CRACK SURVEYS OF LOW-CRACKING HIGH- PERFORMANCE CONCRETE BRIDGE DECKS IN KANSAS 2006-2008

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CONSTRUCTION OF CRACK-FREE BRIDGE DECKS
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ABSTRACT

The purpose and specifications for the construction of Low-Cracking, High-Performance Concrete (LC-HPC) bridge decks are discussed. The survey process for evaluating the cracking performance of bridge decks is described. Seven LC-HPC decks and seven control decks were surveyed according to this process. Crack densities were calculated for each deck and trends in crack patterns were noted. The LC-HPC decks yielded significantly lower crack densities than did the control decks. Most cracks in LC-HPC and control decks were oriented in the transverse direction and were located directly above the transverse reinforcement. For superelevated decks, crack densities were greater in areas of the deck at higher elevations, likely due to greater settlement cracking and inadequate curing on the elevated portion of the decks.

ACKNOWLEDGEMENTS

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INTRODUCTION

Cracking is a common problem for all types of concrete bridge decks. Some bridges will crack more than others, and some earlier than others. In any case, cracking will affect bridge durability in the long term. Age, weather conditions, construction methods, and concrete quality all have differing effects on the types and locations of cracking in bridge decks.

Work is currently underway in Kansas to limit, and eventually eliminate cracking in concrete bridges. This goal is the focus of a pooled-fund project conducted by the University of Kansas. As part of this study, continuing research identifies causes of cracking and potential methods to improve performance. This process includes examining concrete mix designs, adjusting construction practices, and specifying other relevant parameters to create an environment conducive to minimized cracking in concrete bridge decks. Decks that are constructed under these more stringent requirements are referred to in this report as Low-Cracking High-Performance Concrete (LC-HPC) bridge decks.

To determine the effectiveness of these improved bridge placement practices, crack surveys are regularly performed on both LC-HPC bridge decks and control decks to compare cracking over a period of time. The LC-HPC and control decks are paired such that they are similar in type, age, and exposure. In conducting crack surveys on these bridges, it is important to use standard, consistent procedures to ensure a fair and objective comparison. This report summarizes cracking observed on decks constructed in Kansas as part of this program in 2005, 2006, and 2007.

SPECIFICATIONS

Special provisions to the standard specifications have been written specifically for LC-HPC bridges in Kansas. These provisions (most recently 90P-5085, 90P-5095, 90P-5097) cover requirements for aggregates, concrete, and construction practices. The following paragraphs summarize these specifications.

Aggregate

The provisions address requirements for both the coarse and fine aggregates used in LC-HP concrete. Coarse aggregates should consist of gravel, chat, or crushed stone. They must have a minimum soundness of 0.90 and a maximum absorption of 0.7. Maximum deleterious substance values (by weight) are listed in Table 1. Aggregate segregation should be avoided, especially during transportation.

Table 1 – Deleterious Substance Standards for Coarse Aggregates

Substance	Maximum % by weight
Material passing No. 200 sieve	2.50%
Shale and/or shale-like material	0.50%
Clay lumps and friable particles	1.00%
Sticks (including absorbed water)	0.10%
Coal	0.50%

Fine aggregates should consist of natural sand and chat. Limitations of deleterious substances in fine aggregates are found in Table 2. Like coarse aggregate, precautions should be taken when transporting to minimize segregation.

Coarse and fine aggregates should be proportioned using a proven optimization method (e.g. Shilstone Method, KU Mix Method).

Table 2 – Deleterious Substance Standards for Type FA-A (Natural Sand)

Substance	Maximum % by weight
Material passing No. 200 sieve	2.00%
Shale and/or shale-like material	0.50%
Clay lumps and friable particles	1.00%
Sticks (including absorbed water)	0.10%

Table 3 – Deleterious Substance Standards for Type FA-B (Chat)

Substance	Maximum % by weight
Material passing No. 200 sieve	2.00%
Clay lumps and friable particles	0.25%

Concrete

LC-HP concrete must contain between 500 lb and 535 lb of cement per cubic yard of concrete and have a maximum water/cement ratio (by weight) ranging from 0.42 to 0.45. However, based on recent experience, new provisions are being developed to increase the maximum cement weight to 540 lb/yd^3 and to establish a minimum water/cement ratio of 0.43. In addition, the first two LC-HPC decks were cast with a cement content of 540 lb/yd^3. No mineral, set retarding, or set accelerating admixtures are allowed to be used in LC-HP concrete. Air-entraining admixtures must be vinsol resin or tall oil based.

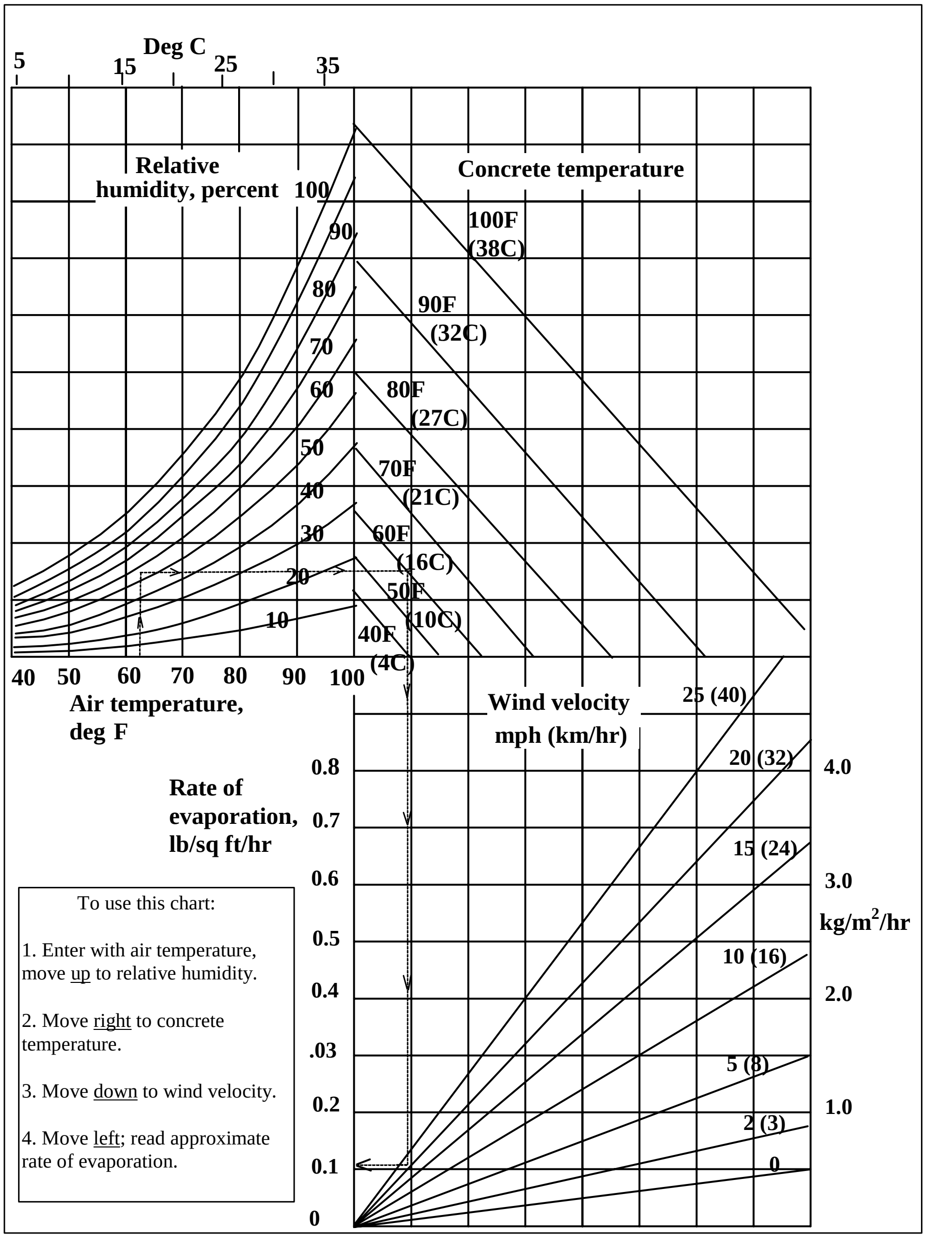
Concrete slump should be between 1½ and 3 in. at the time and point of placement. However, a maximum slump of 4 in. is allowed. In upcoming specifications, the maximum allowable slump will be decreased to 3½ in. Air content must be between 6.5% and 9.5%, and concrete temperature at placement should measure from 55°F to 70°F. The temperature may exceed these limits by 5°F with the engineer's approval.

Before any concrete may be place, a qualification batch must be produced to demonstrate the concrete supplier's ability to meet the specifications. Jobsite haul time should be simulated before the qualification batch is tested. The mix design used in the qualification batch should match the design used on the LC-HPC bridge deck, including admixtures. Batching procedures should also mirror those used on the placement. The batch must pass tests for slump, air content, temperature, unit weight, and compressive strength to be qualified for use on the LC-HPC bridge.

Construction

Prior to placement of the LC-HPC bridge deck, a qualification slab must be constructed to demonstrate the contractor's ability to meet the KDOT specifications and special provisions. The qualification slab has a width that is equal to that of the deck and is 33 ft long. The slab should be constructed using the same equipment, crew, and procedures as will be used on the LC-HPC bridge deck.

For the deck placement, environmental evaporation rates must remain below 0.2 lb/ft^2/hour. To ensure that this takes place, air temperature, concrete temperature, wind speed, and humidity must be monitored on an hourly basis, at minimum. These measurements (excluding concrete temperature) are to be taken approximately 12 in. above the surface of the deck. The evaporation rate can be determined using KDOT software or the chart shown in Figure 1. Fogging may be used on the deck, but is not considered in the calculation of the evaporation rate. Therefore, other measures must be taken to control wind speed, ambient temperature, or concrete temperature when necessary. These control measures are outlined and submitted in a Quality Control Plan prior to placement of the LC-HPC bridge.



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

Concrete should be placed with a conveyor belt or bucket unless the ability to pump the concrete is demonstrated in construction of the qualification slab. Upcoming specifications will also require that if a pump is used, an air cuff or bladder valve must be fixed at the end of the hose to limit the loss of air content in the concrete. For similar reasons, the maximum allowable vertical drop from a conveyor belt or bucket is 6 ft.

Concrete consolidation should be performed using machine-mounted internal gang vibrators where possible on the deck surface and hand-held vibrators elsewhere (outside edges, rails, etc.) Each vibrator must have a head diameter of 1.75 to 2.5 in., a loaded vibration frequency between 8,000 and 12,000 vibrations per minute, and an average vibration amplitude of 0.025 to 0.05 in. Vibrators should be mounted at a maximum center-to-center distance of 12 in. All insertions should be made vertically and held between 3 and 15 seconds. The vibrators should then be extracted vertically at a rate such that no voids or holes are created.

The surface should be struck off with a vibrating or drum roller screed. Mounted tamping devices are not allowed. The surface may be finished with a metal pan, burlap drag, or both. Bullfloats may be used to remove voids and other irregularities. Water is not to be used as a finishing aid, and tining of the plastic concrete is prohibited.

Within 10 minutes of strike-off, one layer of presoaked burlap must be placed over the finished concrete for curing. A second layer is to be applied within 5 minutes. The burlap used must be soaked for a minimum of 12 hours prior to placement of the deck. The applied burlap should remain wet for the duration of the 14-day curing period. This can be accomplished by continually rewetting with spray hoses until the concrete sets up, at which time soaker hoses are placed across the deck so that all burlap will remain saturated. Within 12 hours of LC-HPC placement, white polyethylene film must be placed over the soaker hoses and the sheets sealed together such that a completely waterproof cover is formed over the entire surface of the deck.

When the 14-day curing period is complete, the plastic film and burlap are removed, and within 30 minutes of removal, two coats of an opaque curing membrane must be applied to the concrete surface.

CRACK SURVEYS

Upon completion of LC-HPC and control deck construction, crack surveys are performed on a regular basis to evaluate the performance of each deck over time. The procedures used to perform these crack surveys are described below.

Procedures

Standard procedures are used for each crack survey to ensure a fair comparison of the results. Surveys are only conducted between sunrise and sunset on days forecasted to be mostly sunny. Surveyed decks must be completely dry, and temperatures on the bridge must be 60°F or higher during the surveys. At least one lane of traffic is closed to vehicles at any given time during the survey.

For each bridge, a scaled deck plan (to be used for the crack map) is drawn to serve as a template for indicating the locations and lengths of cracks on the actual deck. The plan is produced at a scale of 1 in. = 10 ft. A grid of the same scale is placed underneath each portion of the deck plan to allow for accurate transfer of data from the deck to the plan.

Before a survey begins, grid markings are placed on the deck using lumber crayons, every 5 ft longitudinally and transversely, corresponding with the scaled bridge plan. The survey process consists of two members of the survey team marking visible cracks with a lumber crayon as they walk over the deck. Each surveyor, bending at the waist, marks only the cracks seen from this position. Each portion of the deck is checked one time per surveyor. The method has been shown to provide a consistent measure of cracking from bridge to bridge (Lindquist, Darwin, and Browning 2005, 2008). A third member of the survey team transfers the marked cracks on the deck to the crack map, being careful to accurately represent every crack found on the deck. A complete specification of the survey process and requirements can be found in Appendix A.

Once a survey is complete, the crack maps are scanned and prepared for computer analysis. This involves editing each scanned map so that pixels are easily distinguishable and crack lines are continuous from beginning to end. Crack densities are calculated using a program that, in effect, tracks the number of adjacent pixels that are sufficiently dark, and records the length of these lines (Lindquist et al. 2005). Crack densities for the entire deck, as well as various portions of the deck, are measured and reported.

Results

All of the LC-HPC decks and all but one of the control decks, Control-8/10, reported here were supported by steel girders. Control-8/10 was supported by precast, prestressed concrete girders. The decks are numbered in the order in which they were bid, not the order in which they were constructed.

Table B.1 (Lindquist et al. 2008) shows the crack densities calculated using this method for each crack survey performed on LC-HPC and control decks within the project scope. The completed crack maps corresponding to each survey are contained in the following pages.

LC-HPC-1

LC-HPC-1 was cast in two placements separated by 19 days. Each survey yielded relatively small crack densities. At placement ages of 5.3 and 5.9 months, the crack density was 0.007 m/m^2, as shown in Fig. 2. At ages of 18.5 and 17.9 months (Fig. 3), the overall crack density was 0.027 m/m^2, but more of the cracking occurred on the first placement (south) than on the second. At approximately 31.5 months (Fig. 4), the crack density was 0.034 m/m^2, with a significant percentage of the cracks due to map cracking in the southeast portion of the deck. Most of the other cracks were found near and parallel to the pier separating the two spans and near the southeast and southwest deck edges where small sections of concrete extrude from the main portion of the deck. The cracks along the piers are likely due, in part, to tensile stresses at the surface resulting from being located in a negative moment region.

