WJE

CONDITION SURVEY OF OLDER WEST VIRGINIA BRIDGE DECKS CONSTRUCTED WITH EPOXY-COATED REINFORCING BARS






Final Report
December 22, 2009
WJE No. 2007.1402

Prepared for:
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EXECUTIVE SUMMARY

Chloride-induced corrosion of steel reinforcing bars is a major cause of deterioration in concrete bridge decks in northern climates where deicing salt use is prevalent. Epoxy coatings applied to reinforcing bars were introduced in the early 1970s as a strategy to reduce this type of corrosion-related deterioration. In 1993, the Materials Control, Soils and Testing Division of the West Virginia Department of Transportation (WVDOT) performed a survey of selected bridge decks reinforced with epoxy-coated reinforcing bars (ECR) and uncoated bars built in West Virginia in the mid-1970s to evaluate the effectiveness of this strategy (Kessler & Lipscomb, 1994). While deterioration was observed on uncoated bar decks, deterioration of the decks reinforced with ECR was limited.

This investigation consisted of: 1) a questionnaire and review of the condition of the decks originally examined by the WVDOT in 1993, and 2) a field condition survey of six of the decks built with ECR. The condition survey involved in-depth field and laboratory studies intended to determine how the ECR is performing and to provide data to evaluate the chloride exposure and concrete quality, needed to predict future performance.

The field investigation consisted of visual inspections, crack measurements, delamination survey, continuity testing, depth of cover measurements, and removal of six to seven core samples containing reinforcing bars from each deck. In the laboratory, the reinforcing steel segments were extracted for visual inspection, adhesion and backside cleanliness testing and coating thickness measurements. The cores were sectioned for chloride analysis and determination of the chloride surface concentration and diffusion coefficient.

The six bridge decks inspected during this study, which included three interstate highway bridges, one interstate overpass and two urban bridges, were in good to excellent condition with the exception of two spans of Bridge No. 2930, which, as learned during this investigation, were reinforced with uncoated black bar. The ECR reinforced decks exhibited less than 0.15 percent corrosion-induced deterioration by area in each case. The deterioration that was observed on the ECR decks was concentrated at cracks and at the construction joints.

Only 5 of 45 ECR segments that were obtained showed indications of active corrosion. This active corrosion correlated to locations that had low coating thickness and extended exposure to high chloride concentrations well above the uncoated bar chloride threshold. All actively corroding bars had coating thickness less than 7 mils, which is the current minimum specified thickness in AASHTO M284-09. Low coating thickness is known to be associated with greater likelihood of coating defects that may reduce the protection provided by the epoxy coating.

Approximately 85 percent (22 of 26) of the ECR segments that were exposed to chloride concentrations in excess of the level expected to corrode uncoated reinforcement did not exhibit active corrosion.

The current status of the decks constructed between 1971 and 1976 and surveyed by WVDOT in 1993 was determined. The decks reinforced with uncoated black bars had an initial service life of 18 to 21 years, and an overlay has been applied to all of these decks to address corrosion related damage. The

decks constructed with ECR are now 33 to 35 years old and none have required rehabilitation to address corrosion-related deterioration. Given the lack of deterioration observed in the ECR decks inspected during this study, many more years of service life are expected from the decks containing ECR.

INTRODUCTION

Background

Epoxy coating applied to reinforcing bars was introduced in the early 1970s as a strategy to reduce corrosion of steel reinforcing bars in northern concrete bridge decks where deicing salt use is prevalent. In 1993, the Materials Control, Soils and Testing Division of the West Virginia Department of Transportation (WVDOT) performed a survey of selected bridge decks built in West Virginia in the mid-1970s to evaluate the effectiveness of this strategy (Kessler & Lipscomb, 1994). This report is attached as Appendix A.

A total of 33 decks were inspected as part of this effort: 14 decks reinforced with epoxy-coated reinforcing bars (ECR) and 19 decks reinforced with uncoated bars. While deterioration was observed on uncoated bar decks (from 1% to as high as 29% of the deck areas were delaminated), deterioration of the decks reinforced with ECR was identified on only three decks, where the amount of deterioration was limited (from 0% to 1% of the deck areas were delaminated)[1].

In particular, performance of eight bridge decks along a four-mile stretch of Interstate 79 (4 reinforced with ECR and 4 reinforced with uncoated bars) were highlighted as they were of similar age and exposed to identical conditions and traffic. In 1993, the decks reinforced with ECR were found to have essentially no delamination (just 1 ft^2 in one of the four decks), while the decks reinforced with uncoated bars exhibited 8.5% delamination on average.

These decks surveyed by WVDOT represent some of the earliest use of ECR. To provide a basis for evaluating the long-term performance of ECR in comparison to uncoated bars, the bridge decks studied in 1993 have been revisited, and an investigation of their current condition has been performed.

The objective of the current investigation is to determine the long-term performance of aged ECR compared to uncoated reinforcing bars in bridge decks. The study included in-depth field and laboratory studies intended to determine how the ECR is performing and provide essential field data, including chloride exposure and concrete quality, needed to predict future performance.

METHODS

This study consisted of a review of the current condition of the bridges built between 1971 and 1976 that were surveyed in 1993 and an in-depth field investigation of six selected bridge decks. The field investigation consisted of visual inspections, crack mapping, delamination survey, continuity testing, depth of cover measurements, and removal of core samples. In the laboratory, the following tests were performed on the core samples obtained from the decks: examination of extracted bar samples, chloride analysis and determination of concrete chloride surface concentration and chloride diffusion coefficient.

Review of History of Decks Surveyed in 1993

Information on the current condition of the decks was collected based on a survey sent in 2009 to the bridge engineers responsible for the individual districts within the WVDOT. Specific information

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[1] Note that one of the three decks thought to be reinforced with ECR where deterioration was found in 1993 actually contained uncoated reinforcing bars rather than epoxy-coated bars in two spans, and thus the report needs to be reinterpreted based upon this fact, which was discovered during this investigation.

regarding the location of the bridge, the traffic conditions, the most recent National Bridge Inventory (NBI) deck rating, and the repair history of each bridge was solicited.

Bridge Condition Assessment

The WVDOT bridge engineers reported that all the decks constructed with uncoated bar previously studied by WVDOT (Kessler & Lipscomb, 1994) have been rehabilitated with concrete overlays. Therefore, six bridge decks with ECR, including one ECR deck that showed limited distress in 1993, were selected for further investigation. These are identified in Table 1 and described in Table 2. Maps locating the surveyed bridges are provided in Appendix B. The surveyed decks include three of the four ECR decks on I-79 highlighted in the 1993 Kessler and Lipscomb report for WVDOT. Where a single WV Bridge number refers to two decks, for the purposes of this report, the decks will be identified by the bridge number followed by N or S to denote whether traffic on the bridge is northbound or southbound.

The entire surface of Bridge Nos. 2673 and 2930 were examined, while the surveys were limited to only the right (travel) lane and shoulder of the bridges on I-79 and the westbound lane of Bridge No. 2953.

While all decks surveyed were initially believed to be constructed with ECR, it became clear during the examination and bar sampling process that the top reinforcing mat in the southern two spans of Bridge No. 2930 contained uncoated reinforcing bars. This is further discussed below with the other findings of the survey conducted on that deck.

Physical Condition Survey

A detailed visual examination of the selected deck area was made on each bridge deck. A delamination survey was also performed using conventional chain dragging or hammer sounding methods (Figure 1). The cracks, spalls, delaminations, and patches were documented and estimates of the size of the delaminations and crack lengths were made. The ratio of the total damaged surface area (spalled, delaminated or patched areas) to the total surface area that was inspected was calculated. The crack density (ft/ft^2) of the bridge deck was calculated by dividing the total length of the identified cracks by the total inspected surface area.

Cover Measurement

An electromagnetic reinforcing bar covermeter (Elcometer 331² Model B Concrete Covermeter) was used to locate the reinforcing bars and to estimate the cover over the reinforcing bars. At least one measurement of cover was made for every 200 ft^2 of bridge deck on a grid evenly spaced over the deck area surveyed. Wherever the reinforcing bars were exposed at the coring locations, the electromagnetic cover readings were compared to actual depth.

Coring

A portable coring drill was used to take six to seven 3.75-in. diameter concrete core samples per bridge deck. The location of each core was taken so that it intersected at least one piece of reinforcing bar and so that samples were obtained from the shoulder, right wheel path and middle of the travel of the lane. This process is pictured in Figure 2. At least one core was taken through a delaminated area on each bridge if delaminations were identified. Both cracked and sound concrete were sampled, and all cores were sealed in plastic bags after extraction. After the cores were taken, the decks were immediately patched with a rapid setting repair material.

Electrical Continuity Measurements

Electrical continuity tests were performed to verify the degree of electrical contact between sections of the reinforcing bar mat. Low resistance indicates that coated bars are in near or direct contact through bare metal (continuous) and signifies that defects or cuts are likely present in the coating. If the electrical resistance is high, then it indicates that the coating is generally intact and that the bars tested are electrically isolated from each other (not continuous). The performance of ECR is greatly improved if bars are electrically isolated, since the formation of corrosion cells (which require both cathodes and anodes) between bars are reduced. Testing for electrical continuity was done by measuring the DC resistance across the two portions of reinforcing bar exposed during coring using a high-impedance multimeter as shown in Figure 3.

Laboratory Analysis

The cores and the steel samples they contained were shipped to WJE's laboratory, photographed and characterized. The concrete cover thicknesses and lengths of the cores were measured. A number of the cores contained both transverse and longitudinal reinforcing bars. The reinforcing steel segments were extracted for visual inspection, adhesion and backside cleanliness testing, and coating thickness measurement. The cores were sectioned for chloride analysis and determination of chloride surface concentration and diffusion coefficient.

Examination of Extracted Bars

The coating thickness on each bar segment was measured with an electromagnetic coating thickness gage (Elcometer 456 Coating Thickness Gauge). In most cases, three readings were taken from opposite sides of each bar segment for a total of six readings per bar segment. The average of three readings taken between consecutive deformations was considered as one measurement.

The extent of coating damage on each extracted coated bar was visually determined as a percentage of bar surface area. Each bar was visually classified in terms of a corrosion condition rating based on the 5-point system developed by Sohanghpurwala & Scannell (Sohanghpurwala & Scannell, 1998), where a rating of "1" refers to bar with no corrosion and rating of "5" means corrosion is present on more than 60% of the bar area. This rating scale is depicted in Figure 4. In addition to this corrosion condition rating, a judgment was made whether active corrosion was occurring at the bar surface. Corrosion was considered active if corrosion product was present under the coating or significant rust staining was observed surrounding damaged areas of the coating. For ECR, this corresponded to a corrosion condition rating of 3 or higher.

A knife adhesion test was performed on each side of the bar, and the results were qualitatively evaluated as detailed in Report FHWA-RD-94-103 (McDonald, Sherman, & Pfiefer, 1995). In this test, an "X" is cut in the coating using a utility knife and the coating is peeled back using the point of the knife. The adhesion is quantitatively evaluated by a 5-point rating system. A rating of "1" corresponds to no peeling (excellent adhesion), and a rating of "5" correlates to easy peeling (poor adhesion). This rating scale is depicted in Figure 5.

The backside cleanliness of the coating sections peeled back during the adhesion test was assessed visually and assigned a rating of 1 to 4. The rating scale was consistent with the visual rating system used by coating applicator plants during the Backside Contamination Tape Test (Concrete Reinforcing Steel Institute, 2008) and is depicted in Figure 6.

Chloride Concentration Profiles and Analysis

For corrosion to initiate on reinforcing steel that is embedded in sound concrete, chloride ions must accumulate to a sufficient concentration, known as the chloride threshold, to break down the naturally occurring protective film that develops on the steel surface in the highly alkaline environment within concrete. The onset of corrosion is governed by the time required for chloride to penetrate through the concrete cover over the steel and build up at the bar depth to the chloride threshold value. To evaluate the current distribution of chloride ions within the decks and to permit estimates of chloride concentrations in the future, the chloride concentration verse depth profiles were determined for each core.

The top approximately 1/8-in. of each of the concrete cores was removed and the cores were sectioned to obtain 1/4-in. slices centered at approximately the following depths (inches): 3/8; 1; 2; and 3-1/2. These section depths were generally selected to obtain three slices above and one slice below the top mat of reinforcing. The slices were pulverized for acid-soluble chloride content analysis according to a modified version of ASTM C114-09 *Standard Test Methods for Chemical Analysis of Hydraulic Cement*, which was performed by Exova Accutest, of Ottawa, Ontario. For each bridge, one slice was cut from three uncracked cores at a depth of approximately 5 inches or more. The average chloride content of these three samples was used as the baseline chloride concentration (C_0).

The movement of chlorides in concrete can be represented as a diffusion process. Chloride diffusion in concrete, driven by a concentration gradient, can be described by Fick's Second Law of Diffusion:

$$\frac{dC}{dt} = D \times \frac{d^2C}{dx^2} \qquad (1)$$

where C is the chloride concentration at a depth of x from the concrete surface at time t, and D is the effective chloride diffusion coefficient.

If the surface chloride concentration C_s and D are assumed to be constants, the concentration C(x, t) at depth of x and time t is given by the following solution (Poulsen & Mejlbro, 2006):

$$C(x,t) = C_s - \left((C_s - C_0) \times erf\,(\frac{x}{2 \times \sqrt{D \times t}}) \right) \qquad (2)$$

where erf() is the Gaussian error function, and C_0 is the background or original chloride concentration.

Based on this relationship, the values of C_s and D that provided the best fit to the measured chloride concentration depth profiles were determined using a least squares fitting method. The term t was assigned as the age of the bridge. With these values, the chloride concentration at any depth can be predicted for any given time. Using this approach, the current chloride concentration at the bar depth has been calculated. Figure 7 shows an example of the result of this analysis for one of the sampled cores.

The values of C_s and D are determined largely by the exposure conditions (i.e. severity of deicing salt application) and the quality of the concrete, respectively. Based on studies of bridge decks in northern states conducted by WJE, the C_s can range from greater than 0.8 percent by weight of concrete in New York to 0.15 percent by weight of concrete in Virginia (Lee & Krauss, 2003). Exposure conditions may be considered mild, moderate and severe if C_s falls in the following ranges, respectively: up to 0.25 percent by weight of concrete; 0.25 to 0.55 percent by weight of concrete; and 0.55 percent by weight of concrete or higher (Krauss, Lawler, & Steiner, 2009).

