CRACK SURVEYS OF LOW-CRACKING HIGH-PERFORMANCE CONCRETE BRIDGE DECKS IN KANSAS 2009-2010

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CONSTRUCTION OF CRACK-FREE BRIDGE DECKS
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ABSTRACT

The specifications for the construction of Low-Cracking High-Performance Concrete (LC-HPC) bridge decks are summarized and the survey procedure used for analysis of cracking performance of bridge decks is described. Thirteen LC-HPC decks and thirteen control decks were evaluated using the survey procedure. Crack densities were calculated and crack locations marked. LC-HPC bridge decks have significantly lower crack densities than do the control bridge decks. The majority of cracks develop in the transverse direction, directly above and parallel to the reinforcing steel. Longitudinal cracks often propagate from the abutments. The results suggest that crack densities will increase on the upper portions of superelevated decks due to increased settlement cracking caused by the use of high slump concrete and less than optimum curing when water is not directly supplied to the superelevated side of the deck. Overfinishing of concrete by means of a double-drum roller screed may increase cracking by increasing the amount of cement paste at the deck surface.

Key Words: bridge decks, cracking, high performance concrete

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INTRODUCTION

Cracking of reinforced concrete bridge decks decreases the protection provided by the concrete to the reinforcing steel, which can lead to the early onset of corrosion (Lindquist, Darwin, and Browning 2005, 2006). Cracks in bridge decks can also accelerate freeze-thaw damage by allowing water to penetrate and expand in the concrete. Factors, such as deck age, construction methods, weather conditions, and concrete properties, affect the amount, type, and location of bridge deck cracks.

As part of the current project, specifications for the construction of Low-Cracking High-Performance Concrete (LC-HPC) bridge decks have been developed to reduce bridge deck cracking. The specifications focus on modifying concrete properties and construction methods to improve cracking performance. Ongoing research works to enhance the LC-HPC specifications by analyzing the causes of cracking and developing means to extend the life of bridge decks.

Fifteen bridge decks have been constructed in Kansas that comply with the Kansas Department of Transportation (KDOT) LC-HPC specification, LC-HPC 1 through 13, 15, and 16. The bridge originally designated as LC-HPC 14 is now designated as OP (for Overland Park) because the contractor did not follow nor did the owner enforce the LC-HPC specifications. The results for LC-HPC 15 and 16 are not presented in this report because they were not constructed until the end of 2010. The cracking performance of LC-HPC bridge decks is determined based on annual crack surveys. The decks are paired with control decks of similar bridge type, age, and environmental exposure to determine the effectiveness of new specifications in reducing cracking. Standard crack survey procedures have been developed to ensure consistency in crack survey data collected over time. This report summarizes crack survey data obtained as part of this program in 2009 and 2010. Crack survey data for 2006 – 2008 are summarized by Gruman, Darwin, and Browning (2009). LC-HPC bridge deck construction experiences and the influence of bridge design parameters and environmental conditions on bridge deck cracking are covered by McLeod, Darwin, and Browning (2009). LC-HPC construction experiences and the impact of deck age on bridge deck cracking are summarized by Lindquist, Darwin, and Browning (2008). The work is also summarized by Darwin et al. (2010).

SPECIFICATIONS

Special provisions to the KDOT standard specifications have been developed for LC-HPC bridge decks, covering the requirements for aggregates, concrete, and construction practices. Summaries of these special provisions are described below.

Aggregates

The provisions cover requirements for both coarse and fine aggregate used in LC-HPC bridge decks. The coarse aggregate must be a gravel, chat, or crushed stone with a minimum soundness of 0.9 and maximum absorption of 0.7. Deleterious substance requirements for coarse aggregate are summarized in Table 1.

Table 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%

Fine aggregate must consist of either natural sand (Type FA-A) or chat (Type FA-B) and must meet requirements of mortar strength per KDOT specifications and organic impurities per

AASHTO specifications. The provisions governing deleterious substances for both types of fine aggregate are shown in Tables 2 and 3.

A proven optimization method, such as the Shilstone or KU Mix Method, must be used for the proportioning the combined aggregate gradation. Precautions must be taken to minimize coarse and fine aggregate segregation during transportation and stockpiling.

Table 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 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%

Concrete

In the current specification, LC-HP concrete must contain between 500 and 540 lb of cement per cubic yard of concrete (297 – 320 kg/m^3) with a water/cement ratio (by weight) ranging between 0.44 and 0.45. The water/cement ratio can be reduced to 0.43 at the construction site with approval from the engineer. The specification for LC-HPC bridge decks 1 through 7 permitted between 522 and 563 lb of cement per cubic yard of concrete (310 – 334 kg/m^3) with a maximum water/cement ratio (by weight) of 0.45. The specification for LC-HPC bridge decks 8 through 13 permitted between 500 and 535 lb of cement per cubic yard of concrete (297 – 317 kg/m^3) with a maximum water/cement ratio (by weight) of 0.42. All LC-HPC decks described in this report contained concrete with a cement content of 535 or 540 lb/yd^3 (317 or 320 kg/m^3). The designated air content (by volume) is between 7.0 and 9.0% with an allowable range of 6.5 to 9.5%. The designated concrete slump range is between 1.5 and 3 in. (38 and 76 mm) at the location of placement. In the current specifications, the engineer must reject any concrete with a slump greater than 3.5 in. (89 mm) at the truck discharge. For the LC-HPC decks described in this report, the specification stated that the engineer must reject any concrete with a slump greater than 4.0 in. (100 mm). Concrete samples for air content and slump tests must be obtained at the discharge end of the conveyor, bucket, or pump piping. Current specifications state that concrete compressive strengths must range between 3500 to 5500 psi (24.1 to 37.9 MPa). No upper concrete compressive strength limitation was included at the time of construction for the LC-HPC decks analyzed in this report. The temperature of the concrete immediately before placement must range between 55 and 70°F (13 and 21°C). The concrete temperature can be 5°F (3°C) below or above this range with engineer approval. For LC-HPC decks 1 and 2, the specification stated that the concrete temperature immediately before placement must range between 50 and 75°F (10 and 24°C) with no adjustment by the engineer.

In the current specifications and the specifications for LC-HPC 12 and 13, mineral, set retarding, and accelerating admixtures were and are prohibited from use in LC-HP concrete. A Type A water reducer or dual-rated Type A water reducer – Type F high-range water reducer may be used when necessary to comply with specified fresh and hardened concrete properties. The specifications for LC-HPC 1 through 11 allowed the use of a Type C or E accelerating admixture if approved by the Engineer. The specifications for LC-HPC 1 through 11 also allowed the use of both water reducing and set retarding admixtures if deemed necessary by the Engineer. Accelerating and retarding admixtures, however, were not used on any LC-HPC bridge decks. Slump control may be accomplished at the construction site only by redosing with a water-reducing admixture. The LC-HPC decks analyzed in this report could only use vinsol resin or a tall oil based air-entraining admixture.

A qualification batch must be completed by the concrete supplier before actual bridge construction to demonstrate an ability to meet all concrete specifications. Actual concrete haul time must be simulated prior to discharge of the qualification batch for testing. The qualification batch must meet required specifications for air content, slump, plastic concrete temperature, compressive strength, and unit weight to be qualified for use in the LC-HPC bridge deck.

Construction

After completion of the qualification batch, a qualification slab must be constructed by the contractor prior to bridge deck construction to demonstrate an ability to handle, place, finish, and cure the LC-HPC bridge deck. The qualification slab must be constructed using the same personnel, construction methods, and equipment as will be used for the actual bridge deck. As with the qualification batch, the concrete delivered to the qualification slab must meet the specifications.

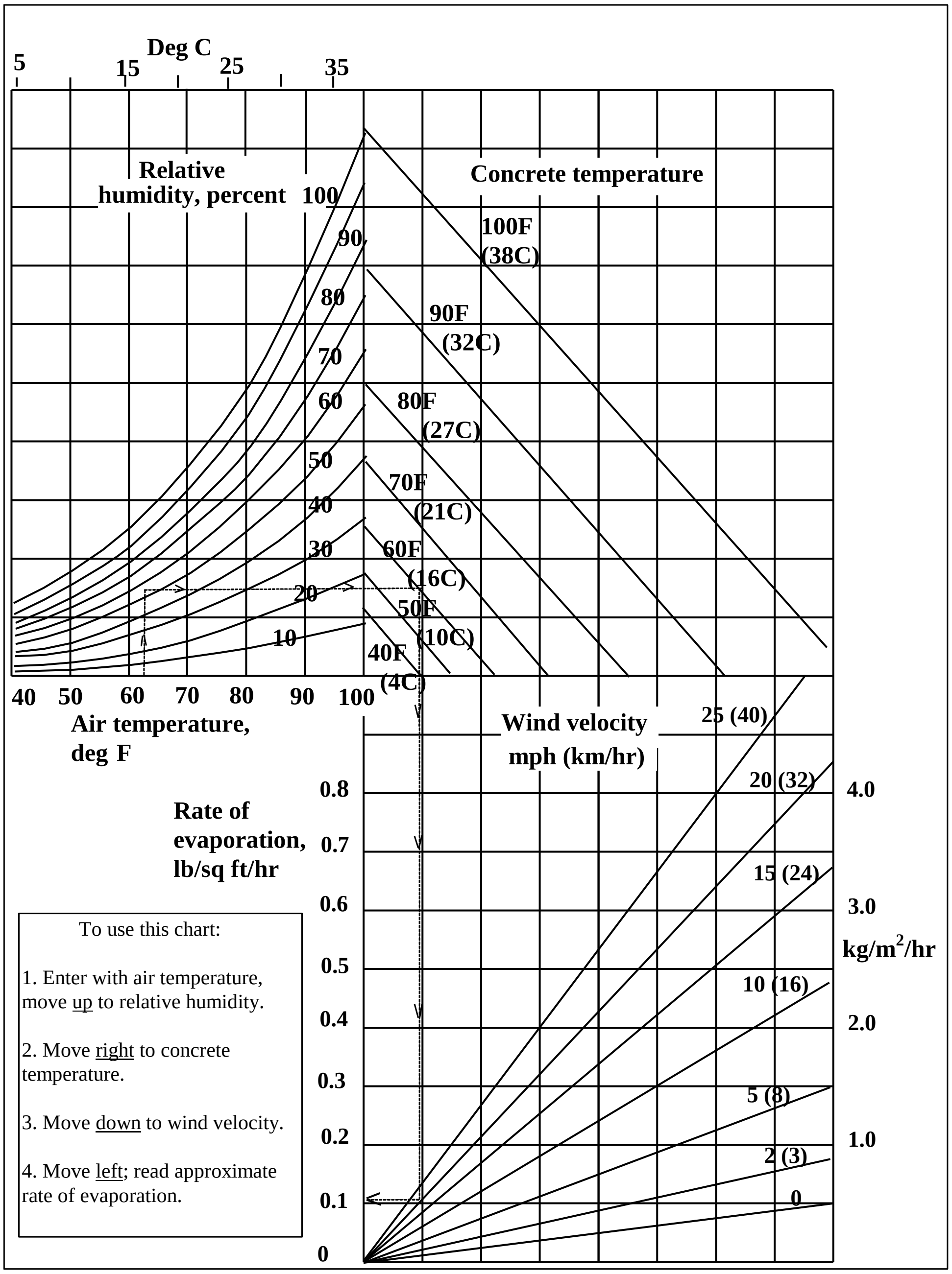
Environmental evaporation rates during deck construction must remain below 0.2 lb/sq ft/hr (1.0 kg/m^2/hr). The engineer must measure and record the air temperature, wind speed, and relative humidity 12 in. (305 mm) above the deck surface as well as concrete temperature at least once per hour during placement to determine evaporation rates using the chart shown in Figure 1. Any fogging used on the deck will not be considered in the estimation of evaporation rate. When the evaporation rate is greater than or equal to 0.2 lb/sq ft/hr (1.0 kg/m^2/hr), actions must be taken, such as concrete cooling or wind break installation, to lower the evaporation rate below the limit level.

Concrete may be placed by conveyor belt or concrete bucket. Concrete pumping is also allowed if the contractor can demonstrate the ability to pump the approved mix (using the same equipment as will be used on the deck) prior to deck construction. To minimize the loss of air, a maximum drop height of 5 ft (1.5 m) is allowed from the end of a conveyor or concrete bucket and all pumps must be fitted with an air cuff or bladder valve.

Concrete consolidation must be performed using machine-mounted internal gang vibrators wherever possible on the deck surface and hand-held vibrators where necessary. Each vibrator must have a head diameter between 1.75 and 2.5 in. (44 and 64 mm), loaded vibration frequency between 8,000 and 12,000 vibrations per minute, and an average vibration amplitude of 0.025 to 0.05 in. (0.635 to 1.27 mm). Vibrators must be inserted vertically, spaced at 12 in. (305 mm), and held in the concrete between 3 and 15 seconds. Vibrators must be extracted vertically at a rate that is slow enough so that no voids are left.

Bridge deck surface strikeoff must be completed using a vibrating or single-drum roller screed. Tamping devices are not allowed to be mounted on roller screeds. The surface should be finished by a burlap drag, metal pan, or both, mounted to the finishing equipment. Irregularities in the surface may be removed, as necessary, using a bullfloat or hand float. Finishing aids, including water, and tining of the plastic concrete are prohibited.

To provide curing, one layer of presoaked burlap must cover the LC-HPC within 10 minutes of strikeoff. A second layer of burlap must be applied within 5 minutes. The burlap must be presoaked a minimum of 12 hours prior to placement, and must remain wet throughout the 14-day curing period. Misting hoses or fogging equipment may be used before the concrete has set up to maintain the burlap in a saturated condition. After the concrete has set, soaker hoses must be placed on the burlap, and the deck must be covered with white plastic to maintain the burlap in a wet condition for the duration of the curing process.



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 1: Evaporation Rate Chart

CRACK SURVEYS

Crack surveys are performed at yearly intervals on each LC-HPC and control bridge deck. The procedures used to conduct these crack surveys are described in this section.

Procedures

Standard procedures are followed for each crack survey to help provide an accurate comparison of results. Surveys are conducted between sunrise and sunset on days that are mostly sunny. Regardless of weather conditions, the bridge decks must be completely dry before the survey can begin, and the air temperature must be 60°F (16°C) or above.

A scaled plan of the deck is created for each bridge deck to serve as a template for indicating locations and lengths of cracks on the actual deck. The plan is created at a scale of 1 in. = 10 ft (25.4 mm = 3.048 m) and should include compass and traffic directions, deck stationing, and a 5 × 5 ft (1.524 × 1.524 m) grid. A scaled grid is placed underneath the deck plan to allow for accurate transfer of data from the deck to the plan.

After traffic has been closed, grid markings are placed on the deck at 5-ft (1.524-m) increments in the longitudinal and transverse directions using a lumber crayon or sidewalk chalk, corresponding with the scaled bridge deck plan. The survey process consists of surveyors marking visible cracks with lumber crayons or sidewalk chalk as they walk over the entire deck. Surveyors bend at the waist and mark cracks that can be seen from this position. After a crack has been located from this position, the surveyor is allowed to get a closer view of the crack to complete the trace to the end of the crack. At least one other surveyor will then recheck the marked portion of the deck for additional cracks. This method has been shown to provide a consistent measure of cracking from bridge to bridge (Lindquist et al. 2005, 2008). Another surveyor will transfer the marked cracks on the deck to the scaled crack map, using the scaled grid to accurately represent crack locations and lengths.

Once a survey is complete, the crack maps are scanned and prepared for computer analysis. Each scanned map is edited so that pixels are darkened to the proper shade and crack lines are continuous from beginning to end. All non-crack lines on the scanned crack map, including deck boundaries, stationing, and compass direction, must be erased in the scanned image so that only the pixels from the cracks are analyzed. Nonlinear cracks are broken into shorter linear segments by removing single pixels so the analysis program, which measures between end points, can accurately calculate total crack lengths. The analysis program tracks the number of adjacent pixels (that are sufficiently dark) (Lindquist et al. 2005). Crack densities for the entire deck, as well as various portions of the deck, are measured and reported. The complete specification of the survey process and requirements is presented in Appendix A.

Results

The bridge decks described in this report are supported by steel girders, with the exception of LC-HPC-8, LC-HPC-10, Control-8/10, and OP-Extra, which are supported by precast, prestressed concrete girders. The decks are numbered in the order in which they were bid, not the order in which they were constructed.

Table B.1 in Appendix B shows the crack densities for each crack survey performed as part of this project. The crack maps corresponding to the surveys completed in 2009 and 2010 are shown on the following pages. Crack survey data from 2006 through 2008 are summarized by Gruman et al. (2009). LC-HPC bridge deck construction experiences and the influence of bridge design parameters and environmental conditions on bridge deck cracking is covered by

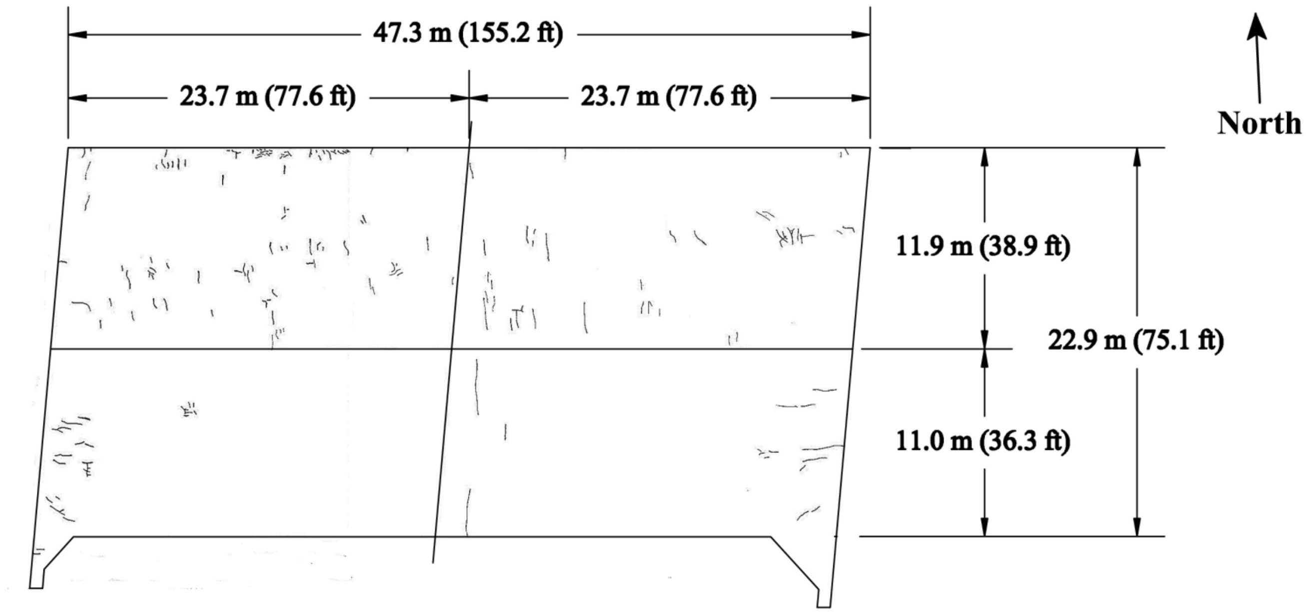
McLeod et al. (2009). LC-HPC construction experiences and the impact of deck age on bridge deck cracking is summarized by Lindquist et al. (2008)

LC-HPC-1

LC-HPC-1 was cast in two placements separated by 19 days. Survey 4 at 43.5 and 44.1 months and Survey 5 at 55.0 and 55.6 months are included in this report. For Survey 4 (43.5 and 44.1 months), the total deck crack density was 0.093 m/m^2, as shown in Figure 2. Approximately twice as much cracking was observed on the second placement (north) as on the first placement (0.125 m/m^2 vs. 0.060 m/m^2). This observation differs from the previous crack survey at approximately 32 months, where the first placement displayed more cracking than the second placement (0.044 m/m^2 vs. 0.024 m/m^2) (Gruman et al. 2009). During Survey 4, significant map cracking was observed throughout the second placement. A few long cracks were found near and parallel to the pier at midspan, the negative moment region of the bridge. The majority of cracks found at 44 months were longitudinal near the abutments, parallel with the length of the bridge; this cracking was most likely due to the restraint provided by the abutments. At ages of 55.0 and 55.6 months (Survey 5), the total deck crack density was significantly lower, at 0.027 m/m^2. The cracks that were not marked in the 55 month survey were the smaller cracks in Survey 4 and could have been overlooked by the surveyors.

Control-1/2

Control-1/2 was also cast in two placements. Survey 4 at 43.6 and 44.2 months and Survey 5 at 55.2 and 55.8 months are included in this report. After 44.2 months (Placement 1) and 43.6 months (Placement 2), this deck exhibited an overall crack density of 0.184 m/m^2, as shown in Figure 4, nearly double the value from the previous year, of 0.099 m/m^2, when the two placements were, respectively 32.2 and 31.6 months old (Gruman et al. 2009).

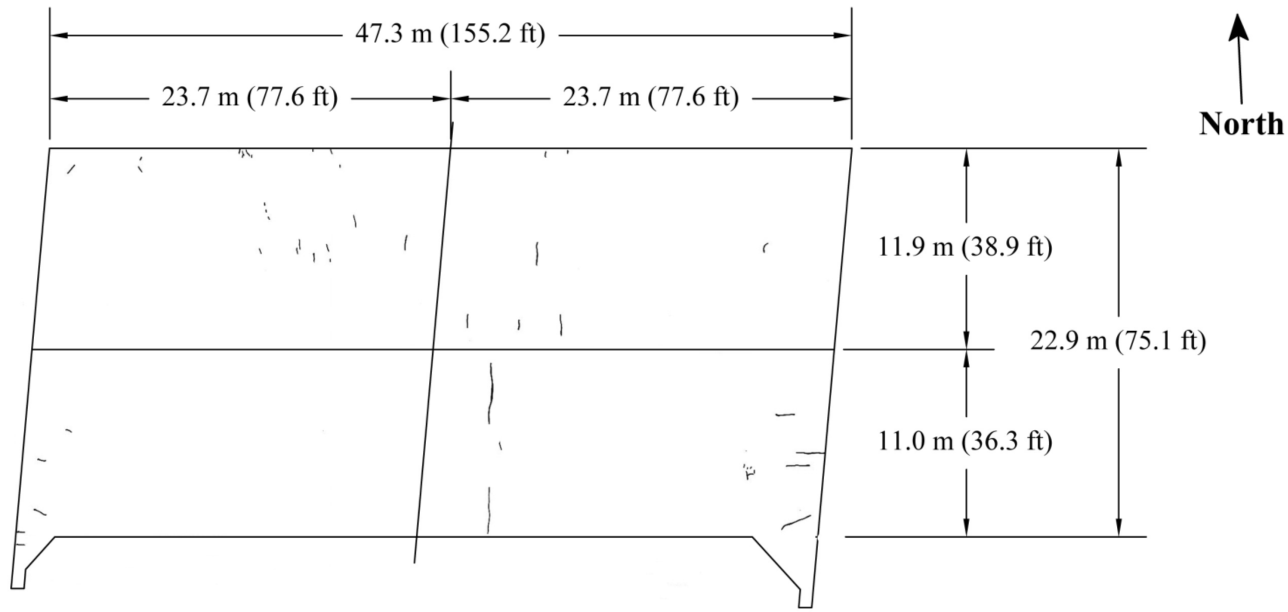


Bridge Number: 105-304 (KU #1)
Bridge Location: EB Parallel Pkwy over I-635
Construction Date:
Placement 1 (South): 10/14/2005
Placement 2 (North): 11/2/2005
Crack Survey Date: 6/17/2009

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: 44.1 months
Placement 2: 43.5 months
Crack Density: 0.093 m/m²
Placement 1: 0.060 m/m²
Placement 2: 0.125 m/m²
Span 1: 0.100 m/m²
Span 2: 0.085 m/m²

Figure 2: LC-HPC-1 (Survey 4)

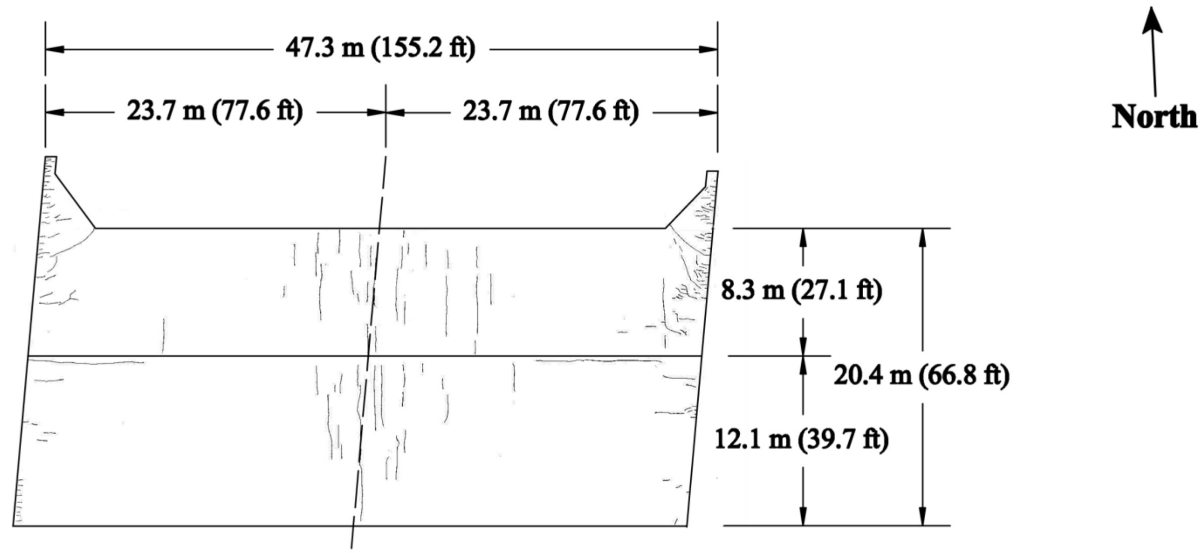


Bridge Number: 105-304 (KU #1)
Bridge Location: EB Parallel Pkwy over I-635
Construction Date:
Placement 1 (South): 10/14/2005
Placement 2 (North): 11/2/2005
Crack Survey Date: 6/3/2010

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: 55.6 months
Placement 2: 55.0 months
Crack Density: 0.027 m/m^2
Placement 1: 0.032 m/m^2
Placement 2: 0.023 m/m^2
Span 1: 0.020 m/m^2
Span 2: 0.035 m/m^2

Figure 3: LC-HPC-1 (Survey 5)



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: 6/17/2009

Bridge Length: 47.3 m (155.2 ft)
Bridge Width: 20.4 m (66.8 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): 44.2 months
Placement 2 (S): 43.6 months
Crack Density: 0.184 m/m²
Placement 1: 0.261 m/m²
Placement 2: 0.133 m/m²
Span 1: 0.159 m/m²
Span 2: 0.208 m/m²

Figure 4: Control-1/2 (Survey 4)

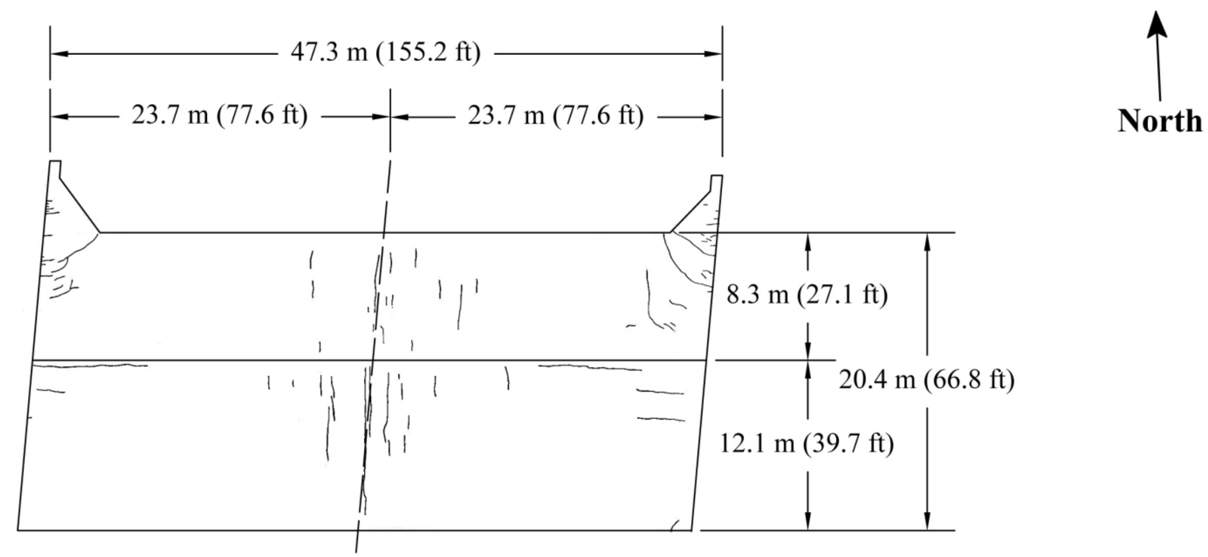
Placement 1 exhibited over twice the crack density of Placement 2 (0.261 m/m^2 vs. 0.133 m/m^2). A majority of the cracks were small, longitudinal cracks near the abutments on Placement 1. As with LC-HPC-1, this cracking is likely due to restraint provided by the abutments. Long cracks were found near and parallel to the pier, similar to LC-HPC-1. At ages of 55.8 and 55.2 months (Figure 5), the total deck crack density of 0.115 m/m^2 is, like that of Survey 5 for LC-HPC 1, lower than the value obtained in Survey 4. The unmarked cracks in the most recent survey were small and could have been overlooked by the surveyors.

LC-HPC-2

Surveys 3 and 4 of LC-HPC-2, at 32.5 and 44.5 months, are included in this report. Surveys 3 and 4 produced crack densities of 0.085 m/m^2 after 32.5 months and 0.059 m/m^2 after 44.5 months, as shown in Figures 6 and 7, respectively. These crack density values are over twice as high as the previous value, 0.028 m/m^2, at 21.2 months, reported by Gruman et al. (2009). The majority of the cracks are parallel to the pier in the negative moment region. The crack density after 43.6 and 44.2 months for Control-1/2 is more than three times the crack density of LC-HPC-2 at 44.5 months (0.184 m/m^2 vs. 0.059 m/m^2).

LC-HPC-3

Surveys 2 and 3 of LC-HPC-3, at 19.2 and 31.5 months, are included in this report. The crack density of LC-HPC-3 at 19.2 months was 0.110 m/m^2, as shown in Figure 8. At 31.5 months, the crack density remained constant at 0.108 m/m^2, shown in Figure 9. These values represent significant increases from the crack density at 6.5 months, 0.028 m/m^2 (Gruman et al. 2009). The majority of the cracks at both 19.2 months and 31.5 months occur near and parallel to the first and third piers, as shown in Figures 8 and 9. No significant cracking has occurred near the second (middle) pier.