Control-1/2

Like LC-HPC-1, Control-1/2 was cast in two placements as well. After 6.1 months (for Placement 1) and 5.5 months (for Placement 2), neither placement had experienced any significant surface cracking, as shown in Fig. 5. Twelve and a half months later, at about 18 months of age, the overall crack density was 0.089 m/m^2 (Fig. 6), but Placement 1 had a significantly higher crack density (0.151 m/m^2) than did Placement 2 (0.044 m/m^2). The same holds true for the survey done at 32.2 months for Placement 1 and 31.6 months for Placement 2 (Fig. 7). At the time of the third survey, the total crack density was 0.099 m/m^2.

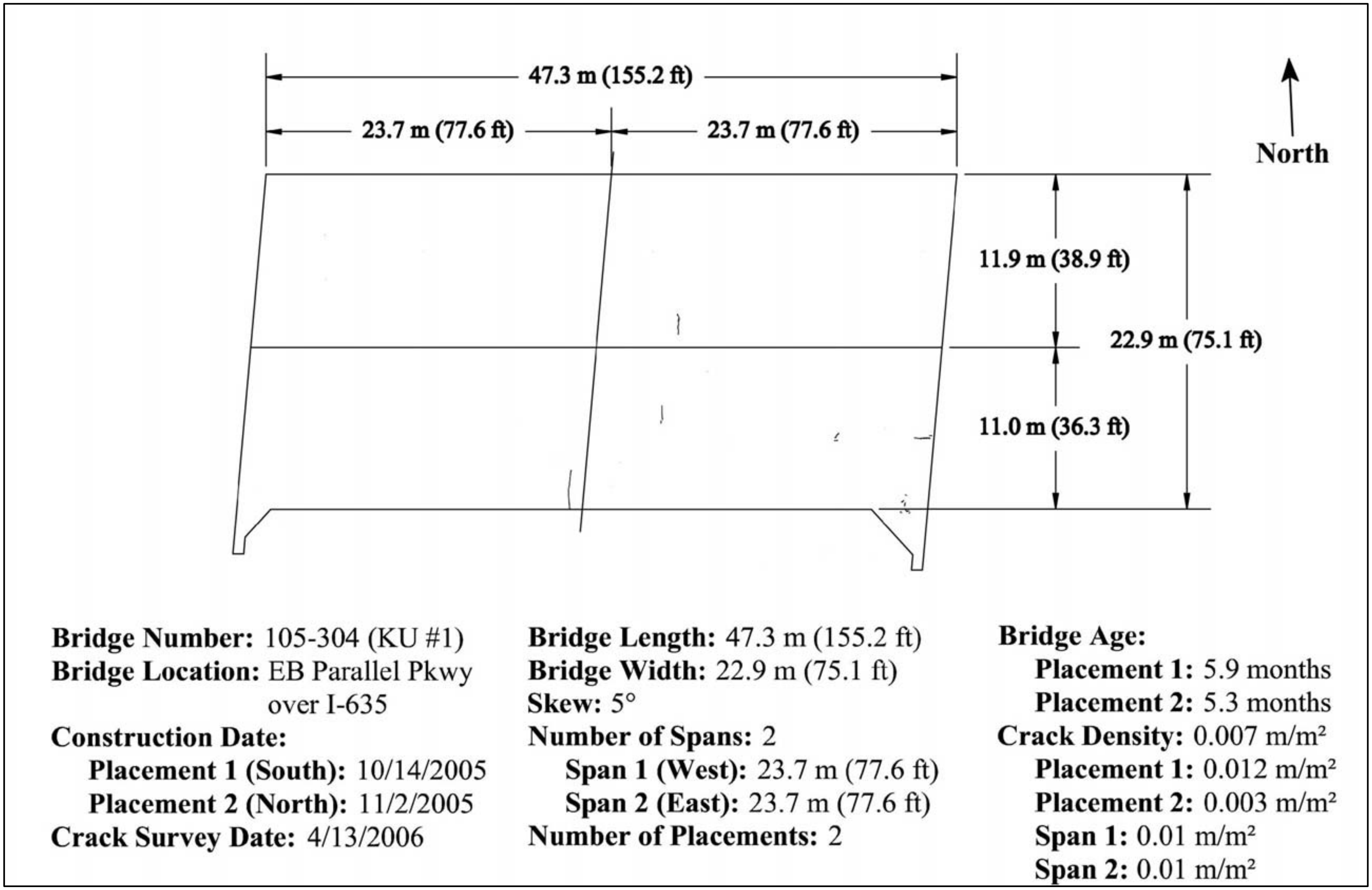


Figure 2: LC-HPC-1 (Survey 1)

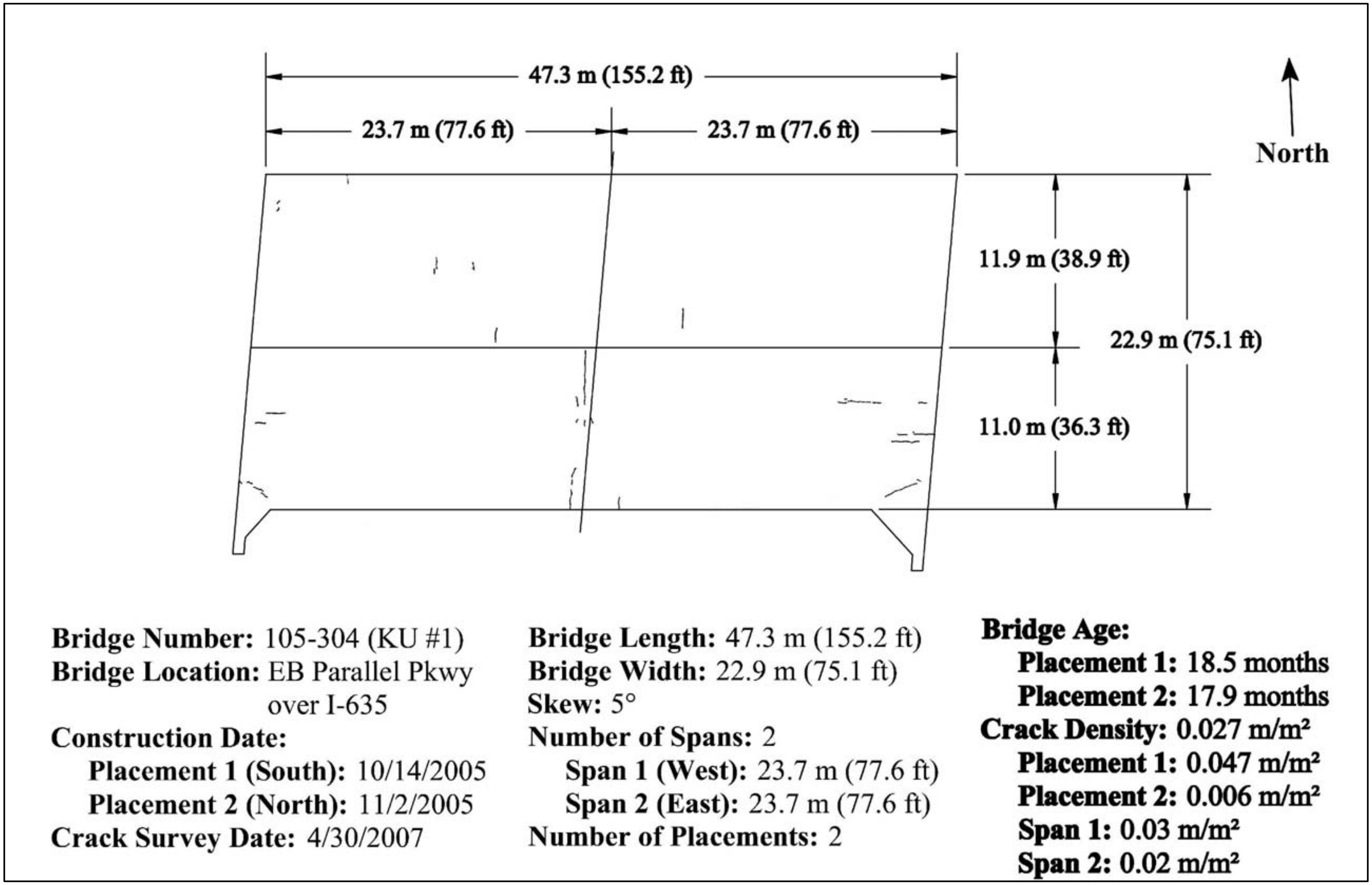
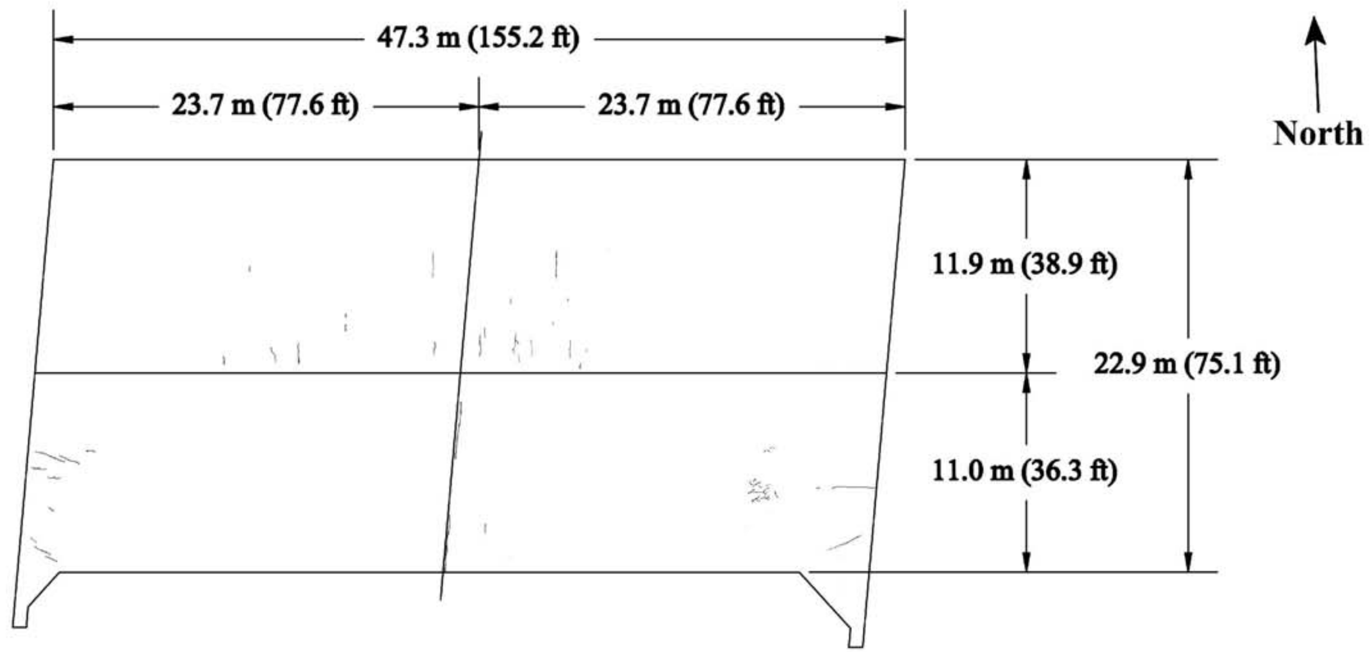


Figure 3: LC-HPC-1 (Survey 2)



Bridge Number: 105-304 (KU #1)
Bridge Location: EB Parallel Pkwy over I-635
Construction Date:
Placement 1 (South): 10/14/2005
Placement 2 (North): 11/2/2005
Crack Survey Date: 6/17/2008

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: 32.1 months
Placement 2: 31.5 months
Crack Density: 0.034 m/m²
Placement 1: 0.044 m/m²
Placement 2: 0.024 m/m²
Span 1: 0.023 m/m²
Span 2: 0.044 m/m²

Figure 4: LC-HPC-1 (Survey 3)