RESULTS

Update of History of Decks Surveyed in 1993

Responses of the WVDOT district engineers to our 2009 questionnaire concerning the current condition of the decks originally surveyed in 1993 are presented in Appendix B. Responses with updated information were obtained from all districts but District 2, and the following discussion is based on the study decks excluding those in District 2. The maintenance history of the decks surveyed by WVDOT in 1993 is summarized in Table 3.

All of the sixteen decks that were constructed with uncoated bars for which current information was obtained during the survey of the WVDOT district engineers had been rehabilitated with latex-modified or microsilica overlays since 1993. When given, the reason cited for the rehabilitation of these uncoated bar decks was deterioration or delaminations.

By comparison, essentially no maintenance to address corrosion-related deterioration had been performed on the nine surveyed decks constructed with ECR. The decks of Bridge Nos. 2668N and 2668S are curved and were overlaid in 2008 with an anti-icing and anti-skid epoxy-based overlay as part of an evaluation program to address safety concerns regarding icing of the bridge. The effort included no concrete repair according to WVDOT. Repairs to address expansion joints and deck spalls were performed in 1998 on Bridge No. 2930. The repairs due to corrosion-related deterioration were later learned to be exclusively located in spans reinforced with uncoated, black bars. Bridge No. 2771 was sealed in 1995 to address cracking, but no other deck repairs have been performed since then. Finally, Bridge No. 2847 received a polymer overlay in 1999. This was thought by WVDOT representatives to be part of an evaluation project, and no specific reason related to deck deterioration for the overlay could be determined.

According to WVDOT, the concrete used in the construction of the decks was typically Class B, which was air-entrained, had a 28-day specified compressive strength of 3000 psi, a minimum cement factor was 6 ¾ Bags/yd^3, and a maximum water-cement ratio of 5 ½ gal./Bag (0.487). Plans for the bridge decks called for a 2 in. concrete clear cover.

The climate in WV is expected to produce numerous freezing and thawing cycles. For the months of December, January and February, the average normal daily maximum, mean and minimum temperatures for Charleston and Clarksburg are shown below. In both Charleston and Clarksburg the cumulative normal precipitation over these three months is nearly 10 in.

Average Normal Daily Temperatures for December through February[2]

City	Average Normal Maximum (°F)	Average Normal Mean (°F)	Average Normal Minimum (°F)
Charleston	45.4	35.9	26.3
Clarksburg	41.2	32.0	22.8

[2] Data obtained from the National Climatic Data Center of the National Oceanic and Atmospheric Association

Bridge Condition Investigations

The findings of the field investigation of each of the six bridge decks examined in 2009 are discussed below. The percent area deteriorated (spalled, delaminated, or patched) and the crack densities are given in Table 4 for each deck. Survey maps are attached in Appendix C. For the purposes of this calculation, concrete chipping and delaminations occurring immediately adjacent to the armored expansion joints were not considered, because this type of shallow deterioration is caused by corrosion at the steel joint and not corrosion of the reinforcing bars. The average and standard deviation of cover measured using the covermeter on each deck are given in Table 5.

Table 6 to Table 12 present the data collected in the laboratory for each core and the associated bar segments. In these tables, the bar depth, coating thickness, adhesion rating, backside cleanliness, corrosion condition, and the presence of active corrosion are given. In addition, the presence of a delamination or crack at the core location is listed. Finally, the calculated surface concentration and diffusion coefficient is listed based on the measured chloride profiles in each core and the fit to Fick's Law solution, along with the calculated chloride concentration at bar depth for each bar. The chloride concentration measured in each slice of each core is given in Appendix D.

The calculated surface concentrations and diffusion coefficients are summarized in Table 13, which shows the average and standard deviation of these values considering all cores and considering just those cores in which cracks are not present.

Bridge No. 2668N

The deck of Bridge No. 2668N is curved, carries I-79, and consists of seven spans supported on steel girders. The average measured cover was 2.7 in. The bridge deck contains ECR in both top and bottom mats. The deck is pictured in Figure 8. This deck was topped with an anti-icing and anti-skid epoxy-based overlay in 2008. This polymer overlay is visible on the core shown as Figure 9. The deck did not show any corrosion related distress at the time the overlay was placed. Since the overlay was installed so recently, this deck was included because it was felt the chloride penetration and conditions of the bars would not have been significantly affected in the year since this overlay was installed.

The delamination survey identified few small delaminations away from the expansion joints. Of the 12,444 ft^2 evaluated, only 9 ft^2 (0.07 percent) of delamination was identified. Sounding could not determine if the delaminations were due to a lack of bond between the thin polymer overlay and the deck or due to concrete deck delaminations. Since the overlay was present, cracks in the deck could not be located visually. However, a core (4T) taken in a delaminated area did include a vertical crack and a delamination at the top bar level. Examination of the deck from below revealed extensive transverse cracking (Figure 10). No corrosion-related deterioration was observed on the deck soffit.

Electrical continuity testing was performed at Core location 6. Two segments of the top reinforcing bar had a DC resistance of 600 ohms, indicating that the bar segments are not electrically connected but that the overall resistance is somewhat lower than fully isolated bars.

The findings of the chloride testing and extracted bar inspection are given in Table 6 for Bridge No. 2668N. The bar (4T) that was extracted at the delamination exhibited active corrosion, but this core was taken at a crack and was only partially recovered; therefore chloride analysis was not performed.

The bar coating thickness varied widely in this bridge. Most of the sample bars had a thickness of 9 to 15 mils, however, one bar (5Tb) had a coating thickness of only 3.5 mils. This bar was sampled at a lap and could represent an end of a bar.

As shown in Table 13, the average surface chloride concentration for all cores was 0.470 percent by weight of concrete. This is indicative of a moderately severe exposure to deicing salts.

Bridge Nos. 2672N, 2672S

The decks of Bridge 2672N and 2672S are similar in design and consist of three spans on concrete girders, carrying I-79. The average measured cover was 2.4 in. in both decks. The bridge decks contain ECR in the top mat and uncoated bar in the bottom mat. The decks are pictured in Figure 11 and Figure 12.

Delaminations 2 ft^2 in size or less and some associated spalls and patching were identified in these decks (Figure 13). A total of 8,544 ft^2 was surveyed between these two decks, and only 9 sf (0.10 percent) of delamination was identified. The majority of these were associated with construction joints separating the deck placements over the piers. According to the design drawings, this joint was to be keyed and edged with 1/4-in. edging tool then filled with a “hot-poured elastic-type construction joint sealer”. Similar construction joint details are given for the other bridge decks that were investigated.

Transverse cracks were also present throughout the decks (Figure 14). These cracks are typical of early-age, transverse deck cracks that were likely caused by concrete drying shrinkage and thermal contraction (Krauss P. D., 1996) and not by corrosion of the reinforcing bars (Figure 15). Such cracking was common on all decks inspected as part of this study. This transverse cracking was also visible on the underside of these decks. Spalling at an uncoated bottom reinforcing bar in Bridge No. 2672N was visible in one location (see Figure 16), and incipient spalling and staining related to corrosion of uncoated bottom bars was visible at a number locations on the soffit of both of these decks, particularly adjacent to the construction joints.

DC resistance between top bar segments in Bridge No. 2672N at Core locations 1, 2 and 3 were 1540, 3,000+, and 5,000+ ohms. DC resistance between top bar segments in Bridge No. 2672S at six core locations (Cores locations 7 to 12) ranged from 180 ohms at a crack location to between 1000 ohms to 800 M-ohms at uncracked locations. This indicates that the top bar segments measured are generally electrically discontinuous, however, lower resistance values were measured at cracks.

The findings of the chloride testing and extracted bar inspection for cores from both of these decks are given in Table 7 and Table 8. Two bars from Bridge No. 2672N (5T and 6T) and one bar from Bridge No. 2672S (10T) were obtained with indications of active corrosion. The calculated chloride concentration at the bar depth for these corroding bars was 0.182, 0.132 and 0.222 percent by weight of concrete, respectively, or approximately 4 to 6 1/2 times higher than the chloride threshold for uncoated steel (about 0.035 percent by weight of concrete). The coating thickness was less than 7 mils in all three cases (6.9, 6.1 and 6.0 mil, respectively), and a crack was present over each of these bars.

The average surface chloride concentration for all cores was similar to that measured in Bridge No. 2668N for both decks (Table 13), indicating that the bridges have a moderately severe exposure to deicing salts.

Bridge No. 2673

Bridge No. 2673 is an overpass over I-79 and sees significantly less traffic than other bridges included in this study. This bridge deck has five spans on steel girders and contains ECR in the top and uncoated bars in the bottom mat. The average measured cover was 2.3 in. The deck is pictured in Figure 17.

Despite the lower traffic, the condition of the deck was similar in nature to the other decks. The largest delamination identified was approximately 5 ft^2 in size and transverse cracking was present throughout and particularly concentrated in Span 4. Spalling concentrated around the construction joints (Figure 18). A total of 16,618 ft^2 of deck was surveyed and only 25 ft^2 (0.15 percent) of delamination was identified.

Relatively fewer cracks were observed on the deck soffit (Figure 19). However, signs of corrosion staining were visible at the construction joints, but no spalls were observed on the underside of the deck.

DC resistance between top bar segments in Bridge No. 2673 varied depending on location. The top bar segments at Core location 1 was continuous across the core with a DC resistance of 0.1 ohm. The top mat ECR segments in Cores 2, 3, 4, 5, 6, and 7 were discontinuous with resistances between 1,100K-ohms and 3,600K-ohms. Bottom uncoated mat steel was exposed in Core holes 3, 4, and 5. The top ECR east bar segment cut in both Cores 3 and 4 were continuous with the bottom uncoated bar mat (0 and 0.7 ohms). The west side top ECR segments in Cores 3 and 4 and both top ECR segments in Core 5 were not continuous with the bottom mat (>3,000K-ohms).

The findings of the chloride testing and extracted bar inspection are given in Table 9. As shown in Table 13, the average surface concentration for all cores was 0.284 percent by weight of concrete. This is indicative of a less severe exposure compared to the other decks. Perhaps because of the lower traffic demand on this deck, deicing salt is applied less frequently. Consistent with this less severe exposure, the chloride concentration at bar depth was less than 0.030 percent by weight of concrete except for two sample locations. One had a chloride concentration of 0.043 percent by weight of concrete and no active corrosion and one had a chloride concentration of 0.153 percent by weight of concrete where a crack was present. The bar segment at the cracked location was undergoing active corrosion. While no delamination was occurring at this bar, a delamination was present approximately 2 ft. away following the crack along the same bar.

Bridge No. 2930

Bridge No. 2930 carries an arterial road in Clarksburg, WV and is pictured in Figure 20. This deck consists of six spans on steel girders and is constructed differently on either side of Pier 4, which is pictured in Figure 21. The girders on Spans 1-4, to the north of Pier 4, are approximately twice as deep as Spans 5-6. In addition, the deck of Spans 1-4 was constructed with stay-in-place forms (Figure 22), while the forms for Spans 5-6 were removed. It was reported by Kessler and Lispcomb (Kessler & Lipscomb, 1994) that the entire bridge deck was reinforced with ECR. However, it was found through core sampling that Spans 5-6 contain uncoated reinforcing bars. The reinforcing in Spans 1-4 consists of ECR in both top and bottom mats. The average measured cover was 2.4 in.

According to WVDOT, some repairs were performed on this deck in 1998. These repairs took one of two forms. The first consisted of conventional patches, which are prevalent at spalls concentrated entirely in Span 5-6 (Figure 23), the black bar spans. In addition, a number of small (less than 1 ft^2), uniform, isolated, essentially square repairs were observed throughout the spans (Figure 24). The reason for these smaller isolated repairs is uncertain, though given their size they do not appear to be related to reinforcing corrosion. Therefore, these isolated repairs have not been counted in the total delaminated areas given in Table 4.

The findings of the chloride testing and extracted bar inspection are given in Table 10 and Table 11 for the ECR and uncoated bar spans, respectively. As characterized by the average surface concentration, the exposure conditions at this urban deck were similar to the interstate bridges (Table 13) and indicative of a moderately severe exposure to deicing salts.

ECR SPANS - The frequency of transverse cracking was higher in this bridge than any of the other decks examined and the crack density was 0.17 ft/ft^2. Despite the presence of cracks throughout the spans containing ECR, essentially no reinforcing corrosion-related deterioration was observed.

Cores 2 and 3 exposed ECR, and none of the exposed bar segments were continuous with any other cut segment (>3,000 ohms).

The measured coating thickness on all bars taken from Spans 1-4 was greater than or equal to 8 mils, and none of these ECR segments exhibited evidence of corrosion.

UNCOATED BAR SPANS - All the corrosion-related deterioration detected on this bridge occurred in the black bar Spans 5-6, with more than 5 percent of the surface area of Spans 5-6 exhibiting repairs, spalling or delaminations. This corresponded to deterioration in 165 of 3,050 ft^2 surveyed. Figure 25 is an example of delaminations related to corrosion of the uncoated bars. This deterioration was concentrated in these spans despite a lower frequency of transverse cracking (0.12 ft/ft^2).

All three cores taken from Spans 5-6 contained uncoated bars. In Core locations 4 and 5, DC resistances between the uncoated top and bottom mat segments ranged from 0.1 to 80 ohms, indicating electrical continuity.

Bridge No. 2953

Bridge No. 2953 is also an urban bridge in Clarksburg, WV. This deck is three spans on steel girders and stay-in-place forms. This bridge deck contains ECR in both the top and bottom mats. The average measured cover was 2.1 in. The deck is pictured in Figure 26.

No corrosion related deterioration was observed in this deck. However, the concrete surface was abraded to a greater extent than was observed on the other bridge decks surveyed, and ultimately concrete abrasion and surface deterioration may be a determining factor controlling the service life of this deck.

The DC electrical resistance between ECR bar samples cut during coring was typically very high on this bridge. All core locations (1 to 6) had electrical resistance values between bar segments of greater than 760 K-ohm, except Core 4 that had a moderately high resistance of over 6,000 ohms. This indicates that the bars in this bridge are essentially electrically isolated by the reinforcing coating.

