CRACK SURVEYS OF LOW-CRACKING HIGH-PERFORMANCE CONCRETE BRIDGE DECKS IN KANSAS 2011-2013

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ABSTRACT

Crack densities of Low-Cracking High-Performance Concrete (LC-HPC) bridge decks are compared to crack densities of control decks to investigate the benefits of the LC-HPC specifications developed at the University of Kansas. Specifications for construction of LC-HPC bridge decks are addressed. Bridge deck crack survey procedures are also summarized. Thirteen LC-HPC decks and thirteen control decks are compared by calculating crack densities and noting trends in cracking patterns over time. The results for eight additional decks are also presented. These include three LC-HPC decks, one control deck, and three decks which are considered neither LC-HPC nor control decks. The LC-HPC bridge decks have, with very few exceptions, lower crack densities than the control decks. Cracks are typically transverse above and parallel to the bars in the top layer of reinforcing steel, except at abutments, where cracks propagate longitudinally or perpendicular to the abutment.

Key Words: bridge decks, cracking, high performance concrete

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INTRODUCTION

Cracks in reinforced concrete bridge decks are a significant problem because they provide access to the reinforcing steel for water and deicing chemicals, which increases the potential for corrosion (Lindquist, Darwin, and Browning 2005, 2006). Concrete cracking also increases the effects of freeze-thaw damage in bridge decks. The location, type, and severity of cracks are based on factors such as deck age, concrete properties, weather conditions, and construction methods.

Current research at the University of Kansas is focused on identifying, analyzing, and working toward eliminating different causes of bridge deck cracking. Specifications have been developed for aggregates, concrete, and construction for the purpose of minimizing cracking in bridge decks. These specifications for Low-Cracking High-Performance Concrete (LC-HPC) bridge decks have been updated since the beginning of the study in 2002.

To determine the performance of the LC-HPC bridge decks, annual crack surveys are performed. The LC-HPC bridge decks are paired with control decks with comparable type, age, and environmental exposure, which are also surveyed. To gain consistency and accurately compare results from crack surveys performed over time, a standard crack survey method has been developed. Sixteen bridge decks have been constructed in Kansas in accordance with the LC-HPC specifications. These decks are designated as LC-HPC 1 through 13, 15, 16, and 17. The bridge initially designated as LC-HPC-14 was not constructed following the LC-HPC specifications, so it is now designated as OP (Overland Park) Bridge. This report summarizes crack survey data obtained as part of this program in 2011, 2012, and 2013. Crack survey data for 2006-2008 are summarized by Gruman, Darwin, and Browning (2009). Crack survey data for 2009 and 2010 are summarized by Pendergrass, Darwin, and Browning (2011). LC-HPC bridge deck construction experience 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 decks. These 3 provisions cover requirements for aggregate, concrete, and construction practices, and are summarized below (Kansas Department of Transportation 2007a,b,c).

Aggregate

Requirements for both coarse and fine aggregate are addressed in the provisions (Kansas Department of Transportation 2007a). The coarse aggregate must consist of gravel, chat, or crushed stone with a minimum soundness of 0.90 and a maximum absorption of 0.7. Maximum deleterious substance requirements 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 natural sand (Type FA-A) or chat (Type FA-B). The mortar strength requirements per KDOT specifications and impurities per AASHTO specifications must also be met. Provisions for deleterious substance for both types of fine aggregate are shown in Table 2 (sand) and Table 3 (chat).

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%

Proportioning of coarse and fine aggregates should be done using an optimization method such as Shilstone or KU Mix Method.

Concrete

The LC-HPC specification (Kansas Department of Transportation 2007b) states that concrete meeting the requirements must contain between 500 and 540 lb (297 and 320 kg/m^3) of cement per cubic yard of concrete and have a water/cement ratio (by weight) ranging between 0.44 and 0.45. With approval of the engineer, the water/cement ratio can be reduced at the construction site to 0.43. LC-HPC bridge decks 1 through 7 were constructed under an LC-HPC specification allowing between 522 and 563 lb (310 and 334 kg/m^3) of cement per cubic yard of concrete with a maximum water/cement ratio (by weight) of 0.45. LC-HPC bridge decks 8 through 13 were constructed under an LC-HPC specification allowing between 500 and 535 lb (297 and 317 kg/m^3) of cement per cubic yard of concrete with a maximum water/cement ratio (by weight) of 0.42. LC-HPC decks 15, 16, and 17 were constructed under a specification allowing between 500 and 540 lb of cement per cubic yard with an allowable range of water/cement ratio of 0.44 - 0.45. All LC-HPC decks in this project contain either 535 or 540 lb (317 or 320 kg/m^3) of cement per cubic yard of concrete, with the exception of LC-HPC-15 and LC-HPC-16. LC-HPC-15 had a cement content of 500 lb/yd^3 (297 kg/m^3), and LC-HPC-16 was placed using cement contents ranging from 520 to 540 lb/yd^3 (308 to 320 kg/m^3).

The specified air content (by volume) is between 7.0% and 9.0% with an allowable range of 6.5% to 9.5%. Concrete slump at placement should be between 1½ and 3 in. (38 and 76 mm), and any concrete with a slump at discharge over 3½ in. (89 mm) must be rejected. For LC-HPC 1-13, the specification stated that concrete with a slump greater than 4 in. (100 mm) must be rejected. Concrete samples used for the slump and air content tests must be collected at the discharge of the conveyor, bucket, or pump piping. Concrete temperature at placement must be between 55°F and 70°F. This range may be adjusted 5°F higher or lower with the engineer's approval. The specification in place during the construction of LC-HPC decks 1 and 2 specifies the temperature range as 50°F to 75°F with no adjustment. Current specifications state that the concrete compressive strength must be 3500 to 5500 psi (24.1 to 37.9 MPa). At the time of construction of LC-HPC 1-13, there was no limit on compressive strength.

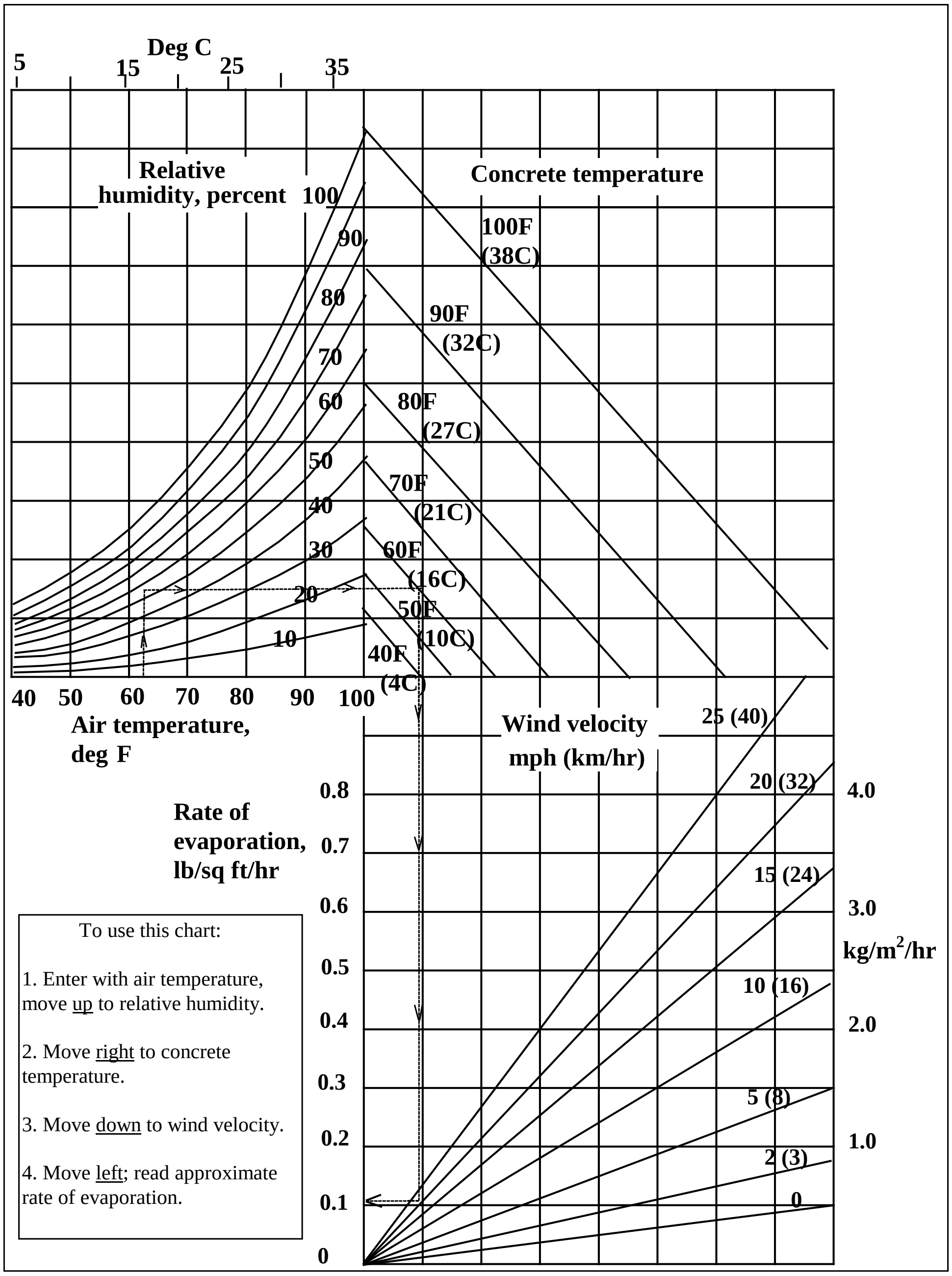
Vinsol resin or tall oil based air-entraining admixtures were allowed for LC-HPC decks in this report. The specification for LC-HPC 12 and 13 and the current specification prohibit the use of mineral, set-retarding, or set accelerating admixtures in LC-HP concrete. The specifications for LC-HPC 1 through 11 allowed the use of water-reducing admixtures and set-retarding admixtures, as well as a Type C or E accelerating admixture, if approved by the engineer. However, no set accelerating or retarding admixtures were used in any LC-HPC bridge decks. The current specification states that a Type A water reducer or a dual-rated Type A water reducer – Type F high-range water reducer may be used to comply with specifications for plastic and hardened concrete properties. On-site slump adjustment may only be performed by redosing with a water-reducing admixture.

Before construction, a qualification batch must be prepared to show the concrete supplier's ability to meet all specifications. The actual jobsite haul time must be simulated before the qualification batch is tested. The LC-HPC bridge deck mix proportions must be used, including any admixtures. The qualification batch must satisfy the requirements for air content, slump, plastic concrete temperature, and compressive strength to be qualified for use in the LC-HPC bridge deck.

Construction

The LC-HPC specification for construction (Kansas Department of Transportation 2007c) states that once the qualification batch is completed, the contractor must construct a qualification slab to show the ability to handle and place the LC-HP concrete on the bridge deck. All equipment and personnel used for construction of the qualification slab must be the same as those used on the actual bridge deck. The concrete used in the qualification slab must also meet the required LC-HPC specifications.

During construction of the deck, KDOT personnel must record the wind speed, air temperature, relative humidity 12 in. (355 mm) above the deck, and concrete temperature at least once per hour, and use these quantities to determine the evaporation rate using Figure 1. The evaporation rate must remain below 0.2 lb/ft^2/hr (1 kg/m^2/hr) at all times. If the evaporation rate exceeds this value, concrete cooling, wind break installation, or other methods (but not fogging) must be applied to lower the rate below the limit.



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

It is acceptable to place concrete using a bucket or conveyor. Concrete must not be dropped more than 5 ft (1.5 m) to avoid loss of air. Concrete may be pumped if, prior to construction, the contractor demonstrates the ability to pump the LC-HPC mixture using the same equipment and procedures as will be used on the deck. All pumps must have an air cuff or bleeder valve to limit the loss of air.

Consolidation of the concrete should be done by vertically mounted internal gang vibrators, with handheld vibrators used in regions not accessible by the gang vibrators. Vibrators must have head diameters between 1.75 and 2.5 in. (44 and 64 mm), loaded vibration frequencies between 8,000 and 12,000 vibrations per minute, and an average vibration amplitude between 0.025 and 0.05 in. (0.635 and 1.27 mm). When operating vibrators, they must be inserted into the concrete vertically and held in the concrete between 3 and 15 seconds. Vibrators must be spaced 12 in. (305 mm) apart and removed slowly so that no voids are left in the plastic concrete.

Strikeoff of the surface is to be completed with a vibrating or single-drum roller screed. This specification was followed on all LC-HPC decks with the exception of LC-HPC-17 and LC-HPC-14 (now designated as OP Bridge), which used double-drum roller screeds. Finishing is to be completed using a burlap drag, metal pan, or both. No tamping devices are permitted to be attached to roller screeds. Bullfloats or hand floats may be used to remove surface imperfections where necessary. Finishing aids and tining are prohibited.

A layer of soaked burlap must be placed on the concrete within 10 minutes of strikeoff. Another layer of burlap must then be placed within 5 minutes of the first layer. The burlap must be soaked at least 12 hours before placement on the concrete surface, and should remain wet throughout the curing period of 14 days. The time between strikeoff and burlap placement exceeded 10 minutes for many of the LC-HPC decks, and there were also some instances of placement of partially-dry burlap. Before the concrete has set, misters or fogging equipment may be used to keep the burlap wet. However, after the concrete has set, soaker hoses must be used on the burlap. A layer of white plastic must be placed on top of the burlap to maintain the wet state throughout the curing period.

CRACK SURVEYS

Crack surveys are performed each year on both the LC-HPC and the control bridges. The procedure for conducting the surveys follows.

Procedure

Surveys are completed using a standard procedure to provide accurate and comparable results. All surveys must be conducted on days that are mostly clear. Surveys cannot be performed if it is raining or the sky is overcast, and the deck must be completely dry before surveying begins. The air temperature must be greater than 60°F (16°C).

Before arriving at the bridge, a plan drawing of the deck, which will serve as the crack map, is prepared at a scale of 1 in. = 10 ft (25.4 mm = 3.048 m) that includes the compass directions. A scaled grid, 5 x 5 ft (1.524 x 1.524 m), is placed behind the plan drawing to facilitate recording of cracks. Curved bridges are represented by straight plan drawings, with the centerline length used for the bridge length. When drawing the scaled grid and transposing cracks on these bridges, approximate locations are used. This introduces little error due to the long lengths and large radii of curvature of the bridges.

Once traffic has been closed on the bridge, sidewalk chalk is used to mark a 5 x 5 ft grid onto the deck to correspond with the grid on the drawing. When the grid is in place, surveyors walk across the bridge deck and mark visible cracks with the sidewalk chalk. Surveyors may bend at the waist while inspecting for cracks and can only mark cracks which are visible from that height. Once a crack is located from waist height, the surveyor may then bend closer and trace the crack to its end. All portions of the deck must be inspected by at least 2 surveyors. This procedure provides consistent measurement of bridge deck cracking (Lindquist et al. 2005, 2008). Once the deck has been marked, another surveyor will transpose the cracks onto the plan drawing with the aid of the 5 x 5 ft grid.

The crack map is scanned into a computer, where it is prepared for analysis. All lines that do not represent cracks are erased so that only pixels representing cracks are analyzed. Non-linear cracks are broken up into smaller linear segments by removing single pixels. This allows the analysis program, which measures between crack endpoints, to calculate an accurate total crack length. Crack densities are reported for the entire deck and for various portions of the deck. Complete specifications for the surveying process are included in Appendix A.

Results

All bridge decks included 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. Decks are numbered in the order in which they were bid, not constructed.

Table B.1 in Appendix B shows crack densities from each survey year for each bridge deck. This report contains crack maps corresponding to survey years 2011, 2012, and 2013. Survey years 2006-2008 are covered by Gruman et al. (2009), and survey years 2009 and 2010 are covered by Pendergrass et al. (2011). Effects of bridge design parameters and environmental conditions on deck cracking are covered by McLeod et al. (2009). The effect of bridge deck age on deck cracking is covered by Lindquist et al. (2008). The overall cracking trends of all bridge decks in the project are shown in Figure 2. In-depth comparisons of LC-HPC and control decks follow.

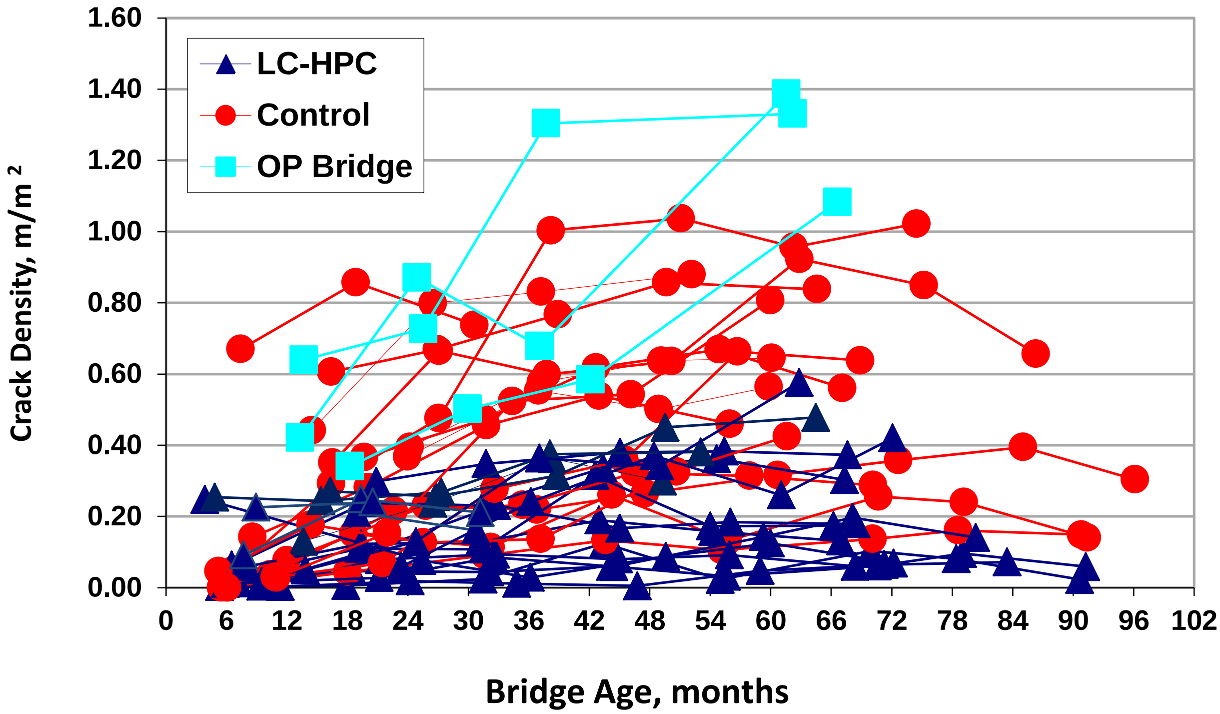


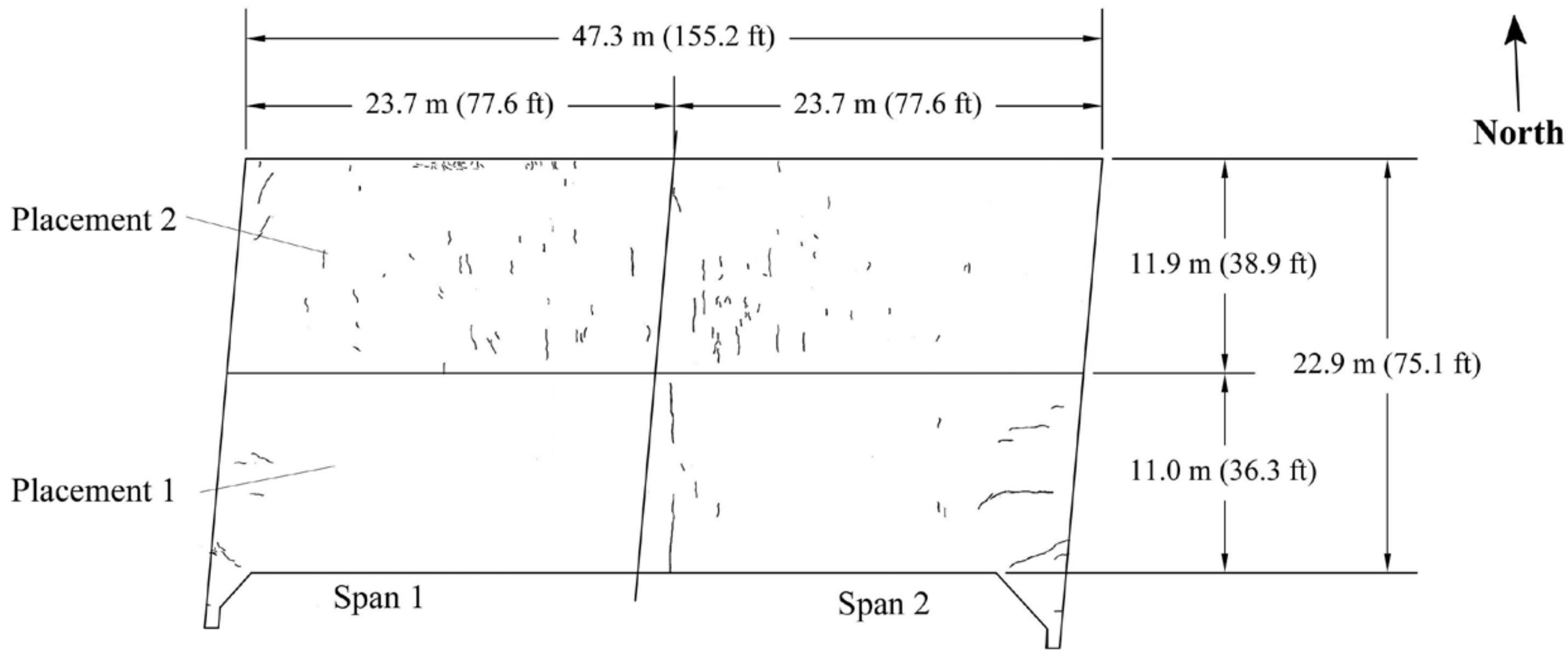
Figure 2: Crack Densities of LC-HPC and Control Decks

LC-HPC-1

LC-HPC-1 was cast in two separate placements, which were placed 19 days apart. The results of Survey 6 at 70.6 and 69.9 months, Survey 7 at 79.0 and 78.4 months, and Survey 8 at 91.3 and 90.6 months are included in this report. At 70.6 months, LC-HPC-1 had a crack density of 0.061 m/m^2 for Placement 1 and 0.103 m/m^2 for Placement 2. These values are both significantly larger than the densities from the previous survey (0.032 m/m^2 for Placement 1 and 0.023 m/m^2 for Placement 2) reported by Pendergrass et al. (2011). The crack densities at 79.0 and 78.4 months increased to 0.096 m/m^2 for Placement 1 and decreased to 0.081 m/m^2 for Placement 2. In Survey 8 at 91.3 and 90.6 months, the crack densities decreased markedly to 0.059 m/m^2 for Placement 1, and Placement 2 fell to 0.023 m/m^2. During Survey 8, it was noted that many surfaces on the bridge had experienced scaling, which exposed the aggregate at the surface of the deck. It is believed that the outlines of these aggregates were mistaken as cracks in previous surveys. Figures 3, 4, and 5 show the crack maps for Surveys 6, 7, and 8. It is evident that many of the small cracks, which are likely misidentified as such, shown in Surveys 6 and 7, are not present in Survey 8. Cracking on LC-HPC-1 consists mainly of small cracks parallel to and directly above the top layer of deck reinforcement, except near the abutments, where cracks propagate longitudinally. Survey 6 has more distinct cracking near the midspan than is present in either of the two later surveys.

Control-1/2

Control-1/2 is adjacent to LC-HPC-1 and serves as the control deck for both LC-HPC-1 and LC-HPC-2. Like LC-HPC-1, Control-1/2 was cast in two separate placements. The results of Survey 6 at 70.7 and 70.1 months, Survey 7 at 79.2 and 78.6 months, and Survey 8 at 91.4 and 90.8 months are included in this report. The crack densities for Placement 1 and 2 measured in Survey 6, shown in Figure 6, were 0.139 and 0.176 m/m^2, which are both higher than measured in Survey 5 (Pendergrass et al. 2011). In Survey 7, the crack density of Placement 1 increased to 0.240 m/m^2 at 79.2 months, while the crack density of Placement 2 decreased to 0.161 m/m^2 at 78.6 months (see Figure 7). Crack densities for both placements decreased in Survey 8, to 0.141 m/m^2 and 0.149 m/m^2, respectively. The crack map for Survey 8 is shown in Figure 8. Cracking on Control-1/2 is very prominent around the pier at midspan. Cracks in this area run directly parallel to and above the reinforcing bars. There is also significant cracking at the ends of the bridge. Particularly, there are two large cracks running longitudinally down the middle of the bridge originating at either abutment. There is also map cracking in the northeast and northwest

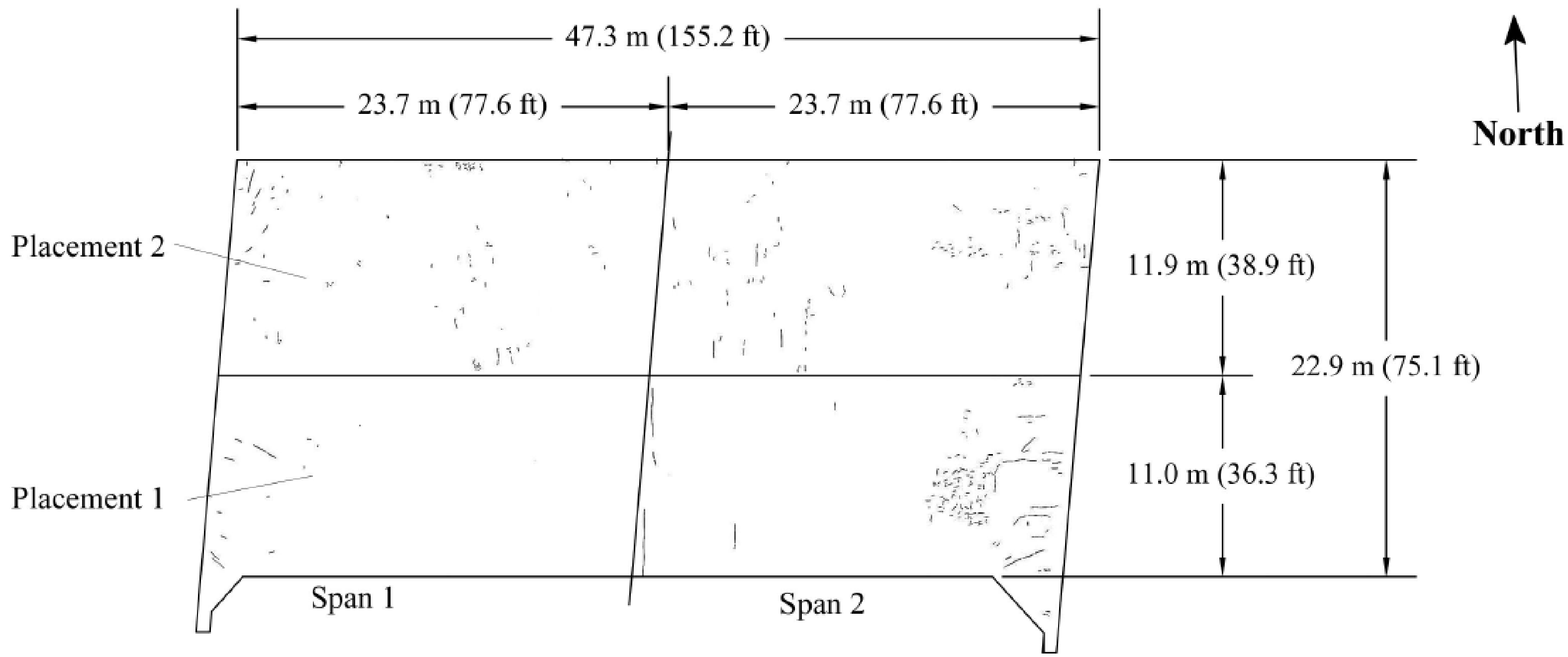


Bridge Number: 105-304 (LC-HPC-1)
Bridge Location: EB Parallel Pkwy over I-635
Construction Date:
Placement 1 (South): 10/14/2005
Placement 2 (North): 11/2/2005
Crack Survey Date: 9/1/2011

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: 70.6 months
Placement 2: 69.9 months
Crack Density: 0.082 m/m²
Placement 1: 0.061 m/m²
Placement 2: 0.103 m/m²
Span 1: 0.073 m/m²
Span 2: 0.089 m/m²

Figure 3: LC-HPC-1 (Survey 6)

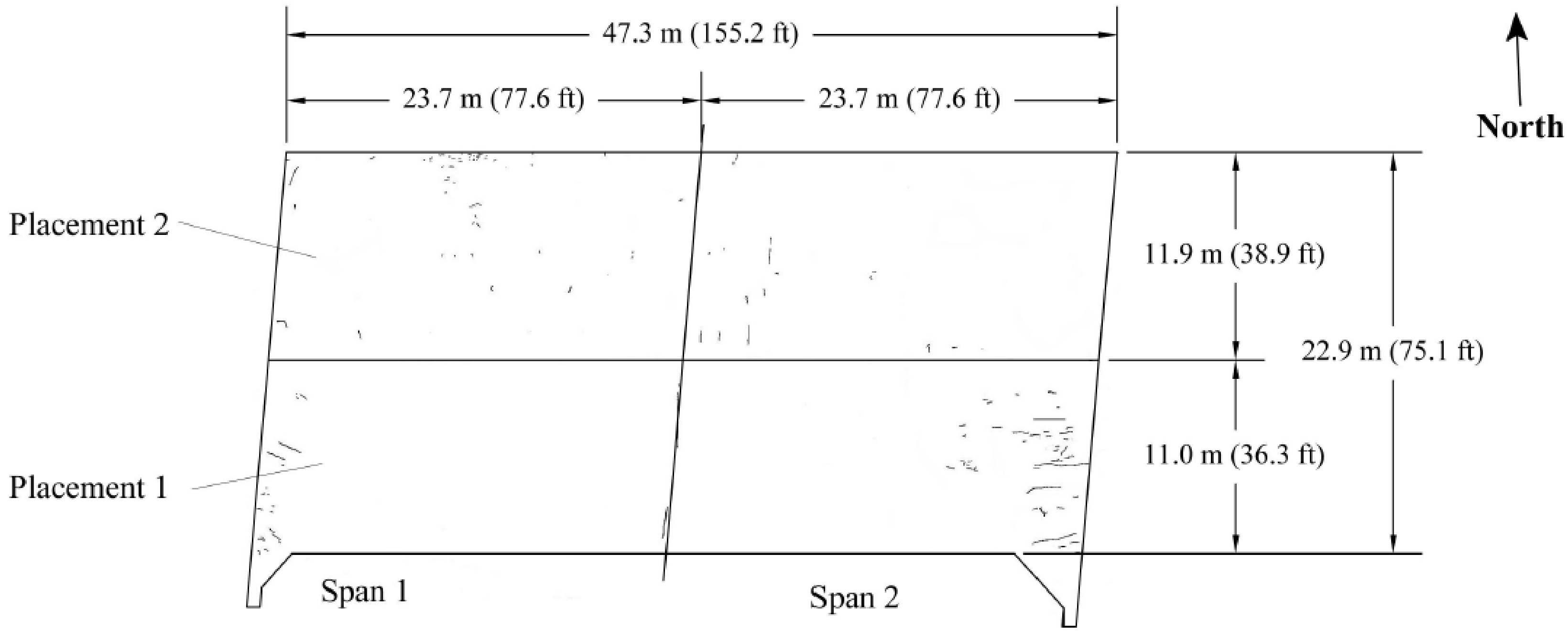


Bridge Number: 105-304 (LC-HPC-1)
Bridge Location: EB Parallel Pkwy over I-635
Construction Date:
Placement 1 (South): 10/14/2005
Placement 2 (North): 11/2/2005
Crack Survey Date: 5/16/2012

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: 79.0 months
Placement 2: 78.4 months
Crack Density: 0.085 m/m²
Placement 1: 0.096 m/m²
Placement 2: 0.081 m/m²
Span 1: 0.046 m/m²
Span 2: 0.124 m/m²

Figure 4: LC-HPC-1 (Survey 7)

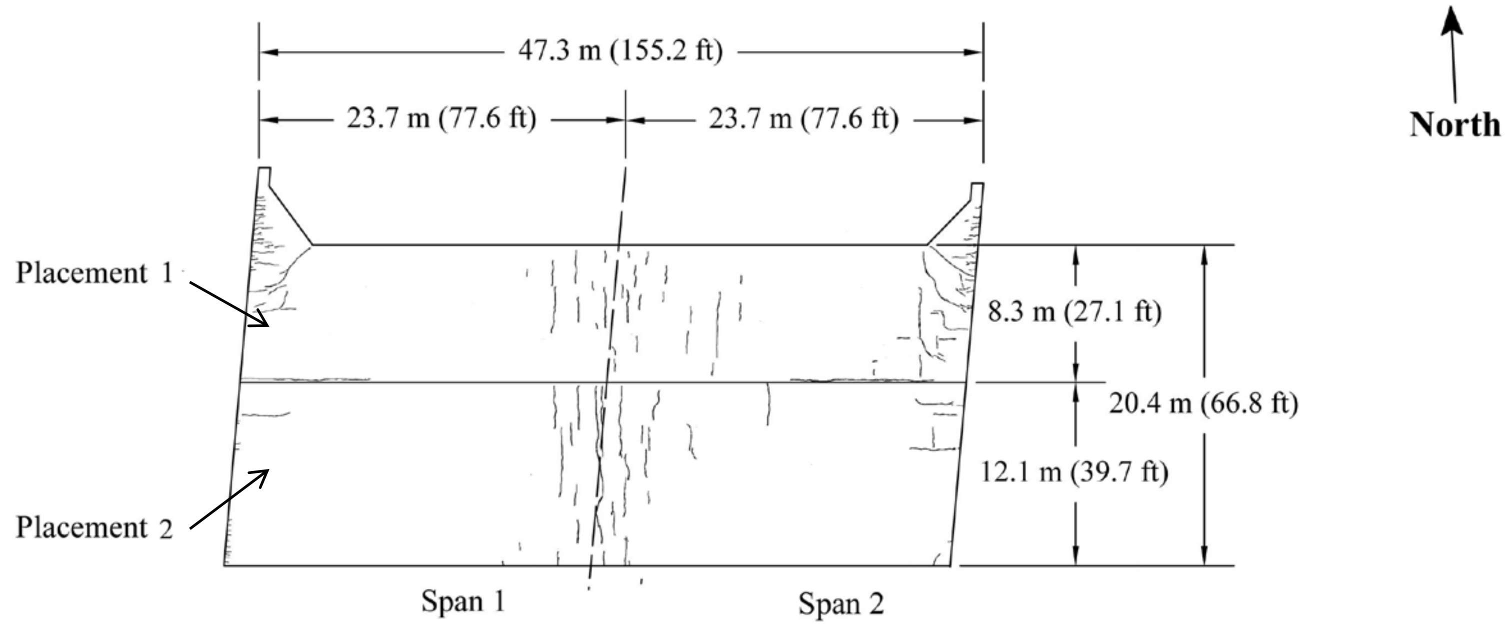


Bridge Number: 105-304 (LC-HPC-1)
Bridge Location: EB Parallel Pkwy over I-635
Construction Date:
Placement 1 (South): 10/14/2005
Placement 2 (North): 11/2/2005
Crack Survey Date: 5/23/2013

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: 91.3 months
Placement 2: 90.6 months
Crack Density: 0.040 m/m²
Placement 1: 0.059 m/m²
Placement 2: 0.023 m/m²
Span 1: 0.030 m/m²
Span 2: 0.051 m/m²

Figure 5: LC-HPC-1 (Survey 8)



Bridge Number: 105-311 (Control-1/2)

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: 9/1/2011

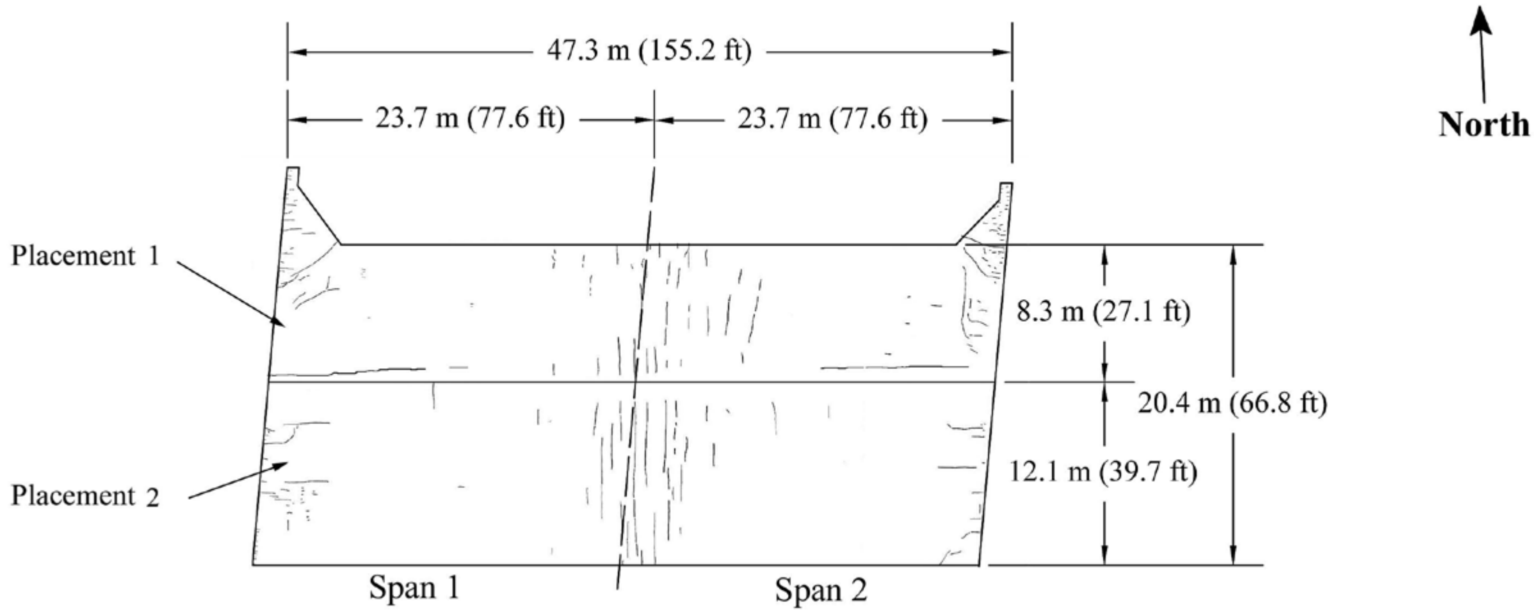
Bridge Length: 47.3 m (155.2 ft)
Bridge Width: 20.7 m (67.8 ft)
Skew: -5°
Number of Spans: 2
- **Span 1 (West):** 23.7 m (77.6 ft)
- **Span 2 (East):** 23.7 m (77.6 ft)

Number of Placements: 2

Bridge Age:
- **Placement 1 (N):** 70.7 months
- **Placement 2 (S):** 70.1 months

Crack Density: 0.190 m/m^2
- **Placement 1:** 0.259 m/m^2
- **Placement 2:** 0.137 m/m^2
- **Span 1:** 0.148 m/m^2
- **Span 2:** 0.227 m/m^2

Figure 6: Control-1/2 (Survey 6)



Bridge Number: 105-311 (Control-1/2)

Bridge Location: WB Parallel Pkwy over I-635

Construction Dates:
- **North Subdeck:** 9/30/2005
- **North Overlay:** 10/10/2005
- **South Subdeck:** 10/18/2005
- **South Overlay:** 10/28/2005

Crack Survey Date: 5/16/2012

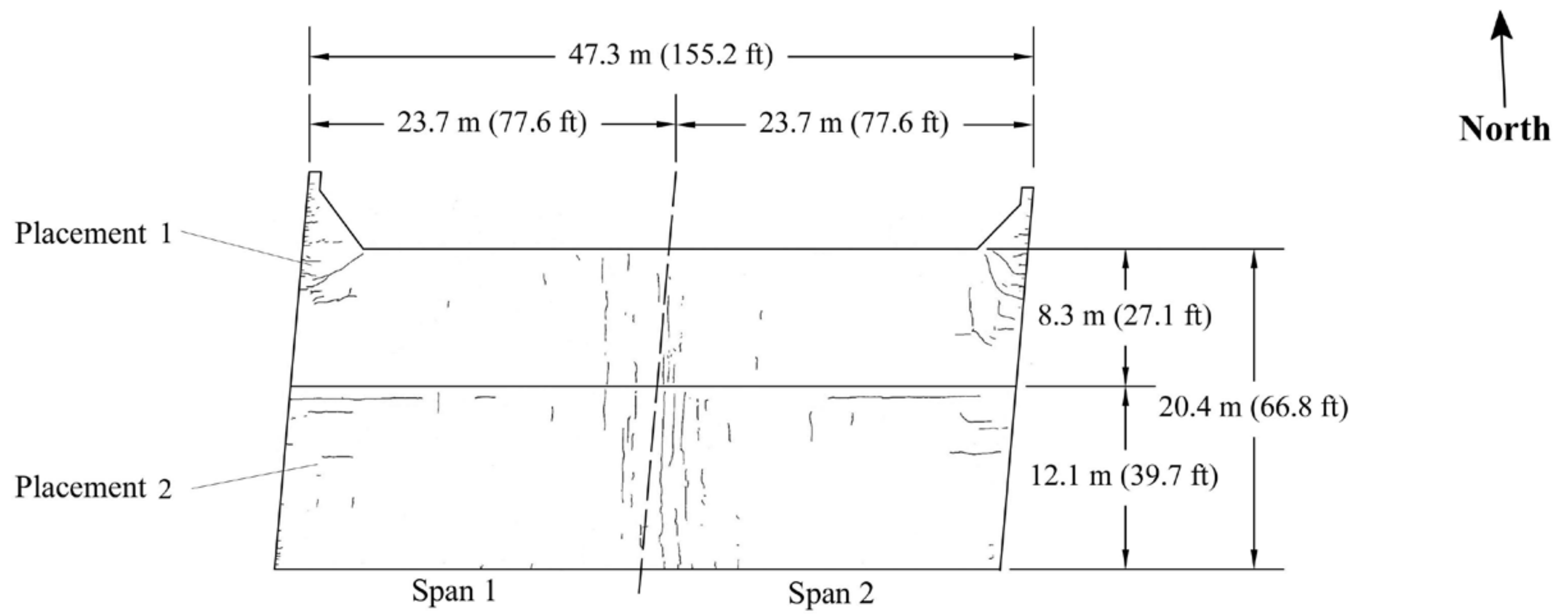
Bridge Length: 47.3 m (155.2 ft)
Bridge Width: 20.7 m (67.8 ft)
Skew: -5°
Number of Spans: 2
- **Span 1 (West):** 23.7 m (77.6 ft)
- **Span 2 (East):** 23.7 m (77.6 ft)

Number of Placements: 2

Bridge Age:
- **Placement 1 (N):** 79.2 months
- **Placement 2 (S):** 78.6 months

Crack Density: 0.196 m/m^2
- **Placement 1:** 0.240 m/m^2
- **Placement 2:** 0.161 m/m^2
- **Span 1:** 0.166 m/m^2
- **Span 2:** 0.226 m/m^2

Figure 7: Control-1/2 (Survey 7)



Bridge Number: 105-311 (Control-1/2)

Bridge Location: WB Parallel Pkwy over I-635

Construction Dates:
- **North Subdeck:** 9/30/2005
- **North Overlay:** 10/10/2005
- **South Subdeck:** 10/18/2005
- **South Overlay:** 10/28/2005

Crack Survey Date: 5/23/2013

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):** 91.4 months
- **Placement 2 (S):** 90.8 months

Crack Density: 0.144 m/m^2
- **Placement 1:** 0.141 m/m^2
- **Placement 2:** 0.149 m/m^2
- **Span 1:** 0.128 m/m^2
- **Span 2:** 0.160 m/m^2

Figure 8: Control-1/2 (Survey 8)

corners of the bridge. Figure 9 compares cracking on Control-1/2 to LC-HPC-1 over time. Crack densities on both placements of Control-1/2 have been consistently higher than densities on both placements of LC-HPC-1 over time.

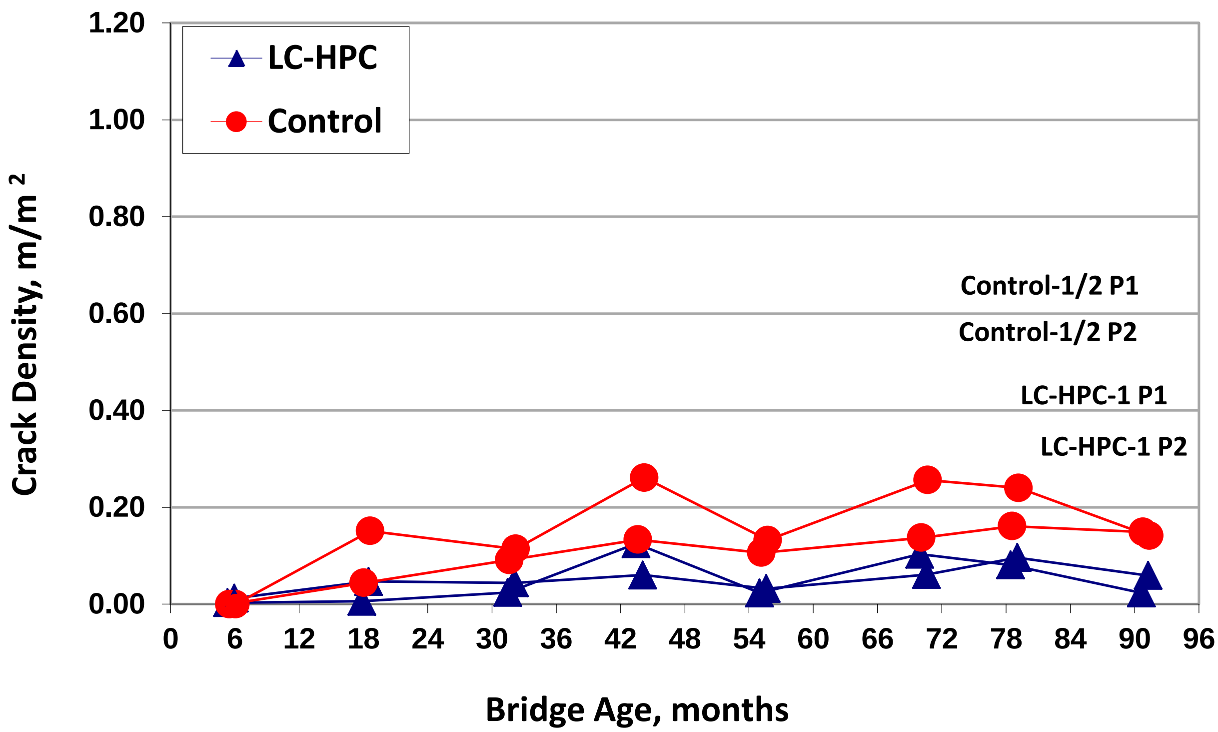
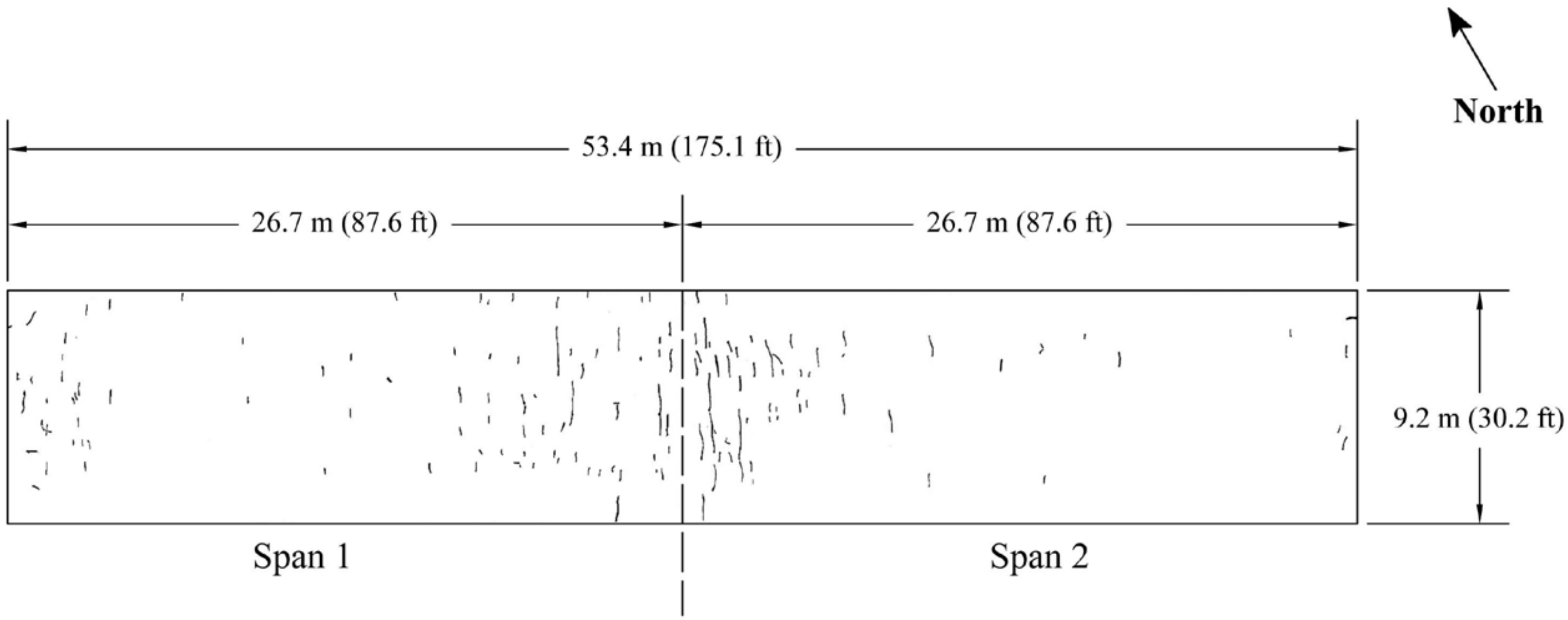


Figure 9: LC-HPC-1 and Control-1/2 Crack Densities

LC-HPC-2

The results of Survey 5 at 59.3 months, Survey 6 at 68.1 months, and Survey 7 at 80.3 months are included in this report. Crack densities of 0.143 m/m^2 and 0.197 m/m^2 were measured at 59.3 months and 68.1 months, respectively. These densities are, respectively, more than two and three times the previous density of 0.059 m/m^2 at 44.5 months reported by Pendergrass et al. (2011). Crack maps for Surveys 5 and 6 are shown in Figures 10 and 11. At 80.3 months, LC-HPC-2 had a crack density of 0.141 m/m^2, more than 25% lower than the density at 68.1 months. Figure 12 shows the crack map for Survey 7. Cracking in all three of these surveys is

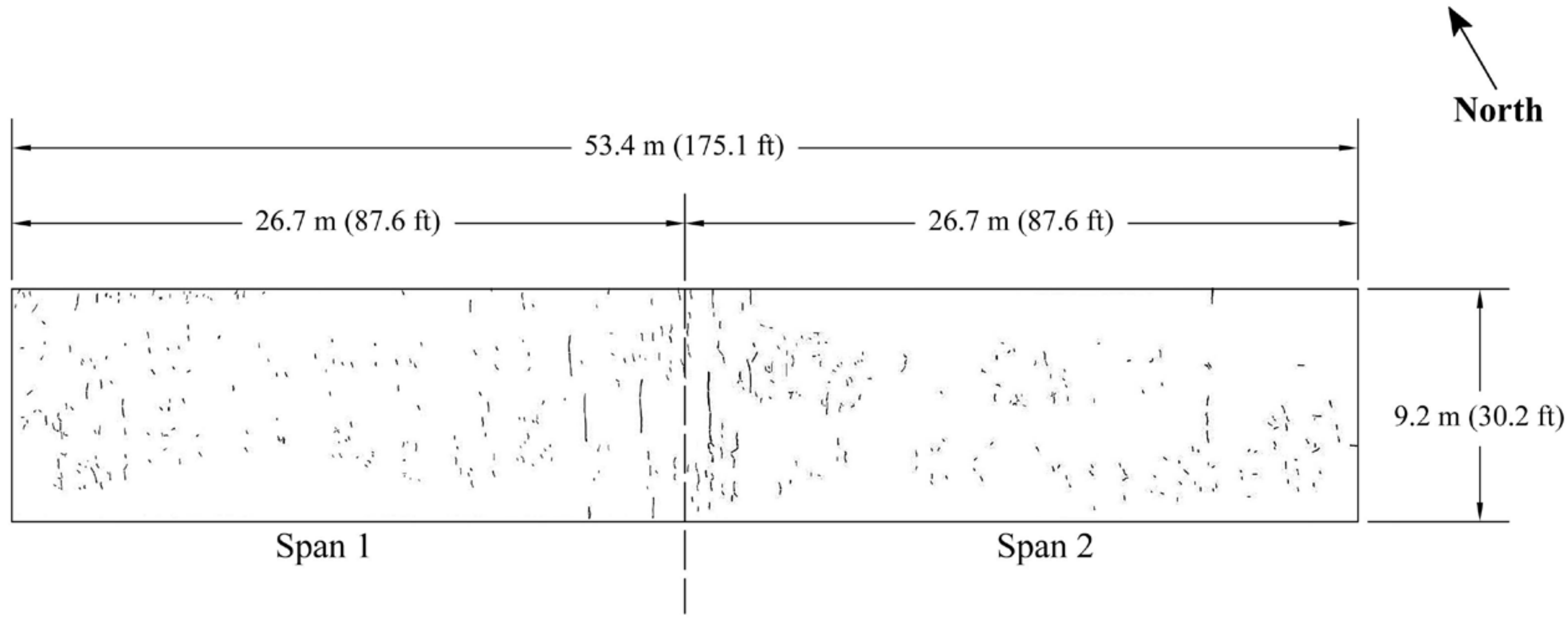


Bridge Number: 105-310 (LC-HPC-2)
Bridge Location: 34th St over I-635
Construction Date: 9/13/2006
Crack survey Date: 8/22/2011

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: 59.3 months
Crack density: 0.144 m/m^2
Span 1 (West): 0.152 m/m^2
Span 2 (East): 0.135 m/m^2

Figure 10: LC-HPC-2 (Survey 5)

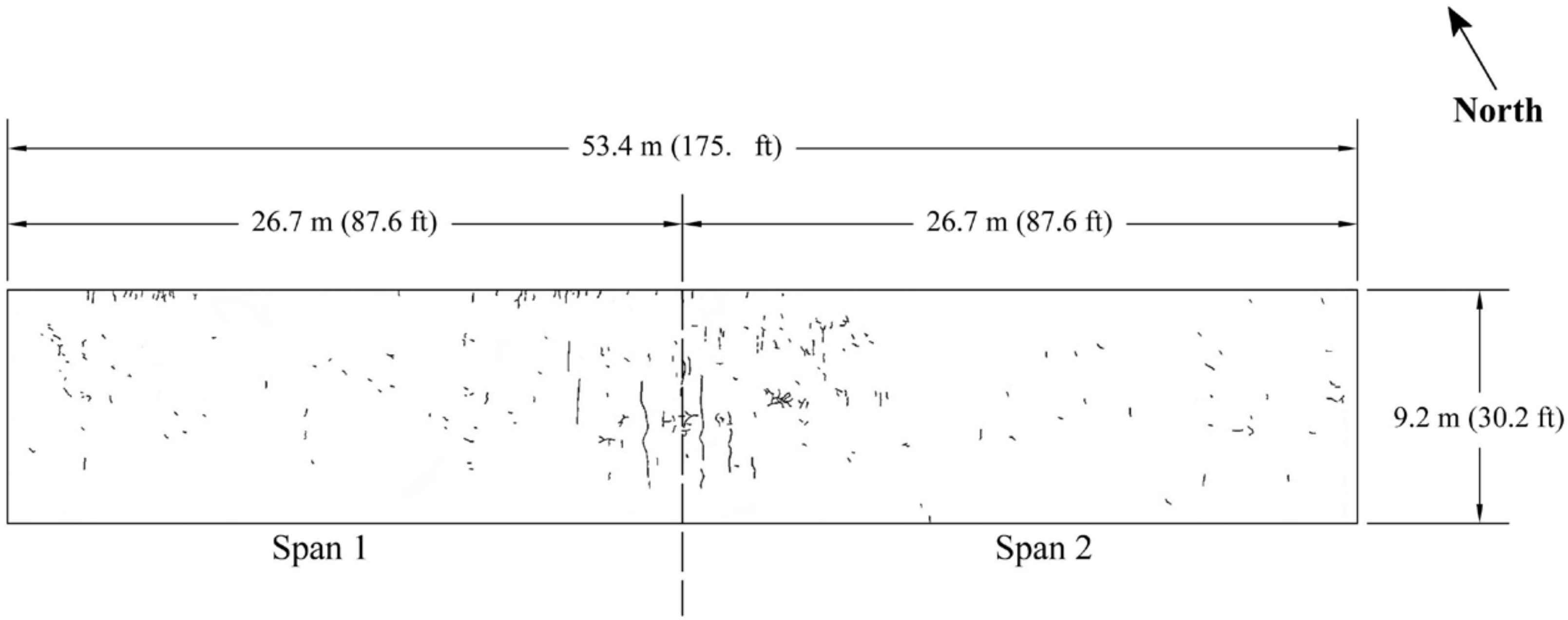


Bridge Number: 105-310 (LC-HPC-2)
Bridge Location: 34th St over I-635
Construction Date: 9/13/2006
Crack survey Date: 5/18/2012

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: 68.1 months
Crack density: 0.197 m/m^2
Span 1 (West): 0.204 m/m^2
Span 2 (East): 0.191 m/m^2

Figure 11: LC-HPC-2 (Survey 6)



Bridge Number: 105-310 (LC-HPC-2)
Bridge Location: 34th St over I-635
Construction Date: 9/13/2006
Crack survey Date: 5/24/2013

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

Bridge Age: 80.3 months
Crack density: 0.141 m/m^2
Span 1 (West): 0.129 m/m^2
Span 2 (East): 0.151 m/m^2

Figure 12: LC-HPC-2 (Survey 7)

prominent in the negative moment region above the pier, with small cracks extending from the northern edge of the deck and distributed throughout the entire deck. The crack map for Survey 6 shows many small cracks throughout the deck that were not captured in any previous surveys, likely the result of mistaking aggregate boundaries for cracks. Figure 13 compares cracking on LC-HPC-2 to Control-1/2 over time. It is evident that cracking on LC-HPC-2 has increased over time, experiencing a sharp rise after 42 months, and has moved closer in value to the crack densities for Control-1/2 in recent years.

