to the top layer of reinforcement in the decks.
3. Near the abutments, cracks usually propagate perpendicular to the abutments.
4. The width of the cracks generally range from 0.006 to 0.025 inches (0.15 to 0.64 mm).
5. Decks supported by precast-prestressed girders may exhibit a reduction in crack density at early ages.
6. Reduced cementitious material and cement paste contents, improved early-age and long-term curing, limitations on or de-emphasis of maximum concrete compressive strength, limitations on maximum slump, concrete temperature control, and minimizing finishing operations help minimize cracking in bridge decks.
7. High-slump concrete, poor consolidation, delayed curing, and over-finishing result in increased cracking in bridge decks.

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Mixture Proportioning Program

KU MIX©, a concrete mixture proportioning program based in Microsoft Excel that includes aggregate optimization, 2005–2012.

Appendix A: Special Provisions

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**.

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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. 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.

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 <u>adjusted</u> 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**.

Chapter 1 - TABLE 1-2: DESIGNATED SLUMP*

Type of Work	Chapter 2 - 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 90°F, cool the forms, reinforcing steel, steel beam flanges, and other surfaces which will come in contact with the mix to below 90°F by means of a water spray or other approved methods. For Grade 3.5 (AE) (LC-HPC) concrete, cool the concrete mixture to maintain the temperature immediately before placement between 55°F and 70°F. With approval by the Engineer, the temperature of the concrete may be up to 5°F below or above this range.

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

Shading the materials storage areas or the production equipment.

Cooling the aggregates by sprinkling with potable water.

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

- Liquid nitrogen injection.

6.0 INSPECTION AND TESTING

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

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

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

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

TABLE 1-3: SAMPLING AND TESTING FREQUENCY CHART

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

Note a: "Type Insp" must = "ACC" when the assignment of a pay quantity is being made. "ACI" when recording test values for additional acceptance information.

Note b: Normal operation. Minimum frequency for exceptional conditions may be reduced by the DME on a project basis, written justification shall be made to the Chief of the Bureau of Materials and Research and placed in the project documents. (Multi-Level Frequency Chart (see page 17, Appendix A of Construction Manual, Part V).

Note c: Applicable only when specifications contain those requirements.

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

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

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

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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.