The findings of the chloride testing and extracted bar inspection are given in Table 12. The coating thicknesses on these bar segments were all greater than 8 mils. None of these ECR segments exhibited evidence of corrosion.

The exposure conditions at this urban deck were also similar to the interstate bridges (Table 13) and indicative of a moderately severe exposure to deicer salts.

ANALYSIS OF BAR CONDITIONS

To further explore the performance of ECR in these decks, the data reported in Table 6 to Table 12 has been combined, and an analysis of the statistical distributions of the properties and exposure conditions of the bars has been performed relative to the presence of corrosion. In the figures created to show this analysis, the data representing bars exhibiting active corrosion are shown as solid markers, while non-actively corroding bars are shown as hollow markers.

Bar Depth

Figure 27 shows the distribution of bar depth measured for each bar segment. The measured bar depth ranged from 1.8 to 3.3 in. and appears to have had little effect on determining whether corrosion is present on the bar segment.

Coating Adhesion

The distribution of coating adhesion is shown in Figure 28. Few ECR segments had an average adhesion rating of less than 3, which would be indicative of a well bonded coating. However, no segments that were judged to be actively corroding had an adhesion rating other than 5. However, this may not reflect a link between corrosion and coating bond, but it is likely that the loss of coating adhesion resulted from the development of corrosion product on the steel surface.

Backside Cleanliness

The distribution of backside cleanliness is shown in Figure 29. The backside cleanliness varied widely among the sampled bar segments. The backside cleanliness rating of all corroding bars was 4, but a number of other bars were identified without active corrosion where the backside cleanliness rating was also 4.

Coating Thickness

In Figure 30, the distribution of coating thickness is shown. With the exception of one bar that was very thin, the coating thickness ranged from 6 to over 16 mils. For this sample set, this property of the coating is strongly correlated to corrosion, with all four bar segments judged to be experiencing active corrosion having a coating thickness of less than 7 mils. The increased presence of coating holidays or other defects is known to be associated with thinner coatings and the presence of such defects may be permitting the more rapid onset of corrosion (Pfeifer, Landgren, & Krauss, 1992).

The West Virginia Department of Transportation Division of Highways Standard Specification from 1978, the first version of that specification to include epoxy-coated rebar, specified a thickness of “seven plus or minus 2 mils” (5 to 12 mils). However, the current standard for ECR, AASHTO M284-09 (ASTM

A775-07b), requires that the coating thickness be between 7 to 12 mils and that no single measurement be less than 80% of the specified minimum thickness (5.6 mils). The change in specified thickness and measurement limits took effect with the introductions of ASTM A775-92 and ASTM A775-04a, respectively. Therefore, while the coating thicknesses on the sampled bar segments appears to have essentially complied with the standard specification developed soon after the time of construction, the coating thickness on bar segments exhibiting active corrosion would be unacceptable or marginally acceptable by current standards.

Chloride Concentration at Bar Depth

Using the surface concentration and diffusion coefficient calculated based on the measured chloride profiles in each core and the Fick's Law solution, the chloride concentration was calculated at the depth of each bar segment. Figure 31 shows this distribution for both the ECR segments and uncoated bar segments from Bridge No. 2930. Also shown on this plot is the chloride threshold, i.e. the concentration of chloride ions above which corrosion is typically expected, for uncoated bar, which is 0.035 percent by weight of concrete.

The only segment of uncoated black bar not undergoing active corrosion is at a location where the chloride concentration is less than the assumed uncoated bar threshold of 0.035 percent by weight of concrete. For the coated bars, 22 ECR segments without active corrosion had a chloride concentration of greater than 0.035 percent by weight of concrete. The chloride concentrations at the four actively corroding ECR segments are greater than 0.132 percent by weight of concrete or nearly 4 times the uncoated bar threshold. Furthermore, five other ECR segments exposed to chloride concentrations greater than 0.132 percent by weight of concrete were not actively corroding, with the greatest at 0.263 percent by weight of concrete. This demonstrates that the epoxy coating provides a significant level of protection against chloride-induced corrosion of the reinforcing steel.

Time Since Chloride Concentration Exceeded Uncoated Bar Threshold

Again using the Fick's Law solution at each core location, the age of the bridge at which the chloride concentration at each bar segment exceeded 0.035 percent by weight of concrete was determined. This was subtracted from the current ages of each bridge to give the time for each bar segment since the chloride concentration at that bar reached the uncoated bar corrosion threshold. The distribution of these times for each bar segment is given in Figure 32. The ECR segments exhibiting active corrosion are among those bar segments that have been exposed to chloride concentrations above the uncoated bar threshold for the longest period of time, exceeding 20 years in all four cases. It is notable that, for these segments, while delaminations were present, concrete surface spalls were not. Some ECR segments examined have been exposed to chloride concentrations higher than the uncoated bar threshold longer than 20 years without active corrosion.

To further explore the possible impact of exposure time, the time since chloride concentration exceeded uncoated bar threshold is plotted versus coating thickness in Figure 33. This plot suggests that, for this sample set, those bars where the coating was thinnest were also the same bars that first saw chloride thresholds greater than the uncoated bar threshold. Therefore, while chloride concentrations above threshold are necessary for corrosion to occur, thin coating may be the primary cause of corrosion of these bars and the length of exposure time may not be the determining factor in the presence of active corrosion on these bars.

DISCUSSION

The age of the six bridge decks that were inspected ranged from 33 to 35 years. The spans of the bridge decks that contained ECR are in good to excellent condition. Five of these decks are heavily exposed to deicing salts and aggressive environmental conditions, while one, although exposed to similar environmental conditions, appears to have been salted somewhat less frequently or with lower amounts of salt. The spans reinforced with ECR in two decks exhibited no corrosion-induced deterioration, while the other four decks showed such deterioration over less than 0.15% of the deck areas surveyed. The only portions of the six bridges that were inspected showing widespread deterioration were the two spans on a single bridge reinforced with uncoated bars.

It is notable that both decks with no deterioration were constructed with both top and bottom mats of ECR. Corrosion of the uncoated bar bottom mats has produced visible distress on the underside of the decks in Bridge Nos. 2672N and 2672S. Decks containing ECR in the top mat only have a risk of increased deterioration due to corrosion of the black bottom mat steel and if the ECR bars are electrically continuous with the bottom black mat, due to the large surface area of uncoated steel available to support the cathodic reaction necessary for corrosion to occur (Lee & Krauss, 2003).

Deterioration in many of these bridges was concentrated around the construction joints, which were built based on a similar design requiring 1/4-in. open tooled joints in the deck. These joints have provided a path for rapid ingress of chloride into the deck and promoted corrosion in their vicinity.

Many of the ECR bars have been exposed to chloride levels higher than the corrosion threshold for uncoated bars (0.035 percent by weight of concrete). The lowest chloride concentration at which active corrosion of an ECR segment was observed was 0.132 percent by weight of concrete, though chloride concentrations surrounding ECR as high as 0.263 percent by weight of concrete were observed without active corrosion. Therefore, the epoxy coating has provided a significant level of protection to the reinforcing steel from the corrosion promoting effects of chloride contamination.

Active corrosion was observed on only 4 of the 45 of ECR segments extracted from the bridge decks. Corrosion byproducts on the bars caused a loss of coating adhesion and estimates of the original backside cleanliness could not be determined for these bars. Therefore, coating adhesion and backside cleanliness measured on samples extracted from the decks was not helpful in predicting the development of corrosion on ECR. However, the occurrence of corrosion was correlated to several factors based on this limited sample including: high chloride concentrations, low coating thickness (all actively corroding bars had coating thickness less than 7 mils), and extended exposure to chloride concentrations above the uncoated bar chloride threshold. While the effect of coating thickness cannot be determined conclusively based on this limited sampling, it is known that greater coating thicknesses reduces the likelihood of coating defects. Therefore, bars with thin coating may have more defects present that permitted the corrosion to initiate on those bars, regardless of the length of exposure to high chloride concentrations.

The survey of WVDOT District staff conducted to determine the current condition of the decks first surveyed in 1993 revealed that all the uncoated bar decks for which updated information was obtained were overlaid or otherwise rehabilitated at ages from 18 to 21 years to address deterioration of the deck surface. By comparison, while polymer overlays and sealers have been applied to some of the decks containing ECR, none of these repair efforts were initiated because of corrosion-induced deterioration and these decks have reached ages of 33 to 35 years.

CONCLUSIONS

This investigation was initiated to assess the corrosion protection provided by ECR to concrete bridge decks built in West Virginia between 1974 and 1976. This investigation consisted of: 1) a questionnaire concerning the condition of the decks containing both uncoated and coated bars originally examined by the WVDOT in 1993, and 2) a field condition survey of six of the decks built with ECR.

The conclusions made based on this investigation are summarized as follows:

- Spans of six bridge decks containing ECR inspected during this study were in good to excellent condition.
- Two spans of Bridge No. 2930 were found to be reinforced with uncoated bars. Three of four uncoated bar samples from these spans exhibited active corrosion, and the deck surface in these two spans exhibited corrosion-related delaminations and spalls over more than 5 percent of the deck area. All black bar samples having chloride contents at the bar depth in excess of 0.035 percent by weight of concrete were corroded. In contrast, spans of the same deck containing ECR did not exhibit any corrosion-related delamination.
- The ECR reinforced decks exhibited less than 0.15 percent corrosion-induced deterioration by area in all decks. Of 59,000 ft^2 of ECR reinforced deck surveyed, only 43 ft^2 of corrosion-induced deterioration was found. The deterioration that was observed in the ECR decks is concentrated at cracks and at the construction joints.
- Only 4 of 45 ECR segments that were obtained by coring showed active corrosion. This active corrosion correlated to high chloride concentration, low coating thickness (all actively corroding bars had coating thickness less than 7 mils), and extended exposure to chloride concentrations above the uncoated bar chloride threshold.
- Approximately 85 percent (22 of 26) of the ECR segments that were exposed to chloride concentrations in excess of the level expected to corrode uncoated reinforcement did not exhibit active corrosion. Corrosion was not observed on ECR in concrete containing less than 0.132 percent chloride by weight of concrete, and an ECR segment was found to be uncorroded even when surrounded by concrete with measured chloride content as high as 0.263 percent chloride by weight of concrete.
- The current status of the decks constructed between 1971 and 1976 and surveyed by WVDOT in 1993 was determined. The decks reinforced with uncoated bars had an initial service life of 18 to 21 years, and an overlay has been applied to all of these decks. The decks constructed with ECR are now 33 to 35 years old and have not required rehabilitation to address corrosion-related deterioration.
- Given the lack of deterioration observed in the ECR decks inspected during this study, many more years of service life are expected for the ECR decks.

WORKS CITED

Bentur, A., Diamond, S., & Berke, N. S. (1997). *Steel Corrosion in Concrete.* New York: E&FN SPON.

Concrete Reinforcing Steel Institute. (2008). *Voluntary Certification Program for Fusion-Bonded Epoxy Coating Applicator Plants, 10th Edition.*

Kessler, R. R., & Lipscomb, D. (1994). *Materials Inspection Report #1261603: Evaluation of Bridge Decks Using Epoxy Coated Reinforcement.* West Virginia Department of Transportation Division of Highways.

Krauss, P. D. (1996). *NCHRP Report 380 - Transverse Cracking in Newly Constructed Bridge Decks.* Washington, DC: Transportation Research Board - National Research Council.

Krauss, P. D., Lawler, J. S., & Steiner, K. A. (2009). *Guidelines for Selection of Bridge Deck Overlays, Sealers and Treatments, NCHRP Project 20-07, Task 234.* Washington, D.C.: National Cooperative Highway Research Program.

Lee, S. K., & Krauss, P. (2003). *Service Life Extension of Northern Bridge Decks Containing Epoxy-Coated Reinforcing Bars.* Northbrook, IL: Wiss, Janney, Elstner Associates, Inc.

McDonald, D. B., Sherman, M. R., & Pfiefer, D. W. (1995). *The Performance of Bendable and Nonbendable Organic Coatings for Reinforcing Bars in Solution and Cathodic Debonding Tests, FHWA-RD-94-103.* Mclean, VA: FHWA.

Pfeifer, D. W., Landgren, J. R., & Krauss, P. D. (1992). *Investigation for CRSI on CRSI-Sponsored Corrosion Studies at Kenneth C. Clear Inc.* Northbrook, IL: Wiss, Janney, Elstner Associates, Inc.

Poulsen, E., & Mejlbro, L. (2006). *Duffusion of Chloride in Concrete: Theory and Application.* New York, NY: Taylor & Francis.

Sohanghpurwala, A. A., & Scannell, W. T. (1998). *Verification of Effectiveness of Epoxy-Coated Rebar-Project No. 94-05, Final Report Submitted to Pennsylvania Department of Transportation.* Concorr Inc.

TABLES

Table 1. Bridges Selected for Field Investigation - Location

WV Bridge No.	WV Project No.	NBI structure No.	Location - Route & Milepost	Latitude	Longitude
2668	I-79-1(39)7 North	20A502	I-79 - Mile 7.38	38°26'11.47"N	81°31'15.07"W
2672	I-79-(38)10 North	20A508	I-79 - Mile 10.64	38°27'59.43"N	81°28'58.45"W
2672	I-79-1(38)10 South	20A509	I-79 - Mile 10.64	38°27'59.43"N	81°28'58.45"W
2673	I-79-1(38) 10 Ovrhd	20A332	Kan CR 53 - Mile 2.52	38°28'44.69"N	81°27'56.44"W
2930	APD 282(70)	17A912	East Main Street	39°16'18.38"N	80°19'17.69"W
2953	HRR-19-16-3657	17A076	US 19 -Adamson St.	39°17'17.33"N	80°21'10.35"W

Table 2. Bridges Selected for Field Investigation - Construction and Condition

WV Bridge No.	ECR in top mat only or both	Year built	Size (length, width, area in feet)	Traffic (ADT)	NBI Deck Rating in 2007 or 2008
2668	Both	1976	980, 40, 39200	10700	5
2672	Top	1976	175, 40, 7000	10000	6
2672	Top	1976	175, 40, 7000	10000	6
2673	Top	1975	400, 42, 17000	500	7
2930	Both	1974	557, 32, 17800	7000	5
2953	Both	1975	300, 30, 9000	6000	5

Table 3. Maintenance of Bridges Surveyed by WVDOT in 1993 through 2009 (Excluding District 2)

Type of reinforcement	Number of decks surveyed	Number of decks repaired due to corrosion-related deterioration	Percent repaired due to corrosion-related deterioration
Uncoated	16	16	100%
Epoxy-coated	9	0*	0%*

* Repairs at expansion joints and delaminations in uncoated bar span of one deck

Table 4. Delaminations and Cracking

Bridge No.	Deck area surveyed (ft^2)	Area of corrosion-related deterioration (ft^2)	Percent deck area with corrosion-related deterioration	Cracking density (ft/ft^2)
2668N	12444	9	0.07	*
2672N	4272	6	0.14	0.10
2672S	4272	3	0.07	0.13
2673	16618	25	0.15	0.09
2930 ECR Spans	13722	0	0.00	0.17
2930 Uncoated bar Spans	3050	165	5.41	0.12
2953	8306	0	0.00	0.08

* Bridge No. 2668N has epoxy-based overlay so no original deck cracks could be observed.