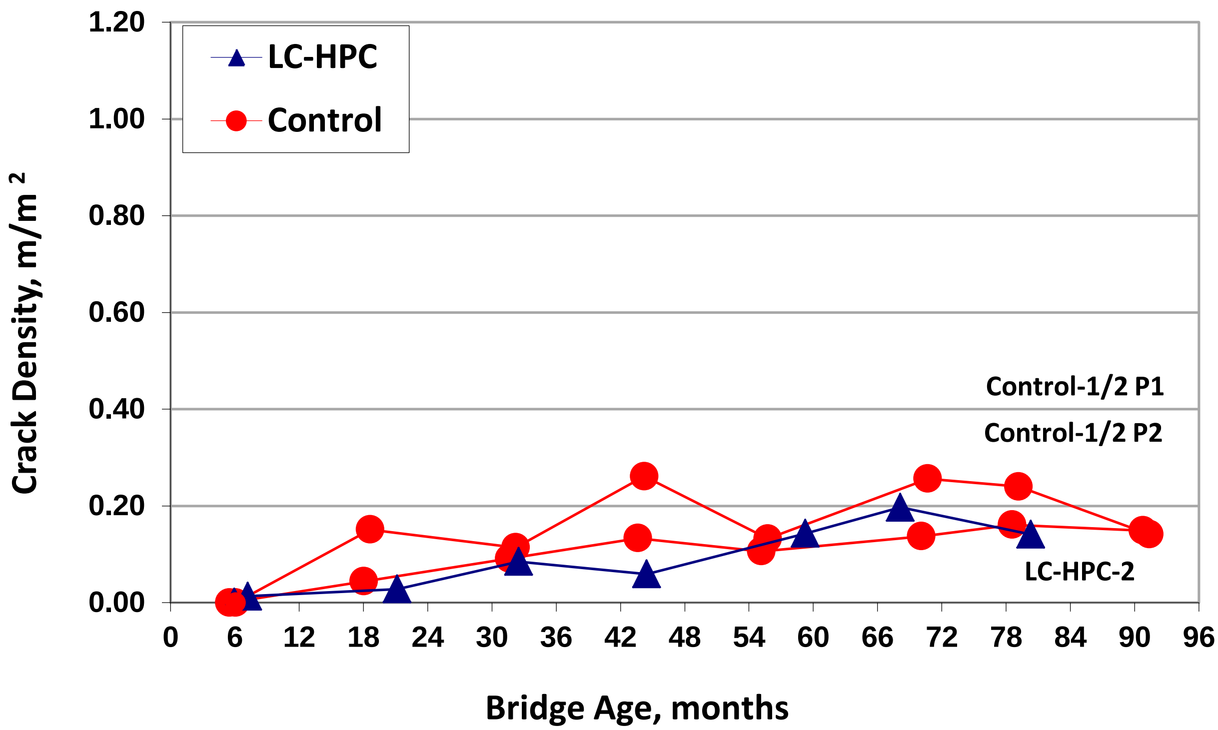


Figure 13: LC-HPC-2 and Control-1/2 Crack Densities

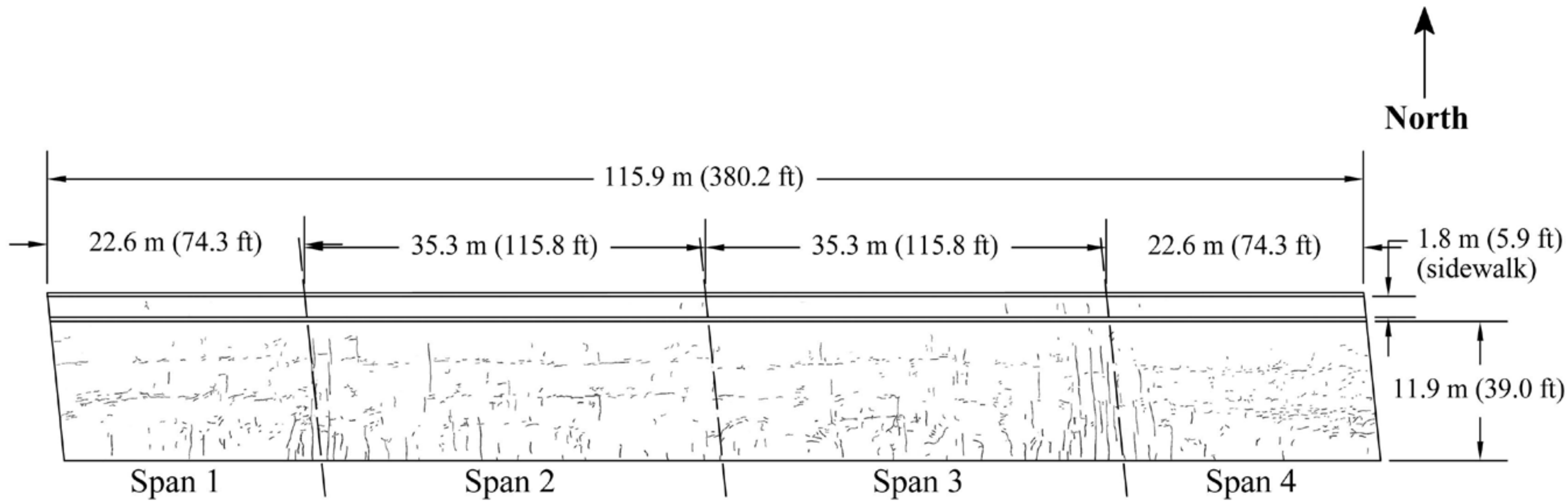
LC-HPC-3

The results of Survey 4 at 42.6 months, Survey 5 at 54.0 months, and Survey 6 at 66.2 months for LC-HPC-3 are included in this report. Crack densities measured in Surveys 4, 5, and 6 were 0.315 m/m^2, 0.173 m/m^2, and 0.174 m/m^2, respectively. These densities represent an increase from Survey 3, which measured a crack density of 0.108 m/m^2, as presented by

Pendergrass et al. (2011). In relation to the crack densities calculated for LC-HPC-3 in previous years, the large increase in crack density corresponding to Survey 4 (0.315 m/m^2) appears to be an outlier. Crack maps for Surveys 4, 5, and 6 are shown in Figures 14, 15, and 16, respectively. Cracking is significant above the outside piers, but not at center span. Smaller cracks are within the spans and at the east end of the bridge. The larger cracks located above the piers appear to lie directly above and parallel to the reinforcement.

Control-3

The results of Survey 4 at 46.6 months, Survey 5 at 57.9 months, and Survey 6 at 70.1 months are included in this report. Crack densities of 0.323 m/m^2 and 0.314 m/m^2 were observed in Surveys 4 and 5, respectively. These values represent a significant increase from crack densities of 0.216 m/m^2 and 0.232 m/m^2 corresponding, respectively, to Surveys 2 and 3 (Pendergrass et al. 2011). The crack density of Control-3 at 57.9 months, 0.314 m/m^2, is nearly double the crack density of LC-HPC 3 at 54 months, 0.173 m/m^2. At 70.1 months, a crack density of 0.288 m/m^2 was recorded in Survey 6, which is slightly lower than the densities measured in Surveys 4 and 5, but is still larger than the crack density of LC-HPC-3 at 66.2 months, 0.174 m/m^2. Figures 17, 18, and 19 show the crack maps for Surveys 4, 5, and 6, respectively. Cracking on Control-3 is largely located parallel to the reinforcement and is relatively evenly distributed throughout the deck. Figure 20 compares cracking on Control-3 to LC-HPC-3 over time. Cracking on LC-HPC-3 has, for the most part, remained lower than cracking on Control-3 over the life of the decks, with the exception of the density of LC-HPC-3 at 42.6 months, which, as discussed earlier in this section, appears to be an outlier.

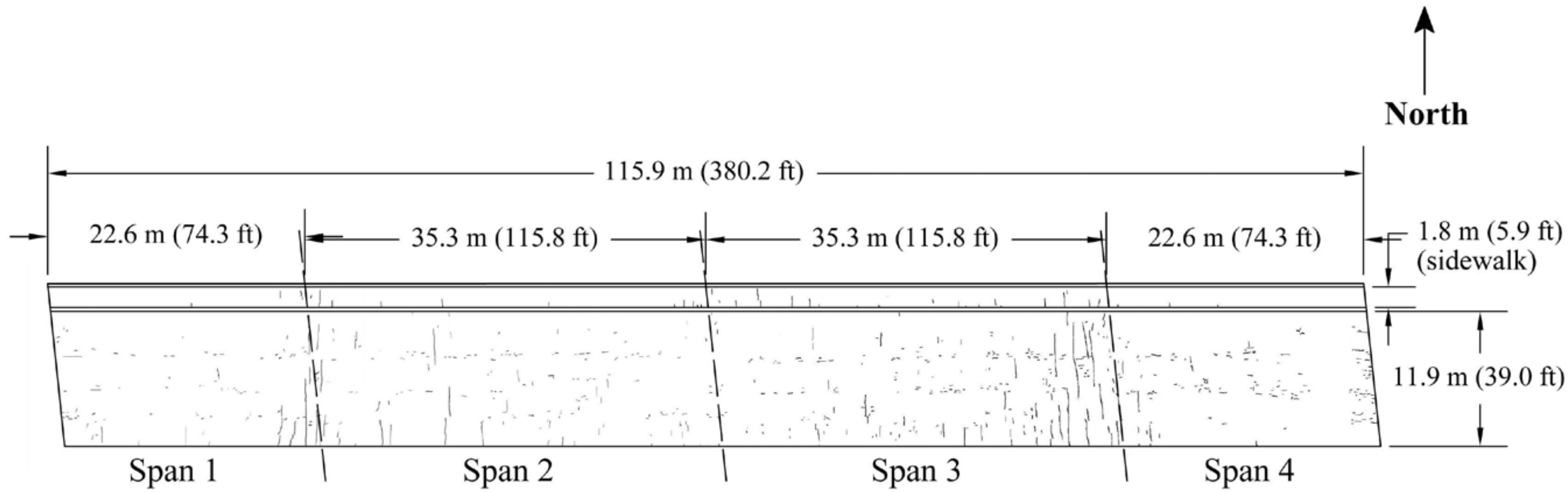


Bridge Number: 46-338 (LC-HPC-3)
Bridge Location: WB 103rd St over US 69
Construction Date: 11/13/2007
Crack survey Date: 6/1/2011

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: 42.6 months
Crack density: 0.315 m/m^2
Span 1 : 0.295 m/m^2
Span 2 : 0.287 m/m^2
Span 3 : 0.355 m/m^2
Span 4 : 0.313 m/m^2

Figure 14: LC-HPC-3 (Survey 4)



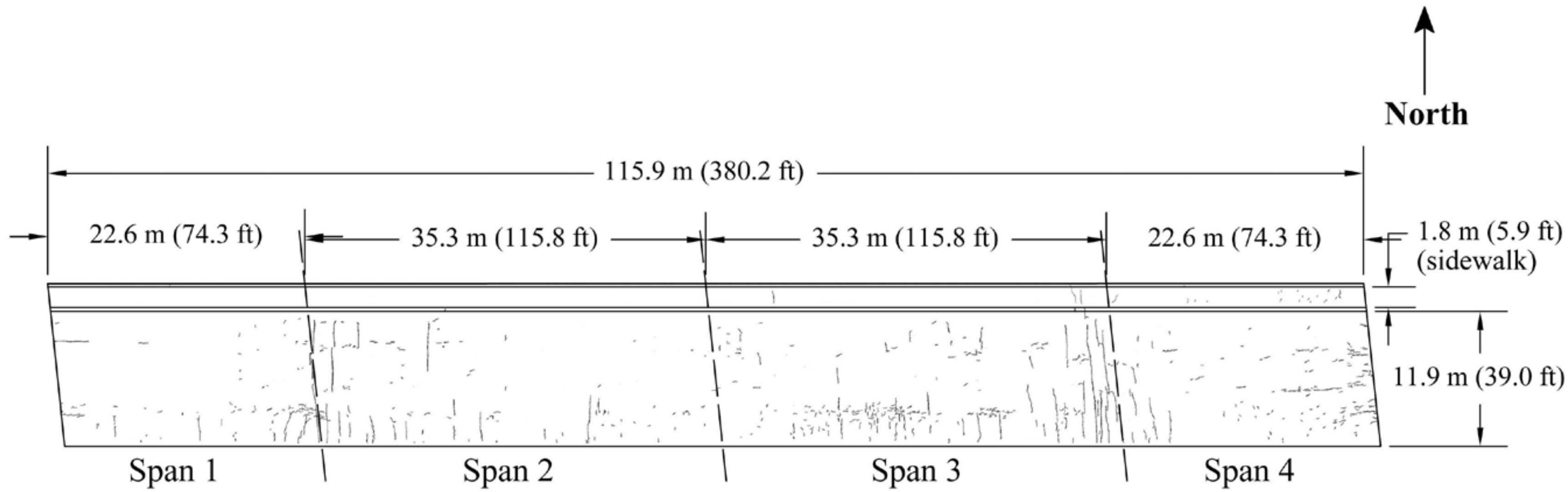
Bridge Number: 46-338 (LC-HPC-3)
Bridge Location: WB 103rd St over US 69
Construction Date: 11/13/2007
Crack survey Date: 5/14/2012

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: 54.0 months
Crack density: 0.173 m/m^2
- **Span 1 :** 0.142 m/m^2
- **Span 2 :** 0.138 m/m^2
- **Span 3 :** 0.244 m/m^2
- **Span 4 :** 0.133 m/m^2

Figure 15: LC-HPC-3 (Survey 5)

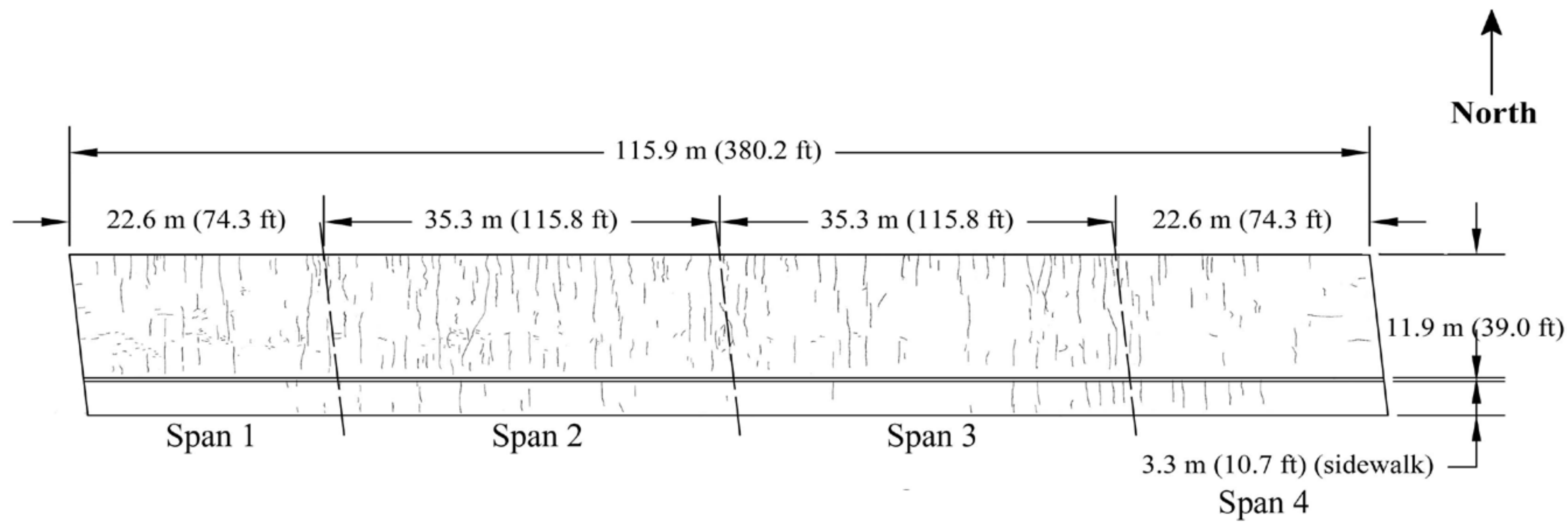


Bridge Number: 46-338 (LC-HPC-3)
Bridge Location: WB 103rd St over US 69
Construction Date: 11/13/2007
Crack survey Date: 5/21/2013

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: 66.2 months
Crack density: 0.174 m/m^2
Span 1 : 0.109 m/m^2
Span 2 : 0.124 m/m^2
Span 3 : 0.249 m/m^2
Span 4 : 0.180 m/m^2

Figure 16: LC-HPC-3 (Survey 6)



Bridge Number: 46-337 (Control-3)

Bridge Location: EB 103rd St. over US-69

Construction Date: 7/17/2007

Crack survey Date: 6/7/2011

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)

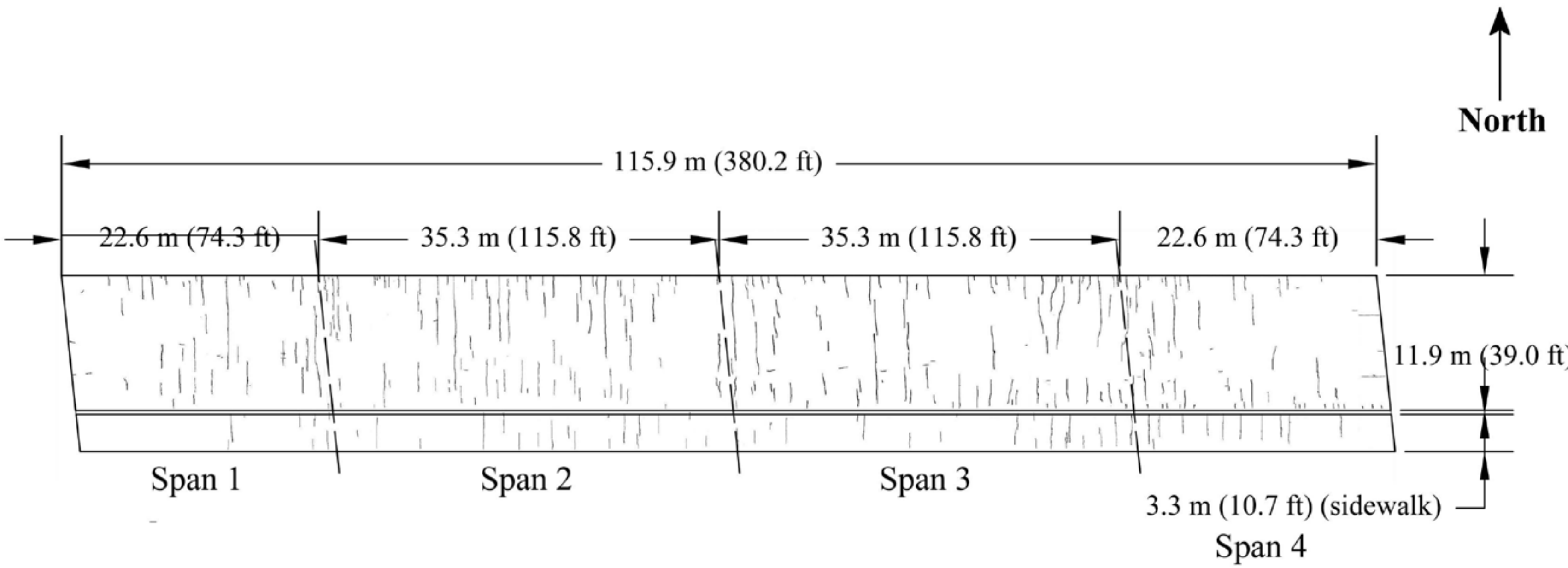
Number of Placements: 1

Bridge Age: 46.6 months

Crack density: 0.323 m/m^2

- **Span 1:** 0.300 m/m^2
- **Span 2:** 0.396 m/m^2
- **Span 3:** 0.323 m/m^2
- **Span 4:** 0.207 m/m^2

Figure 17: Control-3 (Survey 4)



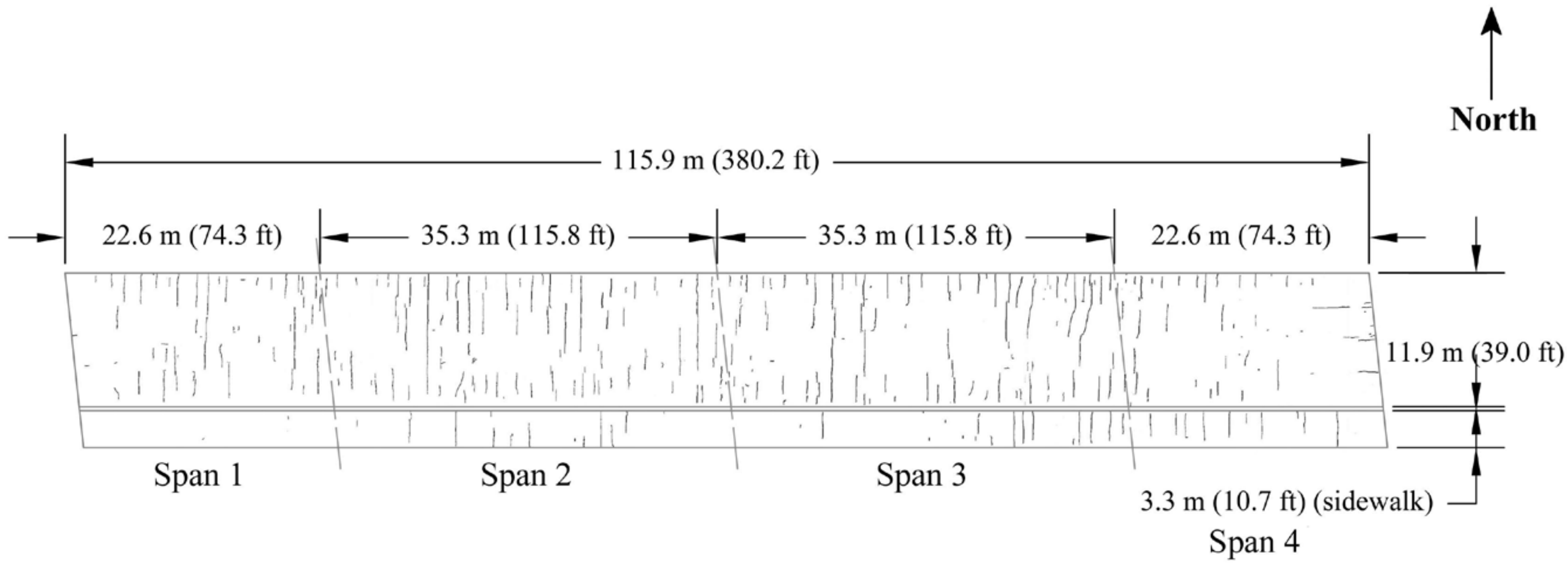
Bridge Number: 46-337 (Control-3)

Bridge Location: EB 103rd St. over US-69
Construction Date: 7/17/2007
Crack survey Date: 5/14/2012

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: 57.9 months
Crack density: 0.314 m/m^2
Span 1: 0.236 m/m^2
Span 2: 0.346 m/m^2
Span 3: 0.329 m/m^2
Span 4: 0.306 m/m^2

Figure 18: Control-3 (Survey 5)



Bridge Number: 46-337 (Control-3)

Bridge Location: EB 103rd St. over US-69

Construction Date: 7/17/2007

Crack survey Date: 5/21/2013

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: 70.1 months

Crack density: 0.288 m/m^2

- **Span 1:** 0.228 m/m^2
- **Span 2:** 0.324 m/m^2
- **Span 3:** 0.345 m/m^2
- **Span 4:** 0.211 m/m^2

Figure 19: Control-3 (Survey 6)

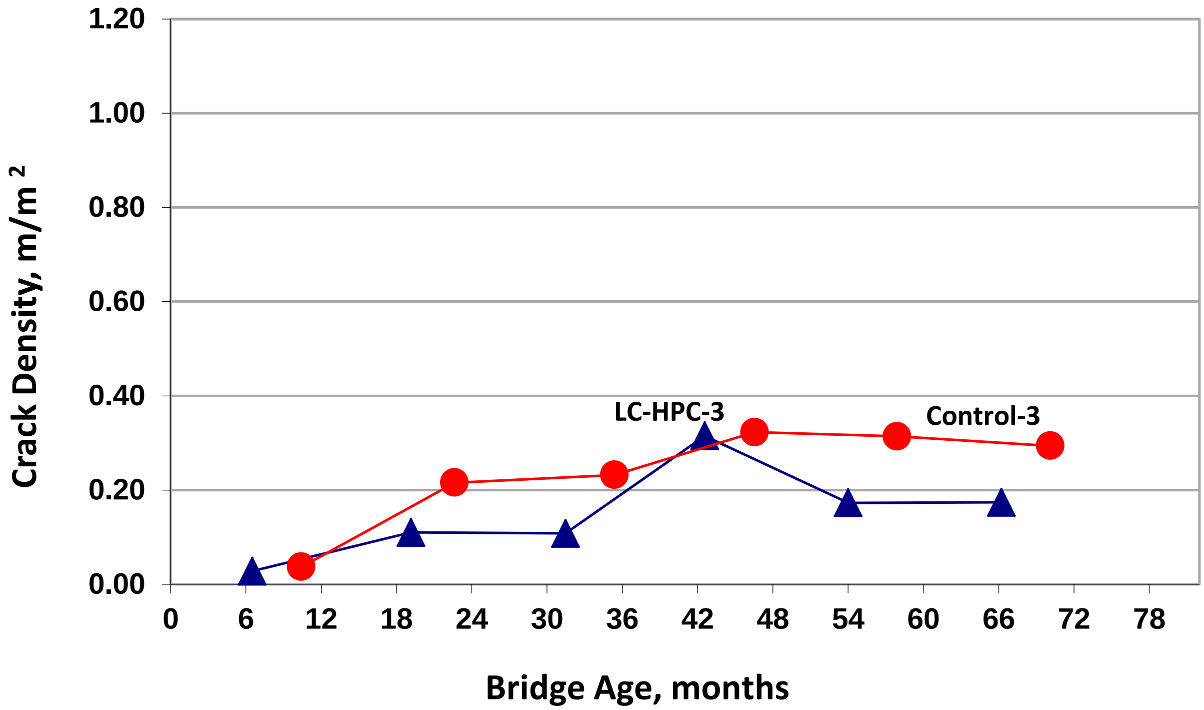
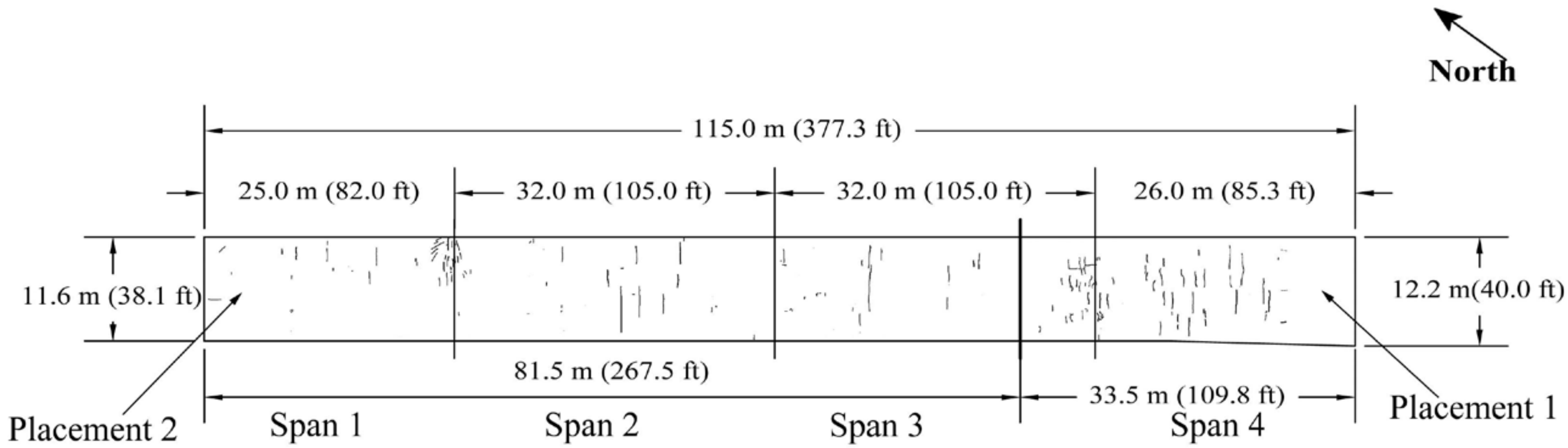


Figure 20: LC-HPC-3 and Control-3 Crack Densities

LC-HPC-4

LC-HPC-4 was constructed in two placements three days apart. The results of Survey 4 at 45.0 and 44.9 months, Survey 5 at 56.0 and 55.9 months, and Survey 6 at 68.5 and 68.4 months are included in this report. Crack maps for Surveys 4, 5, and 6 are shown in Figures 21, 22, and 23. At ages of 45 months for Placement 1 and 44.9 months for Placement 2, the overall crack density was 0.107 m/m^2, with Placement 1 having a density twice that of Placement 2 (0.167 m/m^2 and 0.080 m/m^2). This represents a decrease from the crack densities measured in Survey 3 at 32.8 months for Placement 1 and 32.7 months for Placement 2: 0.146 m/m^2 overall, 0.261 m/m^2 for Placement 1, and 0.094 m/m^2 for Placement 2 (Pendergrass et al. 2011). At ages of 56 months for Placement 1 and 55.9 months for Placement 2 (Survey 5), the overall crack density was 0.120 m/m^2, an increase from Survey 4, but still lower than the crack density measured in Survey 3. Furthermore, the crack density of Placement 1 is still twice as large as the density of

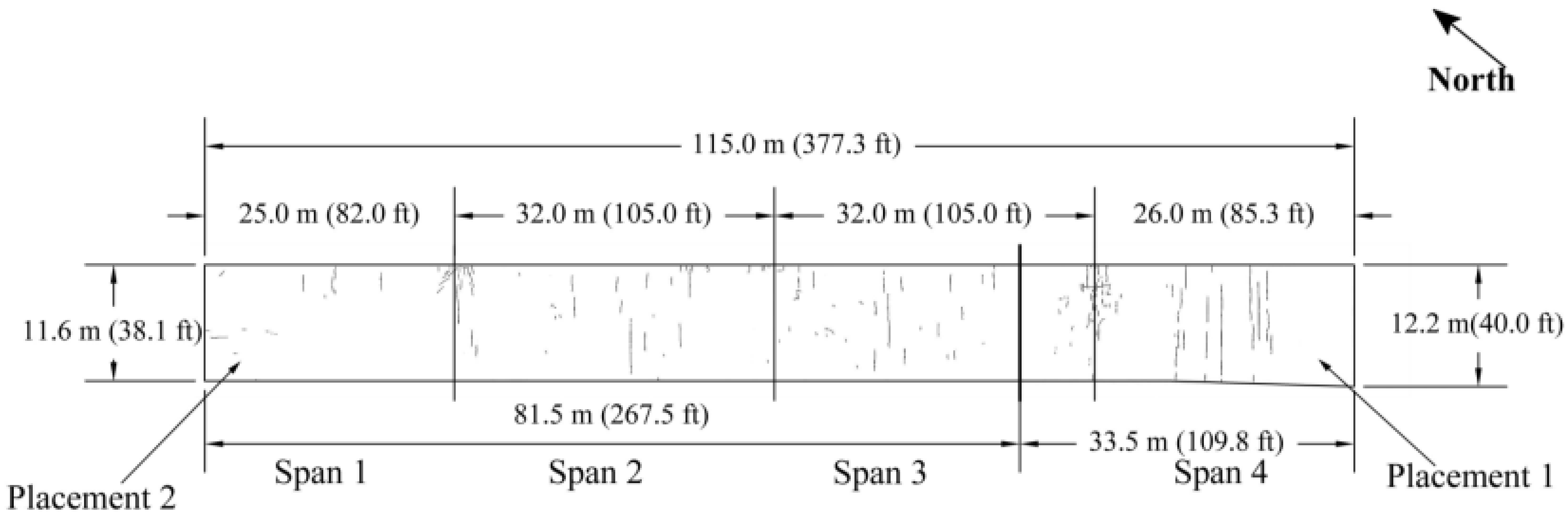


Bridge Number: 46-339 Unit 1
(LC-HPC-4)
Bridge Location: Flyover Ramp
US-69S to I-435W
Construction Date:
Placement 1 (South): 9/29/2007
Placement 2 (North): 10/2/2007
Crack Survey Date: 6/30/2011

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: 45.0 months
Placement 2: 44.9 months
Crack Density: 0.107 m/m^2
Placement 1: 0.167 m/m^2
Placement 2: 0.080 m/m^2
Span 1: 0.080 m/m^2
Span 2: 0.088 m/m^2
Span 3: 0.088 m/m^2
Span 4: 0.174 m/m^2

Figure 21: LC-HPC-4 (Survey 4)

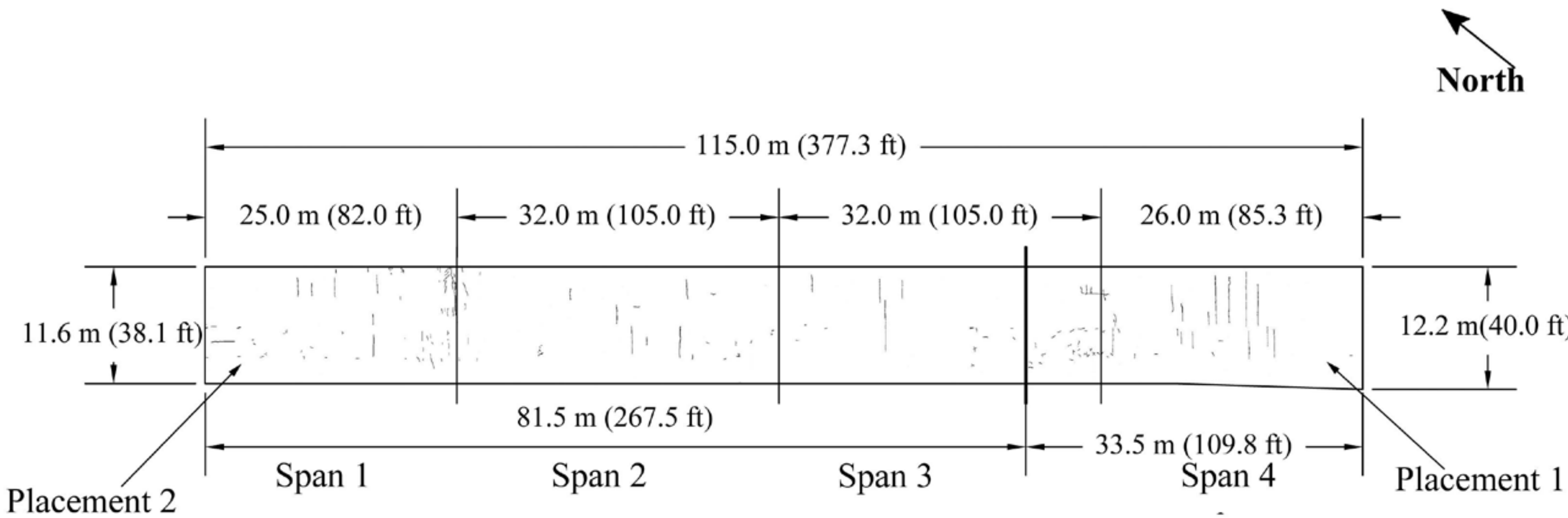


Bridge Number: 46-339 Unit 1 (LC-HPC-4)
Bridge Location: Flyover Ramp US-69S to I-435W
Construction Date:
Placement 1 (South): 9/29/2007
Placement 2 (North): 10/2/2007
Crack Survey Date: 5/30/2012

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: 56.0 months
Placement 2: 55.9 months
Crack Density: 0.120 m/m^2
Placement 1: 0.184 m/m^2
Placement 2: 0.092 m/m^2
Span 1: 0.054 m/m^2
Span 2: 0.110 m/m^2
Span 3: 0.124 m/m^2
Span 4: 0.188 m/m^2

Figure 22: LC-HPC-4 (Survey 5)



Bridge Number: 46-339 Unit 1 (LC-HPC-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: 6/13/2013

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

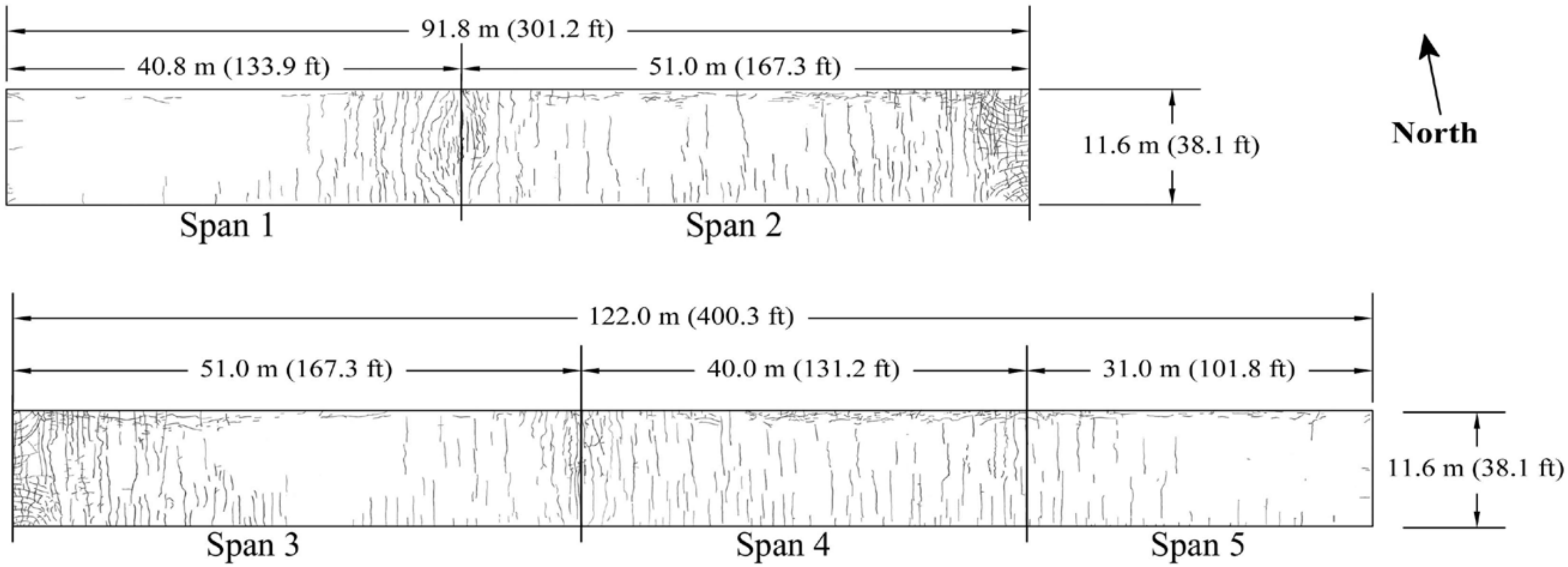
Bridge Age:
Placement 1: 68.5 months
Placement 2: 68.4 months
Crack Density: 0.105 m/m^2
Placement 1: 0.147 m/m^2
Placement 2: 0.077 m/m^2
Span 1: 0.125 m/m^2
Span 2: 0.056 m/m^2
Span 3: 0.070 m/m^2
Span 4: 0.153 m/m^2

Figure 23: LC-HPC-4 (Survey 6)

Placement 2 measured during Survey 5 (0.184 m/m^2 versus 0.092 m/m^2). For Survey 6 at 68.5 months, the overall crack density was 0.097 m/m^2, a decrease from Survey 5. The crack density of Placement 1 decreased slightly to 0.179 m/m^2 and the crack density of Placement 2 at 68.4 months decreased about 35 percent to 0.060 m/m^2. Cracking of LC-HPC-4 Placement 1 occurs around the easternmost pier, along with transverse cracks located in the midspan. Cracking of Placement 2 is most prominent around the westernmost pier. Placement 2 also contains transverse cracks in the midspans.

Control-4

The results of Surveys 4, 5, and 6, at 42.7, 54.9, and 67.1 months, are included in this report. The crack densities of Control-4 measured in Surveys 4 and 5, shown in Figures 24 and 25, were 0.618 m/m^2 and 0.669 m/m^2, respectively. These densities represent a significant increase from the value measured in Survey 3 at 31.6 months of 0.473 m/m^2 (Pendergrass et al. 2011). These densities are also much larger than the crack densities of LC-HPC-4 at 45.0 and 56.0 months. The crack density at 67.1 months was 0.561 m/m^2 (see Figure 26), a decrease from the crack densities measured in Surveys 4 and 5. However, this density is still much greater than the overall crack density of LC-HPC-4 at 68.5 months of 0.105 m/m^2. Control-4 has significant transverse cracking near the piers of the bridge. Above the second pier from the west, there is longitudinal and transverse cracking. There is also significant longitudinal cracking along the northern edge of the deck, which is likely due to a small portion of the bridge deck that is cantilevered out over the exterior girder. Figure 27 compares crack densities on Control-4 to crack densities on LC-HPC-4 over time. Clearly, cracking on Control-4 has been significantly greater than on either placement of LC-HPC-4 over time. While LC-HPC-4 seems to have had relatively stable cracking over its life, Control-4 has had a general trend of increased cracking.