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: 6/3/2010

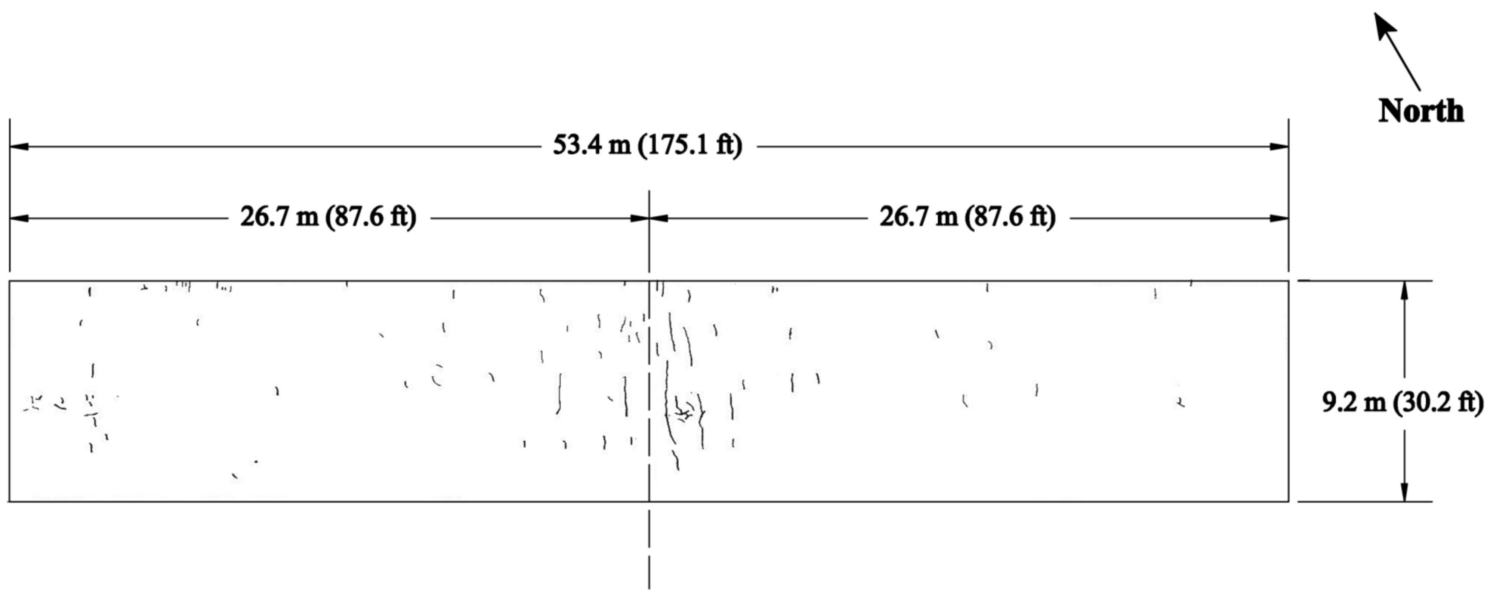
Bridge Length: 47.3 m (155.2 ft)
Bridge Width: 20.7 m (67.8 ft)
Skew: 5°
Number of Spans: 2
- **Span 1 (West):** 23.7 m (77.6 ft)
- **Span 2 (East):** 23.7 m (77.6 ft)

Number of Placements: 2

Bridge Age:
- **Placement 1 (N):** 55.8 months
- **Placement 2 (S):** 55.2 months

Crack Density: 0.115 m/m²
- **Placement 1:** 0.132 m/m²
- **Placement 2:** 0.106 m/m²
- **Span 1:** 0.108 m/m²
- **Span 2:** 0.126 m/m²

Figure 5: Control-1/2 (Survey 5)

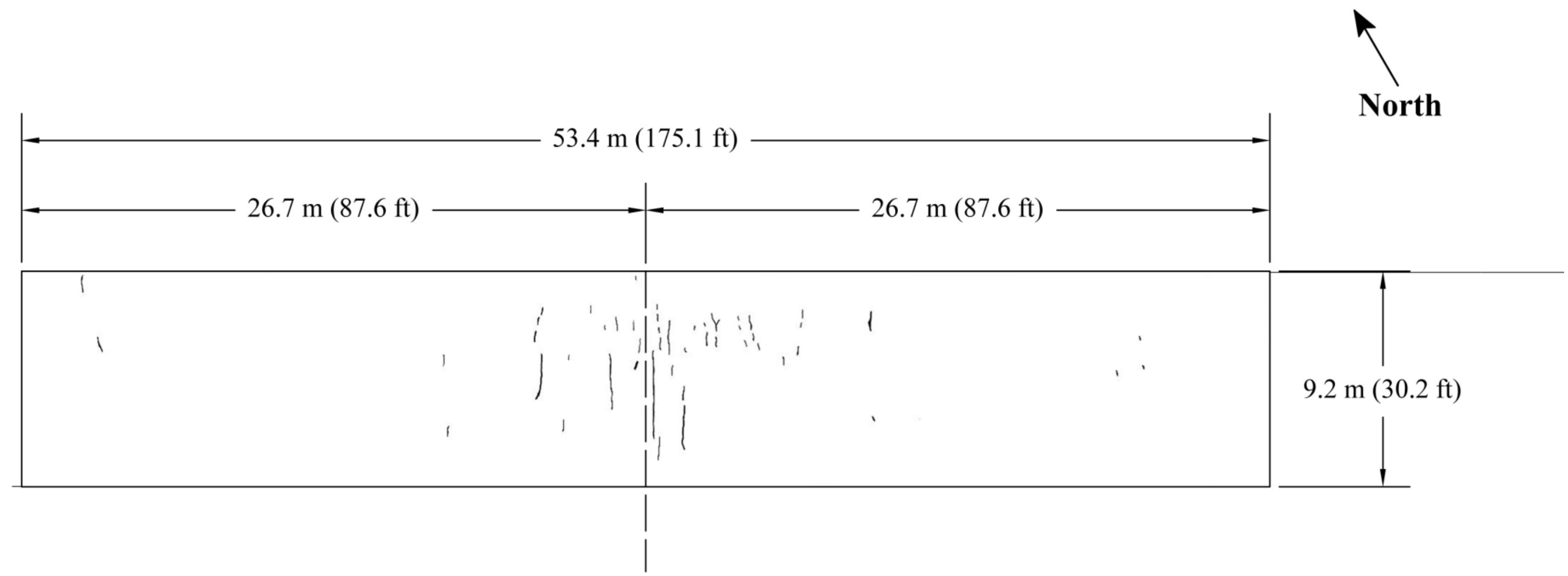


Bridge Number: 105-310 (KU #2)
Bridge Location: 34th St over I-635
Construction Date: 9/13/2006
Crack survey Date: 5/29/2009

Bridge Length: 53.4 m (175.1 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: 32.5 months
Crack density: 0.085 m/m²
Span 1 (West): 0.081 m/m²
Span 2 (East): 0.090 m/m²

Figure 6: LC-HPC-2 (Survey 3)

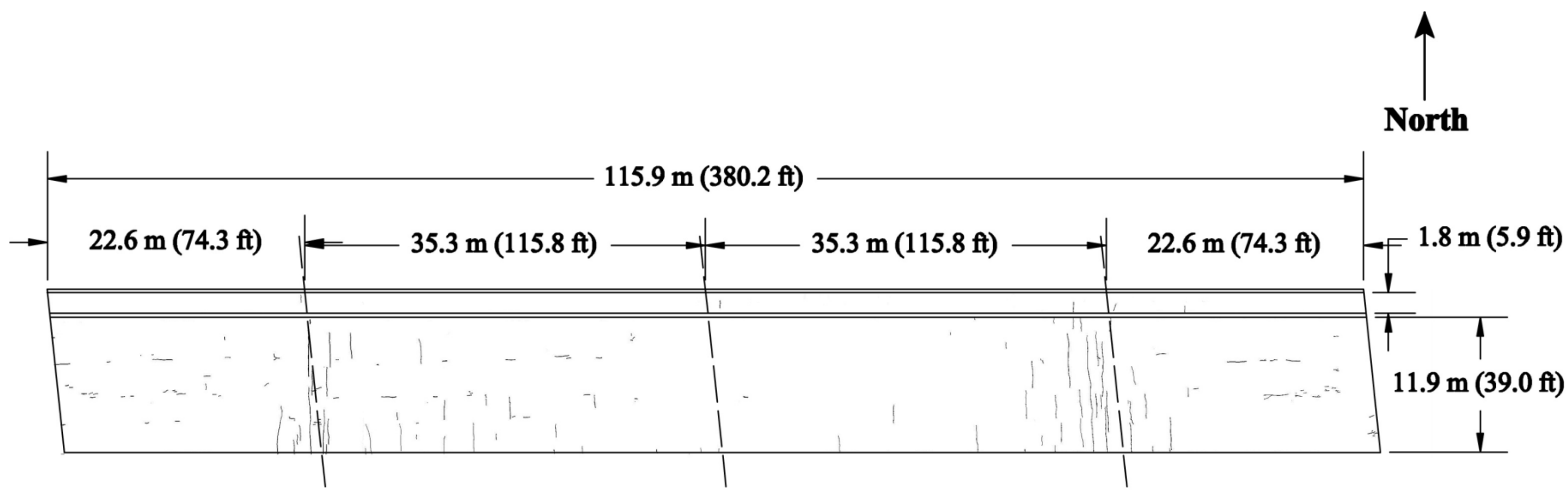


Bridge Number: 105-310 (KU #2)
Bridge Location: 34th St over I-635
Construction Date: 9/13/2006
Crack survey Date: 5/28/2010

Bridge Length: 53.4 m (175.1 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: 44.5 months
Crack density: 0.059 m/m^2
Span 1 (West): 0.046 m/m^2
Span 2 (East): 0.072 m/m^2

Figure 7: LC-HPC-2 (Survey 4)



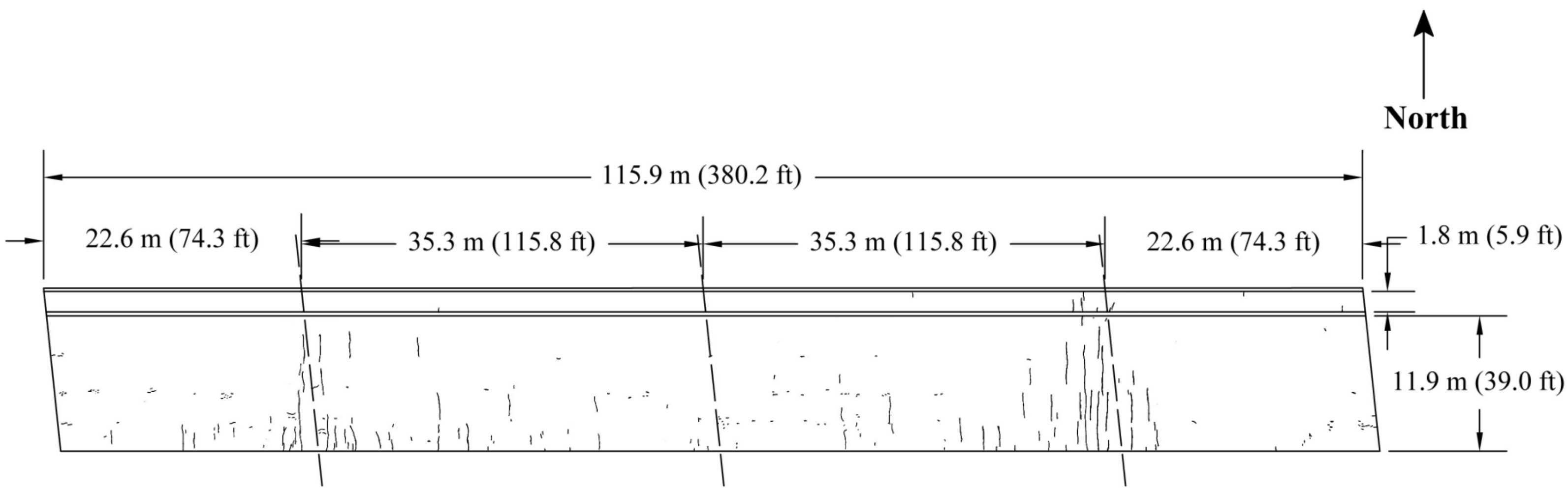
Bridge Number: 46-338 (KU #3)
Bridge Location: WB 103rd St over US 69
Construction Date: 11/13/2007
Crack survey Date: 6/18/2009

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: 19.2 months
Crack density: 0.110 m/m²
- **Span 1 :** 0.116 m/m²
- **Span 2 :** 0.099 m/m²
- **Span 3 :** 0.128 m/m²
- **Span 4 :** 0.094 m/m²

Figure 8: LC-HPC-3 (Survey 2)



Bridge Number: 46-338 (KU #3)
Bridge Location: WB 103rd St over US 69
Construction Date: 11/13/2007
Crack survey Date: 6/28/2010

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: 31.5 months
Crack density: 0.108 m/m^2
Span 1 : 0.098 m/m^2
Span 2 : 0.091 m/m^2
Span 3 : 0.146 m/m^2
Span 4 : 0.060 m/m^2

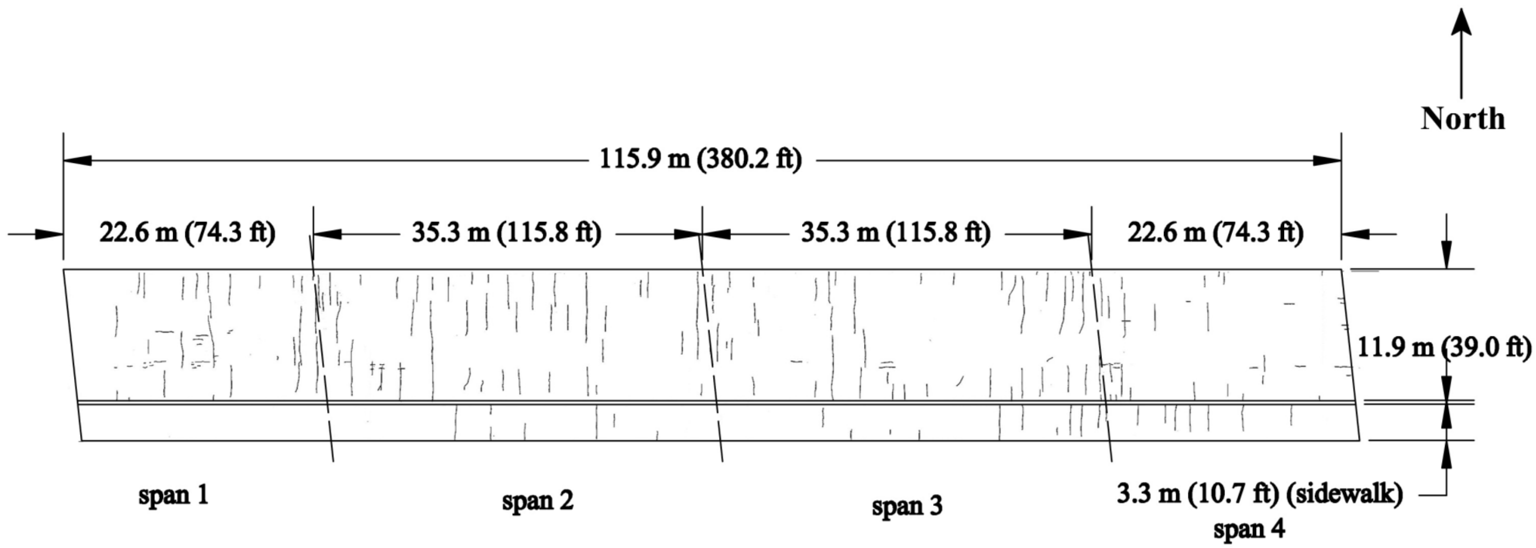
Figure 9: LC-HPC-3 (Survey 3)

Control-3

Surveys 2 and 3 of Control-3, at 22.6 and 35.4 months, are included in this report. The crack density of Control-3 at 22.6 months was 0.216 m/m^2, as shown in Figure 10, nearly double the crack density of LC-HPC-3 at 19.2 months and significantly greater than the value of 0.037 m/m^2 at 10.4 months (Gruman et al. 2009). The crack density at 35.4 months for Control-3 has increased again to 0.232 m/m^2, as shown in Figure 11, more than double the crack density of LC-HPC-3 at 31.5 months. The cracks in Control-3 are primarily transverse and spread across the full length of the bridge. They appear to be directly above the top reinforcing steel. This transverse cracking is most likely due to settlement and shrinkage at the reinforcing steel. This is unlike the cracking observations from LC-HPC-3, where the majority of cracks have occurred near to the piers.

LC-HPC-4

LC-HPC-4 was cast in two placements, separated by a cold joint. Survey 2 at 21.2 and 21.3 months and Survey 3 at 32.7 and 32.8 months are included in this report. At ages of 21.3 months for Placement 1 and 21.2 months for Placement 2, the overall crack density was 0.090 m/m^2, as shown in Figure 12; Placement 1 had a higher crack density than Placement 2 (0.113 m/m^2 vs. 0.079 m/m^2). The crack density at ages of 9.4 and 9.5 months for Placements 1 and 2, respectively, was considerably lower, at 0.008 m/m^2 (Gruman et al. 2009). At ages of 32.8 months for Placement 1 and 32.7 months for Placement 2, the overall crack density increased to 0.146 m/m^2, as shown in Figure 13, with the crack density of Placement 1 again significantly higher than that of Placement 2 (0.261 m/m^2 vs. 0.094 m/m^2). Notably more cracking occurred in Placement 1 than Placement 2 between 21 months and 32 months. In Placement 1, small, transverse cracks developed near the easternmost pier. Transverse cracks developed near

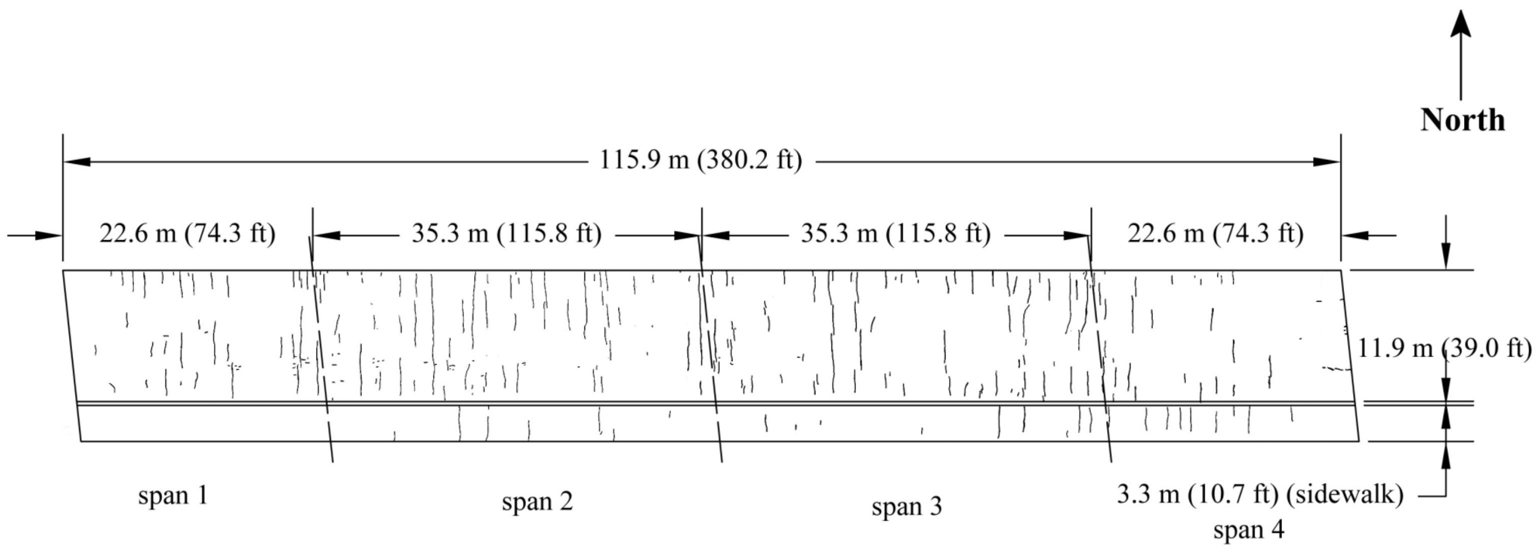


Bridge Number: 46-337 (KU #3 Control)
Bridge Location: EB 103rd St. over US-69
Construction Date: 7/17/2007
Crack survey Date: 6/5/2009

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: 22.6 months
Crack density: 0.216 m/m²
Span 1: 0.204 m/m²
Span 2: 0.243 m/m²
Span 3: 0.230 m/m²
Span 4: 0.165 m/m²

Figure 10: Control-3 (Survey 2)



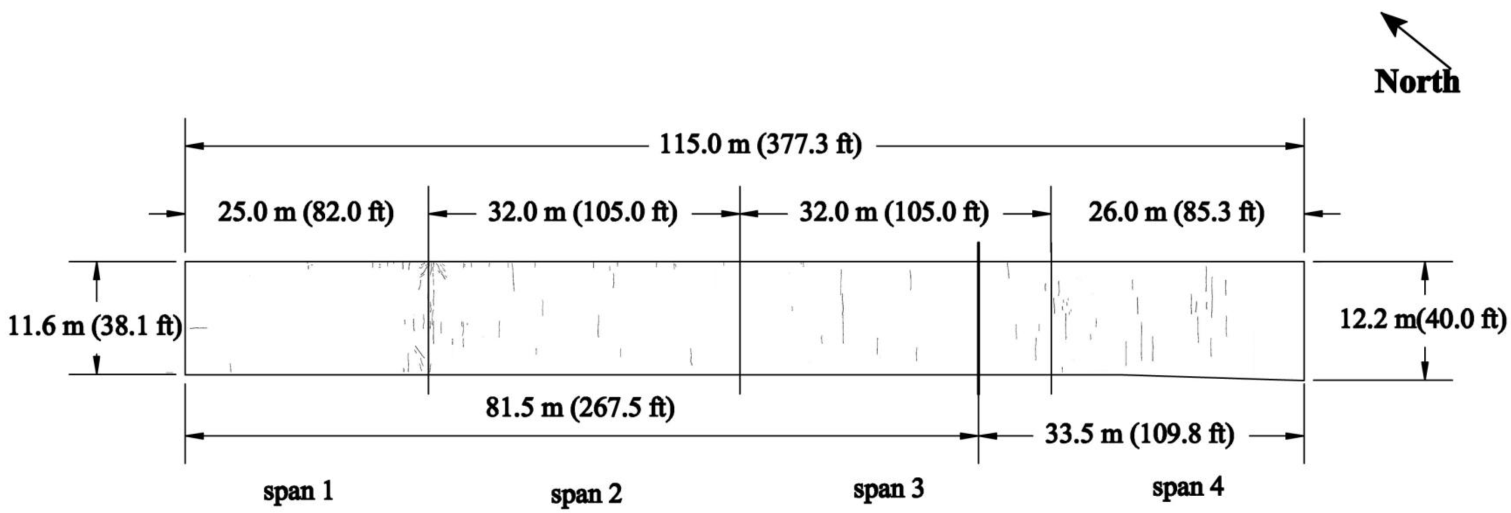
Bridge Number: 46-337 (KU #3 Control)
Bridge Location: EB 103rd St. over US-69
Construction Date: 7/17/2007
Crack survey Date: 6/28/2010

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: 35.4 months
Crack density: 0.232 m/m^2
- **Span 1:** 0.172 m/m^2
- **Span 2:** 0.252 m/m^2
- **Span 3:** 0.247 m/m^2
- **Span 4:** 0.169 m/m^2

Figure 11: Control-3 (Survey 3)

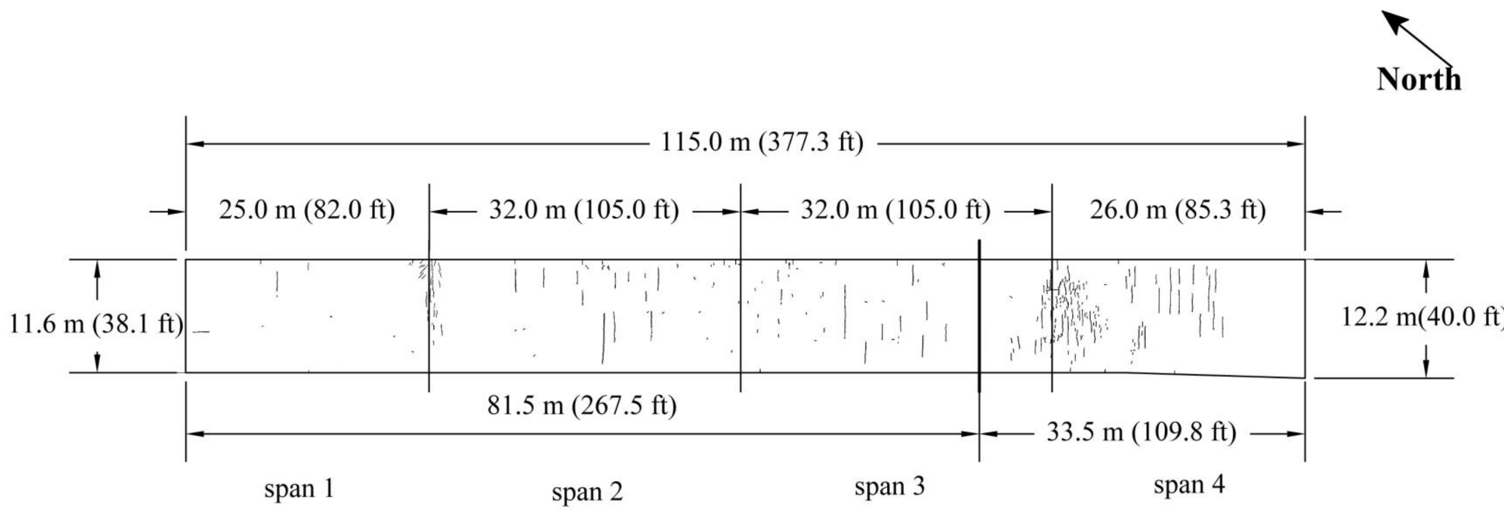


Bridge Number: 46-339 Unit 1 (KU #4)
Bridge Location: Flyover Ramp US-69S to I-435W
Construction Date:
Placement 1 (South): 9/29/2007
Placement 2 (North): 10/2/2007
Crack Survey Date: 7/8/2009 and 7/9/2009

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: 21.3 months
Placement 2: 21.2 months
Crack Density: 0.090 m/m²
Placement 1: 0.113 m/m²
Placement 2: 0.079 m/m²
Span 1: 0.065 m/m²
Span 2: 0.111 m/m²
Span 3: 0.058 m/m²
Span 4: 0.122 m/m²

Figure 12: LC-HPC-4 (Survey 2)



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: 6/24/2010

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: 32.8 months
Placement 2: 32.7 months
Crack Density: 0.146 m/m^2
Placement 1: 0.261 m/m^2
Placement 2: 0.094 m/m^2
Span 1: 0.043 m/m^2
Span 2: 0.123 m/m^2
Span 3: 0.140 m/m^2
Span 4: 0.266 m/m^2

Figure 13: LC-HPC-4 (Survey 3)

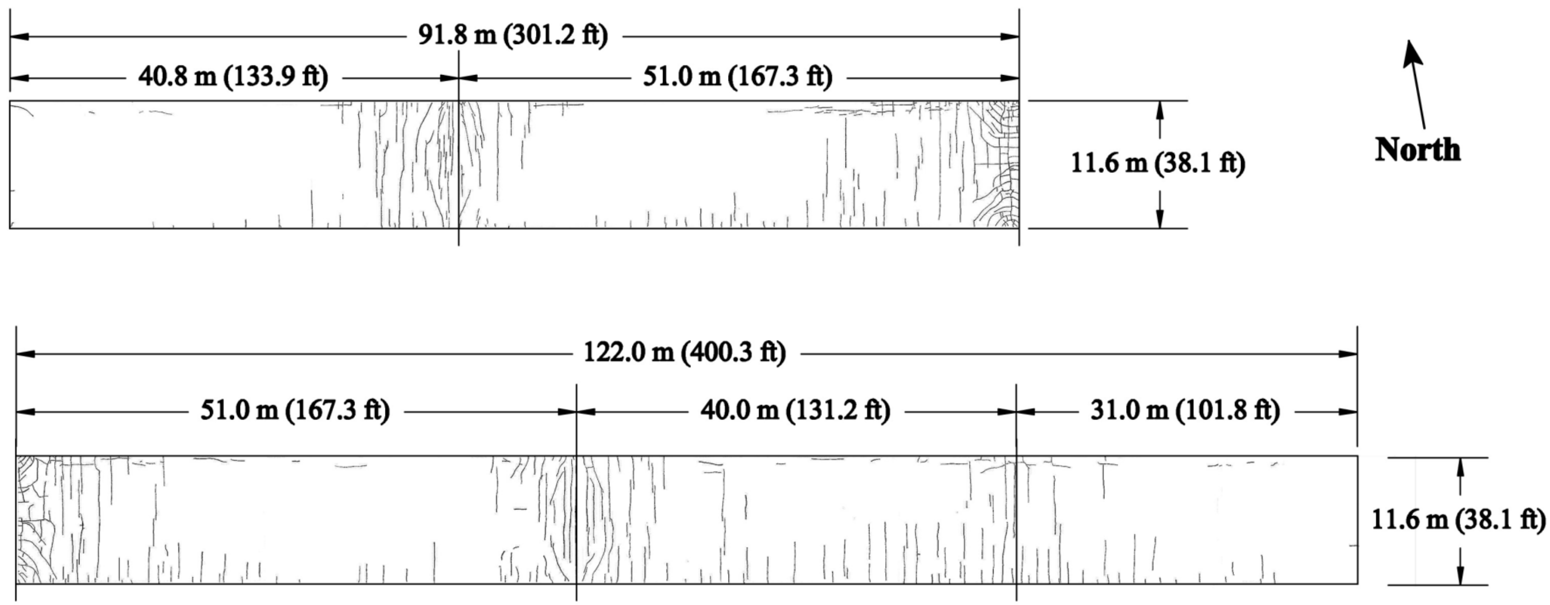
midspan in Placement 1. In Placement 2, a number of small cracks developed near the westernmost pier, with several longer transverse cracks developing randomly throughout the rest of Placement 2.

Control-4

Surveys 2 and 3 of Control-4, at 19.7 and 31.6 months, are included in this report. The crack density for Control-4 at 19.7 months was high, at 0.366 m/m^2, as shown in Figure 14, a value that was much higher than the value of 0.050 m/m^2 at 6.8 months (Gruman et al. 2009). The crack density at 31.6 months increased to 0.473 m/m^2, as shown in Figure 15, which is over three times the crack density at 32.7 and 32.8 months for LC-HPC-4. For Control-4, significant cracking occurred near and parallel to each pier. In addition, significant cracking has occurred at both abutments, propagating concentrically from each corner of the deck. Most cracks are oriented transversely to the bridge, directly above the reinforcing steel. A number of cracks are also oriented longitudinally along the edges of the deck.