Table 5. Cover Measured in Inspected Decks using Covermeter

Bridge No.	Cover (in.)	
	Average	Standard deviation
2668N	2.71*	0.37
2672N	2.40	0.26
2672S	2.43	0.21
2673	2.27	0.28
2930	2.42	0.28
2953	2.11	0.24
* includes epoxy-based overlay		

Table 6. Cores and Extracted Bars from Bridge 2668N (Age of deck = 33 years, C_0=0.004% by wt. conc.)

Core	**1**	**2**	**3**	**4**	**5**			**6**		**7**	
Bar ID	1T	2T	3T	4T	5B	5Ta	5Tb	6B	6T	7B	7T
Cover (in.)	2.4	2.6	2.8	2.4	3.2	2.4	2.4	2.5	1.8	2.8	2.1
Coating Thickness (mils)	15.3	14.7	12.9	N/A	15.1	11.9	3.5	12.9	14.4	13.2	9.1
Adhesion Rating	4	4	4	5	3	3	2	4	3	3	4
Backside Cleanliness	1	1.5	2.5	4	2.5	2.5	4	3	2	2.5	3
Crack in core?	N	N	N	Y	N			N		N	N
Epoxy coated?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Active Corrosion?	N	N	N	Y	N	N	N	N	N	N	N
Corrosion Condition	1	1	1	5	1	1	2	1	1	1	1
Delamination in deck at core?	N	N	N	Y	N			N		N	N
C_s (% by wt. conc.)	0.455	0.544	0.484	N/A	0.624			0.408		0.306	
D (in^2/yr)	0.025	0.025	0.033	N/A	0.023			0.043		0.070	
Current chloride concentration at bar depth (% by wt. conc.)	0.031	0.027	0.032	N/A	0.009	0.032	0.032	0.061	0.117	0.064	0.107

Table 7. Cores and Extracted Bars from Bridge 2672N (Age of deck = 33 years, C_0=0.009% by wt. conc.)

Core	**1**	**2**	**3**	**4**	**5**		**6**
Bar ID	1T	2T	3T	4T	5B	5T	6T
Depth (in.)	2.6	3.0	2.4	2.3	2.5	1.9	2.1
Coating Thickness (mils)	9.2	8.4	14.0	10.9	9.5	6.9	6.1
Adhesion Rating	2	3.5	4	5	4	5	5
Backside Cleanliness	1	2.5	4	4	4	4	4
Crack in core?	N	N	N	Y	Y		Y
Epoxy coated?	Y	Y	Y	Y	Y	Y	Y
Active Corrosion?	N	N	N	N	N	Y	Y
Corrosion Condition	1	1	1	1	2	4	3
Delamination in deck at core?	N	N	N	N	Y		N
C_s (% by wt. conc.)	0.592	0.388	0.399	0.376	0.439		0.351
D (in^2/yr)	0.008	0.022	0.028	0.077	0.075		0.082
Current chloride concentration at bar depth (% by wt. conc.)	0.009	0.014	0.039	0.123	0.123	0.182	0.132

Table 8. Cores and Extracted Bars from Bridge 2672S (Age of deck = 33 years, C_0=0.004% by wt. conc.)

Core	**7**	**8**	**9**	**10**	**11**		**12**
Bar ID	7T	8T	9T	10T	11B	11T	12
Depth (in.)	2.9	2.5	2.4	2.4	2.8	2.1	2.8
Coating Thickness (mils)	10.2	9.0	6.7	6.0	14.4	8.7	8.4
Adhesion Rating	5	5	4	5	2	5	2.5
Backside Cleanliness	4	4	3	4	1.5	4	1.5
Crack in core?	N	Y	N	Y	Y		N
Epoxy coated?	Y	Y	Y	Y	Y	Y	Y
Active Corrosion?	N	N	N	Y	N	N	N
Corrosion Condition	1	2	1	5	1	1	1
Delamination in deck at core?	N	N	N	Y	N		N
C_s (% by wt. conc.)	0.469	0.250	0.456	0.553	0.339		0.397
D (in^2/yr)	0.031	0.136	0.025	0.121	0.057		0.024
Current chloride concentration at bar depth (% by wt. conc.)	0.024	0.102	0.031	0.222	0.054	0.100	0.013

Table 9. Cores and Extracted Bars from Bridge 2673 (Age of deck = 34 years, C_0=0.003% by wt. conc.)

Core	**1**	**2**		**3**	**4**	**5**	**6**	**7**
Bar ID	1T	2B	2T	3T	4T	5T	6T	7T
Depth (in.)	2.7	2.9	2.2	2.1	2.3	2.1	2.4	2.7
Coating Thickness (mils)	9.7	8.9	7.9	9.1	8.5	9.0	6.3	8.0
Adhesion Rating	3	3	3	3	4	1.5	5	4
Backside Cleanliness	3	3	2.5	2	4	1.5	4	3.5
Crack in core?	N	N		N	Y	N	Y	N
Epoxy coated?	Y	Y	Y	Y	Y	Y	Y	Y
Active Corrosion?	N	N	N	N	N	N	Y	N
Corrosion Condition	1	1	1	1	1	1	4	2
Delamination in deck at core?	N	N		N	Y	N	N*	N
C_s (% by wt. conc.)	0.230	0.383		0.308	N/A	0.277	0.289	0.218
D (in^2/yr)	0.005	0.015		0.027	N/A	0.017	0.198	0.038
Current chloride concentration at bar depth (% by wt. conc.)	0.003	0.005	0.016	0.043	N/A	0.016	0.153	0.022

* delamination 2 ft. away

Table 10. Cores and Extracted Bars from Spans 1 to 4 of Bridge 2930 (Age of deck = 35 years, C_0=0.003% by wt. conc.)

Core	**1**		**2**	**3**	**7**
Bar ID	1B	1T	2T	3T	7T
Depth (in.)	3.1	2.5	2.8	2.6	2.7
Coating Thickness (mils)	9.9	8.0	8.6	15.8	14.6
Adhesion Rating	3.5	3	4	3	4
Backside Cleanliness	1.5	1	1.5	4	2.5
Crack in core?	N	N	N	N	N
Epoxy coated?	Y	Y	Y	Y	Y
Active Corrosion?	N	N	N	N	N
Corrosion Condition	1	1	1	1	1
Delamination in deck at core?	N		N	N	N
C_s (% by wt. conc.)	0.503		0.490	N/A	0.567
D (in^2/yr)	0.044		0.052	N/A	0.090
Current chloride concentration at bar depth (% by wt. conc.)	0.041	0.082	0.075	N/A	0.157

Table 11. Cores and Extracted Bars from Spans 5 and 6 of Bridge 2930 (Age of deck = 35 years, C_0=0.003% by wt. conc.)

Core	**4**	**5**	**6**	
Bar ID	4T	5T	6B	6T
Depth (in.)	2.8	2.6	3.3	2.6
Coating Thickness (mils)	N/A	N/A	N/A	N/A
Adhesion Rating	N/A	N/A	N/A	N/A
Backside Cleanliness	N/A	N/A	N/A	N/A
Crack in core?	N	Y	N	
Epoxy coated?	N	N	N	N
Active Corrosion?	N	Y	Y	Y
Corrosion Condition	3	5	4	4
Delamination in deck at core?	N	Y	N	
C_s (% by wt. conc.)	0.539	0.464	0.468	
D (in^2/yr)	0.015	0.163	0.078	
Current chloride concentration at bar depth (% by wt. conc.)	0.007	0.204	0.079	0.131

Table 12. Cores and Extracted Bars from Bridge 2953 (Age of deck = 34 years, C_0=0.003% by wt. conc.)

Core	**1**	**2**		**3**	**4**	**5**	**6**
Bar ID	1T	2B	2T	3T	4T	5T	6T
Depth (in.)	2.2	2.9	2.3	2.4	1.9	1.9	2.0
Coating Thickness (mils)	8.0	9.0	8.0	11.9	8.5	8.7	10.0
Adhesion Rating	3	4	3	4	4	4	3
Backside Cleanliness	2	3	3	3	2	3	3
Crack in core?	N	N		N	N	Y	N
Epoxy coated?	Y	Y	Y	Y	Y	Y	Y
Active Corrosion?	N	N	N	N	N	N	N
Corrosion Condition	1	1	1	1	1	1	1
Delamination in deck at core?	N	N		N	N	N	N
C_s (% by wt. conc.)	0.443	0.453		0.498	0.491	0.572	0.483
D (in^2/yr)	0.039	0.068		0.051	0.078	0.095	0.051
Current chloride concentration at bar depth (% by wt. conc.)	0.083	0.082	0.133	0.100	0.199	0.263	0.138

Table 13. Summary of Calculated Surface Concentrations and Diffusion Coefficients for Each Bridge

Bridge No.	Property	All cores		Cores without cracks	
		Average	Standard deviation	Average	Standard deviation
2668N	Cs (% by wt. conc.)	0.470	0.110	0.470	0.110
2672N	Cs (% by wt. conc.)	0.424	0.087	0.460	0.115
2672S	Cs (% by wt. conc.)	0.411	0.107	0.441	0.038
2673	Cs (% by wt. conc.)	0.291	0.062	0.283	0.067
2930	Cs (% by wt. conc.)	0.507	0.044	0.516	0.043
2953	Cs (% by wt. conc.)	0.490	0.046	0.474	0.024
2668N	D (in^2/yr)	0.036	0.018	0.036	0.018
2672N	D (in^2/yr)	0.049	0.033	0.019	0.010
2672S	D (in^2/yr)	0.066	0.050	0.027	0.004
2673	D (in^2/yr)	0.042	0.055	0.020	0.013
2930	D (in^2/yr)	0.073	0.051	0.054	0.028
2953	D (in^2/yr)	0.064	0.021	0.058	0.015

FIGURES

Figure 1. Mechanical sounding to identify delaminations.

Figure 2. Core sample extraction.

Figure 3. Measuring continuity (electrical resistance) of reinforcing bar mat.

Value	Description	Representative photographs	
		Epoxy-coated	Uncoated
1	No evidence of corrosion		
2	A number of small, countable corrosion spots		
3	Corrosion area less than 20% of total surface area		
4	Corrosion area between 20% to 60% of total surface area		
5	Corrosion area greater than 60% of total surface area		

Figure 4. Rating scale used to assess corrosion condition of bars taken from cores.

Value	Description	Representative photographs	
1	Excellent adhesion; epoxy does not peel from bar		
2	Epoxy peels from bar in 1/8-inch sections		
3	Moderate adhesion; epoxy peels from bar in 1/4-inch sections		
4	Epoxy peels from bar in 3/8-inch sections		
5	Poor adhesion; epoxy peels from bar in 1/2-inch sections		

Figure 5. Rating scale used to assess epoxy adhesion on bars taken from cores.

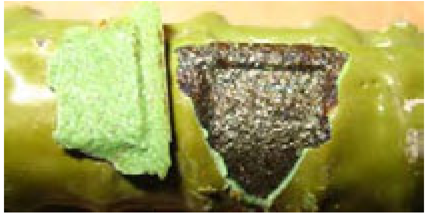
Value	Backside Cleanliness	Representative photographs
1	0 to 2% of area	
2	2 to 10% of area	
3	10 to 30% of area	
4	30 to 50% of area	

Figure 6. Rating scale used to assess backside cleanliness on bars taken from cores.

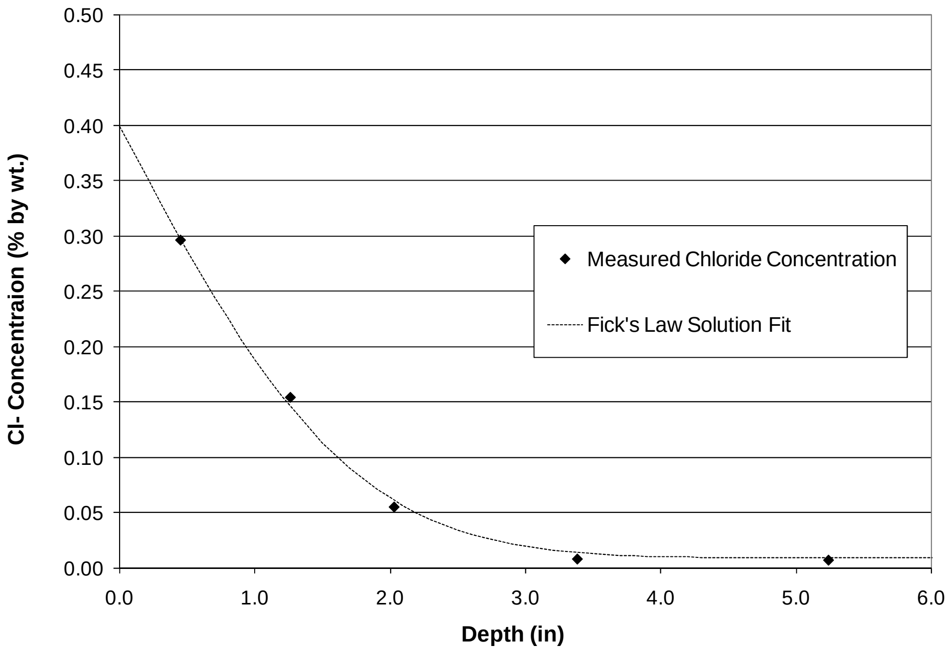


Figure 7. Measured chloride concentration and fitted solution to Fick's Law

Figure 8. Bridge No. 2668N

Figure 9. Thin polymer overlay visible on top (left) of core from Bridge No. 2668N.