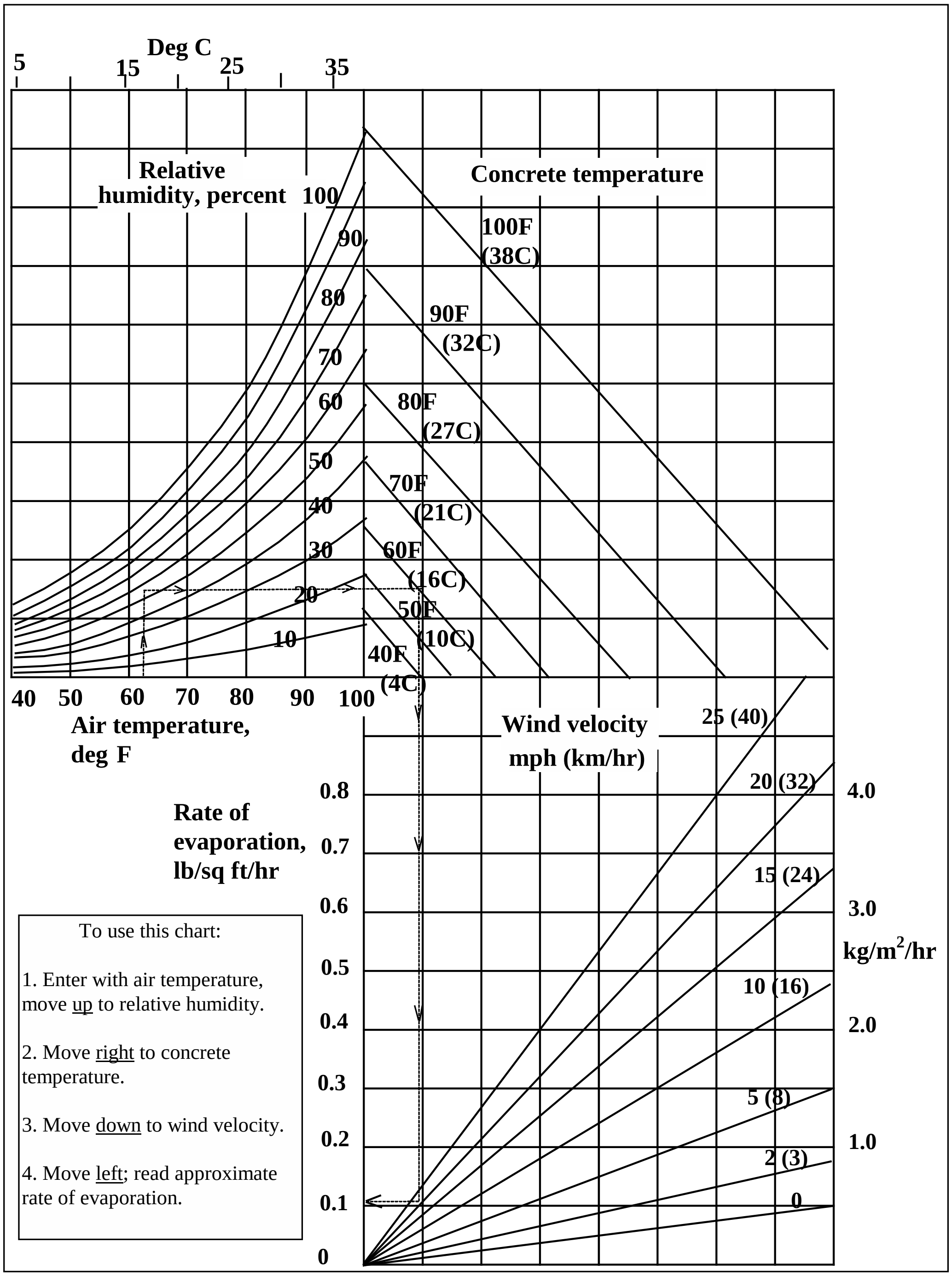
For additional requirements regarding forms and falsework, see **SECTION 708**.

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



To use this chart:

1. Enter with air temperature, move <u>up</u> to relative humidity.
2. Move <u>right</u> to concrete temperature.
3. Move <u>down</u> to wind velocity.
4. Move <u>left</u>; read approximate rate of evaporation.

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

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. Cracks not attached to the crack being traced must not be marked unless they can been seen from waist height. Surveyors must return to the location

where they started tracing a crack and continue the survey. Areas covered by sand or other debris need not be surveyed. Trace the cracks using a different color crayon than was used to mark the grid and stationing.

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

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

c. Weather Limitations.

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

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

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

3.0 BRIDGE SURVEY.

a. Crack Surveys.

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

b. Delamination Survey.

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

c. Under Deck Survey.