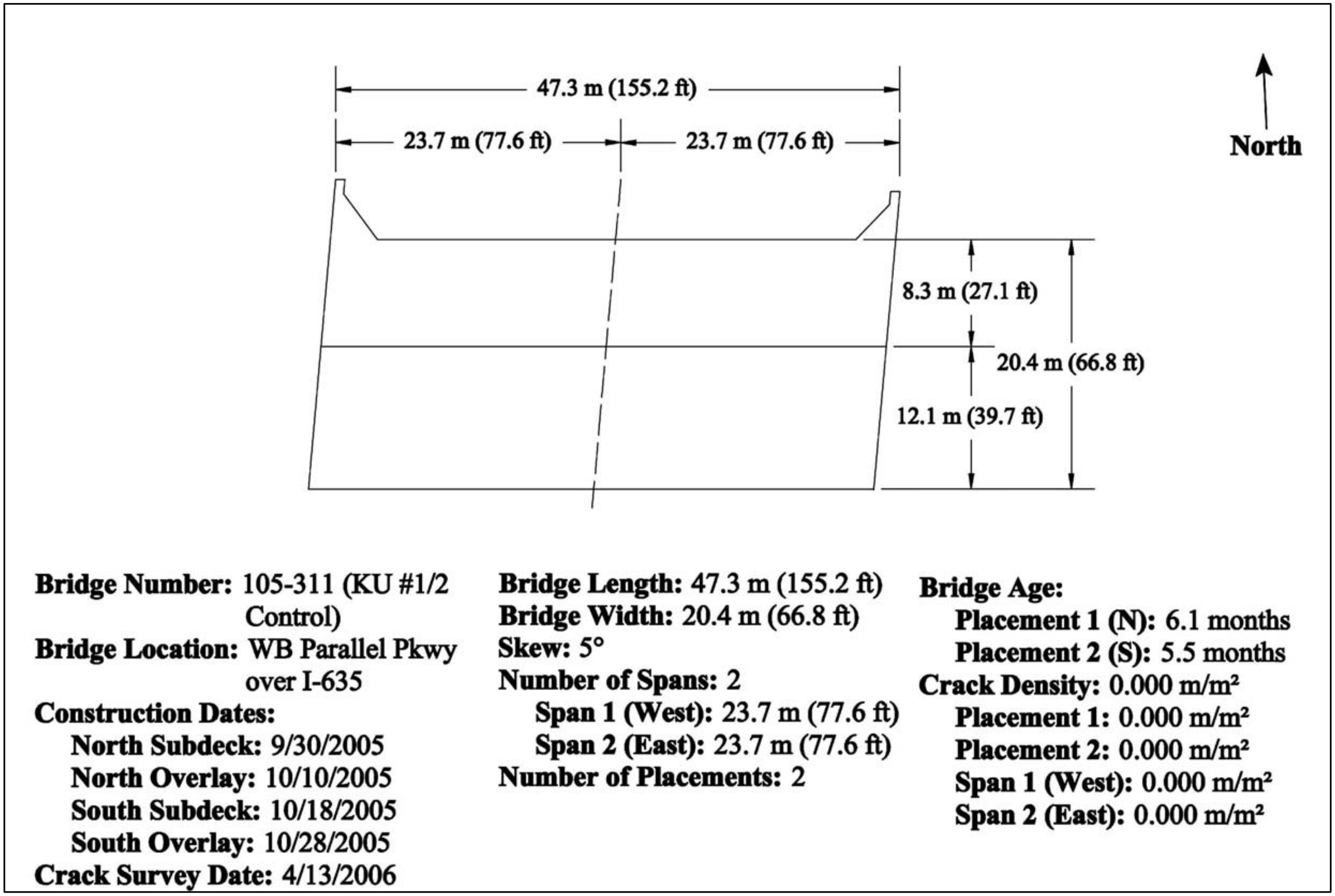
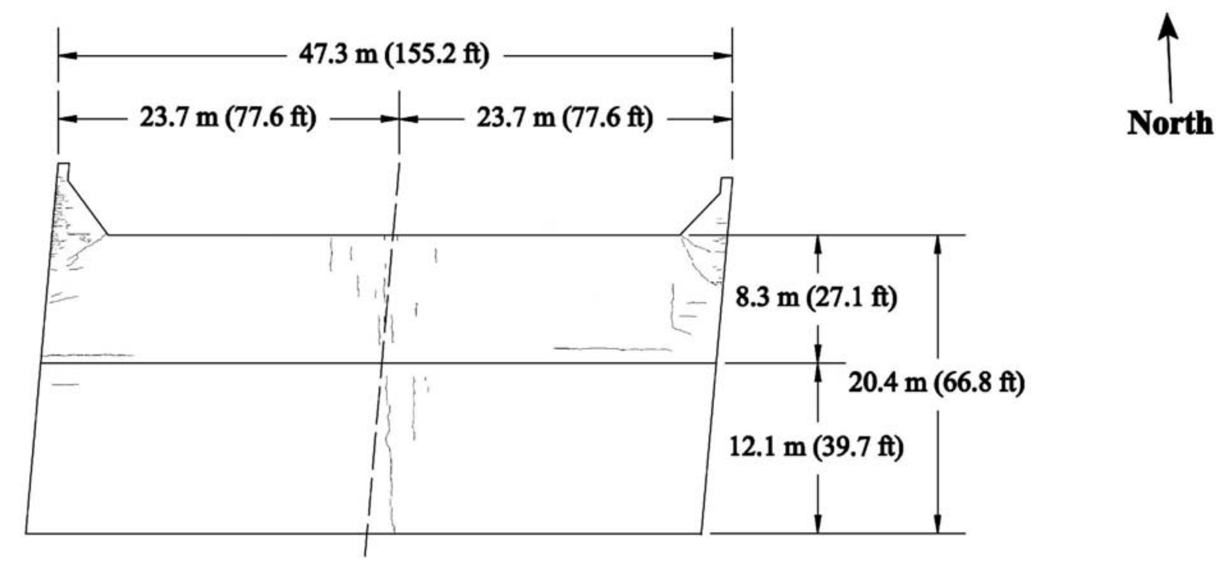


Figure 5: Control-1/2 (Survey 1)

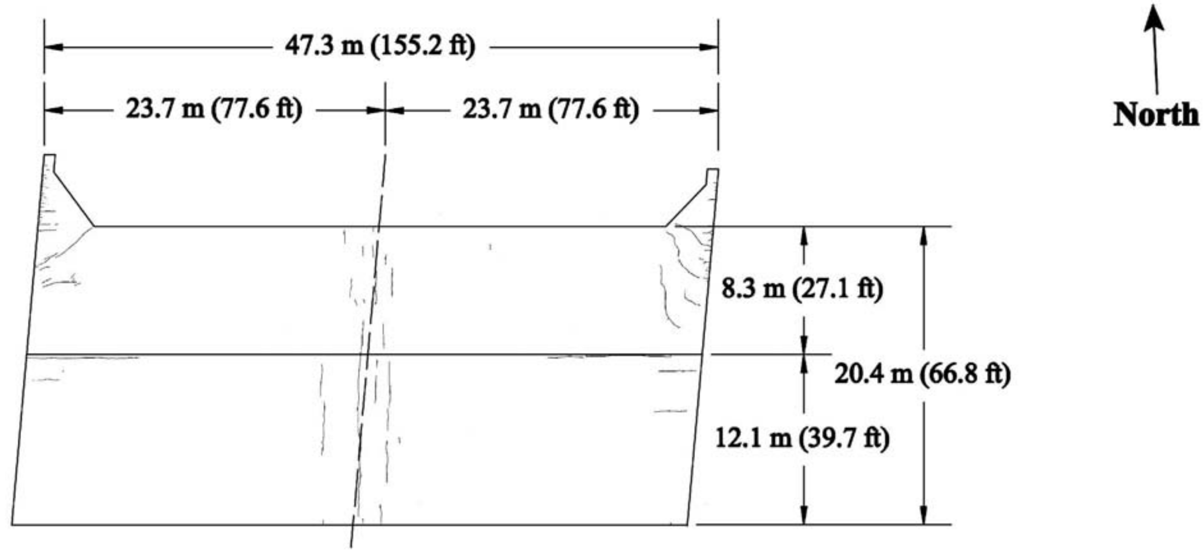


Bridge Number: 105-311 (KU #1/2 Control)
Bridge Location: WB Parallel Pkwy over I-635
Construction Dates:
North Subdeck: 9/30/2005
North Overlay: 10/10/2005
South Subdeck: 10/18/2005
South Overlay: 10/28/2005
Crack Survey Date: 4/30/2007

Bridge Length: 47.3 m (155.2 ft)
Bridge Width: 20.4 m (66.8 ft)
Skew: 5°
Number of Spans: 2
Span 1 (West): 23.7 m (77.6 ft)
Span 2 (East): 23.7 m (77.6 ft)
Number of Placements: 2

Bridge Age:
Placement 1 (N): 18.6 months
Placement 2 (S): 18.0 months
Crack Density: 0.089 m/m²
Placement 1: 0.151 m/m²
Placement 2: 0.044 m/m²
Span 1 (West): 0.075 m/m²
Span 2 (East): 0.105 m/m²

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



Bridge Number: 105-311 (KU #1/2 Control)
Bridge Location: WB Parallel Pkwy over I-635
Construction Dates:
North Subdeck: 9/30/2005
North Overlay: 10/10/2005
South Subdeck: 10/18/2005
South Overlay: 10/28/2005
Crack Survey Date: 6/17/2008

Bridge Length: 47.3 m (155.2 ft)
Bridge Width: 20.4 m (66.8 ft)
Skew: 5°
Number of Spans: 2
Span 1 (West): 23.7 m (77.6 ft)
Span 2 (East): 23.7 m (77.6 ft)
Number of Placements: 2

Bridge Age:
Placement 1 (N): 32.2 months
Placement 2 (S): 31.6 months
Crack Density: 0.099 m/m²
Placement 1: 0.114 m/m²
Placement 2: 0.091 m/m²
Span 1: 0.085 m/m²
Span 2: 0.114 m/m²

Figure 7: Control-1/2 (Survey 3)

LC-HPC-2

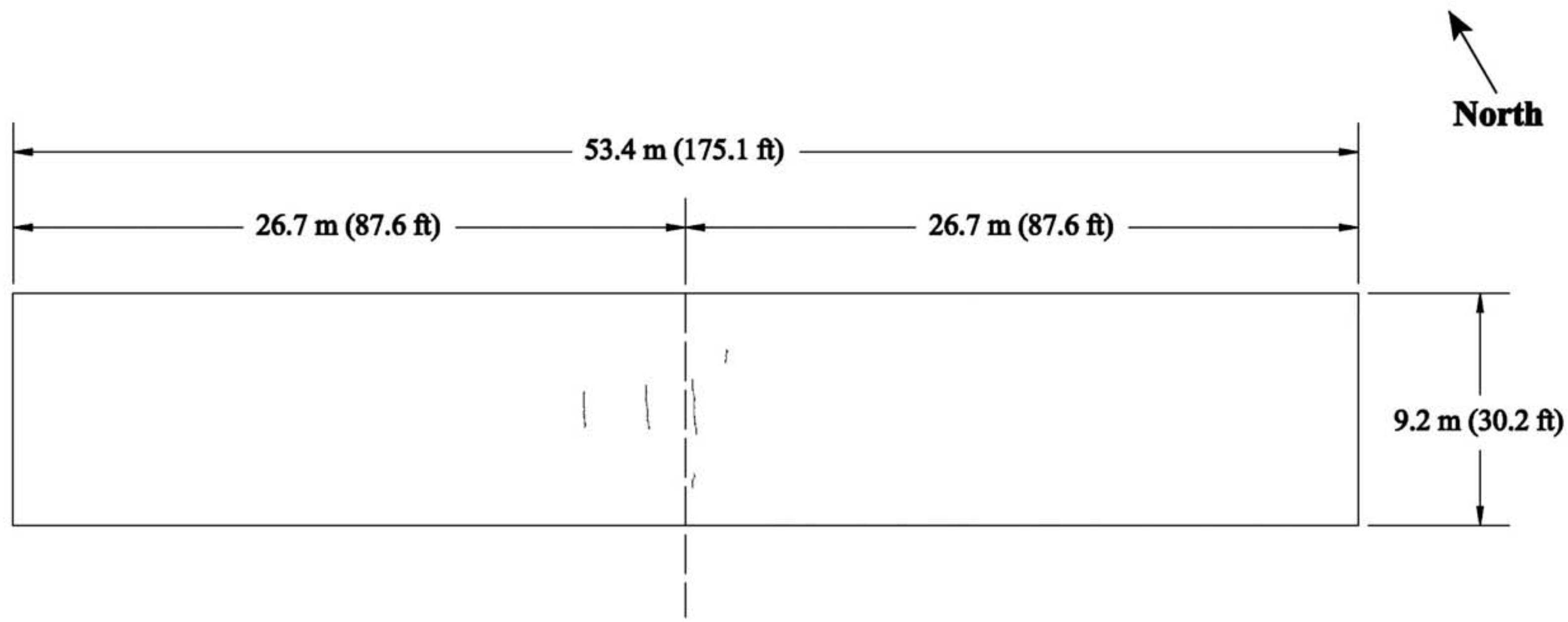
The surveys of LC-HPC-2 yielded a crack density of 0.013 m/m^2 after 7.2 months and 0.028 m/m^2 after 21.2 months, as shown in Figs. 8 and 9, respectively. Much of the cracking on this deck was found near and parallel to the pier. Small areas of map cracking were noted along the northern edge of the bridge.

LC-HPC-3

LC-HPC-3, at an age of 6.5 months (Fig. 10), had a crack density of 0.028 m/m^2. In this case, all of the cracking occurred in the transverse direction along the first and third piers. It is unclear why the portion of deck near the middle pier did not crack. This may be the result of differences in the plastic concrete properties.

Control-3

Control-3, at an age of 10.4 months, had a crack density of 0.037 m/m^2, as shown in Fig. 11. This value is only slightly larger than that of LC-HPC-3, despite the control bridge being more than 5 months older at the time of the survey. While all of the cracking was in the transverse direction, the locations were seemingly more random than for LC-HPC-3, and many of the cracks were found on the sidewalk portion of the deck, likely due to finishing and curing operations that differed significantly from those used on the deck.

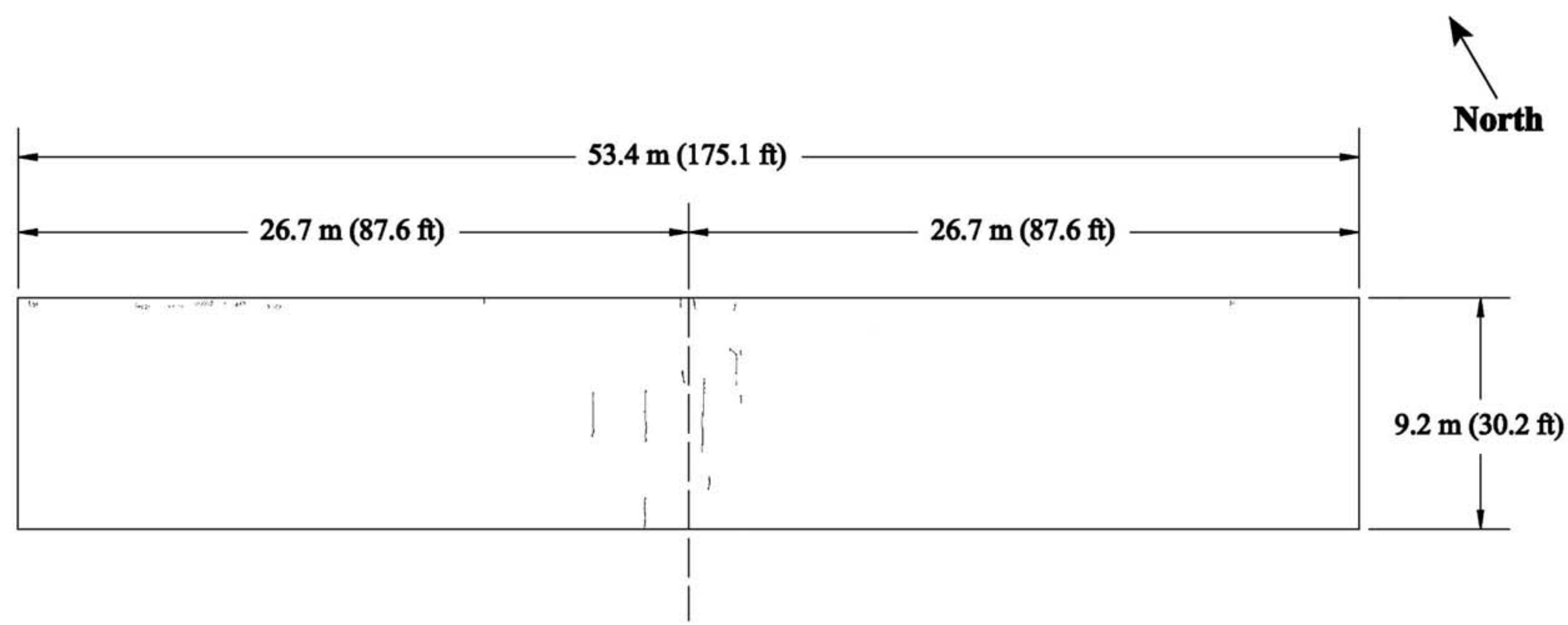


Bridge Number: 105-310 (KU #2)
Bridge Location: 34th St. over I-635
Construction Date: 9/13/2006
Crack Survey Date: 4/20/2007