Figure 10. Transverse cracking on underside of Bridge No. 2668N.

Figure 11. Bridge No. 2672N.

Figure 12. Bridge No. 2672S.

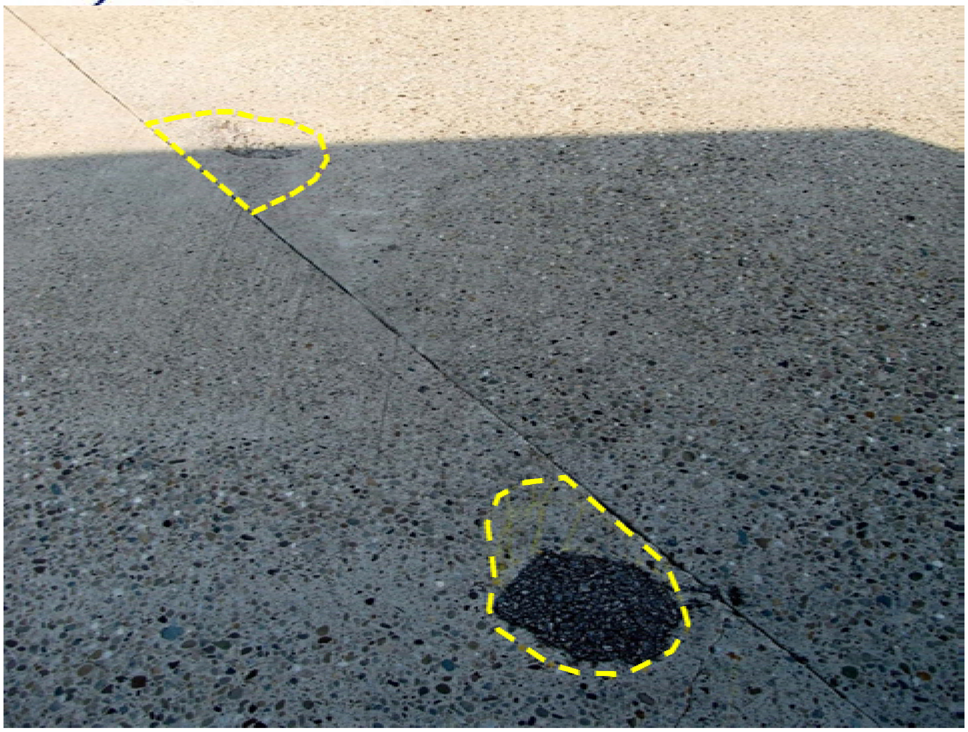


Figure 13. Patch and spall at construction joint on Bridge No. 2672N. Delaminations are highlighted by yellow dashed lines.

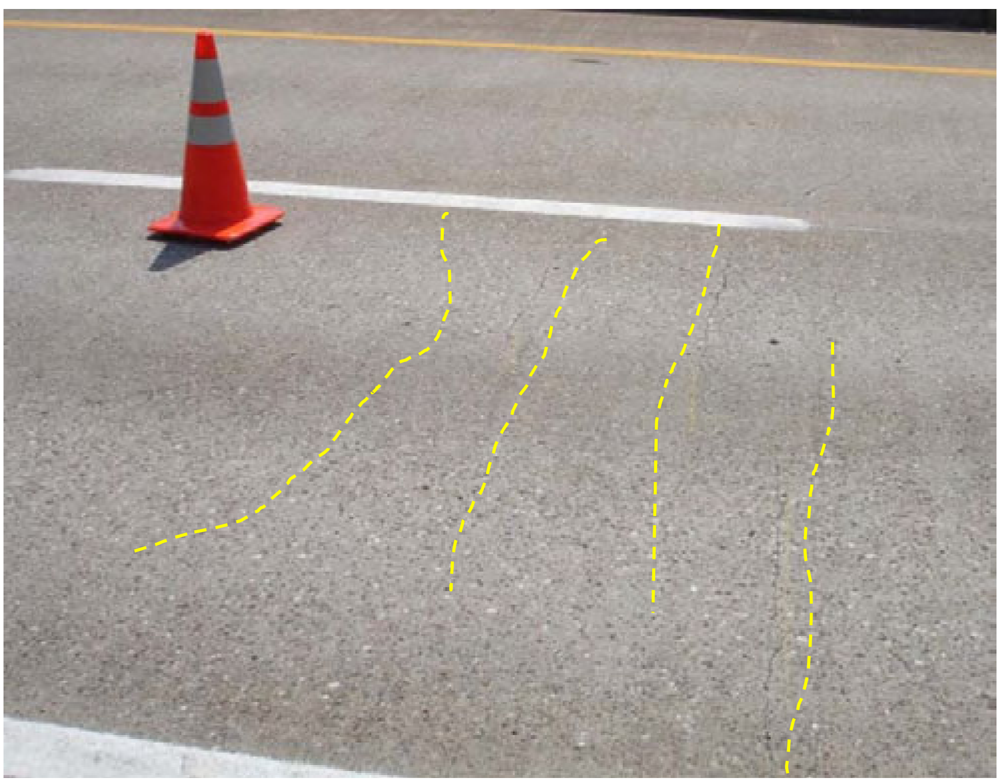


Figure 14. Transverse cracking in Bridge No. 2672S. Cracks are highlighted by yellow dashed lines.

Figure 15. Transverse cracking core 6 from Bridge No. 2672N.

Figure 16. Spall due to corrosion of uncoated bottom bar in Bridge No. 2672N.

Figure 17. Bridge No. 2673.

Figure 18. Spall at construction joint on Bridge No. 2673.

Figure 19. Underside of Bridge No. 2673.

Figure 20. Bridge No. 2930.

Figure 21. West side of Pier 4 of Bridge No. 2930.

Figure 22. Stay-in-place forms in Spans 1-4 of Bridge No. 2930.

Figure 23. Repair on Span 5 of Bridge No. 2930.

Figure 24. Isolated repairs on Bridge No. 2930.

Figure 25. Delamination at bar level caused by corrosion of uncoated black bar in Bridge No. 2930.

Figure 26. Bridge No. 2953

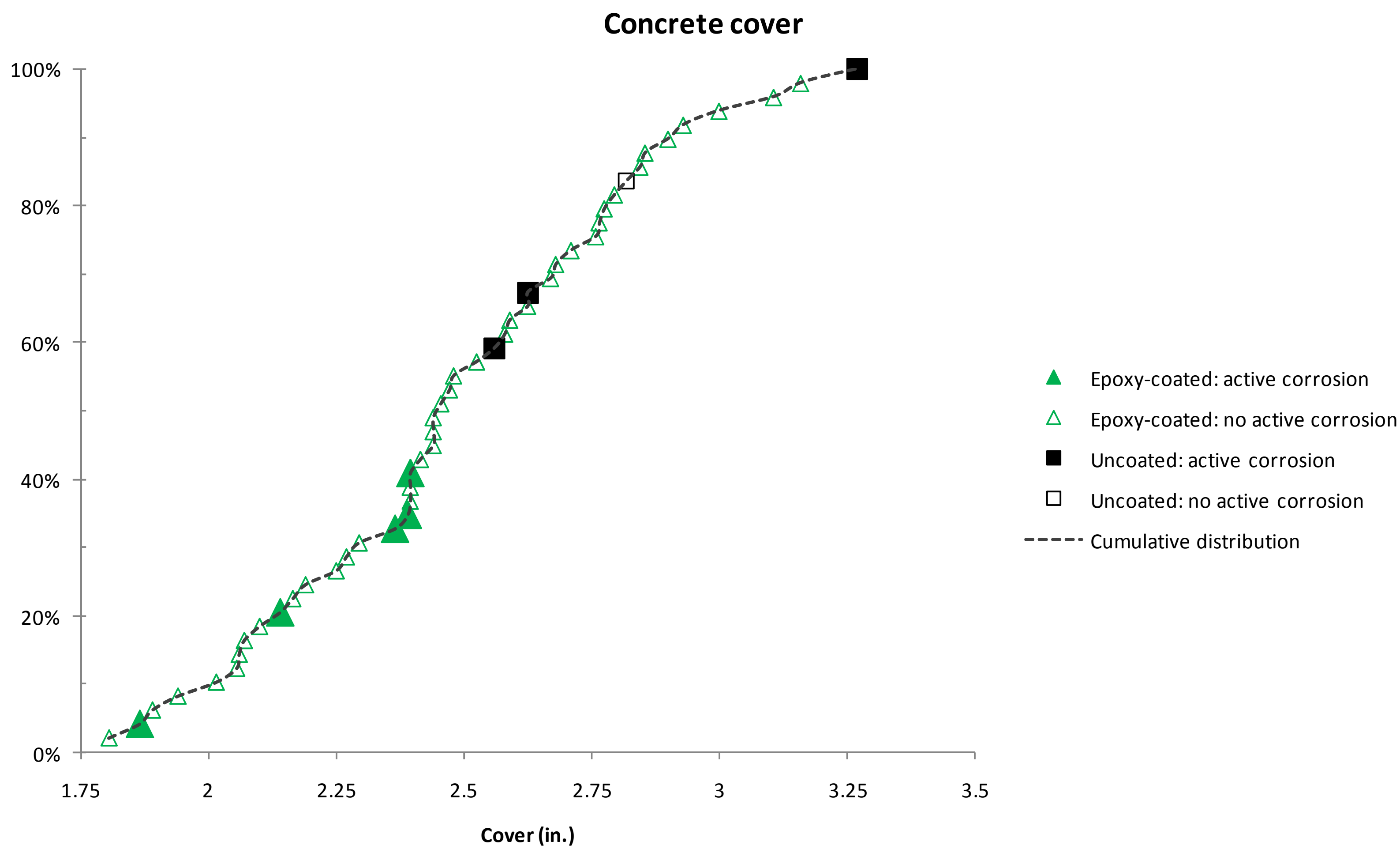


Figure 27. Distribution of cover depth above bars for cores from all bridges.

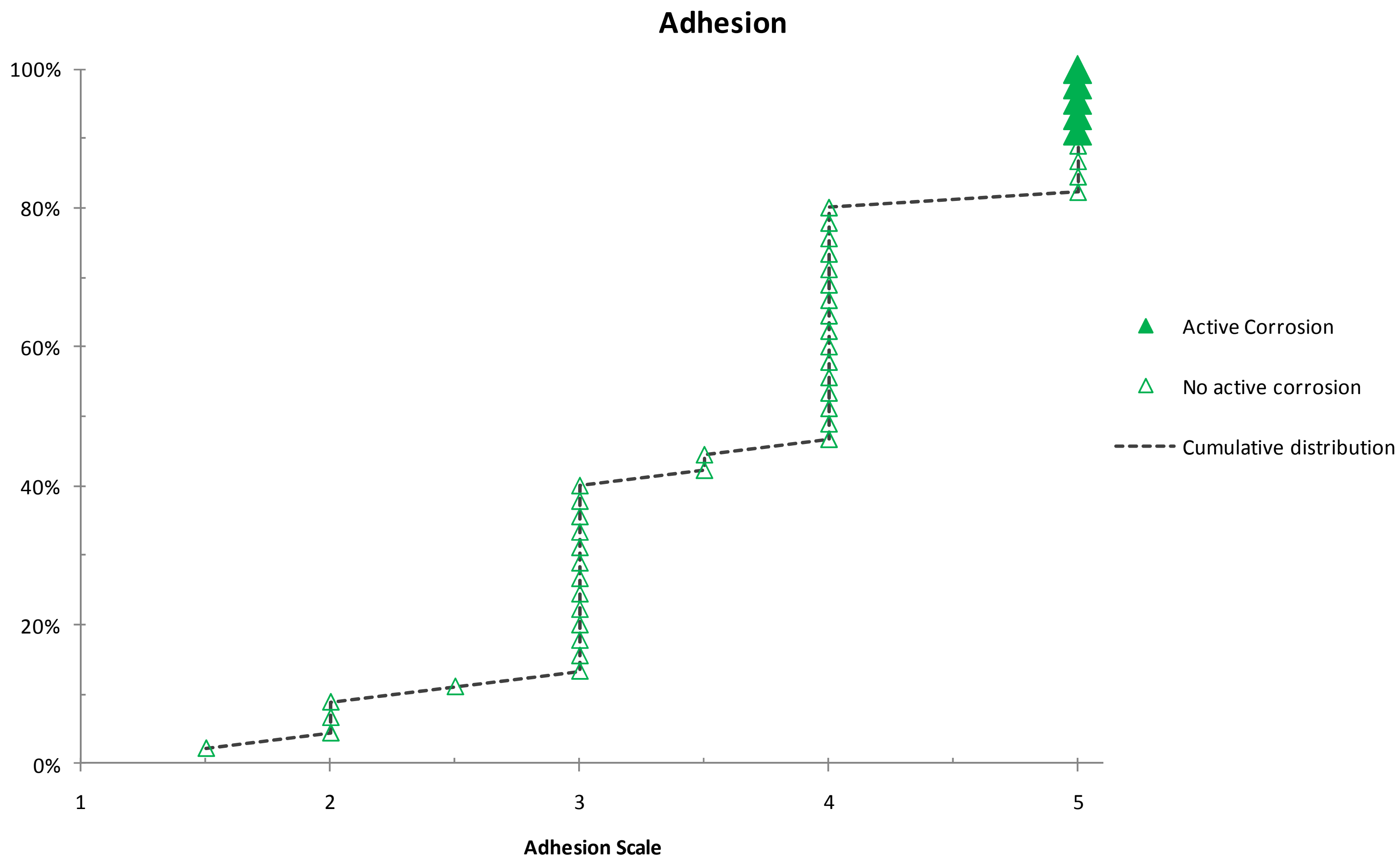


Figure 28. Distribution of epoxy-coating adhesion measured on bars in cores sampled from all bridges.