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

Appendix C: Bridge Deck Data

Table C.1: Crack Densities for Individual Bridge Placements

Bridge Number	County and Serial Number	Portion Placed	Date of Placement	Survey # 1			Survey # 2		
				Date of Survey	Age (months)	Crack Density (m/m^2)	Date of Survey	Age (months)	Crack Density (m/m^2)
LC-HPC-1	105-304	South	10/14/2005	4/13/2006	5.9	0.012	4/30/2007	18.5	0.047
		North	11/2/2005	4/13/2006	5.3	0.003	4/30/2007	17.9	0.006
		Entire Deck	-	4/13/2006	-	0.007	4/30/2007	-	0.027
LC-HPC-2	105-310	Deck	9/13/2006	4/20/2007	7.2	0.014	6/18/2008	21.2	0.029
Control-1/2	105-311	South	10/10/2005	4/13/2006	6.1	0.000	4/30/2007	18.6	0.151
		North	10/28/2005	4/13/2006	5.5	0.000	4/30/2007	18.0	0.044
		Entire Deck	-	4/13/2006	-	0.000	4/30/2007	-	0.089
LC-HPC-3	46-338	Deck	11/13/2007	5/29/2008	6.5	0.032	6/18/2009	19.2	0.110
Control-3	46-337	Deck	7/17/2007	5/29/2008	10.4	0.037	6/5/2009	22.6	0.216
LC-HPC-4	46-339	South	9/29/2007	7/15/2008	9.5	0.017	7/9/2009	21.3	0.113
		North	10/2/2007	7/15/2008	9.4	0.004	7/9/2009	21.2	0.079
Control-4	46-347	Deck	11/16/2007	6/10/2008	6.8	0.050	7/7/2009	19.7	0.366
LC-HPC-5	46-340 Unit 1	Deck	11/14/2007	7/15/2008	8.0	0.059	6/26/2009	19.4	0.123
Control-5	46-341 Unit 3	Deck	11/25/2008	7/9/2009	7.4	0.670	6/22/2010	18.9	0.857
LC-HPC-6	46-340 Unit 2	Deck	11/3/2007	5/20/2008	6.5	0.063	6/26/2009	19.7	0.238
Control-6	46-341 Unit 4	Deck	10/20/2008	7/9/2009	8.6	0.142	6/22/2010	20.0	0.282
LC-HPC-7	43-33	Deck	6/24/2006	6/5/2007	11.4	0.003	7/1/2008	24.2	0.019
Control-7	46-334	East	3/29/2006	8/10/2007	16.4	0.293	6/30/2008	27.1	0.476
		West	9/15/2006	8/10/2007	10.8	0.030	6/30/2008	21.5	0.069
LC-HPC-8	54-53	Deck	10/3/2007	6/29/2009	20.9	0.298	5/27/2010	31.8	0.348
LC-HPC-10	54-60	Deck	5/17/2007	6/29/2009	25.4	0.076	5/22/2010	36.2	0.029

Source: Lindquist et al. (2008); Gruman et al. (2009); McLeod et al. (2009); Yuan et al. (2011); Pendergrass et al. (2011); Kaul et al. (2012); Bohaty et al. (2013); Pendergrass and Darwin (2014); and Alhmood et al. (2015)

Table C.1: Crack Densities for Individual Bridge Placements (Continued)

Bridge Number	Survey # 3			Survey # 4			Survey # 5		
	Date of Survey	Age	Crack Density	Date of Survey	Age	Crack Density	Date of Survey	Age	Crack Density
		(months)	(m/m^2)		(months)	(m/m^2)		(months)	(m/m^2)
LC-HPC-1	6/17/2008	32.1	0.044	6/17/2009	44.1	0.060	6/3/2010	55.6	0.032
	6/17/2008	31.5	0.024	6/17/2009	43.5	0.125	6/3/2010	55.0	0.023
	6/17/2008	--	0.034	6/17/2009	--	0.093	6/3/2010	--	0.027
LC-HPC-2	5/29/2009	32.5	0.085	5/28/2010	44.5	0.059	8/22/2011	59.3	0.144
Control-1/2	6/17/2008	32.2	0.114	6/17/2009	44.2	0.261	6/3/2010	55.8	0.132
	6/17/2008	31.6	0.091	6/17/2009	43.6	0.133	6/3/2010	55.2	0.106
	6/17/2008	-	0.099	6/17/2009	-	0.184	6/3/2010	-	0.115
LC-HPC-3	6/28/2010	31.5	0.108	6/1/2011	42.6	0.315	5/14/2012	54.0	0.173
Control-3	6/28/2010	35.4	0.232	6/7/2011	46.6	0.323	5/14/2012	57.9	0.314
LC-HPC-4	6/24/2010	32.8	0.231	6/30/2011	45.0	0.167	5/30/2012	56.0	0.184
	6/24/2010	32.7	0.094	6/30/2011	44.9	0.080	5/30/2012	55.9	0.092
Control-4	7/5/2010	31.6	0.473	6/7/2011	42.7	0.618	6/12/2012	54.9	0.669
LC-HPC-5	6/17/2010	31.1	0.128	6/14/2011	43.0	0.190	5/23/2012	54.3	0.158
Control-5	6/15/2011	30.6	0.738	-	-	-	-	-	-
LC-HPC-6	6/17/2010	31.4	0.231	6/14/2011	43.3	0.336	5/23/2012	54.6	0.362
Control-6	6/14/2011	31.8	0.456	5/30/2012	43.0	0.539	6/19/2013	56.0	0.46
LC-HPC-7	5/18/2009	34.8	0.012	5/18/2010	46.8	0.005	5/23/2011	58.9	0.048
Control-7	6/4/2009	38.2	1.003	7/1/2010	51.1	1.037	6/7/2011	62.3	0.957
	6/4/2009	32.6	0.277	7/1/2010	45.5	0.359	6/7/2011	56.7	0.653
LC-HPC-8	7/5/2011	45	0.380	5/15/2012	55.4	0.383	5/22/2013	67.7	0.373
LC-HPC-10	7/5/2011	49.6	0.088	5/15/2012	60	0.125	5/22/2013	72.2	0.069