Bridge Number: 46-347 (Control-4)

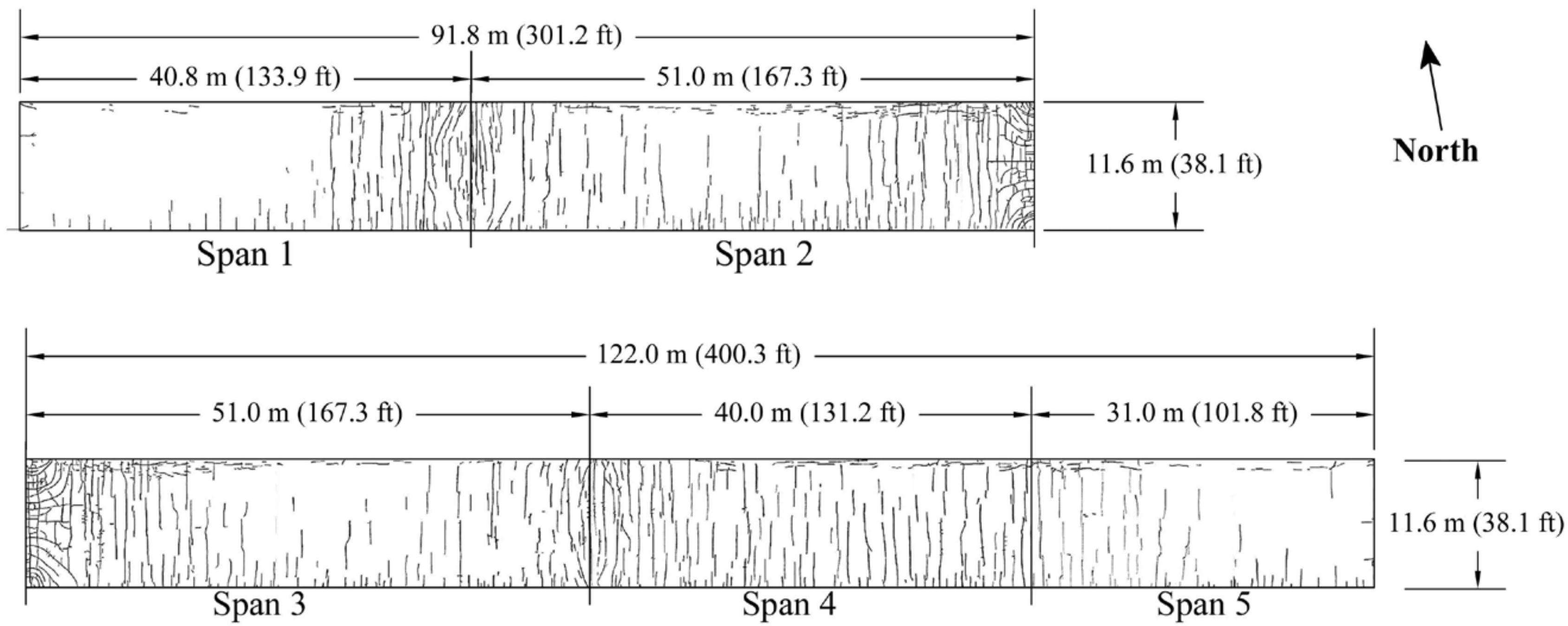
Bridge Location: NB US-69 Rd
Construction Date: 11/16/2007
Crack survey Date: 6/7/2011

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: 42.7 months
Crack density: 0.618 m/m^2
- **Span 1:** 0.406 m/m^2
- **Span 2:** 0.807 m/m^2
- **Span 3:** 0.715 m/m^2
- **Span 4:** 0.710 m/m^2
- **Span 5:** 0.294 m/m^2

Figure 24: Control-4 (Survey 4)



Bridge Number: 46-347 (Control-4)

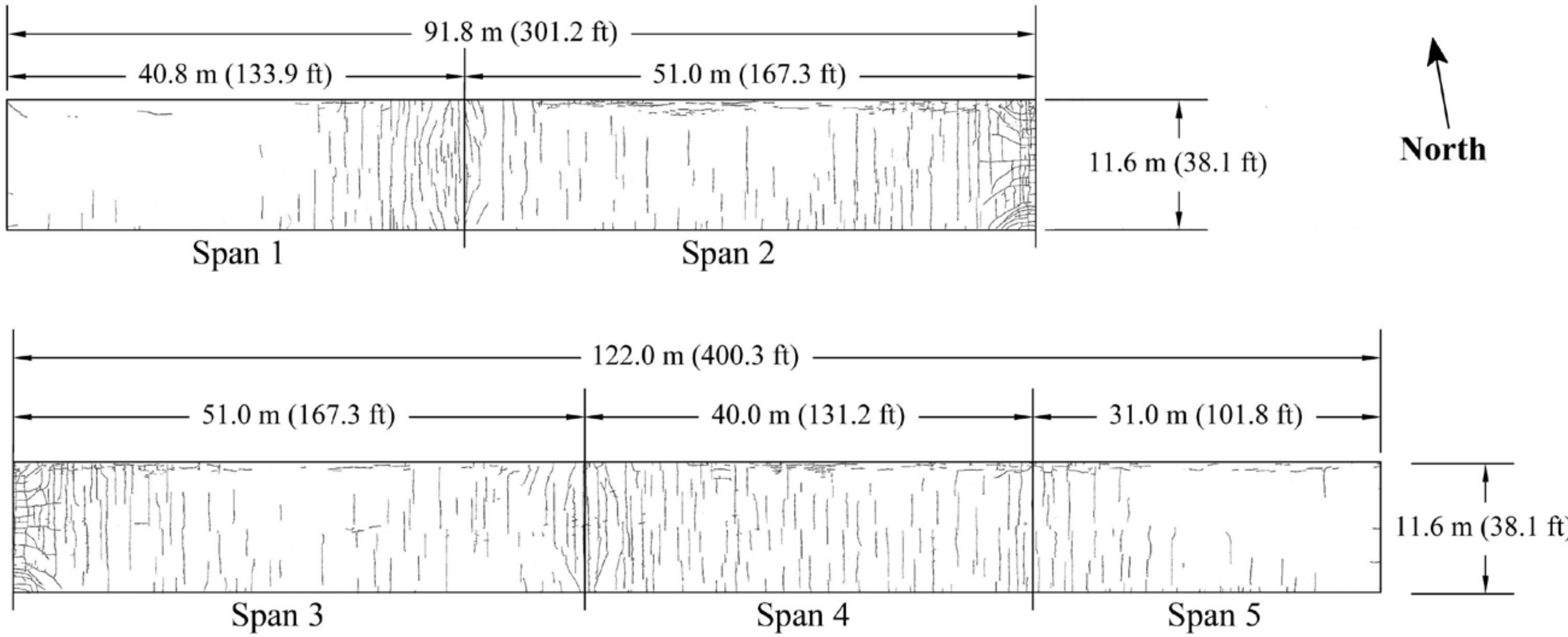
Bridge Location: NB US-69 Rd
Construction Date: 11/16/2007
Crack survey Date: 6/12/2012

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: 54.9 months
Crack density: 0.669 m/m^2
- **Span 1:** 0.523 m/m^2
- **Span 2:** 0.649 m/m^2
- **Span 3:** 0.931 m/m^2
- **Span 4:** 0.885 m/m^2
- **Span 5:** 0.134 m/m^2

Figure 25: Control-4 (Survey 5)



Bridge Number: 46-347 (Control-4)

Bridge Location: NB US-69 Rd
Construction Date: 11/16/2007
Crack survey Date: 6/20/2013

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: 67.1 months
Crack density: 0.561 m/m^2
- **Span 1:** 0.348 m/m^2
- **Span 2:** 0.667 m/m^2
- **Span 3:** 0.609 m/m^2
- **Span 4:** 0.720 m/m^2
- **Span 5:** 0.312 m/m^2

Figure 26: Control-4 (Survey 6)

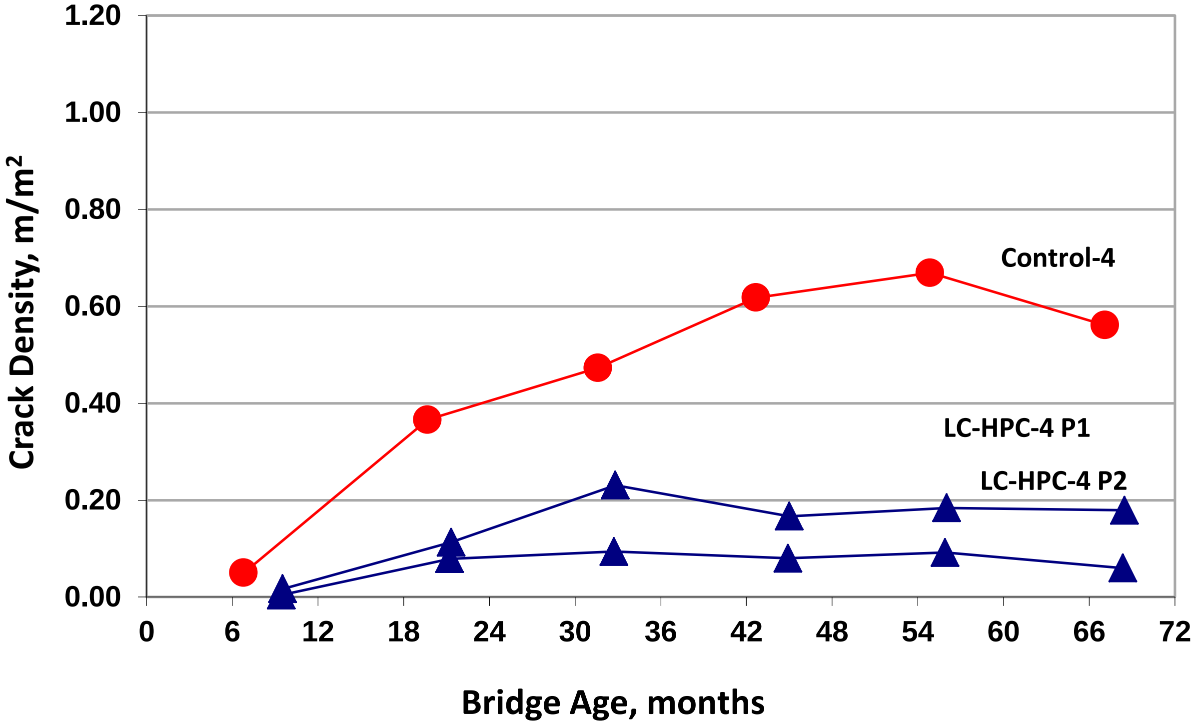
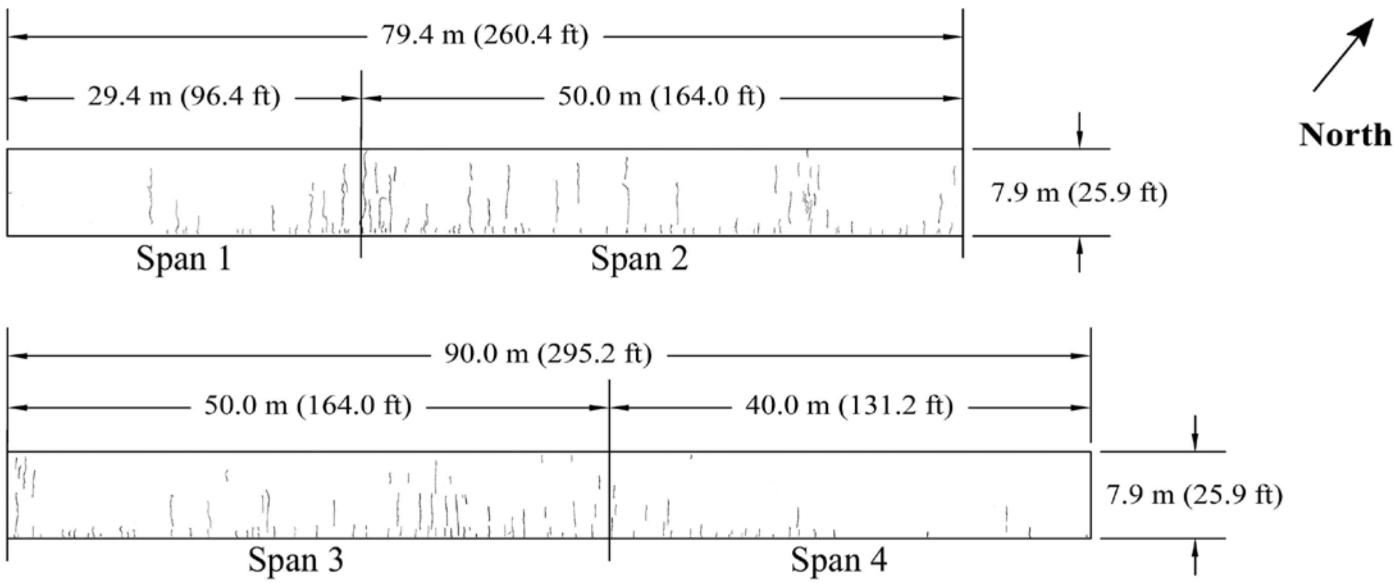


Figure 27: LC-HPC-4 and Control-4 Crack Densities

LC-HPC-5

The results of Surveys 4, 5, and 6 of LC-HPC-5, at 43.0, 54.2, and 67.0 months, are included in this report. The crack density of LC-HPC-5 at 43.0 months was 0.190 m/m^2, shown in Figure 28, represents an increase from the Survey 3 result at 31.1 months, 0.128 m/m^2 (Pendergrass et al. 2011). The crack densities from Surveys 5 and 6 show decreases from Survey 4. The crack density for LC-HPC-5 at 54.2 months was 0.158 m/m^2, as shown in Figure 29. The crack density for LC-HPC-5 at 67.0 months was 0.131 m/m^2, as shown in Figure 30. Due to the small amount of cracking in the deck, overlooking just a few cracks can make an impact in the crack density, and is likely the cause of this decrease. Most of the cracks are transverse, propagating from the south side of the deck. The south side is superelevated, which



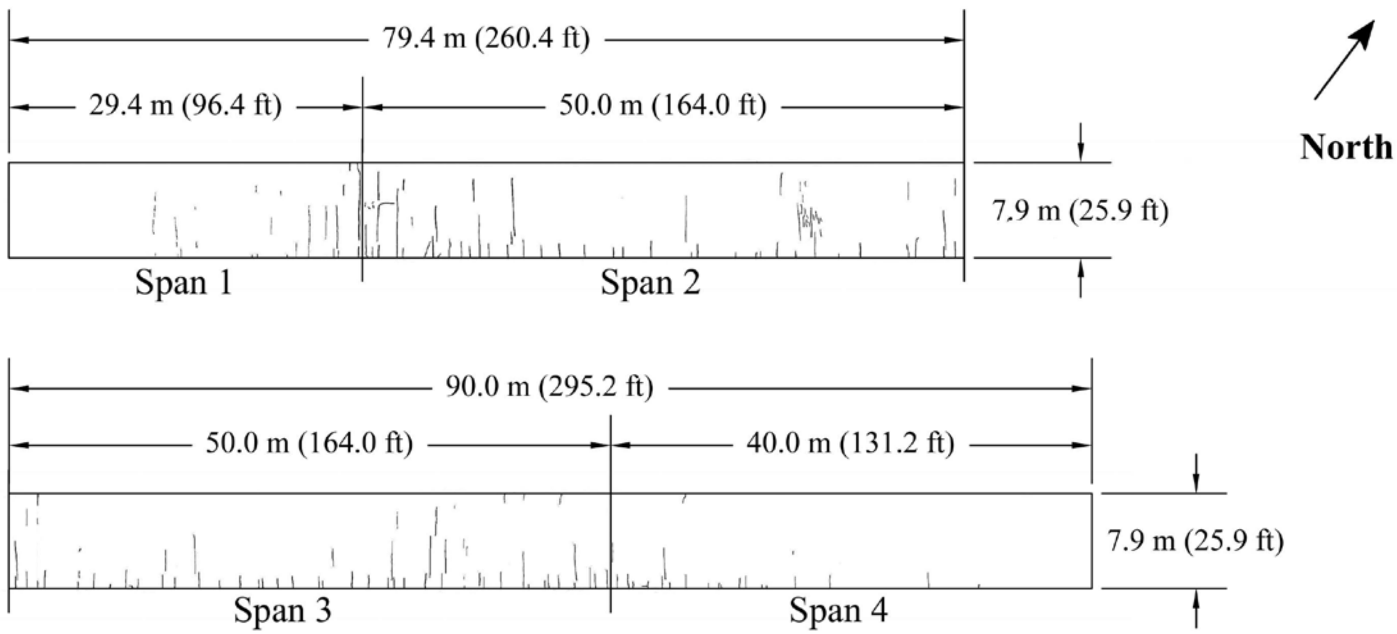
Bridge Number: 46-340 Unit 1 (LC-HPC-5)
Bridge Location: Flyover Ramp US-69 to I-435 W
Construction Date: 11/14/2007
Crack survey Date: 6/14/2011

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: 43.0 months
Crack density: 0.190 m/m^2
- **Span 1:** 0.133 m/m^2
- **Span 2:** 0.267 m/m^2
- **Span 3:** 0.241 m/m^2
- **Span 4:** 0.064 m/m^2

Figure 28: LC-HPC-5 (Survey 4)



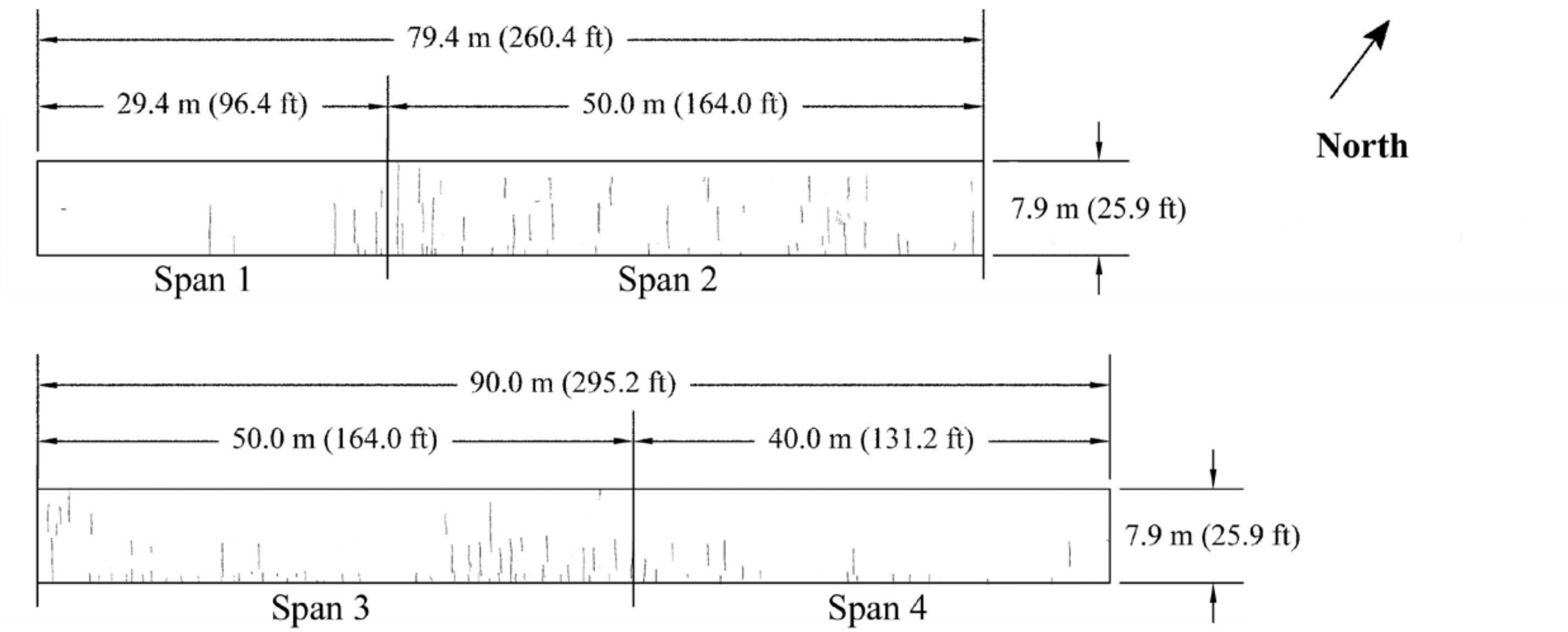
Bridge Number: 46-340 Unit 1 (LC-HPC-5)
Bridge Location: Flyover Ramp US-69 to I-435 W
Construction Date: 11/14/2007
Crack survey Date: 5/23/2012

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: 54.3 months
Crack density: 0.158 m/m^2
- **Span 1:** 0.131 m/m^2
- **Span 2:** 0.231 m/m^2
- **Span 3:** 0.175 m/m^2
- **Span 4:** 0.045 m/m^2

Figure 29: LC-HPC-5 (Survey 5)



Bridge Number: 46-340 Unit 1 (LC-HPC-5)
Bridge Location: Flyover Ramp US-69 to I-435 W
Construction Date: 11/14/2007
Crack survey Date: 6/13/2013

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

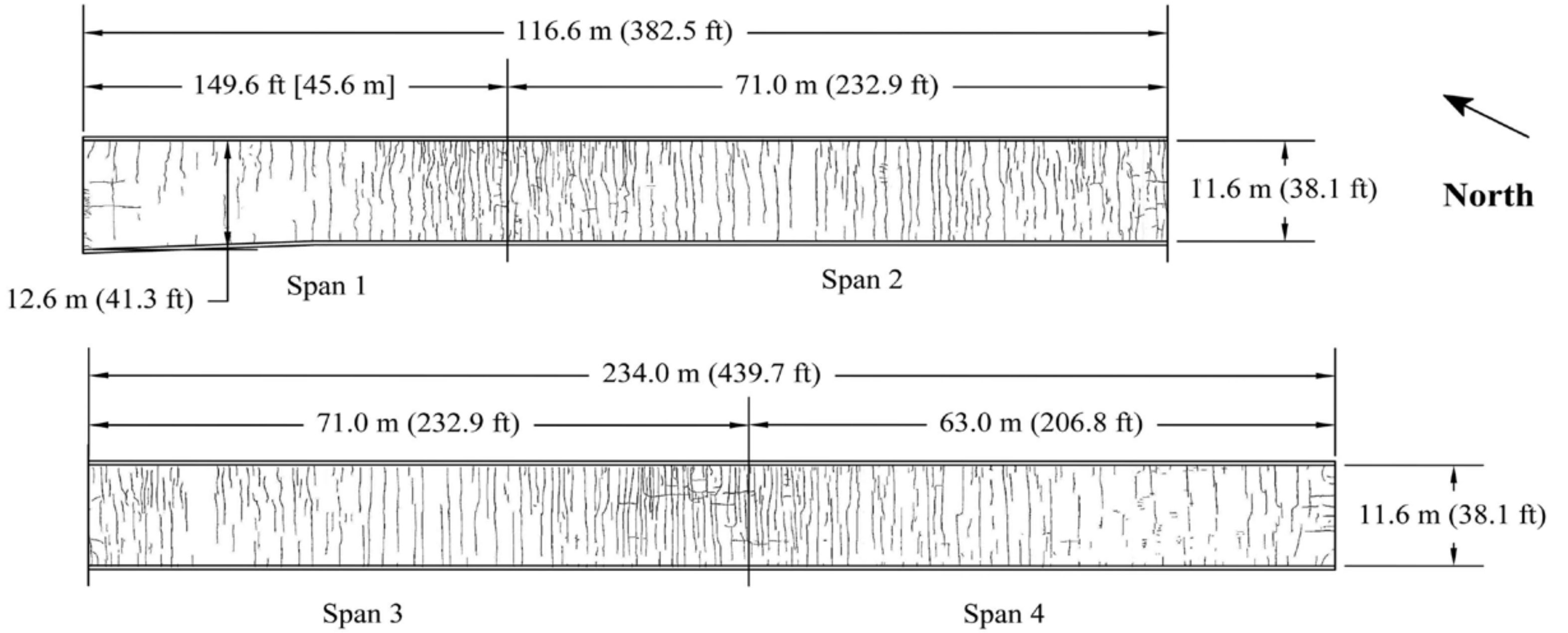
Bridge Age: 67.0 months
Crack density: 0.131 m/m^2
Span 1: 0.080 m/m^2
Span 2: 0.197 m/m^2
Span 3: 0.165 m/m^2
Span 4: 0.056 m/m^2

Figure 30: LC-HPC-5 (Survey 6)

may have caused plastic concrete to flow away from it, leaving the hardened concrete more susceptible to cracking. Furthermore, the soaker hoses were placed at the center of the deck, thus not providing curing water to the more elevated side of the deck. The effects of the superelevation can be seen in the crack maps, which show that the cracks occur only near the southern edge of the deck.

Control-5

The results of Survey 3 for Control-5 at 30.6 months are included in this report. Because of the high crack density, an overlay was applied to the bridge in 2012, after which crack surveys ceased being conducted. As shown in Figure 31, the crack density of Control-5 at 30.6 months was 0.738 m/m^2, a decrease from the crack density at 18.9 months of 0.857 m/m^2 (Pendergrass et al. 2011). Control-5 has an extremely high crack density with long transverse cracks every few feet for the length of the bridge. The crack density increases near the piers and some longitudinal cracks are present near the piers and propagate from the abutments. Figure 32 compares crack densities on Control-5 to crack densities on LC-HPC-5 over time. Even with only three survey data points for Control-5, it is clear that LC-HPC-5 has performed much better than Control-5. Overall, crack densities appear to be more than four times larger on Control-5 than on LC-HPC-5.



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: 6/15/2011

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: 1

Bridge Age: 30.6 months
Crack density: 0.738 m/m^2
Span 1: 0.601 m/m^2
Span 2: 0.874 m/m^2
Span 3: 0.862 m/m^2
Span 4: 0.657 m/m^2

Figure 31: Control-5 (Survey 3)

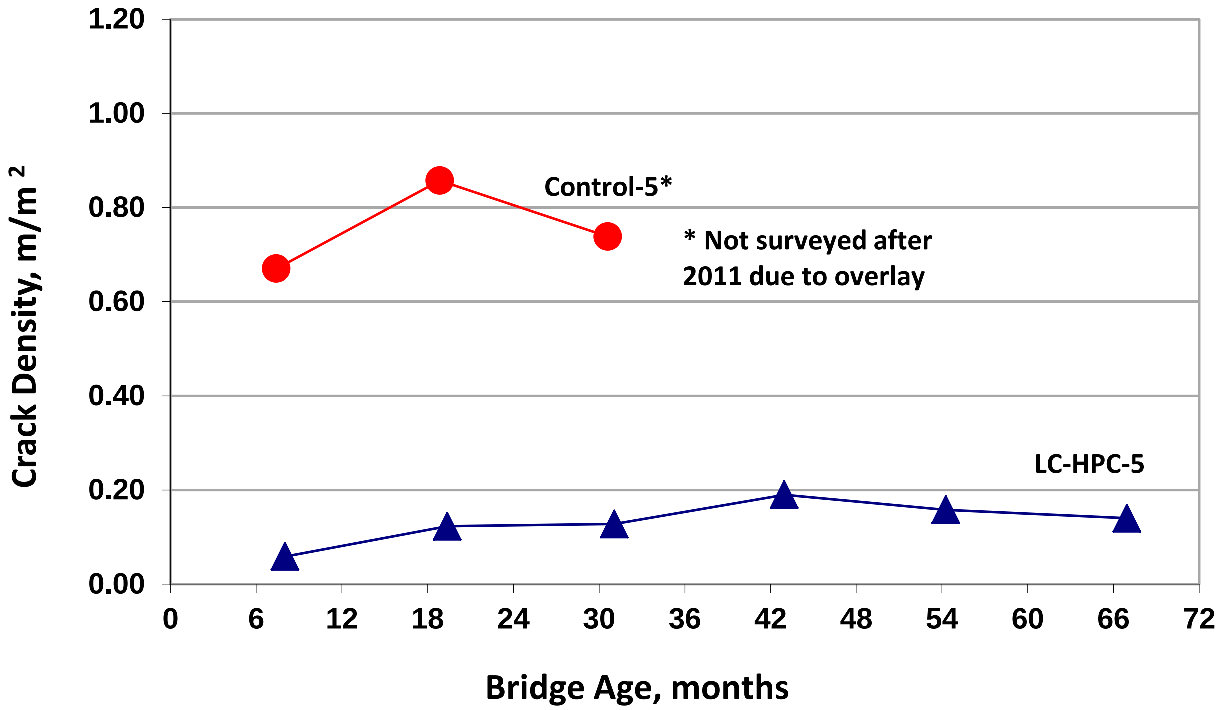


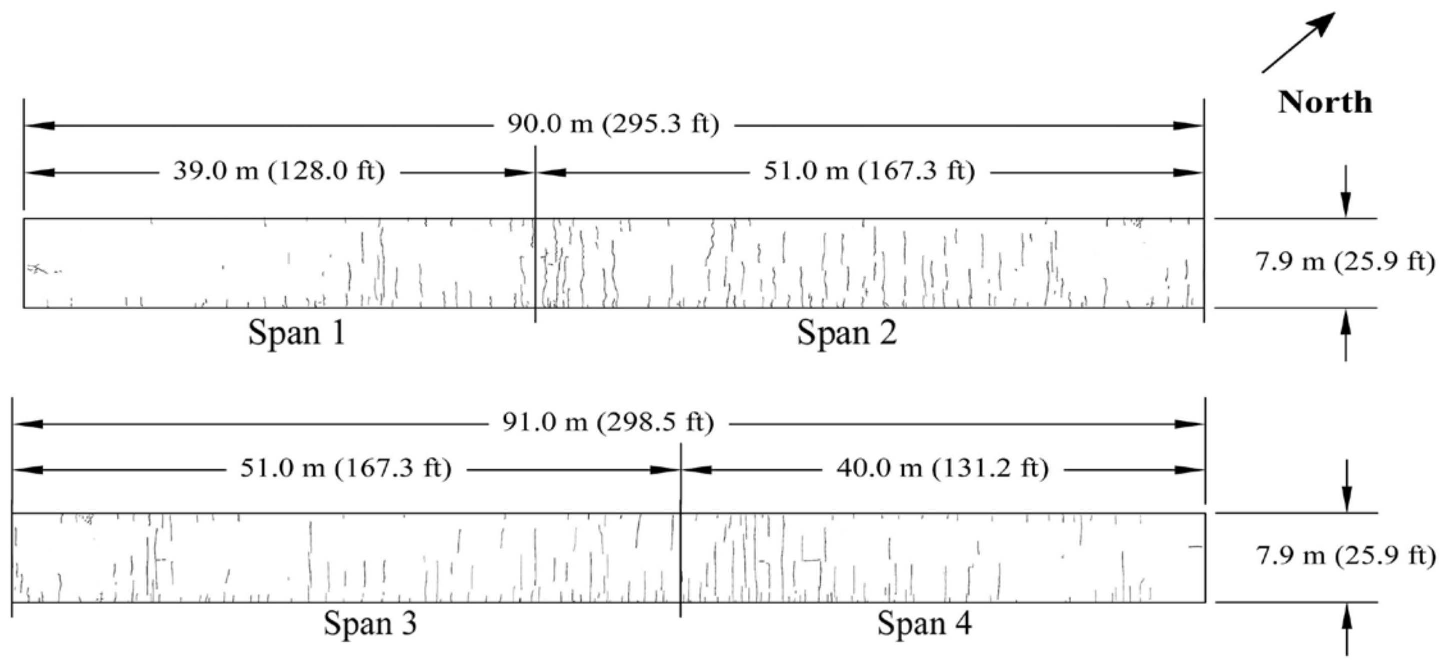
Figure 32: LC-HPC-5 and Control-5 Crack Densities

LC-HPC-6

The results of Surveys 4, 5, and 6 of LC-HPC-6, at 43.3, 54.6, and 67.3 months, are included in this report. The crack density of LC-HPC-6 at 43.3 months was 0.336 m/m^2, as shown in Figure 33. This is an increase from the crack density at 31.4 months of 0.231 m/m^2 (Pendergrass et al. 2011). The crack density at 54.6 months was 0.362 m/m^2, as shown in Figure 34. The crack density at 67.3 months was 0.303 m/m^2, as shown in Figure 35. Like LC-HPC-5, the cracking is mainly transverse, propagating from the superelevated southern edge. Similar to LC-HPC-5, the superelevation caused concrete and water to flow away from the southern edge of the deck. Most of the cracks are above the piers and spread throughout the second span.

Control-6

The results of Surveys 3, 4, and 5, at 31.8, 43.0, and 56.0 months, are included in this report and shown in Figures 36, 37, and 38. The crack densities in Surveys 3 and 4, 0.456 m/m^2

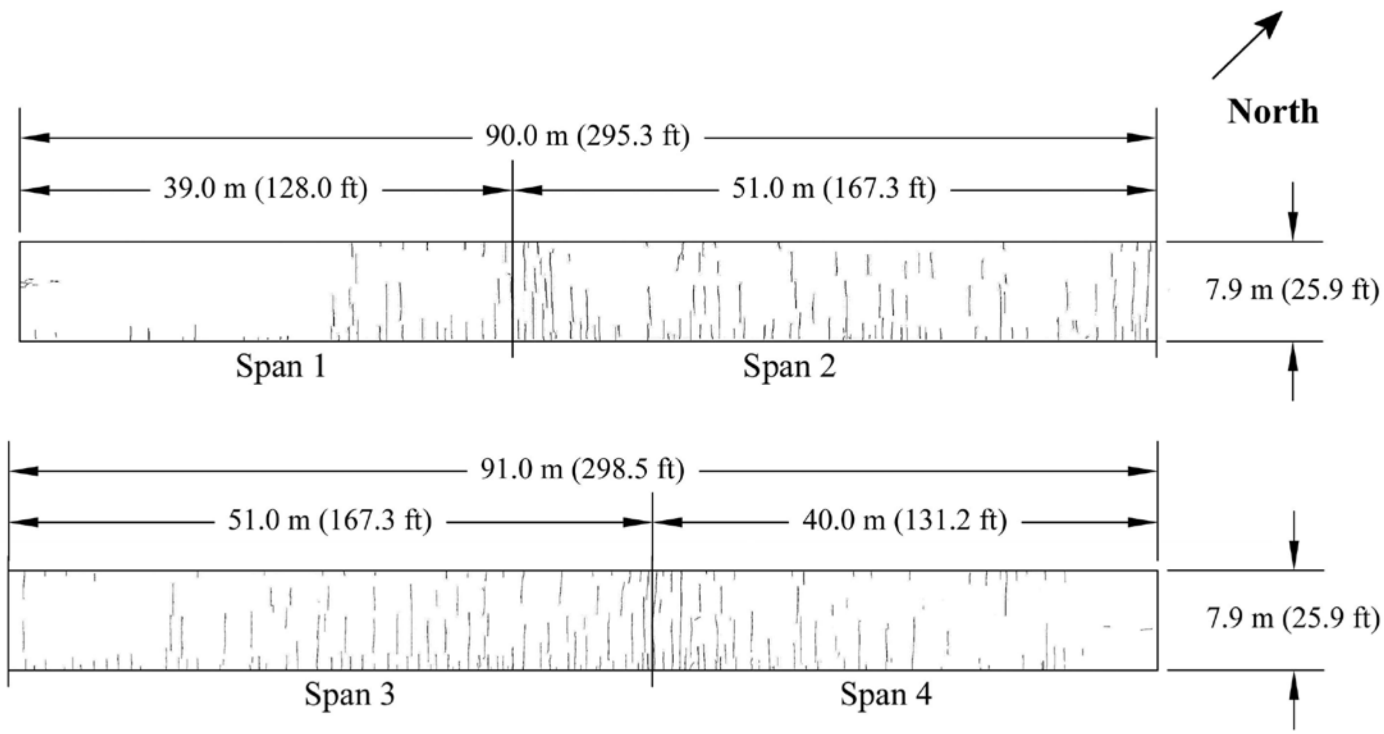


Bridge Number: 46-340 Unit 2 (LC-HPC-6)
Bridge Location: SB US-69 to WB I-435
Construction Date: 11/3/2007
Crack survey Date: 6/14/2011

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: 43.3 months
Crack density: 0.336 m/m^2
Span 1: 0.194 m/m^2
Span 2: 0.451 m/m^2
Span 3: 0.334 m/m^2
Span 4: 0.328 m/m^2

Figure 33: LC-HPC-6 (Survey 4)

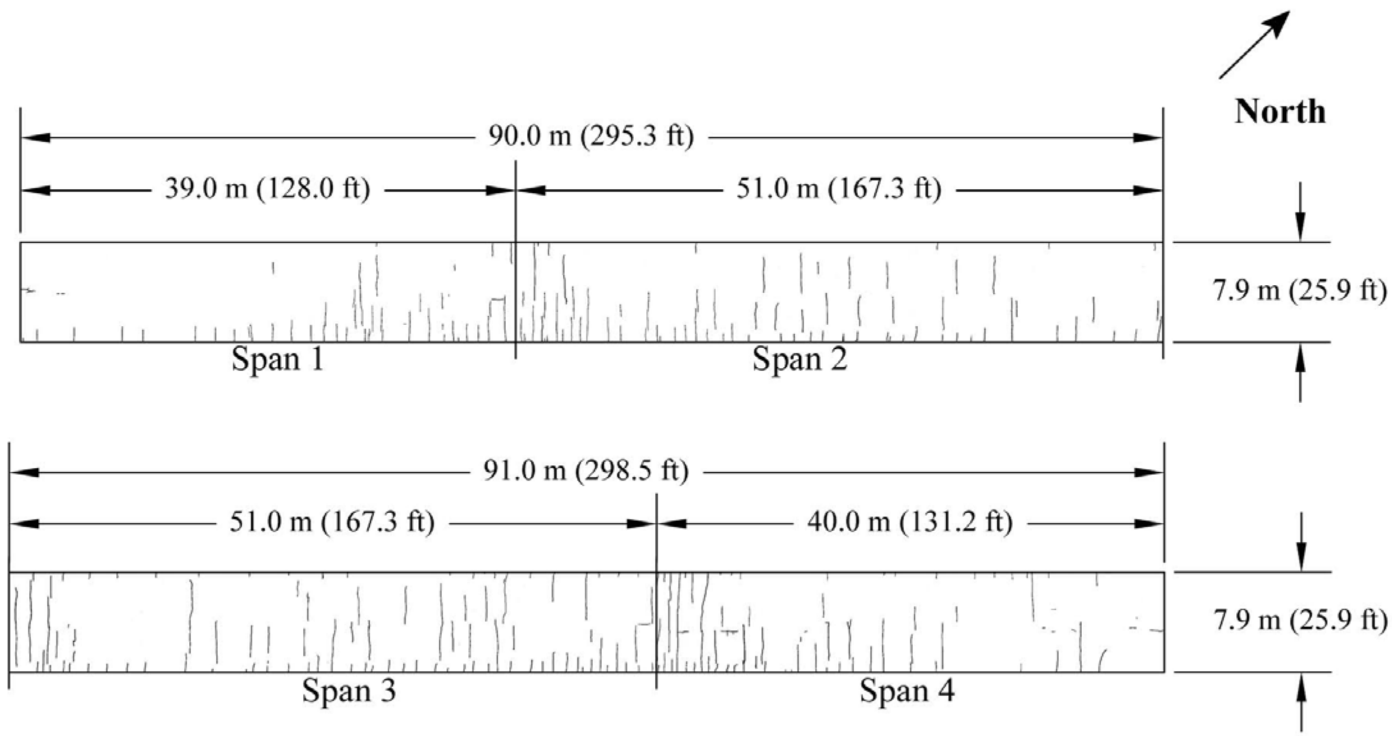


Bridge Number: 46-340 Unit 2 (LC-HPC-6)
Bridge Location: SB US-69 to WB I-435
Construction Date: 11/3/2007
Crack survey Date: 5/23/2012

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: 54.6 months
Crack density: 0.362 m/m^2
Span 1: 0.168 m/m^2
Span 2: 0.451 m/m^2
Span 3: 0.418 m/m^2
Span 4: 0.365 m/m^2

Figure 34: LC-HPC-6 (Survey 5)

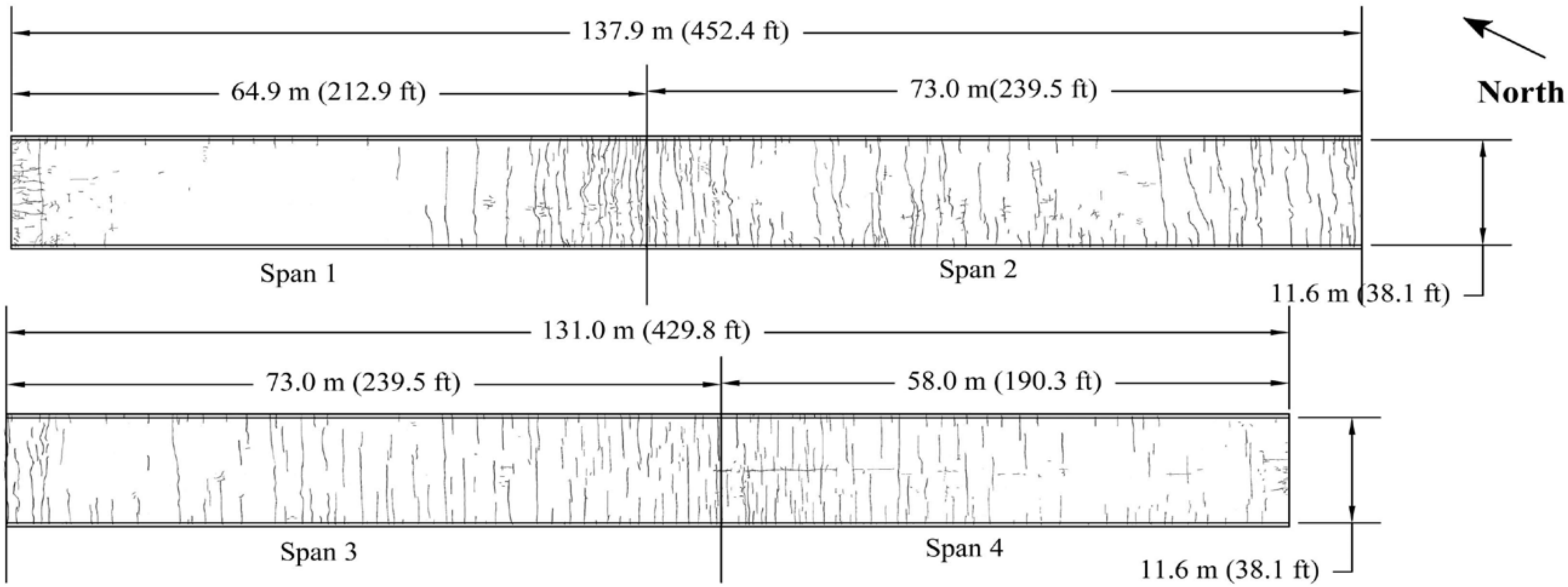


Bridge Number: 46-340 Unit 2 (LC-HPC-6)
Bridge Location: SB US-69 to WB I-435
Construction Date: 11/3/2007
Crack survey Date: 6/13/2013

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: 67.3 months
Crack density: 0.303 m/m^2
Span 1: 0.211 m/m^2
Span 2: 0.290 m/m^2
Span 3: 0.345 m/m^2
Span 4: 0.319 m/m^2

Figure 35: LC-HPC-6 (Survey 6)

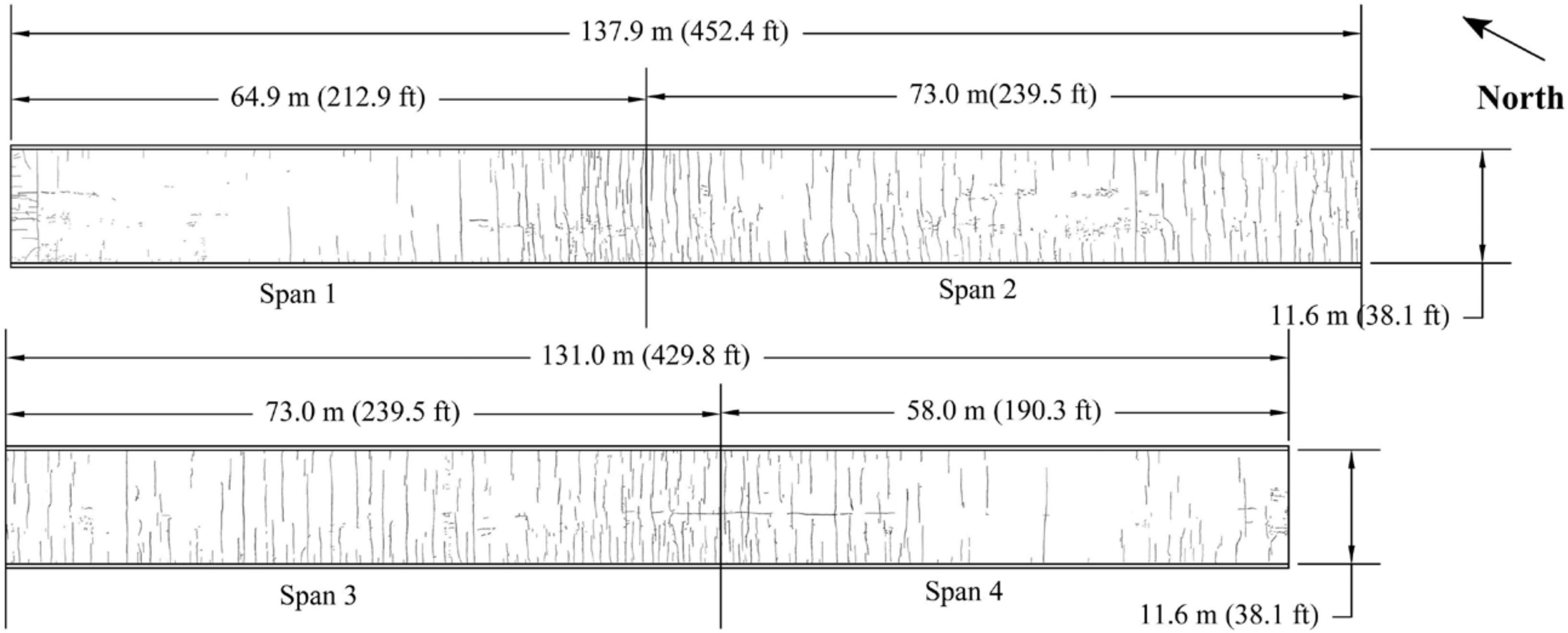


Bridge Number: 46-341 Unit 4 (Control-6)
Bridge Location: Flyover Ramp S-69 to I-435 E, Kansas City, KS
Construction Date: 10/20/2008
Crack survey Date: 6/14/2011

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: 31.8 months
Crack density: 0.456 m/m^2
Span 1: 0.368 m/m^2
Span 2: 0.538 m/m^2
Span 3: 0.462 m/m^2
Span 4: 0.444 m/m^2

Figure 36: Control-6 (Survey 3)

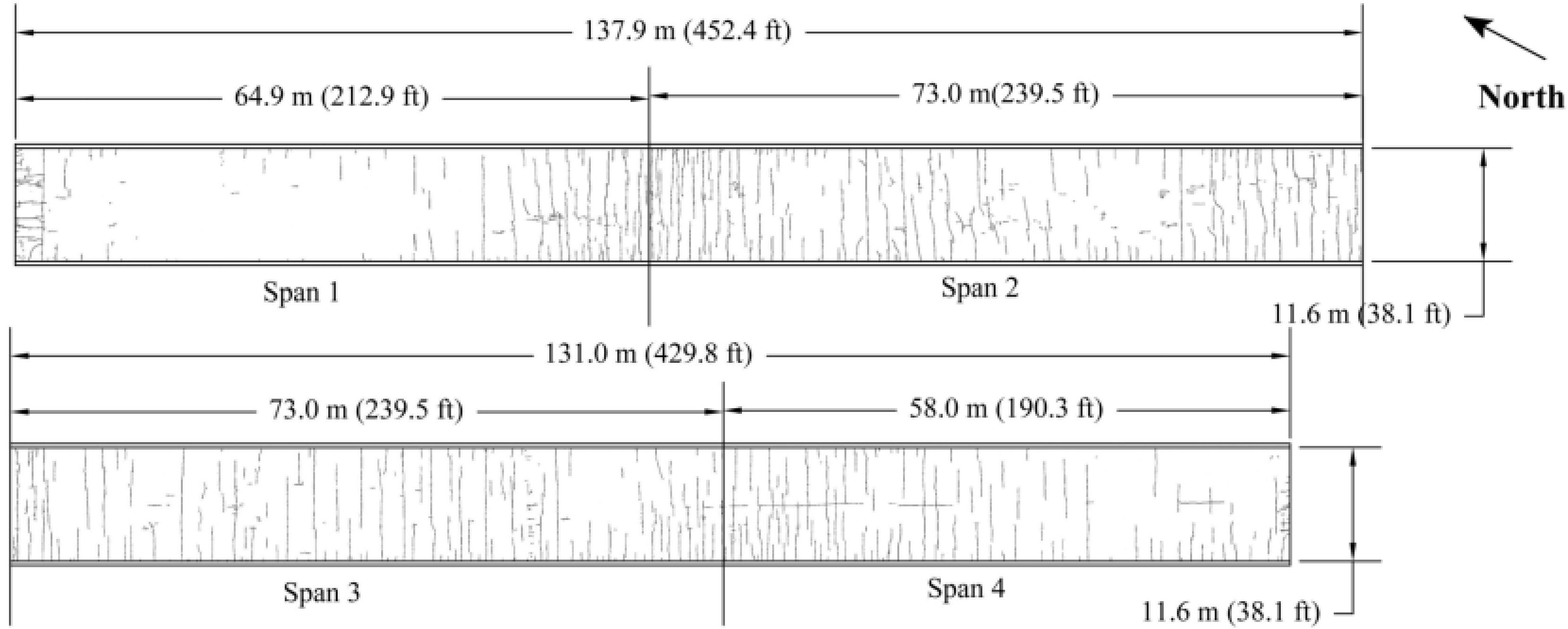


Bridge Number: 46-341 Unit 4 (Control-6)
Bridge Location: Flyover Ramp S-69 to I-435 E, Overland Park, KS
Construction Date: 10/20/2008
Crack survey Date: 5/30/2012

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: 43.0 months
Crack density: 0.539 m/m^2
  Span 1: 0.433 m/m^2
  Span 2: 0.643 m/m^2
  Span 3: 0.605 m/m^2
  Span 4: 0.400 m/m^2

Figure 37: Control-6 (Survey 4)



Bridge Number: 46-341 Unit 4 (Control-6)
Bridge Location: Flyover Ramp S-69 to I-435 E, Overland Park, KS
Construction Date: 10/20/2008
Crack survey Date: 6/19/2013

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: 56.0 months
Crack density: 0.460 m/m^2
- **Span 1:** 0.305 m/m^2
- **Span 2:** 0.571 m/m^2
- **Span 3:** 0.492 m/m^2
- **Span 4:** 0.453 m/m^2

Figure 38: Control-6 (Survey 5)

and 0.539 m/m^2, respectively, are over 60% higher than the crack density at 20.0 months of 0.282 m/m^2 (Pendergrass et al. 2011). These densities are also larger than crack densities of LC-HPC-6 at 31.4 and 43.3 months. Survey 5, as shown in Figure 38, indicated a decrease in crack density to 0.460 m/m^2. This density, however, is still greater than the overall crack density of LC-HPC-6 at 54.6 months, 0.362 m/m^2. Most cracks on Control-6 are transverse, many of which are concentrated near the piers. A portion of span 4 has a single longitudinal crack through the center of the deck, and there are small longitudinal cracks propagating from both abutments. Figure 39 compares cracking on Control 6 to cracking on LC-HPC-6 over time. It can be seen that Control 6 consistently has more than LC-HPC-6. Both Control 6 and LC-HPC-6 experienced a similar rate of increase in crack density at early ages.

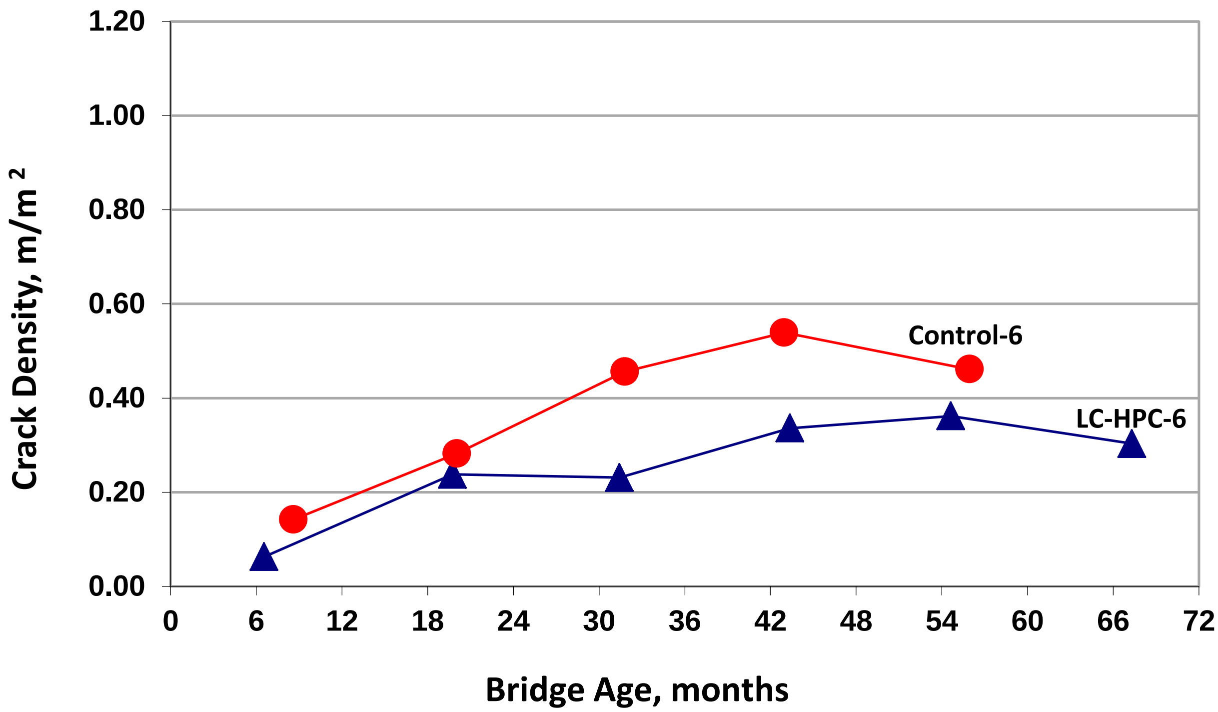


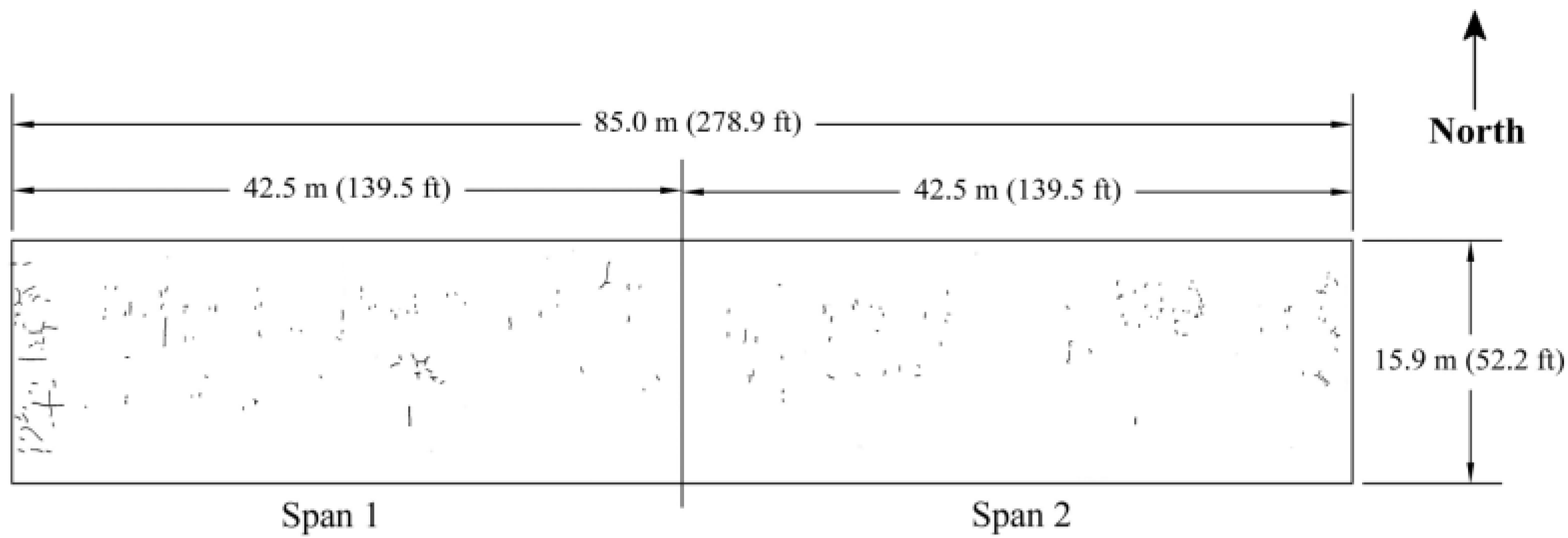
Figure 39: LC-HPC-6 and Control-6 Surveyed Crack Densities

LC-HPC-7

The results of Surveys 5, 6, and 7 of LC-HPC-7, at 58.9, 71.3, and 83.4 months, are included in this report. The crack density of LC-HPC-7 at 58.9 months is 0.048 m/m^2, as shown in Figure 40. This represents an increase from Survey 4 at 46.8 months, when the deck had a crack density of just 0.005 m/m^2 (Pendergrass et al. 2011). The crack density of LC-HPC-7 at 71.3 months was 0.065 m/m^2, as shown in Figure 41. The crack density of LC-HPC-7 at 83.4 months was 0.072 m/m^2, as shown in Figure 42. LC-HPC-7 has some of the lowest crack densities of all of the bridges in the project. There are some small-to-medium length longitudinal cracks near and propagating from the west abutment and the remainder of the cracks are very short and distributed along the entire length of the bridge.

Control-7

Control-7 was constructed in two placements, six months apart. The results of Survey 5 at 62.3 and 56.7 months and Survey 6 at 74.5 and 68.9 months are included in this report. The crack density of Placement 1 measured in Survey 5 was 0.957 m/m^2 (see Figure 43), while Placement 2 had a crack density of 0.663 m/m^2, nearly double the crack density of Placement 2 from Survey 4. The overall crack density was 0.856 m/m^2. Although the crack density of Placement 1 decreased from Survey 4, there was an overall increase in cracking from Survey 4, for which the crack densities were 1.037 m/m^2, 0.359 m/m^2, and 0.819 m/m^2 for Placement 1, Placement 2, and overall, respectively (Pendergrass et al. 2011). The crack densities measured during Survey 6 were 1.022 m/m^2 at 74.5 months for Placement 1 and 0.638 m/m^2 at 68.9 months for Placement 2 (see Figure 44). The overall crack density resulting from Survey 6 was 0.899 m/m^2. These values are slightly smaller than the corresponding crack densities from Survey 5. All of the surveys have shown much higher cracking for Control-7 than for LC-HPC-7.