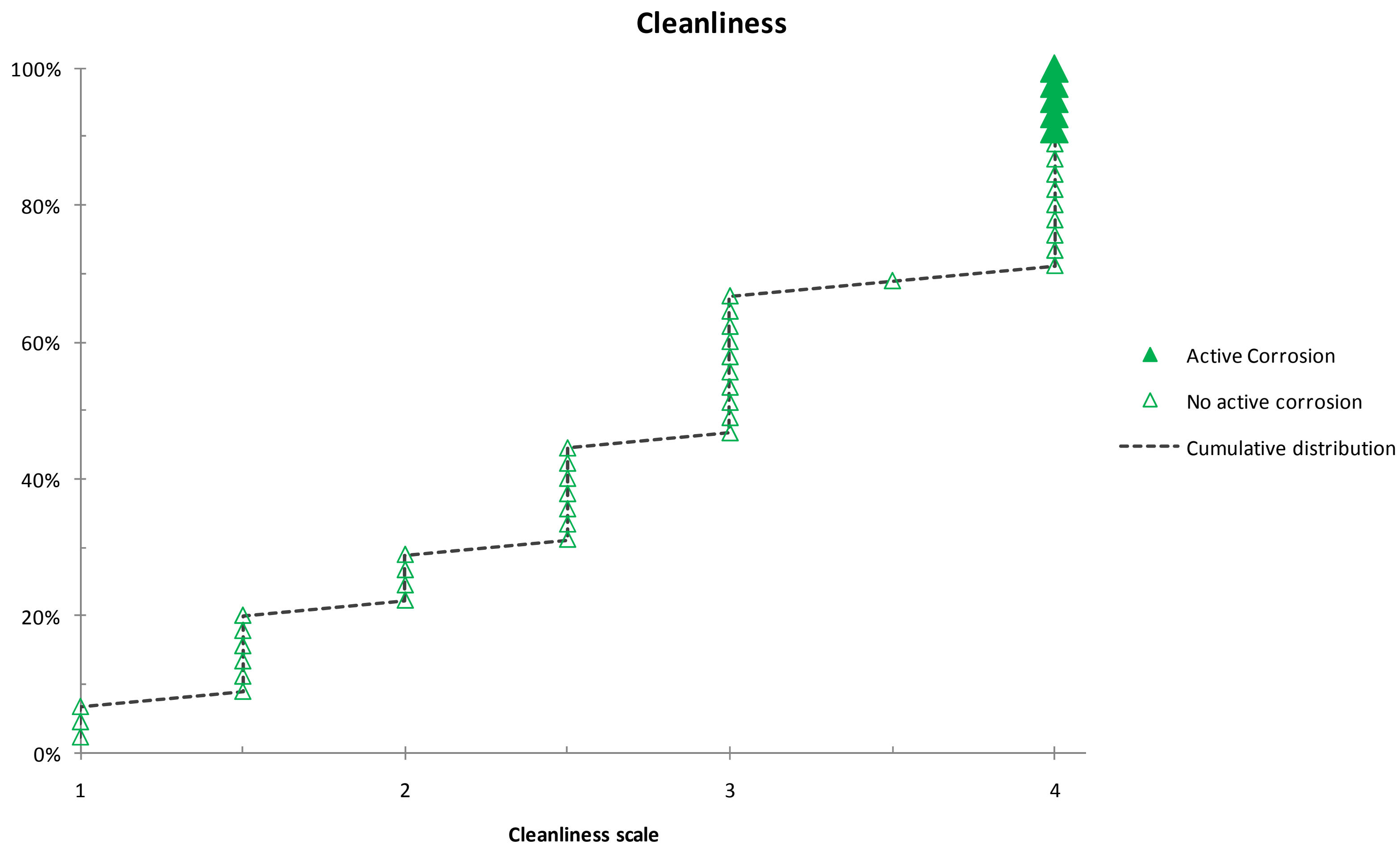


Figure 29. Distribution plot of epoxy-coating cleanliness measured on bars in cores sampled from all bridges.

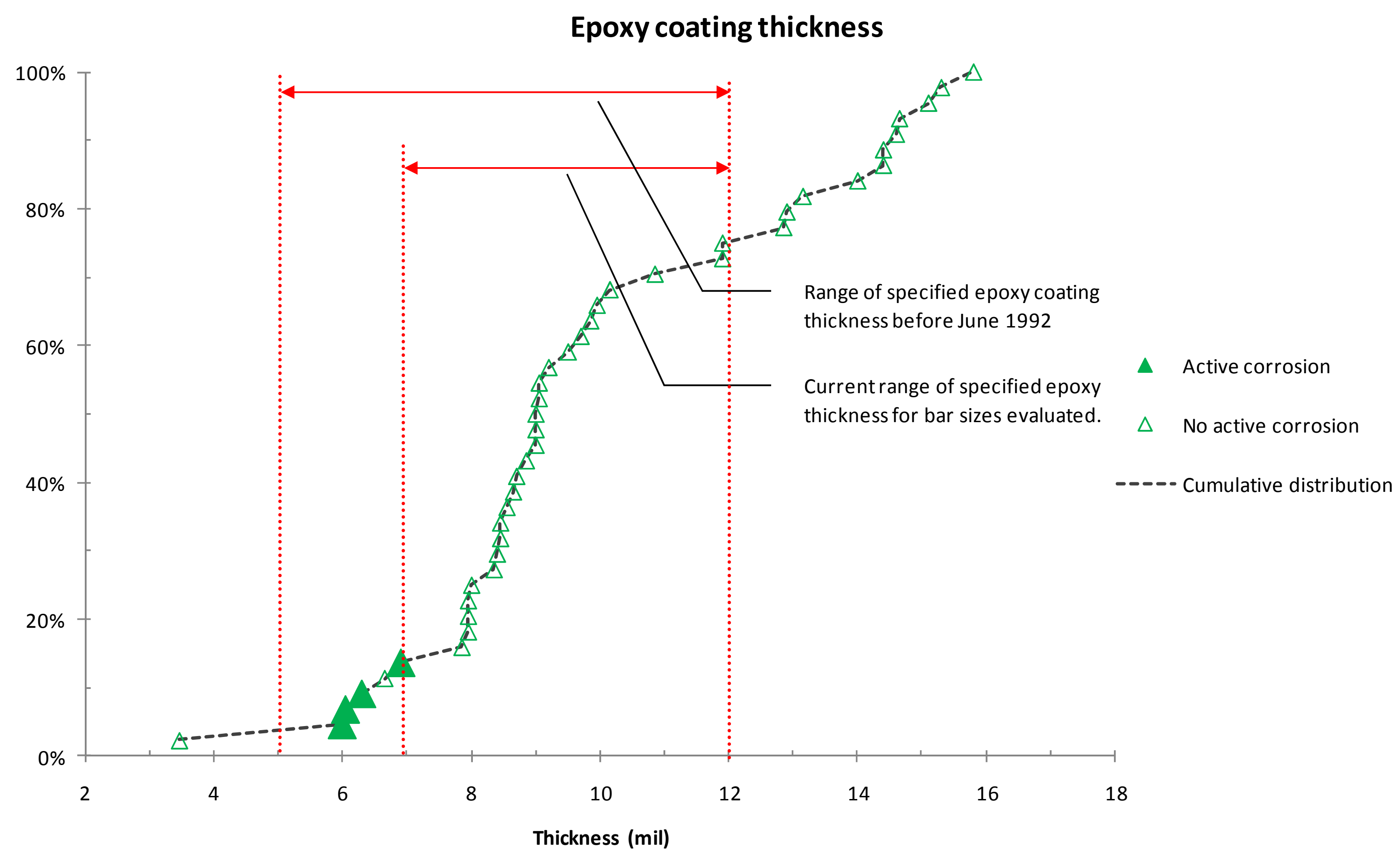


Figure 30. Distribution plot of epoxy coating thickness on bars in cores sampled from all bridges. Note actively corroding bars have thinner coatings.

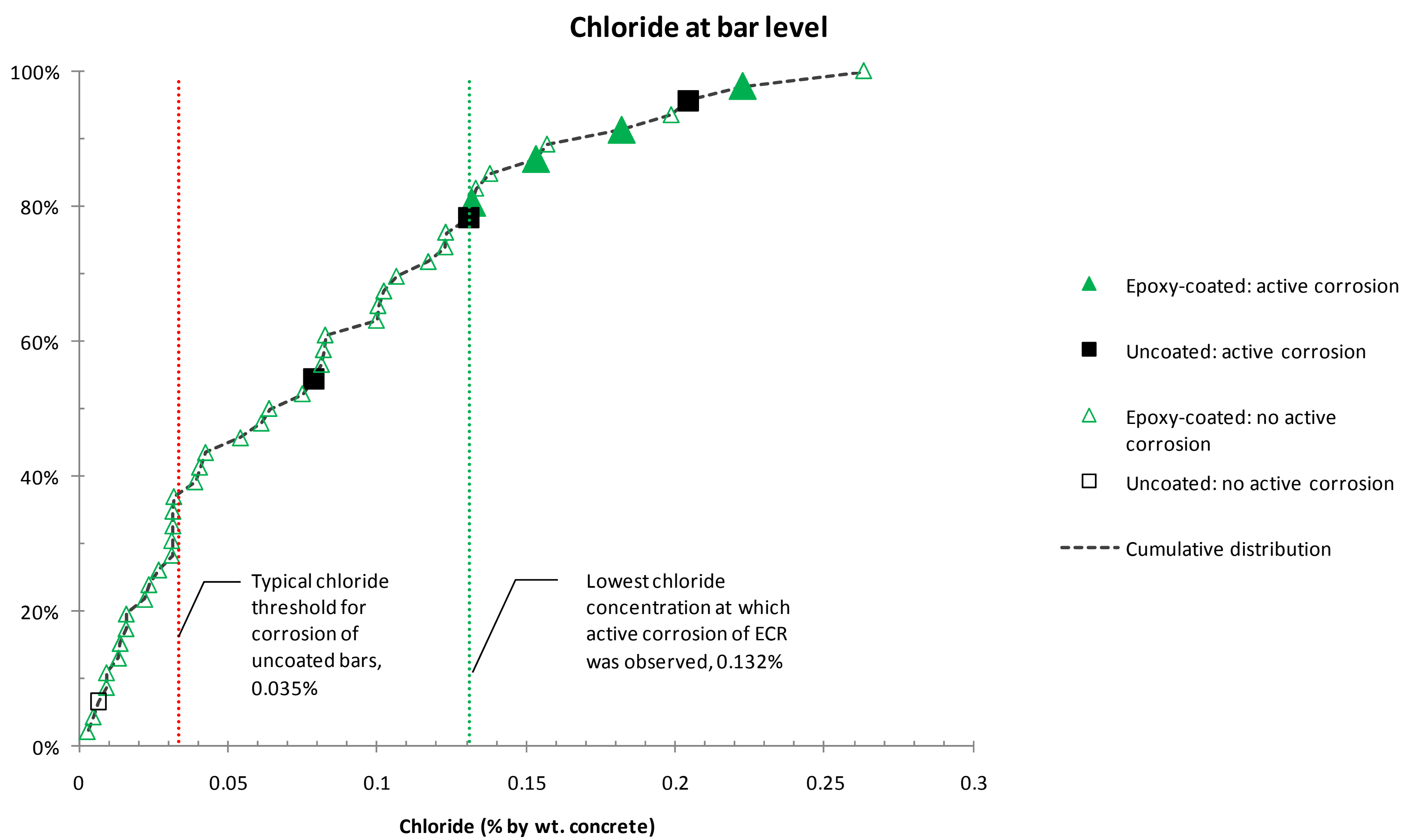


Figure 31. Distribution plot of chloride concentration at bar depth from all bridges. Note that all uncoated bars above uncoated-bar chloride threshold are actively corroding while the uncoated bar below this threshold is not corroding.

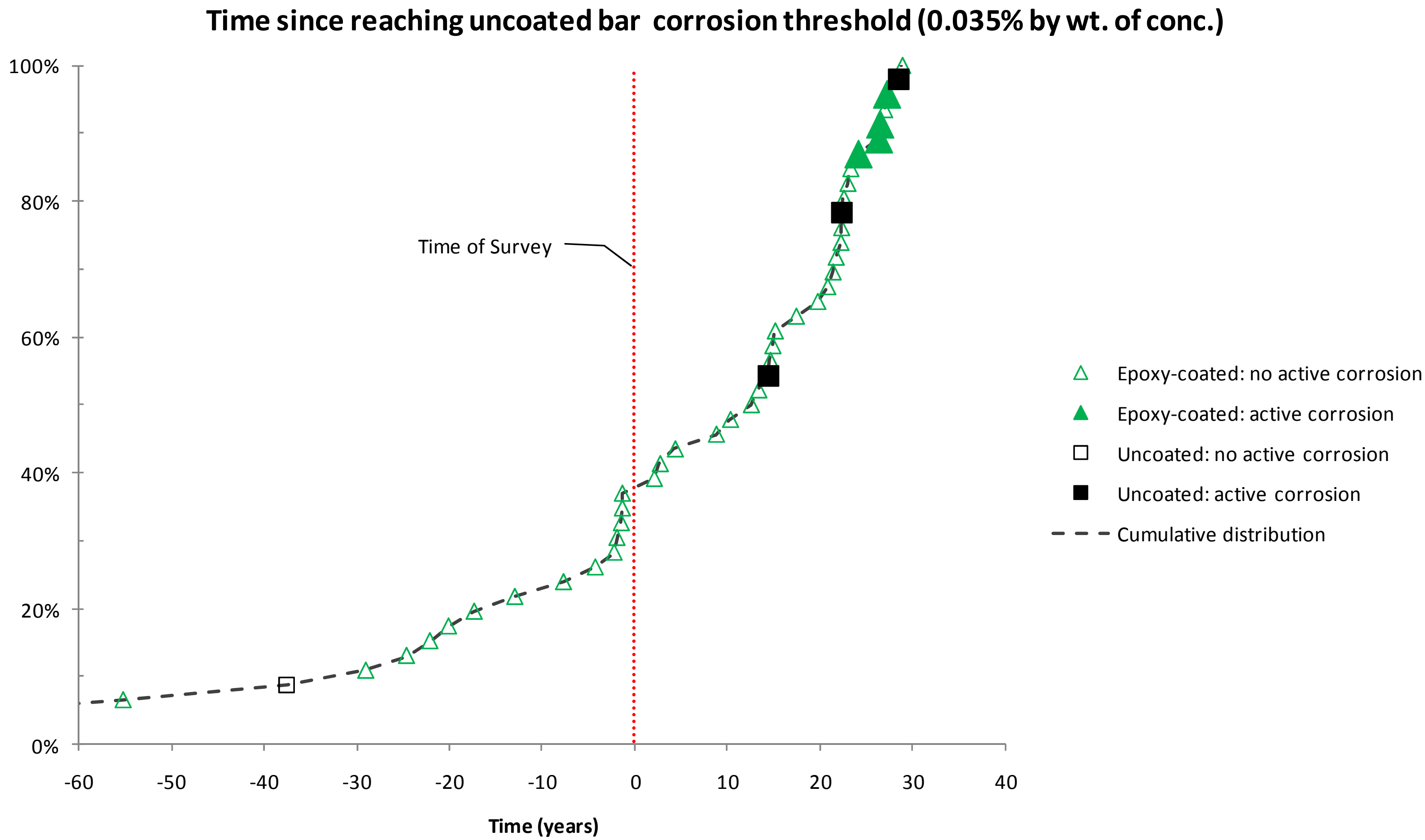


Figure 32. Plot of time since reaching uncoated bar corrosion threshold (0.035% by weight of concrete) at bar depths from all bridges. (A negative value implies that the bar has yet to reach the threshold.)