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: 7.2 months
Crack Density: 0.013 m/m²
Span 1 (West): 0.012 m/m²
Span 2 (East): 0.013 m/m²

Figure 8: LC-HPC-2 (Survey 1)

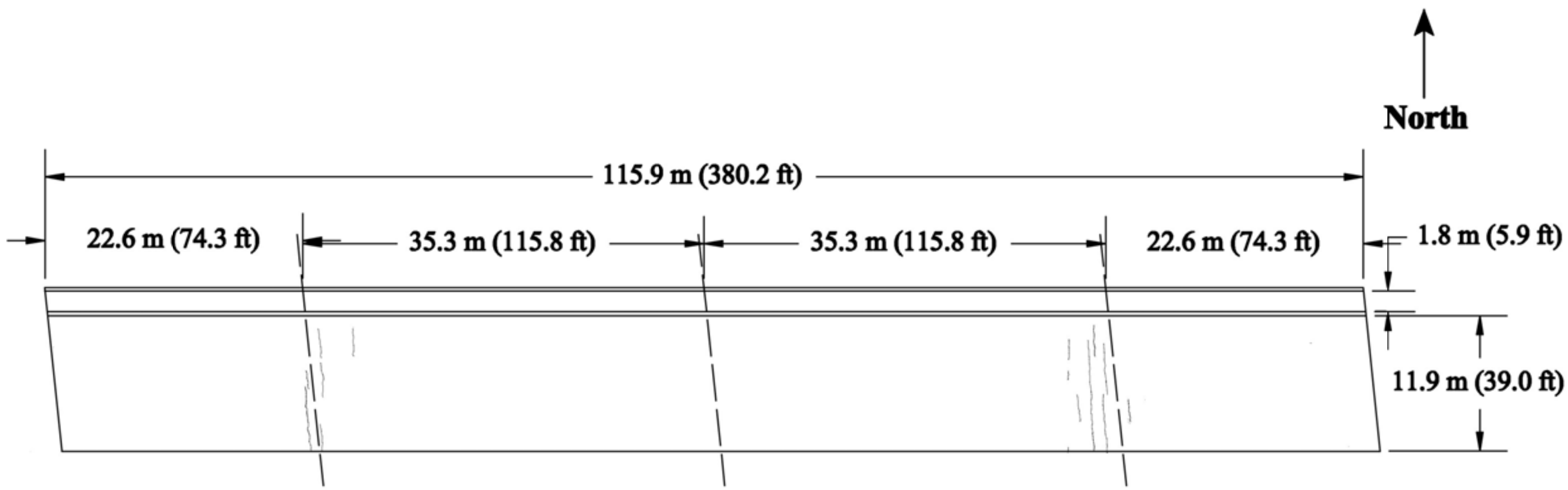


Bridge Number: 105-310 (KU #2)
Bridge Location: 34th St. over I-635
Construction Date: 9/13/2006
Crack Survey Date: 6/18/2008

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: 21.2 months
Crack Density: 0.028 m/m^2
Span 1 (West): 0.032 m/m^2
Span 2 (East): 0.024 m/m^2

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

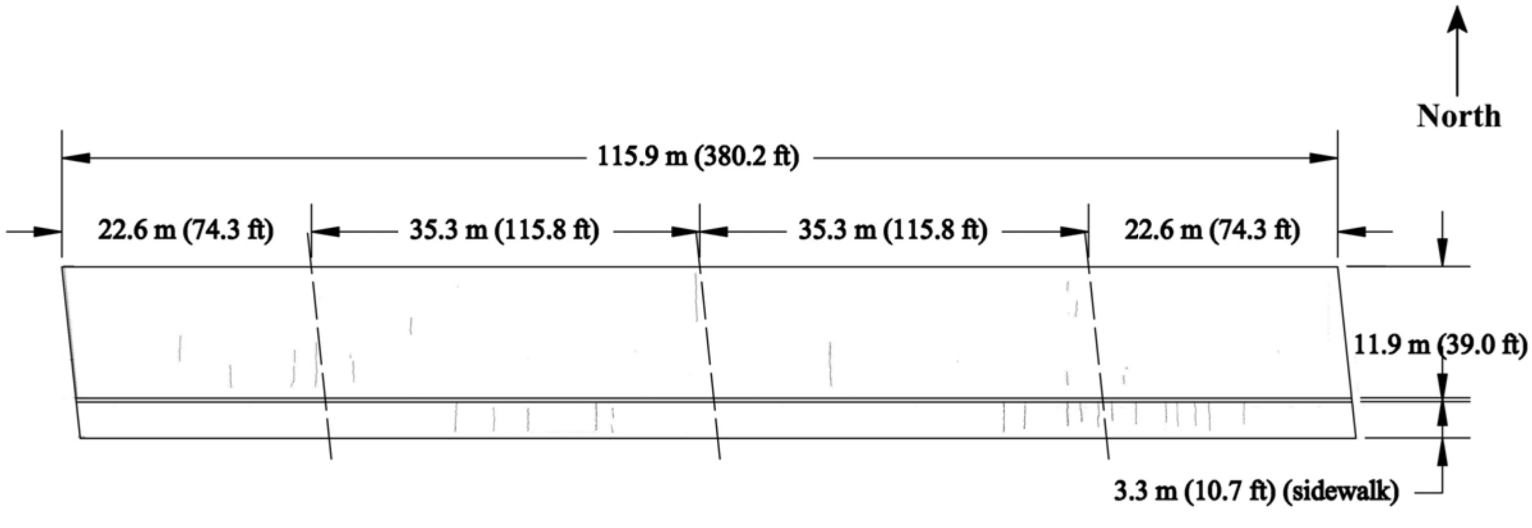


Bridge Number: 46-338 (KU #3)
Bridge Location: WB 103rd St over US 69
Construction Date: 11/13/2007
Crack survey Date: 5/29/2008

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: 6.5 months
Crack density: 0.028 m/m^2
Span 1 : 0.020 m/m^2
Span 2 : 0.019 m/m^2
Span 3 : 0.052 m/m^2
Span 4 : 0.005 m/m^2

Figure 10: LC-HPC-3



Bridge Number: 46-337 (KU #3 Control)
Bridge Location: EB 103rd St. over US-69
Construction Date: 7/17/2007
Crack survey Date: 5/29/2008

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: 10.4 months
Crack density: 0.037 m/m²
Span 1: 0.033 m/m²
Span 2: 0.035 m/m²
Span 3: 0.035 m/m²
Span 4: 0.046 m/m²

Figure 11: Control-3

LC-HPC-4

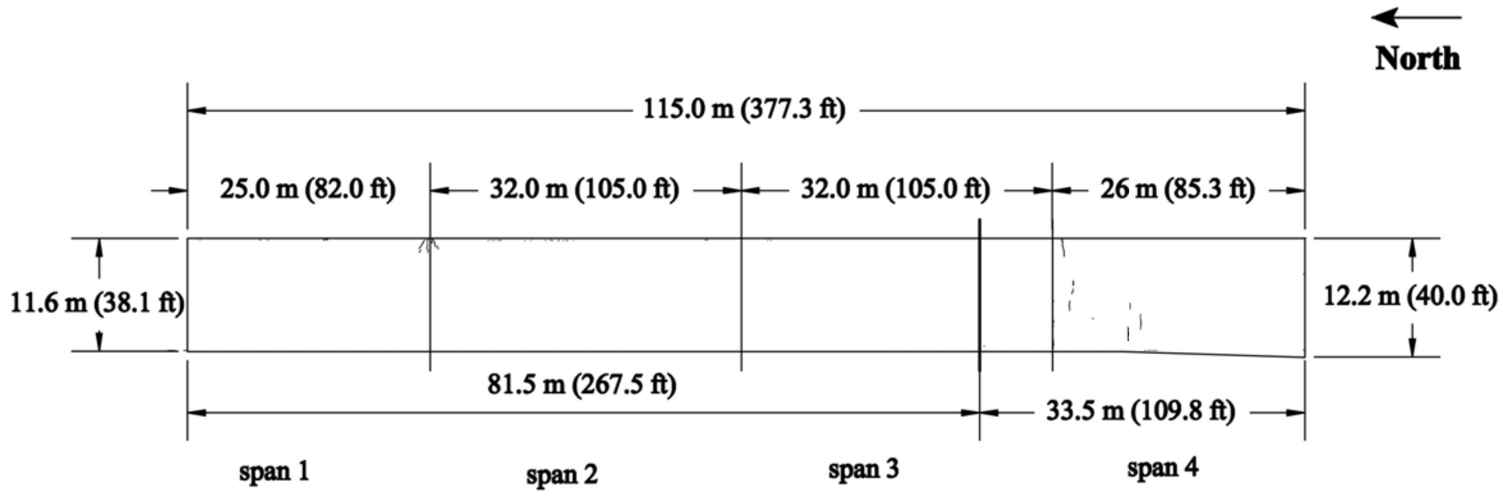
LC-HPC-4 was cast in two placements, separated by a cold joint. After 9.5 months, the total crack density was 0.008 m/m^2 (Fig. 12). However, the crack density of the first placement (0.017 m/m^2) was much larger than that of the second placement (0.004 m/m^2). For the first placement, there was no pattern to the crack locations. For the second placement, the only observed cracks propagated from the eastern edge of the deck along the northernmost pier.

Control-4

Control-4 (Fig. 13) had an overall crack density of 0.050 m/m^2 at 6.8 months, much greater than that of LC-HPC-4. Again, most of the cracking occurred near the piers. While most of the cracks are transverse, there are a number that are oriented diagonally. At the first (westernmost) and third piers, the diagonal cracks are further away from the pier at the middle portion of the deck width, and closer to the pier at the edges of the deck. For the second pier, the crack orientations are opposite.

LC-HPC-5

The crack survey results for LC-HPC-5 are particularly unusual. The overall crack density was 0.059 m/m^2 at 8.0 months (Fig. 14), a higher value than found on most LC-HPC decks. No correlation was seen between crack and pier positions, but nearly all of the cracks seemed to propagate from the southern edge of the deck, as seen in Figure 14. This was likely due to the superelevation of the bridge deck. The southern edge was constructed at a higher elevation that the northern edge, so it is likely that, during curing, the southern edge dried out as the curing water would run down to the northern edge. This would certainly leave the southern portion more prone to early cracking. Another

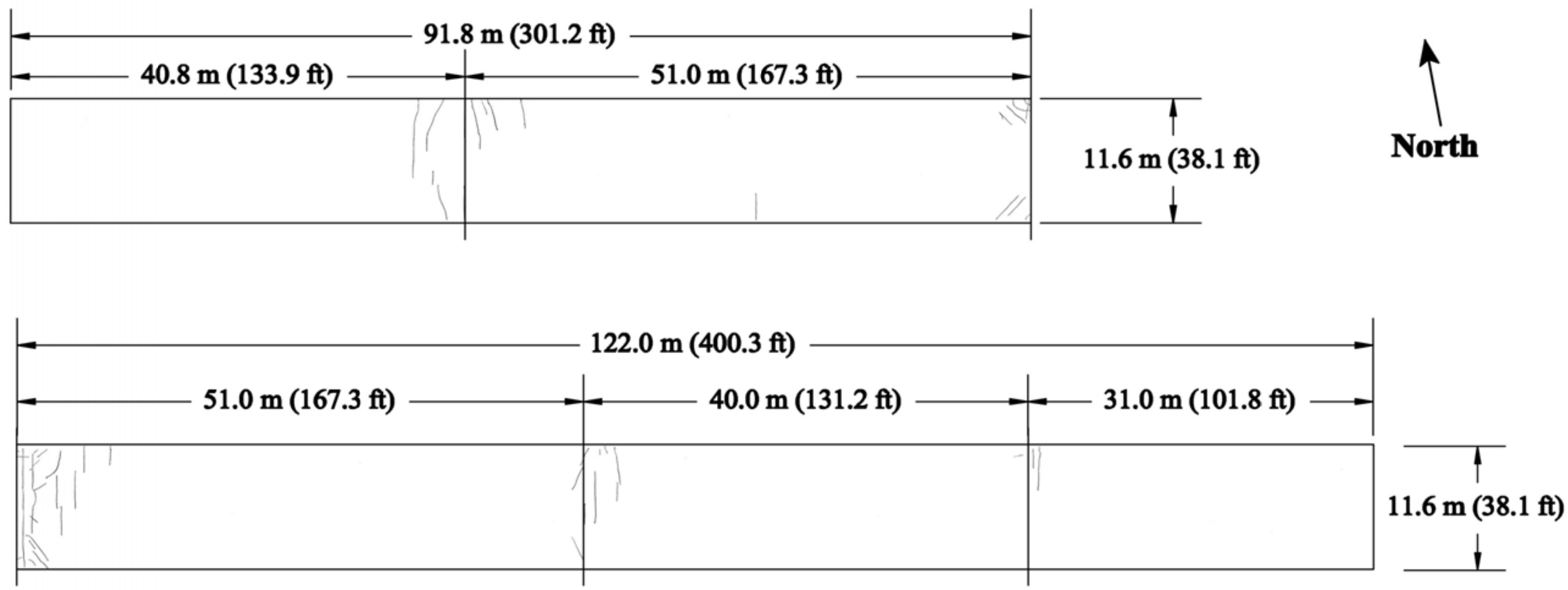


Bridge Number: 46-339 Unit 1 (KU #4)
Bridge Location: Flyover Ramp US-69S to I-435W
Construction Date:
Placement 1 (South): 9/29/2007
Placement 2 (North): 10/2/2007
Crack Survey Date: 7/15/2008

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: 9.5 months
Placement 2: 9.4 months
Crack Density: 0.008 m/m^2
Placement 1: 0.017 m/m^2
Placement 2: 0.004 m/m^2
Span 1: 0.009 m/m^2
Span 2: 0.003 m/m^2
Span 3: 0.000 m/m^2
Span 4: 0.021 m/m^2