LC-HPC-5

Surveys 2 and 3 of LC-HPC-5, at 19.4 and 31.1 months, are included in this report. The crack density for LC-HPC-5 at 19.4 months was higher than most other LC-HPC decks at 0.123 m/m^2 (Figure 16). The previous survey had yielded a crack density of 0.059 m/m^2 at 8.0 months (Gruman et al. 2009). The crack density at 31.1 months increased slightly to 0.128 m/m^2. Nearly all cracks propagated transversely from the south side of the bridge, as shown in Figure 17. This is most likely due to the superelevation of the bridge deck, as the south side of the deck was constructed at a higher elevation than the north side. In addition, the south side of the deck likely dried out during curing because the curing water flowed to the north side, which



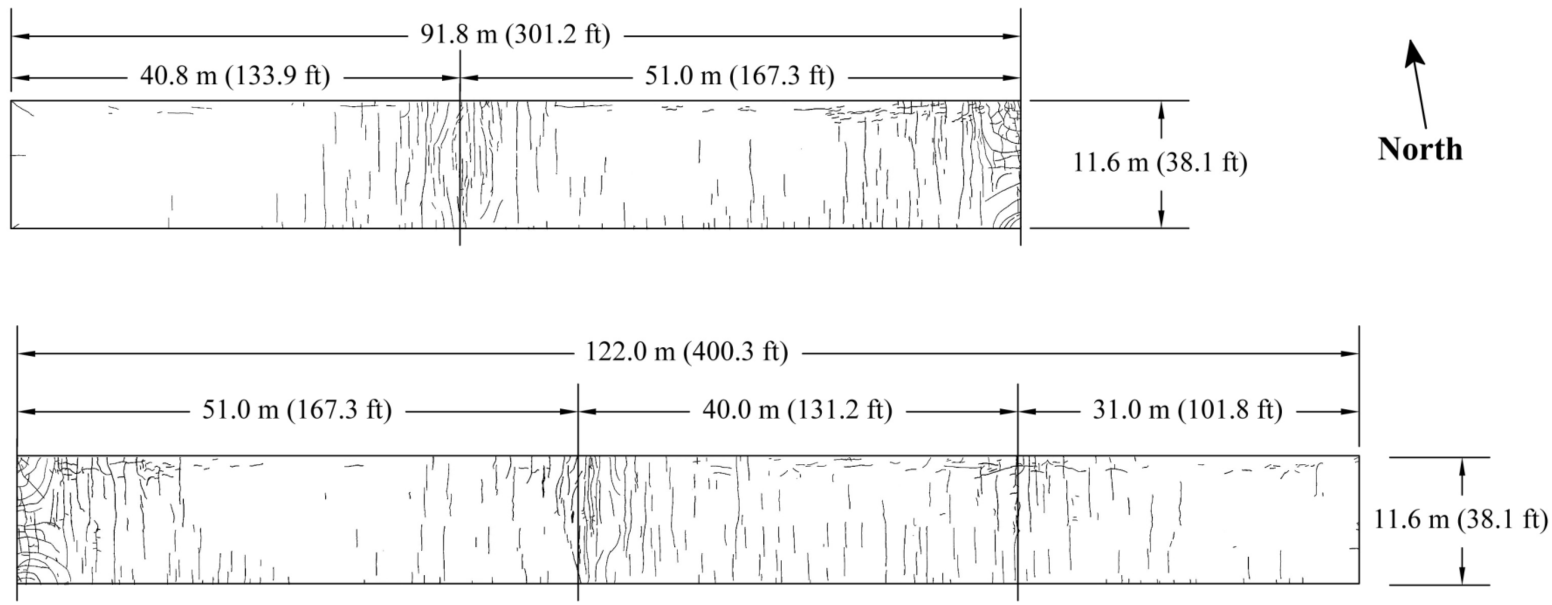
Bridge Number: 46-347 (KU #4 Control)
Bridge Location: NB US-69 Rd
Construction Date: 11/16/2007
Crack survey Date: 7/7/2009

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: 19.7 months
Crack density: 0.366 m/m^2
- **Span 1:** 0.261 m/m^2
- **Span 2:** 0.457 m/m^2
- **Span 3:** 0.428 m/m^2
- **Span 4:** 0.439 m/m^2
- **Span 5:** 0.158 m/m^2

Figure 14: Control-4 (Survey 2)

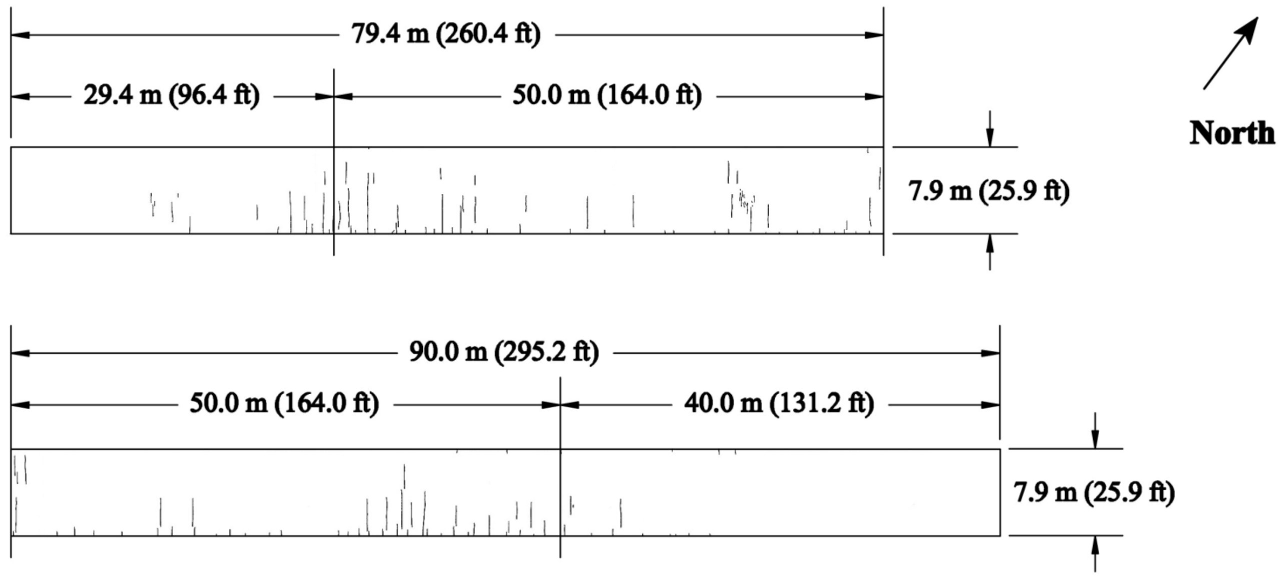


Bridge Number: 46-347 (KU #4 Control)
Bridge Location: NB US-69 Rd
Construction Date: 11/16/2007
Crack survey Date: 7/1/2010 & 7/9/2010

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: 31.6 months
Crack density: 0.473 m/m^2
Span 1: 0.271 m/m^2
Span 2: 0.596 m/m^2
Span 3: 0.520 m/m^2
Span 4: 0.617 m/m^2
Span 5: 0.268 m/m^2

Figure 15: Control-4 (Survey 3)

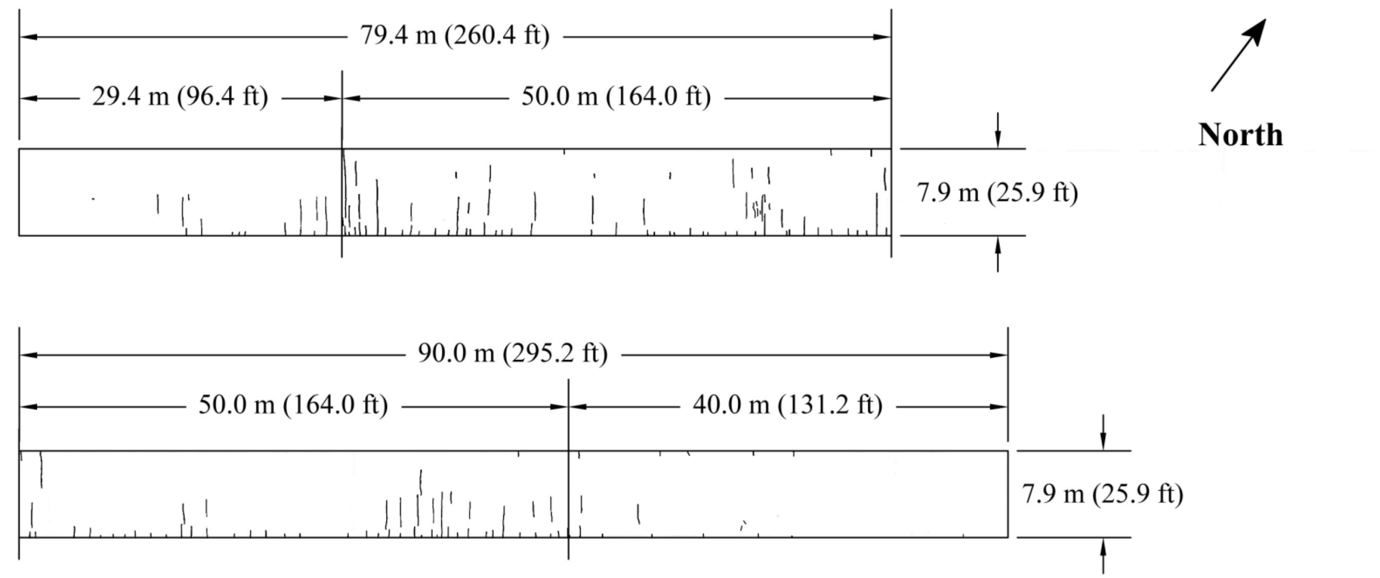


Bridge Number: 46-340 Unit 1 (KU #5)
Bridge Location: Flyover Ramp US-69 to I-435 W
Construction Date: 11/14/2007
Crack survey Date: 6/26/2009

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: 19.4 months
Crack density: 0.123 m/m²
Span 1: 0.126 m/m²
Span 2: 0.172 m/m²
Span 3: 0.152 m/m²
Span 4: 0.026 m/m²

Figure 16: LC-HPC-5 (Survey 2)



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: 6/17/2010

Bridge Length: 169.4 m (555.7 ft)
Bridge Width: 7.9 m (25.9 ft)
Skew: 0^{o}
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: 31.1 months
Crack density: 0.128 m/m^2
Span 1: 0.078 m/m^2
Span 2: 0.217 m/m^2
Span 3: 0.147 m/m^2
Span 4: 0.030 m/m^2

Figure 17: LC-HPC-5 (Survey 3)

had a lower elevation. Settlement could have also played a role in the increased cracking of the south side of the deck due to concrete settling towards the lower side of the deck.

Control-5

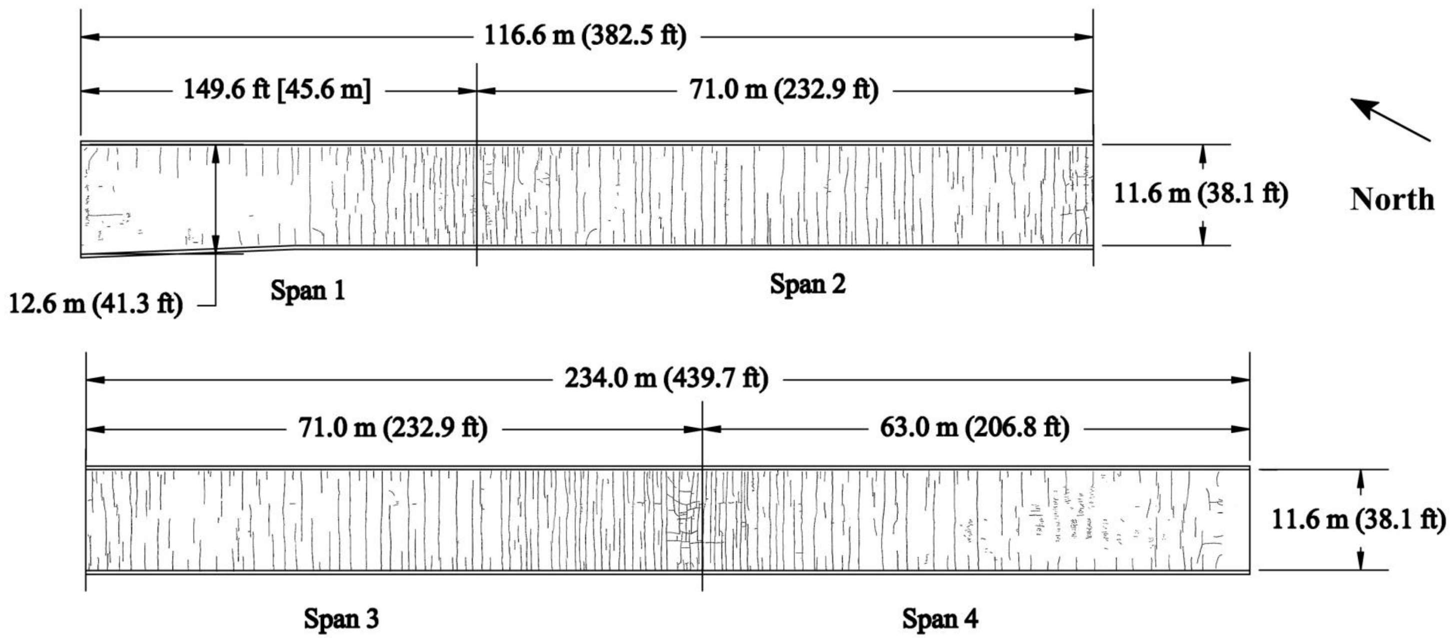
Surveys 1 and 2 of Control-5, at 7.4 and 18.9 months, are included in this report. Control-5 has one of the highest crack densities of all surveyed bridge decks. At 7.4 months, the crack density for Control-5 was 0.670 m/m^2, as shown in Figure 18. After 18.9 months, the crack density was 0.857 m/m^2, as shown in Figure 19. This crack density at 18.9 months is nearly seven times the crack density of LC-HPC-5 at 19.4 months. Cracks have formed parallel and directly above the reinforcing steel, every one to three feet, along the entire width of the deck for the majority of the bridge length, increasing in number near each pier. Fewer cracks have formed near the midspan of Span 1 and small, longitudinal cracks have developed at each abutment.

LC-HPC-6

Surveys 2 and 3 of LC-HPC-6, at 19.7 and 31.4 months, are included in this report. The crack density for LC-HPC-6 at 19.7 months was 0.238 m/m^2, as shown in Figure 20. This is a high crack density for a LC-HPC deck, nearly twice as high as LC-HPC-5, at 19.4 months of age. The previous crack survey at 6.5 months yielded a crack density of 0.063 m/m^2 (Gruman et al. 2009). The crack density at 31.4 months has remained nearly constant, at 0.231 m/m^2 (Figure 21). As with LC-HPC-5, the majority of the cracks have propagated transversely above the reinforcing steel from the southeastern edge of the deck where the deck is superelevated.

Control-6

Surveys 1 and 2 of Control-6, at 8.6 and 20.0 months, are included in this report. At 8.6 months, the crack density for Control-6 was 0.142 m/m^2, as shown in Figure 22. The crack



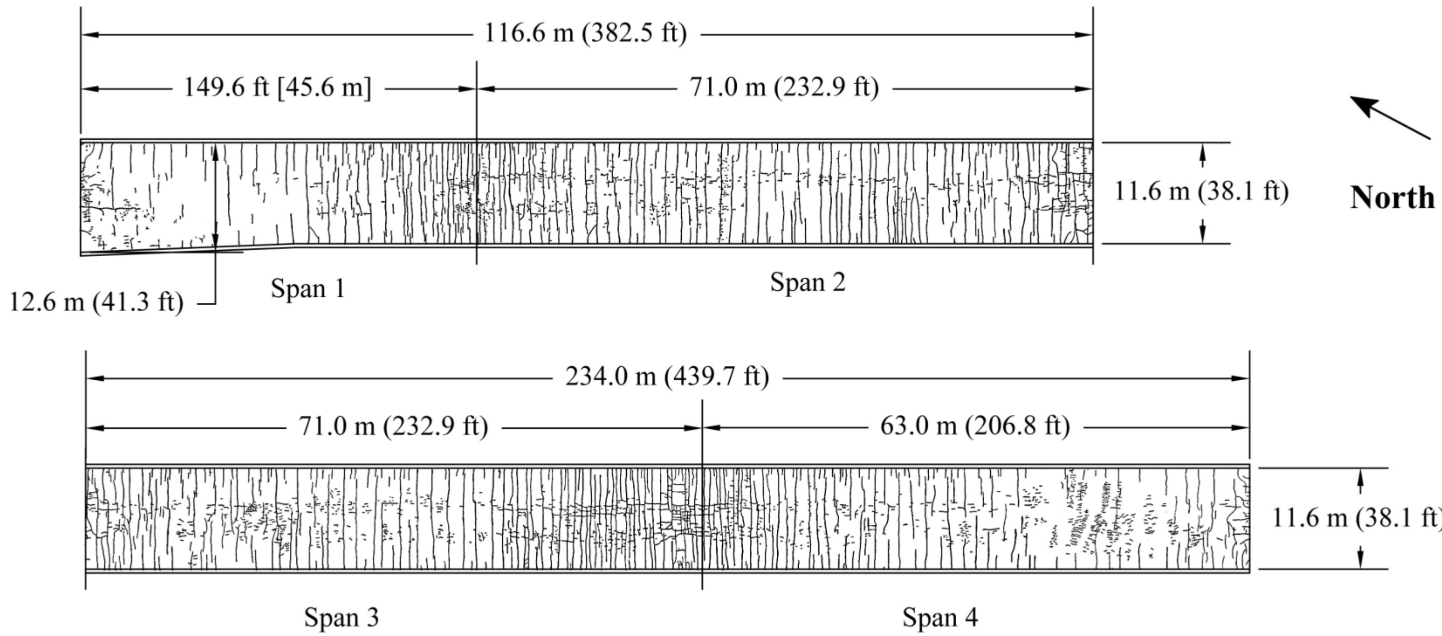
Bridge Number: 46-341 Unit 3 (Control #5)
Bridge Location: Flyover Ramp S-69 to I-435 E, Kansas City, KS
Construction Date: 11/25/2008
Crack survey Date: 7/8/2009 and 7/9/2009

Bridge Length: 250.6 m (822.2 ft)
Bridge Width: 11.6 m (38.1 ft)
Skew: 0°
Number of Spans: 4
- **Span 1:** 45.6 m (149.6 ft)
- **Span 2:** 71.0 m (232.9 ft)
- **Span 3:** 71.0 m (232.9 ft)
- **Span 4:** 63.0 m (206.8 ft)

Number of Placements: 2

Bridge Age: 7.4 months
Crack density: 0.670 m/m²
- **Span 1:** 0.395 m/m²
- **Span 2:** 0.755 m/m²
- **Span 3:** 0.822 m/m²
- **Span 4:** 0.634 m/m²

Figure 18: Control-5 (Survey 1)

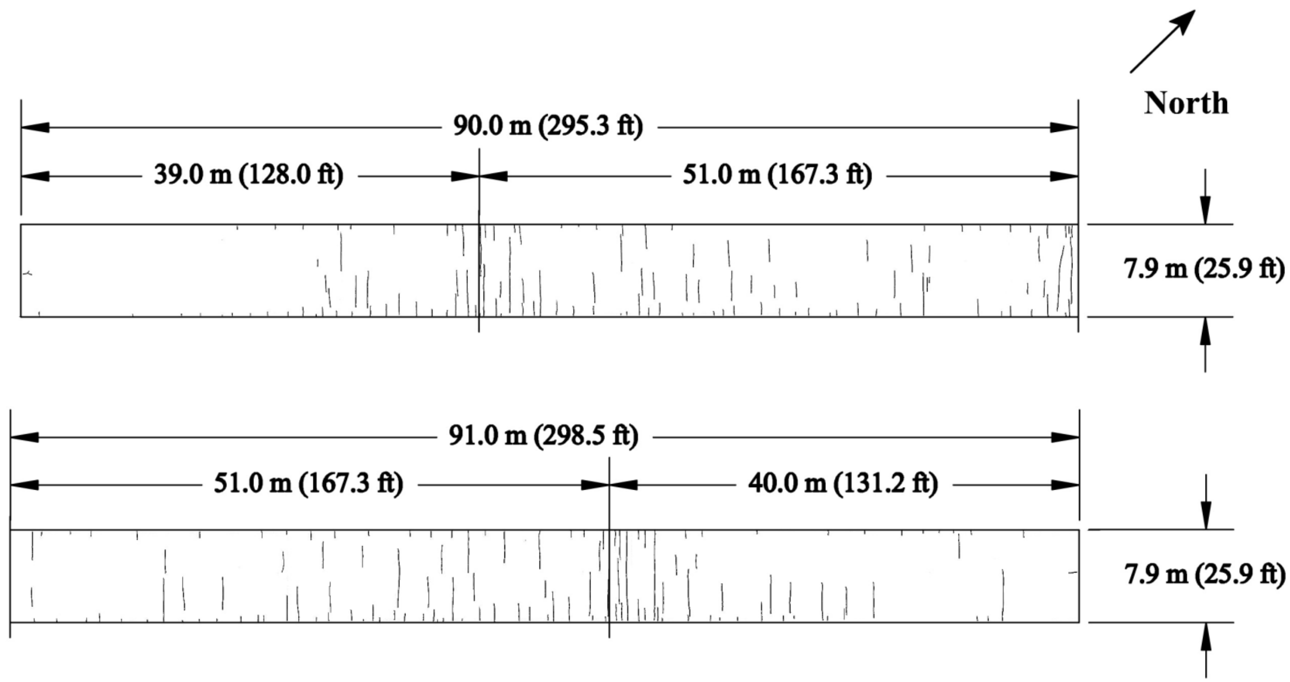


Bridge Number: 46-341 Unit 3 (Control #5)
Bridge Location: Flyover Ramp S-69 to I-435 E, Kansas City, KS
Construction Date: 11/25/2008
Crack survey Date: 6/22/2010

Bridge Length: 250.6 m (822.2 ft)
Bridge Width: 11.6 m (38.1 ft)
Skew: 0°
Number of Spans: 4
Span 1: 45.6 m (149.6 ft)
Span 2: 71.0 m (232.9 ft)
Span 3: 71.0 m (232.9 ft)
Span 4: 63.0 m (206.8 ft)
Number of Placements: 2

Bridge Age: 18.9 months
Crack density: 0.857 m/m^2
Span 1: 0.510 m/m^2
Span 2: 0.958 m/m^2
Span 3: 1.064 m/m^2
Span 4: 0.845 m/m^2

Figure 19: Control-5 (Survey 2)



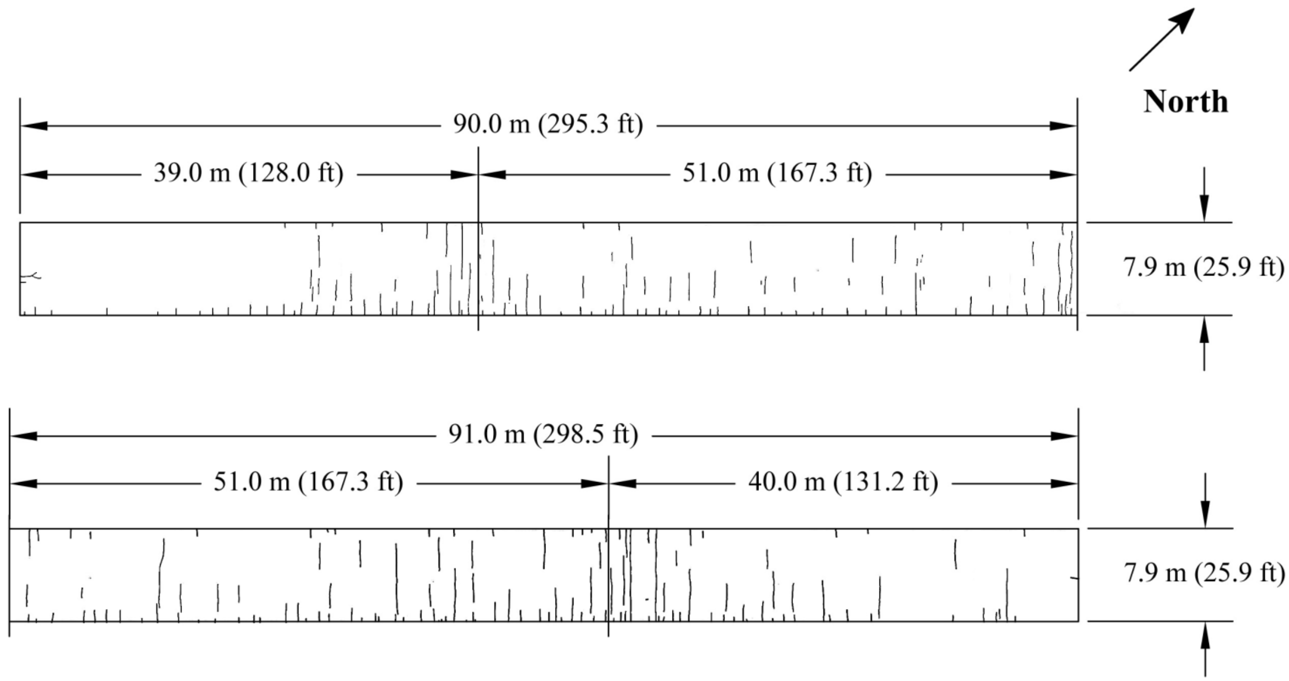
Bridge Number: 46-340 Unit 2 (KU #6)
Bridge Location: SB US-69 to WB I-435
Construction Date: 11/3/2007
Crack survey Date: 6/26/2009

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: 19.7 months
Crack density: 0.238 m/m²
- **Span 1:** 0.128 m/m²
- **Span 2:** 0.282 m/m²
- **Span 3:** 0.263 m/m²
- **Span 4:** 0.256 m/m²

Figure 20: LC-HPC-6 (Survey 2)

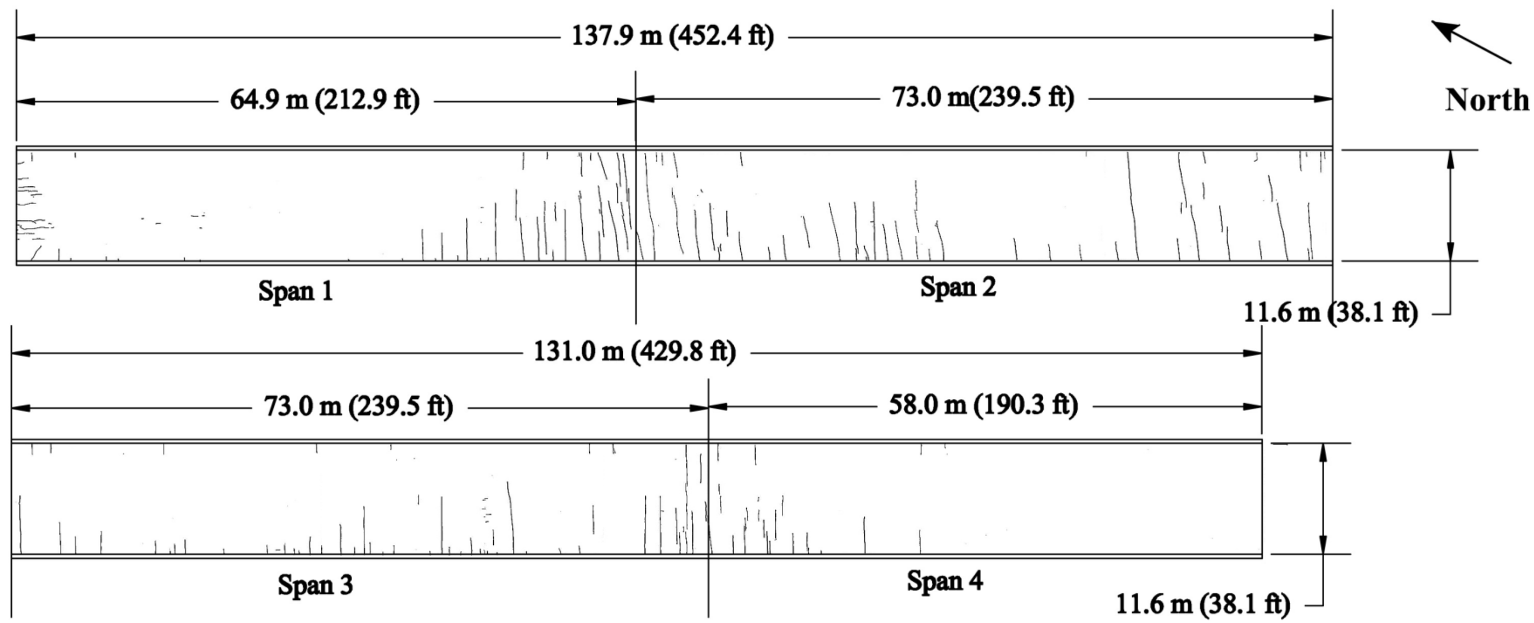


Bridge Number: 46-340 Unit 2 (KU #6)
Bridge Location: SB US-69 to WB I-435
Construction Date: 11/3/2007
Crack survey Date: 6/17/2010

Bridge Length: 181.0 m (593.8 ft)
Bridge Width: 7.9 m (25.9 ft)
Skew: 0^{o}
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: 31.4 months
Crack density: 0.231 m/m^2
Span 1: 0.183 m/m^2
Span 2: 0.217 m/m^2
Span 3: 0.269 m/m^2
Span 4: 0.254 m/m^2

Figure 21: LC-HPC-6 (Survey 3)



Bridge Number: 46-340 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: 7/8/2009 and 7/9/2009

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: 8.6 months
Crack density: 0.142 m/m²
- **Span 1:** 0.167 m/m²
- **Span 2:** 0.195 m/m²
- **Span 3:** 0.135 m/m²
- **Span 4:** 0.059 m/m²

Figure 22: Control-6 (Survey 1)

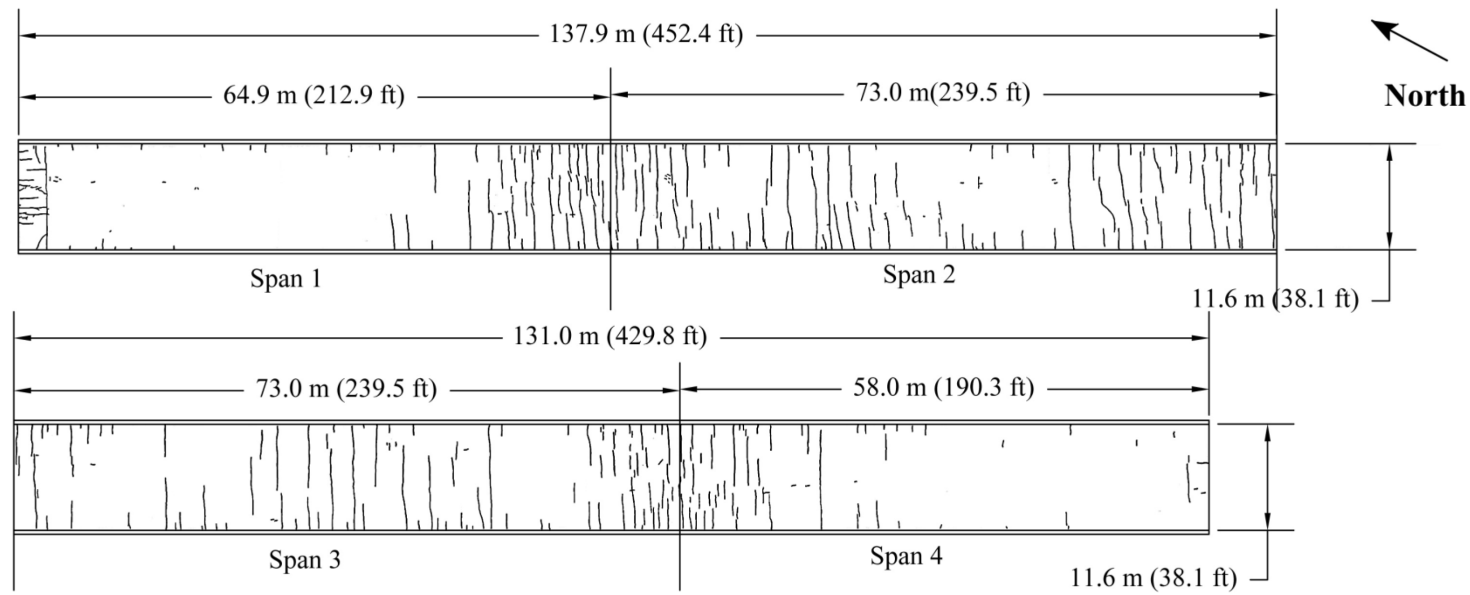
density at 20.0 months was 0.282 m/m^2 (Figure 23). This crack density at 20.0 months is higher than the crack density of LC-HPC-6 at 19.7 months. The majority of the cracks have propagated transversely from the western edge of the bridge deck, most likely due to the superelevation. By the time of the survey at 20.0 months, many of the cracks had propagated from the western edge across the entire deck width directly above and parallel to the reinforcing steel. A significant amount of cracking has developed near and parallel to each pier. Longitudinal cracks are evident at the northern abutment.