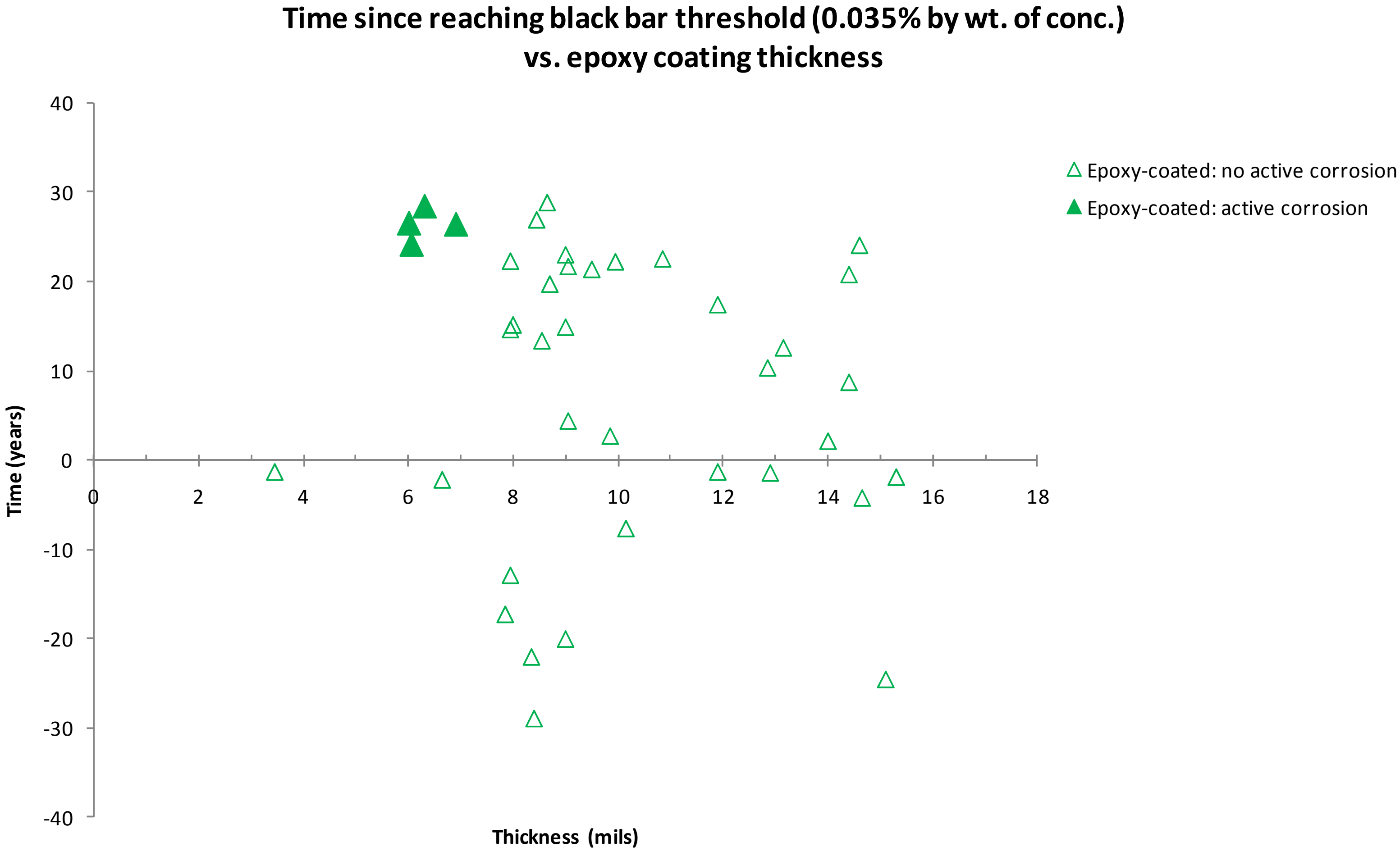


Figure 33. Time since chloride concentration exceeded uncoated bar threshold versus epoxy coating thickness on bars from all bridges.

APPENDIX A - 1993 WVDOT SURVEY REPORT

RESEARCH REPORT

MIR #1261603
EVALUATION OF BRIDGE DECKS
USING EPOXY COATED
REINFORCEMENT

Submitted by:
WEST VIRGINIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS

REPORT NUMBER:	1261603
MATERIALS INSPECTION REPORT	
SUBJECT:	Evaluation of Bridge Decks Using Epoxy Coated Reinforcement
DATE OF REPORT:	January 26, 1994

1.0 INTRODUCTION

1.1 Bridge decks constructed in West Virginia prior to the early 1970's used bare or black reinforcement steel. Many of these decks developed surface defects, such as spalls, that were directly related to oxidation of the reinforcement mat.

1.2 In an effort to minimize this damage and to prolong the useful life of bridge decks, several strategies were employed. One of the more popular attempts was the use of epoxy coated reinforcement. This report focuses on West Virginia's initial efforts in using this strategy.

2.0 INVESTIGATION

2.1 Twelve project sites were identified as being among the first decks using epoxy coated reinforcement. Two of these sites were on Interstate 79 and, therefore, consisted of two decks each. The project numbers, bridge numbers, locations, and approximate date of construction are presented in Attachment 1.

2.2 Each deck was investigated in an identical manner. A complete delamination survey was conducted using the acoustic chain drag method in accordance with ASTM D4580. A visual condition survey was performed on the surface of each deck and on the under surface when accessible. This visual survey was performed using ACI guidelines. Chloride content of the bridge deck concrete was determined using AASHTO Procedure T260 on three of the decks. Chloride sampling was suspended due to inclement weather. The results of the visual survey is included in Attachment 2 and the delamination survey and the chloride testing are presented in Attachment 3 along with the delamination and chloride results of decks not employing epoxy coated reinforcement.

3.0 DISCUSSION

3.1 A number of attributes of bridge decks of this age may be generalized. Visual surveys of fifteen to twenty year old decks not using epoxy coated steel normally reveal significant numbers of transverse cracks often extending through the entire depth of the deck. These cracks are very apparent from the bottom of the deck due to the presence of efflorescence.

3.2 The decks surveyed in this investigation, with few exceptions, exhibited transverse cracking on the surface of the decks. The cracking and associated efflorescence at the underside was uniformly lighter than is normally detected in decks of this age. Nearly all the surface cracks appear to be associated with expansion and contraction due to temperature changes rather than reinforcement associated stress.

3.3 Decks of this age and use also often exhibit defects known as pop-outs or spalls. If this type of defect has occurred recently, a pothole is left in the deck often penetrating to the top mat of the reinforcement. If the spall occurred earlier, it will normally have been filled with patching material during normal maintenance.

3.4 The percentage of spalling in this survey is mathematically non-existent.

4.0 CONCLUSIONS

4.1 Conclusions regarding the condition of the decks investigated are based on the present condition of these decks and in large to past experience conducting surveys on decks not using coated reinforcement. To quantify the differences, a number of surveys on decks not using coated steel built at approximately the same time were reviewed. Results of the portion of the testing involved in these reports are presented in Attachment 3.

4.2 From comparisons based on the cracking of the decks it may be concluded that while the use of epoxy coated reinforcement does not necessarily reduce the number of transverse cracks found in a bridge deck, the damage incurred to the deck by allowing water to penetrate through these cracks and accelerating the corrosion of the uncoated steel is greatly reduced, if not eliminated, with the use of epoxy coated reinforcement.

4.3 No patching was observed on any of the decks. Since spalling is normally accelerated by pressure being exerted by corrosion of the top mat, it may be concluded that this process is either not occurring or is occurring at a reduced rate in these decks.

4.4 The delamination surveys provide the most striking differences between the decks involved in this project and those using uncoated steel. Previous experience on decks not using epoxy coated steel has produced widely varying percentages of delamination. Often the percentage of delamination reaches as high as 60 to 80 percent although 5 to 20 percent is more common. Comparing this to the uniform absence of any measurable reinforcement associated delamination in the decks investigated in this project leads to only one conclusion. This conclusion is that the epoxy coated reinforcement must be directly responsible for the lack of delamination in these decks.

4.5 This conclusion is probably best illustrated by comparing Bridge Numbers 2668 and 2672 located at Mileposts 7.38 and 10.64 on Interstate 79 with Bridge Numbers 2669 and 2670 located at Mileposts 8.48 and 9.20 respectively. Bridge Numbers 2668 and 2672 incorporate epoxy coated reinforcement while Bridge Numbers 2669 and 2670 do not. All eight structures were constructed at approximately the same time. Due to their proximity to each other, they should have identical traffic loads and identical exposure to factors such as weather and de-icing maintenance.

The decks using epoxy coated reinforcement exhibits only one square foot of reinforcement associated delamination in a total deck area of 92,400 square feet. Mathematically this is 0.001 percent. The decks not using epoxy coated steel exhibit delaminations averaging 8.5 percent or 8,500 times the amount of the decks using protected reinforcement.

4.6 The average chloride content for those decks incorporating the epoxy coated reinforcement is similar to those without the coating. Therefore, it may be concluded that the typical corrosion acceleration process due to chlorides is present in both types of decks.

4.7 Overall, the condition survey of the epoxy coated decks exhibited little to no distress. In comparison with decks not employing the coated strategy, the most significant difference is in the area of delaminations.

It could be concluded that from the data gathered in this investigation that the use of epoxy coated reinforcement does result in a dramatic reduction of delamination in bridge decks and by inference an increase in the useful life expected of the deck.

Don Lipscomb
Engineering Technician

Robert R. Kessler
Testing Group Leader
Materials Control, Soils
and Testing Division

GLR:Sdlb

ATTACHMENT 1

Project No.	Bridge No.	Date of Const	Location
APD 282(70)	2930	1974	Industrial Bridge - Clarksburg
HRR-19-16-3657	2953	1975	Adamson St. Bridge - Clarksburg
ER-277(1) C-4	2776	1975	Buffalo Creek
736(1) C-2	2771	1976	Hinton Bridge
BRF-0312(019)	2665	1976	Rt 2 Bridge - Huntington
I-79-1(38)10	2673	1975	Overhead Bridge - Charleston
RF284(12)	2655	1976	Rt 52 Bridge - Kermit
BRF-0824(011)	2847	1976	Rt 52 - I McDowell County
BRS-0754(002)	2975	1976	East Lynn Bridge
ER-277(1) C-7	2768	1976	Buffalo Creek
I-79-1(38)10	2672	1976	Mainline - Charleston
I-79-1(39)7	2668	1976	Big Sandy Bridge - Charleston

ATTACHMENT 2

Bridge # 2975
WV 37 East Lynn Bridge
June 29, 1993

This is a two lane deck with a pedestrian walkway separated by a parapet. The deck is 172 feet long and 30 feet wide. The area of the deck is 5160 square feet.

No steel associated delamination. There is what could be considered normal transverse cracking the full width of the deck. These cracks are very light and are not associated with any delamination. The only 'defects' observable on the deck three small circular spalled areas. The first two areas are approximately 8 to 10 inches in diameter and approximately 1/2 to 3/4 inches in depth. These two areas are located at the center of the northbound lane 51 feet from the southern end of the structure. The third area is located in the southbound lane approximately 30 feet from the south end of the deck and approximately 2 feet from the centerline. The depth of this spall is approximately 1/2 inch. No delaminations were detected at these spalled areas.

Bridge # 2665
Rt 2 Huntington Bridge
July 28, 1993

This deck is a two lane structure with an attached pedestrian walkway opened to traffic in 1976. The deck is 584 feet in length with two 15 foot lanes and a 6 foot walkway separated from the traffic lanes by a 1 foot parapet. This comprises approximately 21,000 square feet. The deck is slightly arched with the high point of the arch being approximately 200 feet from the south end of the deck.

Visual investigation found no spalling or patches. Transverse cracking was evident in much of the deck. No cracking was found in the deck north of the north-end expansion device. In the immediate vicinity of the highest portion of the slight arch, the transverse cracking was more frequent occurring at approximately 2 foot intervals. In the remaining area of the deck the cracking appeared approximately on 4 foot centers. Nearly all the area of the wheelpaths had completely exposed aggregate. No popouts were observed. The underside of the deck was not visible due to corrugated metal (possibly forms) completely covering the bottom of the deck.

The delamination survey found no rebar associated delaminations. Delamination associated with the expansion dams occurred only on the northern expansion dam in the southbound lane.

ATTACHMENT 2

Bridge # 2655
US 52 Kermit
July 21, 1993

The deck consists of two fifteen foot lanes with a four foot shoulder on either side. The length of this deck is approximately 445 feet. The area is 17000 square feet.

The interesting aspect of the visual investigation was the lack of defects. No patching, spalling or cracking was evident. The bottom of the deck showed no signs of cracking.

No delamination other than scaling associated with the expansion dams were detected.

Bridge # 2768
Co. 37 Buffalo Creek
June 14, 1993

The deck measured 116 feet in length with two 12 foot wide traffic lanes and two eleven foot shoulders. The area of this deck is 5300 feet.

No spalling, patching, or cracking were observed on either the deck surface or the underside.