Figure 12: LC-HPC-4



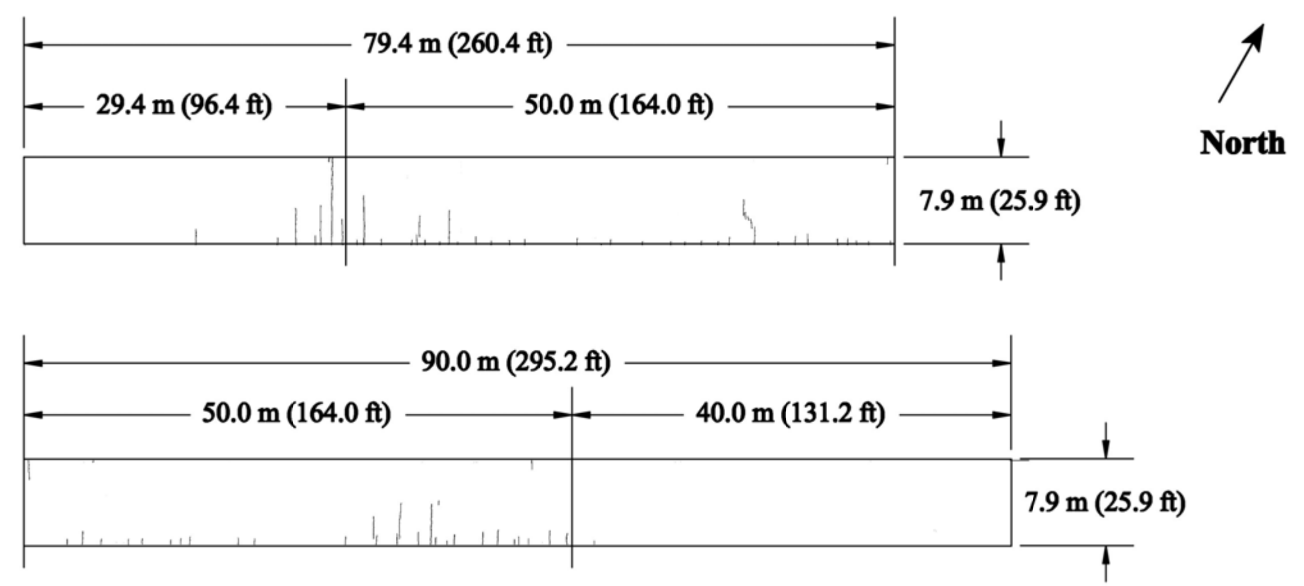
Bridge Number: 46-347 (KU #4 Control)
Bridge Location: NB US-69 Rd
Construction Date: 11/16/2007
Crack survey Date: 6/10/2008

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: 6.8 months
Crack density: 0.050 m/m^2
- **Span 1:** 0.045 m/m^2
- **Span 2:** 0.058 m/m^2
- **Span 3:** 0.093 m/m^2
- **Span 4:** 0.026 m/m^2
- **Span 5:** 0.016 m/m^2

Figure 13: Control-4



Bridge Number: 46-340 Unit 1 (KU #5)
Bridge Location: Flyover Ramp US-69 to I-435 W
Construction Date: 11/14/2007
Crack survey Date: 7/15/2008

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: 8.0 months
Crack density: 0.059 m/m²
- **Span 1:** 0.087 m/m²
- **Span 2:** 0.071 m/m²
- **Span 3:** 0.077 m/m²
- **Span 4:** 0.001 m/m²

Figure 14: LC-HPC-5

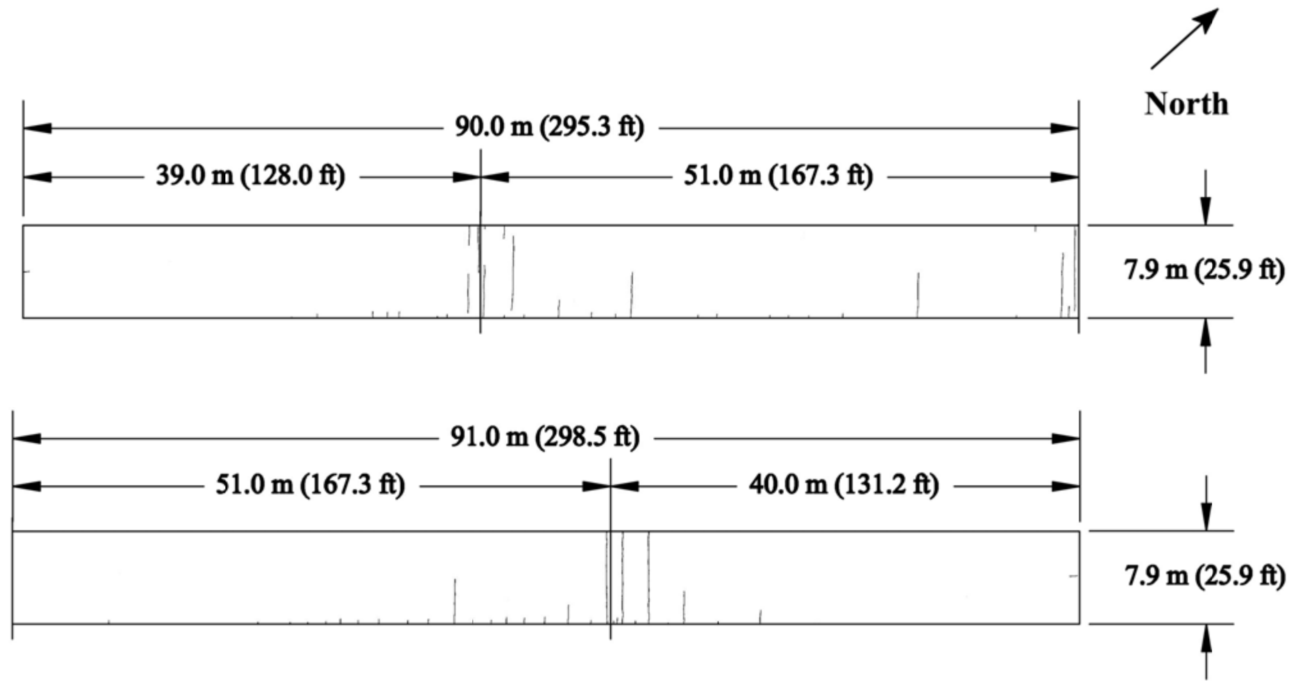
contributor could have been the slump of the concrete used on this deck. With most of the slump readings near the maximum allowable value of 4 in., the concrete at the higher elevations may have been susceptible to increased settlement cracking compared to the lower portions of the deck.

LC-HPC-6

LC-HPC-6 had a significant number of cracks along the piers. As shown in Fig. 15, the total crack density for the deck was 0.063 m/m^2 at 6.5 months, an even higher value than that of LC-HPC-5. Again, most of the cracks propagated from the southern (or southeastern) edge of the deck width where the elevation was greatest.

LC-HPC-7

LC-HPC-7 displayed very few cracks at 11.4 months of age. Several small longitudinal cracks were found at the far west end, and the overall crack density was 0.003 m/m^2 (Fig. 16). At 24.2 months, the crack density was 0.019 m/m^2, as shown in Fig. 17. Additional cracks were found at the west end, and short, transverse cracks had developed throughout the deck. A small area of map cracking was also surveyed in the northeast corner of the deck.

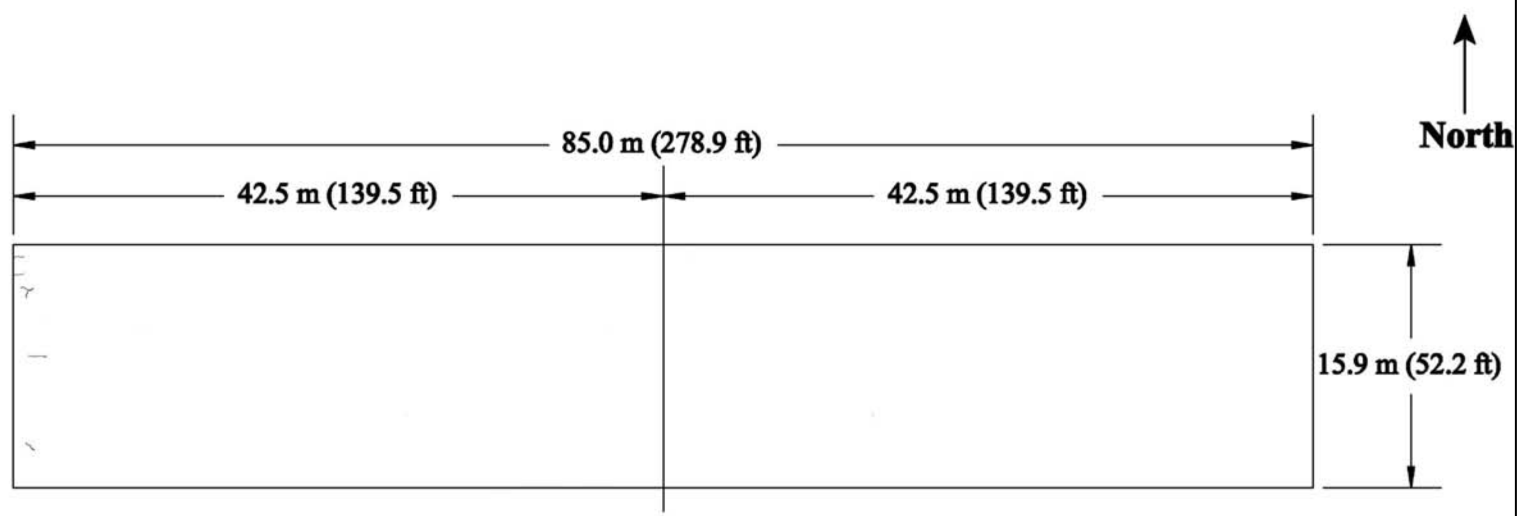


Bridge Number: 46-340 Unit 2 (KU #6)
Bridge Location: SB US-69 to WB I-435
Construction Date: 11/3/2007
Crack survey Date: 5/20/2008

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: 6.6 months
Crack density: 0.063 m/m²
Span 1: 0.039 m/m²
Span 2: 0.095 m/m²
Span 3: 0.047 m/m²
Span 4: 0.068 m/m²

Figure 15: LC-HPC-6



Bridge Number: 43-33 (KU #7)
Bridge Location: Co. Rd. 150 over US-75
Construction Date: 6/24/2006
Crack Survey Date: 6/5/2007

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

Bridge Age: 11.4 months
Crack Density: 0.003 m/m^2
Span 1: 0.006 m/m^2
Span 2: 0.000 m/m^2

Figure 16: LC-HPC-7 (Survey 1)

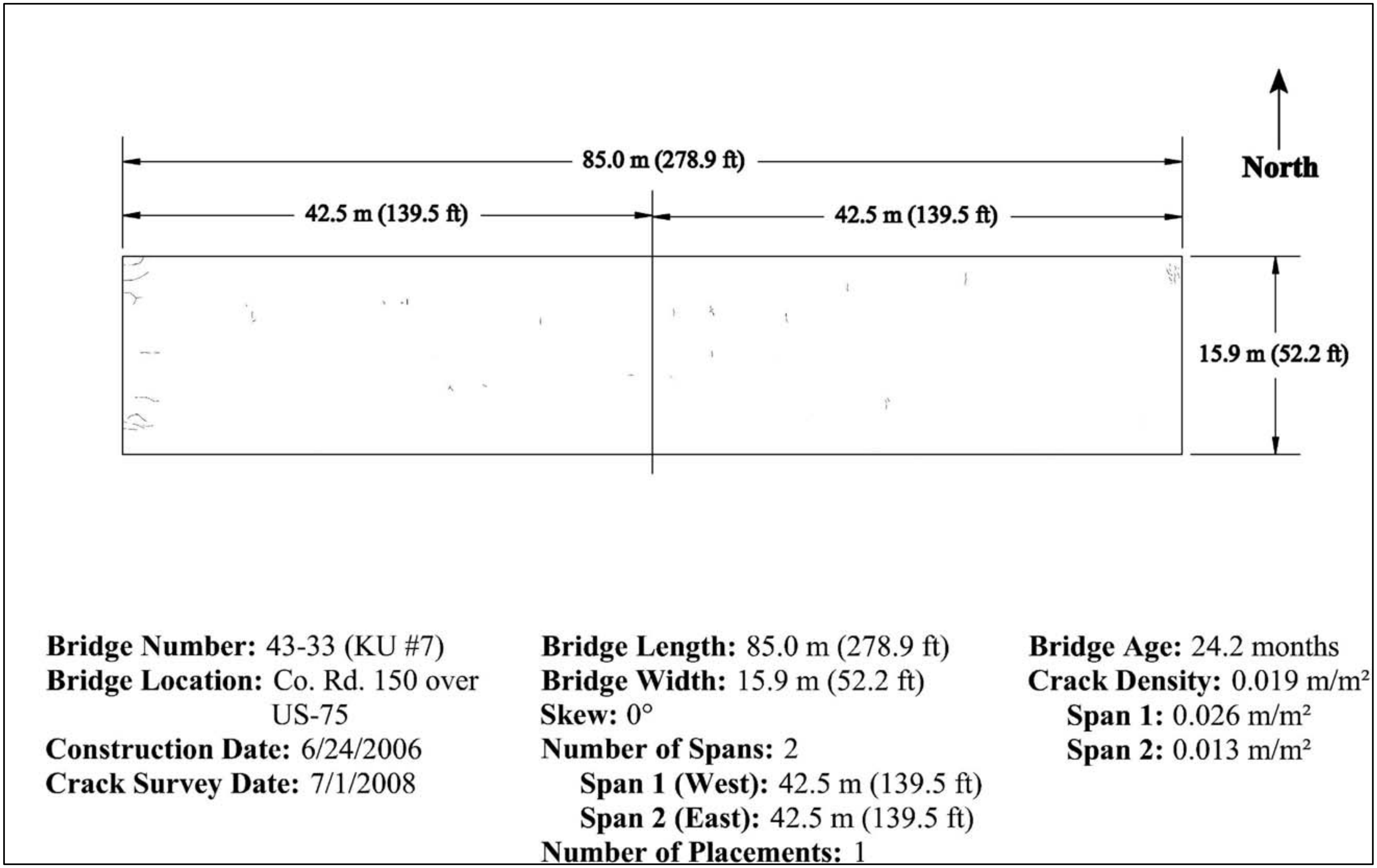


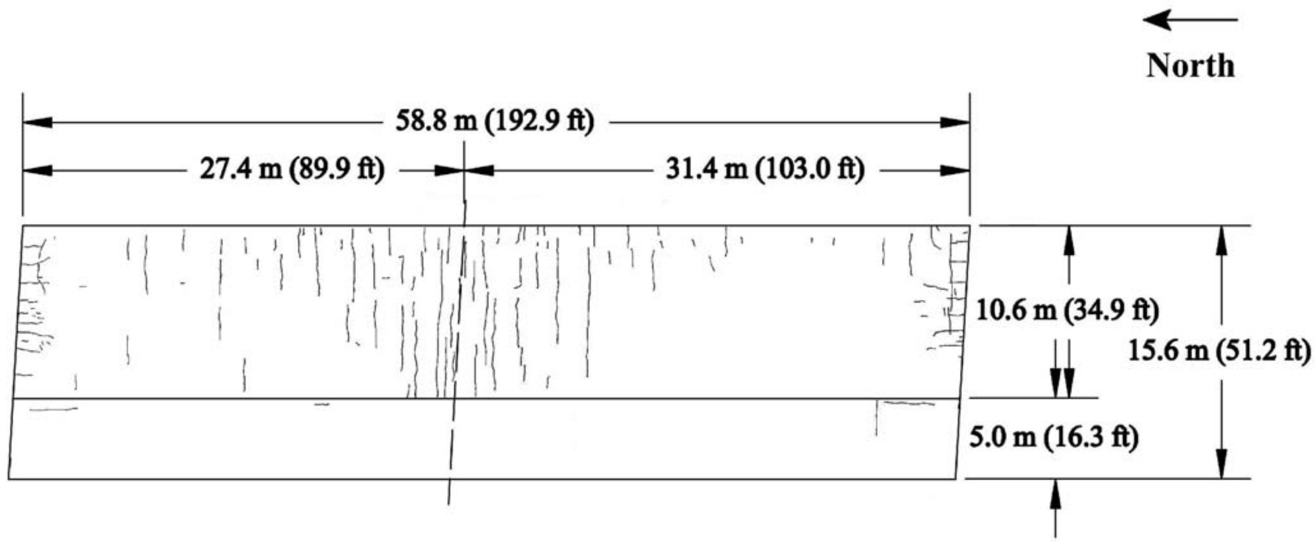
Figure 17: LC-HPC-7 (Survey 2)