LC-HPC-7

Surveys 3 and 4 of LC-HPC-7, at 34.8 and 46.8 months, are included in this report. The bridge deck with the lowest crack density of all those surveyed is LC-HPC-7. At 34.8 months, the crack density was 0.012 m/m^2, as shown in Figure 24. Small longitudinal cracks were found at the west end near the abutment. In the previous survey at 24.2 months, the crack density was higher at 0.019 m/m^2 (Gruman et al. 2009). The survey at 46.8 months yielded a crack density of 0.005 m/m^2 (Figure 25). The differences in these three crack densities are not significant enough to state that the bridge deck has decreased cracking with time. The cracks that were not marked in the most recent surveys were small and could have been overlooked by the surveyors. The surveys at 34.8 months and 46.8 months were both completed on May 18 of their respective years, while the survey at 24.2 months was completed on July 1. The higher temperatures in July could have expanded the steel girders and widened the deck cracks. This point will be evaluated further as the study continues.

Control-7

Control-7 was constructed in two placements that were separated by six months. Survey 3 at 32.6 and 38.2 months and Survey 4 at 45.5 and 51.1 months are included in this report. The



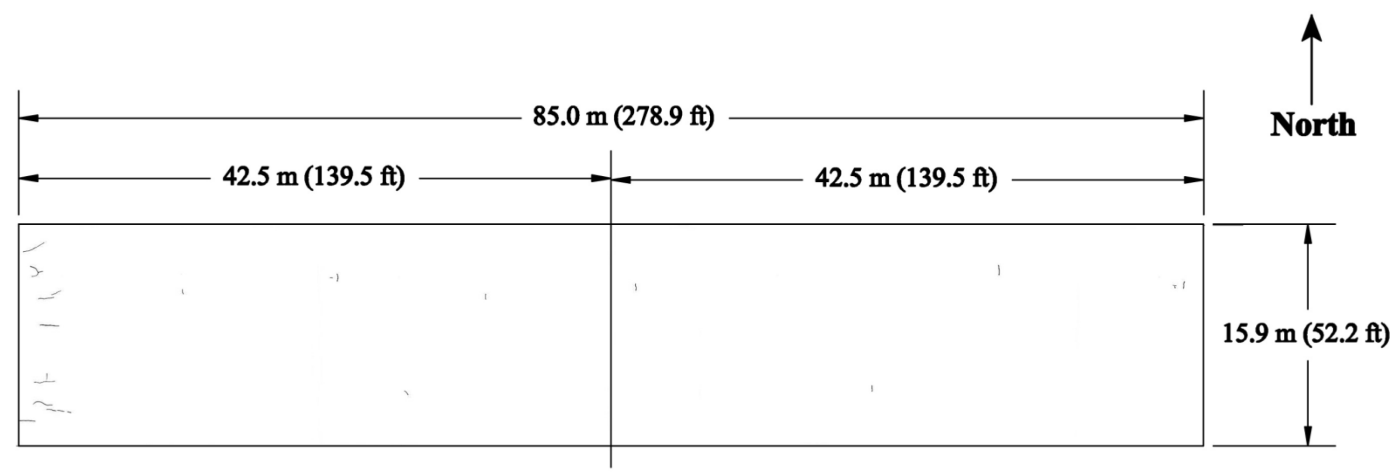
Bridge Number: 46-341 Unit 4 (Control #6)
Bridge Location: Flyover Ramp S-69 to I-435 E, Kansas City, KS
Construction Date: 10/20/2008
Crack survey Date: 6/22/2010

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: 20.0 months
Crack density: 0.282 m/m^2
- **Span 1:** 0.251 m/m^2
- **Span 2:** 0.384 m/m^2
- **Span 3:** 0.308 m/m^2
- **Span 4:** 0.156 m/m^2

Figure 23: Control-6 (Survey 2)

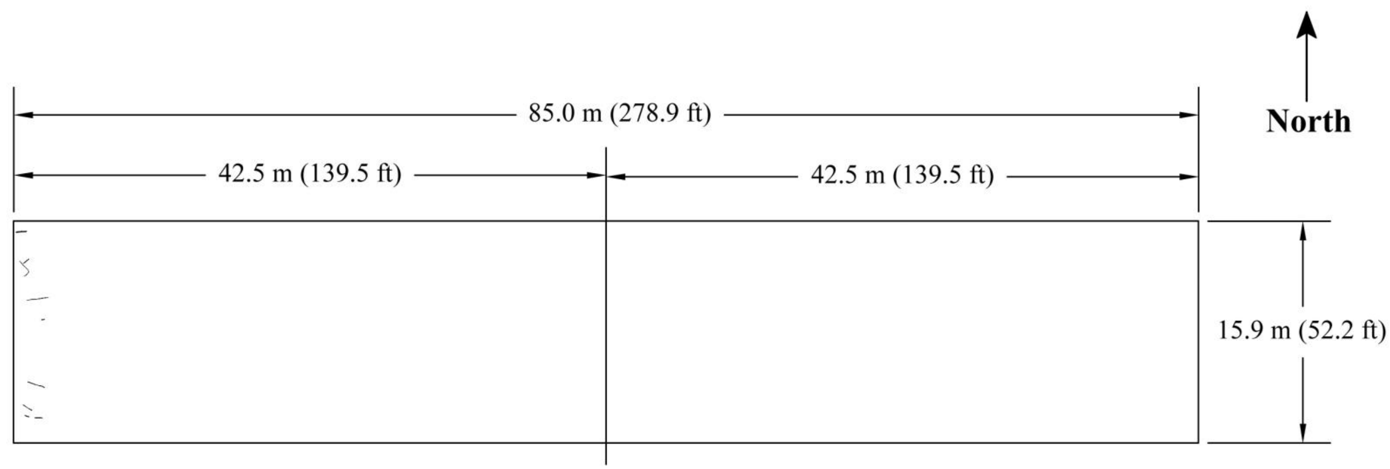


Bridge Number: 43-33 (KU #7)
Bridge Location: Co. Rd. 150 over US-75
Construction Date: 6/24/2006
Crack survey Date: 5/18/2009

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: 34.8 months
Crack density: 0.012 m/m
Span 1: 0.021 m/m^2
Span 2: 0.004 m/m^2

Figure 24: LC-HPC-7 (Survey 3)



Bridge Number: 43-33 (KU #7)
Bridge Location: Co. Rd. 150 over US-75
Construction Date: 6/24/2006
Crack survey Date: 5/18/2010

Bridge Length: 85.0 m (278.9 ft)
Bridge Width: 15.9 m (52.2 ft)
Skew: 0^{o}
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

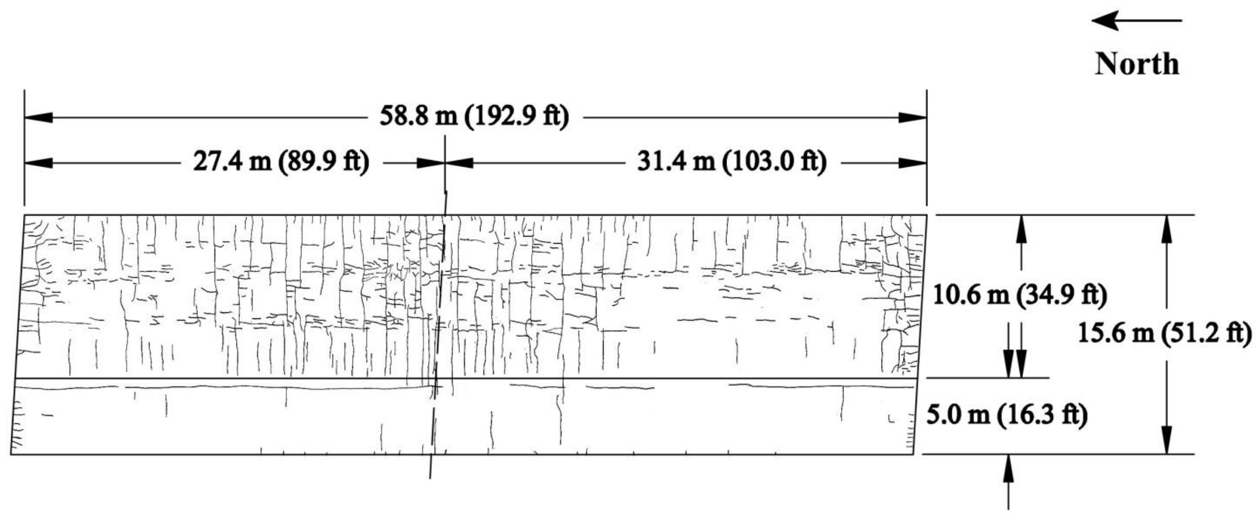
Bridge Age: 46.8 months
Crack density: 0.005 m/m^2
Span 1: 0.011 m/m^2
Span 2: 0.000 m/m^2

Figure 25: LC-HPC-7 (Survey 4)

first (east) placement had a crack density of 1.003 m/m^2 at 38.2 months, as shown in Figure 26. Transverse cracks were found throughout the placement, but were somewhat more extensive near the pier. Smaller longitudinal cracks developed at both abutments. The second (west) placement had a crack density of 0.277 m/m^2 at 32.6 months. One long, continuous crack extends nearly the entire length of the deck near and parallel to the joint between the two placements. The overall crack density for this survey is 0.772 m/m^2. The previous crack survey yielded crack densities of 0.476 m/m^2 for Placement 1 at 27.1 months and 0.069 m/m^2 for Placement 2 at 21.5 months (Gruman et al. 2009). The crack density of Placement 1 more than doubled between 27.1 months and 38.2 months, and the crack density of Placement 2 was four times greater at 32.6 months than at 21.5 months. At 51.1 and 45.5 months for Placements 1 and 2, respectively, the crack densities for each placement are 1.037 m/m^2 and 0.359 m/m^2, respectively, as shown in Figure 27.

LC-HPC-8

Surveys 1 and 2 of LC-HPC-8, at 20.9 and 31.8 months, are included in this report. LC-HPC-8 is one of two LC-HPC bridges with precast, prestressed concrete girders. The crack density for LC-HPC-8 at 20.9 months was 0.298 m/m^2, as shown in Figure 28, increasing to 0.348 m/m^2 at 31.8 months, as shown in Figure 29. The majority of the cracks consist of long, transverse cracks that nearly extend across the entire width of the deck parallel with the top reinforcement, likely due to shrinkage and settlement. The cracks are evenly spaced along the entire length of the deck. No increase in cracking is observed near the piers. A small decrease in cracking is observed near the center pier, perhaps due to a combination of increased girder shrinkage and camber. A few small longitudinal cracks are observed propagating from each abutment.

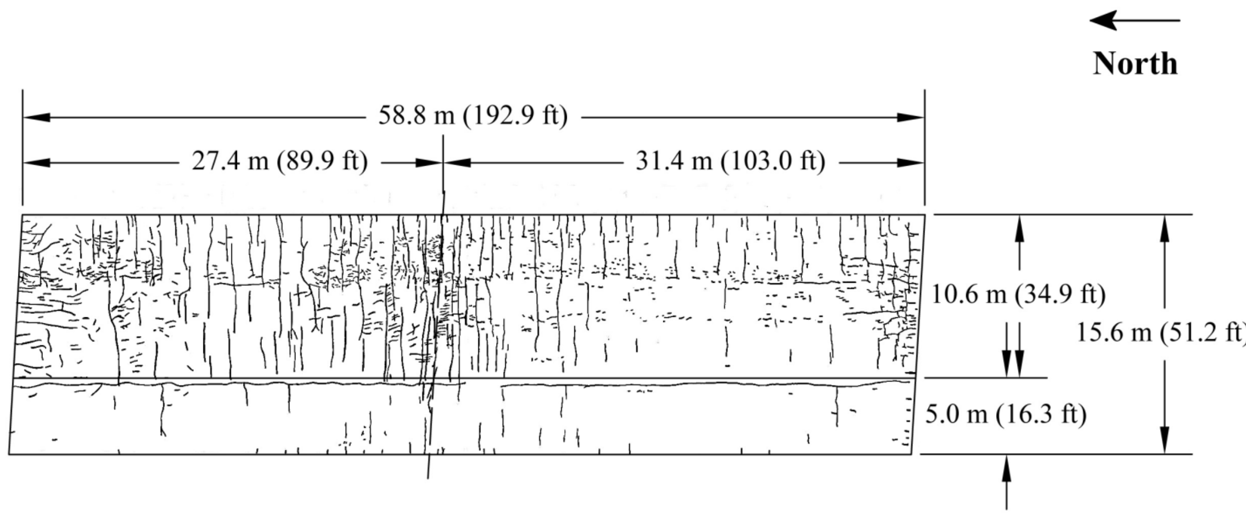


Bridge Number: 46-334 (KU #7 Control)
Bridge Location: NB Antioch over I-435
Construction Date:
Placement 1 (East): 3/29/2006
Placement 2 (West): 9/15/2006
Crack survey Date: 6/4/2009

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

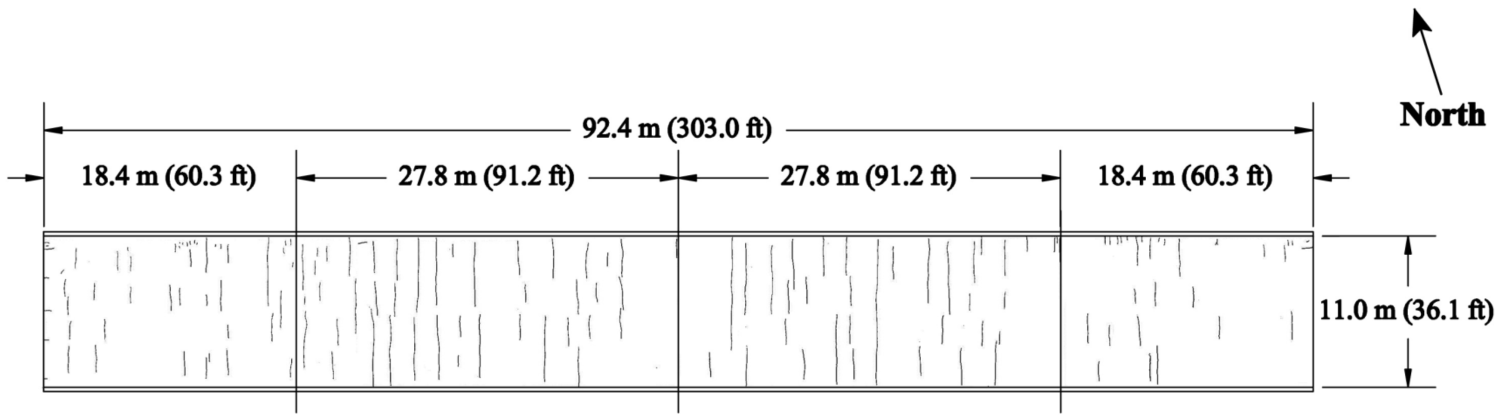
Bridge Age:
Placement 1: 38.2 months
Placement 2: 32.6 months
Crack density: 0.772 m/m²
Span 1: 0.877 m/m²
Span 2: 0.681 m/m²
Placement 1: 1.003 m/m²
Placement 2: 0.277 m/m²

Figure 26: Control-7 (Survey 3)



Bridge Number: 46-334 (KU #7 Control)	**Bridge Length:** 58.8 m (192.9 ft)	**Bridge Age:**
Bridge Location: NB Antioch over I-435	**Bridge Width:** 15.6 m (51.2 ft)	**Placement 1:** 51.1 months
Construction Date:	**Skew:** -3.3°	**Placement 2:** 45.5 months
Placement 1 (East): 3/29/2006	**Number of Spans:** 2	**Crack density:** 0.819 m/m^2
Placement 2 (West): 9/15/2006	**Span 1 (North):** 27.4 m (89.9 ft)	**Span 1:** 0.981 m/m^2
Crack survey Date: 7/1/2010	**Span 2 (South):** 31.4 m (103.0 ft)	**Span 2:** 0.684 m/m^2
	Number of Placements: 2	**Placement 1:** 1.037 m/m^2
		Placement 2: 0.359 m/m^2

Figure 27: Control-7 (Survey 4)

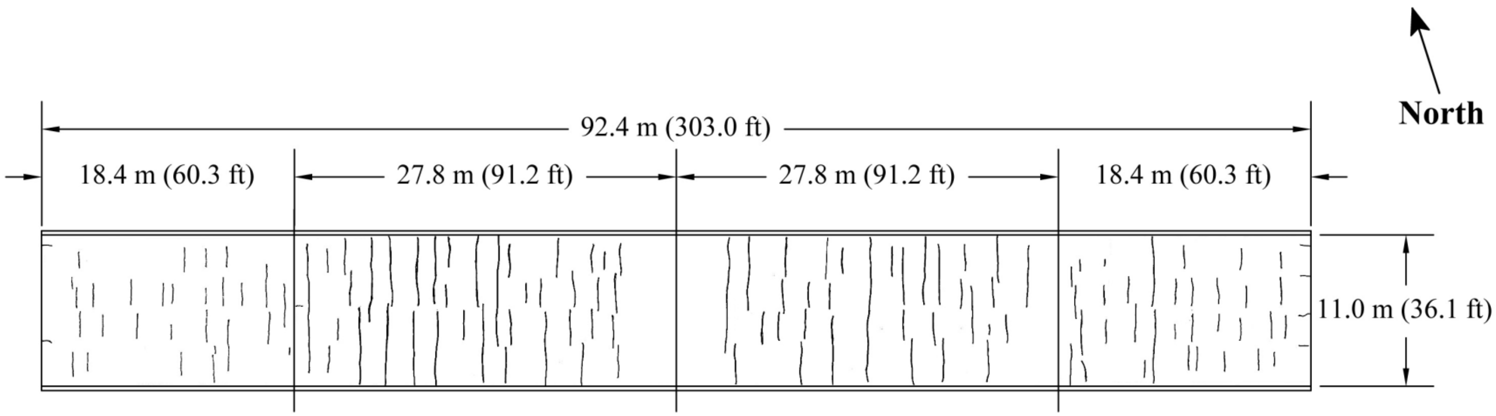


Bridge Number: 54-53 (KU 8)
Bridge Location: E 1350 Rd over US-69
Construction Date: 10/3/2007
Crack survey Date: 6/29/2009

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: 20.9 months
Crack density: 0.298 m/m^2
Span 1 (West): 0.257 m/m^2
Span 2 (West): 0.372 m/m^2
Span 3 (East): 0.335 m/m^2
Span 4 (East): 0.170 m/m^2

Figure 28: LC-HPC-8 (Survey 1)



Bridge Number: 54-53 (KU 8)
Bridge Location: E 1350 Rd over US-69
Construction Date: 10/3/2007
Crack survey Date: 5/27/2010

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: 31.8 months
Crack density: 0.348 m/m^2
Span 1 (West): 0.242 m/m^2
Span 2 (West): 0.434 m/m^2
Span 3 (East): 0.347 m/m^2
Span 4 (East): 0.325 m/m^2

Figure 29: LC-HPC-8 (Survey 2)

Control-8/10

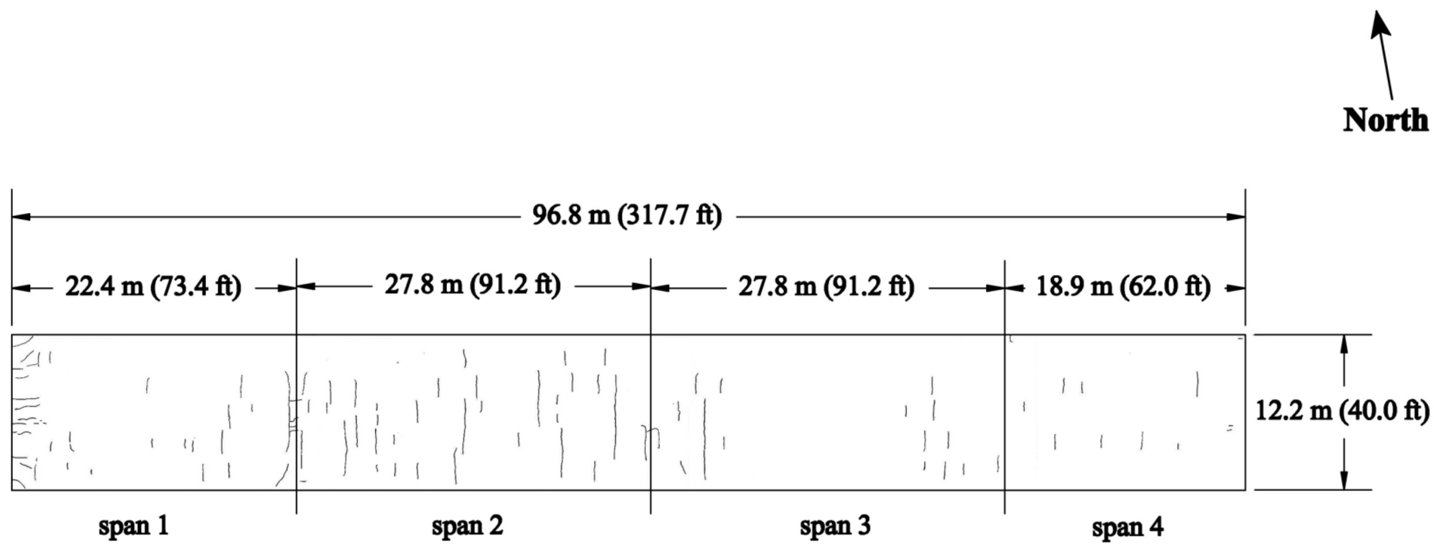
Surveys 3 and 4 of Control-8/10, at 25.5 and 37.3 months, are included in this report. Control-8/10 is the only control bridge with precast, prestressed concrete girders. At 25.5 months, the deck had a crack density of 0.127 m/m^2, as shown in Figure 30. The previous crack density at 14.4 months was greater, at 0.177 m/m^2 (Gruman et al. 2009). The most recent survey at 37.3 months yielded a crack density of 0.137 m/m^2, as shown in Figure 31. The majority of the cracks occur in spans 1 and 2 on the west end of the deck. Most cracks are transverse, extending nearly across the entire deck width. An increase in cracking occurs near the pier between spans 1 and 2. Short longitudinal cracks extend from the west abutment.

LC-HPC-9

LC-HPC-9 has only been surveyed once, at 13.6 months, yielding a crack density of 0.130 m/m^2, as shown in Figure 32. The majority of the cracks are transverse, parallel with the top reinforcement, and located near the piers and middle of center span. More cracks propagated from southeastern edge of the deck than from the northeastern edge.

Control-9

Control-9 has been surveyed one time. It was constructed in two placements eight days apart. Survey 1 at 24.0 and 24.2 months is included in this report. At 24.2 months, Placement 1 has a crack density of 0.395 m/m^2, while Placement 2 has a crack density of 0.368 m/m^2 at 24.0 months. The overall crack density for Control-9 is 0.390 m/m^2, as shown in Figure 33. Transverse cracks are observed along the entire bridge deck, increasing in density near the piers and middle span. A few longitudinal cracks on both sides of the joint between placements continue along nearly the entire length of the deck.

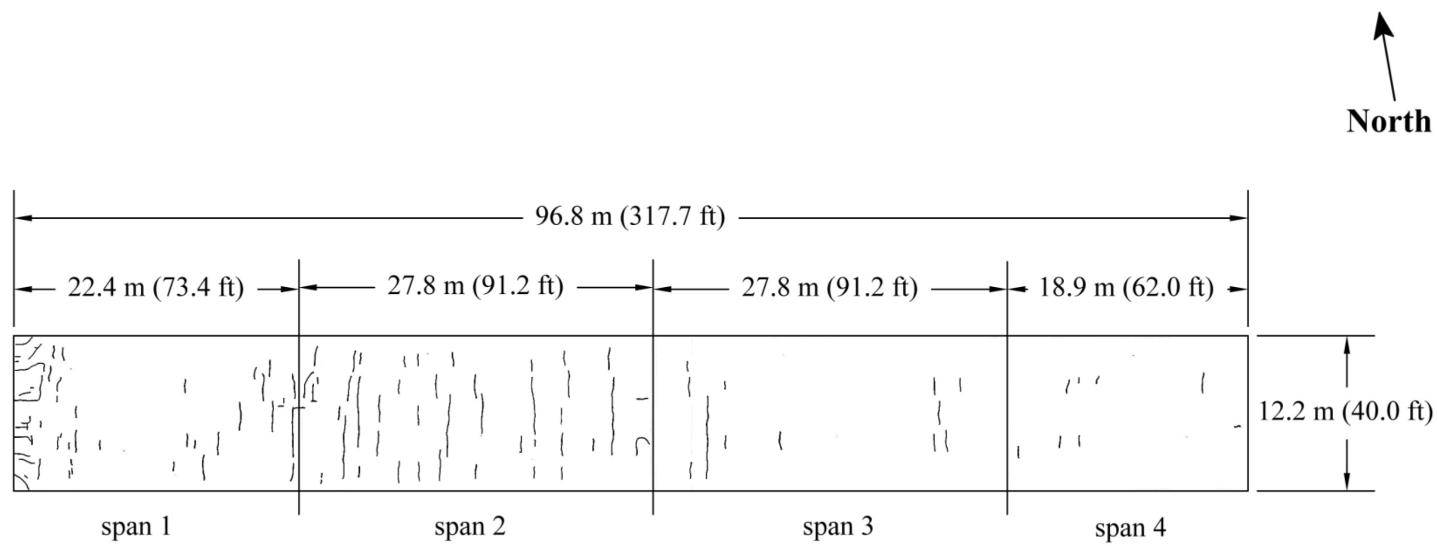


Bridge Number: 54-59 (KU #8-#10 Control)
Bridge Location: K-52 over US-69
Construction Date: 4/16/2007
Crack survey Date: 5/31/2009

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: 25.5 months
Crack density: 0.127 m/m^2
Span 1: 0.172 m/m^2
Span 2: 0.199 m/m^2
Span 3: 0.075 m/m^2
Span 4: 0.046 m/m^2

Figure 30: Control-8/10 (Survey 3)

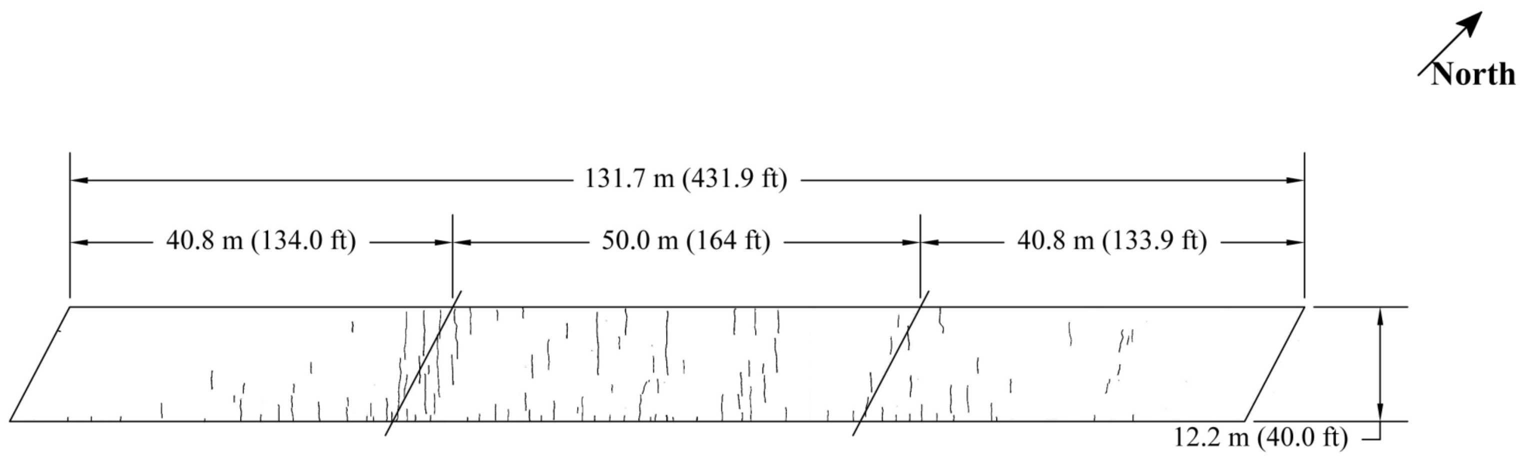


Bridge Number: 54-59 (KU #8-#10 Control)
Bridge Location: K-52 over US-69
Construction Date: 4/16/2007
Crack survey Date: 5/22/2010

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: 37.3 months
Crack density: 0.137 m/m^2
Span 1: 0.210 m/m^2
Span 2: 0.229 m/m^2
Span 3: 0.060 m/m^2
Span 4: 0.030 m/m^2

Figure 31: Control-8/10 (Survey 4)

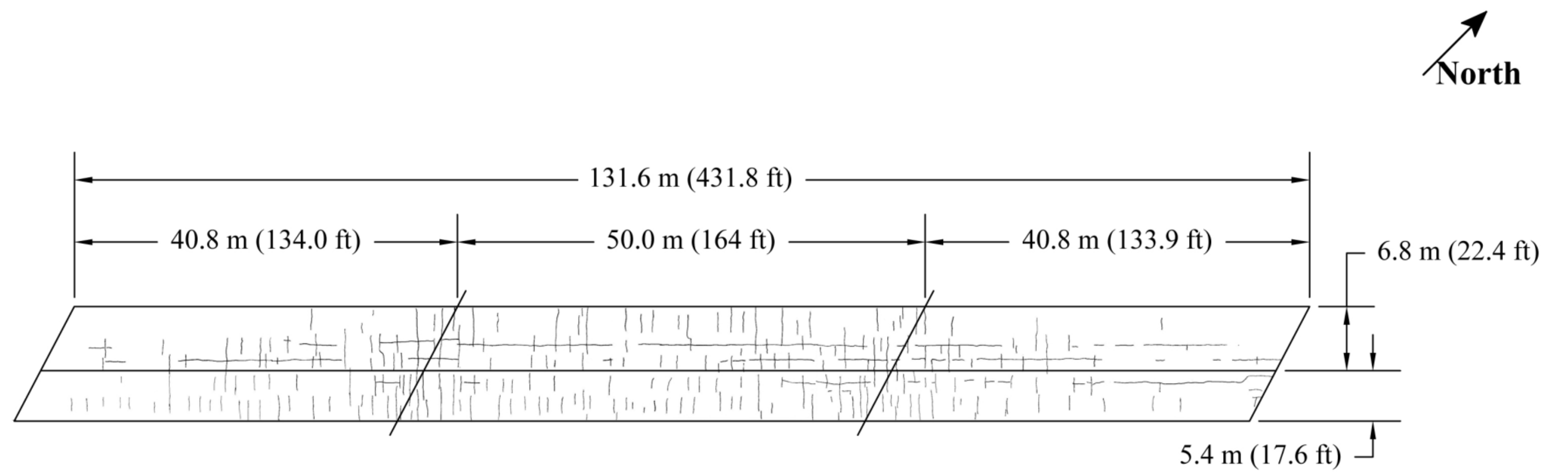


Bridge Number: 54-57 (KU 9)
Bridge Location: NB US-69 over Marair Des Cygnes Rv
Construction Date: 4/15/2009
Crack survey Date: 6/4/2010

Bridge Length: 131.7 m (431.9 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -27.7^{o}
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: 13.6 months
Crack density: 0.130 m/m^2
Span 1 (South): 0.101 m/m ^{2}
Span 2 (Middle): 0.203 m/m^2
Span 3 (North): 0.069 m/m^2

Figure 32: LC-HPC-9 (Survey 1)



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: 5/28/2010

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: 24.2 months
Placement 2: 24.0 months
Crack density: 0.390 m/m²
Placement 1: 0.395 m/m²
Placement 2: 0.368 m/m²
Span 1 (South): 0.294 m/m²
Span 2 (Middle): 0.492 m/m²
Span 3 (North): 0.325 m/m²

Figure 33: Control-9 (Survey 1)

LC-HPC-10

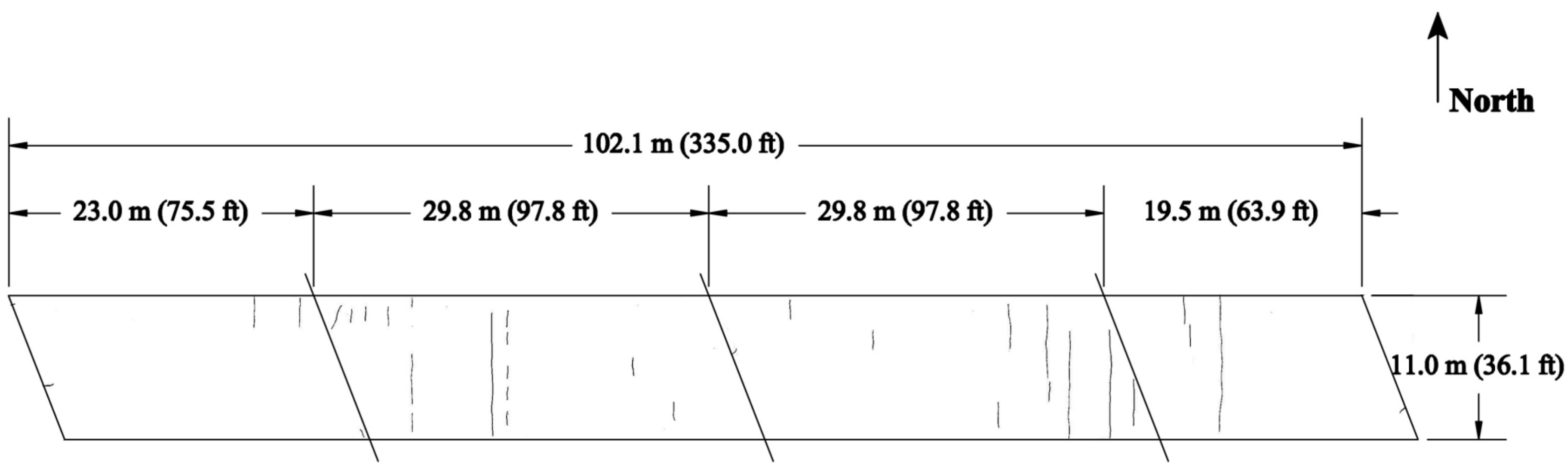
Surveys 1 and 2 of LC-HPC-10, at 25.4 and 36.2 months, are included in this report. LC-HPC-10 is the second of two LC-HPC bridges with precast, prestressed concrete girders. At 25.4 months, LC-HPC-10 had a crack density of 0.076 m/m^2, as shown in Figure 34. Transverse cracks occurred near the eastern pier and extended nearly across the entire bridge width. Minor transverse cracking was observed near the western pier. Little to no cracking had developed near the middle pier. At 36.2 months, the deck yielded a lower crack density of just 0.029 m/m^2, as shown in Figure 35.