Source: Lindquist et al. (2008); Gruman et al. (2009); McLeod et al. (2009); Yuan et al. (2011); Pendergrass et al. (2011); Kaul et al. (2012); Bohaty et al. (2013); Pendergrass and Darwin (2014); and Alhmood et al. (2015)

Table C.1: Crack Densities for Individual Bridge Placements (Continued)

Bridge Number	Survey # 9			Survey # 10		
	Date of Survey	Age	Crack Density	Date of Survey	Age	Crack Density
		(months)	(m/m^2)		(months)	(m/m^2)
LC-HPC-1	5/19/2014	103.1	0.050	5/18/2015	115.1	0.037
	5/19/2014	102.5	0.027	5/18/2015	114.5	0.055
	5/19/2014	-	0.038	5/18/2015	-	0.045
LC-HPC-2	5/19/2015	104.2	0.222	-	-	-
Control-1/2	5/19/2014	103.3	0.106	5/18/2015	115.6	0.239
	5/19/2014	102.7	0.217	5/18/2015	115.3	0.164
	5/19/2014	-	0.151	5/18/2015	-	0.186
LC-HPC-3	-	-	-	-	-	-
Control-3	-	-	-	-	-	-
LC-HPC-4	-	-	-	-	-	-
	-	-	-	-	-	-
Control-4	-	-	-	-	-	-
LC-HPC-5	-	-	-	-	-	-
Control-5	-	-	-	-	-	-
LC-HPC-6	-	-	-	-	-	-
Control-6	-	-	-	-	-	-
LC-HPC-7	5/21/2015	106.9	0.036	-	-	-
Control-7	-	-	-	-	-	-
	-	-	-	-	-	-
LC-HPC-8	-	-	-	-	-	-
LC-HPC-10	-	-	-	-	-	-

Source: Lindquist et al. (2008); Gruman et al. (2009); McLeod et al. (2009); Yuan et al. (2011); Pendergrass et al. (2011); Kaul et al. (2012); Bohaty et al. (2013); Pendergrass and Darwin (2014); and Alhmood et al. (2015)

Table C.1: Crack Densities for Individual Bridge Placements (Continued)