Control-7

Control-7 was constructed in two placements that were separated by 6 months. The first (east) placement had a crack density of 0.293 m/m^2 at 16.4 months (Fig. 18). Transverse cracks were found throughout the placement, but were longer and more tightly packed near the pier. Shorter longitudinal cracks were also present at either end. The second (west) placement had a crack density of 0.030 m/m^2 at 10.8 months (Fig. 18). Only five cracks were found in this portion of the deck, three of which were near and oriented parallel to the joint separating the two placements. The overall crack density of the bridge deck was 0.205 m/m^2 for this first survey. At 27.1 months (Fig. 19), the crack density of the first placement had increased to 0.476 m/m^2. A similar cracking pattern was observed to the first survey, and several longitudinal cracks were found near the middle of the placement width. The second placement, then at an age of 21.5 months, had a crack density of 0.069 m/m^2, as shown in Fig. 19. Most of the cracks were, again, longitudinal (parallel to the joint).

Control-8/10

Control-8/10, the only control bridge with precast, prestressed concrete girders, had a crack density of 0.050 m/m^2 (Fig. 20) at 5.2 months. Most of the cracks were transverse cracks found in the second (from west) of four spans. The crack density had greatly increased 9 months later, when the crack density was calculated to be 0.177 m/m^2 at 14.4 months. Again, most of the cracks were transverse, and the largest portion was found within span 2, as shown in Figure 21.

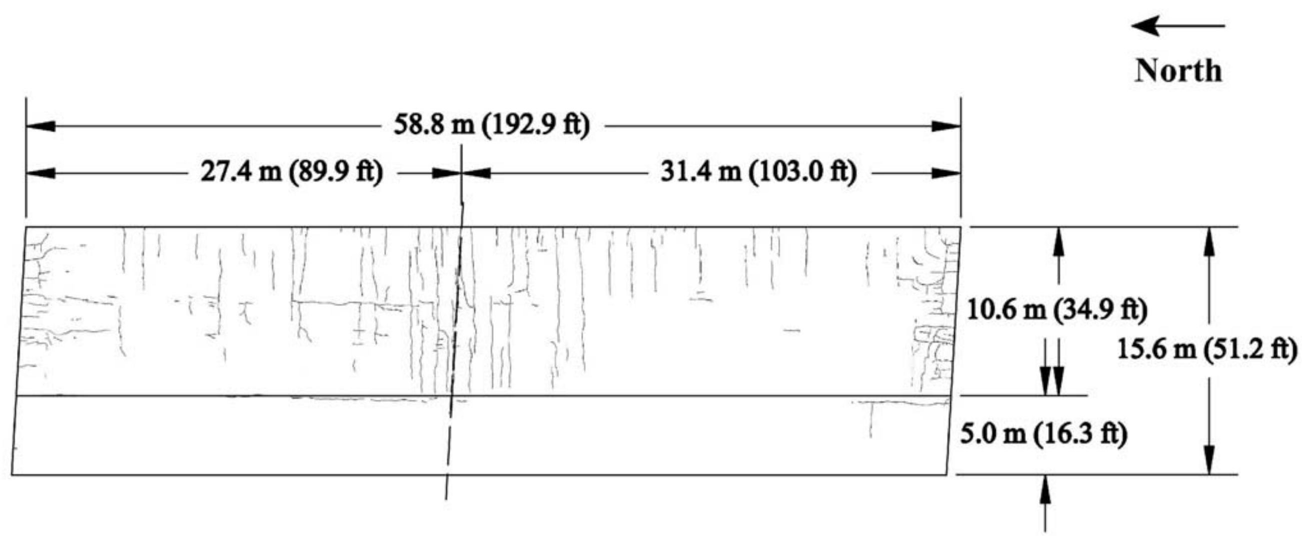


Bridge Number: 46-334 (KU #7 Control)
Bridge Location: NB Antioch Rd over I-435
Construction Date:
Placement 1 (East): 3/29/2006
Placement 2 (West): 9/15/2006
Crack Survey Date: 8/10/2007

Bridge Length: 58.8 m (192.9 ft)
Bridge Width: 15.6 m (51.2 ft)
Skew: 3.29°
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: 16.4 months
Placement 2: 10.8 months
Crack Density: 0.205 m/m²
Placement 1: 0.293 m/m²
Placement 2: 0.030 m/m²
Span 1: 0.201 m/m²
Span 2: 0.207 m/m²

Figure 18: Control-7 (Survey 1)

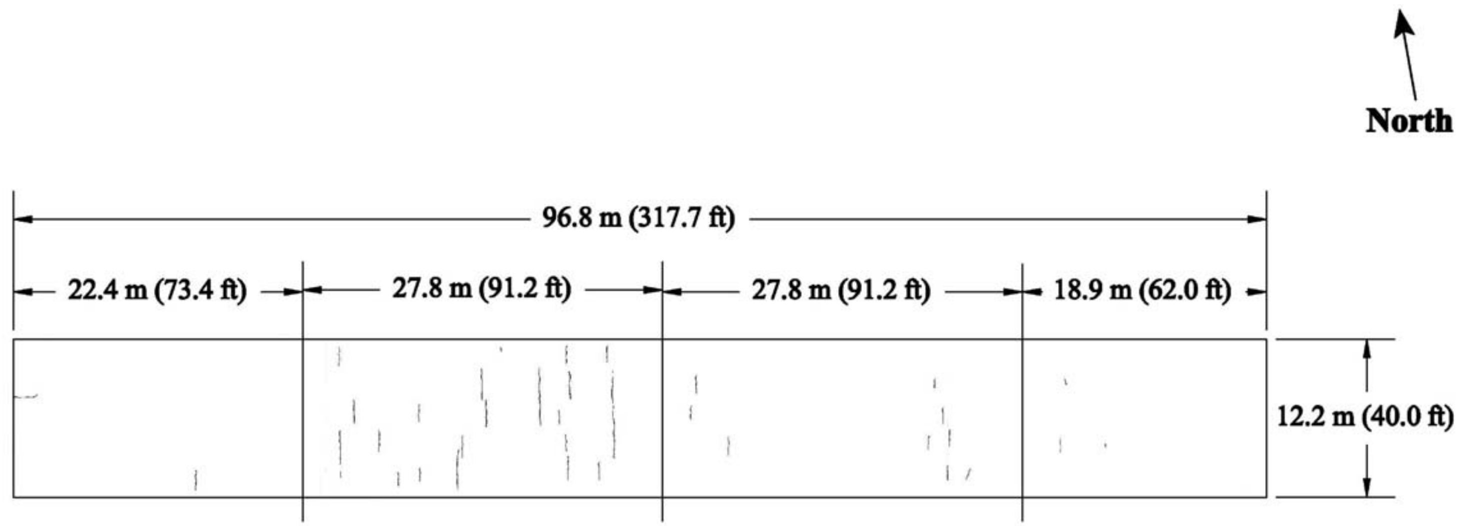


Bridge Number: 46-334 (KU #7 Control)
Bridge Location: NB Antioch Rd over I-435
Construction Date:
Placement 1 (East): 3/29/2006
Placement 2 (West): 9/15/2006
Crack Survey Date: 6/30/2008

Bridge Length: 58.8 m (192.9 ft)
Bridge Width: 15.6 m (51.2 ft)
Skew: 3.29°
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: 27.1 months
Placement 2: 21.5 months
Crack Density: 0.346 m/m²
Placement 1: 0.476 m/m²
Placement 2: 0.069 m/m²
Span 1: 0.374 m/m²
Span 2: 0.325 m/m²

Figure 19: Control-7 (Survey 2)

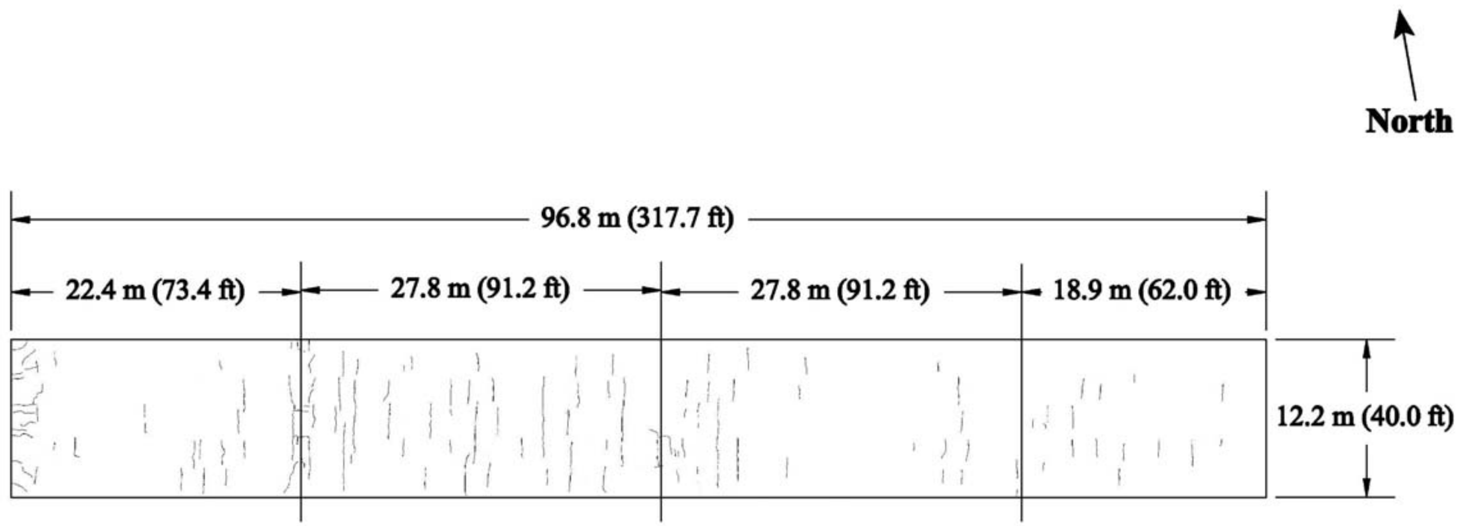


Bridge Number: 54-59 (KU #8/10 Control)
Bridge Location: K-52 over US-69
Construction Date: 4/16/2007
Crack Survey Date: 9/22/2007

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: 5.2 months
Crack Density: 0.050 m/m²
Span 1: 0.012 m/m²
Span 2: 0.117 m/m²
Span 3: 0.025 m/m²
Span 4: 0.007 m/m²

Figure 20: Control-8/10 (Survey 1)



Bridge Number: 54-59 (KU #8/10 Control)
Bridge Location: K-52 over US-69
Construction Date: 4/16/2007
Crack Survey Date: 6/26/2008

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: 14.4 months
Crack Density: 0.177 m/m^2
- **Span 1:** 0.196 m/m^2
- **Span 2:** 0.281 m/m^2
- **Span 3:** 0.124 m/m^2
- **Span 4:** 0.078 m/m^2

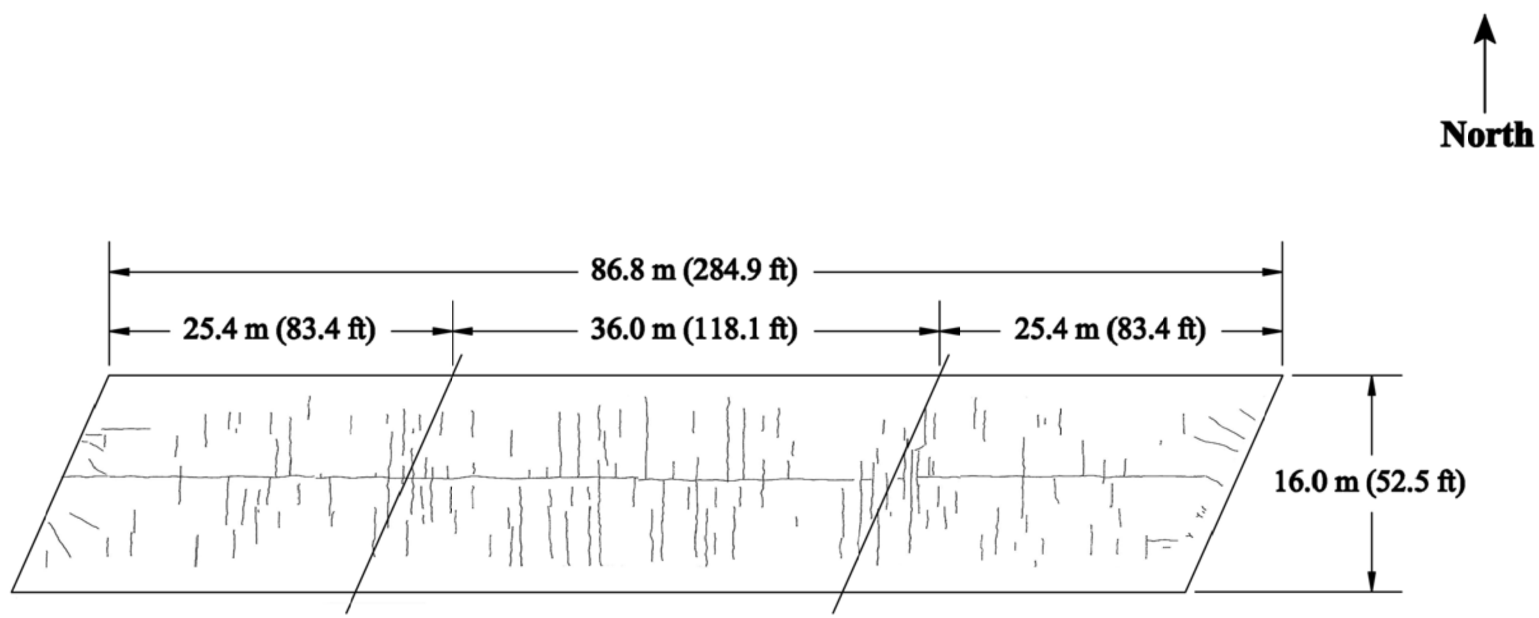
Figure 21: Control-8/10 (Survey 2)

Control-11

The first survey of Control-11 yielded a large amount of cracking. At 16.5 months, the crack density was already 0.351 m/m^2 (Fig. 22). Unlike the other bridge surveys, the cracking on this deck was characterized, in large part, by one long longitudinal crack down the center of the deck, with many of the transverse cracks propagating on either side of this longitudinal crack. In addition, there were several smaller longitudinal and diagonal cracks found at the west and east ends of the bridge. The second survey (Fig. 23) of this bridge yielded a greatly increased crack density (0.665 m/m^2 at 27.1 months), with many of the transverse cracks extending all of the way to the north and south barriers and new transverse cracks appearing at the barriers.