LC-HPC-11

Surveys 1 and 2 of LC-HPC-11, at 23.4 and 36.2 months, are included in this report. At 23.4 months, LC-HPC-11 had a low crack density of 0.059 m/m^2, as shown in Figure 36. The cracks were primarily minor and longitudinal near the west abutment and transverse over the rest of the deck. At 36.2 months, however, the crack density increased considerably to 0.241 m/m^2 (Figure 37), with more transverse cracks appearing across the deck. Longitudinal cracks have developed at various locations throughout the deck.

Control-11

Surveys 3 and 4 of Control-11, at 37.8 and 50.2 months, are included in this report. Control-11 experienced a large amount of cracking, with a crack density of 0.599 m/m^2 at 37.8 months (Figure 38). This crack density is over two times larger than the crack density of LC-HPC-11 at 36.2 months. The crack density for Control-11 at 50.2 months is 0.636 m/m^2, as shown in Figure 39. This deck exhibits transverse cracks across the width of the deck that are distributed parallel to and above the top reinforcement along the deck length. Longitudinal cracks extend perpendicularly from each abutment. A single, longitudinal crack extends the

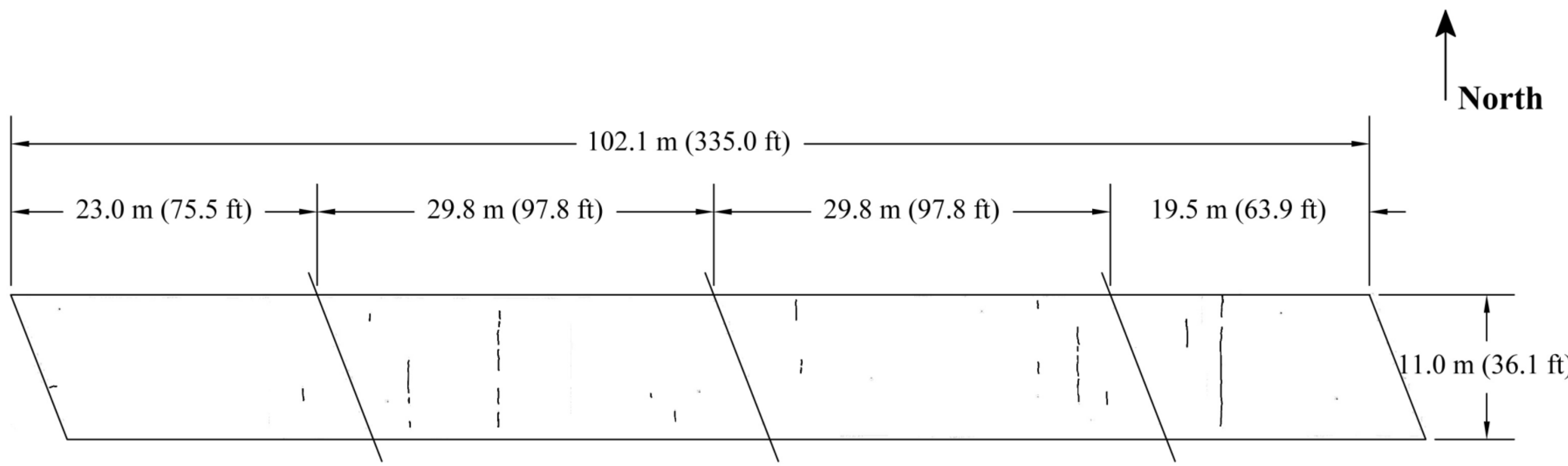


Bridge Number: 54-60 (KU 10)
Bridge Location: E1800Rd over US-69
Construction Date: 5/17/2007
Crack survey Date: 6/29/2009

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: 25.4 months
Crack density: 0.076 m/m^2
Span 1 (West): 0.025 m/m^2
Span 2 (West): 0.088 m/m^2
Span 3 (East): 0.109 m/m^2
Span 2 (East): 0.069 m/m^2

Figure 34: LC-HPC-10 (Survey 1)

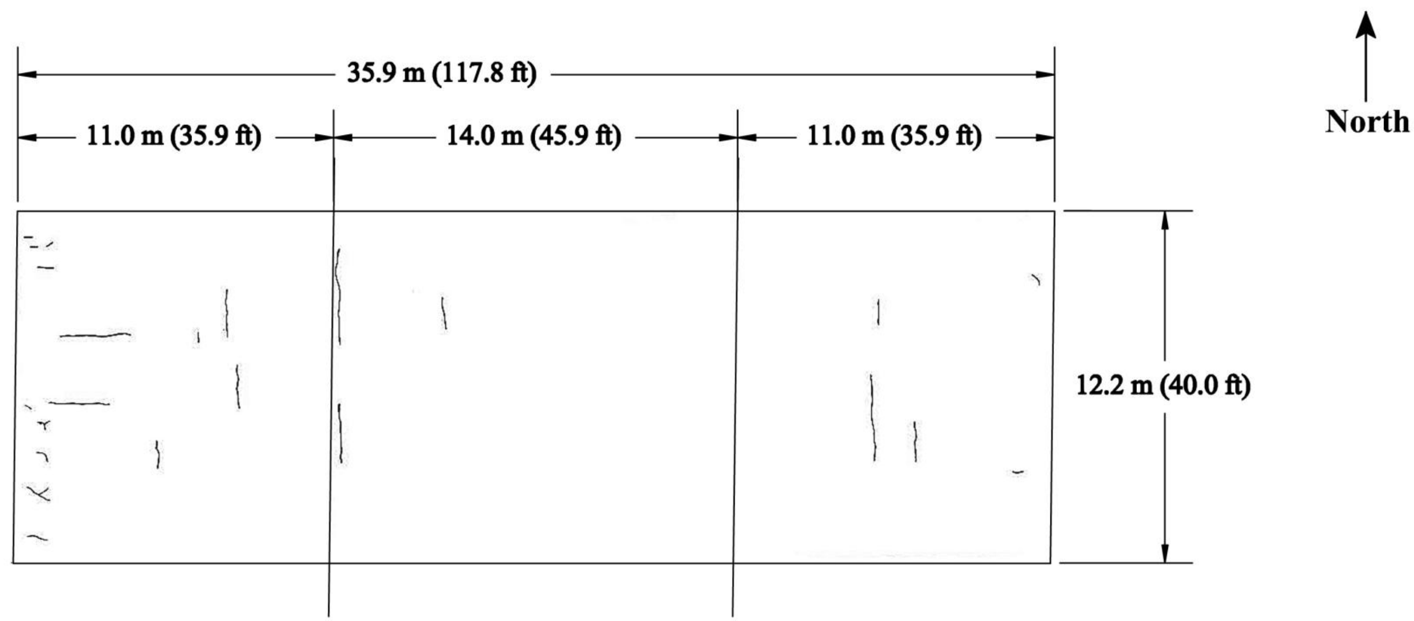


Bridge Number: 54-60 (KU 10)
Bridge Location: E1800Rd over US-69
Construction Date: 5/17/2007
Crack survey Date: 5/22/2010

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: 36.2 months
Crack density: 0.029 m/m^2
Span 1 (West): 0.005 m/m^2
Span 2 (West): 0.033 m/m^2
Span 3 (East): 0.029 m/m^2
Span 4 (East): 0.051 m/m^2

Figure 35: LC-HPC-10 (Survey 2)

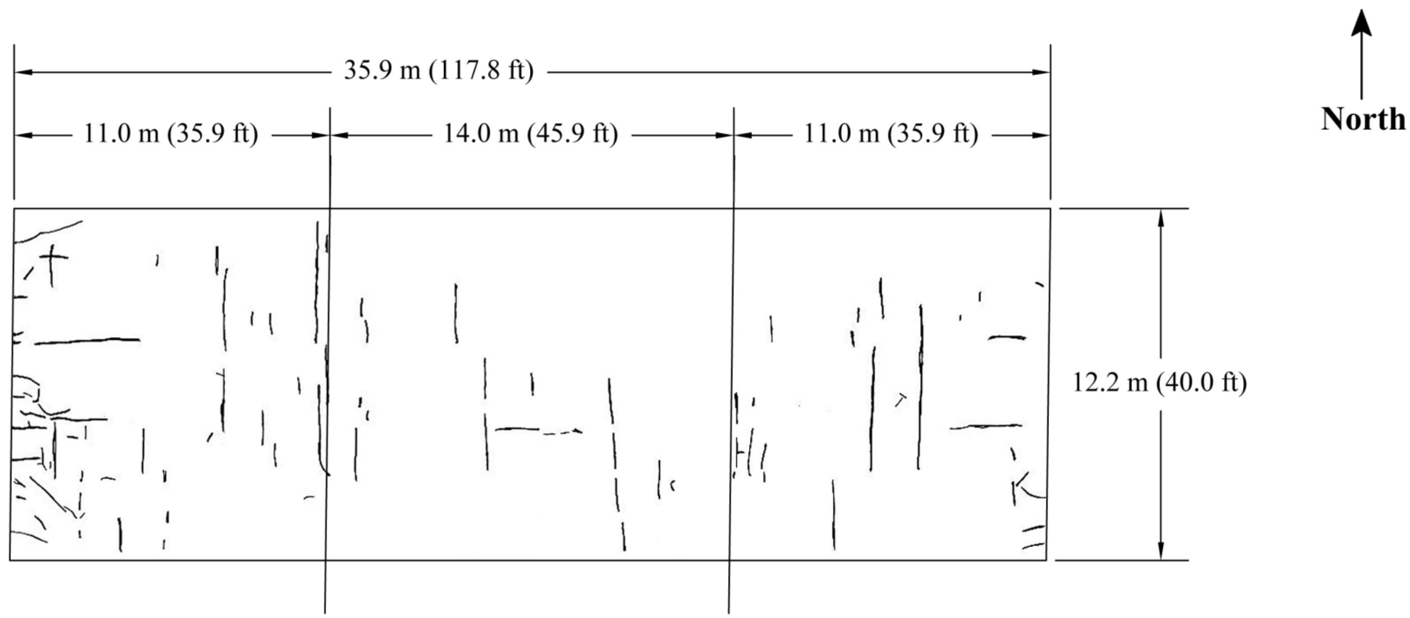


Bridge Number: 78-119 (KU #11)
Bridge Location: EB US-50 over K &ORR, Hutchinson, KS
Construction Date: 6/9/2007
Crack Survey Date: 5/20/2009

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: 23.4 months
Crack Density: 0.059 m/m²
Span 1: 0.091 m/m²
Span 2: 0.038 m/m²
Span 3: 0.046 m/m²

Figure 36: LC-HPC-11 (Survey 1)

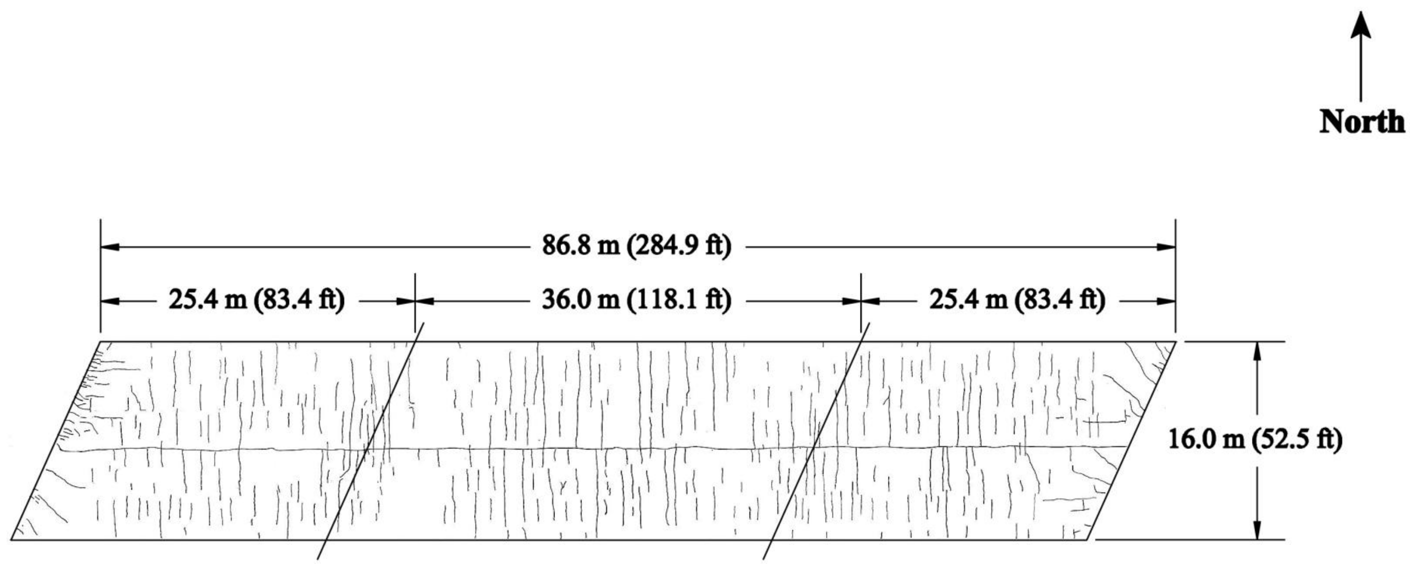


Bridge Number: 78-119 (KU #11)
Bridge Location: EB US-50 over K &ORR, Hutchinson, KS
Construction Date: 6/9/2007
Crack Survey Date: 6/15/2010

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: 36.2 months
Crack Density: 0.241 m/m^2
Span 1: 0.412 m/m^2
Span 2: 0.120 m/m^2
Span 3: 0.233 m/m^2

Figure 37: LC-HPC-11 (Survey 2)



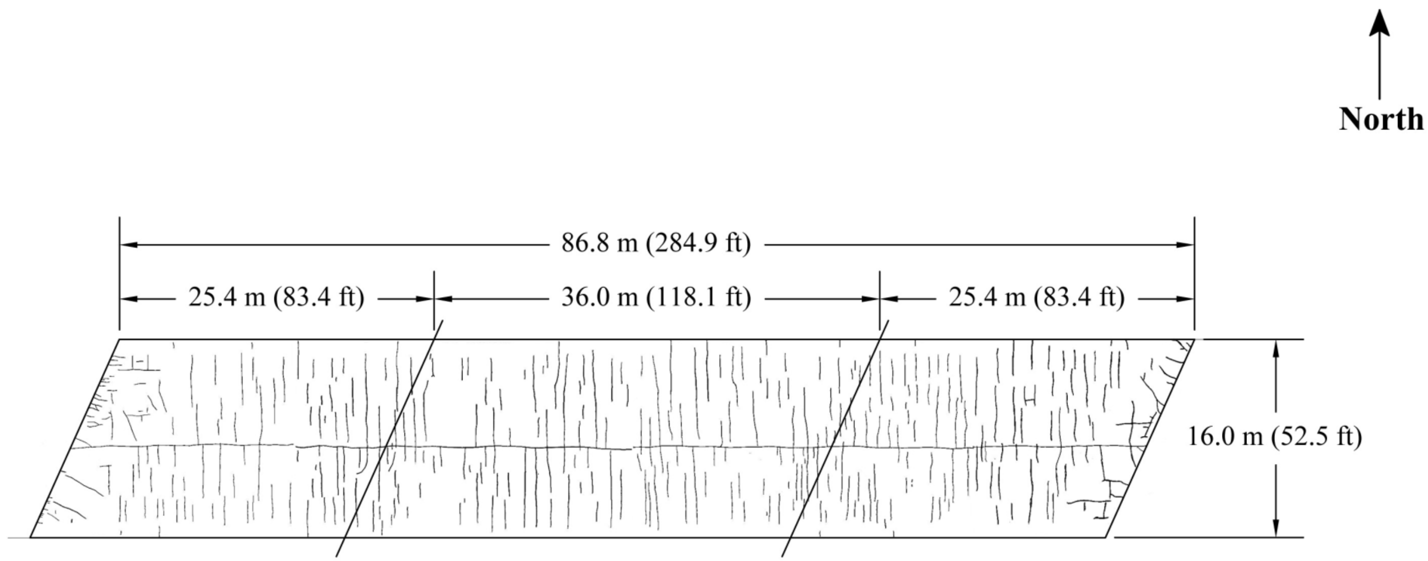
Bridge Number: 56-155 (KU #11 Control)
Bridge Location: US-50 over BNSF Railroad, Emporia, KS
Construction Date: 3/28/2006
Crack Survey Date: 5/21/2009

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: 37.8 months
Crack Density: 0.599 m/m^2
- **Span 1:** 0.608 m/m^2
- **Span 2:** 0.575 m/m^2
- **Span 3:** 0.624 m/m^2

Figure 38: Control-11 (Survey 3)



Bridge Number: 56-155 (KU #11 Control)
Bridge Location: US-50 over BNSF Railroad, Emporia, KS
Construction Date: 3/28/2006
Crack Survey Date: 6/2/2010

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: 50.2 months
Crack Density: 0.636 m/m^2
- **Span 1:** 0.596 m/m^2
- **Span 2:** 0.638 m/m^2
- **Span 3:** 0.677 m/m^2

Figure 39: Control-11 (Survey 4)

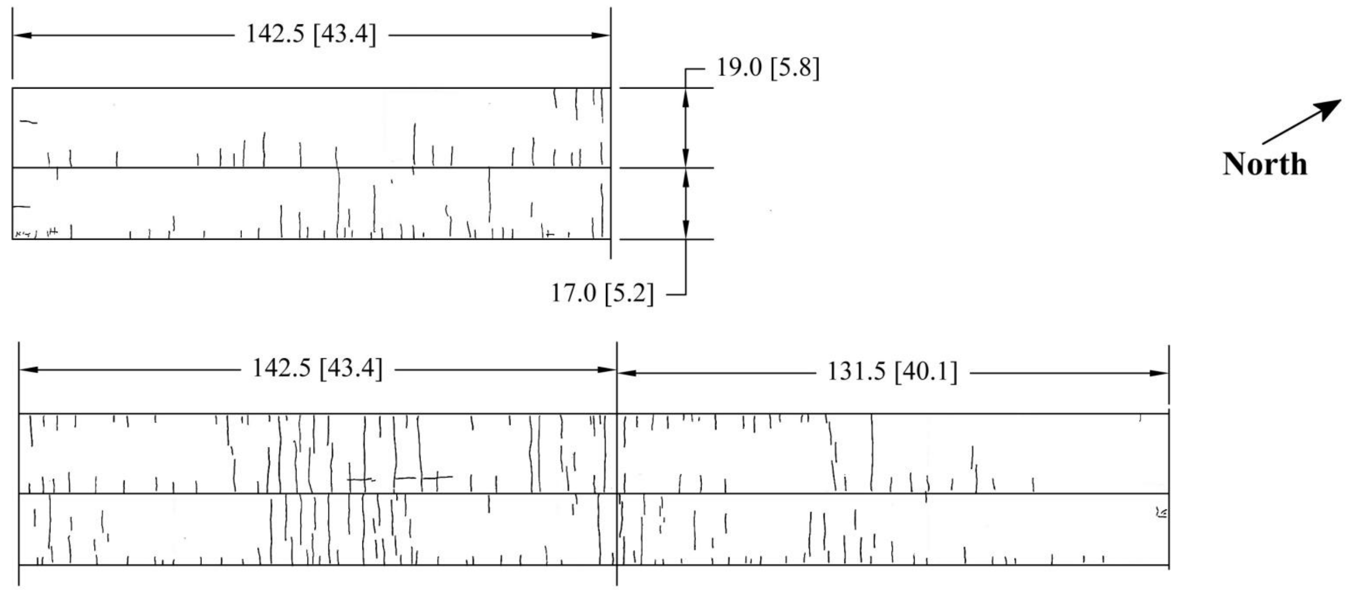
entire length of the bridge along the bridge centerline.

LC-HPC-12

The deck on LC-HPC-12 was cast using phased construction in two placements, 11.4 months apart. Survey 1 at 4.9 and 16.3 months and Survey 2 at 15.4 and 26.8 months are included in this report. The first survey was conducted at ages of 16.3 months for Placement 1 and 4.9 months for Placement 2 and yielded crack densities of 0.271 m/m^2 and 0.254 m/m^2, respectively. The overall crack density was 0.262 m/m^2, as shown in Figure 40. Transverse cracks extended from both edges of the deck from the longitudinal construction joint. The crack density was highest in the middle of the center span. No increased cracking occurred near the piers. During construction of Placement 2, construction equipment, including a crane, was placed on the completed Placement 1 to simplify construction. This increased loading may have affected the cracking behavior of Placement 1 due to increased torsional loading on the bridge. The second survey was conducted at 26.8 months for Placement 1 and 15.4 months for Placement 2, and the crack densities were 0.256 m/m^2 and 0.244 m/m^2, respectively, with an overall crack density of 0.250 m/m^2 (Figure 41).

Control-12

The construction of Control-12, the south half of the same bridge as LC-HPC-12, was similar to LC-HPC-12 in that it was constructed in two placements, 12.4 months apart. Survey 1 at 16.4 months and Survey 2 at 14.5 and 26.9 months are included in this report. Placement 1 was first surveyed at 16.4 months and exhibited a crack density of 0.606 m/m^2, as shown in Figure 42. Placement 2 was not surveyed at that time. The crack density for LC-HPC-12, Placement 1 at 16.3 months was less than half of the crack density of Control-12, Placement 1 at 16.4 months. The second crack survey was completed at 26.9 months for Placement 1 and at



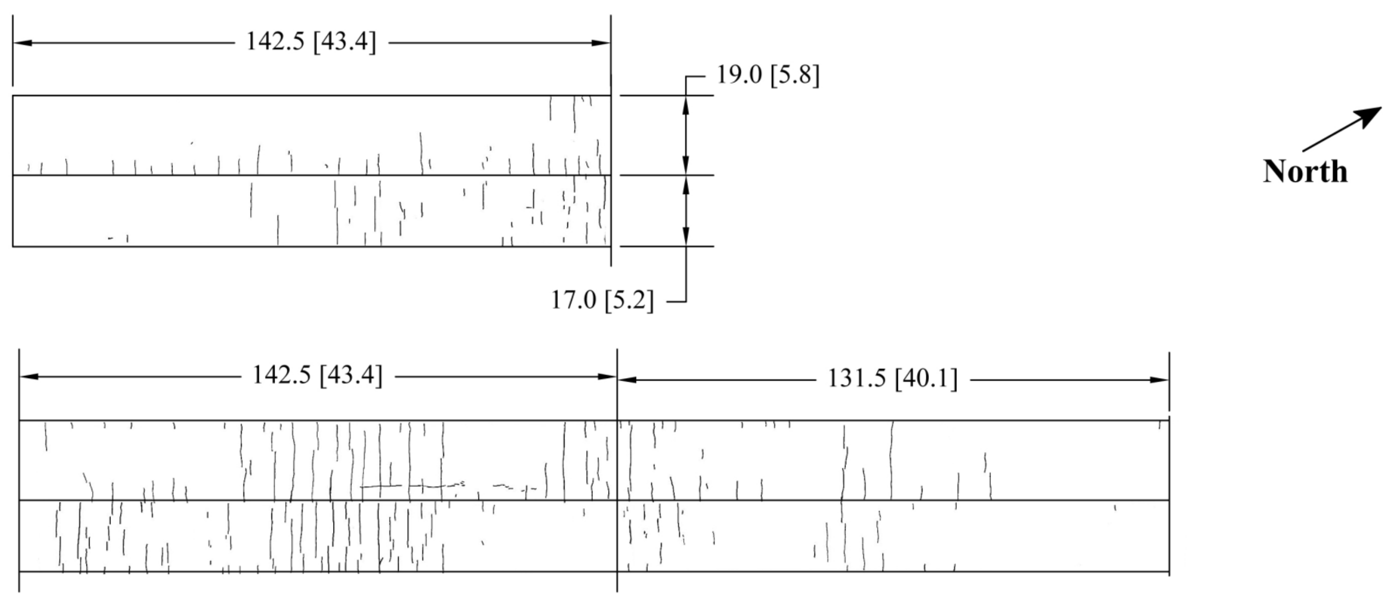
Bridge Number: 56-057 (KU 12)
Bridge Location: K-130 over Neosho Rv Unit 2
Construction Date:
Placement 1: 4/4/2008
Placement 2: 3/18/2009

Crack Survey Date: 8/13/2009

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: 16.3 months
Placement 2: 4.9 months
Crack Density: 0.262 m/m^2
Placement 1: 0.271 m/m^2
Placement 2: 0.254 m/m^2
Span 1: 0.182 m/m^2
Span 2: 0.408 m/m^2

Figure 40: LC-HPC-12 (Survey 1)



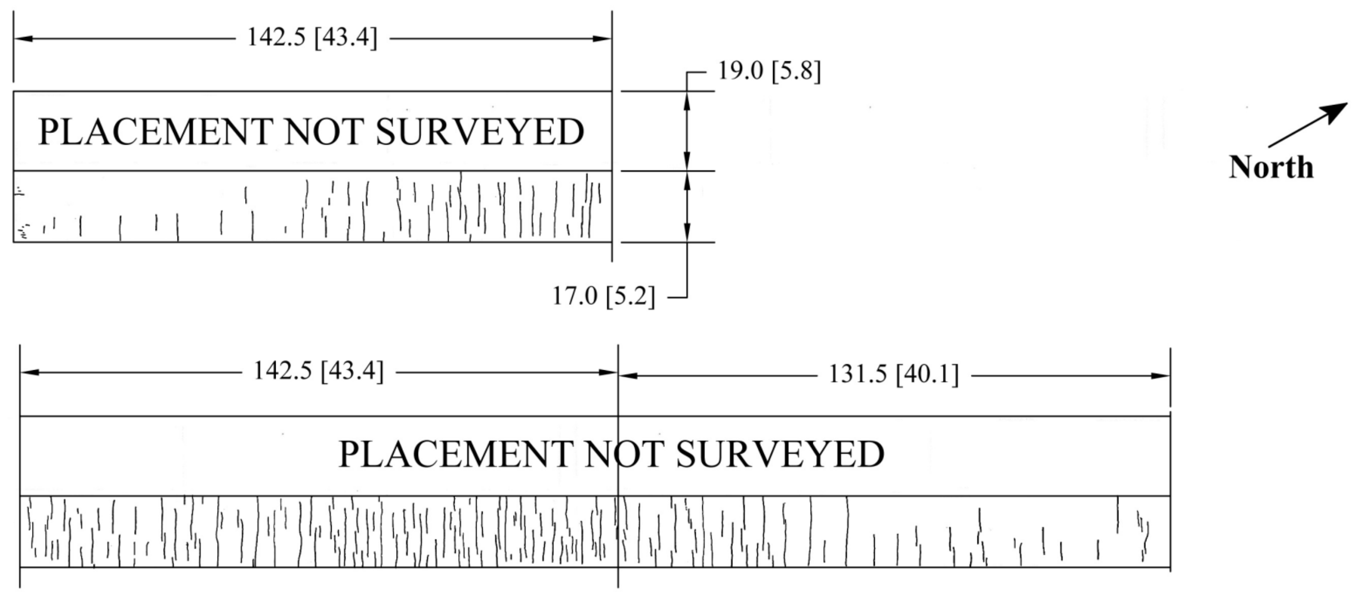
Bridge Number: 56-057 (KU 12)
Bridge Location: K-130 over Neosho Rv Unit 2
Construction Date:
Placement 1(east): 4/4/2008
Placement 2(west): 3/18/2009

Crack Survey Date: 6/29/2010

Bridge Length: 416.5' (126.95m)
Bridge Width: 36' (10.97m)
Skew: 0^{o}
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: 26.8 months
Placement 2: 15.4 months
Crack Density: 0.250 m/m^2
Placement 1: 0.256 m/m^2
Placement 2: 0.244 m/m^2
Span 1: 0.157 m/m^2
Span 2: 0.445 m/m^2

Figure 41: LC-HPC-12 (Survey 2)



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

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

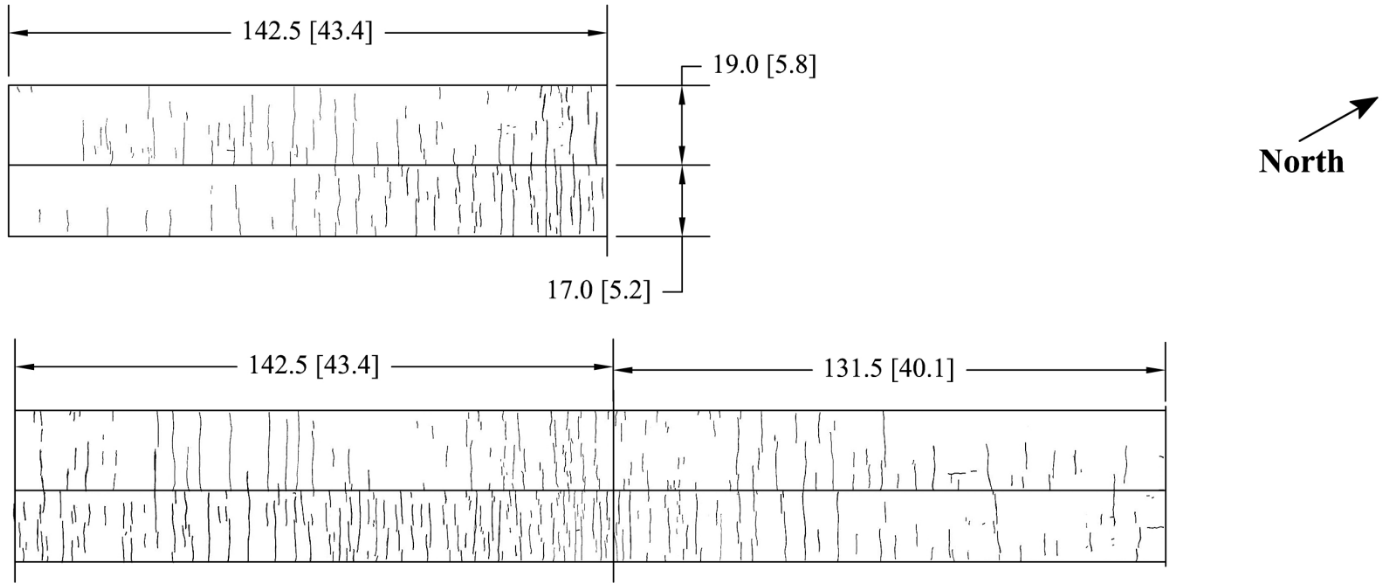
Bridge Age: months
Crack Density: 0.287 m/m²
Placement 1: 0.606 m/m²
Placement 2: Not Surveyed
Span 1: 0.188 m/m²
Span 2: 0.448 m/m²
Span 3: 0.222 m/m²

Figure 42: Control-12 (Survey 1)

14.5 months for Placement 2, giving crack densities of 0.669 m/m^2 and 0.442 m/m^2, respectively. The overall crack density was 0.548 m/m^2, as shown in Figure 43. Control-12 once again exhibited crack densities more than two times that of LC-HPC-12 at similar placement ages. Transverse cracking was found throughout the bridge deck, with the cracks extending nearly across the entire bridge width at most locations. Less cracking was experienced near the ends of the deck. As with LC-HPC-12, construction equipment had been placed on Placement 1 during the construction of Placement 2.