Bridge Number	County and Serial Number	Portion Placed	Date of Placement	Survey # 1			Survey # 2		
				Date of Survey	Age (months)	Crack Density (m/m^2)	Date of Survey	Age (months)	Crack Density (m/m^2)
Control-8/10	54-59	Deck	4/16/2007	6/26/2008	14.4	0.177	5/31/2009	25.5	0.127
LC-HPC-9	54-57	Deck	4/15/2009	6/4/2010	13.6	0.130	6/30/2011	26.5	0.237
Control-9	54-58	West	5/21/2008	5/28/2010	24.2	0.368	6/28/2011	37.2	0.553
		East	5/29/2008	5/28/2010	24.0	0.395	6/28/2011	37	0.577
LC-HPC-11	78-119	Deck	6/9/2007	5/20/2009	23.4	0.059	6/15/2010	36.2	0.241
Control-11	56-155	Deck	3/28/2006	8/13/2007	16.5	0.351	6/30/2008	27.1	0.665
LC-HPC-12	56-57	East	4/4/2008	8/13/2009	16.3	0.271	6/29/2010	26.8	0.256
		West	3/18/2009	8/13/2009	4.9	0.254	6/29/2010	15.4	0.244
Control-12	56-57	East	4/1/2008	8/13/2009	16.4	0.606	6/29/2010	26.9	0.669
		West	4/14/2009	-	-	-	6/29/2010	14.5	0.442
LC-HPC-13	54-66	Deck	4/29/2008	6/24/2009	13.8	0.050	5/24/2010	24.8	0.129
Control-13	54-67	Deck	7/25/2008	6/24/2009	11.0	0.028	5/24/2010	21.9	0.154
LC-HPC-15	46-351	Deck	11/10/2010	6/8/2012	18.9	0.211	6/3/2013	30.8	0.161
LC-HPC-16	46-352	Deck	10/28/2010	6/20/2011	7.7	0.092	6/8/2012	19.4	0.249
LC-HPC-17	46-373	Deck	9/28/2011	6/26/2012	8.9	0.226	6/14/2013	20.5	0.240

Source: Lindquist et al. (2008); Gruman et al. (2009); McLeod et al. (2009); Yuan et al. (2011); Pendergrass et al. (2011); Kaul et al. (2012); Bohaty et al. (2013); Pendergrass and Darwin (2014); and Alhmood et al. (2015)

Table C.1: Crack Densities for Individual Bridge Placements (Continued)

Bridge Number	Survey # 3			Survey # 4			Survey # 5		
	Date of Survey	Age (months)	Crack Density (m/m^2)	Date of Survey	Age (months)	Crack Density (m/m^2)	Date of Survey	Age (months)	Crack Density (m/m^2)
Control-8/10	5/22/2010	37.2	0.137	7/5/2011	50.6	0.326	6/4/2012	61.6	0.425
LC-HPC-9	6/25/2012	38.3	0.362	5/24/2013	49.3	0.299	-	-	-
Control-9	6/25/2012	49.1	0.637	5/24/2013	60.1	0.645	-	-	-
	6/25/2012	48.9	0.501	5/24/2013	59.8	0.564	-	-	-
LC-HPC-11	6/22/2011	48.4	0.370	7/10/2012	61	0.260	6/11/2013	72.1	0.42
Control-11	5/21/2009	37.8	0.599	6/2/2010	50.2	0.636	6/23/2011	62.9	0.923
LC-HPC-12	6/28/2011	38.8	0.315	5/21/2012	49.5	0.450	8/19/2013	64.5	0.478
	6/28/2011	27.4	0.268	5/21/2012	38.1	0.375	8/19/2013	53.1	0.381
Control-12	6/29/2011	38.9	0.767	5/21/2012	49.6	0.857	8/19/2013	64.6	0.838
	6/29/2011	26.5	0.799	5/21/2012	37.2	0.831	8/19/2013	52.5	0.88
LC-HPC-13	6/1/2011	37.1	0.364	5/29/2012	49	0.342	7/25/2013	62.9	0.576
Control-13	6/6/2011	34.4	0.524	5/29/2012	46.1	0.543	7/25/2013	60	0.807
LC-HPC-15	-	-	-	-	-	-	-	-	-
LC-HPC-16	6/3/2013	31.2	0.211	-	-	-	-	-	-
LC-HPC-17	-	-	-	-	-	-	-	-	-