Control-Alt

At an age of 12.0 months, the alternate control bridge had a crack density of 0.077 m/m^2, as shown in Fig. 24. Nearly all of the cracks were transverse and parallel to the top reinforcement, but not to the piers, as the reinforcing steel and piers on this bridge do not run in the same direction. The piers run parallel to the bridge ends, while the top reinforcing steel runs perpendicular to the sides of the bridge. Based on the crack pattern, it is likely that shrinkage and settlement at the reinforcing steel played a larger role in crack development than did the tensile stresses created by the negative moment regions at the piers. The cracks are located directly above and parallel to the reinforcement. This trend continued for the second and third surveys. At 25.8 (Fig. 25) and 36.8 months (Fig. 26), the crack densities were 0.230 m/m^2 and 0.219 m/m^2, respectively. For each survey, most of the cracks were found in the transverse direction, with some longitudinal cracks found at the ends of the deck.

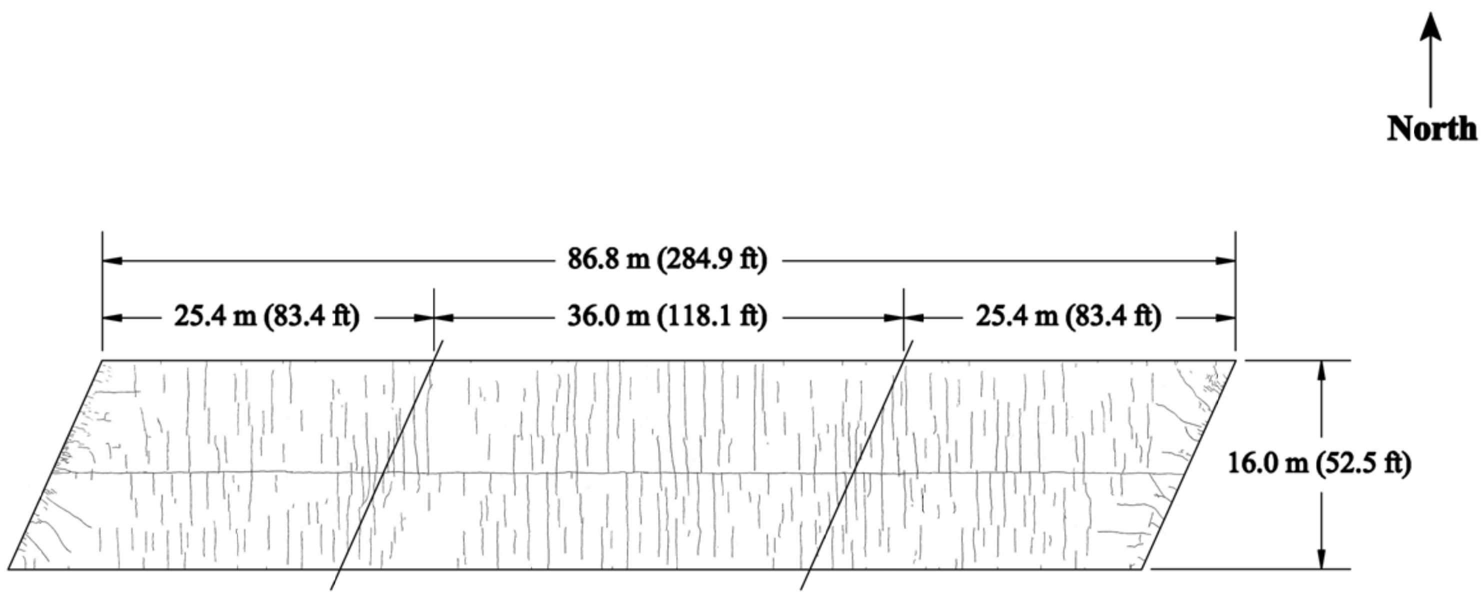


Bridge Number: 56-155 (KU #11 Control)
Bridge Location: US-50 over BNSF Railroad
Construction Date: 3/28/2006
Crack Survey Date: 8/13/2007

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: 16.5 months
Crack Density: 0.351 m/m²
Span 1: 0.281 m/m²
Span 2: 0.433 m/m²
Span 3: 0.308 m/m²

Figure 22: Control-11 (Survey 1)

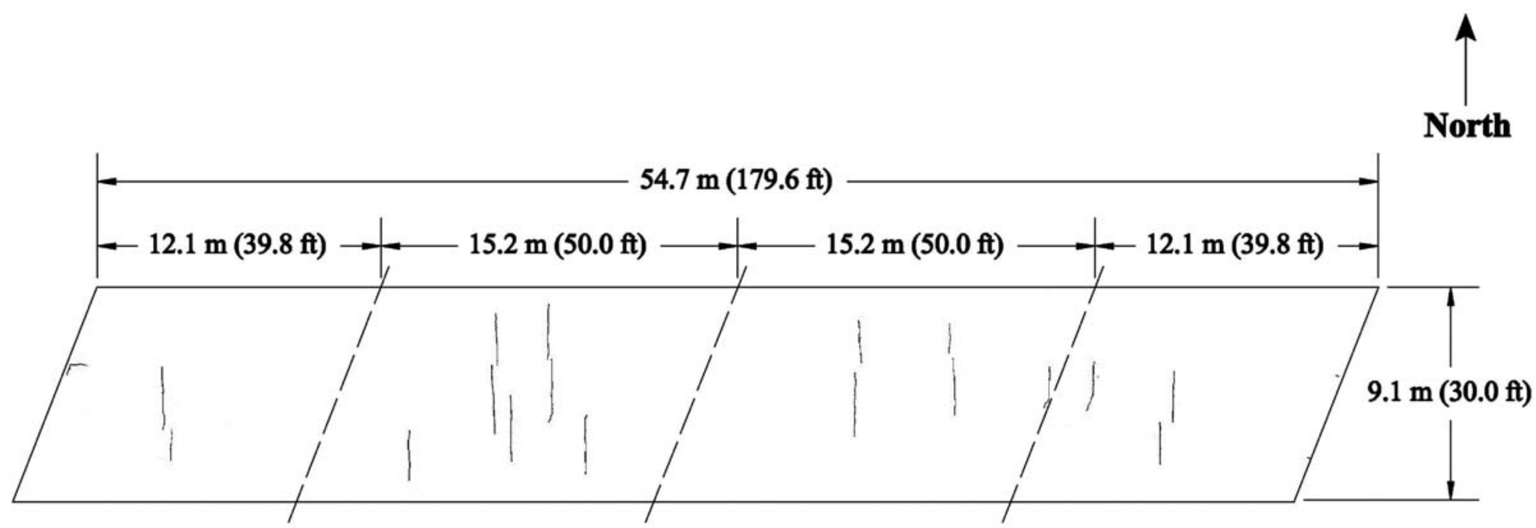


Bridge Number: 56-155 (KU #11 Control)
Bridge Location: US-50 over BNSF Railroad
Construction Date: 3/28/2006
Crack Survey Date: 6/30/2008

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: 27.1 months
Crack Density: 0.665 m/m²
Span 1: 0.629 m/m²
Span 2: 0.663 m/m²
Span 3: 0.703 m/m²

Figure 23: Control-11 (Survey 2)



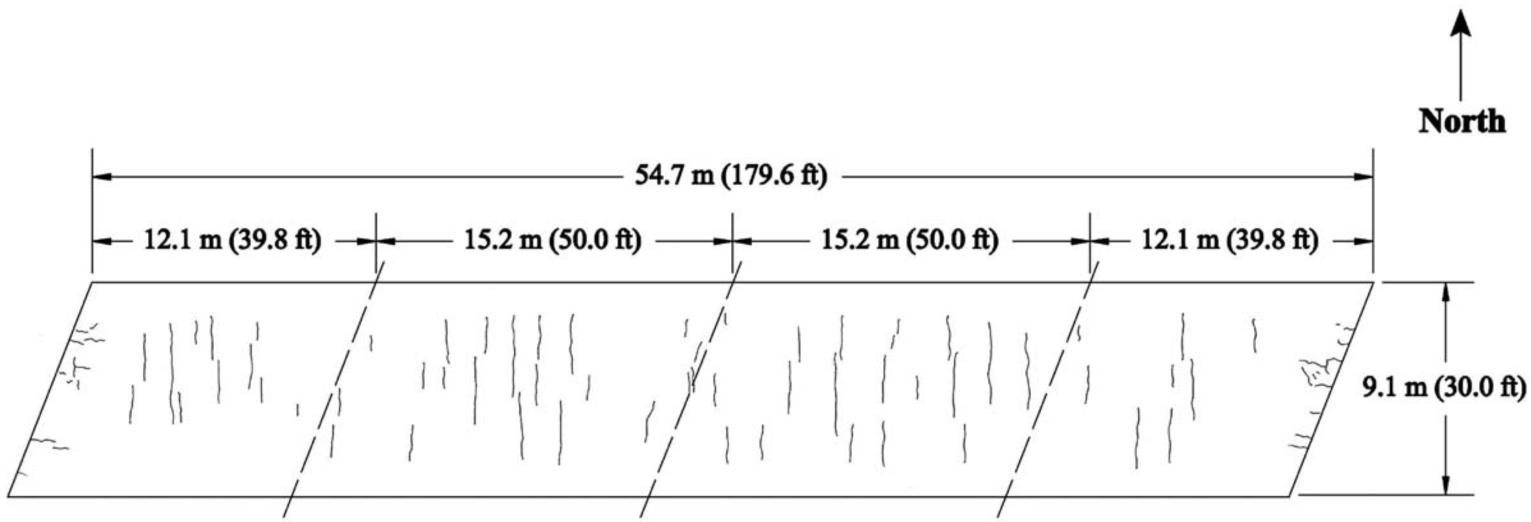
Bridge Number: 56-49 (KU Control Alt)
Bridge Location: K-99 over I-335
Construction Date: 6/2/2005
Crack Survey Date: 6/2/2006

Bridge Length: 54.7 m (179.6 ft)
Bridge Width: 9.1 m (30.0 ft)
Skew: 21.4°
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: 12.0 months
Crack Density: 0.077 m/m²
- **Span 1:** 0.042 m/m²
- **Span 2:** 0.125 m/m²
- **Span 3:** 0.070 m/m²
- **Span 4:** 0.056 m/m²

Figure 24: Control-Alt (Survey 1)



Bridge Number: 56-49 (KU Control Alt)
Bridge Location: K-99 over I-335
Construction Date: 6/2/2005
Crack Survey Date: 7/27/2007

Bridge Length: 54.7 m (179.6 ft)
Bridge Width: 9.1 m (30.0 ft)
Skew: 21.4°
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: 25.8 months
Crack Density: 0.230 m/m²
  Span 1: 0.224 m/m²
  Span 2: 0.246 m/m²
  Span 3: 0.252 m/m²
  Span 4: 0.191 m/m²

Figure 25: Control-Alt (Survey 2)

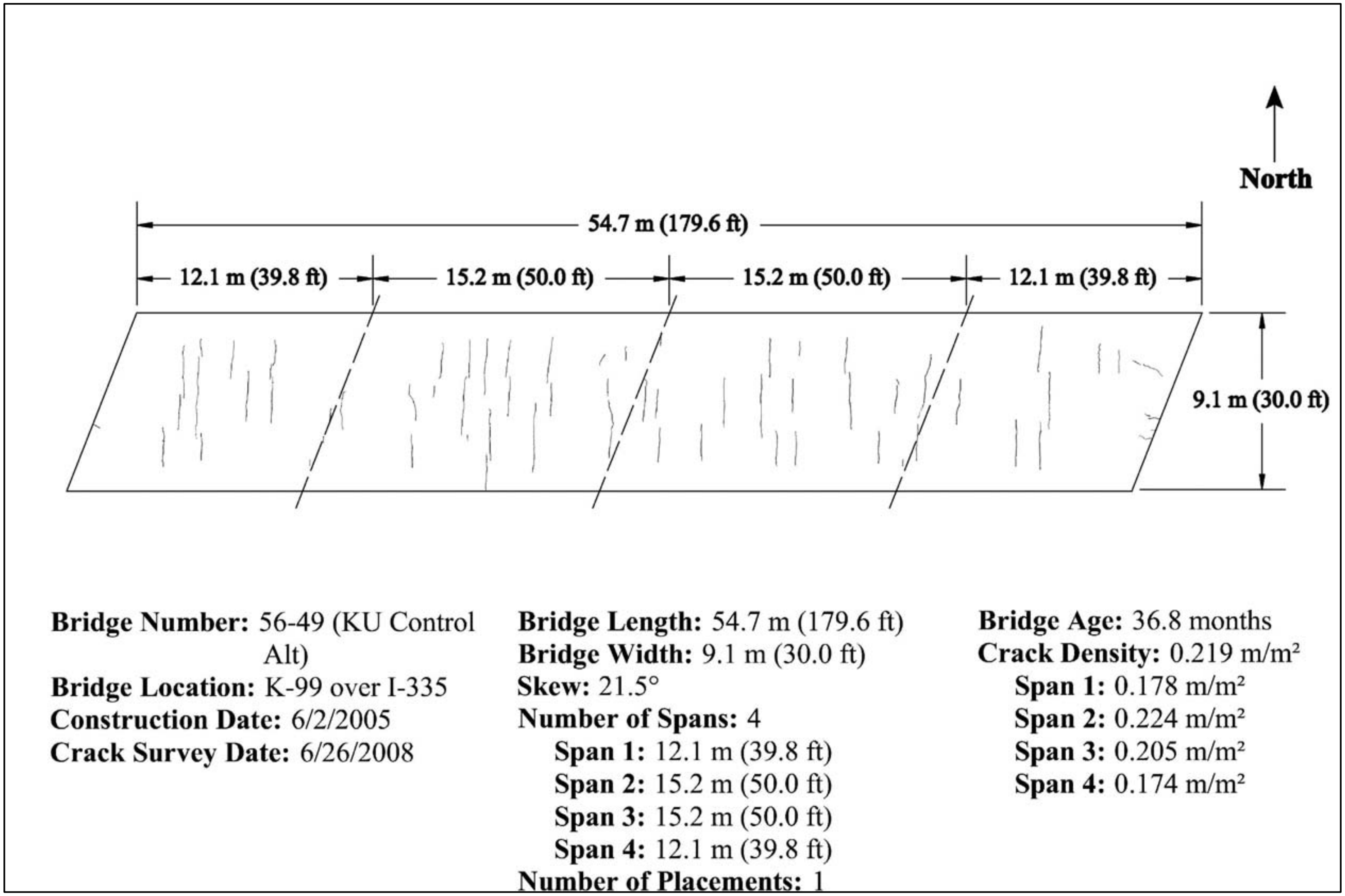


Figure 26: Control-Alt (Survey 3)

Summary of Results

The overall effectiveness of low-cracking high-performance concrete for use in bridge decks is demonstrated by a comparison of the crack densities of the LC-HPC and control decks, as shown in Fig. 27. The maximum crack density to date of 0.063 m/m^2 on LC-HPC decks compared to a maximum density of 0.665 m/m^2 on the control decks. These decks will continue to be monitored as the project continues through 2013.