LC-HPC-13

Surveys 1 and 2 of LC-HPC-13, at 13.8 and 24.8 months, are included in this report. LC-HPC-13 had a crack density of 0.050 m/m^2 at 13.8 months (Figure 44). The cracks were primarily transverse with lengths of 1 to 2 m (3 to 6 ft) spread throughout the deck. Due to the skew of the bridge, the transverse cracks were parallel with the top reinforcement, but not parallel with the piers. This observation indicates the cracking was most likely caused by settlement and shrinkage at the top reinforcement. No increase in cracking was observed near the piers or abutments. A pattern of cracks extending nearly across the entire deck width parallel to the top reinforcement developed at the center of the west span. At 24.8 months, the crack density had increased to 0.129 m/m^2, as shown in Figure 45. Transverse cracks with length of 1 to 2 m (3 to 6 ft) once again made up the majority of the cracking. Less cracking had developed in the east span compared to the middle and west span. LC-HPC-13 was one of two LC-HPC decks that used a double drum roller screed for finishing.

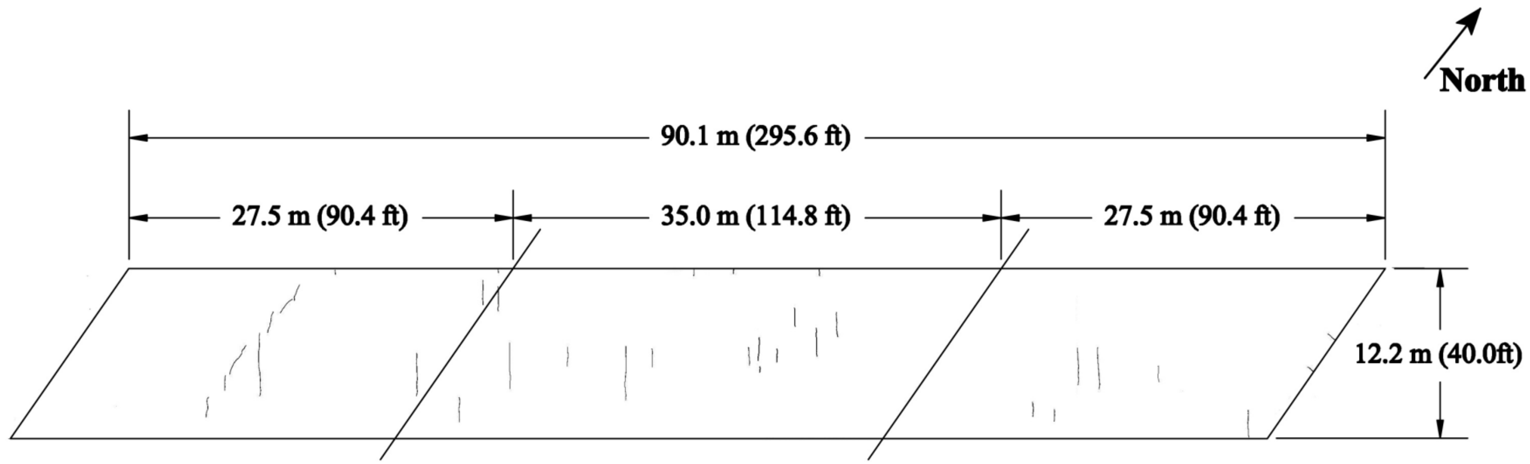


Bridge Number: 56-057 (Control 12)
Bridge Location: K-130 over Neosho Rv Unit 1
Construction Date:
Placement 1: 4/1/2008
Placement 2: 4/14/2009
Crack Survey Date: 6/29/2010

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: 26.9 months
Placement 2: 14.5 months
Crack Density: 0.548 m/m^2
Placement 1: 0.669 m/m^2
Placement 2: 0.442 m/m^2
Span 1: 0.468 m/m^2
Span 2: 0.747 m/m^2
Span 3: 0.421 m/m^2

Figure 43: Control-12 (Survey 2)

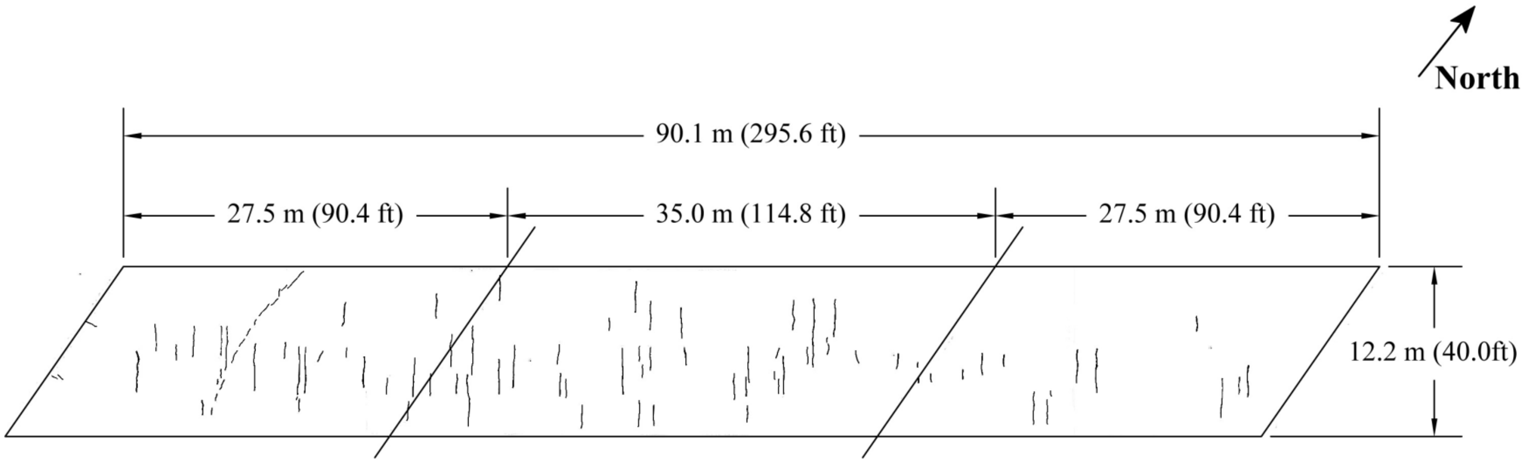


Bridge Number: 54-66 (KU 13)
Bridge Location: NB US-69 over BNSF RR, Linn County, KS
Construction Date: 4/29/2008
Crack survey Date: 6/24/2009

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: 13.8 months
Crack density: 0.050 m/m²
Span 1 (West): 0.058 m/m²
Span 2 (middle): 0.056 m/m²
Span 3 (East): 0.035 m/m²

Figure 44: LC-HPC-13 (Survey 1)



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: 5/24/2010

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: 24.8 months
Crack density: 0.129 m/m^2
Span 1 (West): 0.155 m/m^2
Span 2 (middle): 0.162 m/m^2
Span 3 (East): 0.061 m/m^2

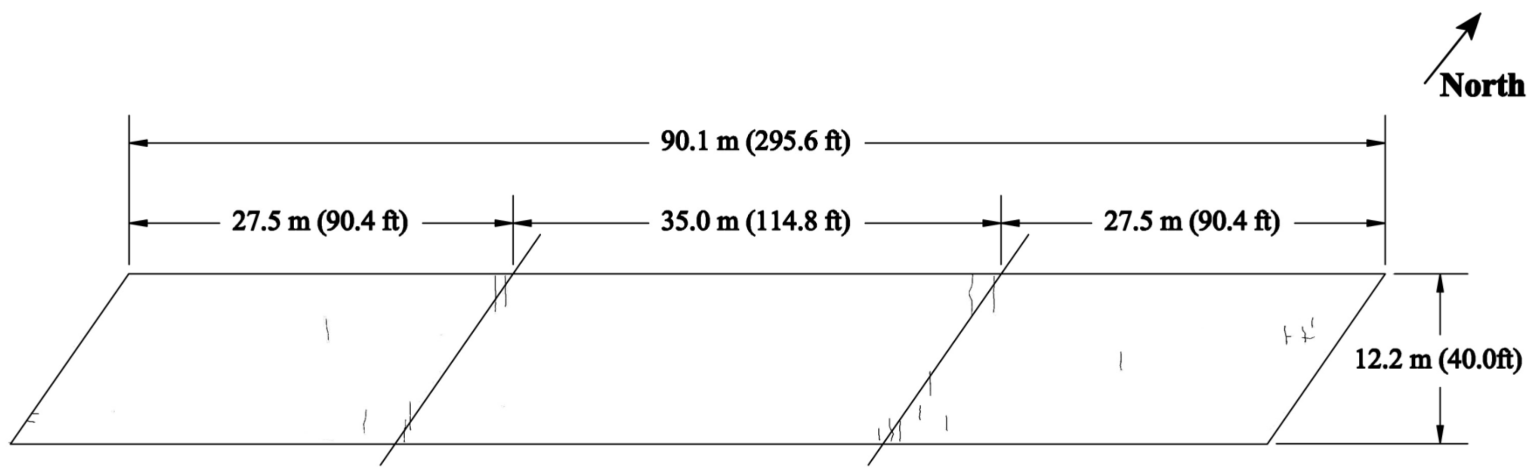
Figure 45: LC-HPC-13 (Survey 2)

Control-13

Surveys 1 and 2 of Control-13, at 11.0 and 21.9 months, are included in this report. At 11.0 months, Control-13 had a crack density of just 0.028 m/m^2, as shown in Figure 46. Nearly all of the cracks were transverse and located near the piers. The crack density at 21.9 months increased to 0.154 m/m^2, slightly more than the crack density of LC-HPC-13 at 24.8 months. Significant map cracking developed near the east end of the deck (Figure 47). Increased transverse cracking developed near both piers.

OP Bridge – Placement 1

Surveys 1 and 2 of OP Bridge – Placement 1, at 18.3 and 30.0 months, are included in this report. The OP deck has a considerably higher crack density than any of the other bridge decks constructed under LC-HPC specifications. The contractor did not follow and the owner did not enforce many of the key provisions of the LC-HPC specifications (McLeod et al. 2009), and the higher crack densities are most likely due to the myriad of issues that arose during construction. Placement 1 was completed on two separate dates due to concrete pumping issues. After only thirty feet of deck placement, construction was halted due to concrete backing up in the pump. This concrete was later removed from the deck and a second attempt was successfully completed several weeks later. During the second attempt, some of the concrete used in the deck had slumps above 5 in. Concrete consolidation proved to be inadequate, with coarse aggregate visible at the concrete surface after the vibrators were removed. The vibrators were also removed from the concrete too quickly, leaving holes at the vibrator locations. The contractor spent considerable time finishing the deck by bullfloating, leaving the deck overfinished at times, with an excess amount of cement paste at the deck surface (Lindquist et al. 2008). The time to burlap placement after finishing exceeded the ten minute limit throughout construction, primarily

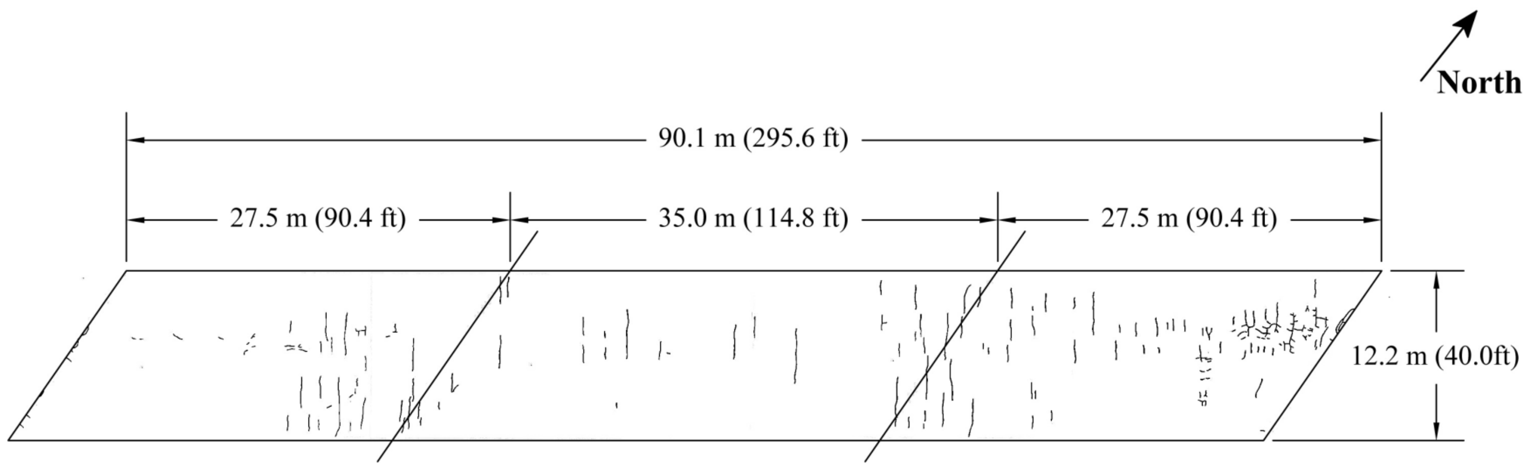


Bridge Number: 54-67
(KU 13 Control)
Bridge Location: SB US-69 over BNSF RR, Linn County, KS
Construction Date: 7/25/2008
Crack survey Date: 6/24/2009

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: 11.0 months
Crack density: 0.028 m/m²
Span 1 (West): 0.031 m/m²
Span 2 (middle): 0.025 m/m²
Span 3 (East): 0.035 m/m²

Figure 46: Control-13 (Survey 1)



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: 5/24/2010

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

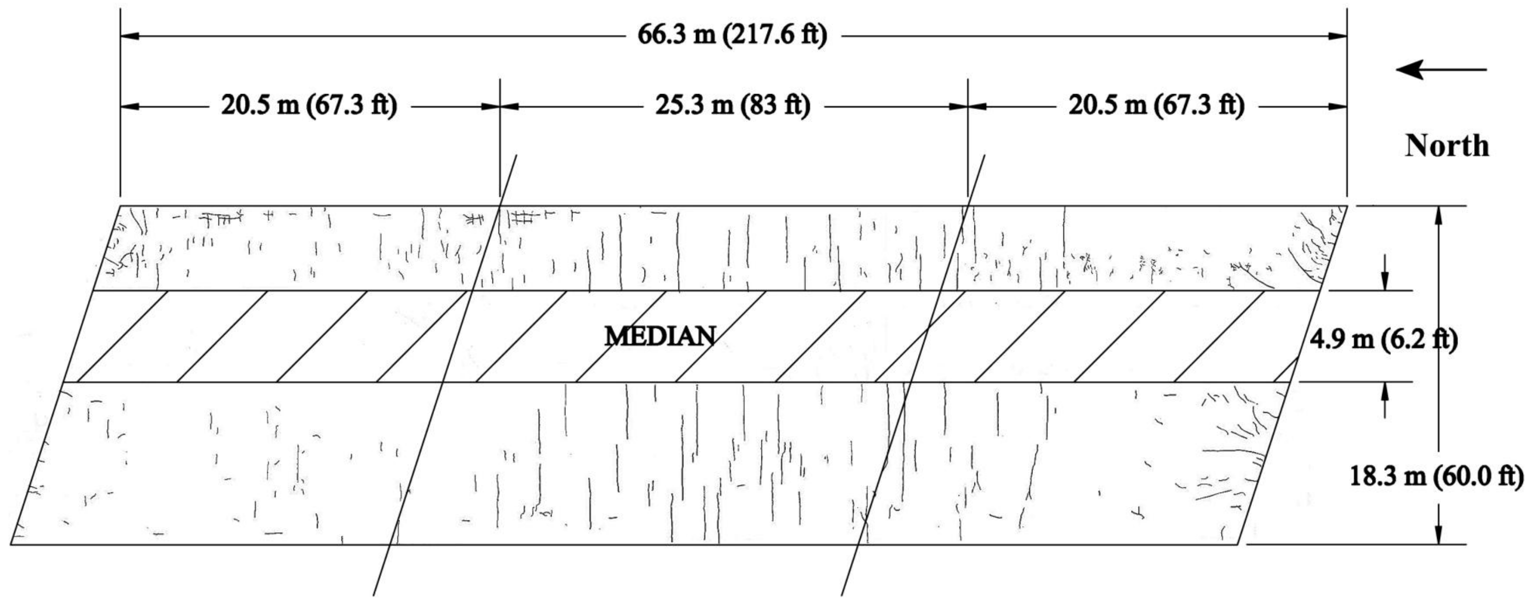
Bridge Age: 21.9 months
Crack density: 0.154 m/m^2
Span 1 (West): 0.128 m/m^2
Span 2 (middle): 0.108 m/m^2
Span 3 (East): 0.239 m/m^2

Figure 47: Control-13 (Survey 2)

due to the overfinishing. The contractor used water from the fogging equipment as a finishing agent (McLeod et al. 2009). At 18.3 months, Placement 1 had a crack density of 0.341 m/m^2, as shown in Figure 48. Transverse cracks extended nearly across the bridge width above the top reinforcement in the middle of the center span. Longitudinal cracks extended from the south abutment. A large number of short map cracks developed on the two outside spans. No increased cracking was detected at the piers. By 30.0 months, the crack density had increased to 0.502 m/m^2, as shown in Figure 49. The cracking patterns were similar to those in the first survey.

OP Bridge – Placement 2

Surveys 1 and 2 of OP Bridge – Placement 2, at 13.7 and 25.5 months, are included in this report. Placement 2 for the OP deck also has considerably higher crack densities compared to the other decks constructed under LC-HPC specifications. Once again, problems developed during construction that are the likely causes of these high crack densities. The concrete placed in the deck generally had a higher slump and air content than specified in the LC-HPC specifications. High slumps place the deck at risk for settlement cracking. Heavy rain from the previous night made it difficult for the concrete supplier to accurately determine the aggregate moisture contents. A double-drum roller was used for finishing on this placement, possibly contributing to overfinishing of the concrete and increased cement paste at the deck surface. The time of burlap placement after finishing exceeded the ten minute limit throughout construction. During a delay in concrete delivery, a portion of the concrete was shoveled from a wingwall and placed into the deck. At 13.7 months, Placement 2 had a crack density of 0.640 m/m^2 (Figure 50). Significant transverse cracking developed from the center of the north span to the center of the south span. Extensive map cracking developed throughout the deck. The crack density is

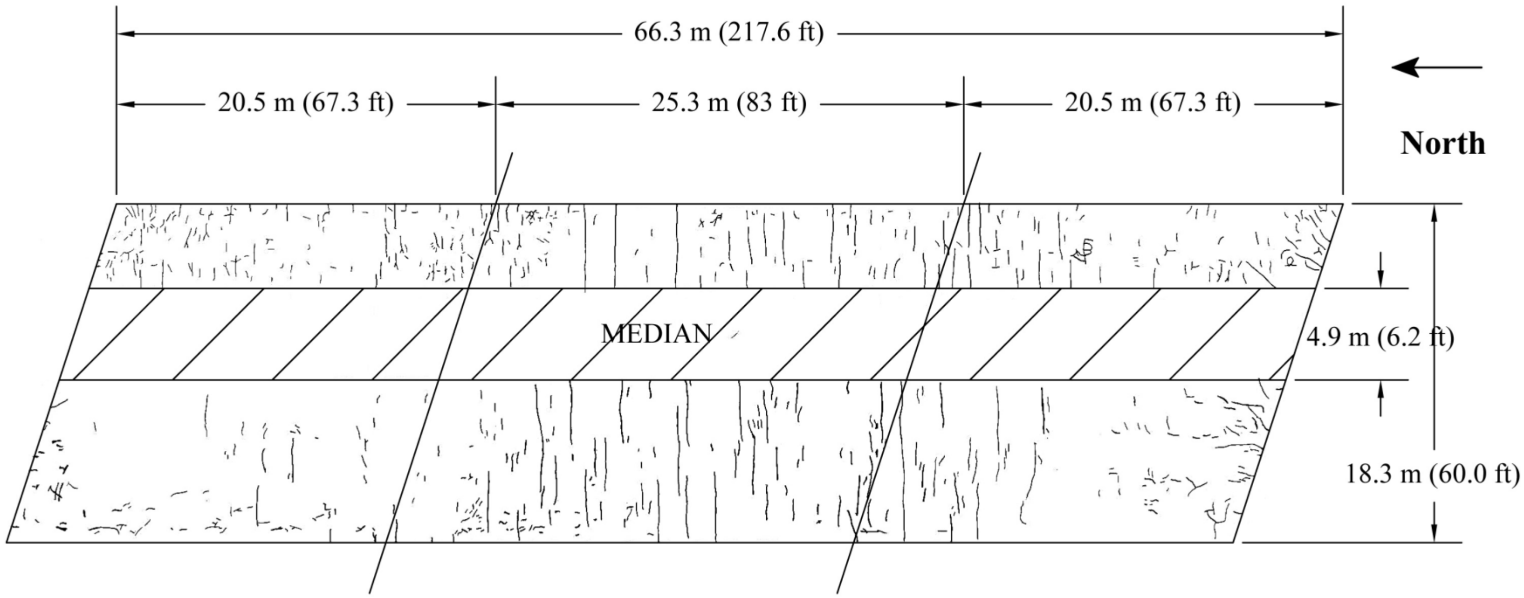


Bridge Number: 46-363 placement 1 (KU #14)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 12/19/2007
Crack Survey Date: 6/23/2009 and 7/1/2009

Bridge Length: 66.3 m (217.6 ft)
Bridge Width: 18.3 m (60.0 ft)
Skew: -18 °
Number of Spans: 3
Span 1: 20.5 m (67.3 ft)
Span 2: 25.3 m (83.0 ft)
Span 3: 20.5 m (67.3 ft)
Number of Placements: 1

Bridge Age: 18.3 months
Crack Density: 0.341 m/m²
Span 1: 0.243 m/m²
Span 2: 0.404 m/m²
Span 3: 0.361 m/m²

Figure 48: OP Bridge – Placement 1 (Survey 1)

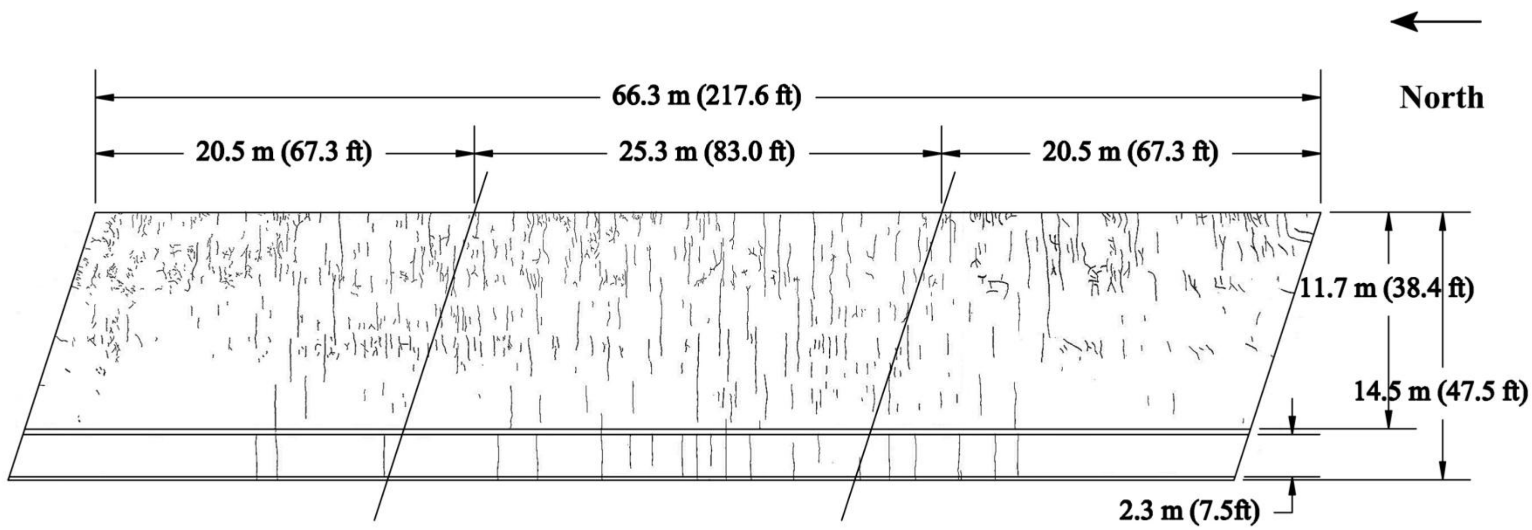


Bridge Number: 46-363 placement 1 (KU #14)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 12/19/2007
Crack Survey Date: 6/18/2010

Bridge Length: 66.3 m (217.6 ft)
Bridge Width: 18.3 m (60.0 ft)
Skew: -18^{o}
Number of Spans: 3
Span 1: 20.5 m (67.3 ft)
Span 2: 25.3 m (83.0 ft)
Span 3: 20.5 m (67.3 ft)
Number of Placements: 1

Bridge Age: 30.0 months
Crack Density: 0.502 m/m^2
Span 1: 0.388 m/m^2
Span 2: 0.583 m/m^2
Span 3: 0.518 m/m^2

Figure 49: OP Bridge – Placement 1 (Survey 2)



Bridge Number: 46-363 placement 2 (KU #14)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 5/2/2008
Crack Survey Date: 6/23/2009

Bridge Length: 66.3 m (217.6 ft)
Bridge Width: 14.5 m (47.5 ft)
Skew: -18 °
Number of Spans: 3
Span 1: 20.5 m (67.3 ft)
Span 2: 25.3 m (83.0 ft)
Span 3: 20.5 m (67.3 ft)
Number of Placements: 1

Bridge Age: 13.7 months
Crack Density: 0.640 m/m²
Span 1: 0.609 m/m²
Span 2: 0.756 m/m²
Span 3: 0.528 m/m²

Figure 50: OP Bridge – Placement 2 (Survey 1)

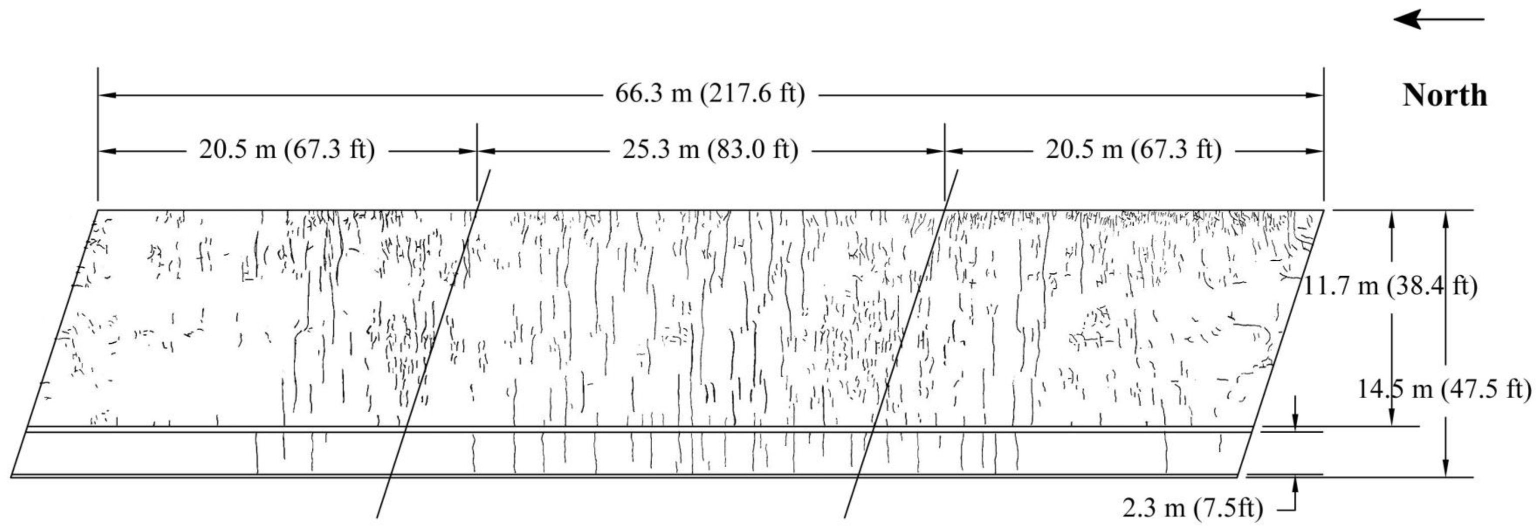
higher on the east side of the placement, where it ties in with Placement 1. At 25.5 months, the crack density increased to 0.727 m/m^2, as shown in Figure 51. Similar cracking patterns to those in Survey 1 are observed.

OP Bridge – Placement 3

Surveys 1 and 2 of OP Bridge – Placement 3, at 13.3 and 24.9 months, are included in this report. Placement 3 also had problems during the construction process leading to increased crack densities. The concrete used in this placement had very high slumps and high air contents. Deck reinforcement was observed to be not tightly supported and had a tendency to spring up, potentially increasing the risk of settlement cracking. As with Placement 2, a double-drum roller screed was used for finishing. Placements 2 and 3 of the OP Bridge were the only LC-HPC specified bridges that used a double-drum roller screed for finishing. The majority of locations exceeded the ten minute limit for wet burlap placement after finishing (Gruman et al. 2009). The crack density for Placement 3 at 13.3 months was 0.421 m/m^2, as shown in Figure 52. The majority of cracks were transverse and located in the middle span. Shorter transverse cracks developed in each of the outside spans. At 24.9 months, the crack density more than doubled to 0.871 m/m^2, as shown in Figure 53. Extensive map cracking has developed throughout the outer spans. Longer transverse cracks are located within the middle span.