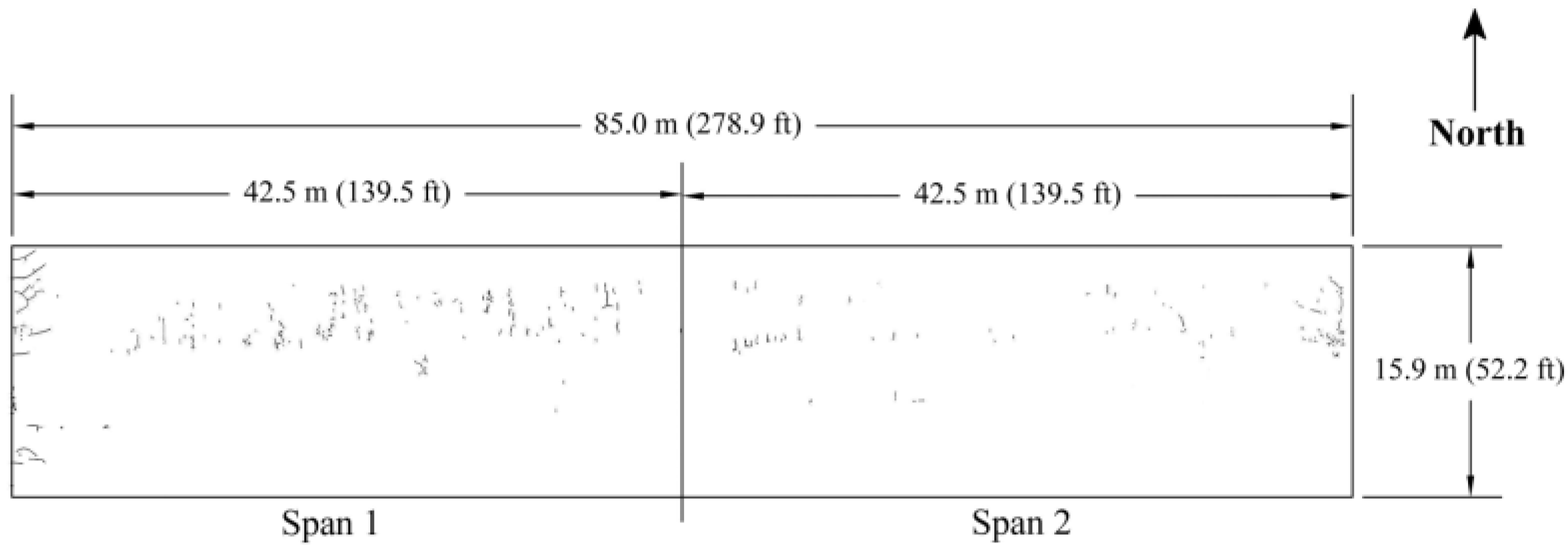


Bridge Number: 43-33 (LC-HPC-7)
Bridge Location: Co. Rd. 150 over US-75
Construction Date: 6/24/2006
Crack survey Date: 5/23/2011

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: 58.9 months
Crack density: 0.048 m/m^2
Span 1: 0.062 m/m^2
Span 2: 0.033 m/m^2

Figure 40: LC-HPC-7 (Survey 5)

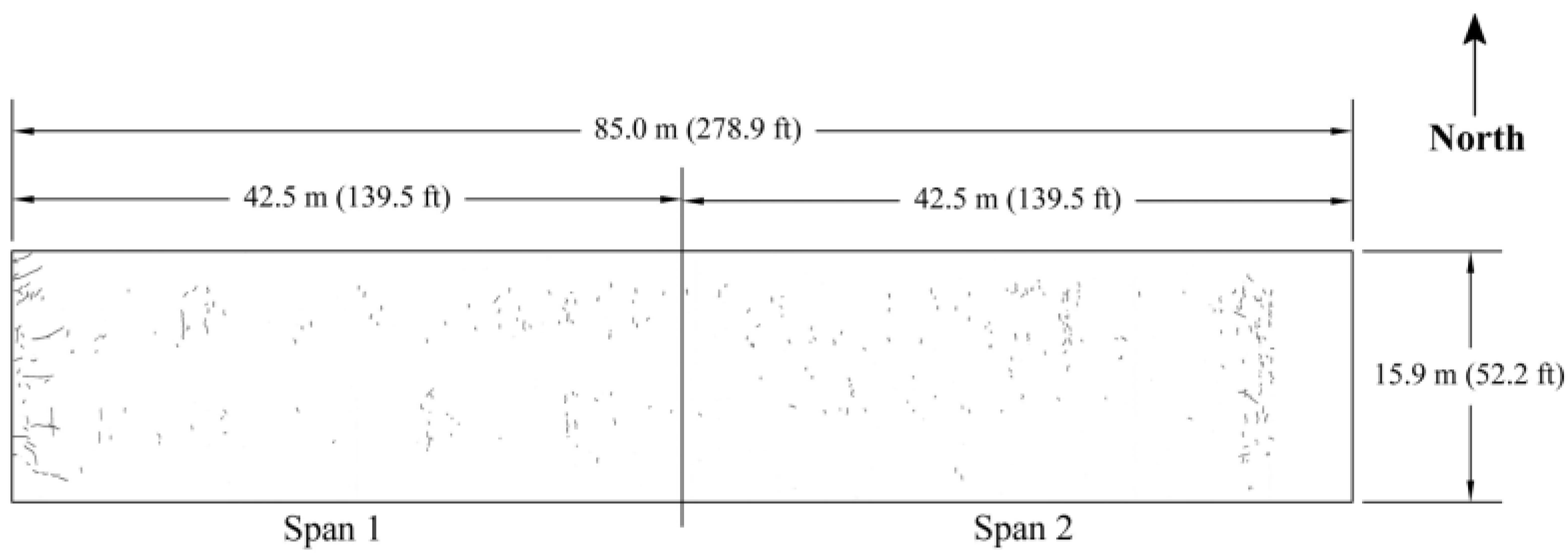


Bridge Number: 43-33 (LC-HPC-7)
Bridge Location: Co. Rd. 150 over US-75
Construction Date: 6/24/2006
Crack survey Date: 6/1/2012

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: 71.3 months
Crack density: 0.065 m/m^2
Span 1: 0.088 m/m^2
Span 2: 0.036 m/m^2

Figure 41: LC-HPC-7 (Survey 6)

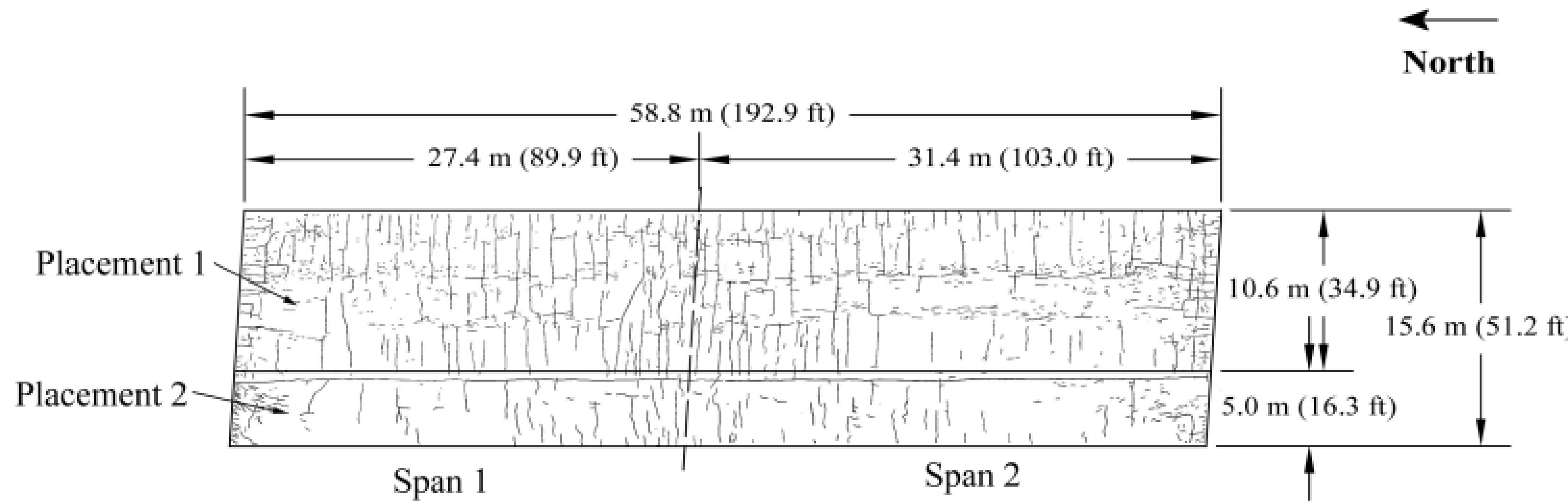


Bridge Number: 43-33 (LC-HPC-7)
Bridge Location: Co. Rd. 150 over US-75
Construction Date: 6/24/2006
Crack survey Date: 6/7/2013

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: 83.4 months
Crack density: 0.072 m/m^2
Span 1: 0.080 m/m^2
Span 2: 0.064 m/m^2

Figure 42: LC-HPC-7 (Survey 7)

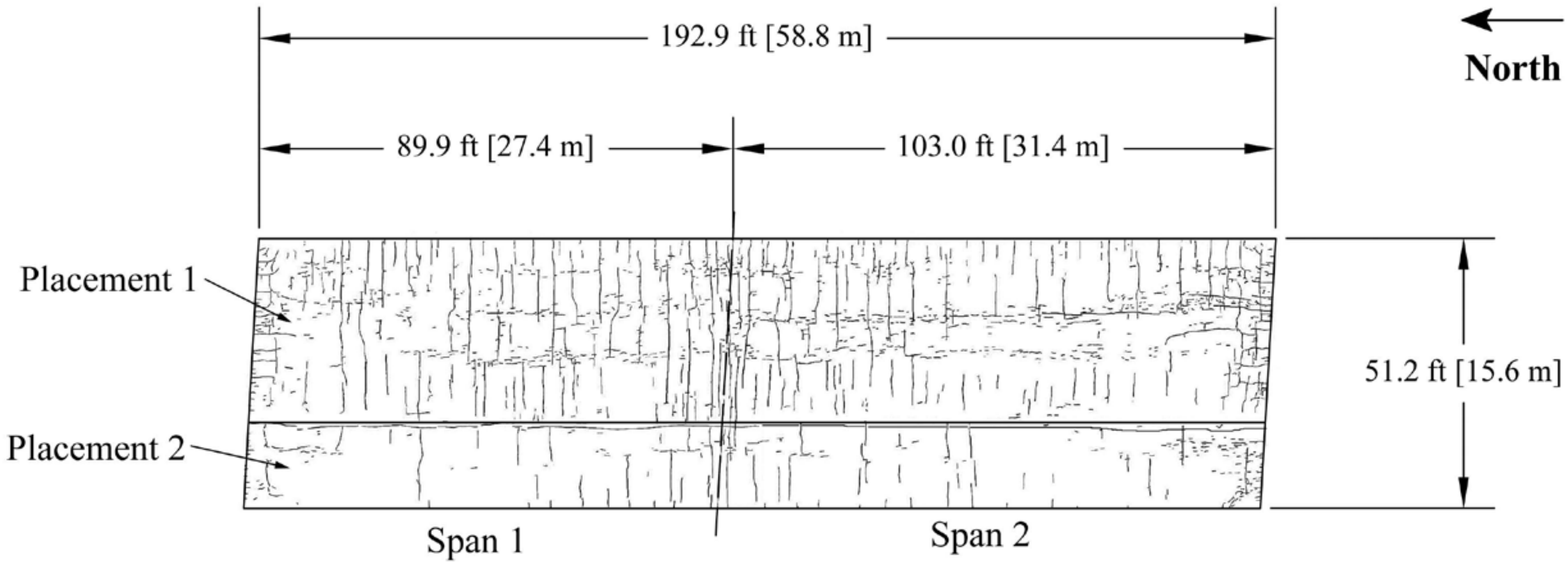


Bridge Number: 46-334 (Control-7)
Bridge Location: NB Antioch over I-435
Construction Date:
Placement 1 (East): 3/29/2006
Placement 2 (West): 9/15/2006
Crack survey Date: 6/7/2011

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: 62.3 months
Placement 2: 56.7 months
Crack density: 0.856 m/m^2
Span 1: 0.897 m/m^2
Span 2: 0.824 m/m^2
Placement 1: 0.957 m/m^2
Placement 2: 0.663 m/m^2

Figure 43: Control-7 (Survey 5)



Bridge Number: 46-334 (Control-7)
Bridge Location: NB Antioch over I-435
Construction Date:
Placement 1 (East): 3/29/2006
Placement 2 (West): 9/15/2006
Crack survey Date: 6/12/2012

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: 74.5 months
Placement 2: 68.9 months
Crack density: 0.899 m/m^2
Span 1: 0.904 m/m^2
Span 2: 0.895 m/m^2
Placement 1: 1.022 m/m^2
Placement 2: 0.638 m/m^2

Figure 44: Control-7 (Survey 6)

Placement 1 has transverse cracks throughout, but the cracks are more concentrated near the pier. There are also longitudinal cracks propagating from both abutments and small longitudinal cracks running the length of the deck. Placement 2 has a continuous longitudinal crack parallel and adjacent to the joint, as well as some transverse cracking and small longitudinal cracks propagating from both abutments. Figure 45 compares cracking on Control 7 to cracking on LC-HPC-7 over time. Throughout both bridge lives, LC-HPC-7 has had significantly less cracking than either placement of Control 7. While Control 7 experienced sharp increases in cracking between 12 months and 60 months of age, cracking on LC-HPC-7 has been relatively stable, experiencing relatively small increases after 48 months.

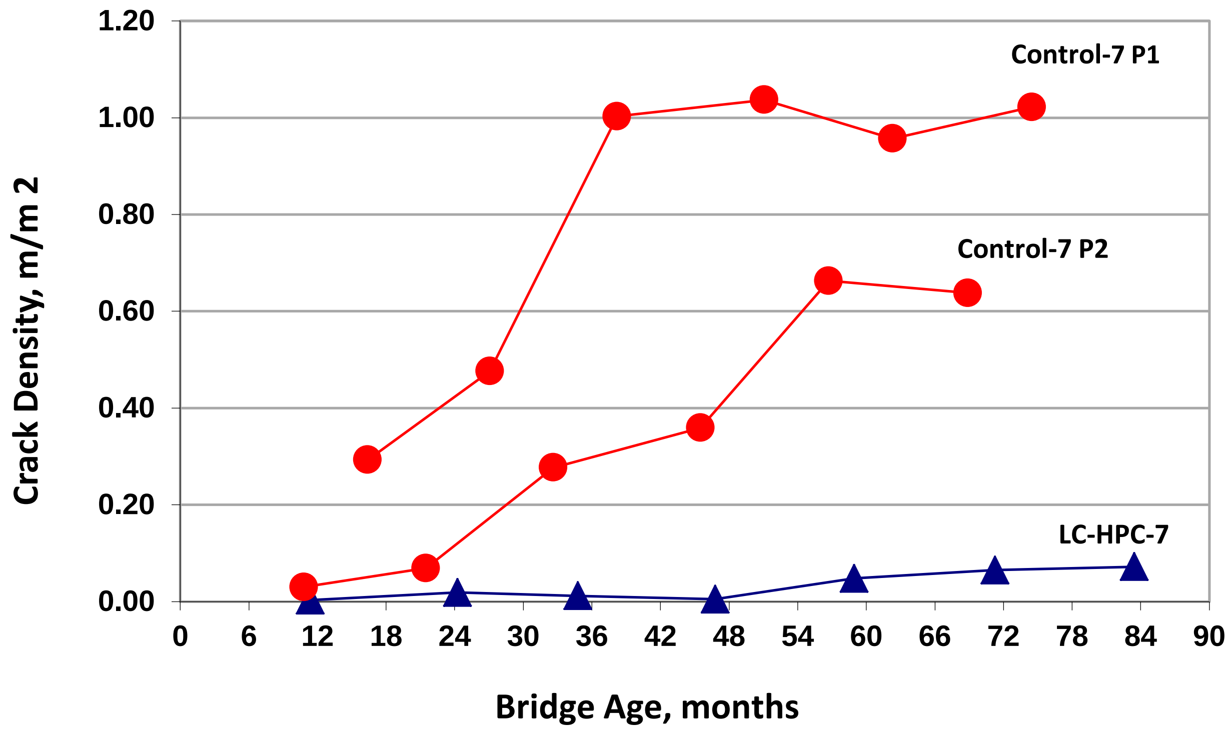


Figure 45: LC-HPC-7 and Control-7 Crack Densities

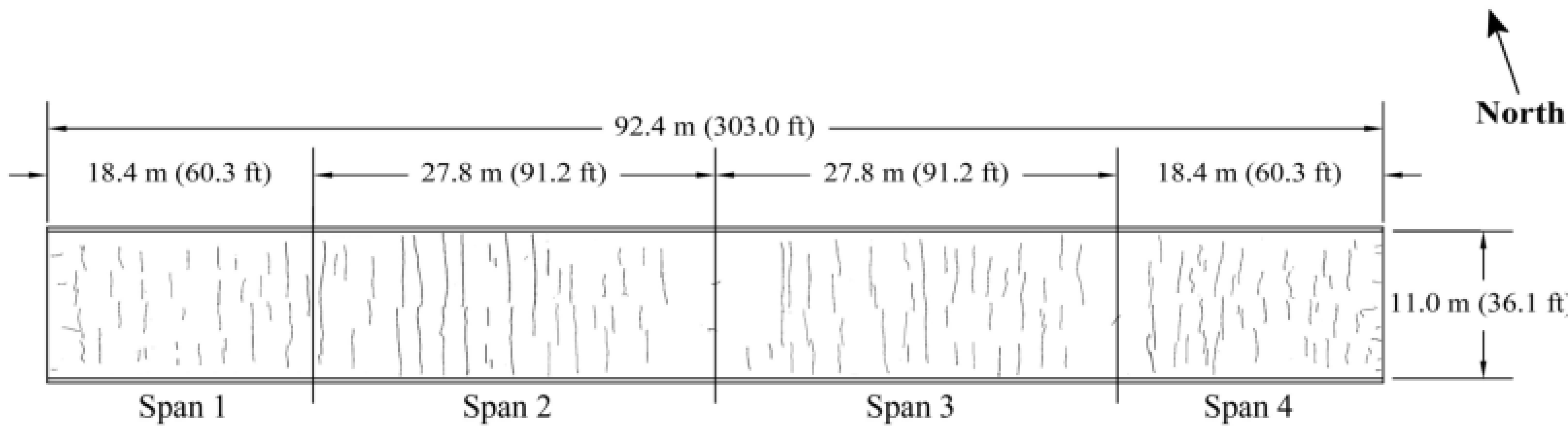
LC-HPC-8

The results of Surveys 3, 4, and 5 of LC-HPC-8 at 45.0, 55.4, and 67.7 months, respectively, are included in this report. LC-HPC-8 is one of two LC-HPC bridges in this study with precast, prestressed concrete girders. The crack density of LC-HPC-8 at 45.0 months was 0.380 m/m^2, shown in Figure 46, represents an increase from Survey 2 at 31.8 months, when the crack density was 0.348 m/m^2 (Pendergrass et al. 2011). Cracking has been stable since, with values of 0.383 m/m^2 at 55.4 months (Figure 47) and 0.373 m^2 at 67.7 months (Figure 48). Most of the cracks are long transverse cracks, evenly spaced along the deck. There is less cracking near the center pier, which could be a result of camber and increased girder shrinkage. There is also a small amount of longitudinal cracking at each abutment.

Control-8/10

Like LC-HPC-8 and LC-HPC-10, Control-8/10 is a monolithic deck cast on precast, prestressed girders. The results of Surveys 4, 5 and 6 at 50.6, 61.6, and 75.5 months, respectively, are included in this report. The crack density of Control-8/10 at 50.6 months was 0.326 m/m^2, as shown in Figure 49. This crack density is more than double the value from Survey 3 at 37.2 months, 0.137 m/m^2 (Pendergrass et al. 2011). The crack density has continued to increase with values of 0.425 m/m^2 and 0.581 m/m^2, respectively, measured during Surveys 5 and 6. The crack maps from Surveys 5 and 6 are shown in Figures 50 and 51. The cracking on Control-8/10 consists of a small number of medium-length transverse cracks, as well as a large number of smaller cracks. Map cracking is prevalent on Control-8/10, particularly near the west abutment, where map cracking has increased drastically over the past three surveys. Control 8/10 had less cracking at 50.6 months than LC-HPC-8 at 45.0 months, but has had more cracking in the two most recent surveys. Figure 52 compares cracking on Control 8/10 to cracking on LC-

HPC-8

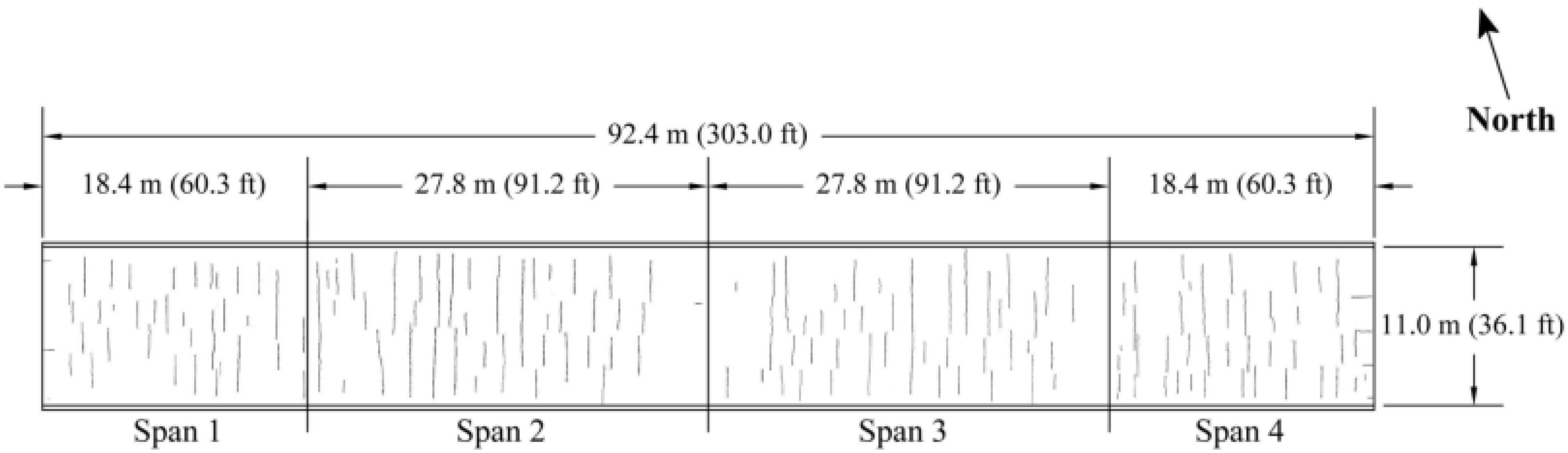


Bridge Number: 54-53 (LC-HPC-8)
Bridge Location: E 1350 Rd over US-69
Construction Date: 10/3/2007
Crack survey Date: 7/5/2011

Bridge Length: 92.4 m (303.0 ft)
Bridge Width: 11.0 m (36.1 ft)
Skew: 0^{o}
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: 45.0 months
Crack density: 0.380 m/m^2
Span 1 (West): 0.310 m/m^2
Span 2 (West): 0.408 m/m^2
Span 3 (East): 0.369 m/m^2
Span 4 (East): 0.412 m/m^2

Figure 46: LC-HPC-8 (Survey 3)

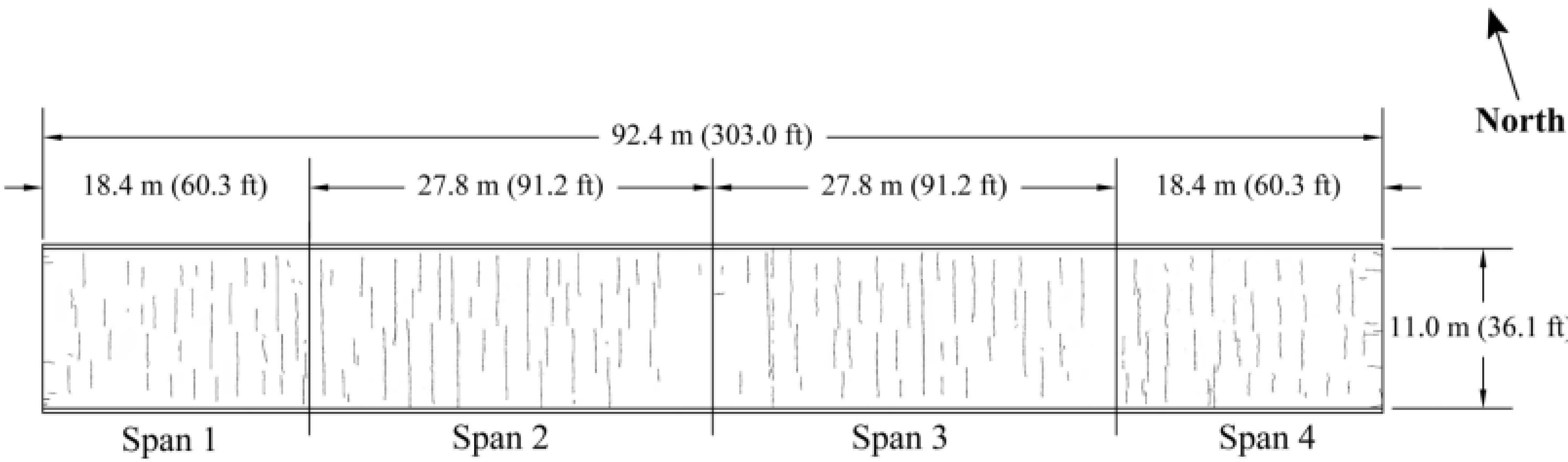


Bridge Number: 54-53 (LC-HPC-8)
Bridge Location: E 1350 Rd over US-69
Construction Date: 10/3/2007
Crack survey Date: 5/15/2012

Bridge Length: 92.4 m (303.0 ft)
Bridge Width: 11.0 m (36.1 ft)
Skew: 0^o
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: 55.4 months
Crack density: 0.383 m/m^2
Span 1 (West): 0.341 m/m^2
Span 2 (West): 0.400 m/m^2
Span 3 (East): 0.357 m/m^2
Span 4 (East): 0.425 m/m^2

Figure 47: LC-HPC-8 (Survey 4)

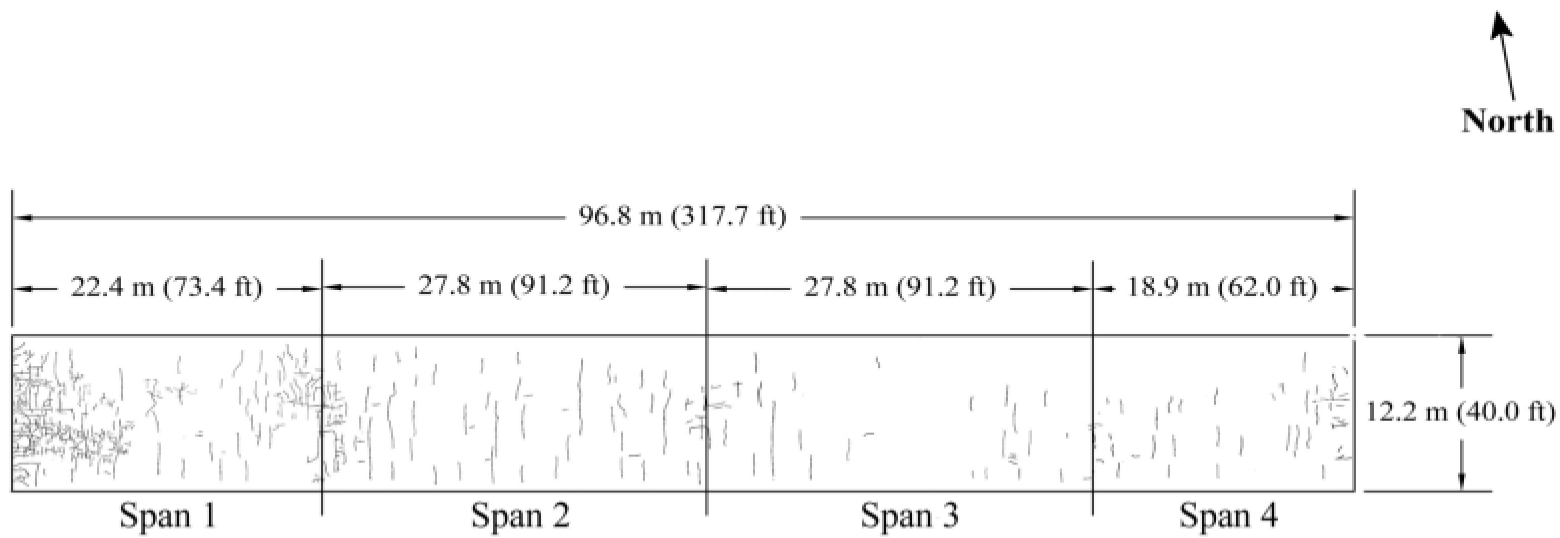


Bridge Number: 54-53 (LC-HPC-8)
Bridge Location: E 1350 Rd over US-69
Construction Date: 10/3/2007
Crack survey Date: 5/22/2013

Bridge Length: 92.4 m (303.0 ft)
Bridge Width: 11.0 m (36.1 ft)
Skew: 0^o
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: 67.7 months
Crack density: 0.373 m/m^2
Span 1 (West): 0.351 m/m^2
Span 2 (West): 0.406 m/m^2
Span 3 (East): 0.350 m/m^2
Span 4 (East): 0.357 m/m^2

Figure 48: LC-HPC-8 (Survey 5)



Bridge Number: 54-59 (Control-8/10)

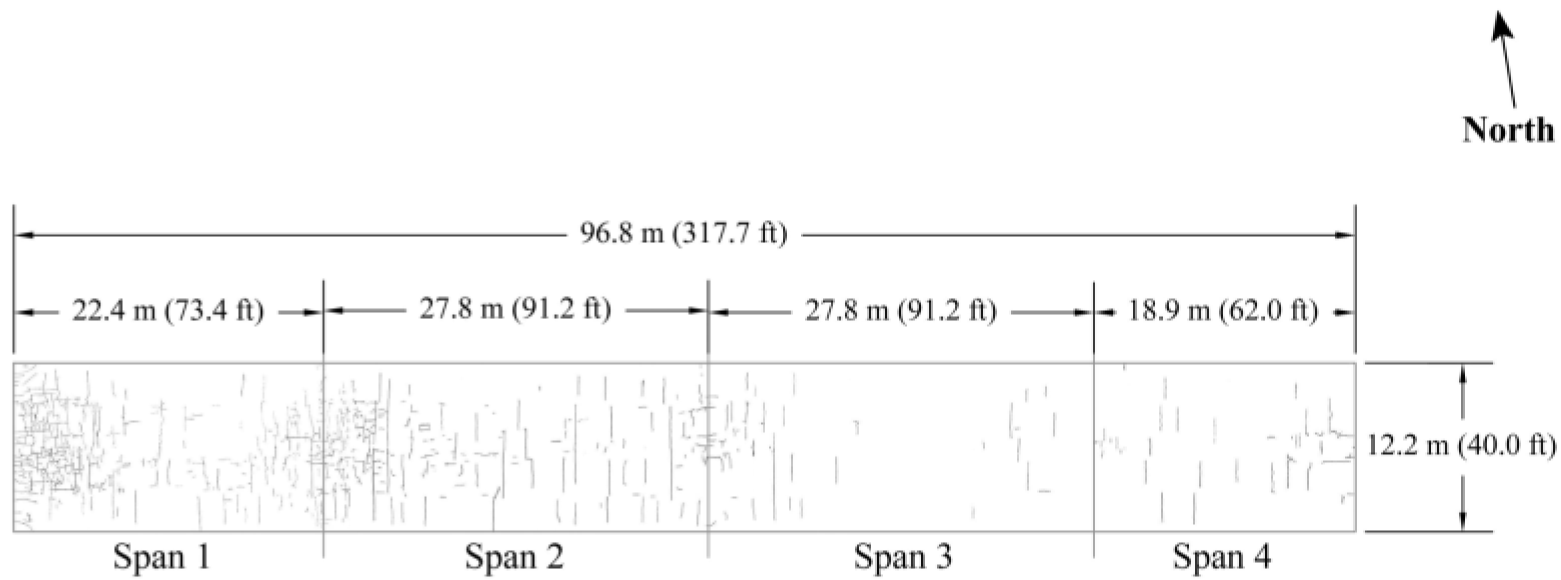
Bridge Location: K-52 over US-69
Construction Date: 4/16/2007
Crack survey Date: 7/5/2011

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: 50.6 months
Crack density: 0.326 m/m²
- **Span 1:** 0.655 m/m²
- **Span 2:** 0.334 m/m²
- **Span 3:** 0.135 m/m²
- **Span 4:** 0.212 m/m²

Figure 49: Control-8/10 (Survey 4)



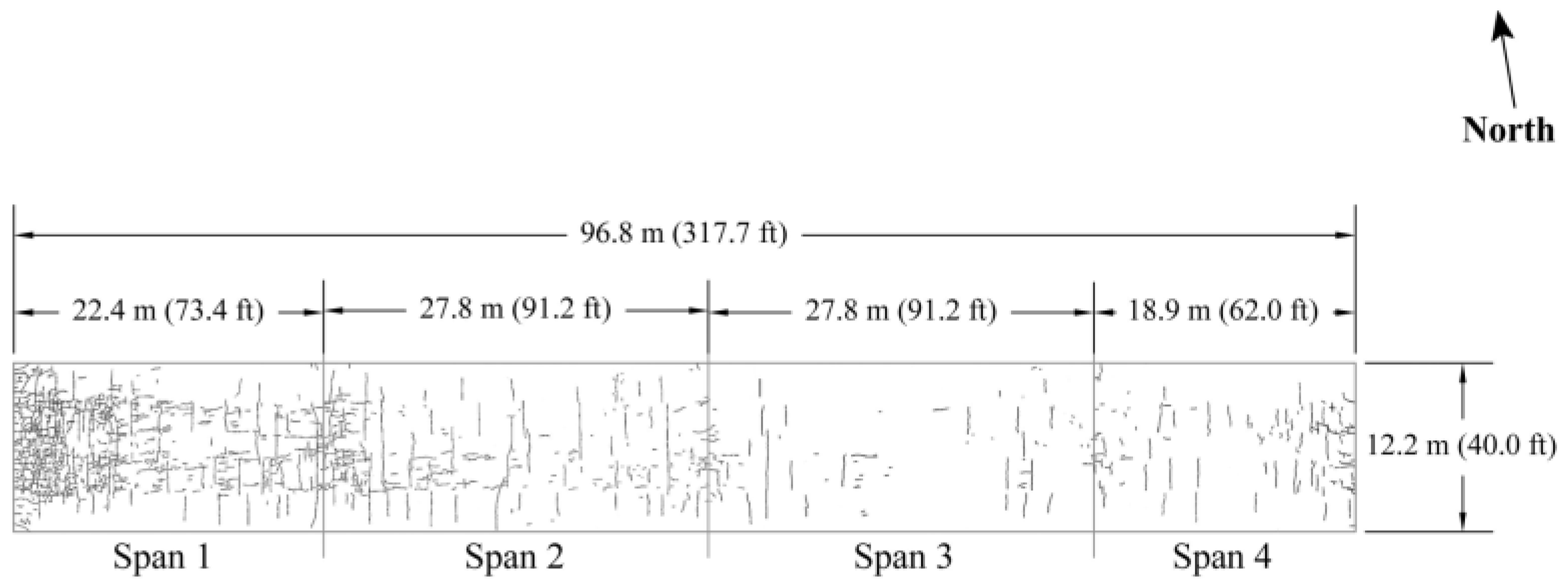
Bridge Number: 54-59 (Control-8/10)

Bridge Location: K-52 over US-69
Construction Date: 4/16/2007
Crack survey Date: 6/4/2012

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: 61.6 months
Crack density: 0.425 m/m^2
Span 1: 0.825 m/m^2
Span 2: 0.522 m/m^2
Span 3: 0.149 m/m^2
Span 4: 0.193 m/m^2

Figure 50: Control-8/10 (Survey 5)



Bridge Number: 54-59 (Control-8/10)

Bridge Location: K-52 over US-69
Construction Date: 4/16/2007
Crack survey Date: 8/1/2013

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: 75.5 months
Crack density: 0.581 m/m^2
Span 1: 1.282 m/m^2
Span 2: 0.568 m/m^2
Span 3: 0.183 m/m^2
Span 4: 0.350 m/m^2

Figure 51: Control-8/10 (Survey 6)

over time. LC-HPC-8 is one of the only decks in the project which has experienced significantly higher cracking than its control deck. However, Control 8/10 has experienced a marked rise in crack density after 36 months of age and is now experiencing more cracking than LC-HPC-8.

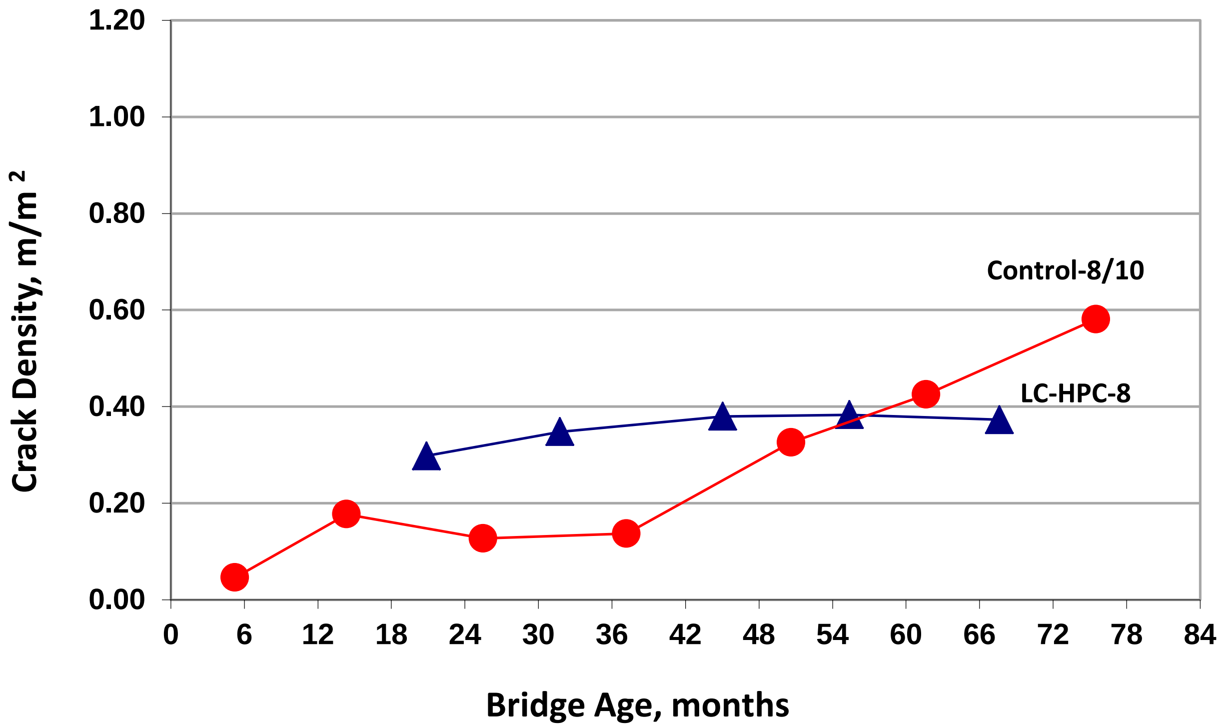
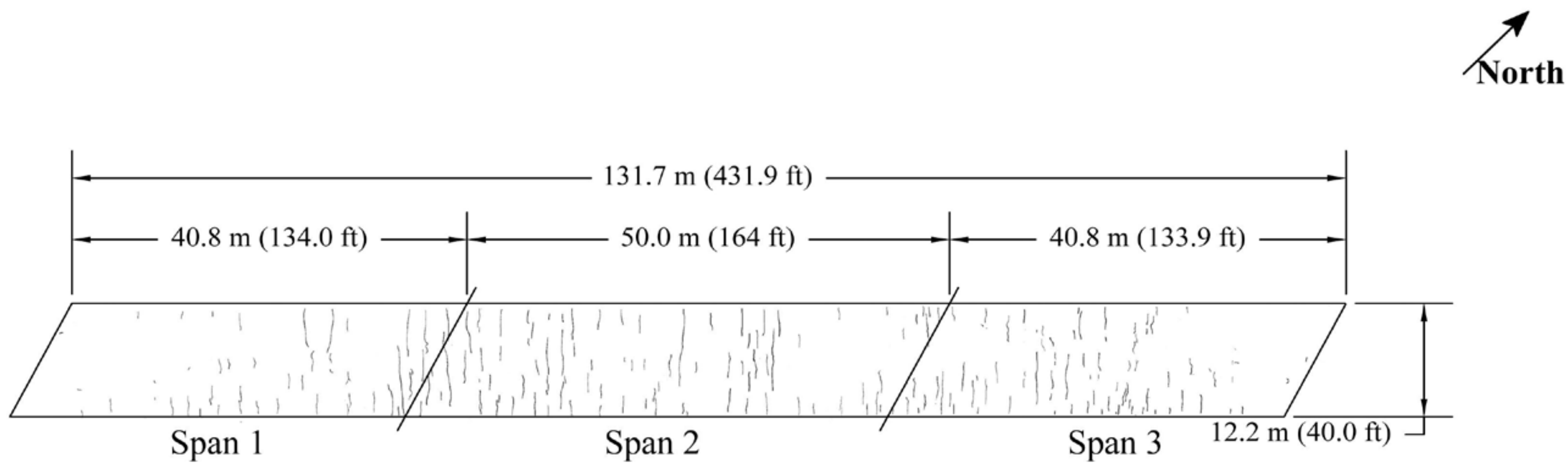


Figure 52: LC-HPC-8 and Control-8/10 Crack Densities

LC-HPC-9

The results of Surveys 2, 3, and 4 of LC-HPC-9, at 26.5, 38.3, and 49.3 months, are included in this report. The crack density of LC-HPC-9 at 26.5 months was 0.237 m/m^2, shown in Figure 53, represents an increase from the previous survey at 13.3 months, for which the crack density was 0.130 m/m^2 (Pendergrass et al. 2011). The crack density at 38.3 months increased to 0.362 m/m^2 (Figure 54) and dropped back to 0.299 m/m^2 at 49.3 months (Figure 55). The cracking is mainly transverse. There is very little cracking near the abutments.

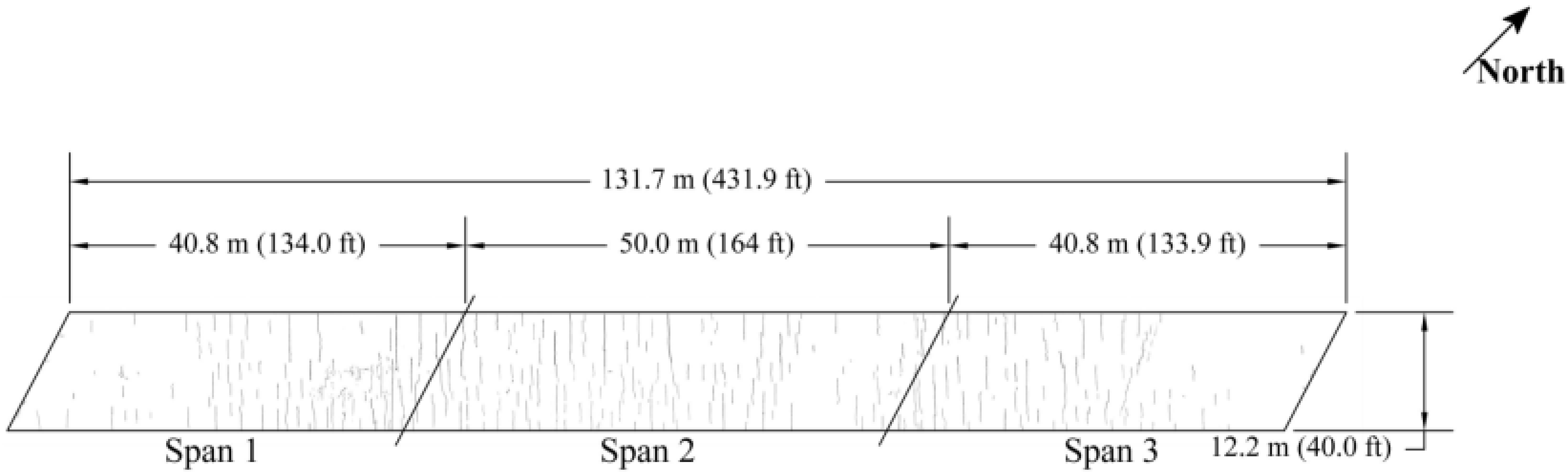


Bridge Number: 54-57 (LC-HPC-9)
Bridge Location: NB US-69 over Marair Des Cygnes Rv
Construction Date: 4/15/2009
Crack survey Date: 6/30/2011

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

Bridge Age: 26.5 months
Crack density: 0.237 m/m²
Span 1 (South): 0.174 m/m²
Span 2 (Middle): 0.281 m/m²
Span 3 (North): 0.221 m/m²

Figure 53: LC-HPC-9 (Survey 2)

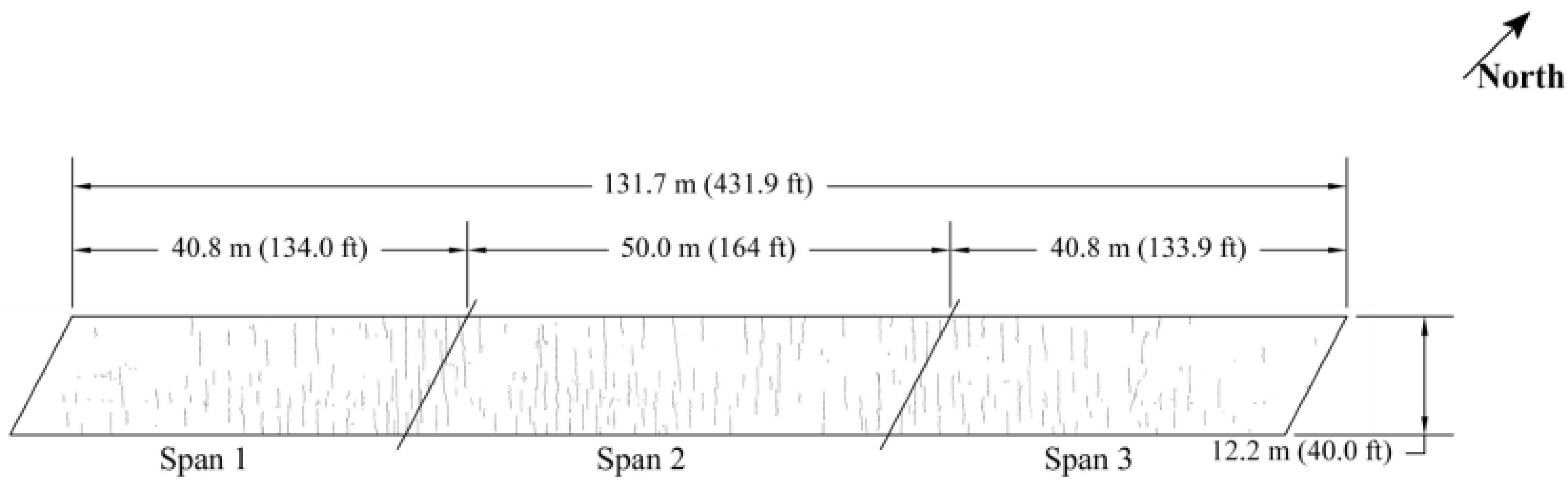


Bridge Number: 54-57 (LC-HPC-9)
Bridge Location: NB US-69 over Marair Des Cygnes Rv
Construction Date: 4/15/2009
Crack survey Date: 6/25/2012

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

Bridge Age: 38.3 months
Crack density: 0.362 m/m^2
Span 1 (South): 0.319 m/m^2
Span 2 (Middle): 0.421 m/m^2
Span 3 (North): 0.325 m/m^2

Figure 54: LC-HPC-9 (Survey 3)



Bridge Number: 54-57 (LC-HPC-9)
Bridge Location: NB US-69 over Marair Des Cygnes Rv
Construction Date: 4/15/2009
Crack survey Date: 5/24/2013

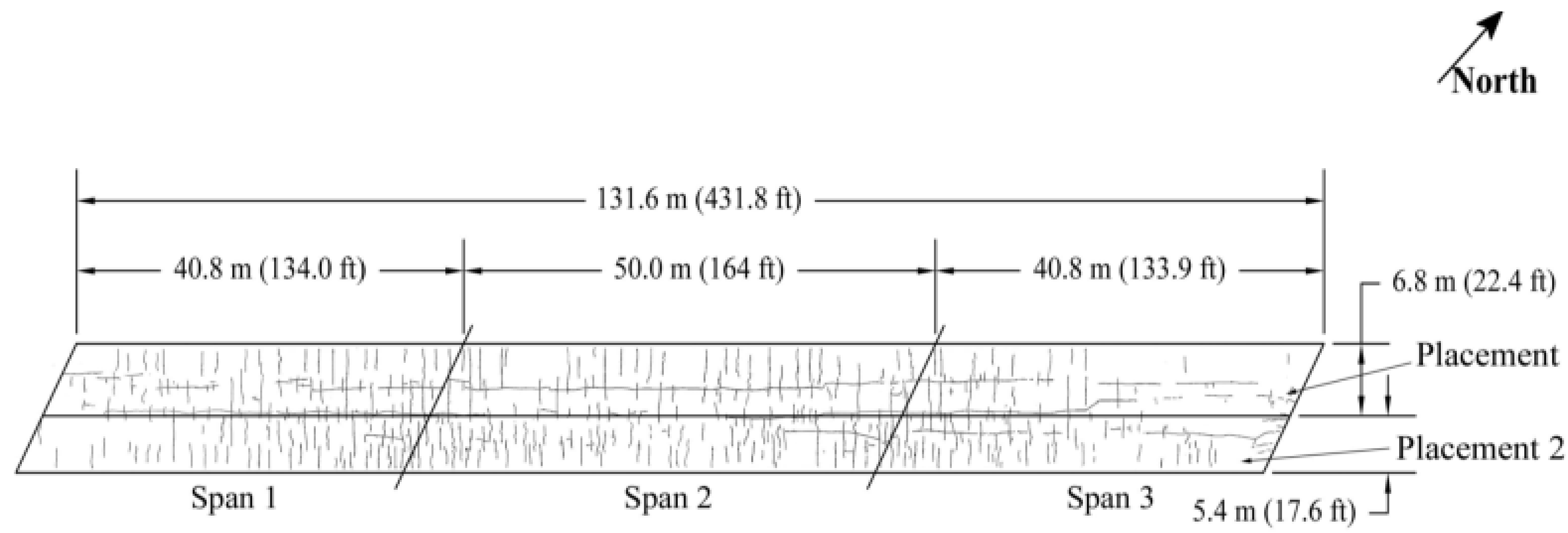
Bridge Length: 131.7 m (431.9 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -27.7°
Number of Spans: 3
Span 1 (South): 40.8 m (134.0 ft)
Span 2 (Middle): 50.0 m (164.0 ft)
Span 3 (North): 40.8 m (133.9 ft)
Number of Placements: 1

Bridge Age: 49.3 months
Crack density: 0.299 m/m^2
Span 1 (South): 0.281 m/m^2
Span 2 (Middle): 0.353 m/m^2
Span 3 (North): 0.243 m/m^2

Figure 55: LC-HPC-9 (Survey 4)

Control-9

Control-9 was constructed in two placements eight days apart. The results of Survey 2 at 37.0 and 37.2 months, Survey 3 at 48.9 and 49.1 months, and Survey 4 at 59.8 and 60.1 months are included in this report. At 37.2 months, Placement 1 had a crack density of 0.553 m/m^2 (see Figure 56). Placement 2 had a crack density of 0.577 m/m^2 at 37.0 months, and the overall crack density resulting from Survey 2 was 0.568 m/m^2. This represents an increase from Survey 1 for which the crack densities were, respectively, 0.395 m/m^2, 0.368 m/m^2, and 0.390 m/m^2 for Placement 1, Placement 2, and the overall crack density (Pendergrass et al. 2011). Placement 1 had a crack density of 0.637 m/m^2 at 49.1 months and Placement 2 had a crack density of 0.501 m/m^2 at 48.9 months (see Figure 57). The overall crack density was 0.577 m/m^2. The crack densities measured during Survey 4 were 0.645 m/m^2 at 60.1 months for Placement 1 (see Figure 58) and 0.564 m/m^2 at 59.8 months for Placement 2, resulting in an overall crack density of 0.609 m/m^2. Both placements have long transverse cracks throughout, with fewer near the abutments. Both placements have continuous longitudinal cracks running nearly the entire length of the bridge, as well as some longitudinal cracking propagating from the abutments. Crack densities have been consistently higher for Control-9 than for LC-HPC-9 over the past three surveys. Figure 59 compares cracking on Control 9 to cracking on LC-HPC-9 over time. LC-HPC-9 has maintained a crack density lower than either placement of Control 9 over time. LC-HPC-9 and Control 9 experienced similar increases in crack density early on, but LC-HPC-9 has less overall cracking because of its significantly lower initial density.