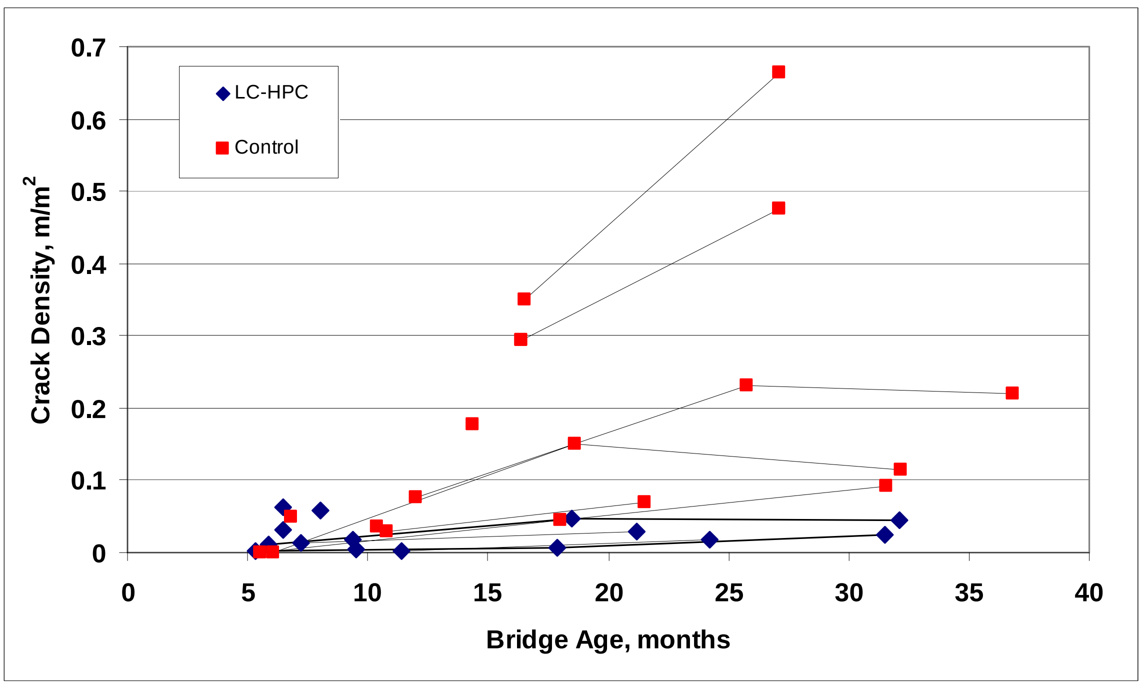


Figure 27: Surveyed Crack Densities of LC-HPC vs. Control Decks

SUMMARY AND CONCLUSIONS

Surveys were performed on LC-HPC and control bridge decks to determine the effect of implementing new material and construction specifications on the crack density of concrete bridge decks within the state of Kansas. These surveys were performed in a consistent and objective manner, and the results analyzed. Crack densities were calculated, and cracking trends were noted.

Based on the results and analysis of the surveys performed as part of this study, the following conclusions were made:

1. LC-HP concrete decks crack less over time than non-LC-HPC decks crack. While certain LC-HPC decks crack more than some control decks at early ages, the overall trend showed lower crack densities in LC-HPC decks.
2. Cracking in concrete bridge decks will commonly occur directly above and parallel to top steel reinforcement. The largest percentage of cracks in both LC-HPC and control decks were oriented in the transverse direction.
3. Bridge decks with superelevations should be carefully cured to reduce cracking in the portions of the deck with the higher elevation. As seen in two of the surveys, most cracks in superelevated decks occurred in the elevated areas, probably due to a lack of water during the curing period, and perhaps resulting from increased settlement cracking due to the use of higher slump concrete. The full deck needs to remain wet to ensure proper curing, and concrete with a slump between 1 and 3 in. should be used to reduce settlement cracks.

REFERENCES

Lindquist, W. D., Darwin, D., and Browning, J., 2005, "Cracking and Chloride Contents in Reinforced Concrete Bridge Decks," *SM Report* No. 78, University of Kansas Center for Research, Inc., Lawrence, Kansas, February, 453 pp.

Lindquist, W. D., Darwin, D., and Browning, J., 2008, "Development and Construction of Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks: Free Shrinkage, Mixture Optimization, and Concrete Production," *SM Report* No. 92, University of Kansas Center for Research, Inc., Lawrence, Kansas, November, 504 pp.

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 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, 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 check over 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 should be on hand for the survey. Crayon 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.

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

c. Under Deck Survey.

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

APPENDIX B

BRIDGE DECK DATA*

* From Lindquist et al. (2008)

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

Bridge Number	County and Serial Number	Portion Placed	Date of Placement	Survey #1				Survey #2	
				Date of Survey	Age (months)	Crack Density (m/m^2)	Age-Corrected Crack Density (m/m^2)	Date of Survey	Age (months)
LC-HPC-1	105-304	South	10/14/2005	04/13/06	5.9	0.012	0.102	4/30/2007	18.5
		North	11/2/2005	04/13/06	5.3	0.003	0.094	4/30/2007	17.9
		Entire Deck	--	04/13/06	--	0.007	0.098	4/30/2007	--
LC-HPC-2	105-310	Deck	9/13/2006	04/20/07	7.2	0.013	0.102	6/18/2008	21.2
Control-1/2	105-311	North	10/10/2005	04/13/06	6.1	0.000	0.204	4/30/2007	18.6
		South	10/28/2005	04/13/06	5.5	0.000	0.206	4/30/2007	18.0
		Entire Deck	--	04/13/06	--	0.000	0.206	4/30/2007	--
LC-HPC-3	46-338	Deck	11/13/2007	05/29/08	6.5	0.028	0.118	--	--
Control-3	46-337	Deck	7/17/2007	05/29/08	10.4	0.037	0.229	--	--
LC-HPC-4	46-339	South	9/29/2007	07/15/08	9.5	0.004	0.090	--	--
		North	10/2/2007	07/15/08	9.4	0.017	0.103	--	--
Control-4	46-347	Deck	11/16/2007	06/10/08	6.8	0.050	0.252	--	--
LC-HPC-5	46-340 Unit 1	Deck	11/14/2007	07/15/08	8.0	0.059	0.147	--	--
LC-HPC-6	46-340 Unit 2	Deck	11/3/2007	05/20/08	6.5	0.063	0.153	--	--
LC-HPC-7	43-33	Deck	6/24/2006	06/05/07	11.4	0.003	0.087	7/1/2008	24.2
Control-7	46-334	East	3/29/2006	08/10/07	16.4	0.293	0.468	6/30/2008	27.1
		West	9/15/2006	08/10/07	10.8	0.030	0.221	6/30/2008	21.5
Control-8/10	54-59	Deck	4/16/2007	06/26/08	14.4	0.177	--	--	--
Control-11	56-155	Deck	3/28/2006	08/13/07	16.5	0.351	0.526	6/30/2008	27.1
Control Alt	56-49	Deck	6/2/2005	06/02/06	12.0	0.077	0.160	7/27/2007	25.8

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

Bridge Number	Survey #2		Survey #3				All Surveys
	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)	Mean Age-Corrected Crack Density (m/m^2)
LC-HPC-1	0.047	0.122	6/17/2008	32.1	0.044	0.102	0.109
	0.006	0.081	6/17/2008	31.5	0.024	0.082	0.086
	0.027	0.102	6/17/2008	--	0.034	0.092	0.098
LC-HPC-2	0.029	0.100	--	--	--	--	0.101
Control-1/2	0.151	0.320	6/17/2008	32.2	0.114	0.244	0.256
	0.044	0.214	6/17/2008	31.6	0.091	0.223	0.214
	0.089	0.259	6/17/2008	--	0.099	0.231	0.232
LC-HPC-3	--	--	--	--	--	--	0.118
Control-3	--	--	--	--	--	--	0.229
LC-HPC-4	--	--	--	--	--	--	0.090
	--	--	--	--	--	--	0.103
Control-4	--	--	--	--	--	--	0.252
LC-HPC-5	--	--	--	--	--	--	0.147
LC-HPC-6	--	--	--	--	--	--	0.153
LC-HPC-7	0.019	0.086	--	--	--	--	0.086
Control-7	0.476	0.621	--	--	--	--	0.544
	0.069	0.229	--	--	--	--	0.225
Control-8/10	--	--	--	--	--	--	--
Control-11	0.665	0.810	--	--	--	--	0.668
Control-Alt	0.230	0.295	6/26/2008	36.8	0.219	0.271	0.242

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

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/m³)	(lb/yd³)	(MPa)	(psi)
1	South	10/14/05	7.9	95	3.75	19.8	68	2251	140.5	35.9	5210
	North	11/02/05	7.8	85	3.25	20.1	68	2238	139.7	34.4	4980
2	Deck	09/13/06	7.7	75	3.00	19.2	67	--	--	31.7	4600
3	Deck	11/13/07	8.7	85	3.25	14.3	58	--	--	41.3	5990
4	Deck - South	09/29/07	8.7	50	2.00	--	--	2202	137.4	--	--
	Deck - North	10/02/07	8.8	80	3.00	17.5	64	2210	137.9	33.1	4790
5	Deck - 0.420 *w/c*	11/14/07	8.3	70	2.75	16.7	62	2249	140.4	44.0	6380
	Deck - 0.428 *w/c*	11/14/07	9.0	60	2.50	16.4	62	2242	140.0	--	--
	Deck - 0.429 *w/c*	11/14/07	9.1	90	3.50	15.2	59	2230	139.2	--	--
	Deck - 0.451 *w/c*	11/14/07	8.7	80	3.25	15.7	60	2228	139.1	--	--
	Average Values	11/14/07	8.7	80	3.00	15.9	61	2236	139.6	--	--
6	Deck	11/03/07	9.5	95	3.75	15.3	60	--	--	40.3	5840
7	Deck	06/24/06	8.0	95	3.75	21.9	71	2221	138.6	26.1	3790
8	Deck	10/03/07	7.9	50	2.00	19.5	67	2264	141.3	32.6	4730
10	Deck	05/17/07	7.3	80	3.25	18.6	66	2212	138.1	31.6	4580
11	Deck	06/09/07	7.8	80	3.00	15.8	60	2278	142.2	32.3	4680
12	Deck	04/04/08	7.4	70	2.75	14.5	58	2259	141.0	31.5	4570
13	Deck	04/29/08	8.1	75	3.00	20.4	69	2266	141.5	29.5	4280
14	Deck - Center	12/19/07	8.7	95	3.75	18.1	65	2237	139.7	30.6	4440
	Deck - West	05/02/08	9.8	110	4.25	17.9	64	2213	138.1	25.6	3710
	Deck - East	05/21/08	9.9	130	5.25	18.3	65	2195	137.1	26.4	3830

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

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

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/yd³)	(MPa)	(psi)
1 / 2	North 1/2 - Subdeck	09/30/05	5.3	110	4.25	19.0	66	2318	144.7	39.1	5670
	North 1/2 - Overlay	10/10/05	5.5	125	5.00	18.0	64	2281	142.4	40.1	5810
	South 1/2 - Subdeck	10/18/05	6.5	80	3.25	24.7	76	2274	142.4	35.1	5090
	South 1/2 - Overlay	10/28/05	7.0	115	4.50	20.0	68	2254	140.7	55.6	8060
3	Subdeck	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
	Overlay	07/17/07	7.3	185	5.75	xx	xx	xx	xx	57.6	8350
4	Subdeck	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
	Overlay	11/16/07	6.9	145	5.75	xx	xx	xx	xx	53	7700
5	Subdeck	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
	Overlay	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
6	Subdeck	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
	Overlay	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
7	East - Subdeck	03/15/06	xx	xx	xx	xx	xx	xx	xx	xx	xx
	East - Overlay	03/29/06	6.4	175	7.00	xx	xx	xx	xx	50.8	7370
	West - Subdeck	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
	West - Overlay	09/15/06	7.4	190	7.50	xx	xx	xx	xx	--	--
8 / 10	Deck	04/16/07	7.4	130	5.00	21.2	70	2234	139.4	33.3	4830
9	Subdeck	11/03/07	6.2	65	2.75	19.0	66	2286	142.7	33.5	4850
	West - Overlay	05/21/08	5.6	90	3.50	24.7	77	2282	142.4	44.0	6380
	East - Overlay	05/28/08	6.2	130	5.00	21.7	71	2262	141.2	42.6	6170
11	North 1/2 - Subdeck	02/03/06	6.8	90	3.50	22.0	72	2263	141.3	40.6	5890
	South 1/2 - Subdeck	02/14/06	7.0	135	5.25	23.0	73	2252	140.6	37.5	5440
	Overlay	03/28/06	6.0	80	3.00	15.5	60	2277	142.1	52.7	7640
12	Subdeck	03/11/08	6.9	110	4.25	21.9	72	2250	140.5	36.4	5270
	Overlay	04/01/08	6.8	95	3.75	14.8	59	2254	140.7	43.0	6240
13	Subdeck	07/11/08	5.8	90	3.50	31.7	89	2271	141.7	--	--
	Overlay	07/25/08	6.3	135	5.25	33.0	91	2269	141.6	57.1	8280
Alt	Deck	06/02/05	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.