Source: Lindquist et al. (2008); Gruman et al. (2009); McLeod et al. (2009); Yuan et al. (2011); Pendergrass et al. (2011); Kaul et al. (2012); Bohaty et al. (2013); Pendergrass and Darwin (2014); and Alhmood et al. (2015)

Table C.1: Crack Densities for Individual Bridge Placements (Continued)

Bridge Number	Survey # 6			Survey # 7			Survey # 8		
	Date of Survey	Age	Crack Density	Date of Survey	Age	Crack Density	Date of Survey	Age	Crack Density
		(months)	(m/m^2)		(months)	(m/m^2)		(months)	(m/m^2)
Control-8/10	8/1/2013	75.5	0.581	7/23/2014	87.2	0.566	6/19/2015	98.1	0.680
LC-HPC-9	6/2/2015	73.6	0.43	-	-	-	-	-	-
Control-9	6/1/2015	84.4	0.722	-	-	-	-	-	-
	6/1/2015	84.1	0.845	-	-	-	-	-	-
LC-HPC-11	7/3/2014	84.8	0.842	-	-	-	-	-	-
Control-11	7/3/2012	75.2	0.849	6/6/2013	86.3	0.657	5/27/2014	98	0.7
LC-HPC-12	8/13/2014	76.3	0.789	-	-	-	-	-	-
	8/13/2014	64.9	0.54	-	-	-	-	-	-
Control-12	8/13/2014	76.4	1.141	-	-	-	-	-	-
	8/13/2014	64	1.163	-	-	-	-	-	-
LC-HPC-13	8/4/2014	75.2	0.471	6/24/2015	85.9	0.486	-	-	-
Control-13	8/8/2014	72.5	0.711	6/22/2015	84.1	0.718	-	-	-
LC-HPC-15	-	-	-	-	-	-	-	-	-
LC-HPC-16	-	-	-	-	-	-	-	-	-
LC-HPC-17	-	-	-	-	-	-	-	-	-

Source: Lindquist et al. (2008); Gruman et al. (2009); McLeod et al. (2009); Yuan et al. (2011); Pendergrass et al. (2011); Kaul et al. (2012); Bohaty et al. (2013); Pendergrass and Darwin (2014); and Alhmood et al. (2015)

Table C.2: Average Properties for the Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks

LC-HPC Number	Portion Placed	Date of Placement	Average Air Content	Average Slump		Average Concrete Temperature		Average Unit Weight		Average Compressive Strength†	
				(mm)	(in.)	(°C)	(°F)	(kg/m^3)	(lb/ft^3)	(MPa)	(psi)
1	South	10/14/2005	7.9	95	3.75	19.8	68	2251	140.5	35.9	5210
	North	11/2/2005	7.8	85	3.25	20.1	68	2238	139.7	34.4	4980
2	Deck	9/13/2006	7.7	75	3.00	19.2	67	--	--	31.7	4600
3	Deck	11/13/2007	8.7	85	3.25	14.3	58	--	--	41.3	5990
4	Deck - South	9/29/2007	8.7	50	2.00	--	--	2202	137.4	--	--
	Deck - North	10/2/2007	8.8	80	3.00	17.5	64	2210	137.9	33.1	4790
5	Deck - 0.420 *w/c*	11/14/2007	8.3	70	2.75	16.7	62	2249	140.4	44.0	6380
	Deck - 0.428 *w/c*	11/14/2007	9.0	60	2.50	16.4	62	2242	140.0	--	--
	Deck - 0.429 *w/c*	11/14/2007	9.1	90	3.50	15.2	59	2230	139.2	--	--
	Deck - 0.451 *w/c*	11/14/2007	8.7	80	3.25	15.7	60	2228	139.1	--	--
	Average Values	11/14/2007	8.7	80	3.00	15.9	61	2236	139.6	--	--
6	Deck	11/3/2007	9.5	95	3.75	15.3	60	--	--	40.3	5840