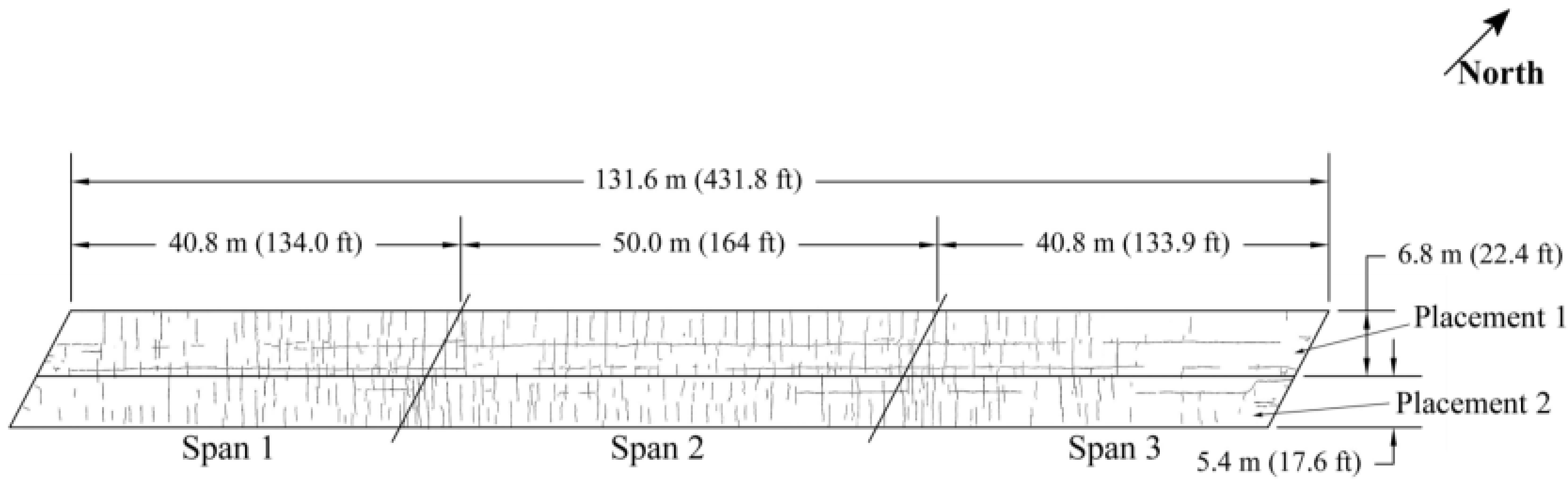
Bridge Number: 54-58 (Control-9)
Bridge Location: NB US-69 over Marair Des Cygnes Rv
Construction Date:
Placement 1 (West): 5/21/2008
Placement 2 (East): 5/29/2008

Crack survey Date: 6/28/2011

Bridge Length: 131.6 m (431.8 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -27.2^{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 (133.8 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: 37.2 months
Placement 2: 37.0 months
Crack density: 0.568 m/m^2
Placement 1: 0.553 m/m^2
Placement 2: 0.577 m/m^2
Span 1 (South): 0.571 m/m^2
Span 2 (Middle): 0.624 m/m^2
Span 3 (North): 0.486 m/m^2

Figure 56: Control-9 (Survey 2)



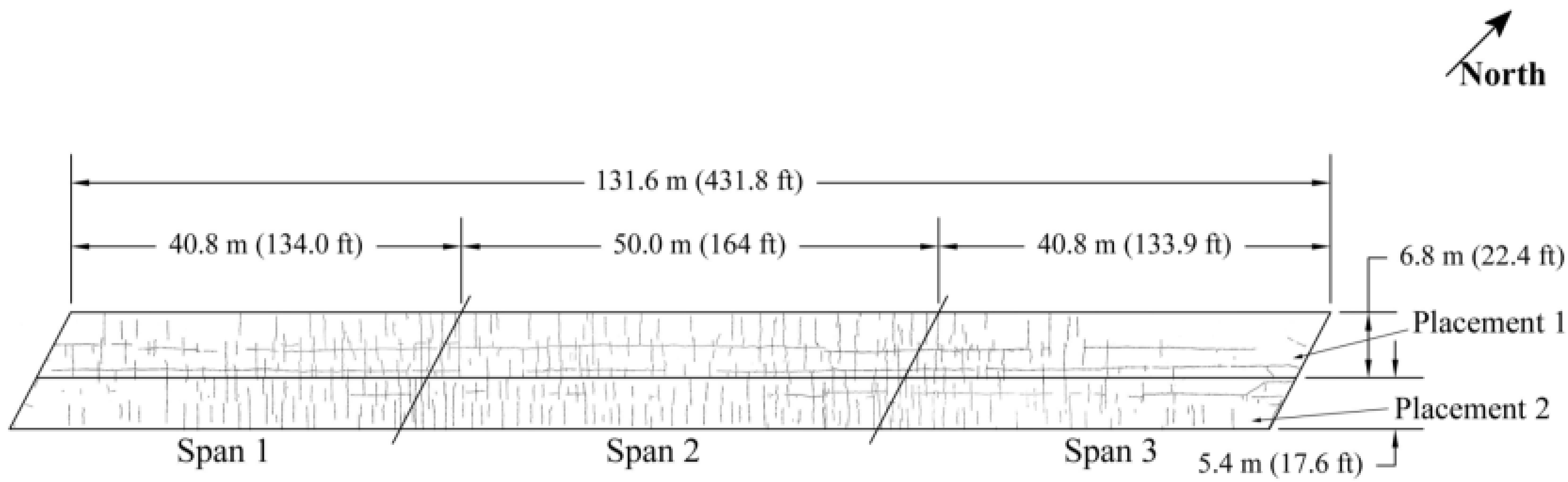
Bridge Number: 54-58 (Control-9)
Bridge Location: NB US-69 over
Marair Des Cygnes Rv
Construction Date:
Placement 1 (West)**:** 5/21/2008
Placement 2 (East): 5/29/2008

Crack survey Date: 6/25/2012

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: 49.1 months
Placement 2: 48.9 months
Crack density: 0.577 m/m^2
Placement 1: 0.637 m/m^2
Placement 2: 0.501 m/m^2
Span 1 (South): 0.574 m/m^2
Span 2 (Middle): 0.651 m/m^2
Span 3 (North): 0.486 m/m^2

Figure 57: Control-9 (Survey 3)



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: 5/24/2013

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: 60.1 months
Placement 2: 59.8 months
Crack density: 0.609 m/m^2
Placement 1: 0.645 m/m^2
Placement 2: 0.564 m/m^2
Span 1 (South): 0.601 m/m^2
Span 2 (Middle): 0.699 m/m^2
Span 3 (North): 0.508 m/m^2

Figure 58: Control-9 (Survey 4)

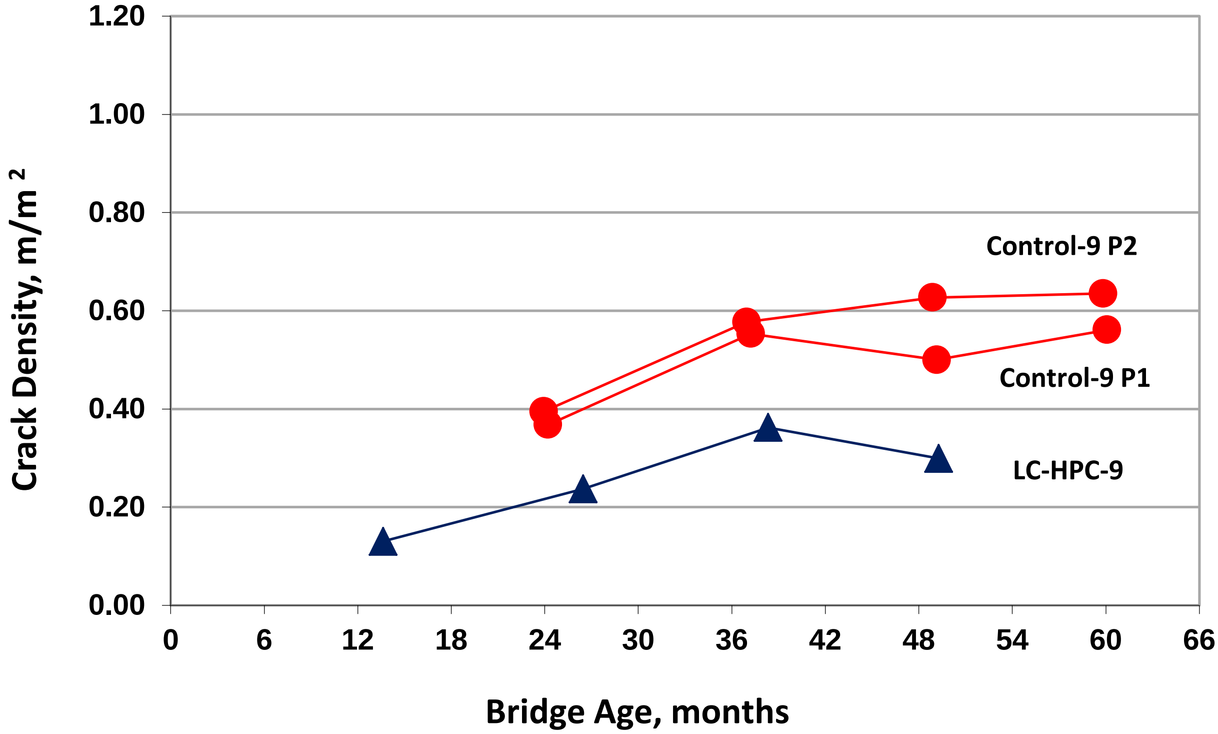
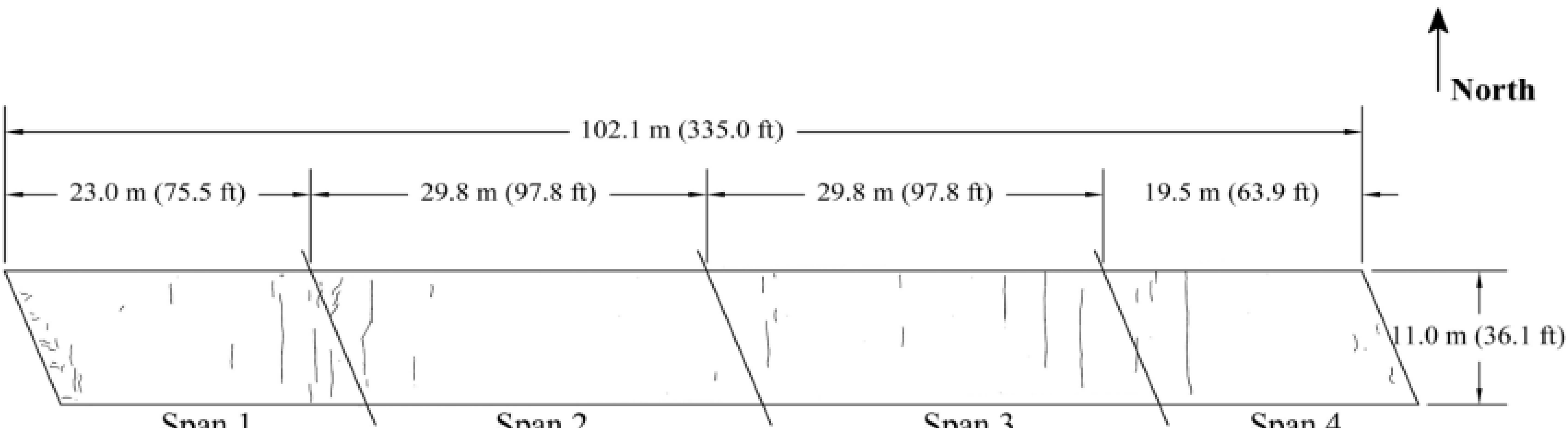


Figure 59: LC-HPC-9 and Control-9 Crack Densities

LC-HPC-10

The results for Surveys 3, 4, and 5 of LC-HPC-10, at 49.6, 60.0, and 72.2 months, are included in this report. LC-HPC-10 is the second of two LC-HPC bridges with precast, prestressed concrete girders. At 49.6 months, the crack density of LC-HPC-10 was 0.088 m/m^2, as shown in Figure 60. This represents an increase from Survey 2 at 36.2 months, when the crack density was 0.029 m/m^2 (Pendergrass et al. 2011). The crack density of LC-HPC-10 was 0.125 m/m^2 at 60.0 months (Figure 61), but only 0.069 m/m^2 at 72.2 months (Figure 62). Most of the cracks are long transverse cracks near the outer two piers, with a small amount of cracking near the center pier and abutments. Figure 63 compares cracking on LC-HPC-10 to cracking on Control 8/10 over time. For most of its life, LC-HPC-10 has experienced less cracking than Control 8/10. LC-HPC-10 started out with a larger density than Control 8/10 because it was



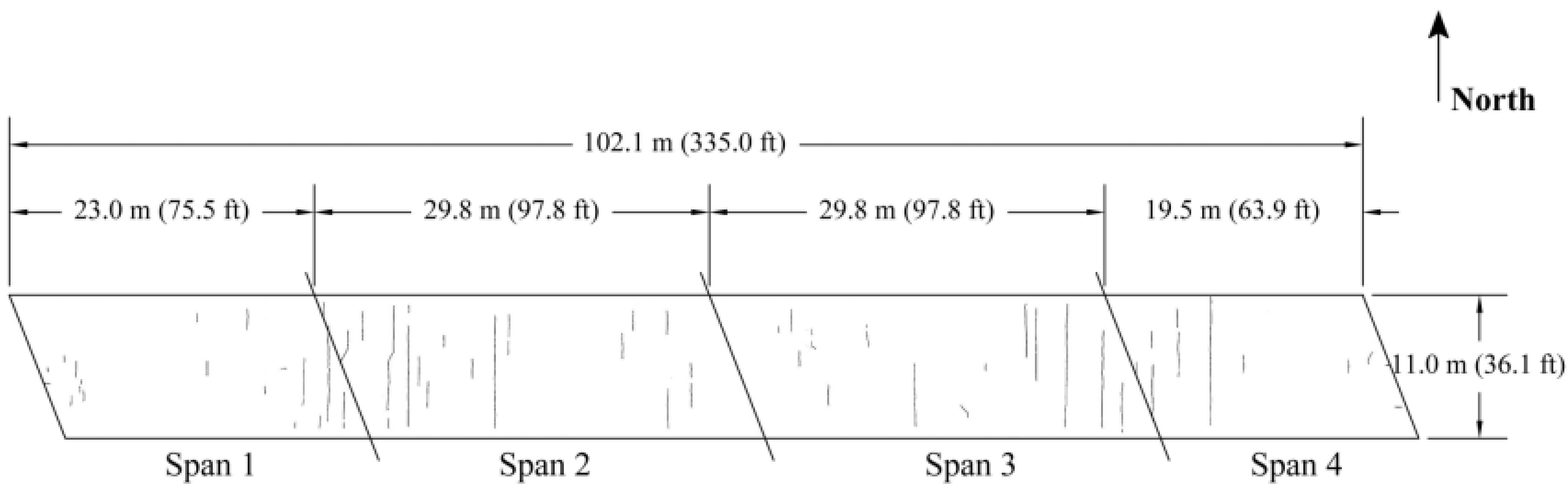
Bridge Number: 54-60 (LC-HPC-10)
Bridge Location: E1800Rd over US-69
Construction Date: 5/17/2007
Crack survey Date: 7/5/2011

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: 49.6 months
Crack density: 0.088 m/m²
- **Span 1 (West):** 0.141 m/m²
- **Span 2 (West):** 0.046 m/m²
- **Span 3 (East):** 0.091 m/m²
- **Span 4 (East):** 0.086 m/m²

Figure 60: LC-HPC-10 (Survey 3)

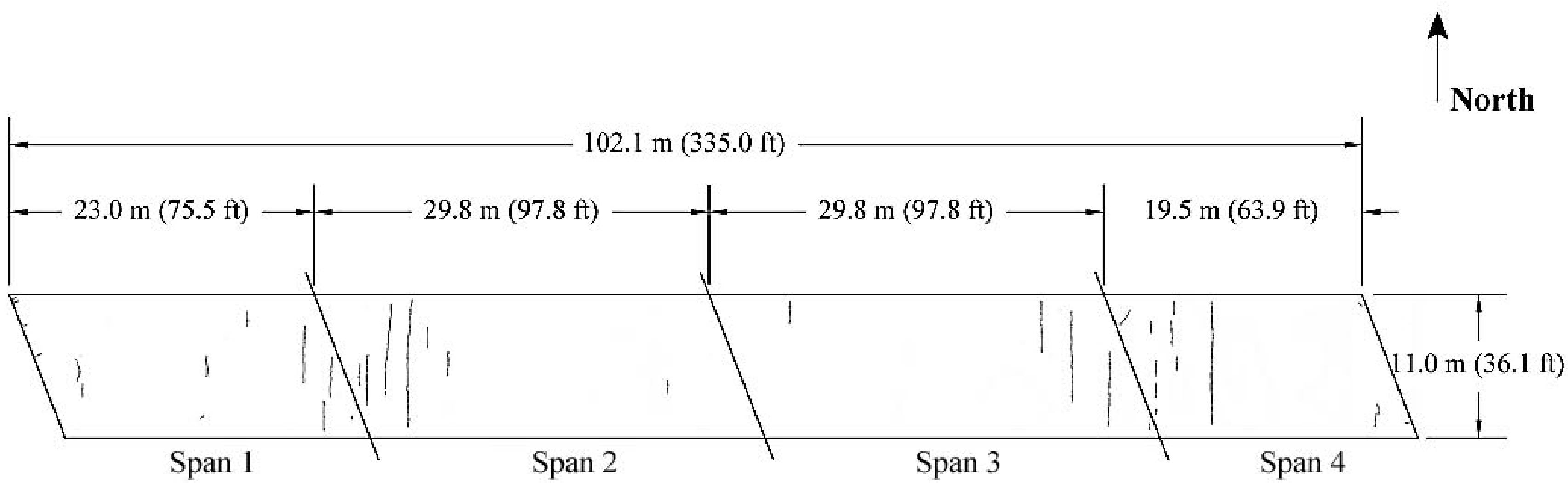


Bridge Number: 54-60 (LC-HPC-10)
Bridge Location: E1800Rd over US-69
Construction Date: 5/17/2007
Crack survey Date: 5/15/2012

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: 60.0 months
Crack density: 0.125 m/m^2
Span 1 (West): 0.091 m/m^2
Span 2 (West): 0.156 m/m^2
Span 3 (East): 0.128 m/m^2
Span 4 (East): 0.114 m/m^2

Figure 61: LC-HPC-10 (Survey 4)



Bridge Number: 54-60 (LC-HPC-10)
Bridge Location: E1800Rd over US-69
Construction Date: 5/17/2007
Crack survey Date: 5/22/2013

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: 72.2 months
Crack density: 0.069 m/m^2
Span 1 (West): 0.059 m/m^2
Span 2 (West): 0.070 m/m^2
Span 3 (East): 0.051 m/m^2
Span 4 (East): 0.089 m/m^2

Figure 62: LC-HPC-10 (Survey 5)

first surveyed when the deck was not grooved. Following grooving, the cracking was not as significant and fell below values on Control 8/10.

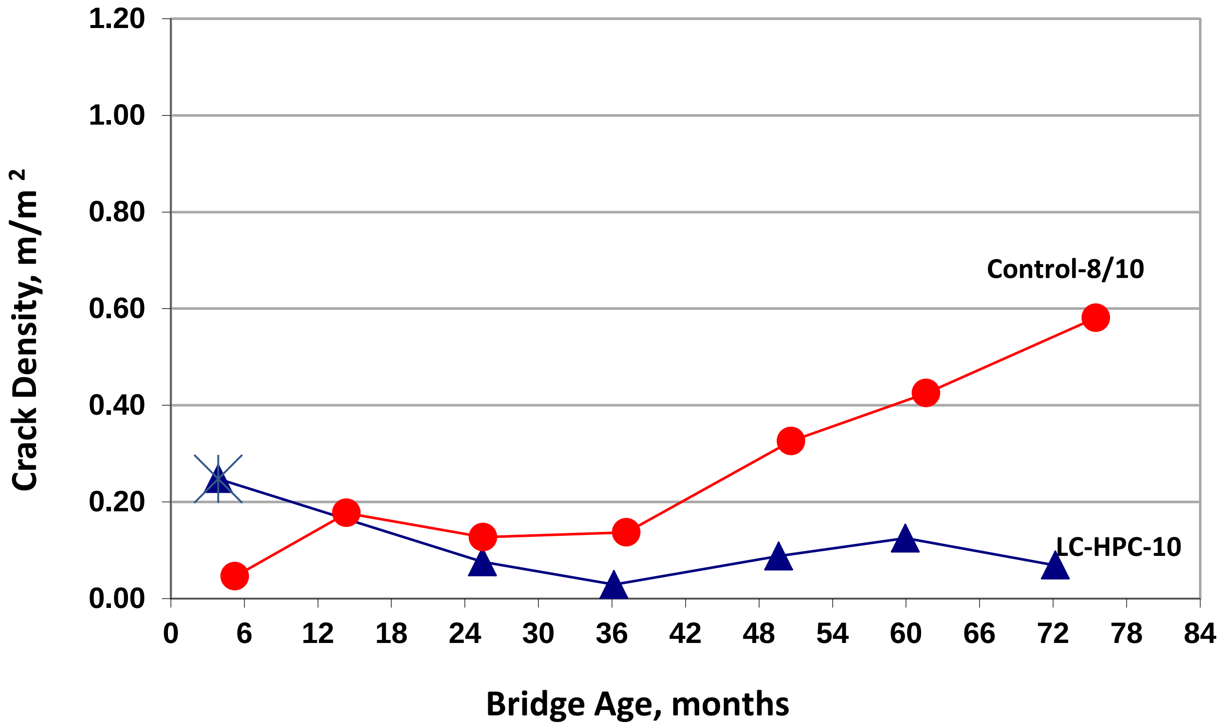
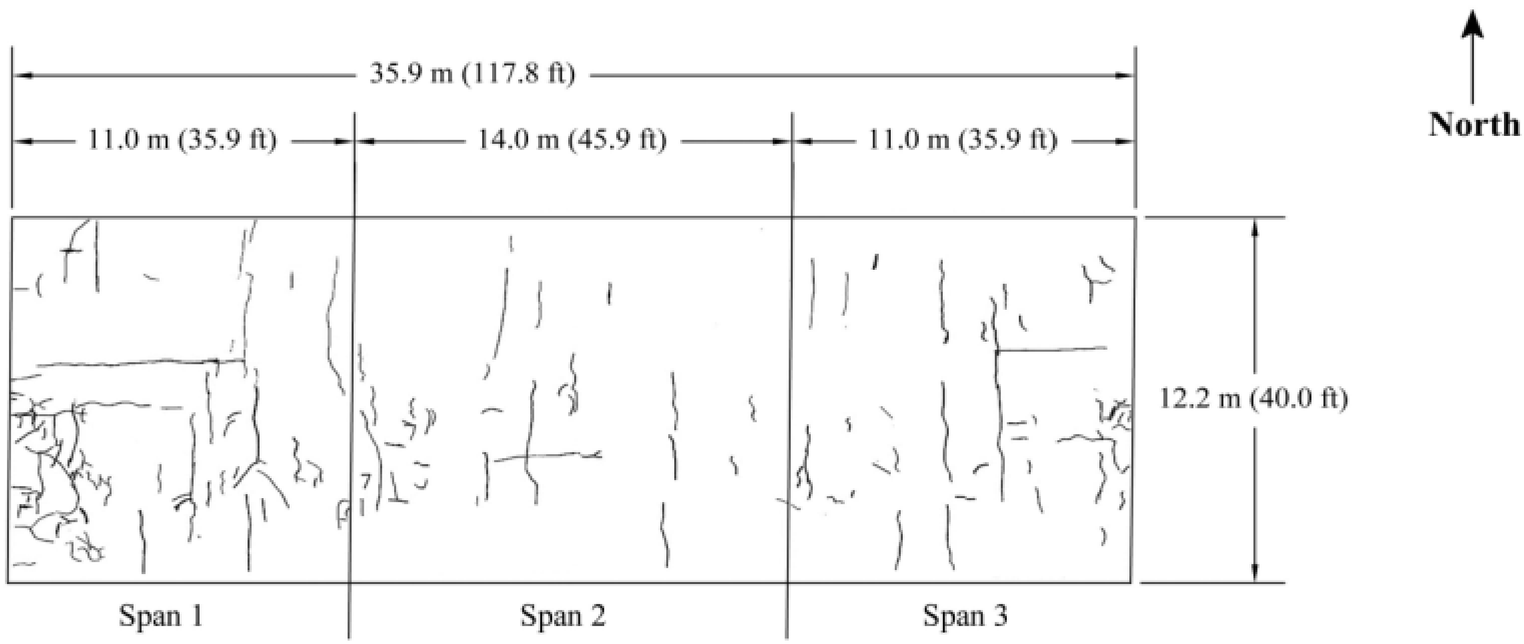


Figure 63: LC-HPC-10 and Control-8/10 Crack Densities

LC-HPC-11

The results of Surveys 3, 4, and 5 of LC-HPC-11, at 48.4, 61.0, and 72.1 months, are included in this report. The crack density of LC-HPC-11 at 48.4 months, 0.370 m/m^2, as shown in Figure 64, represents an increase from the previous survey at 36.2 months, 0.241 m/m^2 (Pendergrass et al. 2011). The crack density of LC-HPC-11 at 61.0 months dropped to 0.260 m/m^2 (Figure 65). The crack density increased at 72.1 months to 0.420 m/m^2 (Figure 66). LC-HPC-11 is one of the shortest bridges in the project, so the decrease in crack density at 61.0 months may have been due to the oversight of a small number of cracks. The bridge exhibits long transverse cracks near the midspans, as well as several long longitudinal cracks near the abutments and first pier. Small longitudinal cracks propagate from both abutments.

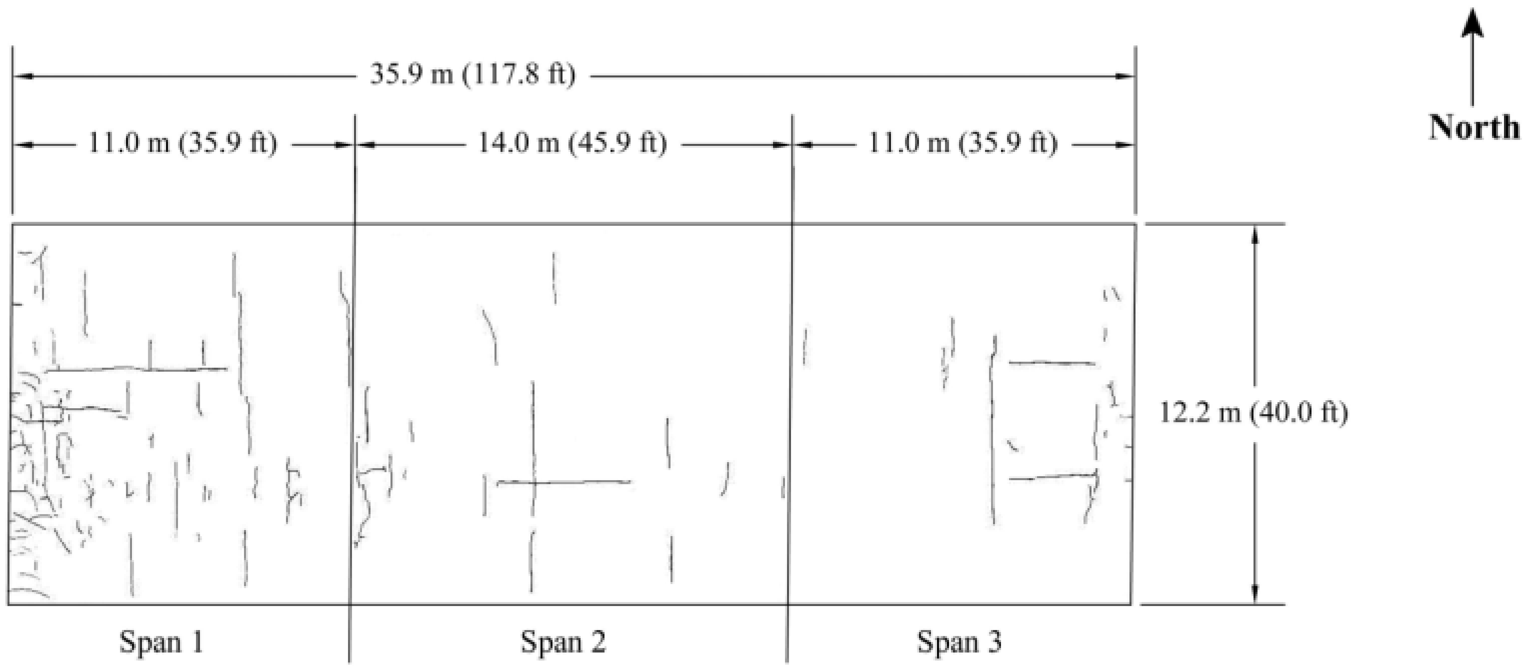


Bridge Number: 78-119 (LC-HPC-11)
Bridge Location: EB US-50 over K &ORR, Hutchinson, KS
Construction Date: 6/9/2007
Crack Survey Date: 6/22/2011

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: 48.4 months
Crack Density: 0.370 m/m²
Span 1: 0.589 m/m²
Span 2: 0.220 m/m²
Span 3: 0.342 m/m²

Figure 64: LC-HPC-11 (Survey 3)

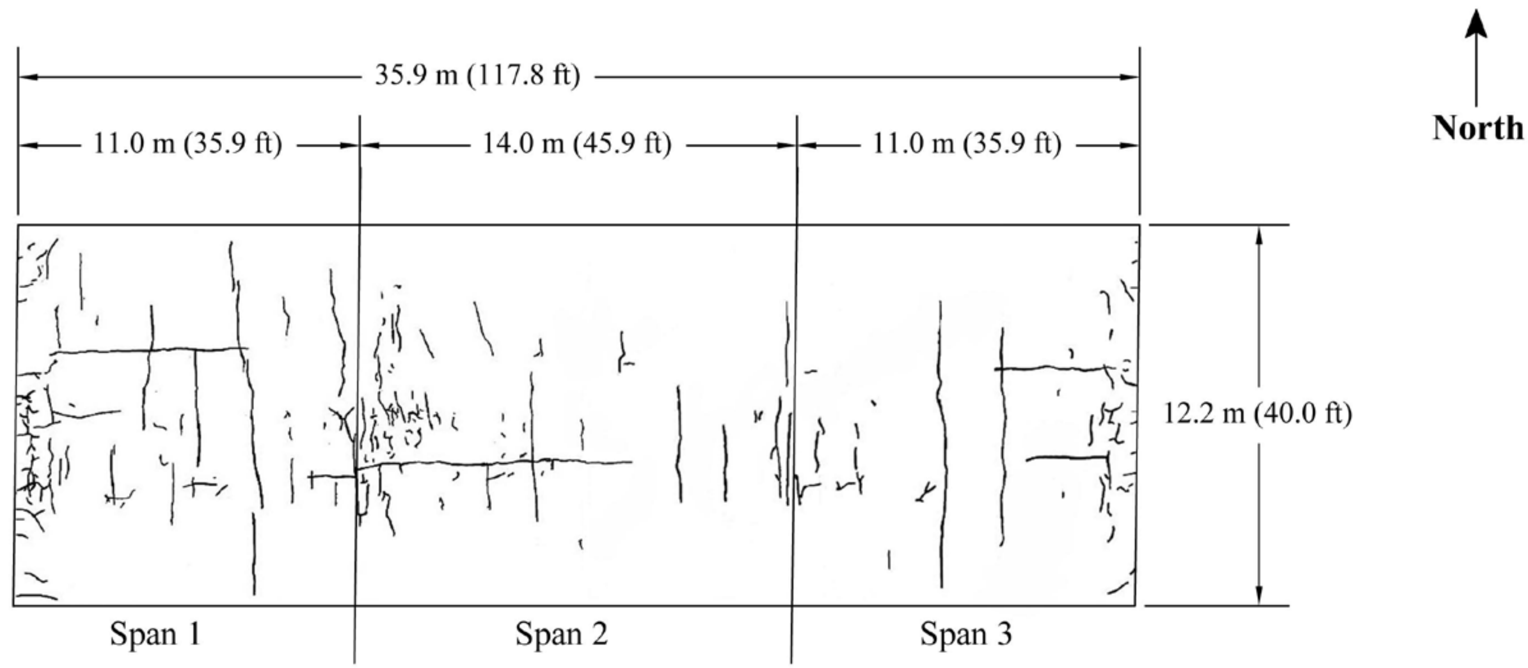


Bridge Number: 78-119 (LC-HPC-11)
Bridge Location: EB US-50 over K &ORR, Hutchinson, KS
Construction Date: 6/9/2007
Crack Survey Date: 7/10/2012

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: 61.0 months
Crack Density: 0.260 m/m^2
Span 1: 0.476 m/m^2
Span 2: 0.159 m/m^2
Span 3: 0.160 m/m^2

Figure 65: LC-HPC-11 (Survey 4)



Bridge Number: 78-119 (LC-HPC-11)
Bridge Location: EB US-50 over K &ORR, Hutchinson, KS
Construction Date: 6/9/2007
Crack Survey Date: 6/11/2013

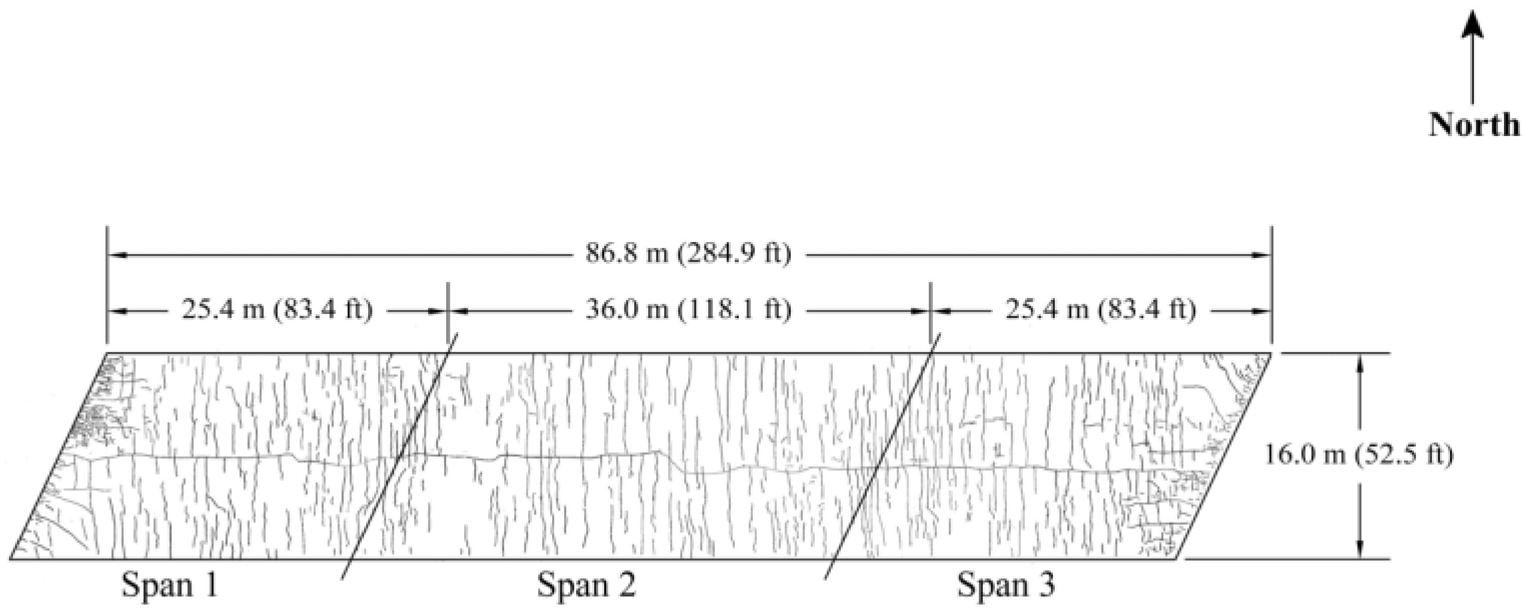
Bridge Length: 35.9 m (117.8 ft)
Bridge Width: 12.2 m (40.0 ft)
Skew: -0.7°
Number of Spans: 3
Span 1: 11.0 m (35.9 ft)
Span 2: 14.0 m (45.9 ft)
Span 3: 11.0 m (35.9 ft)
Number of Placements: 1

Bridge Age: 72.1 months
Crack Density: 0.420 m/m^2
Span 1: 0.569 m/m^2
Span 2: 0.367 m/m^2
Span 3: 0.337 m/m^2

Figure 66: LC-HPC-11 (Survey 5)

Control-11

The results of Surveys 5, 6, and 7 of Control-11, at 62.9, 74.2, and 86.3 months, are included in this report. The crack density of Control-11 at 62.9 months, 0.923 m/m^2 (Figure 67), was 45% higher than the value at 50.2 months, 0.636 m/m^2 (Pendergrass et al. 2011). The crack density of Control-11 decreased to 0.849 m/m^2 at 75.2 months (Figure 68), and decreased even further to 0.657 m/m^2 at 86.3 months (Figure 69). Cracking is higher on Control-11 than on LC-HPC-11 at similar ages. Specifically, Control-11 had a crack density of 0.923 m/m^2 at 62.9 months, which is three times the density of LC-HPC-11 at 61.0 months, 0.260 m/m^2. Similarly, Control-11 had a crack density of 0.849 m/m^2 at 75.2 months, which is more than twice the density on LC-HPC-11 at 72.1 months, 0.420 m/m^2. There are many small, narrow cracks on the deck that may have been overlooked in Surveys 6 and 7, leading to smaller crack densities. Most of the cracks are transverse, spread across the deck parallel to and above the reinforcement. There is a single longitudinal crack in the middle of the deck stretching across the entire length of the bridge, as well as smaller longitudinal cracks propagating from the abutments. Figure 70 compares cracking on Control 11 to cracking on LC-HPC-11 over time. While LC-HPC-11 has had less cracking than Control 11 over time, both decks have experienced significant swings in crack density.



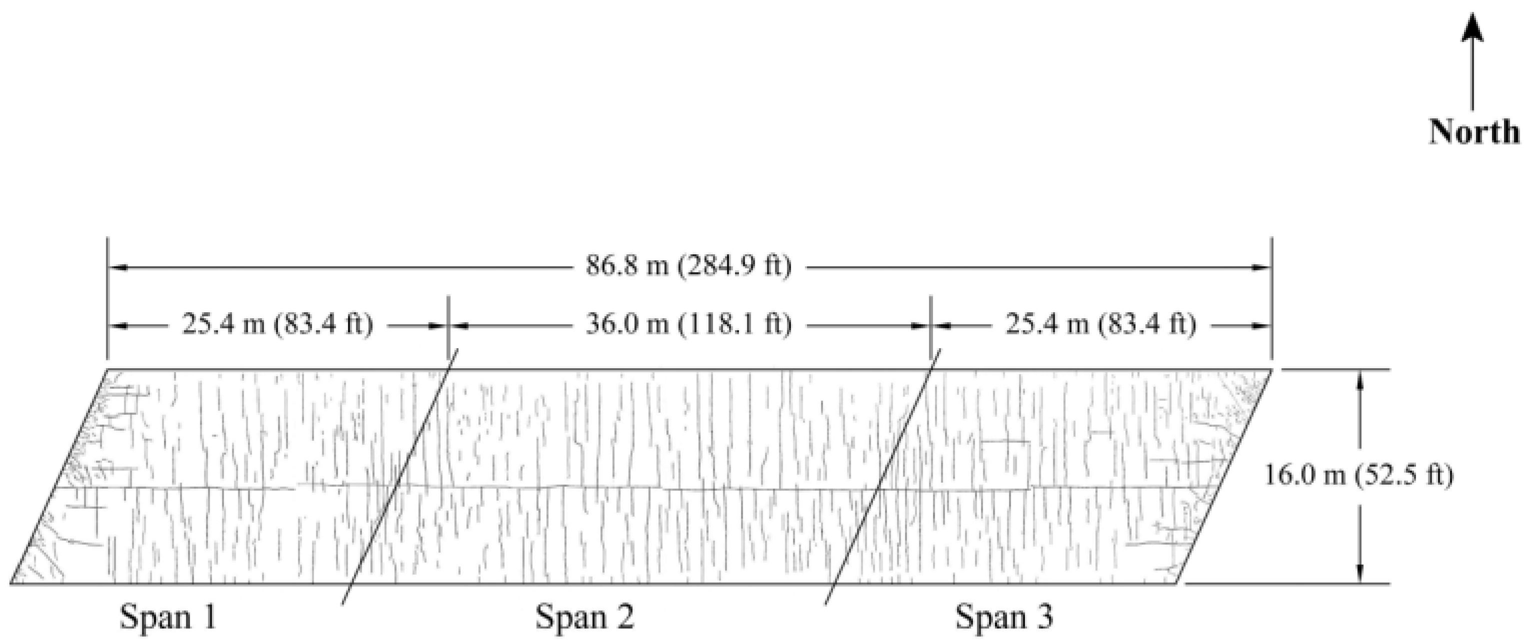
Bridge Number: 56-155 (Control-11)

Bridge Location: US-50 over BNSF Railroad, Emporia, KS
Construction Date: 3/28/2006
Crack Survey Date: 6/23/2011

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: 62.9 months
Crack Density: 0.923 m/m^2
Span 1: 1.001 m/m^2
Span 2: 0.804 m/m^2
Span 3: 1.005 m/m^2

Figure 67: Control-11 (Survey 5)



Bridge Number: 56-155 (Control-11)

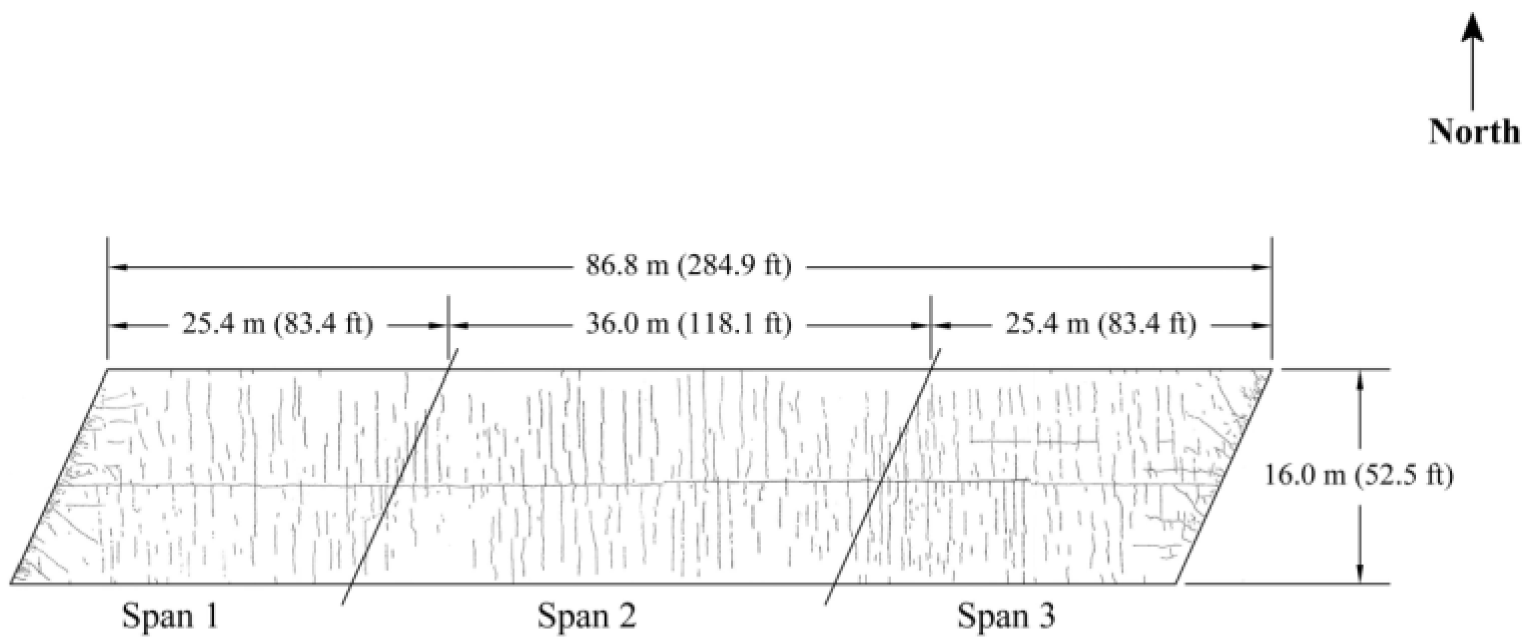
Bridge Location: US-50 over BNSF Railroad, Emporia, KS
Construction Date: 3/28/2006
Crack Survey Date: 7/3/2012

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: 75.2 months
Crack Density: 0.849 m/m^2
- **Span 1:** 0.830 m/m^2
- **Span 2:** 0.793 m/m^2
- **Span 3:** 0.945 m/m^2

Figure 68: Control-11 (Survey 6)



Bridge Number: 56-155 (Control-11)

Bridge Location: US-50 over BNSF Railroad, Emporia, KS
Construction Date: 3/28/2006
Crack Survey Date: 6/6/2013

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: 86.3 months
Crack Density: 0.657 m/m^2
Span 1: 0.621 m/m^2
Span 2: 0.608 m/m^2
Span 3: 0.754 m/m^2

Figure 69: Control-11 (Survey 7)

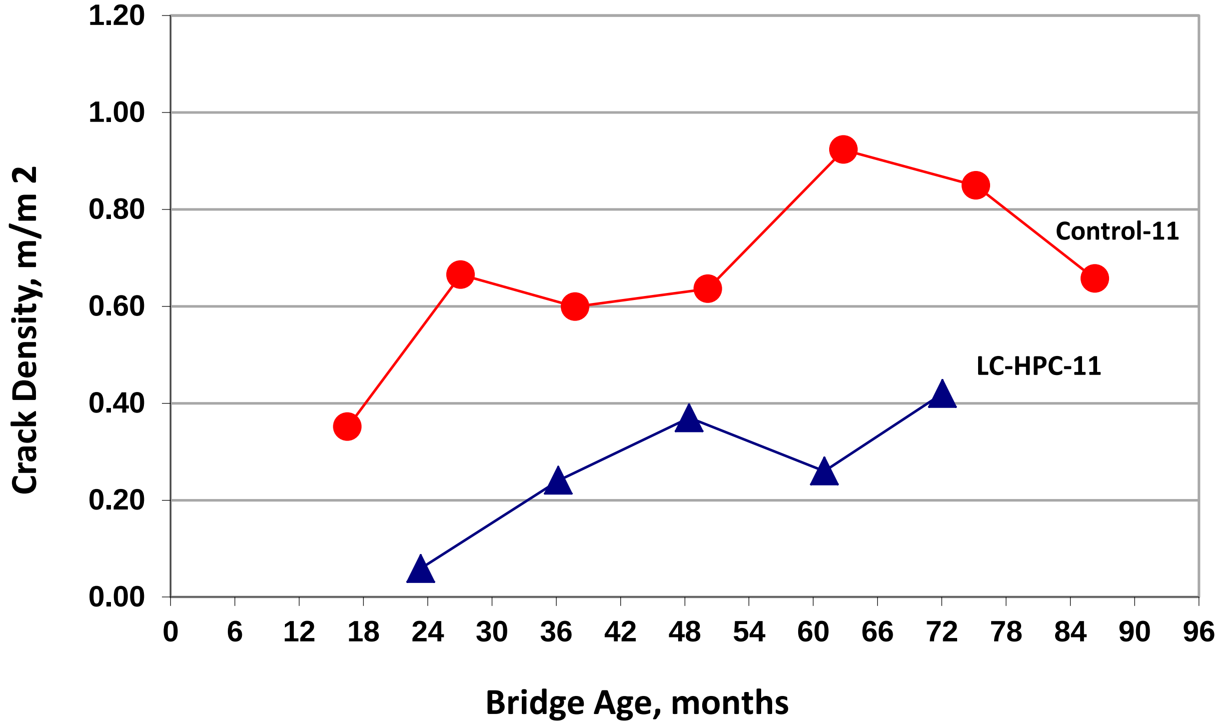
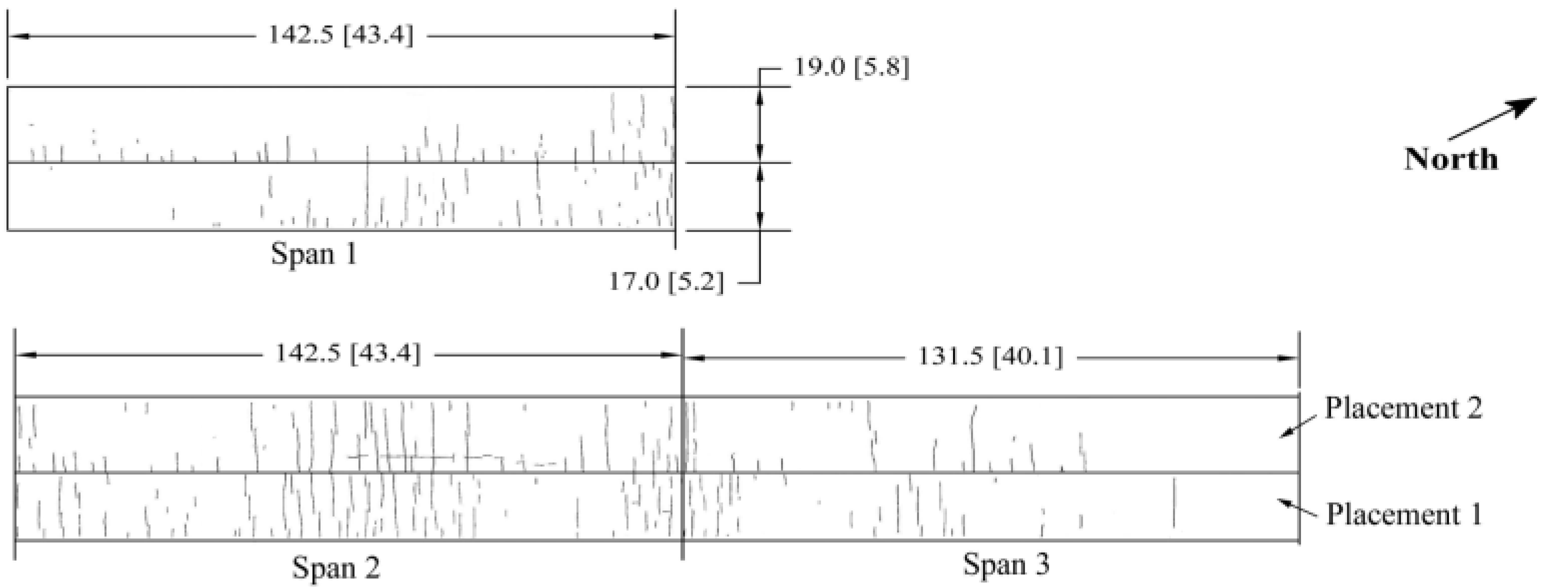


Figure 70: LC-HPC-11 and Control-11 Crack Densities

LC-HPC-12

LC-HPC-12 was constructed in two placements, 11.4 months apart. The results of Survey 3 at 27.4 and 38.8 months, Survey 4 at 38.1 and 49.5 months, and Survey 5 at 53.1 and 64.5 months are included in this report. At 38.8 months, Placement 1 had a crack density of 0.315 m/m^2 (see Figure 71). Placement 2 had a crack density of 0.268 m/m^2 at 27.4 months, resulting in an overall crack density of 0.289 m/m^2. This represents an increase from Survey 2 of LC-HPC-12, which recorded crack densities of 0.256 m/m^2, 0.244 m/m^2, and 0.250 m/m^2, respectively, for Placement 1, Placement 2, and overall (Pendergrass et al. 2011). In Survey 4, Placement 1 had a crack density of 0.450 m/m^2 at 49.5 months and Placement 2 had a crack density of 0.375 m/m^2 at 38.1 months (see Figure 72), producing an overall crack density of 0.410 m/m^2. These values are all larger than the corresponding crack densities from Survey 3. For Survey 5, Placement 1 had a crack density of 0.478 m/m^2 at 64.5 months (see Figure 73), and