Control-Alt

Control-Alt is located in Emporia, KS and was chosen as an additional control structure because it is a monolithic deck, like all LC-HPC decks. All other control decks have a silica fume overlay. Surveys 4 and 5 of Control-Alt, at 47.5 and 60.7 months, are included in this report. The alternate control had a crack density of 0.265 m/m^2 at 47.5 months, as shown in Figure 54. The cracks are primarily transverse and spread throughout the bridge deck. No

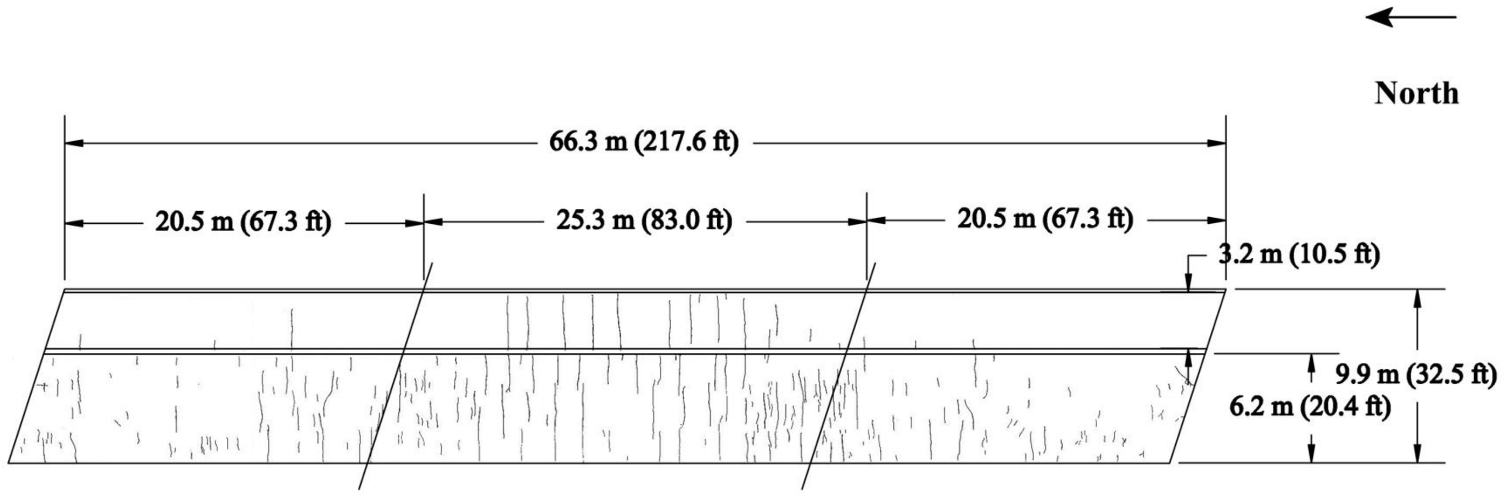


Bridge Number: 46-363 placement 2 (KU #14)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 5/2/2008
Crack Survey Date: 6/18/2010

Bridge Length: 66.3 m (217.6 ft)
Bridge Width: 14.5 m (47.5 ft)
Skew: -18°
Number of Spans: 3
Span 1: 20.5 m (67.3 ft)
Span 2: 25.3 m (83.0 ft)
Span 3: 20.5 m (67.3 ft)
Number of Placements: 1

Bridge Age: 25.5 months
Crack Density: 0.727 m/m^2
Span 1: 0.548 m/m^2
Span 2: 0.836 m/m^2
Span 3: 0.779 m/m^2

Figure 51: OP Bridge – Placement 2 (Survey 2)

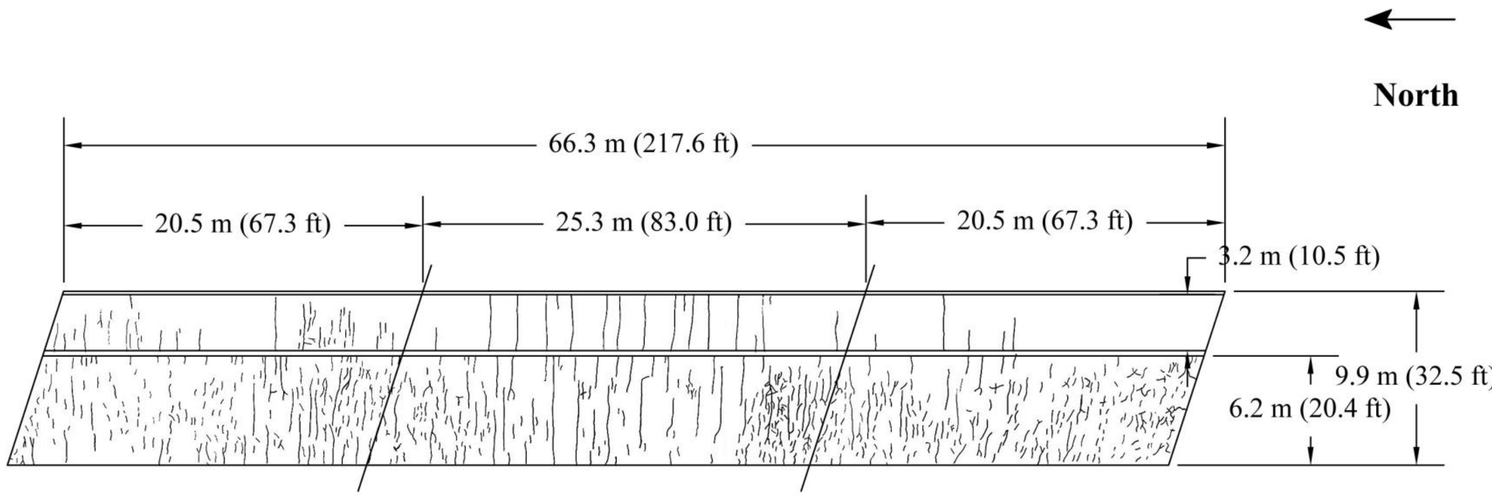


Bridge Number: 46-363 placement 3 (KU #14)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 5/21/2008
Crack Survey Date: 7/1/2009

Bridge Length: 66.3 m (217.6 ft)
Bridge Width: 9.9 m (32.5 ft)
Skew: -18 °
Number of Spans: 3
Span 1: 20.5 m (67.3 ft)
Span 2: 25.3 m (83.0 ft)
Span 3: 20.5 m (67.3 ft)
Number of Placements: 1

Bridge Age: 13.3 months
Crack Density: 0.421 m/m²
Span 1: 0.296 m/m²
Span 2: 0.629 m/m²
Span 3: 0.290 m/m²

Figure 52: OP Bridge – Placement 3 (Survey 1)

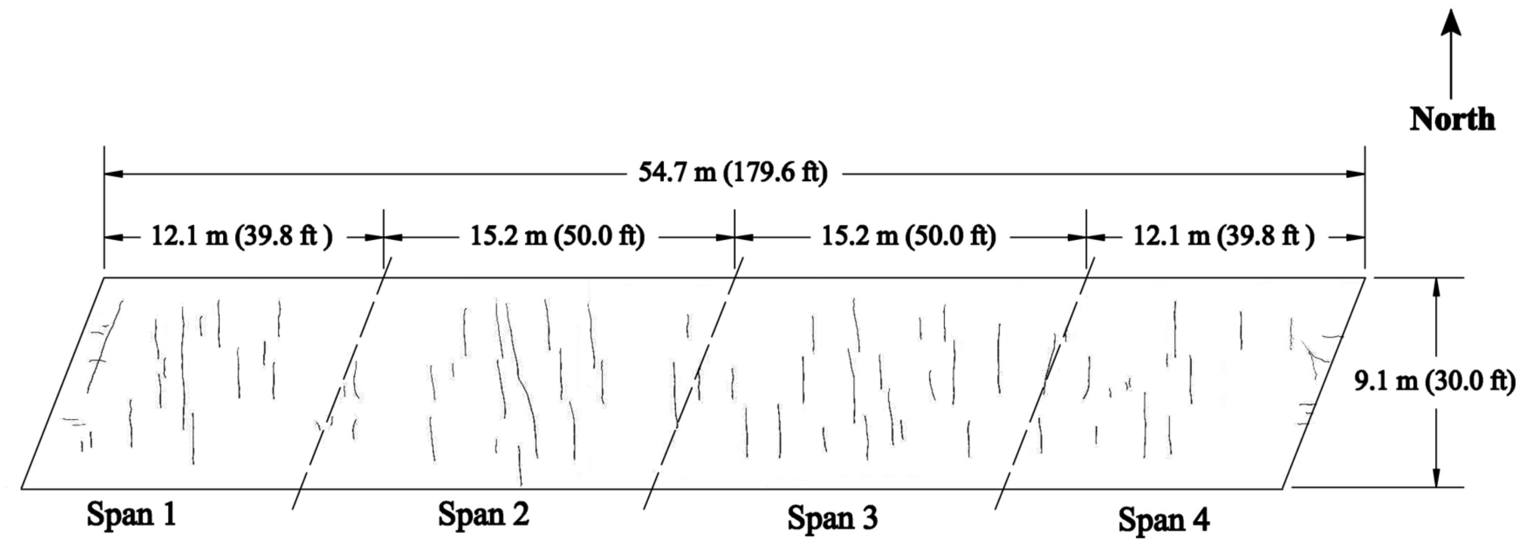


Bridge Number: 46-363 placement 3 (KU #14)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 5/21/2008
Crack Survey Date: 6/18/2010

Bridge Length: 66.3 m (217.6 ft)
Bridge Width: 9.9 m (32.5 ft)
Skew: -18°
Number of Spans: 3
Span 1: 20.5 m (67.3 ft)
Span 2: 25.3 m (83.0 ft)
Span 3: 20.5 m (67.3 ft)
Number of Placements: 1

Bridge Age: 24.9 months
Crack Density: 0.871 m/m^2
Span 1: 0.874 m/m^2
Span 2: 0.943 m/m^2
Span 3: 0.788 m/m^2

Figure 53: OP Bridge – Placement 3 (Survey 2)



Bridge Number: 56-49
Bridge Location: K-99 over I-335
Construction Date: 6/2/2005
Crack survey Date: 5/19/2009

Bridge Length: 54.7 m (179.6 ft)
Bridge Width: 9.1 m (30.0 ft)
Skew: -21.5°
Number of Spans: 4
- **Span 1 :** 12.1 m (39.8 ft)
- **Span 2 :** 15.2 m (50.0 ft)
- **Span 3 :** 15.2 m (50.0 ft)
- **Span 4 :** 12.1 m (39.8 ft)

Number of Placements: 1

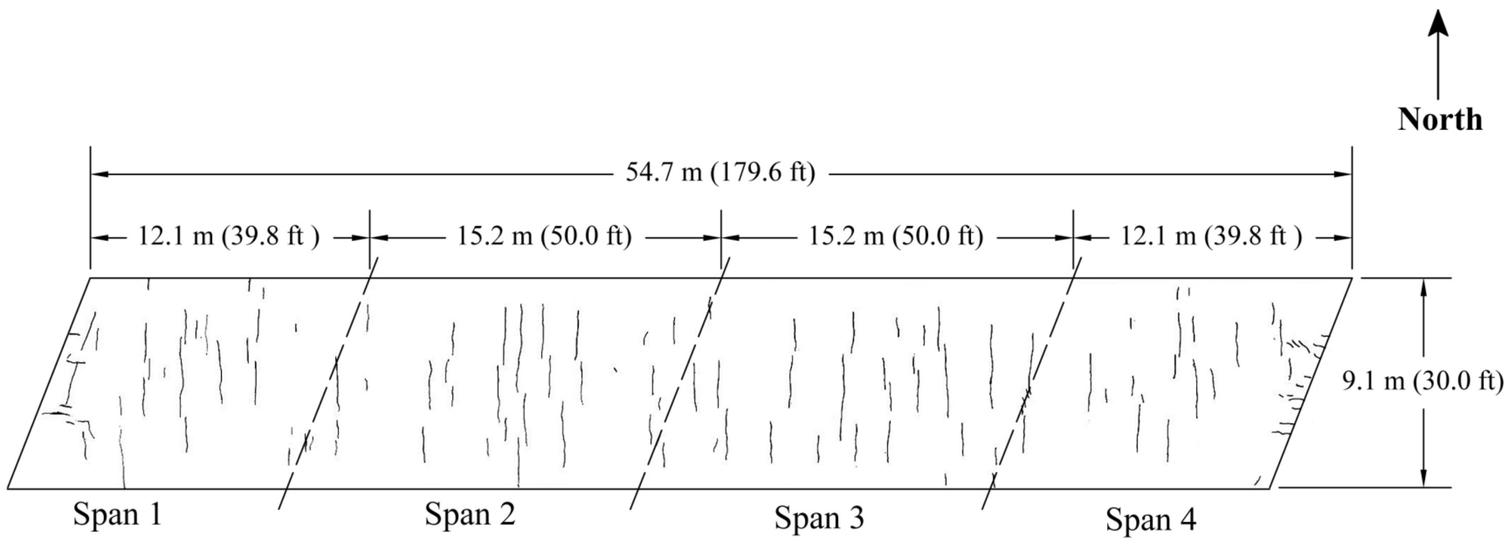
Bridge Age: 47.5 months
Crack density: 0.265 m/m²
- **Span 1 :** 0.283 m/m²
- **Span 2 :** 0.281 m/m²
- **Span 3 :** 0.277 m/m²
- **Span 4 :** 0.208 m/m²

Figure 54: Control-Alt (Survey 4)

increase in cracking was observed near or parallel to the piers. The crack locations suggest that most cracking was due to shrinkage and settlement of the concrete at the reinforcing steel, as opposed to cracking induced by tensile stresses at the negative moment regions near the piers. Minimal longitudinal cracking was also found at each abutment. The crack density of the alternate control increased to 0.316 m/m^2 at 60.7 months (Figure 55). More transverse cracking above the top reinforcement developed throughout the bridge and a minimal increase in longitudinal cracking occurred at the east abutment.

OP-Extra

Surveys 1 and 2 of OP-Extra, at 13.4 and 23.3 months, are included in this report. An extra precast, prestressed concrete girder control bridge was surveyed in Overland Park in 2009 and 2010. The bridge was constructed by the contractor of the OP Bridge. The deck yielded a crack density of 0.284 m/m^2 at 13.4 months, as shown in Figure 56. At 23.3 months, the crack density increased to 0.302 m/m^2 (Figure 57). Considerable cracking developed near each pier in both transverse and longitudinal directions. Transverse cracks that extend nearly the entire bridge width above the reinforcing steel are found throughout the deck, but are more prominent on the west end. Longitudinal cracks extended from each abutment. This deck had a similar crack density at 23.3 months as LC-HPC-8, another prestressed girder bridge, at 20.9 months (0.302 m/m^2 vs. 0.298 m/m^2). OP-Extra had nearly four times the crack density at 23.3 months as LC-HPC-10 at 25.4 months (0.302 m/m^2 vs. 0.076 m/m^2) and more than two times the crack density as Control-8/10 at 25.5 months (0.302 m/m^2 vs. 0.127 m/m^2), all prestressed girder bridges.



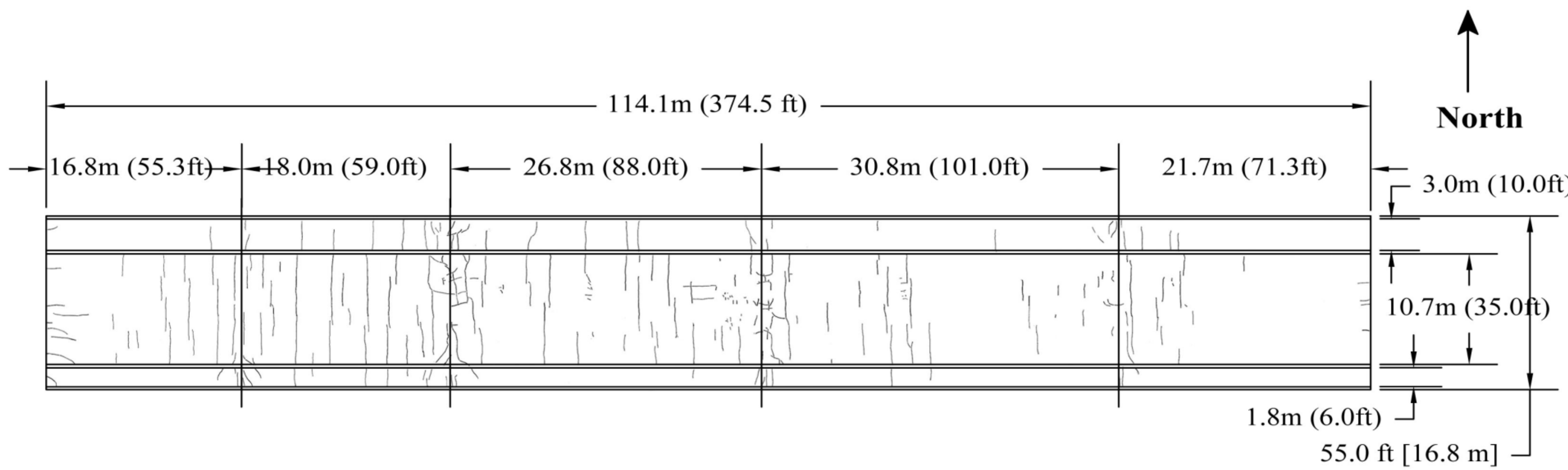
Bridge Number: 56-49
Bridge Location: K-99 over I-335
Construction Date: 6/2/2005
Crack survey Date: 6/24/2010

Bridge Length: 54.7 m (179.6 ft)
Bridge Width: 9.1 m (30.0 ft)
Skew: -21.5°
Number of Spans: 4
- **Span 1 :** 12.1 m (39.8 ft)
- **Span 2 :** 15.2 m (50.0 ft)
- **Span 3 :** 15.2 m (50.0 ft)
- **Span 4 :** 12.1 m (39.8 ft)

Number of Placements: 1

Bridge Age: 60.7 months
Crack density: 0.316 m/m^2
- **Span 1 :** 0.342 m/m^2
- **Span 2 :** 0.315 m/m^2
- **Span 3 :** 0.329 m/m^2
- **Span 4 :** 0.279 m/m^2

Figure 55: Control-Alt (Survey 5)

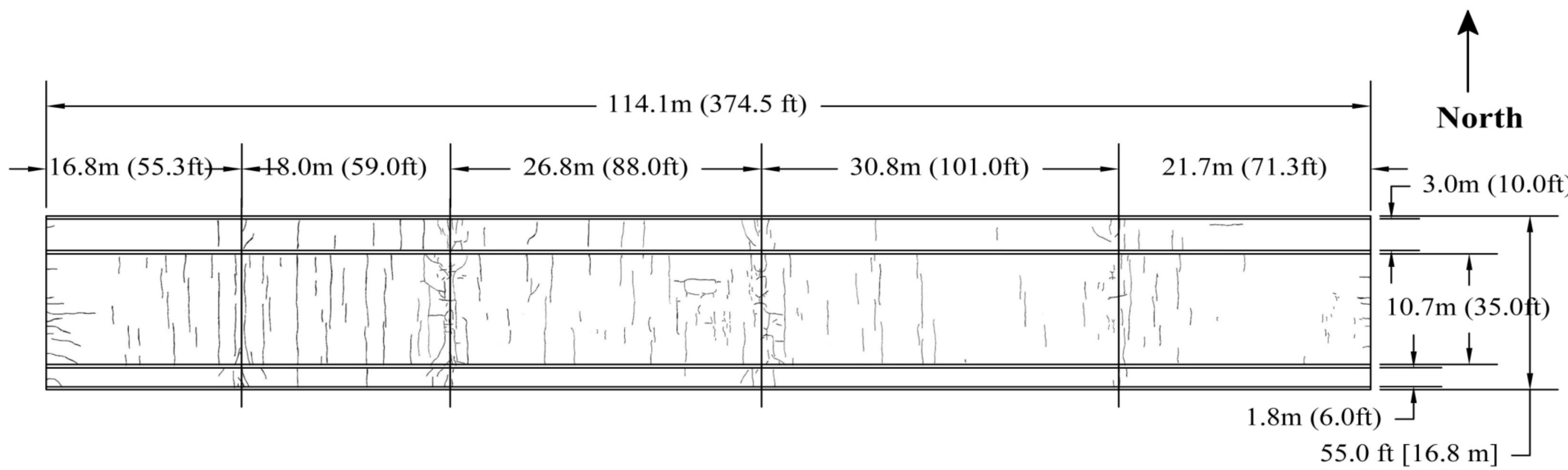


Bridge Number: Overland Park extra
Bridge Location: 132nd street over US 69, OP,KS
Construction Date: 6/30/2008
Crack Survey Date: 8/12/2009

Bridge Length: 114.1 m (374.5 ft)
Bridge Width: 16.8 m (55.0 ft)
Skew: 0°
Number of Spans: 5
Span 1: 16.8 m (55.3 ft)
Span 2: 18.0 m (59.0 ft)
Span 3: 26.8 m (88.0 ft)
Span 4: 30.8 m (101.0 ft)
Span 5: 21.7 m (71.3 ft)
Number of Placements: 1

Bridge Age: 13.4 months
Crack Density: 0.284 m/m^2
Span 1: 0.278 m/m^2
Span 2: 0.490 m/m^2
Span 3: 0.344 m/m^2
Span 4: 0.214 m/m^2
Span 5: 0.137 m/m^2

Figure 56: OP-Extra (Survey 1)



Bridge Number: Overland Park extra
Bridge Location: 132nd street over US 69, OP,KS
Construction Date: 6/30/2008
Crack Survey Date: 6/10/2010

Bridge Length: 114.1 m (374.5 ft)
Bridge Width: 16.8 m (55.0 ft)
Skew: 0°
Number of Spans: 5
Span 1: 16.8 m (55.3 ft)
Span 2: 18.0 m (59.0 ft)
Span 3: 26.8 m (88.0 ft)
Span 4: 30.8 m (101.0 ft)
Span 5: 21.7 m (71.3 ft)
Number of Placements: 1

Bridge Age: 23.3 months
Crack Density: 0.302 m/m^2
Span 1: 0.301 m/m^2
Span 2: 0.535 m/m^2
Span 3: 0.361 m/m^2
Span 4: 0.212 m/m^2
Span 5: 0.170 m/m^2

Figure 57: OP-Extra (Survey 2)

Summary of Results

The crack densities for the LC-HPC and Control decks for the 2010 surveys are summarized in Table 4. Of the thirteen LC-HPC bridge decks with a directly comparable control bridge deck, twelve had a lower crack density than the control deck in 2010. The overall effectiveness of low-cracking high-performance concrete in bridge decks is verified by the comparison of LC-HPC and control bridge deck crack densities shown in Figure 58. Typical LC-HPC specifications were not followed during the construction of OP Bridge Placements 1-3. For this reason, OP Bridge is denoted differently than other LC-HPC decks in Figure 58. The maximum crack density to date on LC-HPC bridge decks that complied with LC-HPC specifications is 0.348 m/m^2, for LC-HPC-8. The maximum crack density to date for a control deck is nearly three times higher, at 1.037 m/m^2, for Control-7 Placement 1. Only in the comparison between LC-HPC-8 and Control 8/10, both prestressed concrete girder bridges, does an LC-HPC deck exhibit a greater crack density in 2010 than the corresponding control did. All LC-HPC decks on steel girders have a lower crack density in 2010 than the comparable control deck. Individual comparisons of crack density are shown in Figures 59 through 65. These bridge decks will continue to be monitored as the project continues through 2013.

Table 4 – 2010 Crack Density Comparison of LC-HPC vs. Control Decks

	2010 Crack Density (m/m^2)	Lower Crack Density	Bridge Girder Type
LC-HPC-1	0.027	LC-HPC	Steel
Control-1/2	0.115		
LC-HPC-2	0.059	LC-HPC	Steel
Control-1/2	0.115		
LC-HPC-3	0.108	LC-HPC	Steel
Control-3	0.232		
LC-HPC-4	0.146	LC-HPC	Steel
Control-4	0.473		
LC-HPC-5	0.128	LC-HPC	Steel
Control-5	0.857		
LC-HPC-6	0.231	LC-HPC	Steel
Control-6	0.282		
LC-HPC-7	0.005	LC-HPC	Steel
Control-7	0.819		
LC-HPC-8	0.242	Control	Prestressed Conc.
Control-8/10	0.137		
LC-HPC-9	0.130	LC-HPC	Steel
Control-9	0.390		
LC-HPC-10	0.029	LC-HPC	Prestressed Conc.
Control-8/10	0.137		
LC-HPC-11	0.241	LC-HPC	Steel
Control-11	0.636		
LC-HPC-12	0.250	LC-HPC	Steel
Control-12	0.548		
LC-HPC-13	0.129	LC-HPC	Steel
Control-13	0.154		