†Average 28-day compressive strength for lab-cured specimens. Strengths were taken at 27 days for the first LC-HPC-1 placement and LC-HPC-11, and 31 days for LC-HPC-7

Source: Lindquist et al. (2008); McLeod et al. (2009); Pendergrass et al. (2011)

Table C.2: Average Properties for the Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks (Continued)

LC-HPC Number	Portion Placed	Date of Placement	Average Air Content	Average Slump		Average Concrete Temperature		Average Unit Weight		Average Compressive Strength[†]	
				(mm)	(in.)	(°C)	(°F)	(kg/m^3)	(lb/ft^3)	(MPa)	(psi)
7	Deck	6/24/2006	8.0	95	3.75	21.9	71	2221	138.6	26.1	3790
8	Deck	10/3/2007	7.9	50	2.00	19.5	67	2264	141.3	32.6	4730
9	Deck	4/15/2009	6.7	90	3.50	17.9	64	2264	141.3	28.9	4190
10	Deck	5/17/2007	7.3	80	3.25	18.6	66	2212	138.1	31.6	4580
11	Deck	6/9/2007	7.8	80	3.00	15.8	60	2278	142.2	32.3	4680
12	Deck - East	4/4/2008	7.4	70	2.75	14.5	58	2259	141.0	31.5	4570
	Deck - West	3/18/2009	7.8	104	4.10	19.0	67	--	--	28.8 (0.45 *w/c*) 31.6 (0.44 *w/c*)	4180 (0.45 *w/c*) 4580 (0.44 *w/c*)
13	Deck	4/29/2008	8.1	75	3.00	20.4	69	2266	141.5	29.5	4280
OP	Deck - Center	12/19/2007	8.7	95	3.75	18.1	65	2237	139.7	30.6	4440
	Deck - West	5/2/2008	9.8	110	4.25	17.9	64	2213	138.1	25.6	3710
	Deck - East	5/21/2008	9.9	130	5.25	18.3	65	2195	137.1	26.4	3830
15	Deck	11/10/2010	9.0	84	3.30	17.2	63	2201	137.4	30.6	4440
16	Deck	10/28/2010	6.4	97	3.80	15.0	59	2260.6195	141.1	34.8	5043
17	Deck	9/28/2011	7.5	64	2.50	22.2	72	2245	140.1	34.5	5007

Source: Lindquist et al. (2008); McLeod et al. (2009); Pendergrass et al. (2011)

Table C.3: Average Properties for Control Bridge Decks

Control Number	Portion Placed	Date of Placement	Average Air Content	Average Slump		Average Concrete Temperature		Average Unit Weight		Average Compressive Strength[†]	
				(mm)	(in.)	(°C)	(°F)	(kg/m^3)	(lb/ft^3)	(MPa)	(psi)
1/2	Subdeck - North	9/30/2005	5.3	110	4.25	19.0	66	2318	144.7	39.1	5670
	Overlay - North	10/10/2005	5.5	125	5.00	18.0	64	2281	142.4	40.1	5810
	Subdeck - South	10/18/2005	6.5	80	3.25	24.7	76	2274	142.4	35.1	5090
	Overlay - South	10/28/2005	7.0	115	4.50	20.0	68	2254	140.7	55.6 (31 days)	8060 (31 days)
3	Subdeck	7/6/2007	5.8	170	6.75	27.1	81	2251	140.5	39.2	5690
	Overlay	7/17/2007	7.3	185	7.25	29.9	86	2249	140.4	57.6	8350
4	Subdeck	10/20/2007	7.3	195	7.75	22.8	73	2240	139.9	43.7	6340
	Overlay	11/16/2007	6.9	145	5.75	20.0	68	2239	140.0	53.0	7700
5	Subdeck - Seq. 1 & 2	11/8/2008	5.6	200	7.75	19.0	66	2278	142.2	--	--
	Subdeck - Seq. 3, 5, & 6	11/13/2008	6.8	230	9.25	20.0	68	2245	140.1	--	--
	Subdeck - Seq. 4 & 7	11/17/2008	5.5	205	8.00	17.0	63	2275	142.0	--	--
	Overlay - West	11/22/2008	7.6	150	6.00	18.0	64	2250	140.5	--	--
	Overlay - East	11/25/2008	6.6	230	9.00	17.0	63	2262	141.2	--	--
6	Subdeck - Seq. 1 & 2	9/16/2008	7.4	205	8.00	24.0	75	2238	139.7	34.1	4950
	Subdeck - Seq. 3	9/18/2008	7.3	180	7.00	21.0	70	2246	140.2	--	--
	Subdeck - Seq. 5, & 6	9/23/2008	6.4	175	6.75	31.0	88	2261	141.1	--	--
	Subdeck - Seq. 4	9/26/2008	6.6	160	6.25	30.0	86	2254	140.7	--	--
	Subdeck - Seq. 7	9/30/2008	5.5	225	8.75	26.0	79	2269	141.6	--	--
	Overlay - West	10/16/2008	7.7	175	7.00	22.0	72	2258	141.0	--	--
	Overlay - East	10/20/2008	8.1	210	8.25	22.0	72	2231	139.3	53.1	7700