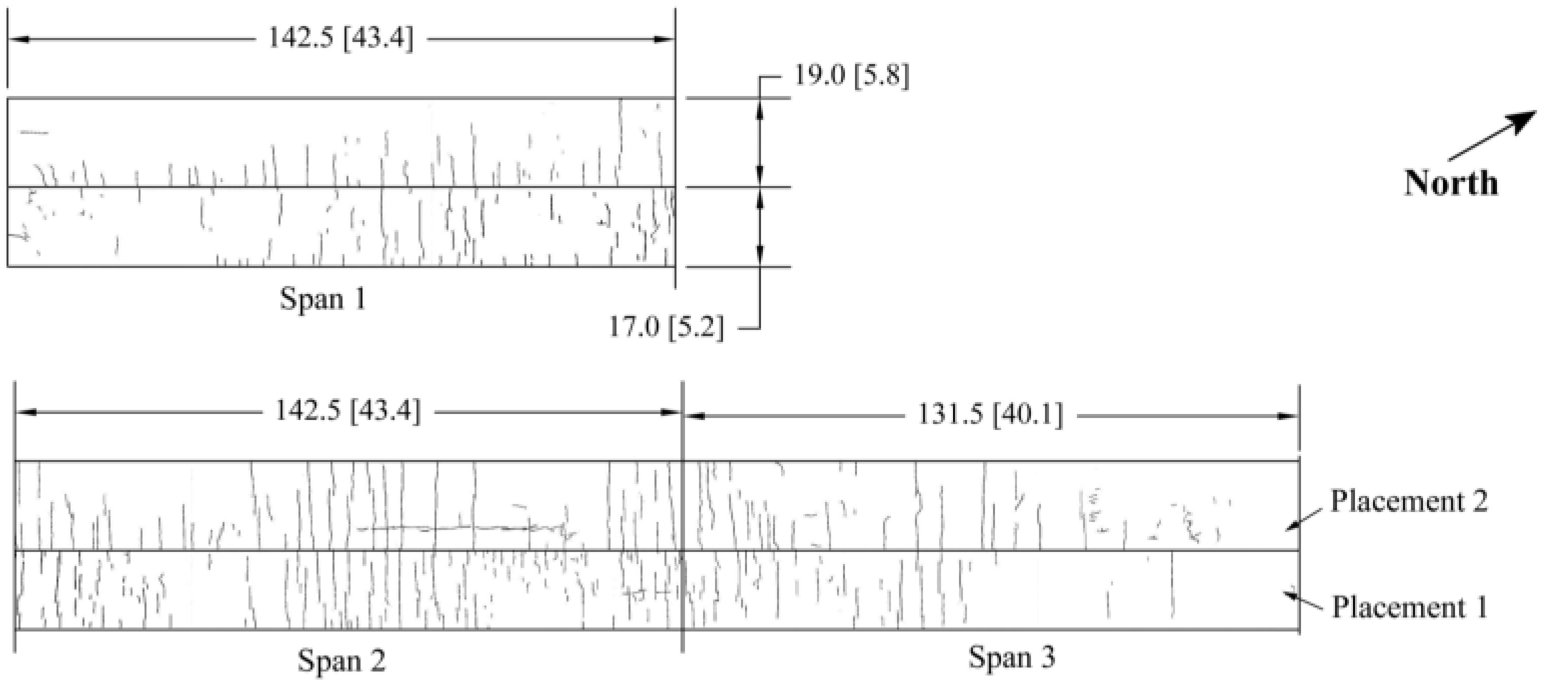
Bridge Number: 56-057 (LC-HPC-12)
Bridge Location: K-130 over Neosho Rv Unit 2
Construction Date:
Placement 1(east): 4/4/2008
Placement 2(west): 3/18/2009

Crack Survey Date: 6/28/2011

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: 38.8 months
Placement 2: 27.4 months
Crack Density: 0.289 m/m²
Placement 1: 0.315 m/m²
Placement 2: 0.268 m/m²
Span 1: 0.216 m/m²
Span 2: 0.474 m/m²
Span 3: 0.168 m/m

Figure 71: LC-HPC-12 (Survey 3)



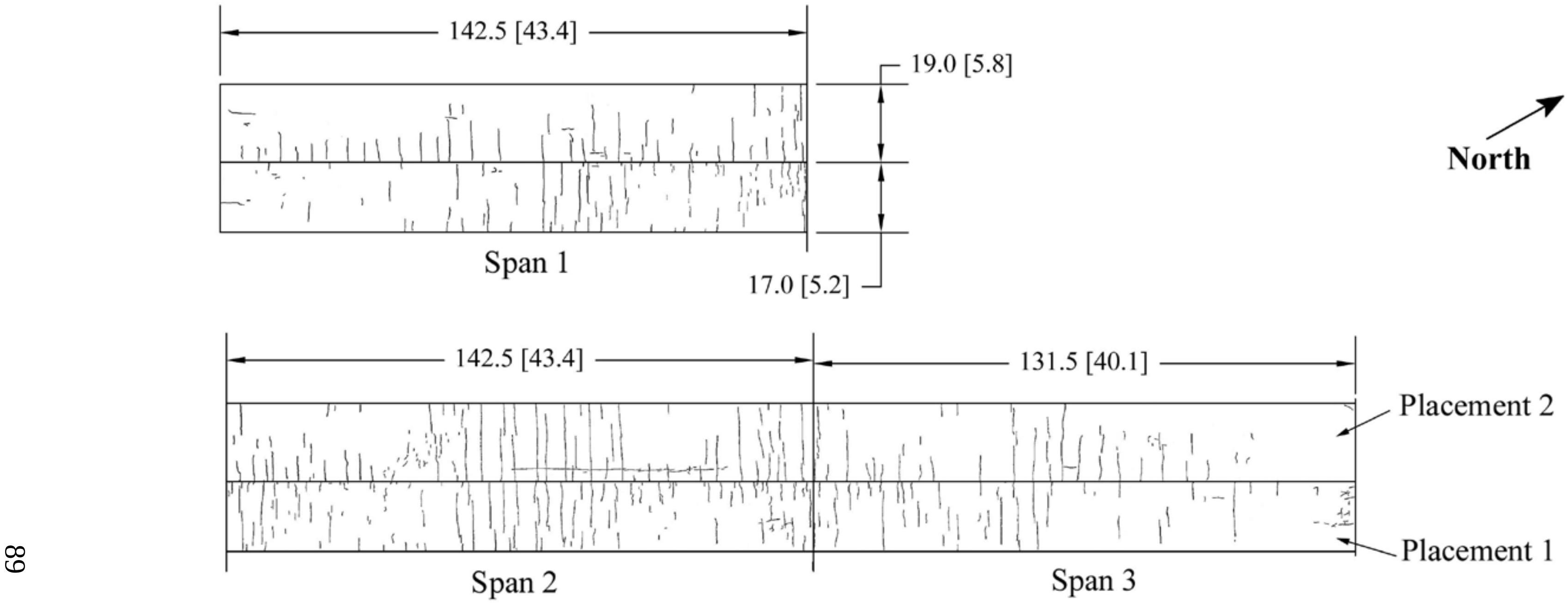
Bridge Number: 56-057 (LC-HPC-12)
Bridge Location: K-130 over Neosho Rv Unit 2
Construction Date:
Placement 1(east): 4/4/2008
Placement 2(west): 3/18/2009

Crack Survey Date: 5/21/2012

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: 49.5 months
Placement 2: 38.1 months
Crack Density: 0.410 m/m²
Placement 1: 0.450 m/m²
Placement 2: 0.375 m/m²
Span 1: 0.283 m/m²
Span 2: 0.604 m/m²
Span 3: 0.331 m/m²

Figure 72: LC-HPC-12 (Survey 4)



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

Crack Survey Date: 8/19/2013

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

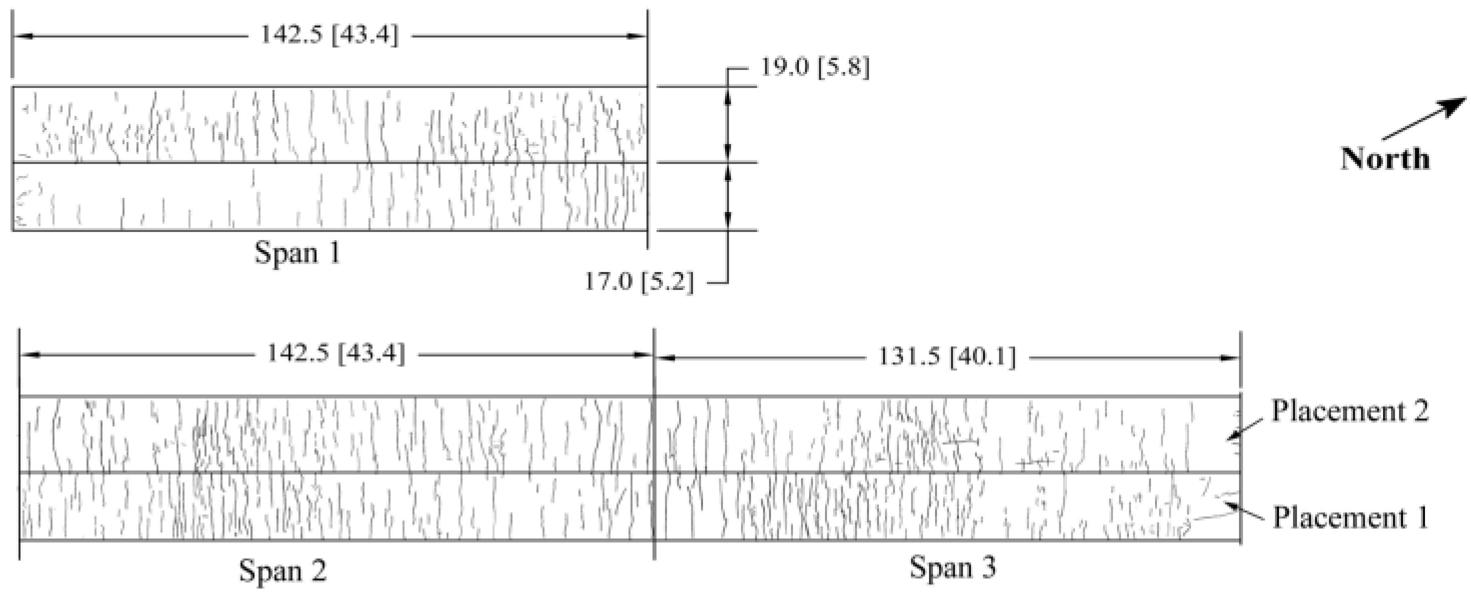
Bridge Age:
Placement 1: 64.5 months
Placement 2: 53.1 months
Crack Density: 0.431 m/m^2
Placement 1: 0.478 m/m^2
Placement 2: 0.381 m/m^2
Span 1: 0.349 m/m^2
Span 2: 0.610 m/m^2
Span 3: 0.327 m/m

Figure 73: LC-HPC-12 (Survey 5)

Placement 2 had a crack density of 0.381 m/m^2 at 53.1 months, resulting in an overall crack density of 0.431 m/m^2. These values are again higher than the densities measured in Survey 4. Both placements have transverse cracks extending from the longitudinal construction joint, with less cracking near the abutments and a greater crack density in the middle of the center span (Span 2). The crack density of Placement 1 has been higher, likely because of the torsional loading caused by equipment that was placed on this portion of the deck during the construction of Placement 2.

Control-12

Control-12, the southern half of the same bridge as LC-HPC-12, was also constructed in two placements, 12.4 months apart. The results of Survey 3 at 26.5 and 38.9 months, Survey 4 at 37.2 and 49.6 months, and Survey 5 at 52.2 and 64.6 months are included in this report. At 38.9 months, Placement 1 had a crack density of 0.767 m/m^2 (see Figure 74) and at 26.5 months, Placement 2 had a crack density of 0.799 m/m^2, resulting in an overall crack density of 0.788 m/m^2. This represents an increase from Survey 2, for which the crack densities were 0.669 m/m^2, 0.442 m/m^2, and 0.548 m/m^2 for Placement 1, Placement 2, and overall, respectively (Pendergrass et al. 2011). For Survey 4, Placement 1 had a crack density of 0.857 m/m^2 at 49.6 months and Placement 2 had a crack density of 0.831 m/m^2 at 37.2 months, resulting in an overall crack density of 0.843 m/m^2 (see Figure 75). These values are all larger than the corresponding crack densities from Survey 3. For Survey 5 at 64.6 months, Placement 1 had a crack density of 0.838 m/m^2, and at 52.2 months, Placement 2 had a crack density of 0.880 m/m^2, resulting in an overall crack density of 0.858 m/m^2 for Survey 5 (See Figure 76). This represents an increase from Survey 4 for Placement 2, but not for Placement 1, which had a crack density that remained unchanged from Survey 4. Control-12 consistently has had crack

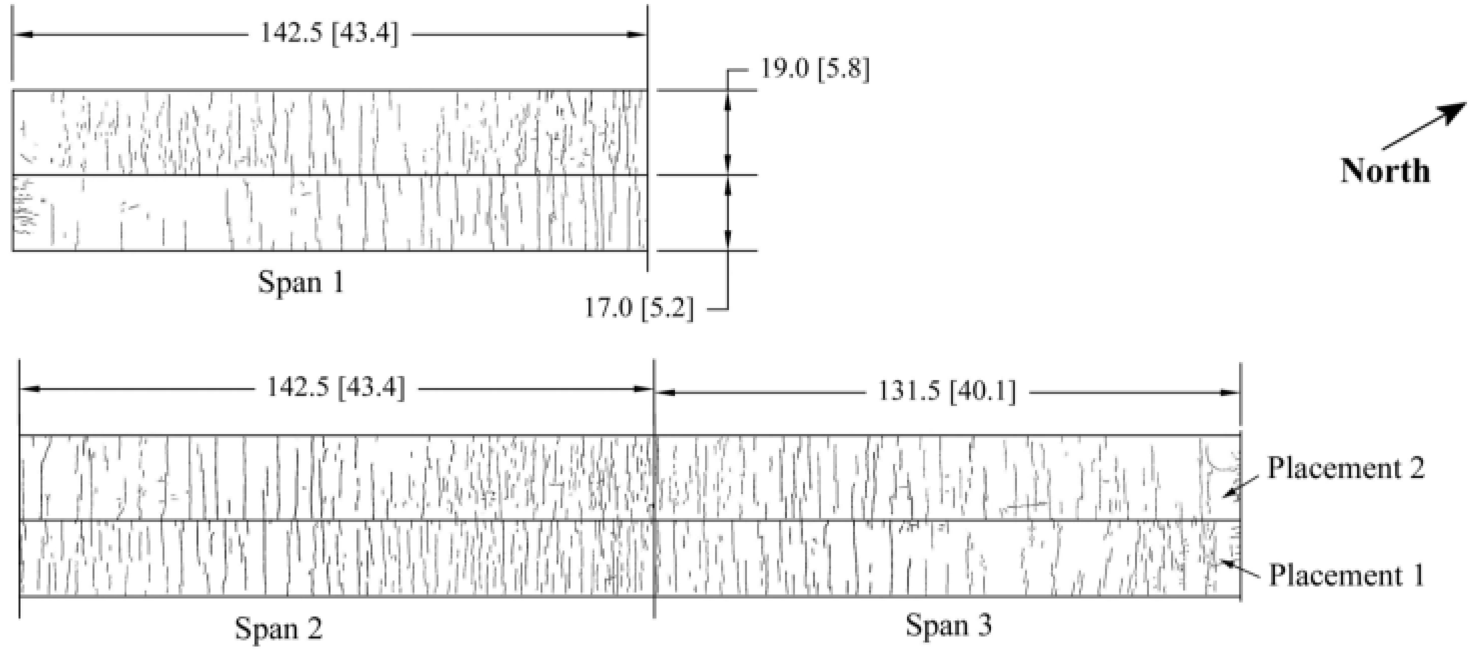


Bridge Number: 56-057 (Control-12)
Bridge Location: K-130 over Neosho Rv Unit 1
Construction Date:
Placement 1(east): 4/1/2008
Placement 2(west): 4/14/2009
Crack Survey Date: 6/29/2011

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: 38.9 months
Placement 2: 26.5 months
Crack Density: 0.788 m/m^2
Placement 1: 0.767 m/m^2
Placement 2: 0.799 m/m^2
Span 1: 0.636 m/m^2
Span 2: 0.892 m/m^2
Span 3: 0.829 m/m^2

Figure 74: Control-12 (Survey 3)

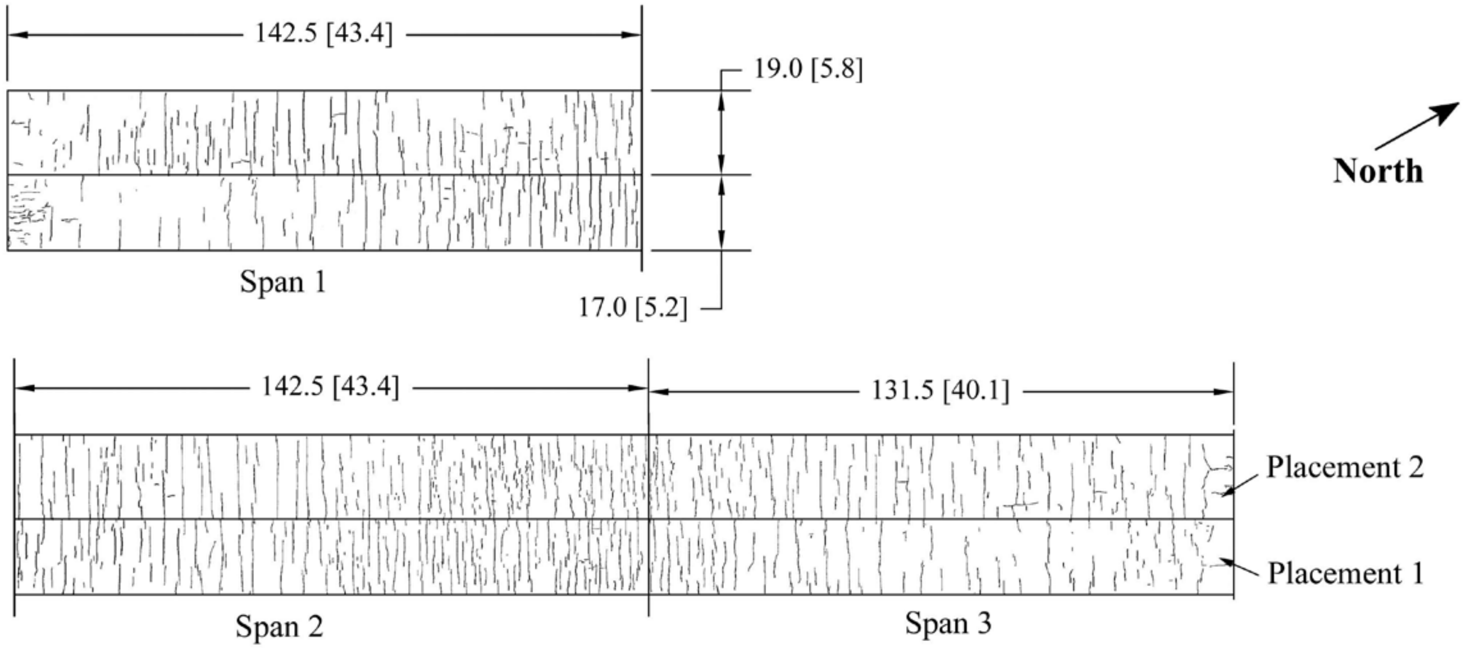


Bridge Number: 56-057 (Control-12)
Bridge Location: K-130 over Neosho Rv Unit 1
Construction Date:
Placement 1(east): 4/1/2008
Placement 2(west): 4/14/2009
Crack Survey Date: 5/21/2012

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: 49.6 months
Placement 2: 37.2 months
Crack Density: 0.843 m/m^2
Placement 1: 0.857 m/m^2
Placement 2: 0.831 m/m^2
Span 1: 0.723 m/m^2
Span 2: 1.015 m/m^2
Span 3: 0.786 m/m^2

Figure 75: Control-12 (Survey 4)



Bridge Number: 56-057 (Control-12)
Bridge Location: K-130 over Neosho Rv Unit 1
Construction Date:
Placement 1 (East): 4/1/2008
Placement 2 (West): 4/14/2009
Crack Survey Date: 8/19/2013

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: 64.6 months
Placement 2: 52.2 months
Crack Density: 0.858 m/m^2
Placement 1: 0.838 m/m^2
Placement 2: 0.880 m/m^2
Span 1: 0.750 m/m^2
Span 2: 1.085 m/m^2
Span 3: 0.728 m/m^2

Figure 76: Control-12 (Survey 5)

densities about twice those of LC-HPC-12. Long transverse cracks span the length of both placements, and there are small longitudinal cracks propagating from both abutments. Similar to LC-HPC-12, construction equipment was placed on Placement 1 during the construction of Placement 2. Figure 77 compares cracking on Control-12 to cracking on LC-HPC-12 over time. LC-HPC-12 has performed significantly better throughout the life of the decks. It appears that crack growth has begun to stabilize on both decks.

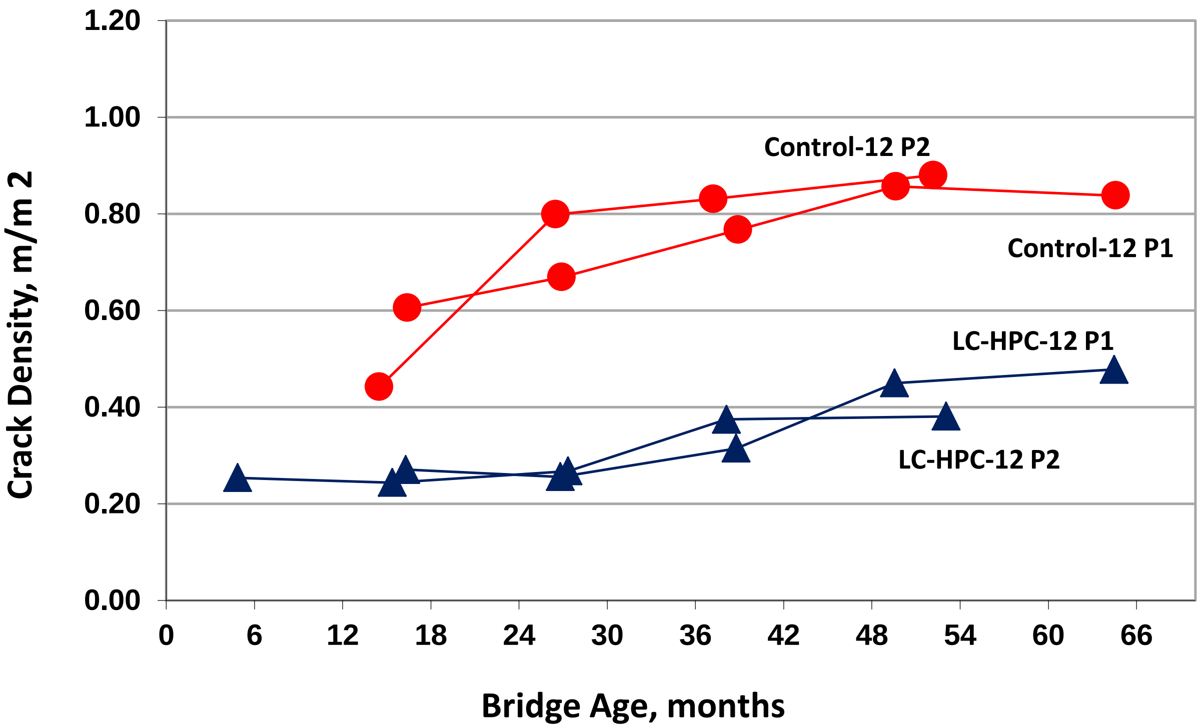
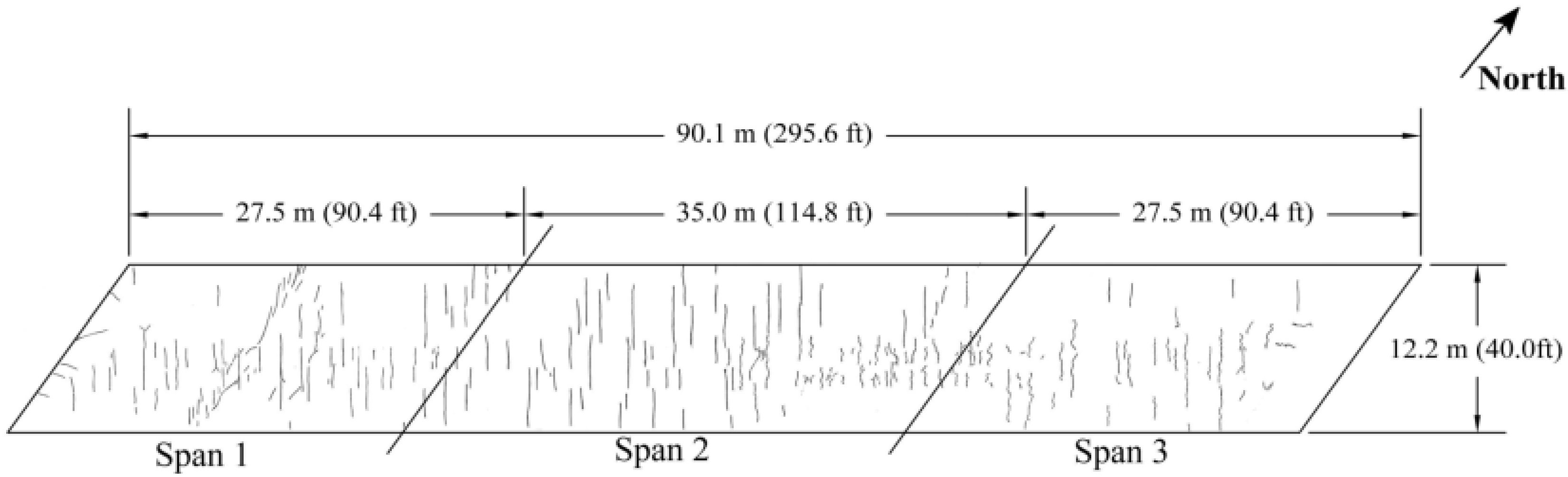


Figure 77: LC-HPC-12 and Control-12 Crack Densities

LC-HPC-13

The results of Surveys 3, 4, and 5 of LC-HPC-13, at 37.1, 49.0, and 62.9 months, are included in this report. The crack density of LC-HPC-13 was 0.364 m/m^2 at 37.1 months (Figure 78), which represents an increase from 0.129 m/m^2 at 24.8 months (Pendergrass et al. 2011). The crack density of LC-HPC-13 at 49.0 months was 0.342 m/m^2 (Figure 79), and increased to 0.576

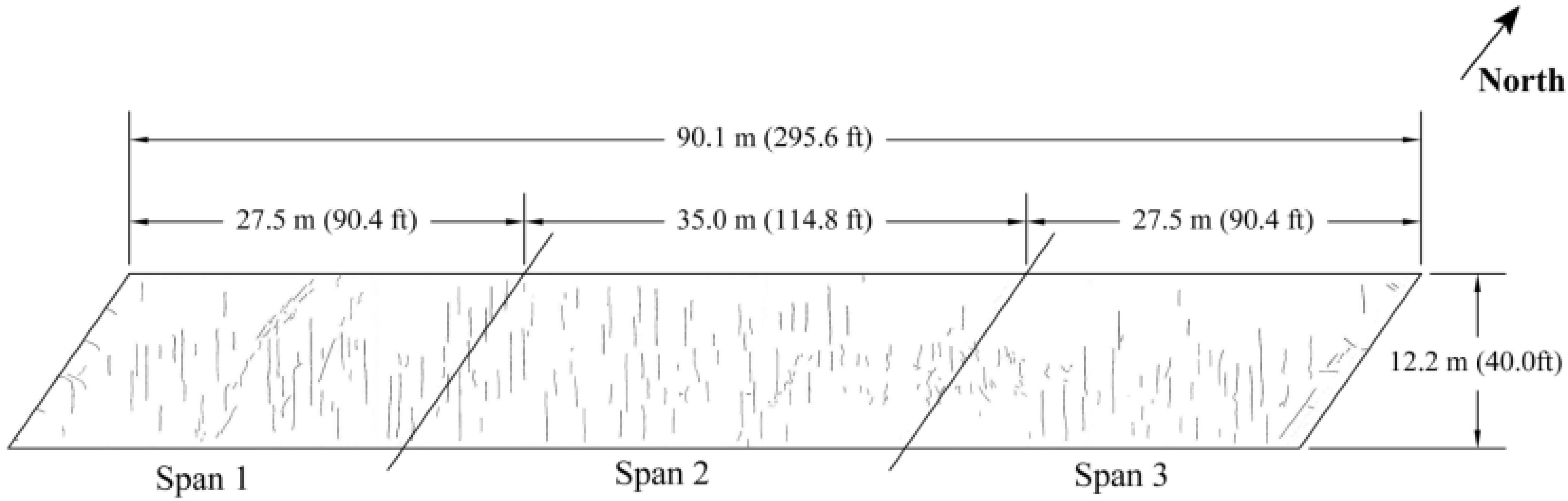


Bridge Number: 54-66 (LC-HPC-13)
Bridge Location: NB US-69 over BNSF RR, Linn County, KS
Construction Date: 4/29/2008
Crack survey Date: 6/1/2011

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: 37.1 months
Crack density: 0.364 m/m^2
Span 1 (West): 0.402 m/m^2
Span 2 (middle): 0.410 m/m^2
Span 3 (East): 0.268 m/m^2

Figure 78: LC-HPC-13 (Survey 3)



Bridge Number: 54-66 (LC-HPC-13)
Bridge Location: NB US-69 over BNSF RR, Linn County, KS
Construction Date: 4/29/2008
Crack survey Date: 5/29/2012

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

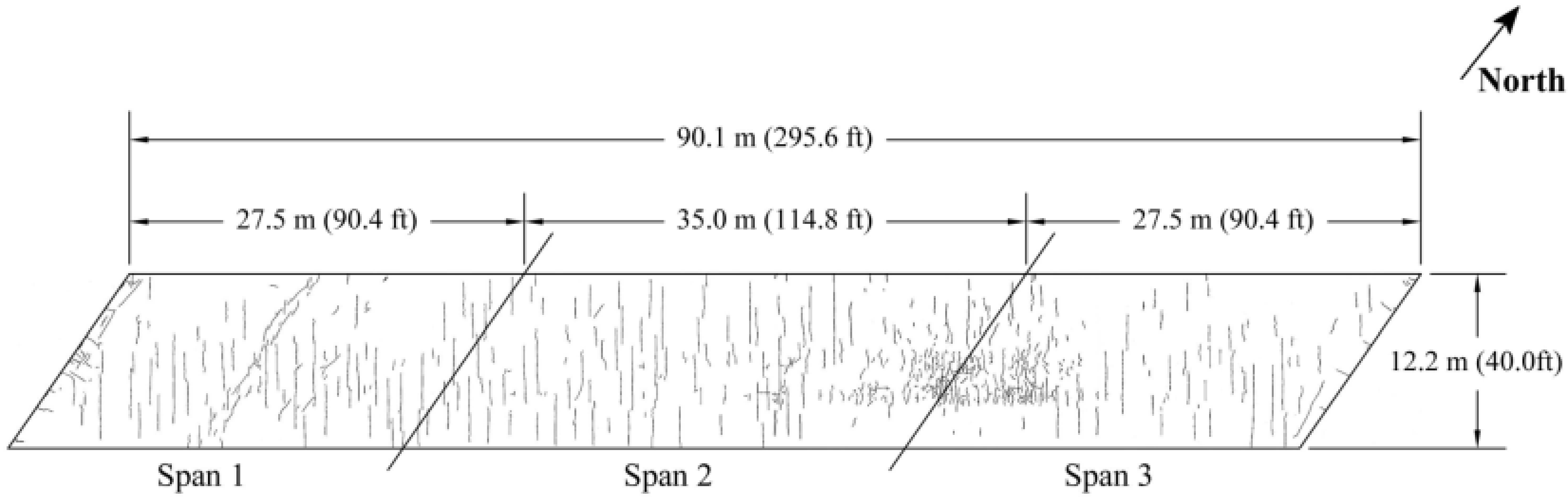
Bridge Age: 49.0 months
Crack density: 0.342 m/m^2
Span 1 (West): 0.392 m/m^2
Span 2 (middle): 0.342 m/m^2
Span 3 (East): 0.291 m/m^2

Figure 79: LC-HPC-13 (Survey 4)

m/m^2 at 62.9 months (Figure 80). Most of the cracks are transverse, parallel to and directly above the top reinforcement and, therefore, likely due to settlement and shrinkage. Map cracking is present above the second pier along with cracks that propagate perpendicular to the abutments and cracking parallel to the skew of the bridge in the center of the first span.

Control-13

The results of Surveys 3, 4, and 5 of Control-13, at 34.4, 46.1, and 60.0 months, are included in this report. The crack density of 0.524 m/m^2 at 34.4 months (Figure 81) represents an increase from the crack density of 0.154 m/m^2 measured in Survey 2 (Pendergrass et al. 2011) and is 44% higher than the density of LC-HPC-13 at 37.1 months, 0.364 m/m^2. The crack density of Control-13 at 46.1 months was 0.543 m/m^2 (Figure 82) and increased to 0.807 m/m^2 at 60.0 months (Figure 83), 59% and 40% higher, respectively, than densities on LC-HPC-13 at 49.0 and 62.9 months, 0.342 m/m^2 and 0.576 m/m^2. Significant map cracking is present at the east abutment, as well as in the middle of the first span. Transverse cracks have developed throughout the deck, with somewhat higher densities near the piers. Small cracks propagate perpendicular to the abutments. Figure 84 compares cracking on Control-13 to cracking on LC-HPC-13 over time. It is clear that LC-HPC-13 has experienced less cracking than Control-13 over the entire life of both bridges. Both decks have remarkably similar crack growth trends, with both decks experiencing an increase from 12 to 36 months, a plateau from 36 to 48 months, and another increase after 48 months. Cracking does not seem to have stabilized on either deck.

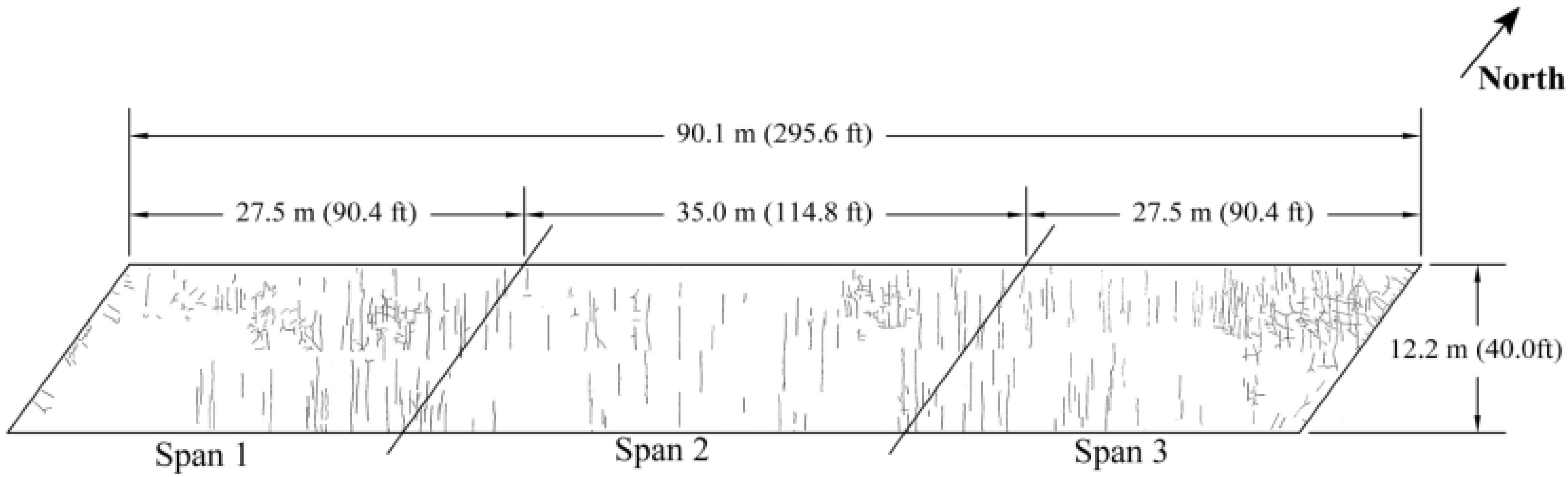


Bridge Number: 54-66 (LC-HPC-13)
Bridge Location: NB US-69 over BNSF RR, Linn County, KS
Construction Date: 4/29/2008
Crack survey Date: 7/25/2013

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: 62.9 months
Crack density: 0.576 m/m^2
Span 1 (West): 0.579 m/m^2
Span 2 (middle): 0.604 m/m^2
Span 3 (East): 0.536 m/m^2

Figure 80: LC-HPC-13 (Survey 5)

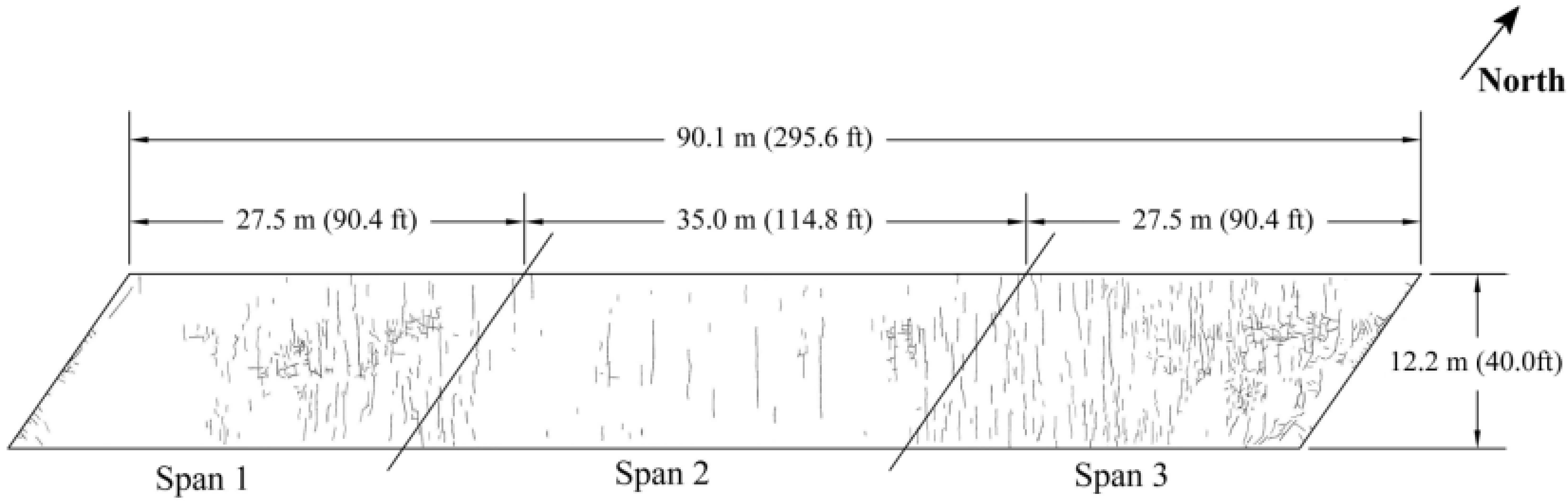


Bridge Number: 54-67
(Control-13)
Bridge Location: SB US-69 over
BNSF RR, Linn County, KS
Construction Date: 7/25/2008
Crack survey Date: 6/6/2011

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: 34.4 months
Crack density: 0.524 m/m^2
Span 1 (West): 0.568 m/m^2
Span 2 (middle): 0.393 m/m^2
Span 3 (East): 0.648 m/m^2

Figure 81: Control-13 (Survey 3)

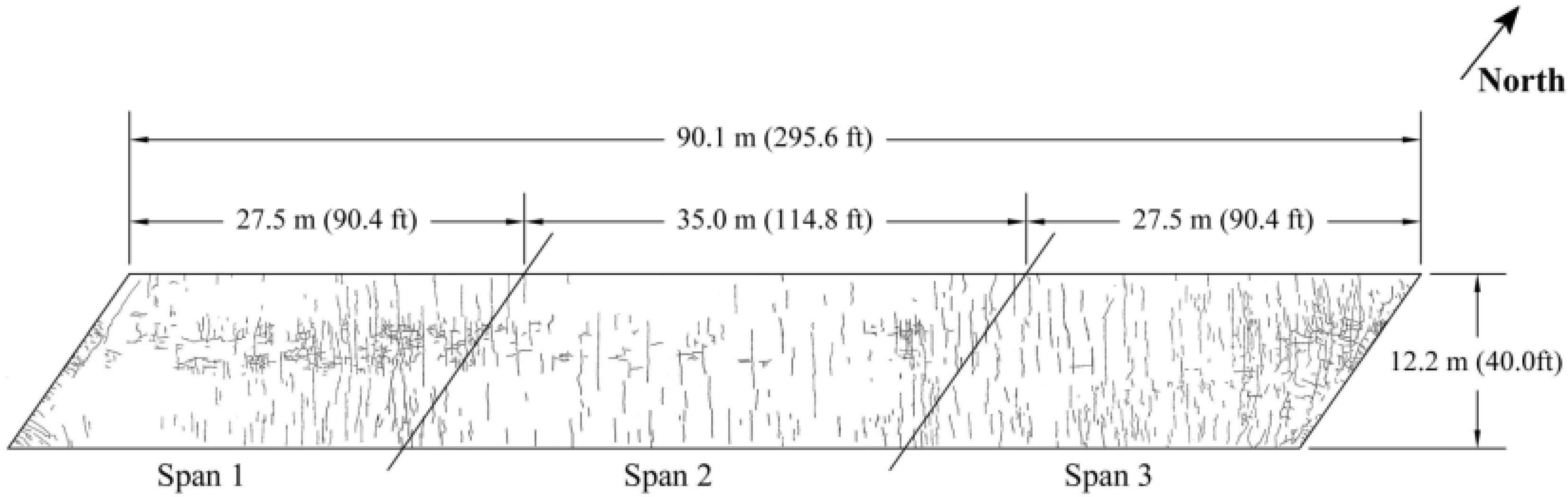


Bridge Number: 54-67
(Control-13)
Bridge Location: SB US-69 over
BNSF RR, Linn County, KS
Construction Date: 7/25/2008
Crack survey Date: 5/29/2012

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: 46.1 months
Crack density: 0.543 m/m^2
Span 1 (West): 0.494 m/m^2
Span 2 (middle): 0.268 m/m^2
Span 3 (East): 0.927 m/m^2

Figure 82: Control-13 (Survey 4)



Bridge Number: 54-67 (Control-13)
Bridge Location: SB US-69 over BNSF RR, Linn County, KS
Construction Date: 7/25/2008
Crack survey Date: 7/25/2013

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: 60.0 months
Crack density: 0.807 m/m^2
Span 1 (West): 0.931 m/m^2
Span 2 (middle): 0.524 m/m^2
Span 3 (East): 1.043 m/m^2

Figure 83: Control-13 (Survey 5)

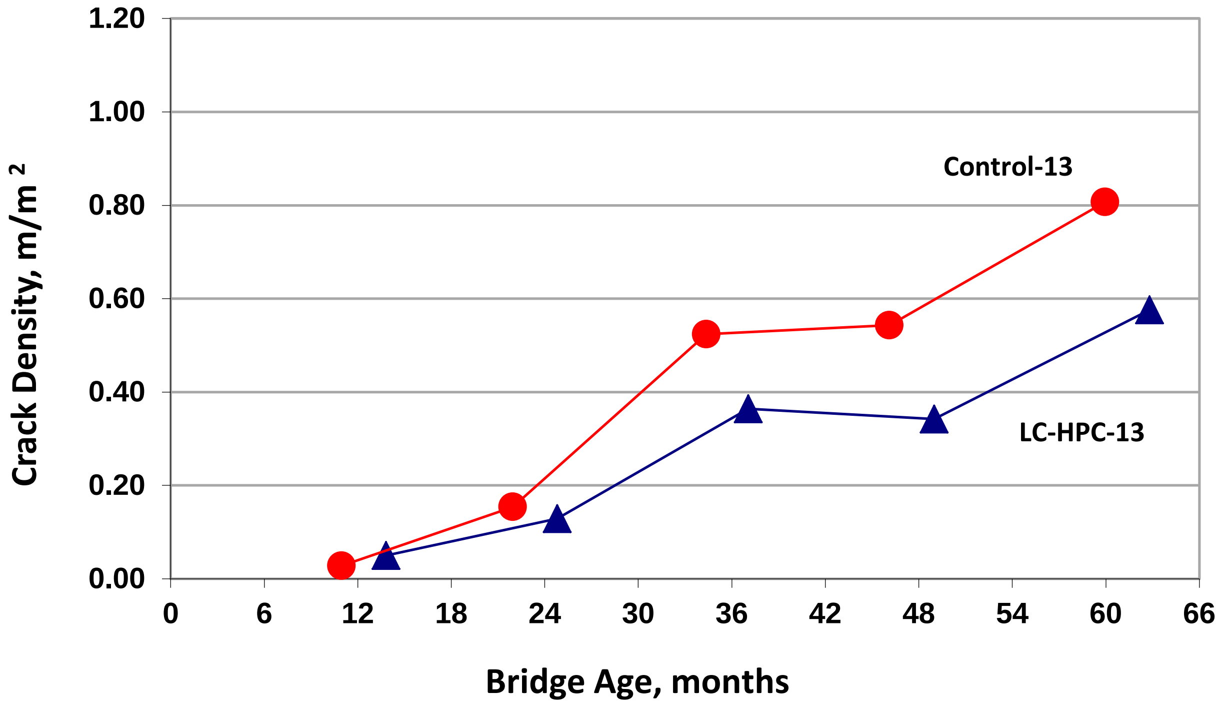
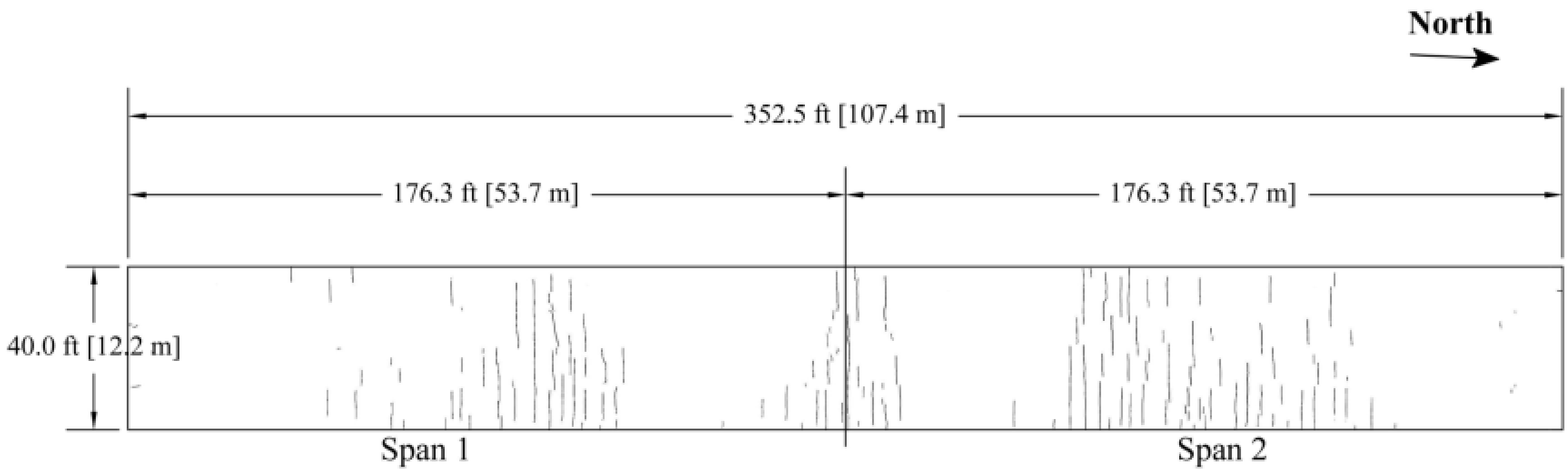


Figure 84: LC-HPC-13 and Control-13 Crack Densities

LC-HPC-15

The results of Surveys 1 and 2 of LC-HPC-15, at 18.9 and 30.8 months, are included in this report. The crack density was 0.211 m/m^2 at 18.9 months (Figure 85) and decreased to 0.161 m/m^2 at 30.8 months (Figure 86). The decrease in crack density is most likely due to several long transverse cracks in the first span that may have been overlooked. The cracks are transverse, mainly clustered near the pier and centers of the spans. Figure 87 shows cracking on LC-HPC-15 over time.

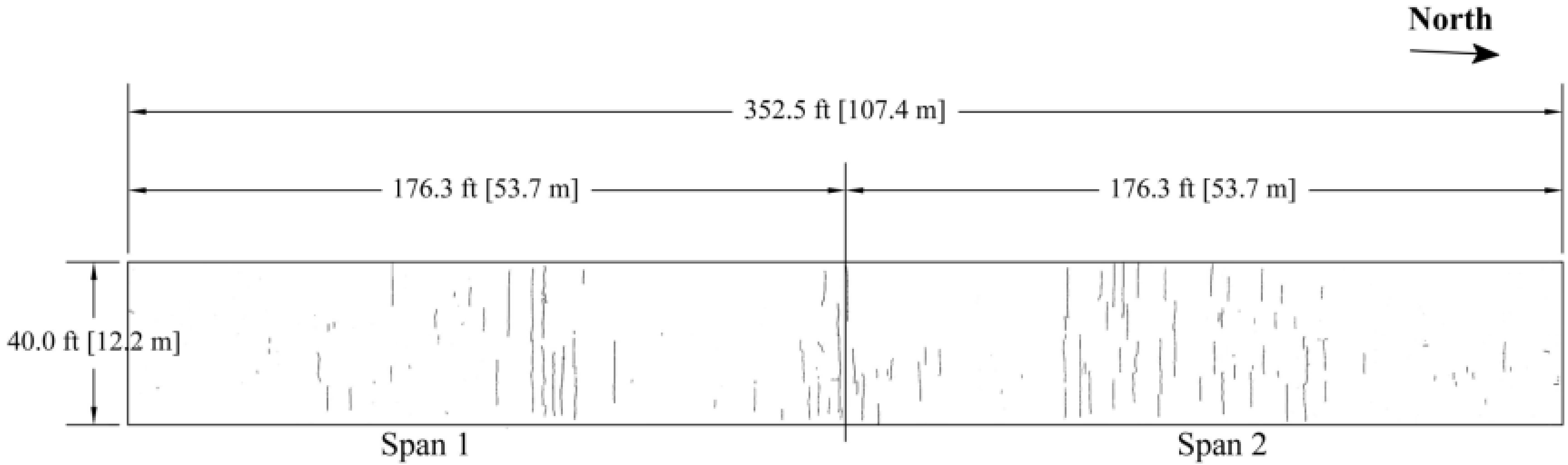


Bridge Number: 46-351 (LC-HPC-15)
Bridge Location: NB K-7 over Johnson Dr./55th St.
Construction Date: 11-10-10
Crack Survey Date: 6-8-2012

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

Bridge Age: 18.9 months
Crack Density: 0.211 m/m^2
Span 1: 0.183 m/m^2
Span 2: 0.236 m/m^2

Figure 85: LC-HPC-15 (Survey 1)



Bridge Number: 46-351 (LC-HPC-15)
Bridge Location: NB K-7 over Johnson Dr./55th St.
Construction Date: 11-10-10
Crack Survey Date: 6-3-2013

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

Bridge Age: 30.8 months
Crack Density: 0.161 m/m^2
Span 1: 0.134 m/m^2
Span 2: 0.182 m/m^2

Figure 86: LC-HPC-15 (Survey 2)

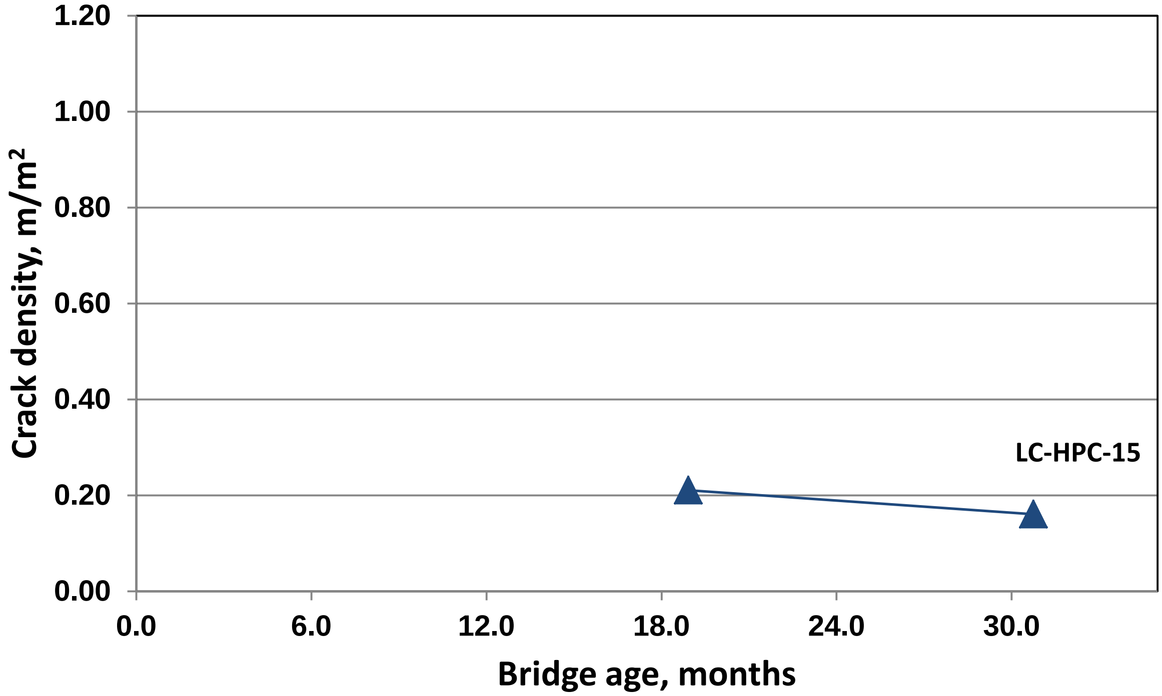
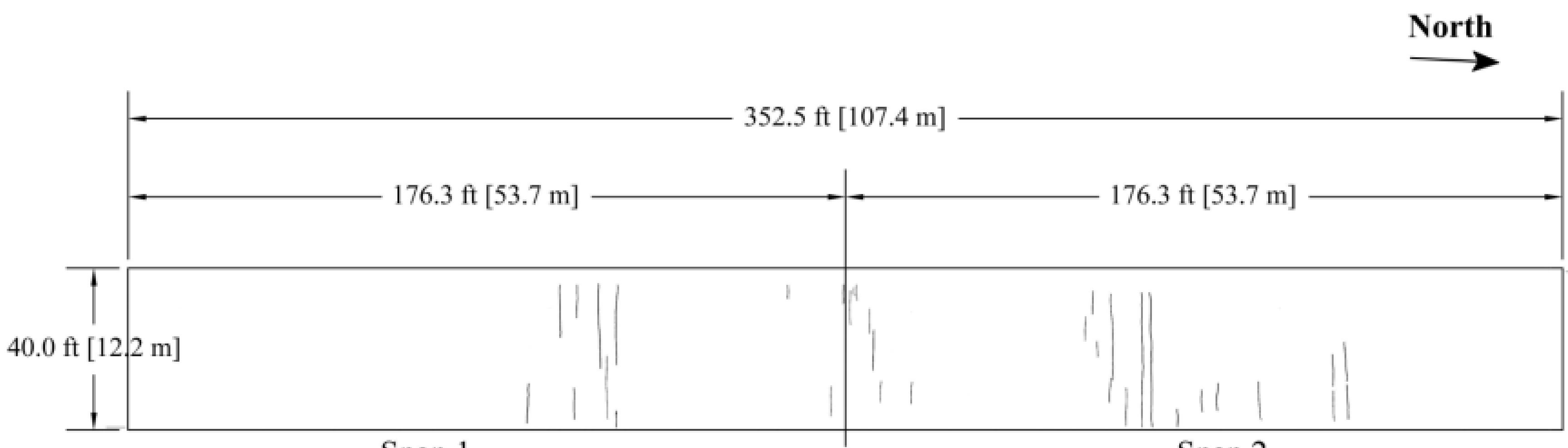


Figure 87: LC-HPC-15 Surveyed Crack Densities

LC-HPC-16

The results of Surveys 1, 2 and 3 of LC-HPC-16, at 7.70, 19.4 and 31.2 months, are included in this report. The crack density was only 0.092 m/m^2 at 7.70 months (Figure 88), and grew to 0.249 m/m^2 at 19.4 months (Figure 89). The crack density then decreased to 0.211 m/m^2 at 31.2 months (Figure 90). The cracks are transverse, mainly clustered near the pier and centers of the spans, similar to LC-HPC-15. Figure 91 shows cracking on LC-HPC-16 over time.