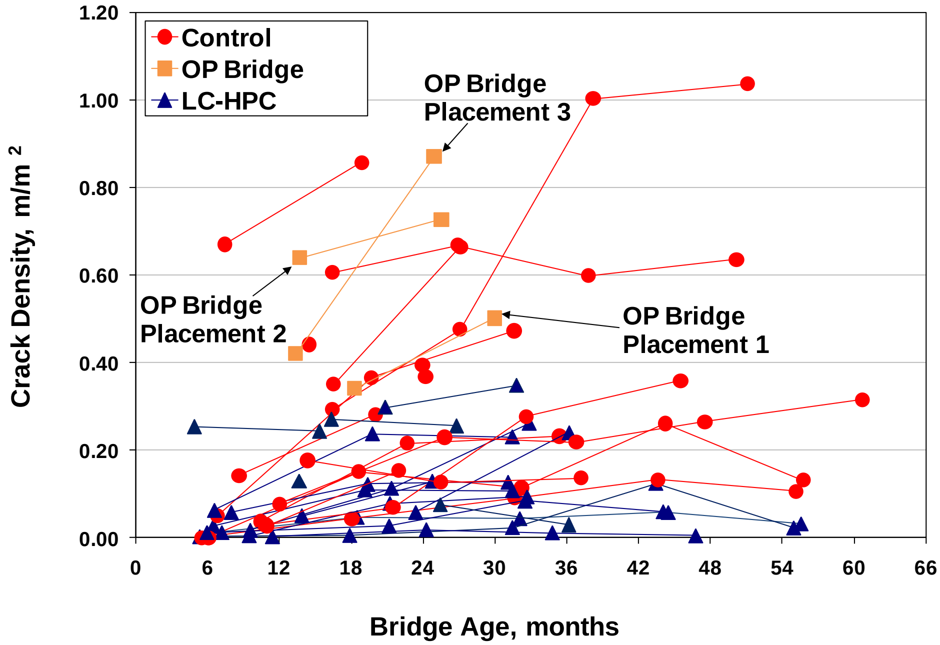


Figure 58: Surveyed Crack Densities of LC-HPC vs. Control Decks

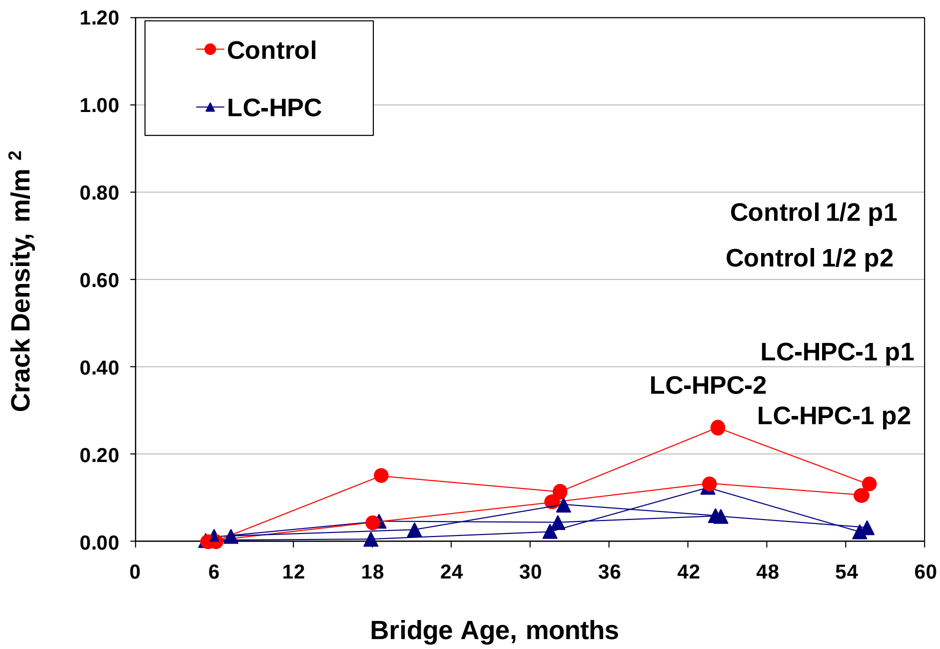


Figure 59: LC-HPC 1 & 2 and Control 1/2 Surveyed Crack Densities

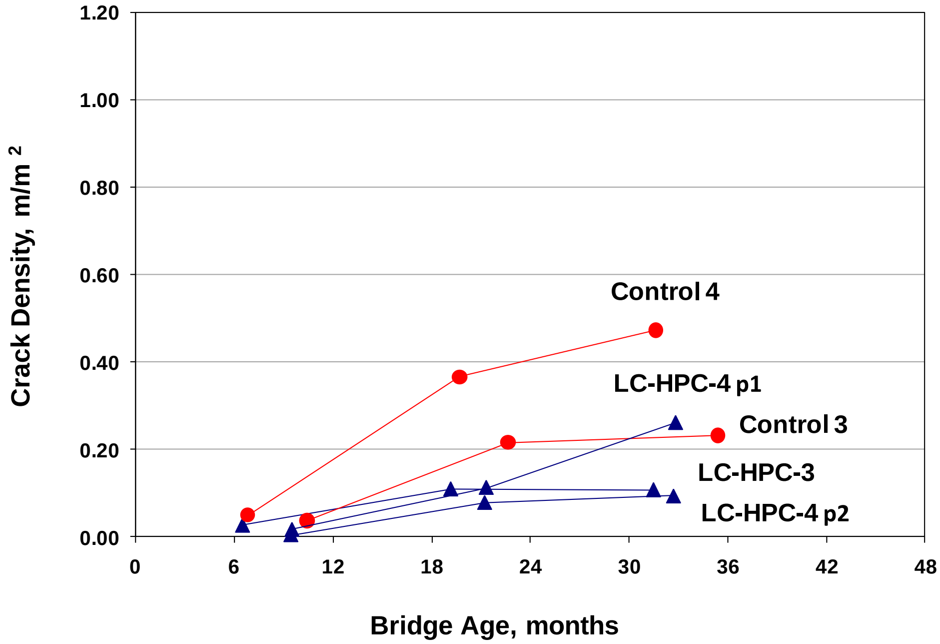


Figure 60: LC-HPC 3 & 4 and Control 3 & 4 Surveyed Crack Densities

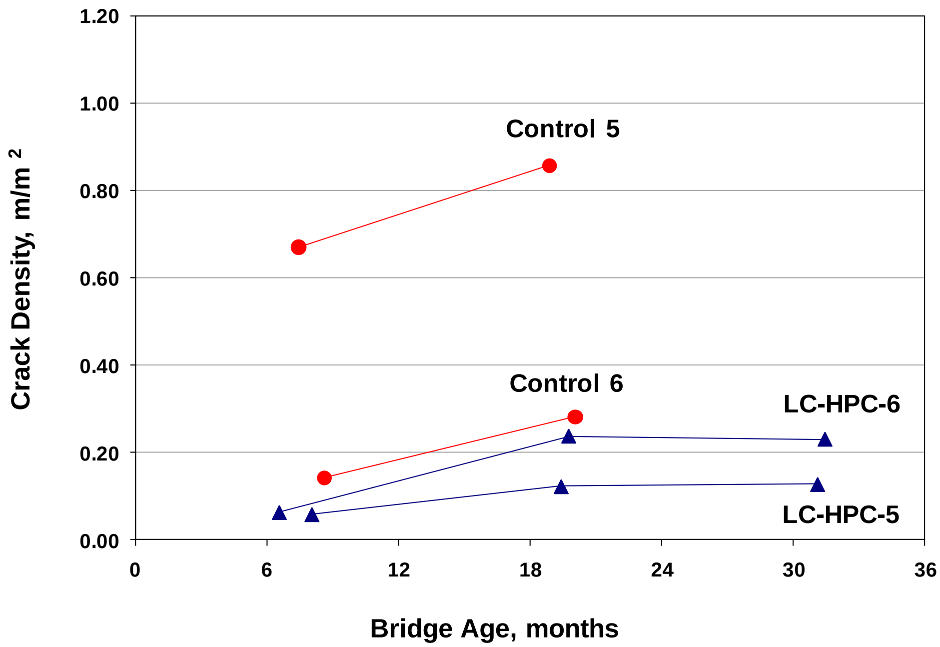


Figure 61: LC-HPC 5 & 6 and Control 5 & 6 Surveyed Crack Densities

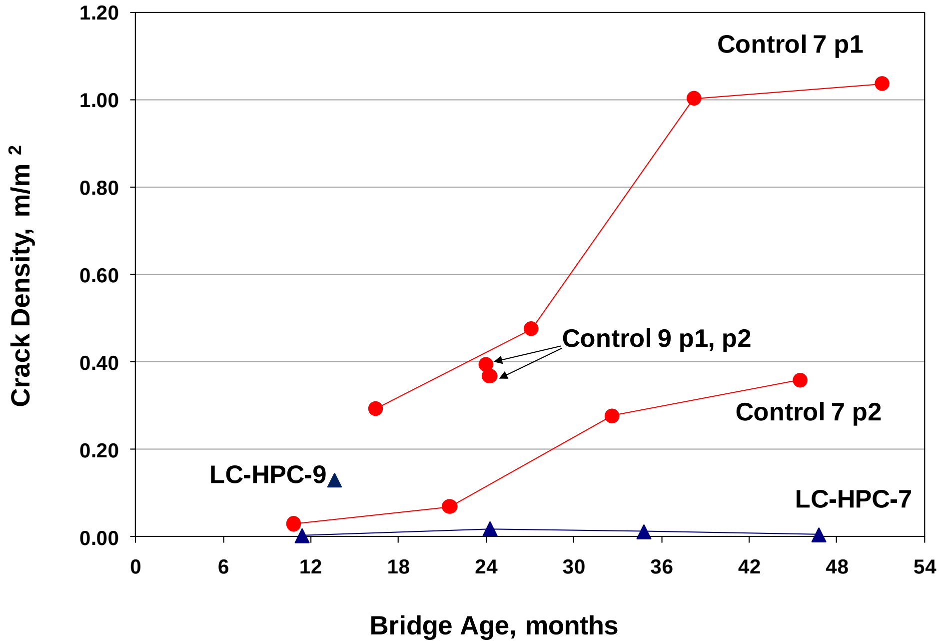


Figure 62: LC-HPC 7 & 9 and Control 7 & 9 Surveyed Crack Densities

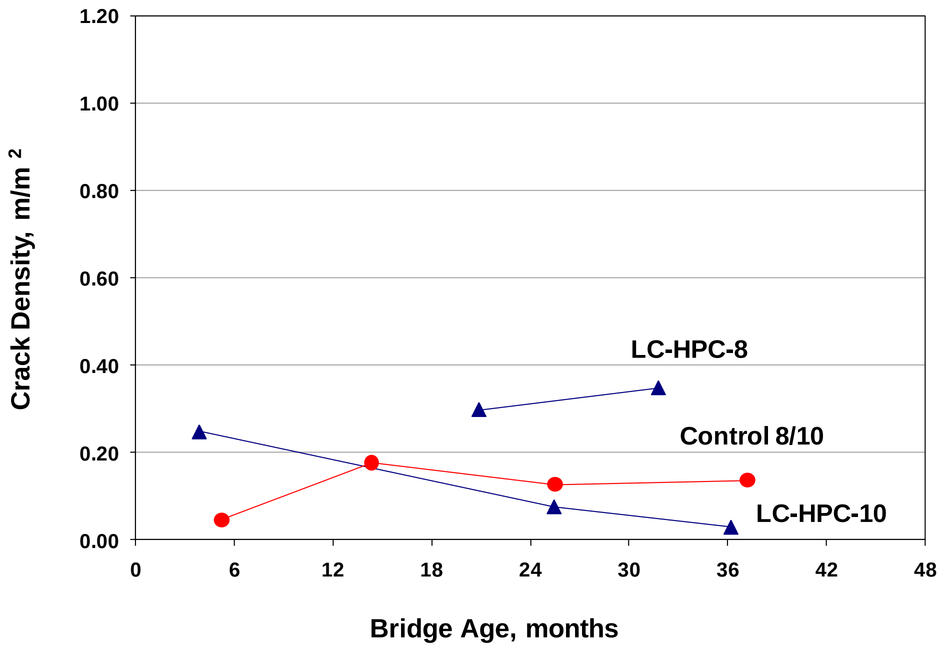


Figure 63: LC-HPC 8 & 10 and Control 8/10 Surveyed Crack Densities

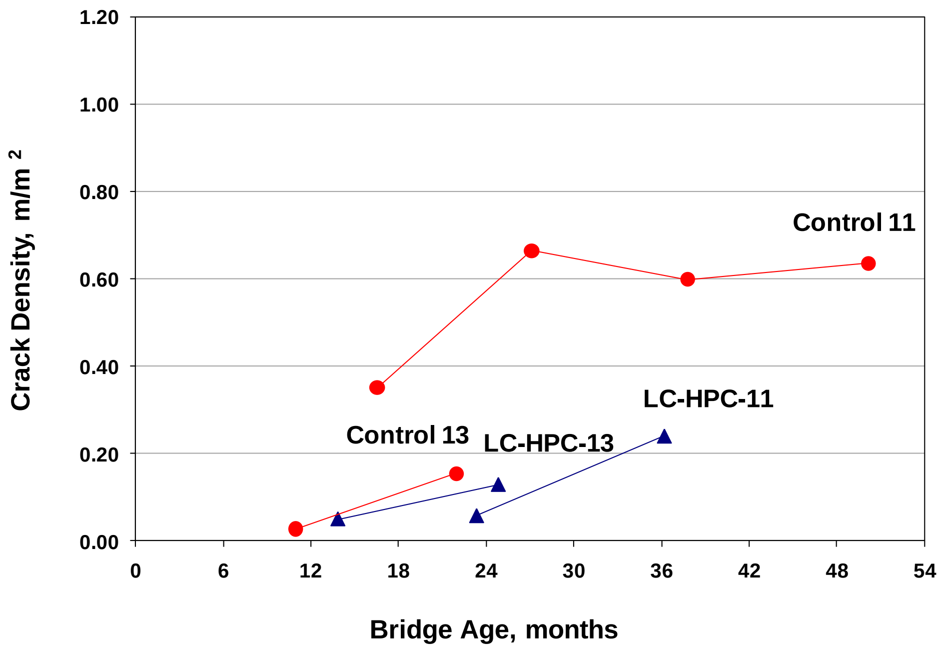


Figure 64: LC-HPC 11 & 13 and Control 11 & 13 Surveyed Crack Densities

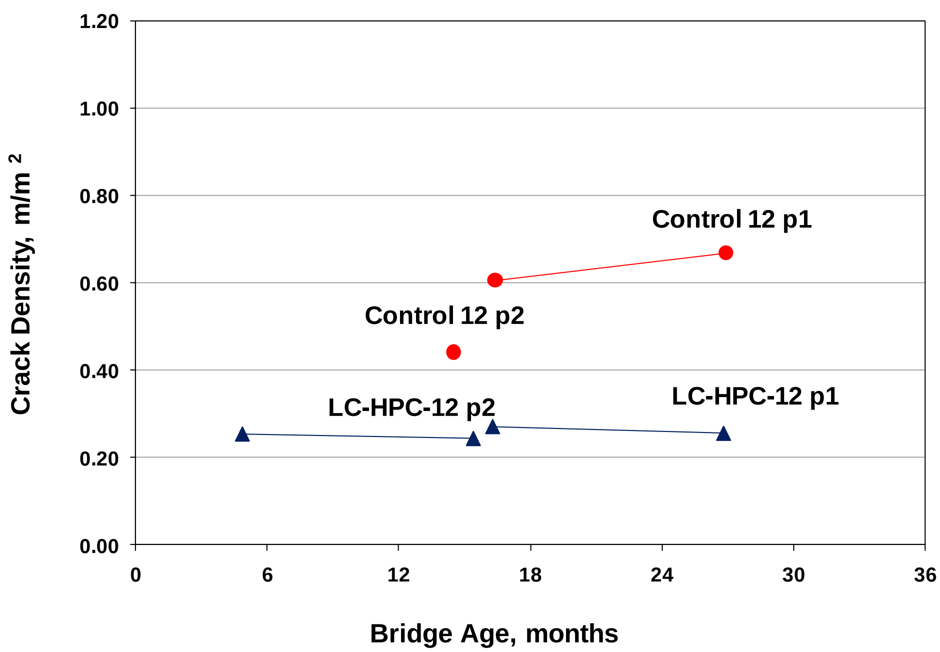


Figure 65: LC-HPC 12 and Control 12 Surveyed Crack Densities

SUMMARY AND CONCLUSIONS

Surveys were performed on both LC-HPC and control bridge decks to determine the effect of modified material, concrete, and construction specifications on the crack density of reinforced concrete bridge decks in the State of Kansas. A standardized survey procedure was followed to obtain consistent and accurate records throughout the data collection process. The results were analyzed, crack densities were calculated, and cracking trends were noted.

The following conclusions are based on the results and analysis of the surveys performed as part of this study:

1. LC-HPC bridge decks crack less over time than non-LC-HPC bridge decks. Trends show that some LC-HPC decks crack more than their paired non-LC-HPC control deck at early ages, but the overall trend over time demonstrates lower crack densities for LC-HPC decks.
2. Cracking in concrete bridge decks commonly occurs directly above and parallel with the top reinforcing steel in the deck. The majority of cracks in both LC-HPC and control decks develop in the transverse direction. Longitudinal cracks regularly extend from the bridge abutments.
3. Superelevated bridge decks have a tendency to crack transversely, with the crack propagating from the elevated edge of the deck, most likely due to a deficiency of water during the curing period as the concrete settles and curing water flows to a lower elevation. Settlement cracking may also increase in the superelevated areas due to the settlement of higher slump concrete. Settlement cracks may not develop if proper curing and low slump concrete are used.
4. Atypical torsional loading from construction equipment on bridge decks can cause stresses that the deck was not designed to carry, leading to increased tensile cracking.

5. Overfinishing of bridge decks by means of a double-drum roller screed may increase cracking by increasing the amount of cement paste at the deck surface.

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APPENDIX A

BRIDGE DECK SURVEY SPECIFICATION*

*From Lindquist et al. (2005)

BRIDGE DECK SURVEY SPECIFICATION

1.0 DESCRIPTION.

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

2.0 SURVEY REQUIREMENTS.

a. Pre-Survey Preparation.

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

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

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

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

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

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

b. Preparation of Surface.

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

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

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

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

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

c. Weather Limitations.

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

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

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

3.0 BRIDGE SURVEY.

a. Crack Surveys.

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

b. Delamination Survey.

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

c. Under Deck Survey.

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

APPENDIX B

BRIDGE DECK DATA*

*From Lindquist et al. (2008)

Table B.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)	Age-Corrected Crack Density (m/m^2)	Date of Survey	Age (months)
LC-HPC-1	105-304	South	10/14/2005	04/13/06	5.9	0.012	0.102	4/30/2007	18.5
		North	11/2/2005	04/13/06	5.3	0.003	0.094	4/30/2007	17.9
		Entire Deck	--	04/13/06	--	0.007	0.098	4/30/2007	--
LC-HPC-2	105-310	Deck	9/13/2006	04/20/07	7.2	0.014	0.103	6/18/2008	21.2
Control-1/2	105-311	North	10/10/2005	04/13/06	6.1	0.000	0.204	4/30/2007	18.6
		South	10/28/2005	04/13/06	5.5	0.000	0.206	4/30/2007	18.0
		Entire Deck	--	04/13/06	--	0.000	0.206	4/30/2007	--
LC-HPC-3	46-338	Deck	11/13/2007	05/29/08	6.5	0.032	0.122	6/18/2009	19.2
Control-3	46-337	Deck	7/17/2007	05/29/08	10.4	0.037	0.229	6/5/2009	22.6
LC-HPC-4	46-339	South	9/29/2007	07/15/08	9.5	0.017	0.094	7/9/2009	21.3
		North	10/2/2007	07/15/08	9.4	0.004	0.081	7/9/2009	21.2
Control-4	46-347	Deck	11/16/2007	06/10/08	6.8	0.050	0.252	7/7/2009	19.7
LC-HPC-5	46-340 Unit 1	Deck	11/14/2007	07/15/08	8.0	0.059	0.147	6/26/2009	19.4
Control-5	46-341 Unit 3	Deck	11/25/2008	07/09/09	7.4	0.670	1.324	6/22/2010	18.9
LC-HPC-6	46-340 Unit 2	Deck	11/3/2007	05/20/08	6.5	0.063	0.153	6/26/2009	19.7
Control-6	46-341 Unit 4	Deck	10/20/2008	07/09/09	8.6	0.142	0.785	6/22/2010	20.0
LC-HPC-7	43-33	Deck	6/24/2006	06/05/07	11.4	0.003	0.087	7/1/2008	24.2
Control-7	46-334	East	3/29/2006	08/10/07	16.4	0.293	0.468	6/30/2008	27.1
		West	9/15/2006	08/10/07	10.8	0.030	0.221	6/30/2008	21.5

*All pre-2009 crack survey data compiled from Lindquist et al. (2008)

Table B.1 (continued) – 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)	Age-Corrected Crack Density (m/m^2)	Date of Survey	Age (months)
LC-HPC-8	54-53	Deck	10/3/2007	06/29/09	20.9	0.298	0.362	5/27/2010	31.8
LC-HPC-10	54-60	Deck	5/17/2007	06/29/09	25.4	0.076	0.135	5/22/2010	36.2
Control-8/10	54-59	Deck	4/16/2007	06/26/08	14.4	0.177	0.257	5/31/2009	25.5
LC-HPC-9	54-57	Deck	4/15/2009	06/04/10	13.6	0.130	0.202	-	-
Control-9	54-58	West	5/21/2008	05/28/10	24.2	0.368	0.866	-	-
		East	5/29/2008	05/28/10	24.0	0.395	0.895	-	-
LC-HPC-11	78-119	Deck	6/9/2007	05/20/09	23.4	0.059	0.120	6/15/2010	36.2
Control-11	56-155	Deck	3/28/2006	08/13/07	16.5	0.351	0.526	6/30/2008	27.1
LC-HPC-12	56-57	East	4/4/2008	08/13/09	16.3	0.271	0.340	6/29/2010	26.8
		West	3/18/2009	08/13/09	4.9	0.254	0.336	6/29/2010	15.4
Control-12	56-57	East	4/1/2008	08/13/09	16.4	0.606	1.176	6/29/2010	26.9
		West	4/14/2009	-	-	-	-	6/29/2010	14.5
LC-HPC-13	54-66	Deck	4/29/2008	06/24/09	13.8	0.050	0.122	5/24/2010	24.8
Control-13	54-67	Deck	7/25/2008	06/24/09	11.0	0.028	0.649	5/24/2010	21.9
OP Bridge-P1	OP #1	Deck	12/19/2007	06/27/09	18.3	0.341	0.408	6/18/2010	30.0
OP Bridge-P2	OP #2	Deck	5/2/2008	06/23/09	13.7	0.640	0.712	6/18/2010	25.5
OP Bridge-P3	OP #3	Deck	5/21/2008	07/01/09	13.3	0.421	0.493	6/18/2010	24.9
OP-Extra	OP-Extra	Deck	6/30/2008	08/12/09	13.4	0.284	0.365	6/10/2010	23.3
Control Alt	56-49	Deck	6/2/2005	06/02/06	12.0	0.077	0.160	7/27/2007	25.8

*All pre-2009 crack survey data compiled from Lindquist et al. (2008)

Table B.1 (continued) – Crack Densities for Individual Bridge Placements

Bridge Number	Survey #2		Survey #3			
	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)	Date of Survey	Age (months)	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)
LC-HPC-1	0.047	0.122	6/17/2008	32.1	0.044	0.102
	0.006	0.081	6/17/2008	31.5	0.024	0.082
	0.027	0.102	6/17/2008	--	0.034	0.092
LC-HPC-2	0.029	0.100	5/29/2009	32.5	0.085	0.136
Control-1/2	0.151	0.320	6/17/2008	32.2	0.114	0.244
	0.044	0.214	6/17/2008	31.6	0.091	0.223
	0.089	0.259	6/17/2008	--	0.099	0.231
LC-HPC-3	0.110	0.176	6/28/2010	31.5	0.108	0.160
Control-3	0.216	0.729	6/28/2010	35.4	0.232	0.627
LC-HPC-4	0.113	0.177	6/24/2010	32.8	0.261	0.312
	0.079	0.143	6/24/2010	32.7	0.094	0.145
Control-4	0.366	0.906	7/5/2010	31.6	0.473	0.903
LC-HPC-5	0.123	0.189	6/17/2010	31.1	0.128	0.181
Control-5	0.857	1.405	-	-	-	-
LC-HPC-6	0.238	0.303	6/17/2010	31.4	0.231	0.283
Control-6	0.282	0.819	-	-	-	-
LC-HPC-7	0.019	0.086	5/18/2009	34.8	0.012	0.060
Control-7	0.476	0.621	6/4/2009	38.2	1.003	1.371
	0.069	0.229	6/4/2009	32.6	0.277	0.697

*All pre-2009 crack survey data compiled from Lindquist et al. (2008)

Table B.1 (continued) – Crack Densities for Individual Bridge Placements

Bridge Number	Survey #2		Survey #3			
	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)	Date of Survey	Age (months)	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)
LC-HPC-8	0.348	0.400	-	-	-	-
LC-HPC-10	0.029	0.076	-	-	-	-
Control-8/10	0.127	0.193	5/22/2010	37.2	0.137	0.188
LC-HPC-9	-	-	-	-	-	-
Control-9	-	-	-	-	-	-
	-	-	-	-	-	-
LC-HPC-11	0.241	0.288	-	-	-	-
Control-11	0.665	0.810	5/21/2009	37.8	0.599	0.971
LC-HPC-12	0.256	0.313	-	-	-	-
	0.244	0.314	-	-	-	-
Control-12	0.669	1.142	-	-	-	-
	0.442	1.030	-	-	-	-
LC-HPC-13	0.129	0.189	-	-	-	-
Control-13	0.154	0.673	-	-	-	-
OP Bridge-P1	0.502	0.556	-	-	-	-
OP Bridge-P2	0.727	0.786	-	-	-	-
OP Bridge-P3	0.871	0.931	-	-	-	-
OP-Extra	0.302	0.371	-	-	-	-
Control-Alt	0.230	0.295	6/26/2008	36.8	0.219	0.271

*All pre-2009 crack survey data compiled from Lindquist et al. (2008)

Table B.1 (continued) – Crack Densities for Individual Bridge Placements

Bridge Number	Survey #4				Survey #5		Survey #5	
	Date of Survey	Age (months)	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)	Date of Survey	Age (months)	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)
LC-HPC-1	06/17/09	44.1	0.060	0.098	6/3/2010	55.6	0.032	0.057
	06/17/09	43.5	0.125	0.164	6/3/2010	55.0	0.023	0.049
	06/17/09	--	0.093	0.131	6/3/2010	--	0.027	0.053
LC-HPC-2	05/28/10	44.5	0.059	0.097	-	-	-	-
Control-1/2	06/17/09	44.2	0.261	0.574	6/3/2010	55.8	0.132	0.338
	06/17/09	43.6	0.133	0.451	6/3/2010	55.2	0.106	0.317
	06/17/09	--	0.184	0.513	6/3/2010	--	0.115	0.328
LC-HPC-3	-	-	-	-	-	-	-	-
Control-3	-	-	-	-	-	-	-	-
LC-HPC-4	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
Control-4	-	-	-	-	-	-	-	-
LC-HPC-5	-	-	-	-	-	-	-	-
Control-5	-	-	-	-	-	-	-	-
LC-HPC-6	-	-	-	-	-	-	-	-
Control-6	-	-	-	-	-	-	-	-
LC-HPC-7	05/18/10	46.8	0.005	0.040	-	-	-	-
Control-7	07/01/10	51.1	1.037	1.286	-	-	-	-
	07/01/10	45.5	0.359	0.660	-	-	-	-

*All pre-2009 crack survey data compiled from Lindquist et al. (2008)

Table B.1 (continued) – Crack Densities for Individual Bridge Placements

Bridge Number	Survey #4				Survey #5		Survey #5	
	Date of Survey	Age (months)	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)	Date of Survey	Age (months)	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)
LC-HPC-8	-	-	-	-	-	-	-	-
LC-HPC-10	-	-	-	-	-	-	-	-
Control-8/10	-	-	-	-	-	-	-	-
LC-HPC-9	-	-	-	-	-	-	-	-
Control-9	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
LC-HPC-11	-	-	-	-	-	-	-	-
Control-11	06/02/10	50.2	0.636	0.894	-	-	-	-
LC-HPC-12	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
Control-12	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
LC-HPC-13	-	-	-	-	-	-	-	-
Control-13	-	-	-	-	-	-	-	-
OP Bridge-P1	-	-	-	-	-	-	-	-
OP Bridge-P2	-	-	-	-	-	-	-	-
OP Bridge-P3	-	-	-	-	-	-	-	-
OP-Extra	-	-	-	-	-	-	-	-
Control-Alt	05/19/09	47.5	0.265	0.303	6/24/2010	60.7	0.316	0.338

*All pre-2009 crack survey data compiled from Lindquist et al. (2008)

Table B.2 – Average Properties for the Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks (Lindquist et al. 2008, McLeod et al. 2009)

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/yd^3)	(MPa)	(psi)
1	South	10/14/05	7.9	95	3.75	19.8	68	2251	140.5	35.9	5210
	North	11/02/05	7.8	85	3.25	20.1	68	2238	139.7	34.4	4980
2	Deck	09/13/06	7.7	75	3.00	19.2	67	--	--	31.7	4600
3	Deck	11/13/07	8.7	85	3.25	14.3	58	--	--	41.3	5990
4	Deck - South	09/29/07	8.7	50	2.00	--	--	2202	137.4	--	--
	Deck - North	10/02/07	8.8	80	3.00	17.5	64	2210	137.9	33.1	4790
5	Deck - 0.420 *w/c*	11/14/07	8.3	70	2.75	16.7	62	2249	140.4	44.0	6380
	Deck - 0.428 *w/c*	11/14/07	9.0	60	2.50	16.4	62	2242	140.0	--	--
	Deck - 0.429 *w/c*	11/14/07	9.1	90	3.50	15.2	59	2230	139.2	--	--
	Deck - 0.451 *w/c*	11/14/07	8.7	80	3.25	15.7	60	2228	139.1	--	--
	Average Values	11/14/07	8.7	80	3.00	15.9	61	2236	139.6	--	--
6	Deck	11/03/07	9.5	95	3.75	15.3	60	--	--	40.3	5840
7	Deck	06/24/06	8.0	95	3.75	21.9	71	2221	138.6	26.1	3790
8	Deck	10/03/07	7.9	50	2.00	19.5	67	2264	141.3	32.6	4730
9	Deck	04/15/09	6.7	90	3.50	17.9	64	2264	141.3	28.9	4190
10	Deck	05/17/07	7.3	80	3.25	18.6	66	2212	138.1	31.6	4580
11	Deck	06/09/07	7.8	80	3.00	15.8	60	2278	142.2	32.3	4680
12	Deck - East	04/04/08	7.4	70	2.75	14.5	58	2259	141.0	31.5	4570
	Deck - West	03/18/09	7.8	104	4.10	19.0	67	-	-	28.8 (0.45 *w/c*)	4180 (0.45 *w/c*)
										31.6 (0.44 *w/c*)	4580 (0.44 *w/c*)
13	Deck	04/29/08	8.1	75	3.00	20.4	69	2266	141.5	29.5	4280
OP	Deck - Center	12/19/07	8.7	95	3.75	18.1	65	2237	139.7	30.6	4440
	Deck - West	05/02/08	9.8	110	4.25	17.9	64	2213	138.1	25.6	3710
	Deck - East	05/21/08	9.9	130	5.25	18.3	65	2195	137.1	26.4	3830

†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.

Table B.3 – Average Properties for Control Bridge Decks (Lindquist et al. 2008, McLeod et al. 2009)

County and Serial Number	Control Number	Portion Placed	Date of Placement	Average Air Content	Average Slump (mm)	Average Slump (in.)
105-311	1 / 2	North 1/2 - Subdeck	09/30/05	5.3	110	4.25
		North 1/2 - Overlay	10/10/05	5.5	125	5.00
		South 1/2 - Subdeck	10/18/05	6.5	80	3.25
		South 1/2 - Overlay	10/28/05	7.0	115	4.50
46-337	3	Subdeck	07/06/07	5.8	170	6.75
		Overlay	07/17/07	7.3	185	7.25
46-347	4	Subdeck	10/20/07	7.3	195	7.75
		Overlay	11/16/07	6.9	145	5.75
46-340 Unit 3	5	Subdeck - Seq. 1 & 2	11/08/08	5.6	200	7.75
		Subdeck Seq. 3, 5, & 6	11/13/08	6.8	230	9.25
		Subdeck - Seq. 4 & 7	11/17/08	5.5	205	8.00
		Overlay - West Half	11/22/08	7.6	150	6.00
		Overlay - East Half	11/25/08	6.6	230	9.00
46-340 Unit 4	6	Subdeck - Seq. 1 & 2	09/16/08	7.4	205	8.00
		Subdeck Seq. 3	09/18/08	7.3	180	7.00
		Subdeck - Seq. 5 & 6	09/23/05	6.4	175	6.75
		Subdeck Seq. 4	09/26/08	6.6	160	6.25
		Subdeck - Seq. 7	09/30/08	5.5	225	8.75
		Overlay - West 2/3	10/16/08	7.7	175	7.00
		Overlay - East 1/3	10/20/08	8.1	210	8.25
46-334	7	East - Subdeck	03/15/06	5.9	235	9.25
		East - Overlay	03/29/06	7.4	190	7.50
		West - Subdeck	08/16/06	7.3	195	7.75
		West - Overlay	09/15/06	6.4	175	7.00
54-59	8 / 10	Deck	04/16/07	7.4	130	5.00

Table B.3 (continued) – Average Properties for Control Bridge Decks (Lindquist et al. 2008, McLeod et al. 2009)

Control Number	Portion Placed	Average Concrete Temperature		Average Unit Weight		Average Compressive Strength†	
		(°C)	(°F)	(kg/m³)	(lb/yd³)	(MPa)	(psi)
1 / 2	North 1/2 - Subdeck	19.0	66	2318	144.7	39.1	5670
	North 1/2 - Overlay	18.0	64	2281	142.4	40.1	5810
	South 1/2 - Subdeck	24.7	76	2274	142.4	35.1	5090
	South 1/2 - Overlay	20.0	68	2254	140.7	55.6	8060
3	Subdeck	27.1	81	2251	140.5	39.2	5690
	Overlay	29.9	86	2249	140.4	57.6	8350
4	Subdeck	22.8	73	2240	139.9	43.7	6340
	Overlay	20.0	68	2239	140	53	7700
5	Subdeck - Seq. 1 & 2	19.0	66	2278	142.2	--	--
	Subdeck Seq. 3, 5, & 6	20.0	68	2245	140.1	--	--
	Subdeck - Seq. 4 & 7	17.0	63	2275	142.0	--	--
	Overlay - West Half	18.0	64	2250	140.5	--	--
	Overlay - East Half	17.0	63	2262	141.2	--	--
6	Subdeck - Seq. 1 & 2	24.0	75	2238	139.7	34.1	4950
	Subdeck Seq. 3	21.0	70	2246	140.2	--	--
	Subdeck - Seq. 5 & 6	31.0	88	2261	141.1	--	--
	Subdeck Seq. 4	30.0	86	2254	140.7	--	--
	Subdeck - Seq. 7	26.0	79	2269	141.6	--	--
	Overlay - West 2/3	22.0	72	2258	141.0	--	--
	Overlay - East 1/3	22.0	72	2231	139.3	53.1	7700
7	East - Subdeck	26.5	80	2239	139.8	38.2	5540
	East - Overlay	23.0	73	2239	139.8	--	--
	West - Subdeck	21.3	70	2226	139.0	37.9	5500
	West - Overlay	18.0	64	2252	140.6	50.8	7370
8 / 10	Deck	21.2	70	2234	139.4	33.3	4830

†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.

Table B.3 (continued) – Average Properties for Control Bridge Decks (Lindquist et al. 2008, McLeod et al. 2009)

County and Serial Number	Control Number	Portion Placed	Date of Placement	Average Air Content	Average Slump	
					(mm)	(in.)
		West - Overlay	05/21/08	5.6	90	3.50
		East - Overlay	05/28/08	6.2	130	5.00
56-155	11	North 1/2 - Subdeck	02/03/06	6.8	90	3.50
		South 1/2 - Subdeck	02/14/06	7.0	135	5.25
		Overlay	03/28/06	6.0	80	3.00
56-57	12	Subdeck - Phase 1	03/11/08	6.9	110	4.25
		Overlay - Phase 1	04/01/08	6.8	95	3.75
		Subdeck - Phase 2	03/13/09	7.2	120	4.70
		Overlay - Phase 2	04/14/09	7.7	57	2.25
54-67	13	Subdeck	07/11/08	5.8	90	3.50
		Overlay	07/25/08	6.3	135	5.25
56-49	Alt	Deck	06/02/05	5.9	85	3.00

Table B.3 (continued) – Average Properties for Control Bridge Decks (Lindquist et al. 2008, McLeod et al. 2009)

Control Number	Portion Placed	Average Concrete Temperature		Average Unit Weight		Average Compressive Strength†	
		(°C)	(°F)	(kg/m³)	(lb/yd³)	(MPa)	(psi)
	West - Overlay	24.7	77	2282	142.4	44.0	6380
	East - Overlay	21.7	71	2262	141.2	42.6	6170
11	North 1/2 - Subdeck	22.0	72	2263	141.3	40.6	5890
	South 1/2 - Subdeck	23.0	73	2252	140.6	37.5	5440
	Overlay	15.5	60	2277	142.1	52.7	7640
12	Subdeck - Phase 1	21.9	72	2250	140.5	36.4	5270
	Overlay - Phase 1	14.8	59	2254	140.7	43.0	6240
	Subdeck - Phase 2	22.0	72	-	-	34.3 (31 days)	4980 (31 days)
	Overlay - Phase 2	16.7	62	-	-	53.1	7710
13	Subdeck	31.7	89	2271	141.7	--	--
	Overlay	33.0	91	2269	141.6	57.1	8280
Alt	Deck	--	--	2255	140.8	38.0	5510

†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.