[†] Average 28-day compressive strength for lab-cured specimens. Strengths were taken at 31 days for the second overlay placement for Control-1/2

Source: Lindquist et al. (2008); McLeod et al. (2009); Pendergrass et al. (2011)

Table C.3: Average Properties for Control Bridge Decks (Continued)

Control Number	Portion Placed	Date of Placement	Average Air Content	Average Slump		Average Concrete Temperature		Average Unit Weight		Average Compressive Strength†	
				(mm)	(in.)	(°C)	(°F)	(kg/m^3)	(lb/ft^3)	(MPa)	(psi)
7	Subdeck - East	3/15/2006	5.9	235	9.25	26.5	80	2239	139.8	38.2	5540
	Overlay - East	3/29/2006	7.4	190	7.50	23.0	73	2239	139.8	--	--
	Subdeck - West	8/16/2006	7.3	195	7.75	21.3	70	2226	139.0	37.9	5500
	Overlay - West	9/15/2006	6.4	175	7.00	18.0	64	2252	140.6	50.8	7370
8/10	Deck	4/16/2007	7.4	130	5.00	21.2	70	2234	139.4	33.3	4830
9	Overlay - West	5/21/2008	5.6	90	3.50	24.7	77	2282	142.4	44.0	6380
	Overlay - East	5/28/2008	6.2	130	5.00	21.7	71	2262	141.2	42.6	6170
11	Subdeck - North	2/3/2006	6.8	90	3.50	22.0	72	2263	141.3	40.6	5890
	Subdeck - South	2/14/2006	7.0	135	5.25	23.0	73	2252	140.6	37.5	5440
	Overlay	3/28/2006	6.0	80	5.00	15.5	60	2277	142.1	52.7	7640
12	Subdeck - Phase 1	3/11/2008	6.9	110	4.25	21.9	72	2250	140.5	36.4	5270
	Overlay - Phase 1	4/1/2008	6.8	95	3.75	14.8	59	2254	140.7	43.0	6240
	Subdeck - Phase 2	3/13/2009	7.2	120	4.75	22.0	72	--	--	34.3	4980
	Overlay - Phase 2	4/14/2009	7.7	57	2.25	16.7	62	--	--	53.1	7710
13	Subdeck	7/11/2008	5.8	90	3.50	31.7	89	2271	141.7	--	--
	Overlay	7/25/2008	6.3	135	5.25	33.0	91	2269	141.6	57.1	8280
Alt	Deck	6/2/2005	5.9	85	3.00	--	--	2255	140.8	38.0	5510

Source: Lindquist et al. (2008); McLeod et al. (2009); Pendergrass et al. (2011)

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