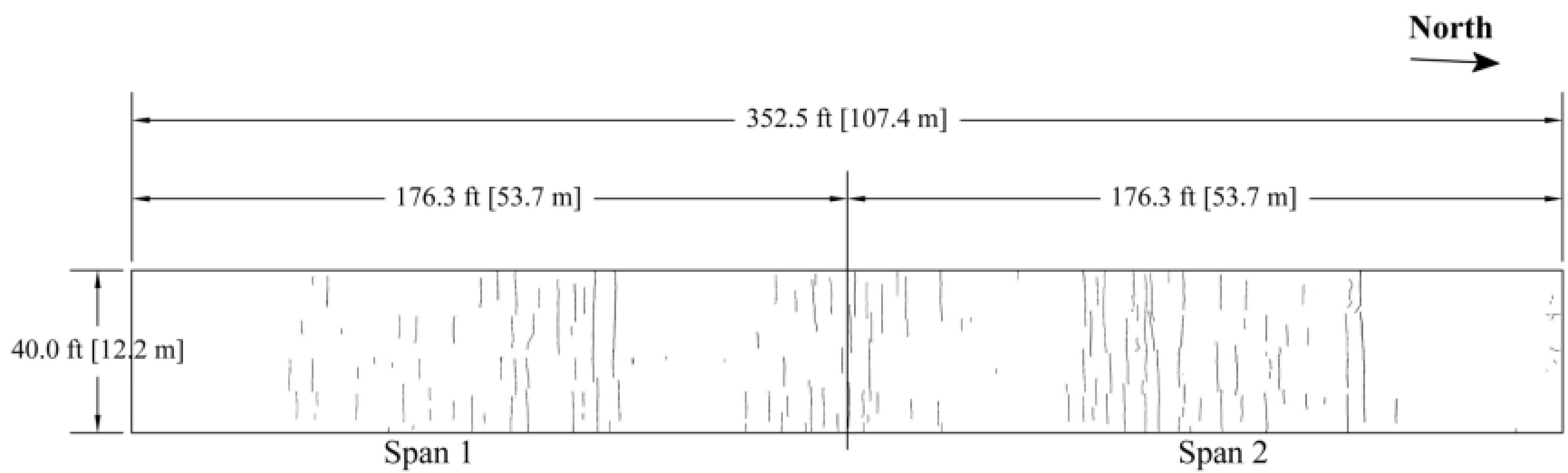


Bridge Number: 46-352 (LC-HPC-16)
Bridge Location: SB K-7 over Johnson Dr./55th St.
Construction Date: 10-28-2010
Crack Survey Date: 6-20-2011

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

Bridge Age: 7.7 months
Crack Density: 0.092 m/m
Span 1: 0.058 m/m^2
Span 2: 0.119 m/m^2

Figure 88: LC-HPC-16 (Survey 1)

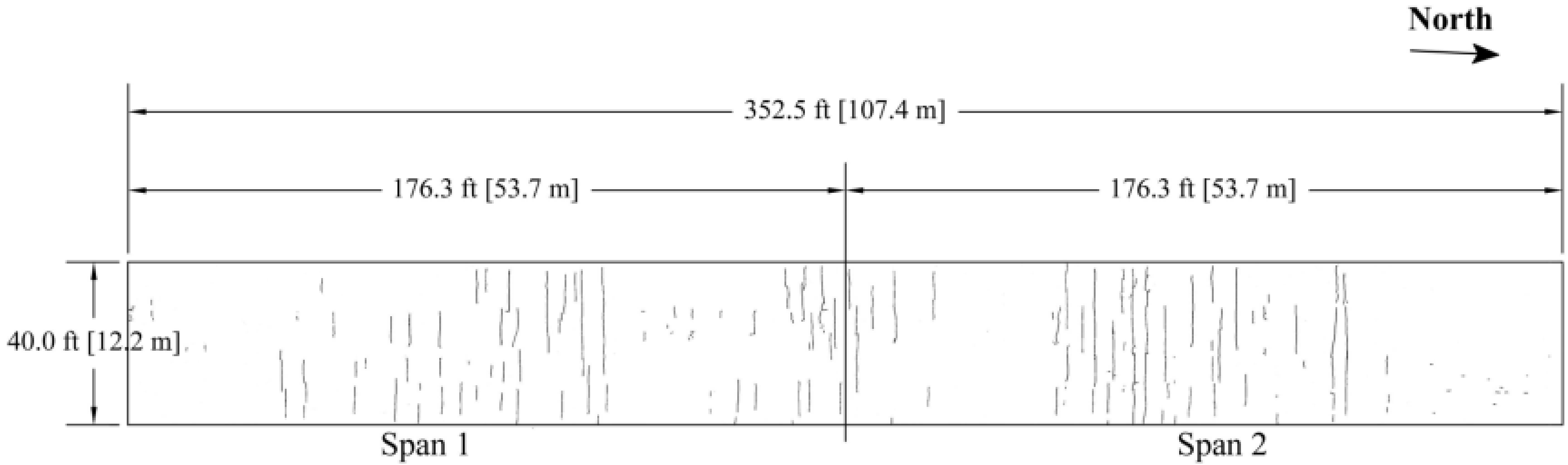


Bridge Number: 46-352 (LC-HPC-16)
Bridge Location: SB K-7 over Johnson Dr./55th St.
Construction Date: 10-28-2010
Crack Survey Date: 6-8-2012

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

Bridge Age: 19.4 months
Crack Density: 0.249 m/m^2
Span 1: 0.204 m/m^2
Span 2: 0.287 m/m^2

Figure 89: LC-HPC-16 (Survey 2)



Bridge Number: 46-352 (LC-HPC-16)
Bridge Location: SB K-7 over Johnson Dr./55th St.
Construction Date: 10-28-2010
Crack Survey Date: 6-3-2013

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

Bridge Age: 31.2 months
Crack Density: 0.211 m/m^2
Span 1: 0.196 m/m^2
Span 2: 0.225 m/m^2

Figure 90: LC-HPC-16 (Survey 3)

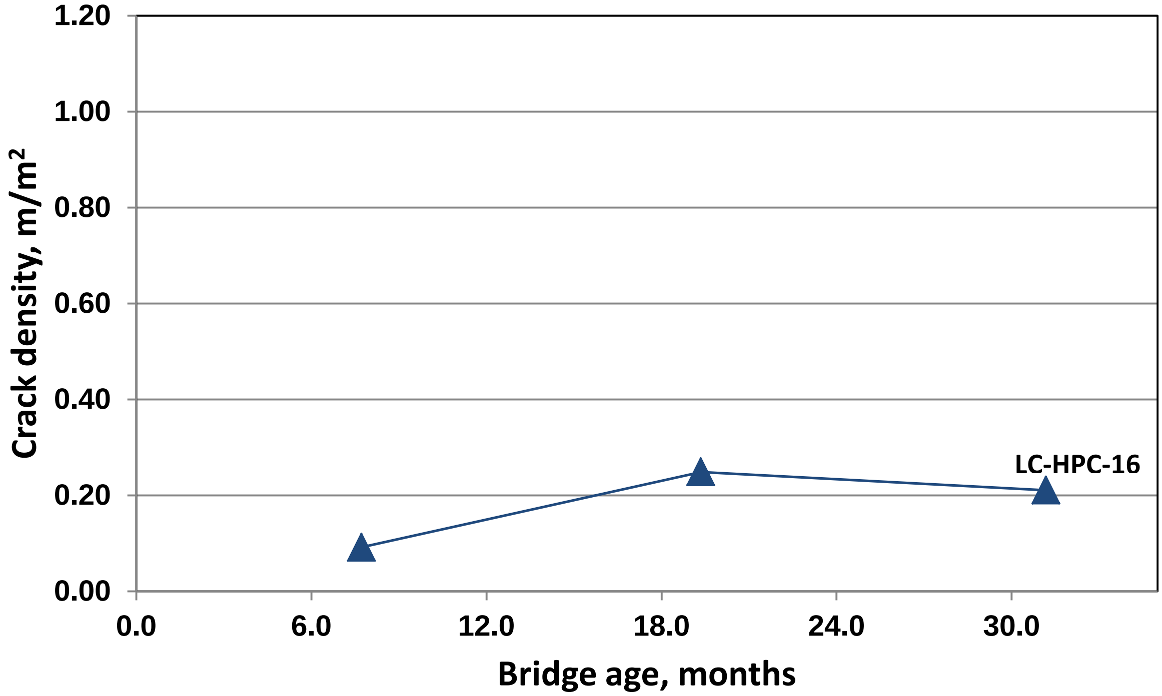
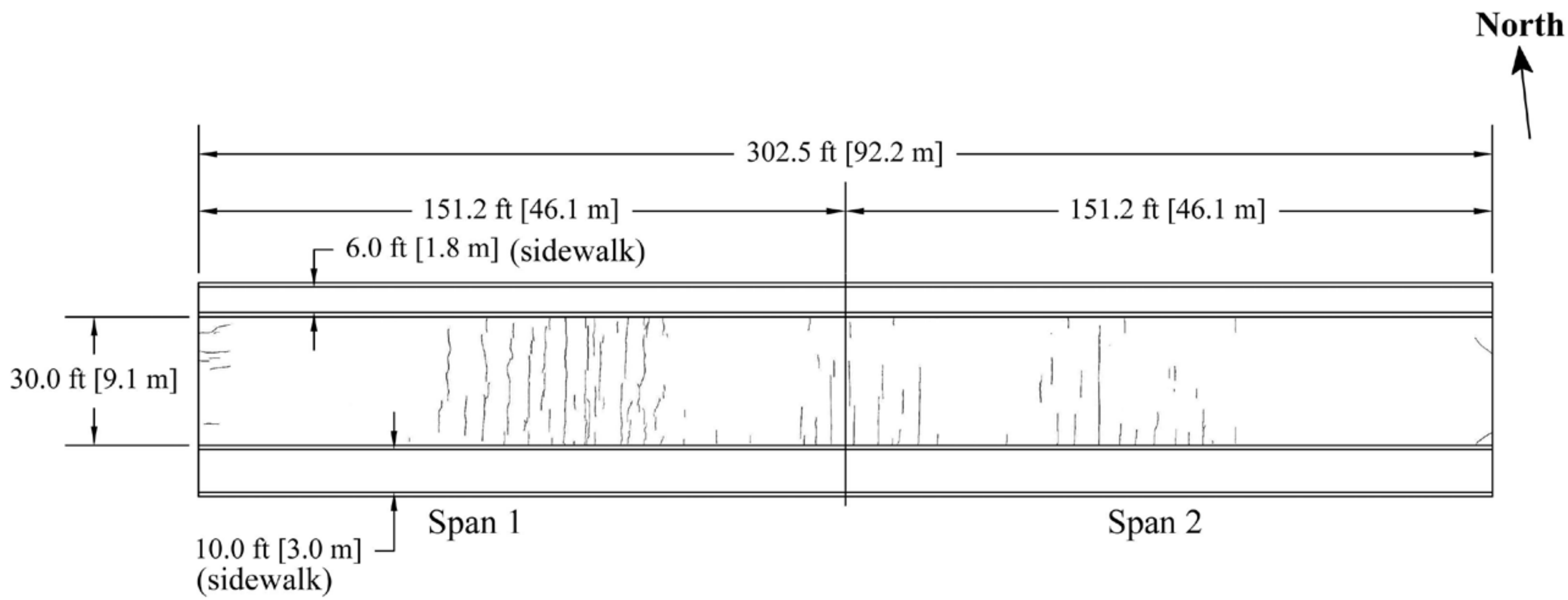


Figure 91: LC-HPC-16 Crack Densities

LC-HPC-17

The results of Surveys 1 and 2 of LC-HPC-17, at 8.94 and 20.5 months, are included in this report. The crack density was 0.226 m/m^2 at 8.94 months (Figure 92), and increased to 0.240 m/m^2 at 20.5 months (Figure 93). The sidewalks on LC-HPC-17 were not surveyed because the concrete was stamped and colored, making it difficult to discern cracks. Similar to LC-HPC-15 and LC-HPC-16, there are transverse cracks near the pier and centers of the spans. There is also a small amount of longitudinal cracking at the west abutment. Figure 94 shows cracking on LC-HPC-17 over time.

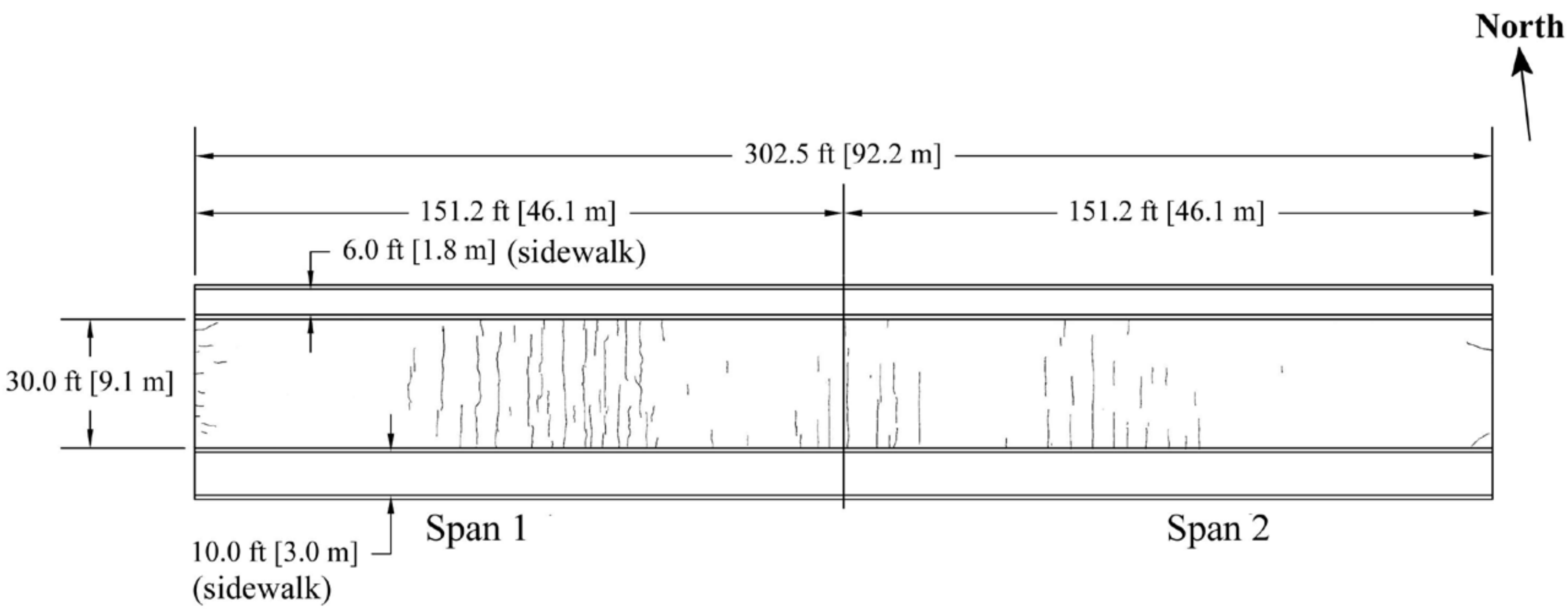


Bridge Number: 46-373 (LC-HPC-17)
Bridge Location: Clear Creek Parkway over K-7
Construction Date: 09-28-11
Crack Survey Date: 6-26-2012

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

Bridge Age: 8.94 months
Crack Density: 0.226 m/m^2
Span 1: 0.302 m/m^2
Span 2: 0.145 m/m^2

Figure 92: LC-HPC-17 (Survey 1)



Bridge Number: 46-373 (LC-HPC-17)
Bridge Location: Clear Creek Parkway over K-7
Construction Date: 09-28-11
Crack Survey Date: 6-14-2013

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

Bridge Age: 20.5 months
Crack Density: 0.240 m/m^2
Span 1: 0.314 m/m^2
Span 2: 0.157 m/m^2

Figure 93: LC-HPC-17 (Survey 2)

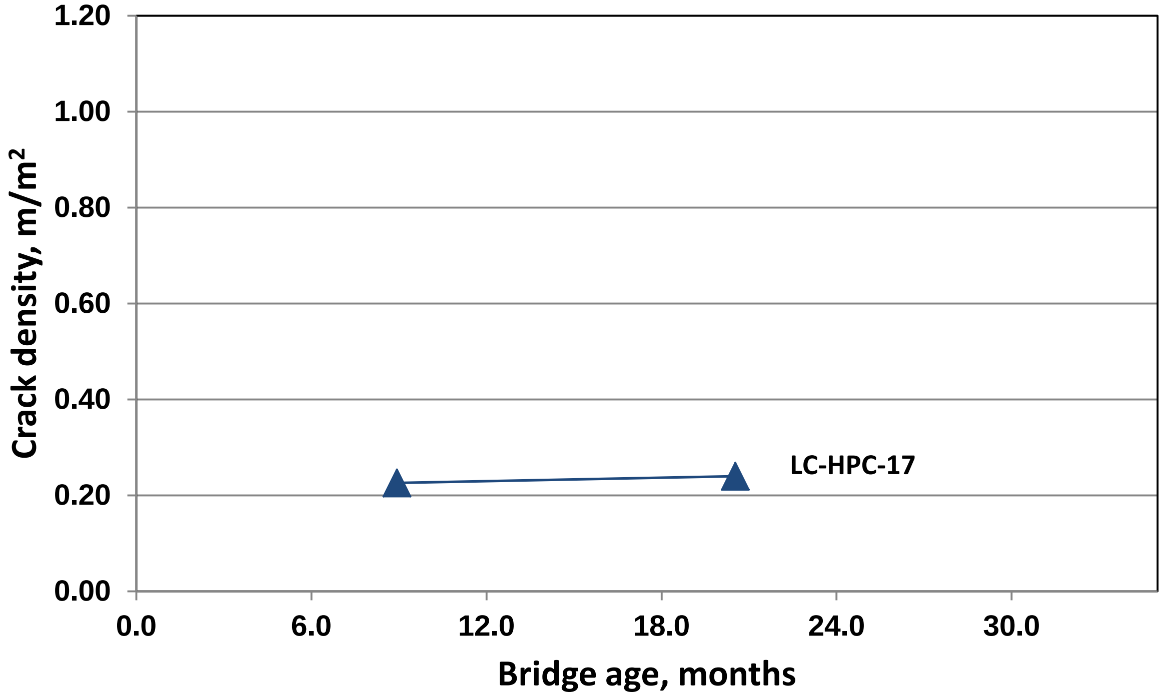


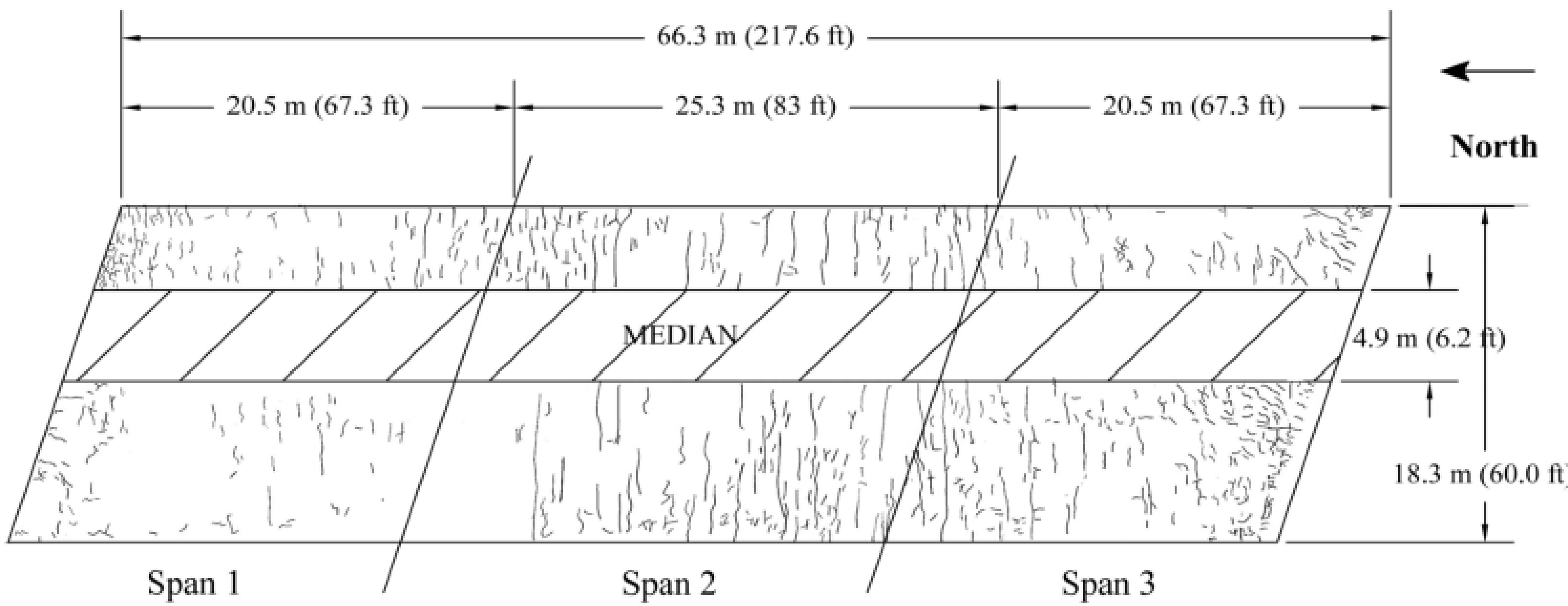
Figure 94: LC-HPC-17 Crack Densities

OP Bridge – Placement 1

The results of Surveys 3 and 4 of OP Bridge – Placement 1, at 42.2 and 66.6 months, are included in this report. The contractor did not follow and the owner did not enforce many of the key LC-HPC specifications (McLeod et al. 2009), causing the OP Bridge deck to have a much higher crack density than any of other decks bid under an LC-HPC specification. Placement 1 was constructed on two separate dates due to a concrete pumping problem. Thirty feet of concrete was placed before construction was halted because concrete was clogging the pump. This portion of the deck was removed and the entire deck, with the exception of the abutment, was placed on the second attempt. Some of the concrete used in the second attempt had a slump greater than 5 in. Consolidation of the concrete was inadequate, with coarse aggregate visible at the surface after removal of the vibrators. The vibrators were also removed too quickly, leaving holes in the concrete at the locations where the vibrators had been inserted. The contractor spent a considerable amount of time bullfloating, bringing excess cement paste to the surface and leaving the concrete overfinished in many locations (Lindquist et al. 2008 and McLeod et al. 2009). The elapsed time between deck finishing and burlap placement exceeded the ten-minute limit throughout construction, mainly due to the overfinishing. The contractor used water from the fogging equipment as a finishing agent (McLeod et al. 2009). The crack density of OP Bridge – Placement 1 was 0.585 m/m^2 at 42.2 months (Figure 95), a slight increase from 0.502 m/m^2 at 30.0 months (Pendergrass et al. 2011). The crack density of OP Bridge – Placement 1 at 66.6 months more than doubled to 1.083 m/m^2 (Figure 96).

OP Bridge – Placement 2

The results of Surveys 3 and 4 of OP Bridge – Placement 2, at 37.7 and 62.2 months, are included in this report. Placement 2 for the OP deck faced many of the same problems during construction as Placement 1, again leading to much higher crack densities than the LC-HPC decks. The slump and air contents specified in the LC-HP concrete specifications were exceeded, and the high slump led to problems with settlement cracking over the reinforcement. There was heavy rain the night before placement, making it difficult for the concrete supplier to accurately determine the aggregate moisture contents (McLeod et al. 2009). A double-drum roller was used for finishing, possibly causing the concrete to be overworked and bringing excess cement paste to the surface. The specified ten-minute maximum elapsed time between finishing and burlap placement was consistently exceeded. Additionally, concrete was removed from a wingwall during a delay in concrete delivery and placed into the deck. The crack density was 1.303 m/m^2 at 37.6 months (Figure 97), almost double the crack density of 0.727 m/m^2 at 25.5 months (Pendergrass et al. 2011), and then increased to 1.331 m/m^2 at 62.2 months (Figure 98). Extensive map cracking has occured throughout the deck, but mainly above the first pier and the



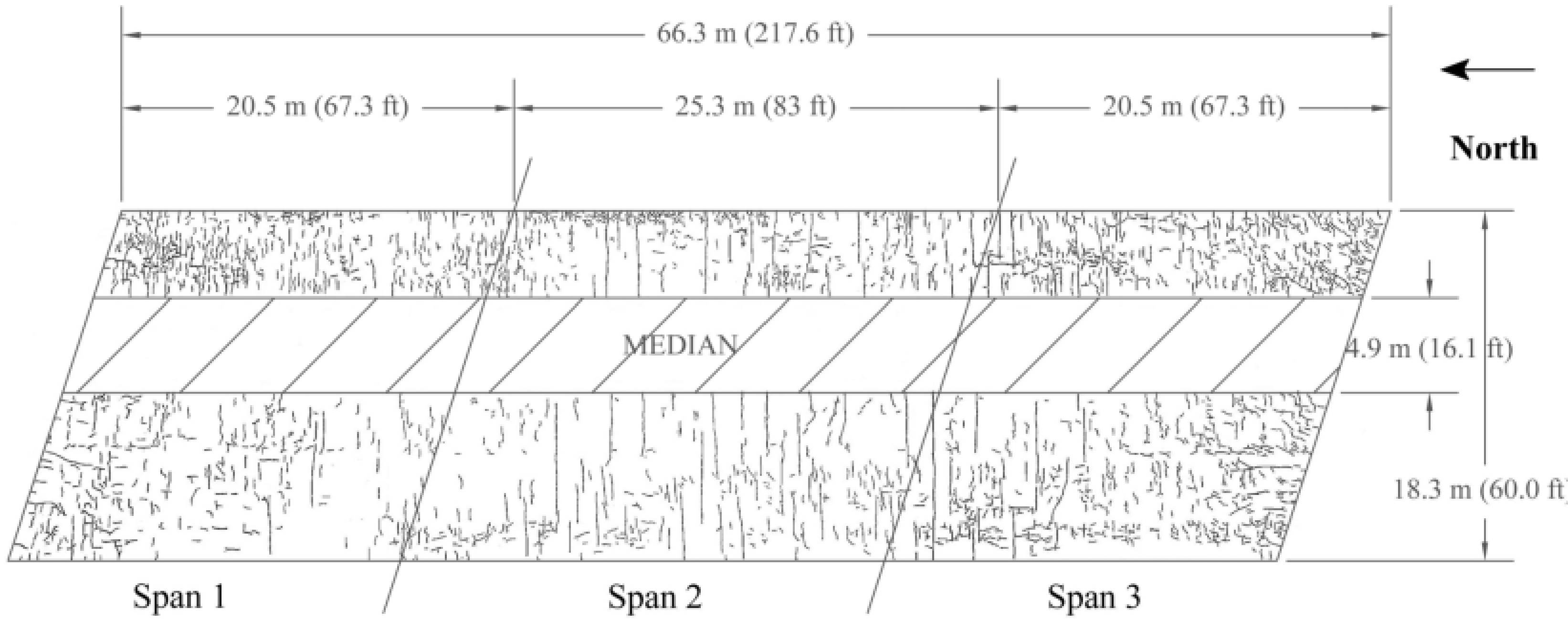
Bridge Number: 46-363 (OP Bridge - Placement 1)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 12/19/2007
Crack Survey Date: 6/24/2011

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: 42.2 months
Crack Density: 0.585 m/m^2
- **Span 1:** 0.410 m/m^2
- **Span 2:** 0.621 m/m^2
- **Span 3:** 0.718 m/m^2

Figure 95: OP Bridge – Placement 1 (Survey 3)



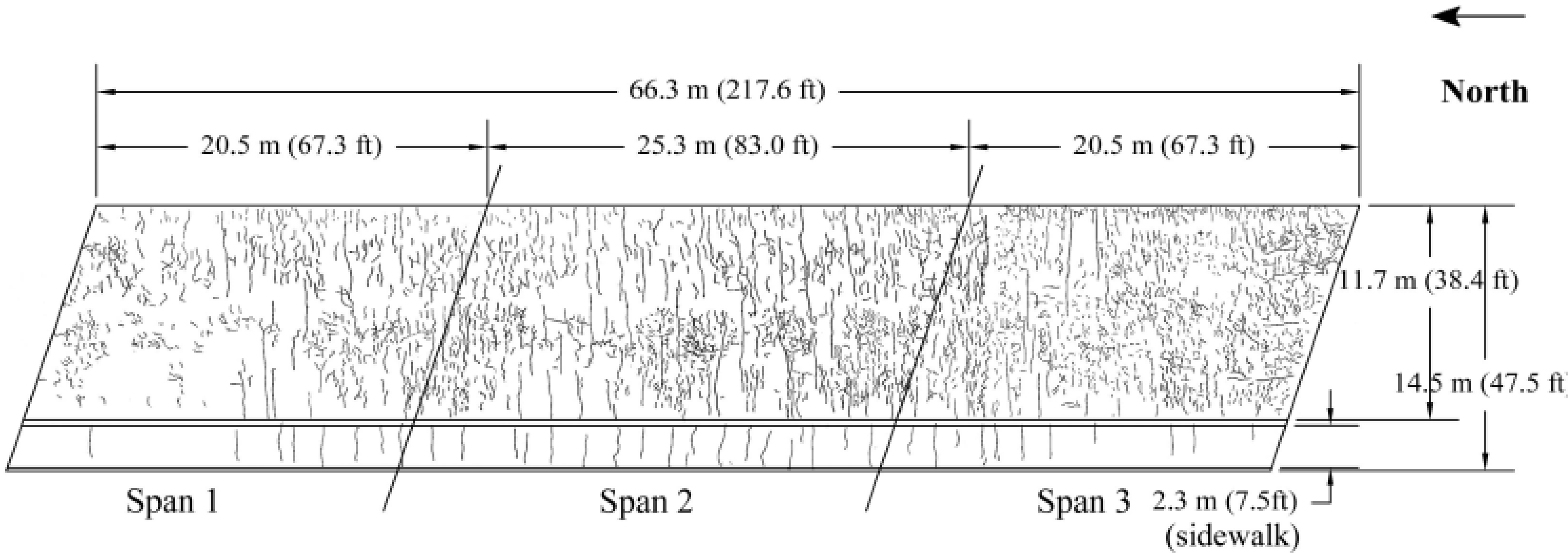
Bridge Number: 46-363 (OP Bridge - Placement 1)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 12/19/2007
Crack Survey Date: 7/8/2013

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: 66.6 months
Crack Density: 1.083 m/m^2
- **Span 1:** 1.040 m/m^2
- **Span 2:** 0.903 m/m^2
- **Span 3:** 0.985 m/m^2

Figure 96: OP Bridge – Placement 1 (Survey 4)

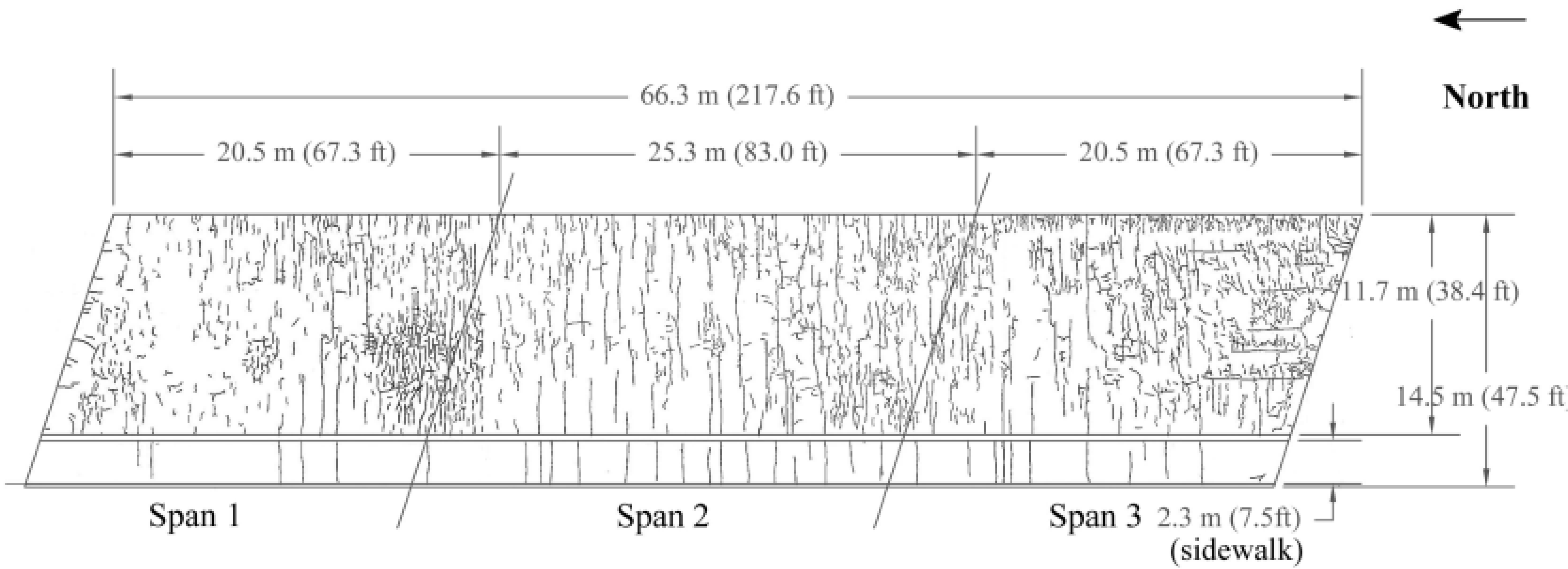


Bridge Number: 46-363 (OP Bridge - Placement 2)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 5/2/2008
Crack Survey Date: 6/24/2011

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: 37.7 months
Crack Density: 1.303 m/m^2
Span 1: 0.940 m/m^2
Span 2: 1.443 m/m^2
Span 3: 1.500 m/m^2

Figure 97: OP Bridge – Placement 2 (Survey 3)



Bridge Number: 46-363 (OP Bridge - Placement 2)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 5/2/2008
Crack Survey Date: 7/8/2013

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

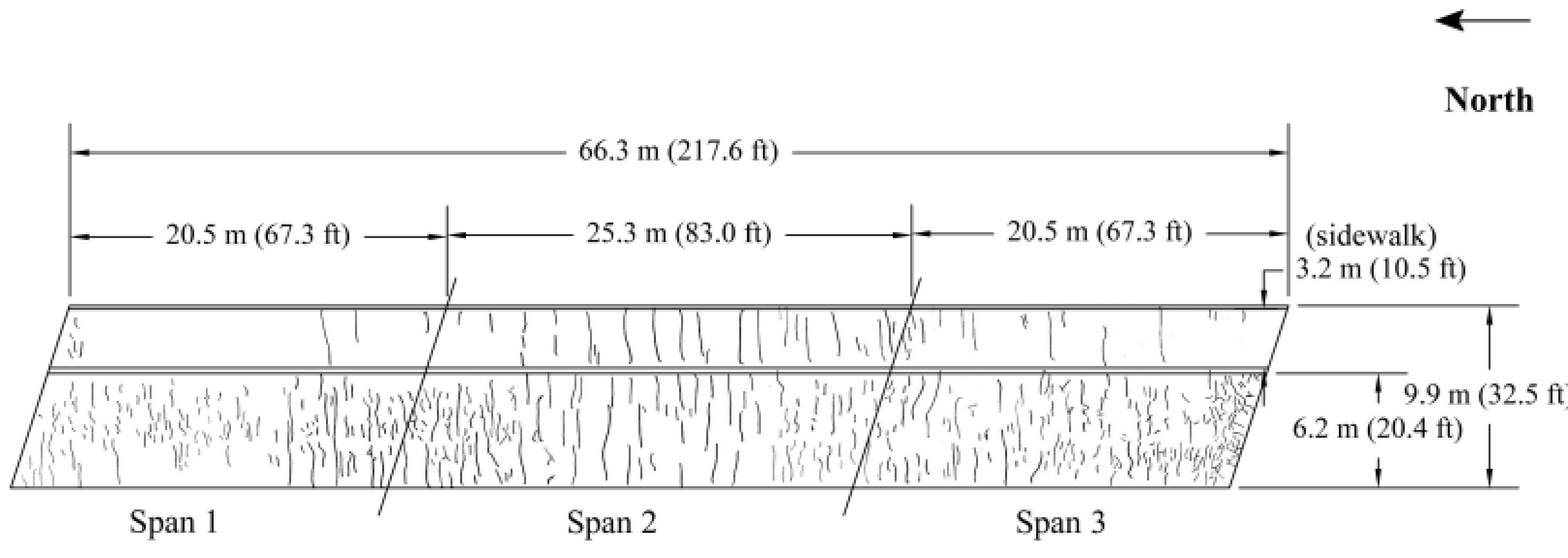
Bridge Age: 62.2 months
Crack Density: 1.331 m/m^2
  Span 1: 1.179 m/m^2
  Span 2: 1.306 m/m^2
  Span 3: 1.521 m/m^2

Figure 98: OP Bridge – Placement 2 (Survey 4)

of south abutment. There are long transverse cracks along the length of the bridge and short cracks extending from the eastern edge the placement. Longitudinal cracks have also formed at both abutments. While the sidewalk on Placement 2 has also experienced longitudinal cracking, but significantly less than on the remainder of the placement.

OP Bridge – Placement 3

The results of Surveys 3 and 4 of OP Bridge – Placement 3, at 37.1 and 61.6 months, are included in this report. Placement 3 had similar problems during construction as Placements 1 and 2, causing higher crack densities than the LC-HPC decks. The concrete used had very high slumps and high air contents. Additionally, it was observed that the reinforcement was not strongly supported, causing it to spring up and possibly increase the amount of settlement cracking. As with Placement 2, a double-drum roller was used for finishing. The time between finishing and burlap placement exceeded 10 minutes over most of the deck (Gruman et al. 2009). For Survey 3, the crack density was 0.678 m/m^2 at 37.1 months (Figure 99), less than the crack density at 24.9 months of 0.871 m/m^2 (Pendergrass et al. 2011). Many of the cracks in Placement 3 are small and may have been overlooked in Survey 3, leading to the lower crack density. The crack density more than doubled to 1.387 m/m^2 at 61.6 months (Figure 100). Transverse cracks have formed along the length of the deck, but the majority of cracks are very small. There are also short cracks extending from the eastern edge of the placement, and longitudinal cracks have formed at both abutments. Similar to Placement 2, the sidewalk of Placement 3 has experienced less cracking than the remainder of the placement. Figure 101 compares cracking for the three OP Bridge placements over time. It is evident that all three placements have experienced high crack growth, which can be attributed to the lack of adherence to the LC-HPC specifications

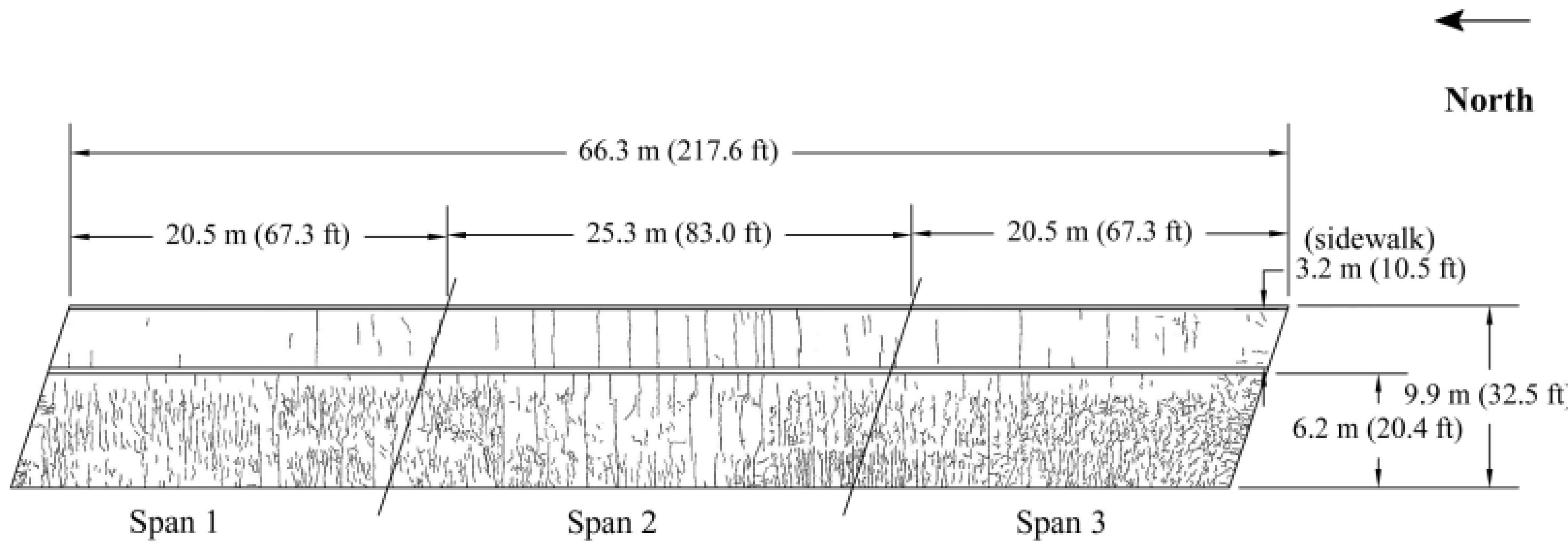


Bridge Number: 46-363 (OP Bridge - Placement 3)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 5/21/2008
Crack Survey Date: 6/24/2011

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: 37.1 months
Crack Density: 0.678 m/m^2
Span 1: 0.558 m/m^2
Span 2: 0.708 m/m^2
Span 3: 0.737 m/m^2

Figure 99: OP Bridge – Placement 3 (Survey 3)



Bridge Number: 46-363 (OP Bridge - Placement 3)
Bridge Location: Metcalf Ave over Indian Creek, OP, Kansas
Construction Date: 5/21/2008
Crack Survey Date: 7/8/2013

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: 61.6 months
Crack Density: 1.387 m/m^2
  Span 1: 1.248 m/m^2
  Span 2: 1.369 m/m^2
  Span 3: 1.555 m/m^2

Figure 100: OP Bridge – Placement 3 (Survey 4)

during construction. While Placement 3 experienced an apparent decline in crack density between ages 24 and 38 months, it now has the highest crack density of the three placements.

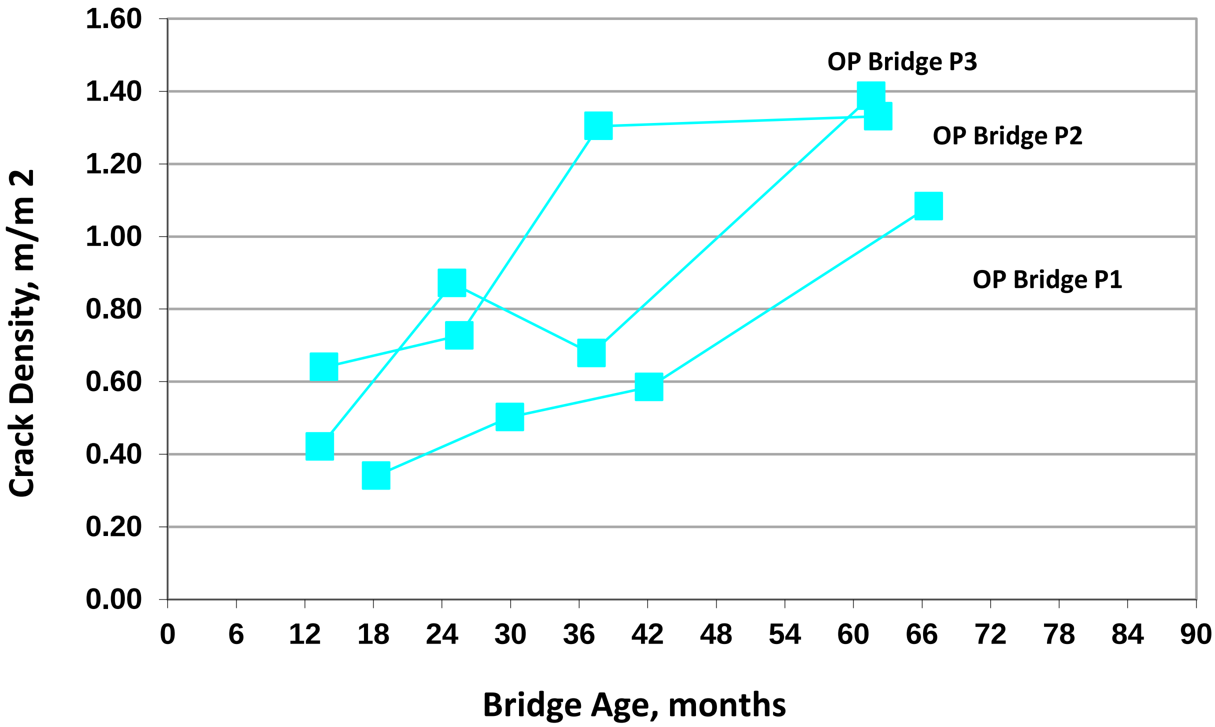
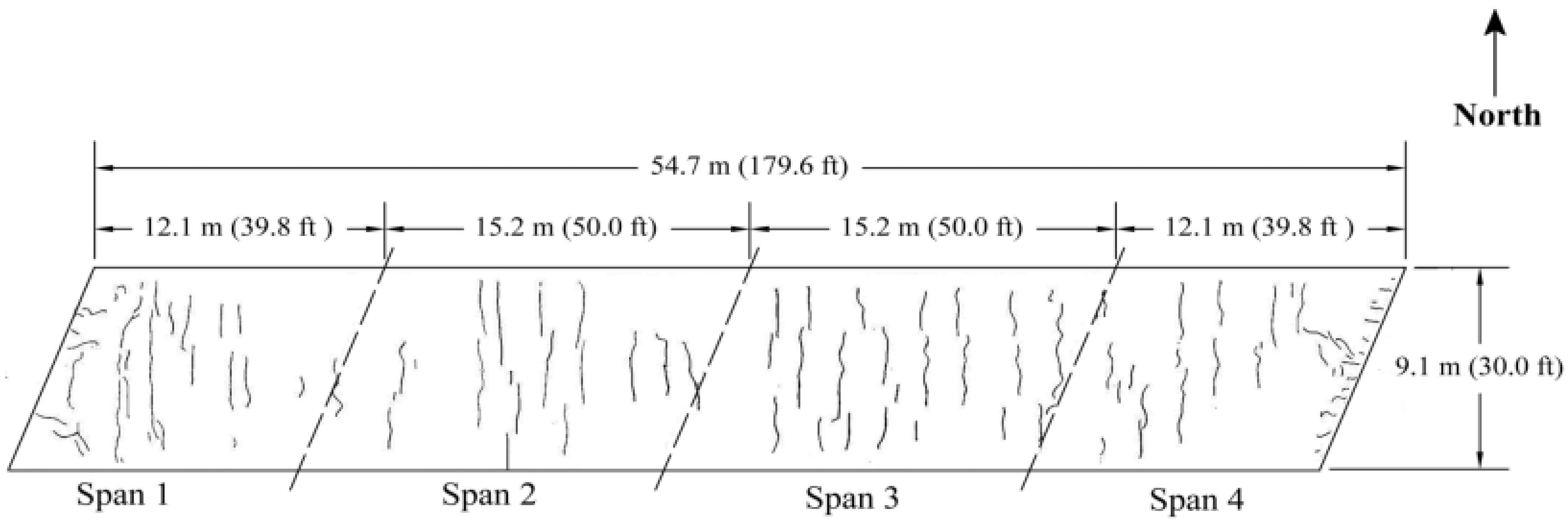


Figure 101: OP Bridge Crack Densities

Control-Alt

Control-Alt, located in Emporia, KS, was chosen as an additional control deck because it is a monolithic deck. All LC-HPC decks in the project are also monolithic, and all of the other control decks except for Control-8/10 have a silica fume overlay. The results of Surveys 6, 7, and 8 of Control-Alt at 72.6, 85.0, and 96.0 months, are included in this report. The crack density of Control-Alt at 72.6 months was 0.358 m/m^2 (Figure 102), representing an increase from the value of 0.316 m/m^2 measured in Survey 5 (Pendergrass et al. 2011). The density increased to 0.395 m/m^2 at 85.0 months (Figure 103), then decreased to 0.304 m/m^2 at 96.0 months (Figure 104). The cracks are mainly transverse and are evenly distributed along the length of the bridge



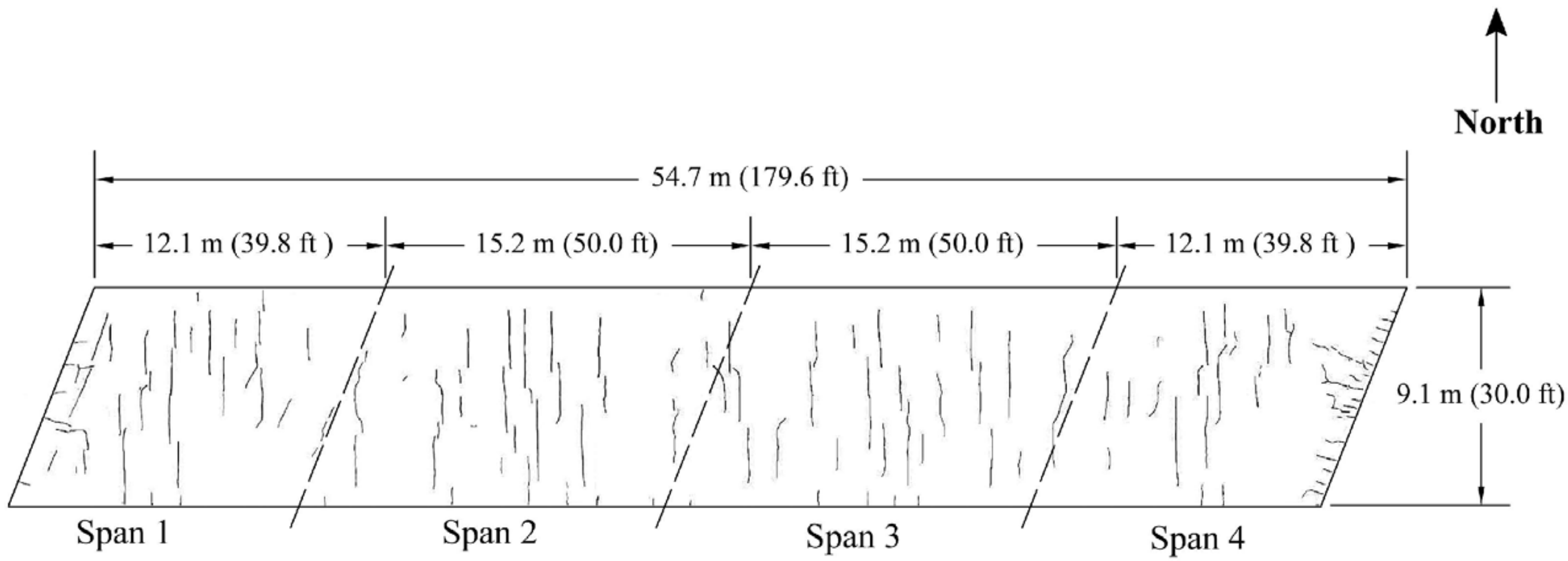
Bridge Number: 56-49 (Control-Alt)
Bridge Location: K-99 over I-335
Construction Date: 6/2/2005
Crack survey Date: 6/23/2011

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: 72.6 months
Crack density: 0.358 m/m^2
- **Span 1 :** 0.417 m/m^2
- **Span 2 :** 0.309 m/m^2
- **Span 3 :** 0.367 m/m^2
- **Span 4 :** 0.346 m/m^2

Figure 102: Control-Alt (Survey 6)



Bridge Number: 56-49 (Control-Alt)

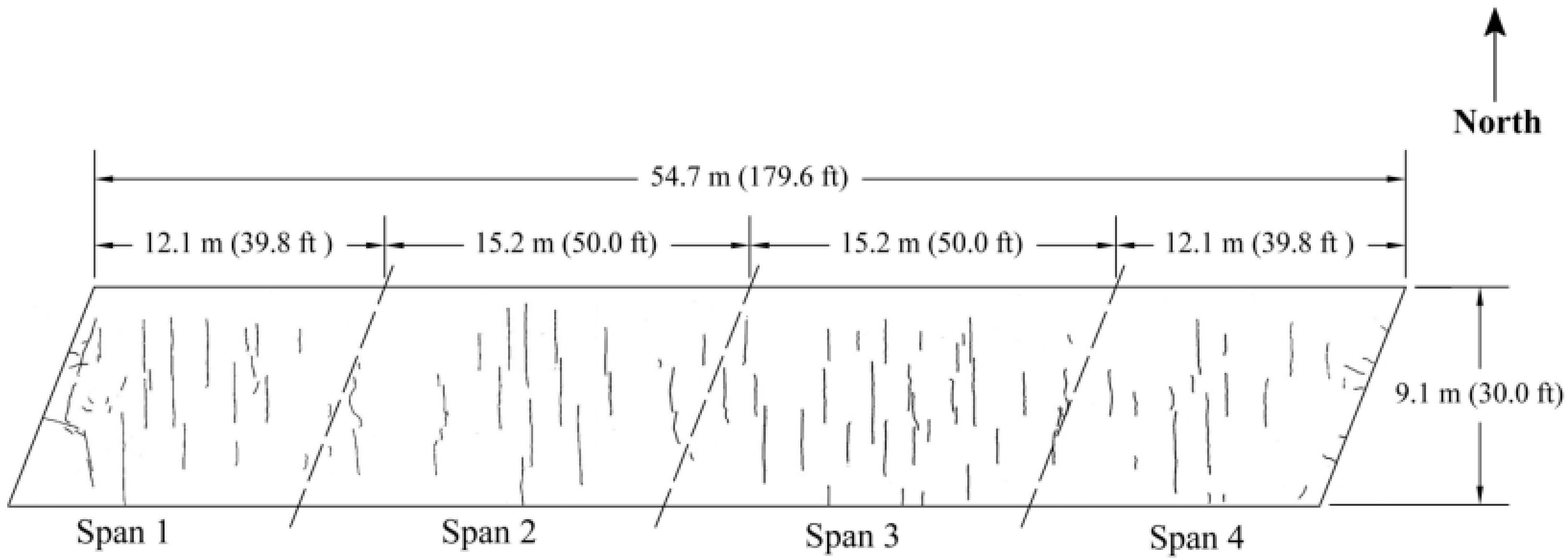
Bridge Location: K-99 over I-335
Construction Date: 6/2/2005
Crack survey Date: 7/3/2012

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: 85.0 months
Crack density: 0.395 m/m^2
- **Span 1 :** 0.443 m/m^2
- **Span 2 :** 0.365 m/m^2
- **Span 3 :** 0.382 m/m^2
- **Span 4 :** 0.389 m/m^2

Figure 103: Control-Alt (Survey 7)



Bridge Number: 56-49 (Control-Alt)

Bridge Location: K-99 over I-335
Construction Date: 6/2/2005
Crack survey Date: 6/6/2013

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: 96.0 months
Crack density: 0.304 m/m^2
Span 1 : 0.351 m/m^2
Span 2 : 0.272 m/m^2
Span 3 : 0.345 m/m^2
Span 4 : 0.233 m/m^2

Figure 104: Control-Alt (Survey 8)

deck, likely caused by shrinkage and settlement over the reinforcement. There are also some small cracks propagating perpendicular to the abutments. Figure 105 shows cracking on Control-Alt over time. The deck has experienced a relatively steady increase in crack density over time.

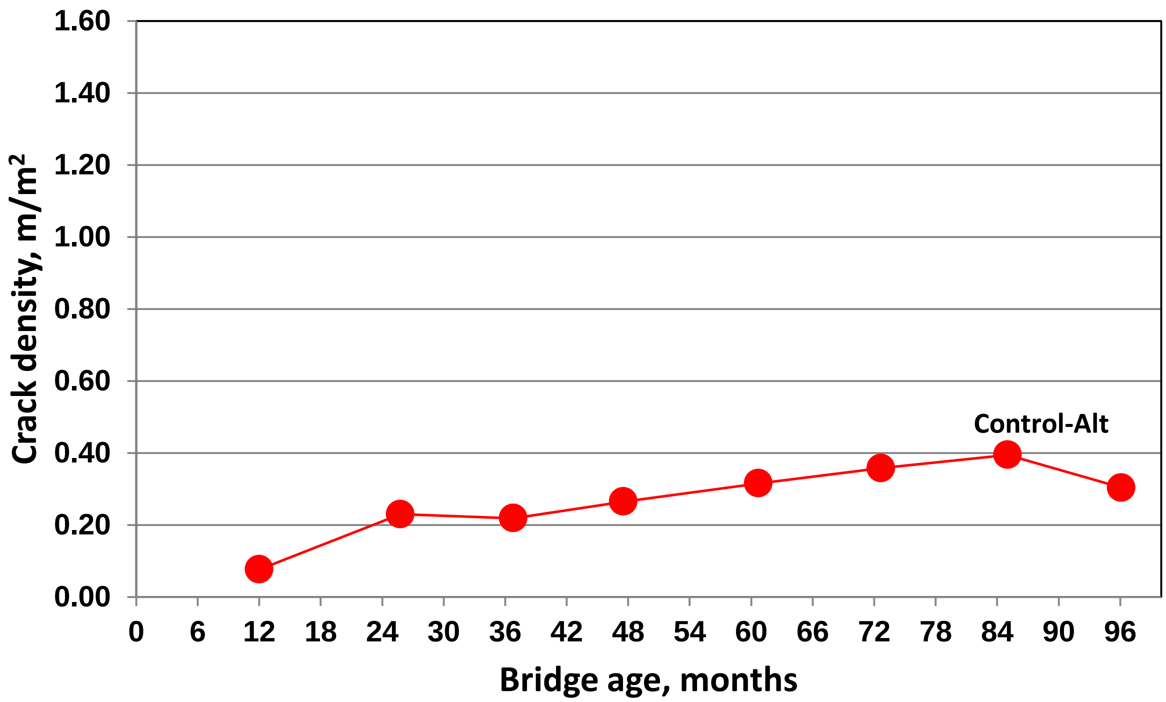
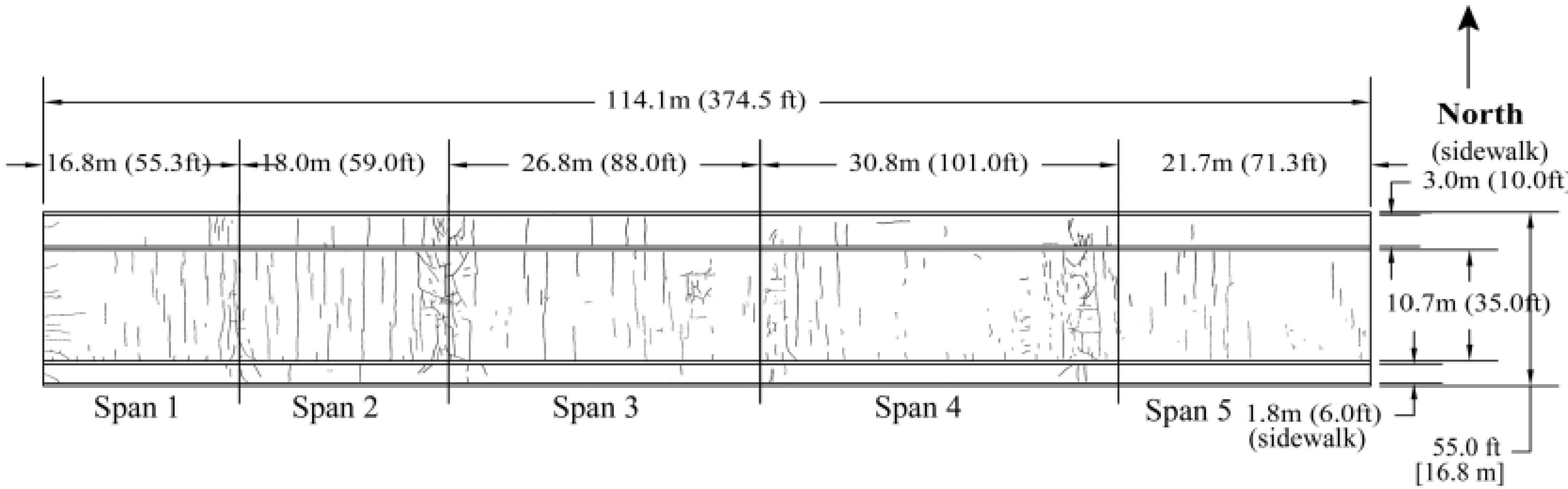


Figure 105: Control-Alt Crack Densities

OP-Extra

OP-Extra is a precast, prestressed concrete girder control bridge in Overland Park, KS constructed by the same contractor as the OP Bridge. The deck is monolithic. The results of Surveys 3, 4, and 5 of OP-Extra at 35.0, 46.7, and 59.2 months, are included in this report. The crack density was 0.344 m/m^2 at 35.0 months (Figure 106), representing an increase from the crack density measured in Survey 2, 0.302 m/m^2 (Pendergrass et al. 2011). At 35.0 months, the crack density of OP-Extra was slightly less than that of LC-HPC-8, another precast, prestressed concrete girder bridge, at a similar age. It was much greater than the density of LC-HPC-10 and Control-8/10,



Bridge Number: Overland Park extra
Bridge Location: 132nd street over US 69, OP,KS
Construction Date: 6/30/2008
Crack Survey Date: 5/27/2011 and 6/3/2011

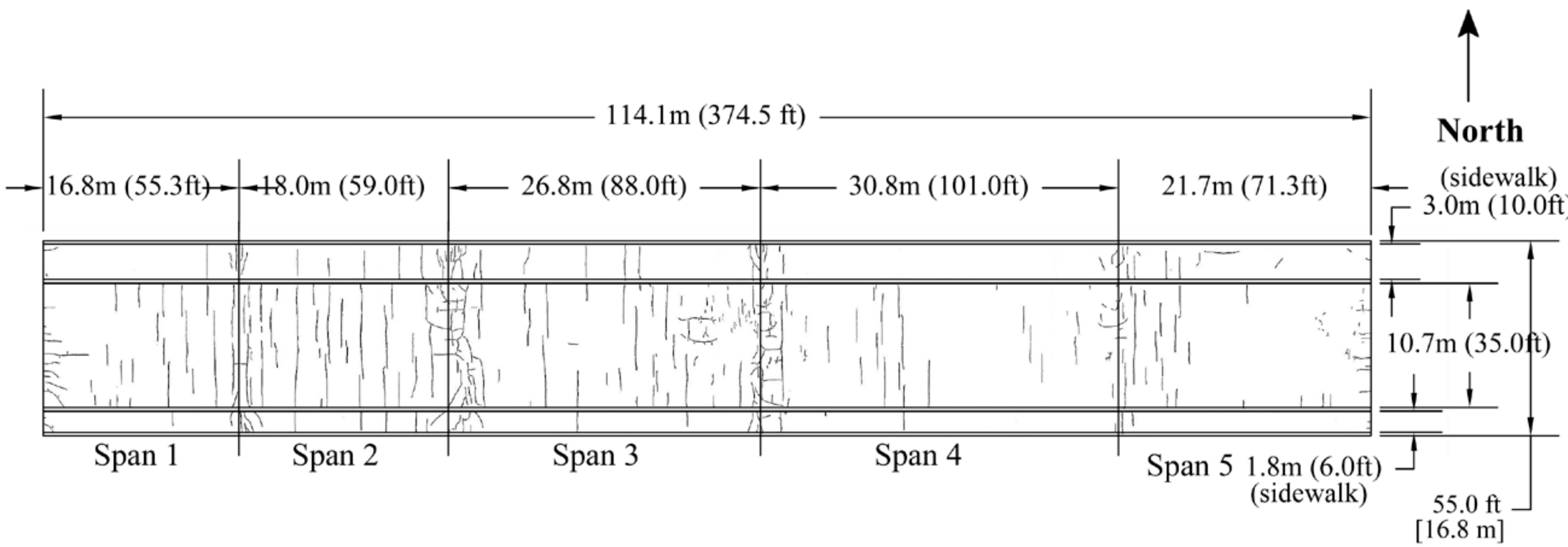
Bridge Length: 114.1 m (374.5 ft)
Bridge Width: 16.8 m (55.0 ft)
Skew: 0°
Number of Spans: 5
- **Span 1:** 16.8 m (55.3 ft)
- **Span 2:** 18.0 m (59.0 ft)
- **Span 3:** 26.8 m (88.0 ft)
- **Span 4:** 30.8 m (101.0 ft)
- **Span 5:** 21.7 m (71.3 ft)

Number of Placements: 1

Bridge Age: 35.0 months
Crack Density: 0.344 m/m^2
Span 1: 0.381 m/m^2
Span 2: 0.551 m/m^2
Span 3: 0.308 m/m^2
Span 4: 0.324 m/m^2
Span 5: 0.169 m/m^2

Figure 106: OP-Extra (Survey 3)

also precast, prestressed concrete girder bridges. The crack density was again 0.344 m/m^2 at 46.7 months (Figure 107), slightly higher than the crack density of Control-8/10 at a similar age (0.326 m/m^2), and remained lower than the density of LC-HPC-8 and higher than the density of LC-HPC-10 at similar ages (0.380 and 0.088 m/m^2). The crack density decreased to 0.300 m/m^2 at 59.2 months (Figure 108), less than the crack densities of Control-8/10 and LC-HPC-8 (0.425 and 0.383 m/m^2), but still greater than the crack density of LC-HPC-10 (0.125 m/m^2) at similar ages. OP-Extra has transverse cracking over nearly the entire deck, as well as longitudinal cracking above the piers and the west abutment. Figure 109 compares cracking on OP-Extra with cracking on LC-HPC-8, LC-HPC-10, and Control-8/10 over time. The deck has experienced relatively stable cracking, falling between 0.20 and 0.40 m/m^2 throughout its life. At about 60 months, cracking on LC-HPC-8 and Control-8/10 is very similar to that on OP-Extra, although the crack density on Control-8/10 is increasing rapidly. Cracking on LC-HPC-10 is consistently lower than that on OP-Extra.



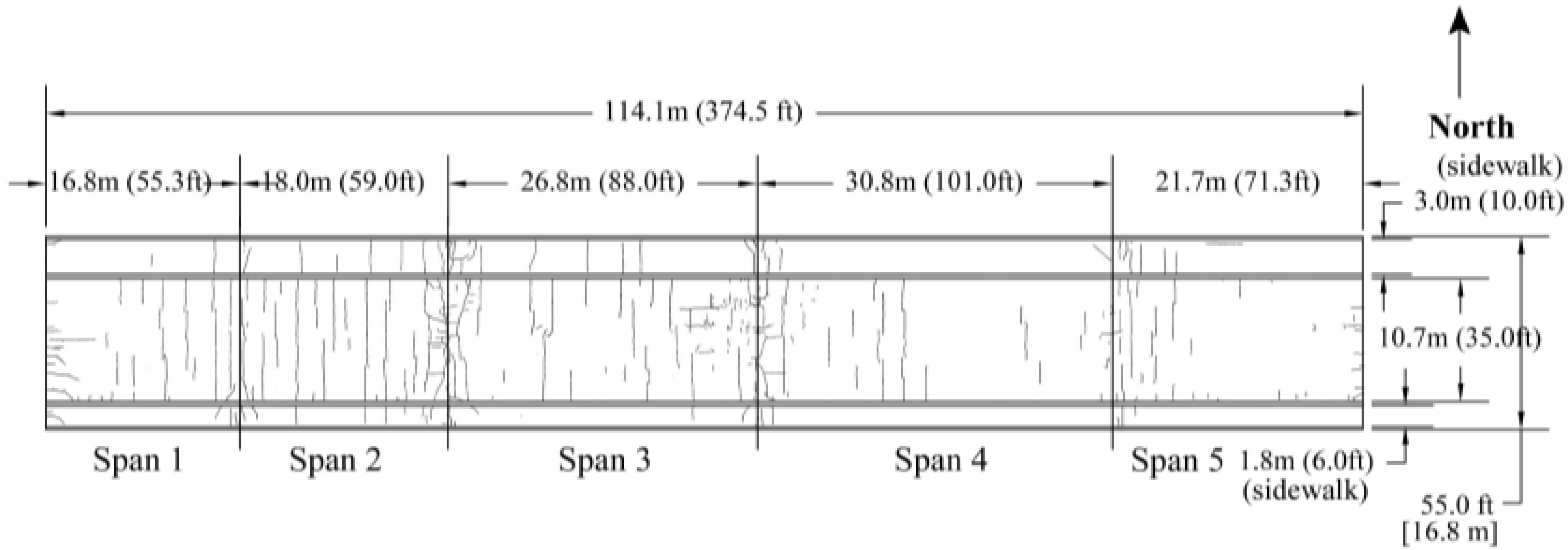
Bridge Number: Overland Park extra
Bridge Location: 132nd street over US 69, OP,KS
Construction Date: 6/30/2008
Crack Survey Date: 5/22/2012

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: 46.7 months
Crack Density: 0.344 m/m^2
Span 1: 0.318 m/m^2
Span 2: 0.531 m/m^2
Span 3: 0.429 m/m^2
Span 4: 0.215 m/m^2
Span 5: 0.227 m/m^2

Figure 107: OP-Extra (Survey 4)



Bridge Number: Overland Park extra
Bridge Location: 132nd street over US 69, OP,KS
Construction Date: 6/30/2008
Crack Survey Date: 6/06/2013

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: 59.2 months
Crack Density: 0.3 m/m^2
Span 1: 0.299 m/m^2
Span 2: 0.498 m/m^2
Span 3: 0.331 m/m^2
Span 4: 0.178 m/m^2
Span 5: 0.197 m/m^2

Figure 108: OP-Extra (Survey 5)

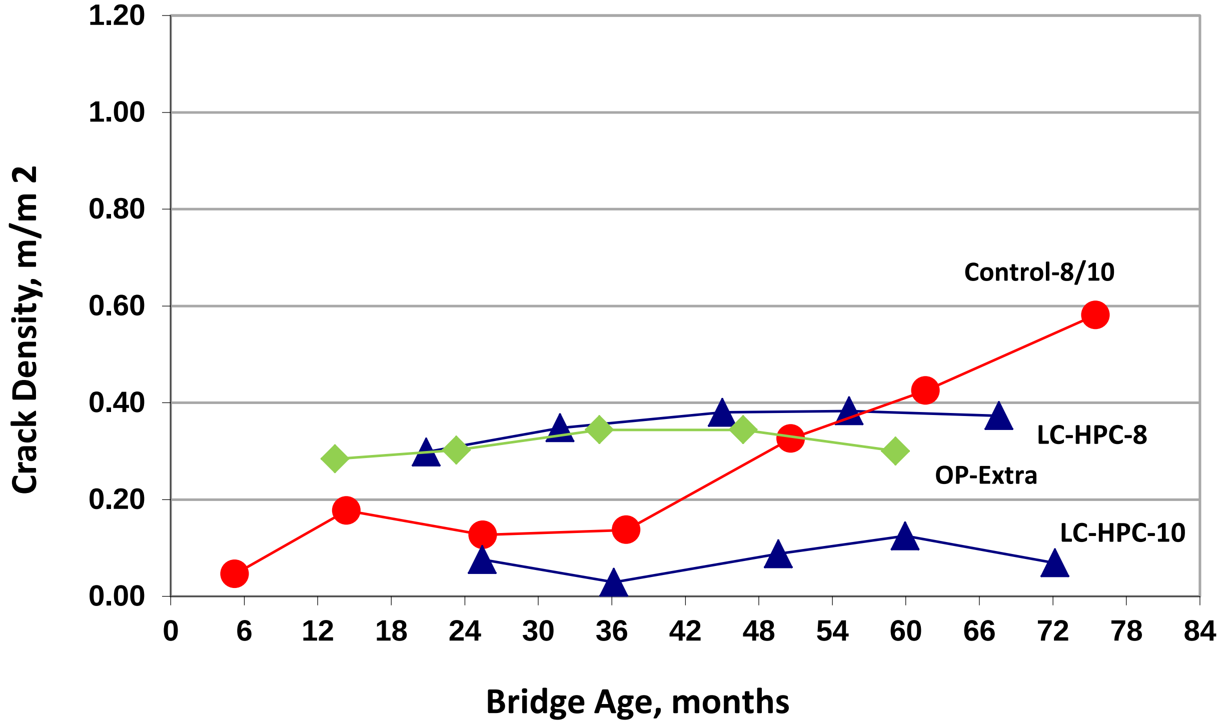


Figure 109: OP-Extra, LC-HPC-8, LC-HPC-10, and Control-8/10 Crack Densities

Summary of Results

As shown in the individual comparisons of the LC-HPC and control decks, at the same age, with few exceptions, the LC-HPC decks exhibit less cracking than the control decks. Crack densities for surveys completed in 2011, 2012, and 2013 are shown in Tables 4, 5, and 6, respectively. These tables also indicate for each LC-HPC/Control pair, which bridge had the lower crack density in that survey year. Because of differences in the dates of placement, comparisons based on the year of the survey do not match the age of the decks in all cases. In 2011, of the thirteen LC-HPC bridge decks with a corresponding control deck, eleven had lower crack densities than their control counterpart. In 2012, of the twelve LC-HPC bridge decks with a corresponding control deck (due to the overlay of Control-5), eleven had lower crack densities than their control counterpart. It is apparent that the LC-HPC bridge decks are performing significantly better than their respective control decks. This is also demonstrated in Figure 2, which provides a plot of crack densities versus age for the bridge decks in the study. The OP Bridge was not constructed in accordance with several provisions of the LC-HPC specifications, and therefore does not represent either an LC-HPC or a control deck. To date, the highest crack density on an LC-HPC bridge deck is 0.576 m/m^2 (LC-HPC-13 at 62.9 months; see Figure 80). The highest crack density on a control deck is 1.037 m/m^2 (Control-7 Placement 1 at 51.1 months). Overall, in the three *survey years* included in this report, there are only 3 instances in which an LC-HPC bridge had a higher crack density than its control counterpart: LC-HPC-2 and LC-HPC-8 in 2011, and LC-HPC-2 in 2012. Finally, although LC-HPC-2 appears to have a higher crack density than Control-1/2 by examination of Tables 4 through 6, Figure 13 shows that, on the whole, LC-HPC-2 performs just as well as, if not better than, Control-1/2.

Table 4 – 2011 Crack Density Comparison of LC-HPC vs. Control Decks

	Deck Age (months)	2011 Crack Density (m/m^2)	Lower Crack Density	Bridge Girder Type
LC-HPC-1	70.6/69.6	0.039	LC-HPC	Steel

Control-1/2	70.7/70.1	0.114		
LC-HPC-2	59.3	0.144	Control	Steel
Control-1/2	70.7/70.1	0.114		
LC-HPC-3	42.6	0.315	LC-HPC	Steel
Control-3	46.6	0.323		
LC-HPC-4	45.0/44.9	0.107	LC-HPC	Steel
Control-4	42.7	0.618		
LC-HPC-5	43.0	0.19	LC-HPC	Steel
Control-5	30.6	0.738		
LC-HPC-6	43.3	0.336	LC-HPC	Steel
Control-6	31.8	0.456		
LC-HPC-7	58.9	0.048	LC-HPC	Steel
Control-7	62.3/56.7	0.856		
LC-HPC-8	45.0	0.38	Control	Prestressed Concrete
Control-8/10	50.6	0.326		
LC-HPC-9	37.2	0.237	LC-HPC	Steel
Control-9	37.0	0.568		
LC-HPC-10	49.6	0.088	LC-HPC	Prestressed Concrete
Control-8/10	50.6	0.326		
LC-HPC-11	48.4	0.37	LC-HPC	Steel
Control-11	62.9	0.923		
LC-HPC-12	38.8/27.4	0.289	LC-HPC	Steel
Control-12	38.9/26.5	0.788		
LC-HPC-13	37.1	0.364	LC-HPC	Steel
Control-13	34.4	0.524		
LC-HPC-15	-	Did not survey	N/A	Steel
LC-HPC-16	7.7	0.092	N/A	Steel
LC-HPC-17	-	Did not survey	N/A	Steel
OP Bridge Placement 1	42.2	0.585	N/A	Steel
OP Bridge Placement 2	37.7	1.303		
OP Bridge Placement 3	37.1	0.678		
Control-Alt	72.6	0.358	N/A	Steel
OP-Extra	35.0	0.344	N/A	Steel

Table 5 – 2012 Crack Density Comparison of LC-HPC vs. Control Decks

	Deck Age (months)	2012 Crack Density (m/m²)	Lower Crack Density	Bridge Girder Type
LC-HPC-1	79.0/78.4	0.085	LC-HPC	Steel
Control-1/2	79.2/78.6	0.196		
LC-HPC-2	68.1	0.197	Control	Steel
Control-1/2	79.2/78.6	0.196		
LC-HPC-3	54.0	0.173	LC-HPC	Steel
Control-3	57.9	0.314		
LC-HPC-4	56.0/55.9	0.12	LC-HPC	Steel
Control-4	54.9	0.669		
LC-HPC-5	54.3	0.158	N/A	Steel
Control-5	-	Did not survey (overlay)		
LC-HPC-6	54.6	0.362	LC-HPC	Steel
Control-6	43.0	0.539		
LC-HPC-7	71.3	0.065	LC-HPC	Steel
Control-7	74.5/68.9	0.899		
LC-HPC-8	55.4	0.383	LC-HPC	Prestressed Concrete
Control-8/10	61.6	0.425		
LC-HPC-9	38.3	0.362	LC-HPC	Steel
Control-9	49.1/48.9	0.577		
LC-HPC-10	60.0	0.125	LC-HPC	Prestressed Concrete
Control-8/10	61.6	0.425		
LC-HPC-11	61.0	0.260	LC-HPC	Steel
Control-11	75.2	0.849		
LC-HPC-12	49.5/38.1	0.410	LC-HPC	Steel
Control-12	49.6/37.2	0.843		
LC-HPC-13	49.0	0.342	LC-HPC	Steel
Control-13	46.1	0.543		
LC-HPC-15	18.9	0.211	N/A	Steel
LC-HPC-16	19.4	0.249	N/A	Steel
LC-HPC-17	8.9	0.226	N/A	Steel
OP Bridge Placement 1	-	Did not survey	N/A	Steel
OP Bridge Placement 2	-	Did not survey		
OP Bridge Placement 3	-	Did not survey		
Control-Alt	85.0	0.395	N/A	Steel
OP-Extra	46.7	0.344	N/A	Steel

Table 6 – 2013 Crack Density Comparison of LC-HPC vs. Control Decks

	Deck Age (months)	2013 Crack Density (m/m^2)	Lower Crack Density	Bridge Girder Type
LC-HPC-1	91.3/90.6	0.040	LC-HPC	Steel
Control-1/2	91.4/90.8	0.144		
LC-HPC-2	80.3	0.141	LC-HPC	Steel
Control-1/2	91.4/90.8	0.144		
LC-HPC-3	66.2	0.174	LC-HPC	Steel
Control-3	70.1	0.288		
LC-HPC-4	68.5/68.4	0.097	LC-HPC	Steel
Control-4	67.1	0.561		
LC-HPC-5	67.0	0.131	N/A	Steel
Control-5	-	Did not survey (overlay)		
LC-HPC-6	67.3	0.303	LC-HPC	Steel
Control-6	56.0	0.460		
LC-HPC-7	83.4	0.072	N/A	Steel
Control-7	-	Did not survey		
LC-HPC-8	67.7	0.373	LC-HPC	Prestressed Concrete
Control-8/10	75.5	0.581		
LC-HPC-9	49.3	0.299	LC-HPC	Steel
Control-9	60.1/59.8	0.609		
LC-HPC-10	72.2	0.069	LC-HPC	Prestressed Concrete
Control-8/10	75.5	0.581		
LC-HPC-11	72.1	0.420	LC-HPC	Steel
Control-11	86.3	0.657		
LC-HPC-12	64.5/53.1	0.431	LC-HPC	Steel
Control-12	64.6/52.5	0.858		
LC-HPC-13	62.9	0.576	LC-HPC	Steel
Control-13	60.0	0.807		
LC-HPC-15	30.8	0.161	N/A	Steel
LC-HPC-16	31.2	0.211	N/A	Steel
LC-HPC-17	20.5	0.240	N/A	Steel
OP Bridge Placement 1	66.6	1.083	N/A	Steel
OP Bridge Placement 2	62.2	1.331		
OP Bridge Placement 3	61.6	1.387		
Control-Alt	96.0	0.304	N/A	Steel
OP-Extra	59.2	0.300	N/A	Steel

SUMMARY AND CONCLUSIONS

Crack densities of Low-Cracking High-Performance Concrete (LC-HPC) bridge decks are compared to crack densities of control decks to investigate the benefits of the LC-HPC specifications developed at the University of Kansas. Specifications for construction of LC-HPC bridge decks are addressed. Bridge deck crack survey procedures are also summarized. Thirteen LC-HPC decks and thirteen control decks are compared by calculating crack densities and noting trends in cracking patterns over time. Results for eight additional decks are also presented. These include three LC-HPC decks, one control deck, and three decks that are considered neither LC-HPC or control decks.

The following conclusions are drawn from this report:

1. Crack densities of control decks are, in general, greater than those of LC-HPC decks.
2. Cracking on bridge decks is typically parallel to the reinforcing steel, except at the abutments, where cracking propagates longitudinally or perpendicular to the abutment.
3. For the three *survey years* included in the report, there are only 3 instances in which an LC-HPC deck has more cracking than its control deck.
4. Superelevated bridge decks have increased potential for transverse cracks to propagate from the elevated edge of the deck due to higher-slump plastic concrete flowing toward the lower elevation, as described for LC-HPC-5 and LC-HPC-6. This potential will be increased if curing water is not provided near the elevated edge.
5. Torsional loads from construction equipment appear to have increased the crack density of one deck.

6. Lack of adherence to the LC-HPC specifications can lead to high crack densities. Specifically, using high-slump concrete, inadequate consolidation, over-finishing and delayed curing will increase the propensity for a deck to crack.

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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

Table B.1 – Crack Densities for Individual Bridge Placements (Lindquist et al. 2008, Pendergrass et al. 2011)

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)	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)
LC-HPC-1	105-304	South	10/14/2005	4/13/2006	5.9	0.012	0.102	4/30/2007	18.5	0.047	0.122
		North	11/2/2005	4/13/2006	5.3	0.003	0.094	4/30/2007	17.9	0.006	0.081
		Entire Deck	--	4/13/2006	--	0.007	0.098	4/30/2007	--	0.027	0.102
LC-HPC-2	105-310	Deck	9/13/2006	4/20/2007	7.2	0.014	0.103	6/18/2008	21.2	0.029	0.100
Control-1/2	105-311	South	10/10/2005	4/13/2006	6.1	0.000	0.204	4/30/2007	18.6	0.151	0.320
		North	10/28/2005	4/13/2006	5.5	0.000	0.206	4/30/2007	18.0	0.044	0.214
		Entire Deck	--	4/13/2006	--	0.000	0.206	4/30/2007	--	0.089	0.259
LC-HPC-3	46-338	Deck	11/13/2007	5/29/2008	6.5	0.032	0.122	6/18/2009	19.2	0.110	0.176
Control-3	46-337	Deck	7/17/2007	5/29/2008	10.4	0.037	0.229	6/5/2009	22.6	0.216	0.729
LC-HPC-4	46-339	South	9/29/2007	7/15/2008	9.5	0.017	0.094	7/9/2009	21.3	0.113	0.177
		North	10/2/2007	7/15/2008	9.4	0.004	0.081	7/9/2009	21.2	0.079	0.143
Control-4	46-347	Deck	11/16/2007	6/10/2008	6.8	0.050	0.252	7/7/2009	19.7	0.366	0.906
LC-HPC-5	46-340 Unit 1	Deck	11/14/2007	7/15/2008	8.0	0.059	0.147	6/26/2009	19.4	0.123	0.189
Control-5	46-341 Unit 3	Deck	11/25/2008	7/9/2009	7.4	0.670	1.324	6/22/2010	18.9	0.857	1.405
LC-HPC-6	46-340 Unit 2	Deck	11/3/2007	5/20/2008	6.5	0.063	0.153	6/26/2009	19.7	0.238	0.303
Control-6	46-341 Unit 4	Deck	10/20/2008	7/9/2009	8.6	0.142	0.785	6/22/2010	20.0	0.282	0.819
LC-HPC-7	43-33	Deck	6/24/2006	6/5/2007	11.4	0.003	0.087	7/1/2008	24.2	0.019	0.086
Control-7	46-334	East	3/29/2006	8/10/2007	16.4	0.293	0.468	6/30/2008	27.1	0.476	0.621
		West	9/15/2006	8/10/2007	10.8	0.030	0.221	6/30/2008	21.5	0.069	0.229
LC-HPC-8	54-53	Deck	10/3/2007	6/29/2009	20.9	0.298	0.362	5/27/2010	31.8	0.348	0.400
LC-HPC-10	54-60	Deck	5/17/2007	6/29/2009	25.4	0.076	0.135	5/22/2010	36.2	0.029	0.076

Table B.1 (Continued) – Crack Densities for Individual Bridge Placements (Lindquist et al. 2008, Pendergrass et al. 2011)

Bridge Number	Survey # 3				Survey # 4				Survey # 5			
	Date of Survey	Age	Crack Density	Age-Corrected Crack Density	Date of Survey	Age	Crack Density	Age-Corrected Crack Density	Date of Survey	Age	Crack Density	Age-Corrected Crack Density
		(months)	(m/m^2)	(m/m^2)		(months)	(m/m^2)	(m/m^2)		(months)	(m/m^2)	(m/m^2)
LC-HPC-1	6/17/2008	32.1	0.044	0.102	6/17/2009	44.1	0.060	0.098	6/3/2010	55.6	0.032	0.057
	6/17/2008	31.5	0.024	0.082	6/17/2009	43.5	0.125	0.164	6/3/2010	55.0	0.023	0.049
	6/17/2008	--	0.034	0.092	6/17/2009	--	0.093	0.131	6/3/2010	--	0.027	0.053
LC-HPC-2	5/29/2009	32.5	0.085	0.136	5/28/2010	44.5	0.059	0.097	8/22/2011	59.3	0.144	0.168
Control-1/2	6/17/2008	32.2	0.114	0.244	6/17/2009	44.2	0.261	0.574	6/3/2010	55.8	0.132	0.338
	6/17/2008	31.6	0.091	0.223	6/17/2009	43.6	0.133	0.451	6/3/2010	55.2	0.106	0.317
	6/17/2008	--	0.099	0.231	6/17/2009	--	0.184	0.513	6/3/2010	--	0.115	0.328
LC-HPC-3	6/28/2010	31.5	0.108	0.160	6/1/2011	42.6	0.315	0.360	5/14/2012	54.0	0.173	0.203
Control-3	6/28/2010	35.4	0.232	0.627	6/7/2011	46.6	0.323	0.363	5/14/2012	57.9	0.314	0.339
LC-HPC-4	6/24/2010	32.8	0.231	0.312	6/30/2011	45.0	0.167	0.209	5/30/2012	56.0	0.184	0.212
	6/24/2010	32.7	0.094	0.145	6/30/2011	44.9	0.080	0.122	5/30/2012	55.9	0.092	0.120
Control-4	7/5/2010	31.6	0.473	0.903	6/7/2011	42.7	0.618	0.663	6/12/2012	54.9	0.669	0.698
LC-HPC-5	6/17/2010	31.1	0.128	0.181	6/14/2011	43.0	0.190	0.234	5/23/2012	54.3	0.158	0.188
Control-5	6/15/2011	30.6	0.738	0.798	-	-	-	-	-	-	-	-
LC-HPC-6	6/17/2010	31.4	0.231	0.283	6/14/2011	43.3	0.336	0.380	5/23/2012	54.6	0.362	0.392
Control-6	6/14/2011	31.8	0.456	0.514	5/30/2012	43.0	0.539	0.583	6/19/2013	56.0	0.46	0.488
LC-HPC-7	5/18/2009	34.8	0.012	0.060	5/18/2010	46.8	0.005	0.040	5/23/2011	58.9	0.048	0.072
Control-7	6/4/2009	38.2	1.003	1.371	7/1/2010	51.1	1.037	1.286	6/7/2011	62.3	0.957	0.977
	6/4/2009	32.6	0.277	0.697	7/1/2010	45.5	0.359	0.660	6/7/2011	56.7	0.653	0.680
LC-HPC-8	7/5/2011	45	0.380	0.422	5/15/2012	55.4	0.383	0.412	5/22/2013	67.7	0.373	0.386
LC-HPC-10	7/5/2011	49.6	0.088	0.124	5/15/2012	60	0.125	0.148	5/22/2013	72.2	0.069	0.076

Table B.1 (Continued) – Crack Densities for Individual Bridge Placements (Lindquist et al. 2008, Pendergrass et al. 2011)

Bridge Number	Survey # 6				Survey # 7				Survey # 8			
	Date of Survey	Age	Crack Density	Age-Corrected Crack Density	Date of Survey	Age	Crack Density	Age-Corrected Crack Density	Date of Survey	Age	Crack Density	Age-Corrected Crack Density
		(months)	(m/m^2)	(m/m^2)		(months)	(m/m^2)	(m/m^2)		(months)	(m/m^2)	(m/m^2)
LC-HPC-1	9/1/2011	70.6	0.061	0.070	5/16/2012	79.0	0.096	0.095	5/23/2013	91.3	0.059	0.042
	9/1/2011	69.6	0.103	0.114	5/16/2012	78.4	0.081	0.080	5/23/2013	90.6	0.023	0.007
	9/1/2011	--	0.082	0.092	5/16/2012	--	0.085	0.084	5/23/2013	--	0.040	0.024
LC-HPC-2	5/18/2012	68.1	0.196	0.208	5/24/2013	80.3	0.141	0.138	-	-	-	-
Control-1/2	9/1/2011	70.7	0.259	0.268	5/16/2012	79.2	0.240	0.238	5/23/2013	91.4	0.141	0.124
	9/1/2011	70.1	0.137	0.147	5/16/2012	78.6	0.161	0.160	5/23/2013	90.8	0.149	0.133
	9/1/2011	--	0.190	0.200	5/16/2012	--	0.196	0.195	5/23/2013	--	0.144	0.127
LC-HPC-3	5/21/2013	66.2	0.174	0.189	-	-	-	-	-	-	-	-
Control-3	5/21/2013	70.1	0.288	0.298	-	-	-	-	-	-	-	-
LC-HPC-4	6/13/2013	68.5	0.179	0.191	-	-	-	-	-	-	-	-
	6/13/2013	68.4	0.060	0.072	-	-	-	-	-	-	-	-
Control-4	6/20/2013	67.1	0.561	0.575	-	-	-	-	-	-	-	-
LC-HPC-5	6/13/2013	67.0	0.131	0.145	-	-	-	-	-	-	-	-
Control-5	-	-	-	-	-	-	-	-	-	-	-	-
LC-HPC-6	6/13/2013	67.3	0.303	0.317	-	-	-	-	-	-	-	-
Control-6	-	-	-	-	-	-	-	-	-	-	-	-
LC-HPC-7	6/1/2012	71.3	0.065	0.073	6/7/2013	83.4	0.072	0.065	-	-	-	-
Control-7	6/12/2012	74.5	1.022	1.026	-	-	-	-	-	-	-	-
	6/12/2012	68.9	0.638	0.649	-	-	-	-	-	-	-	-
LC-HPC-8	-	-	-	-	-	-	-	-	-	-	-	-
LC-HPC-10	-	-	-	-	-	-	-	-	-	-	-	-

Table B.1 (Continued) – Crack Densities for Individual Bridge Placements (Lindquist et al. 2008, Pendergrass et al. 2011)

Bridge Number	County and Serial Number	Portion Placed	Date of Placement	Survey # 1				Survey # 2			
				Date of Survey	Age	Crack Density	Age-Corrected Crack Density	Date of Survey	Age	Crack Density	Age-Corrected Crack Density
					(months)	(m/m^2)	(m/m^2)		(months)	(m/m^2)	(m/m^2)
Control-8/10	54-59	Deck	4/16/2007	6/26/2008	14.4	0.177	0.257	5/31/2009	25.5	0.127	0.193
LC-HPC-9	54-57	Deck	4/15/2009	6/4/2010	13.6	0.130	0.202	6/30/2011	26.5	0.237	0.302
Control-9	54-58	West	5/21/2008	5/28/2010	24.2	0.368	0.866	6/28/2011	37.2	0.553	0.605
		East	5/29/2008	5/28/2010	24.0	0.395	0.895	6/28/2011	37	0.577	0.629
LC-HPC-11	78-119	Deck	6/9/2007	5/20/2009	23.4	0.059	0.120	6/15/2010	36.2	0.241	0.288
Control-11	56-155	Deck	3/28/2006	8/13/2007	16.5	0.351	0.526	6/30/2008	27.1	0.665	0.810
LC-HPC-12	56-57	East	4/4/2008	8/13/2009	16.3	0.271	0.340	6/29/2010	26.8	0.256	0.313
		West	3/18/2009	8/13/2009	4.9	0.254	0.336	6/29/2010	15.4	0.244	0.314
Control-12	56-57	East	4/1/2008	8/13/2009	16.4	0.606	1.176	6/29/2010	26.9	0.669	1.142
		West	4/14/2009	-	-	-	-	6/29/2010	14.5	0.442	1.030
LC-HPC-13	54-66	Deck	4/29/2008	6/24/2009	13.8	0.050	0.122	5/24/2010	24.8	0.129	0.189
Control-13	54-67	Deck	7/25/2008	6/24/2009	11.0	0.028	0.649	5/24/2010	21.9	0.154	0.673
LC-HPC-15	46-351	Deck	11/10/2010	6/8/2012	18.9	0.211	0.286	6/3/2013	30.8	0.161	0.221
LC-HPC-16	46-352	Deck	10/28/2010	6/20/2011	7.7	0.092	0.181	6/8/2012	19.4	0.249	0.323
LC-HPC-17	46-373	Deck	9/28/2011	6/26/2012	8.9	0.226	0.313	6/14/2013	20.5	0.240	0.313
OP Bridge P1	OP #1	Deck	12/19/2007	6/27/2009	18.3	0.341	0.408	6/18/2010	30.0	0.502	0.556
OP Bridge P2	OP #2	Deck	5/2/2008	6/23/2009	13.7	0.640	0.712	6/18/2010	25.5	0.727	0.786
OP Bridge P3	OP #3	Deck	5/21/2008	7/1/2009	13.3	0.421	0.493	6/18/2010	24.9	0.871	0.931
Control-Alt	56-49	Deck	6/2/2005	6/2/2006	12.0	0.077	0.160	7/27/2007	25.8	0.230	0.295
OP-Extra	OP-Extra	Deck	6/30/2008	8/12/2009	13.4	0.284	0.365	6/10/2010	23.3	0.302	0.371

Table B.1 (Continued) – Crack Densities for Individual Bridge Placements (Lindquist et al. 2008, Pendergrass et al. 2011)

Bridge Number	Survey # 3				Survey # 4				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)	Date of Survey	Age (months)	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)
Control-8/10	5/22/2010	37.2	0.137	0.188	7/5/2011	50.6	0.326	0.361	6/4/2012	61.6	0.425	0.446
LC-HPC-9	6/25/2012	38.3	0.362	0.412	5/24/2013	49.3	0.299	0.335	-	-	-	-
Control-9	6/25/2012	49.1	0.637	0.673	5/24/2013	60.1	0.645	0.668	-	-	-	-
	6/25/2012	48.9	0.501	0.538	5/24/2013	59.8	0.564	0.587	-	-	-	-
LC-HPC-11	6/22/2011	48.4	0.370	0.407	7/10/2012	61	0.260	0.281	6/11/2013	72.1	0.42	0.427
Control-11	5/21/2009	37.8	0.599	0.971	6/2/2010	50.2	0.636	0.894	6/23/2011	62.9	0.923	0.942
LC-HPC-12	6/28/2011	38.8	0.315	0.364	5/21/2012	49.5	0.450	0.486	8/19/2013	64.5	0.478	0.495
	6/28/2011	27.4	0.268	0.332	5/21/2012	38.1	0.375	0.425	8/19/2013	53.1	0.381	0.412
Control-12	6/29/2011	38.9	0.767	0.816	5/21/2012	49.6	0.857	0.893	8/19/2013	64.6	0.838	0.855
	6/29/2011	26.5	0.799	0.864	5/21/2012	37.2	0.831	0.883	8/19/2013	52.5	0.88	0.912
LC-HPC-13	6/1/2011	37.1	0.364	0.416	5/29/2012	49	0.342	0.379	7/25/2013	62.9	0.576	0.595
Control-13	6/6/2011	34.4	0.524	0.579	5/29/2012	46.1	0.543	0.583	7/25/2013	60	0.807	0.830
LC-HPC-15	-	-	-	-	-	-	-	-	-	-	-	-
LC-HPC-16	6/3/2013	31.2	0.211	0.270	-	-	-	-	-	-	-	-
LC-HPC-17	-	-	-	-	-	-	-	-	-	-	-	-
OP Bridge P1	6/24/2011	42.2	0.585	0.630	7/8/2013	66.6	1.083	1.097	-	-	-	-
OP Bridge P2	6/24/2011	37.7	1.303	1.354	7/8/2013	62.2	1.331	1.351	-	-	-	-
OP Bridge P3	6/24/2011	37.1	0.678	0.730	7/8/2013	61.6	1.387	1.408	-	-	-	-
Control-Alt	6/26/2008	36.8	0.219	0.271	5/19/2009	47.5	0.265	0.303	6/24/2010	60.7	0.316	0.338
OP-Extra	5/27/2011	35	0.344	0.398	5/18/2012	46.7	0.344	0.384	6/6/2013	59.2	0.3	0.324

Table B.1 (Continued) – Crack Densities for Individual Bridge Placements (Lindquist et al. 2008, Pendergrass et al. 2011)

Bridge Number	Survey # 6				Survey # 7				Survey # 8			
	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)	Date of Survey	Age (months)	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)
Control-8/10	8/1/2013	75.5	0.581	0.584	-	-	-	-	-	-	-	-
LC-HPC-9	-	-	-	-	-	-	-	-	-	-	-	-
Control-9	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-
LC-HPC-11	-	-	-	-	-	-	-	-	-	-	-	-
Control-11	7/3/2012	75.2	0.849	0.853	6/6/2013	86.3	0.657	0.647	-	-	-	-
LC-HPC-12	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-
Control-12	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-
LC-HPC-13	-	-	-	-	-	-	-	-	-	-	-	-
Control-13	-	-	-	-	-	-	-	-				
LC-HPC-15	-	-	-	-	-	-	-	-	-	-	-	-
LC-HPC-16	-	-	-	-	-	-	-	-	-	-	-	-
LC-HPC-17	-	-	-	-	-	-	-	-	-	-	-	-
OP Bridge P1	-	-	-	-	-	-	-	-	-	-	-	-
OP Bridge P2	-	-	-	-	-	-	-	-	-	-	-	-
OP Bridge P3	-	-	-	-	-	-	-	-	-	-	-	-
Control-Alt	6/13/2011	72.6	0.358	0.365	7/3/2012	85	0.395	0.386	6/6/2013	96	0.304	0.281
OP-Extra	-	-	-	-	-	-	-	-	-	-	-	-

Table B.2 – Average Properties for the Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks (Lindquist et al. 2008, McLeod et al. 2009, Pendergrass et.al. 2011)

LC-HPC Number	Portion Placed	Date of Placement	Average Air Content	Average Slump		Average Concrete Temperature		Average Unit Weight		Average Compressive Strength†	
				(mm)	(in.)	(°C)	(°F)	(kg/m^3)	(lb/ft^3)	(MPa)	(psi)
1	South	10/14/2005	7.9	95	3.75	19.8	68	2251	140.5	35.9	5210
	North	11/2/2005	7.8	85	3.25	20.1	68	2238	139.7	34.4	4980
2	Deck	9/13/2006	7.7	75	3.00	19.2	67	--	--	31.7	4600
3	Deck	11/13/2007	8.7	85	3.25	14.3	58	--	--	41.3	5990
4	Deck - South	9/29/2007	8.7	50	2.00	--	--	2202	137.4	--	--
	Deck - North	10/2/2007	8.8	80	3.00	17.5	64	2210	137.9	33.1	4790
5	Deck - 0.420 *w/c*	11/14/2007	8.3	70	2.75	16.7	62	2249	140.4	44.0	6380
	Deck - 0.428 *w/c*	11/14/2007	9.0	60	2.50	16.4	62	2242	140.0	--	--
	Deck - 0.429 *w/c*	11/14/2007	9.1	90	3.50	15.2	59	2230	139.2	--	--
	Deck - 0.451 *w/c*	11/14/2007	8.7	80	3.25	15.7	60	2228	139.1	--	--
	Average Values	11/14/2007	8.7	80	3.00	15.9	61	2236	139.6	--	--
6	Deck	11/3/2007	9.5	95	3.75	15.3	60	--	--	40.3	5840
7	Deck	6/24/2006	8.0	95	3.75	21.9	71	2221	138.6	26.1	3790
8	Deck	10/3/2007	7.9	50	2.00	19.5	67	2264	141.3	32.6	4730
9	Deck	4/15/2009	6.7	90	3.50	17.9	64	2264	141.3	28.9	4190
10	Deck	5/17/2007	7.3	80	3.25	18.6	66	2212	138.1	31.6	4580
11	Deck	6/9/2007	7.8	80	3.00	15.8	60	2278	142.2	32.3	4680
12	Deck - East	4/4/2008	7.4	70	2.75	14.5	58	2259	141.0	31.5	4570
	Deck - West	3/18/2009	7.8	104	4.10	19.0	67	--	--	28.8 (0.45 *w/c*)	4180 (0.45 *w/c*)
										31.6 (0.44 *w/c*)	4580 (0.44 *w/c*)
13	Deck	4/29/2008	8.1	75	3.00	20.4	69	2266	141.5	29.5	4280
OP	Deck - Center	12/19/2007	8.7	95	3.75	18.1	65	2237	139.7	30.6	4440
	Deck - West	5/2/2008	9.8	110	4.25	17.9	64	2213	138.1	25.6	3710
	Deck - East	5/21/2008	9.9	130	5.25	18.3	65	2195	137.1	26.4	3830
15	Deck	11/10/2010	9.0	84	3.30	17.2	63	2201	137.4	30.6	4440
16	Deck	10/28/2010	6.4	97	3.80	15.0	59	2260.61954	141.1	34.8	5043
17	Deck	9/28/2011	7.5	64	2.50	22.2	72	2245	140.1	34.5	5007

†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, Pendergrass et.al. 2011)

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

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

Table B.3 (Continued) – Average Properties for Control Bridge Decks (Lindquist et al. 2008, McLeod et al. 2009, Pendergrass et.al. 2011)

Control Number	Portion Placed	Date of Placement	Average Air Content	Average Slump		Average Concrete Temperature		Average Unit Weight		Average Compressive Strength†	
				(mm)	(in.)	(°C)	(°F)	(kg/m³)	(lb/ft³)	(MPa)	(psi)
7	Subdeck - East	3/15/2006	5.9	235	9.25	26.5	80	2239	139.8	38.2	5540
	Overlay - East	3/29/2006	7.4	190	7.50	23.0	73	2239	139.8	--	--
	Subdeck - West	8/16/2006	7.3	195	7.75	21.3	70	2226	139.0	37.9	5500
	Overlay - West	9/15/2006	6.4	175	7.00	18.0	64	2252	140.6	50.8	7370
8/10	Deck	4/16/2007	7.4	130	5.00	21.2	70	2234	139.4	33.3	4830
9	Overlay - West	5/21/2008	5.6	90	3.50	24.7	77	2282	142.4	44.0	6380
	Overlay - East	5/28/2008	6.2	130	5.00	21.7	71	2262	141.2	42.6	6170
11	Subdeck - North	2/3/2006	6.8	90	3.50	22.0	72	2263	141.3	40.6	5890
	Subdeck - South	2/14/2006	7.0	135	5.25	23.0	73	2252	140.6	37.5	5440
	Overlay	3/28/2006	6.0	80	5.00	15.5	60	2277	142.1	52.7	7640
12	Subdeck - Phase 1	3/11/2008	6.9	110	4.25	21.9	72	2250	140.5	36.4	5270
	Overlay - Phase 1	4/1/2008	6.8	95	3.75	14.8	59	2254	140.7	43.0	6240
	Subdeck - Phase 2	3/13/2009	7.2	120	4.75	22.0	72	--	--	34.3	4980
	Overlay - Phase 2	4/14/2009	7.7	57	2.25	16.7	62	--	--	53.1	7710
13	Subdeck	7/11/2008	5.8	90	3.50	31.7	89	2271	141.7	--	--
	Overlay	7/25/2008	6.3	135	5.25	33.0	91	2269	141.6	57.1	8280
Alt	Deck	6/2/2005	5.9	85	3.00	--	--	2255	140.8	38.0	5510

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