No delaminations were found in either of the two traffic lanes or in much of the shoulders. Approximately 25% of the shoulders could not be examined for delamination due to the large buildup of rubble adjacent to the parapets.

Bridge # 2847
US 52 McDowell County
August 3, 1993

This deck consisted of two 12 foot lanes and two 4 foot shoulder. The length of the deck is approximately 130 feet and the area approximately 4100 square feet.

Visually there were no apparent deficiencies found. The delamination survey found 1 area of approximately 1 square foot in the Westbound lane This delamination is located in the right wheelpath approximately 138 feet from the Eastern end of the deck.

The underside of the deck exhibited no defects of any kind.

ATTACHMENT 2

Bridge # 2672
1-79 Mainline Bridge
June 8, 1993

Two decks are involved in this site. Both decks consist of two 12 foot lanes, 1 twelve foot shoulder and 1 four foot shoulder. Each deck is approximately 7000 square feet in area. No rebar associated delaminations were noted in any portion of the two decks.

A normal amount of transverse cracking was observed with one exception. Each deck was divided into 5 sections by construction joints. There was noticeably more of the transverse cracking in the second and fourth section from the southern end of the Southbound deck and the second section, again from the southern end, of the Northbound deck. Again, this cracking did not appear to be severe or out of the ordinary for decks of this age. It is somewhat more unusual that the remaining section exhibited so little cracking.

The underside of the deck exhibited some light cracking and associated efflorescence

Bridge # 2673
1-79 Overhead Bridge
June 9, 1993

This deck is not part of mainline 1-79 but an overpass carrying a County route over the interstate. Shoulder markings are not visible. The dimensions of the deck are 42 feet by approximately 400 feet. The two-lane deck encompasses approximately 17,000 square feet.

An extremely low number of cracks (approximately 12) were noted on the surface of the deck. No delaminations were noted other than those associated with the expansion dam devices located at either end of the deck and at the first construction joint in from either end. The underside exhibited very light cracking with some light efflorescence

Bridge # 2668
1-79 Big Sandy Bridge
June 7,8, 1993

This is a 2-deck bridge with each deck approximately 980 feet long by 40 feet in width. The area of each deck deck 39,200 square feet.

In both decks there was a noticeably higher number or transverse cracks in the traffic lanes only. These cracks are four to six feet in length on approximately four foot centers. There are no delaminations associated with this cracking pattern

ATTACHMENT 2

The Southbound deck exhibited no delamination. The Northbound deck contained one area of approximately one square foot of delamination. This occurs 92 feet from the Souther expansion dam almost directly on passing lane/left shoulder stripe. There is also a popout approximately two inches deep associated with this delamination.

The underside of both decks were typical in that they exhibited light cracking and some efflorescence.

Bridge # 2771
WV 20 Hinton Bridge
June 14, 1993

This two lane deck with a separated pedestrian walkway is 1300 feet long and approximately 32 feet wide. The area of the deck is 41600 square feet.

This deck visually was in very good condition. The typical light transverse cracking was evident in only six of the fourteen panels separated by construction joints in the deck. No delaminations were encountered.

One unusual feature was a large number of pop-outs, about the size of an individual coarse aggregate particle, in the panel beginning at approximately 327 feet from the southern expansion dam. As was stated, no occurred in this area and the depth of these popouts was not sufficient to reach the top mat of the reinforcing steel.

The underside of the deck was not accessible.

Bridge # 2953
US 19 Adamson St. Bridge
August 10, 1993

This is a two lane deck with a separated pedestrian walkway. The dimensions of the deck are 300 feet in length and 30 feet in width for a total surface area of 9000 square feet.

With the exception of one full width transverse crack 175 feet from the southern expansion dam, there were no defects observable on the surface of the deck. This crack occurs approximately mid-way between the two piers of the bridge. No delaminations and no other cracks were found. There was a uniform exposure of the aggregate on the entire surface of the deck, not just in the wheelpaths.

The underside of the deck was not accessible.

ATTACHMENT 2

Bridge # 2930
Industrial Bridge
August 10, 1993

This deck consisted of two lanes and two separated pedestrian walkways. The length of the deck is 557 feet and the width was measured to be 32 feet. The surface area is 17800 square feet.

Delamination were observed in a number of areas on this deck. All linear measurements were taken from the southern end of the deck.

At 37 feet, a delamination approximately 2 feet wide extends for the width of both lanes. This delamination is centered on a construction joint.

At approximately 62 feet a one square foot delamination was present in the left wheelpath of the Northbound lane

At 82 feet, a delaminated area was detected approximately 1 foot wide and 6 feet in length The area begins at the pedestrian walkway parapet and extends into the Northbound lane approximately two feet.

At 250 feet, an area of approximately one square foot in the right wheelpath of the Northbound lane

At 320 feet, an area of approximately one square foot in the center of the Southbound lane

The total area of all these delaminations is approximately forty square feet.

Some light, full-width and partial-width transverse cracking was observed. No delaminations were associated with any of the cracks.

NO. 1261603

ATTACHMENT 2

Bridge # 2276
Co. 37 Buffalo Creek
June 14, 1993

The deck measured 136 feet in length with two 12 foot wide traffic lanes and two eleven foot shoulders. The area of this deck is 6200 feet.

No spalling, patching, or cracking were observed on the deck surface.

No delaminations were found in either of the two traffic lanes or in much of the shoulders. Approximately 25% of the shoulders could not be examined for delamination due to the large buildup of rubble adjacent to the parapets.

The underside of the deck was not accessible.

ATTACHMENT 3

BRIDGE DECKS USING EPOXY COATED STEEL

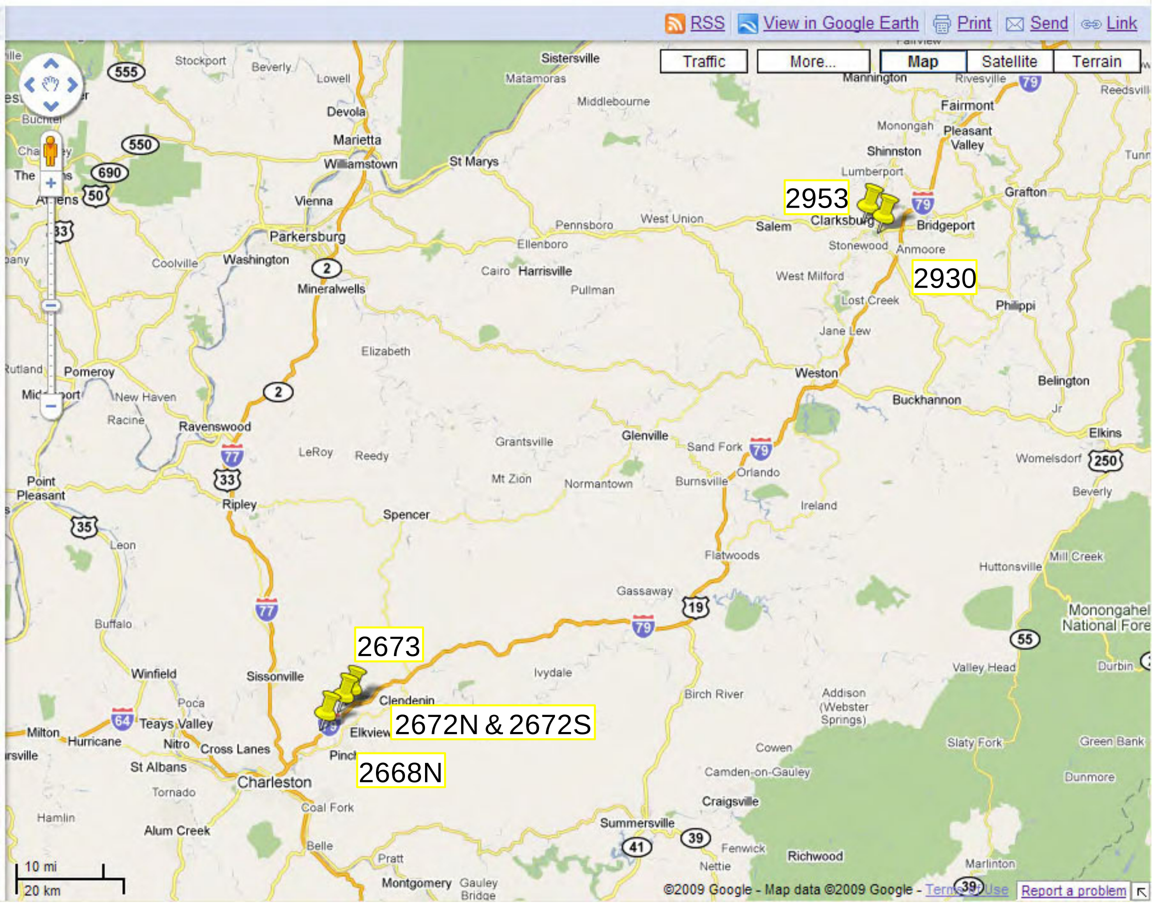
Proj #	Brdg #	Delam %	Ave Chl.
BRF-0312(019)	2665	0.000	2.4
736(1) C-2	2771	0.000	5.3
1-79-1(39)7 north	2668	0.000	3.3
I79-1(39) south	2668	0.002	2.1
APD 282(70)	2930	0.225	
HRR-19-16-3657	2953	0.000	
ER-277(1) C-4	2776	0.000	
I-79-1(38)10 ovrhd	2673	0.000	
RF284(12)	2655	0.000	
BRF-0824(011)	2847	1.000	
BRS-0754(002)	2975	0.000	
ER-277(1) C-7	2768	0.000	
I-79-1(38)10 north	2672	0.000	
1-79-1(38)10 south	2672	0.000	

BRIDGE DECKS NOT USING EPOXY COATED STEEL

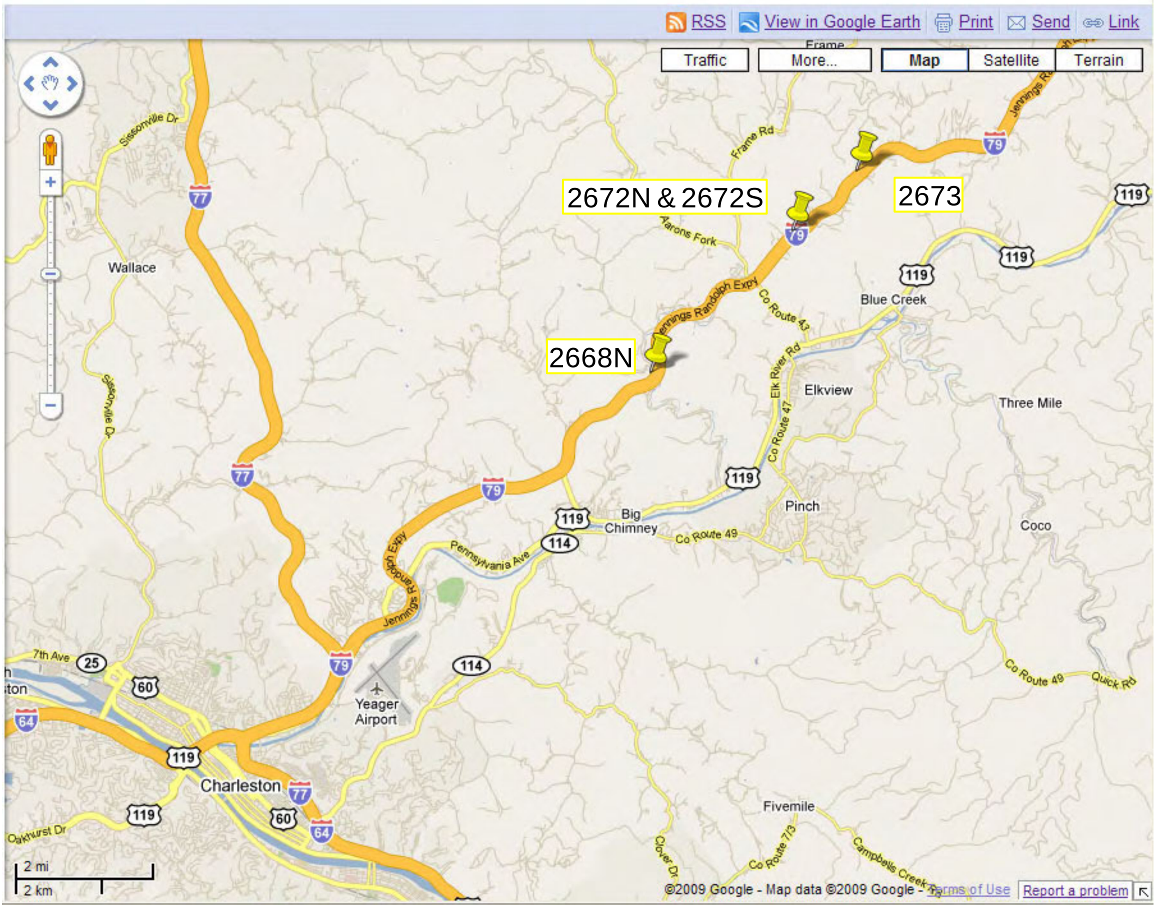
Proj #	Brdg #	Delam %	Ave Chl.
S350-37-30.06	2611	29.000	6.7
S321-79-104.15 north	2713	4.000	4.1
S321-79-104.15 south	2713	1.000	3.2
S331-79-154.87 north	2520	4.000	4.7
S331-79-154.87 south	2520	3.000	7.1
S331-79-155.97 north	2521	1.000	6.8
S331-79-155.97 south	2521	2.000	6.2
S323-119-19.28 north	2648	2.000	6.3
S323-119-19.28 south	2648	3.000	3.3
S317-79-115.33 north	2441	1.000	5.0
S317-79-115.33 south	2441	1.000	3.2
S317-79-117.30 north	2445	4.000	2.8
S317-79-117.30 south	2445	6.000	4.9
S317-79-117.30 north	2446	2.000	2.1
S317-79-117.30 south	2446	8.000	5.2
S320-79-8.48 north	2669	7.000	2.4
S320-79-8.48 south	2669	17.000	1.3
S320-79-9.20 north	2670	7.000	3.3
S320-79-9.20 south	2670	3.000	3.8

APPENDIX B - LOCATION OF DECKS SURVEYED IN 2009

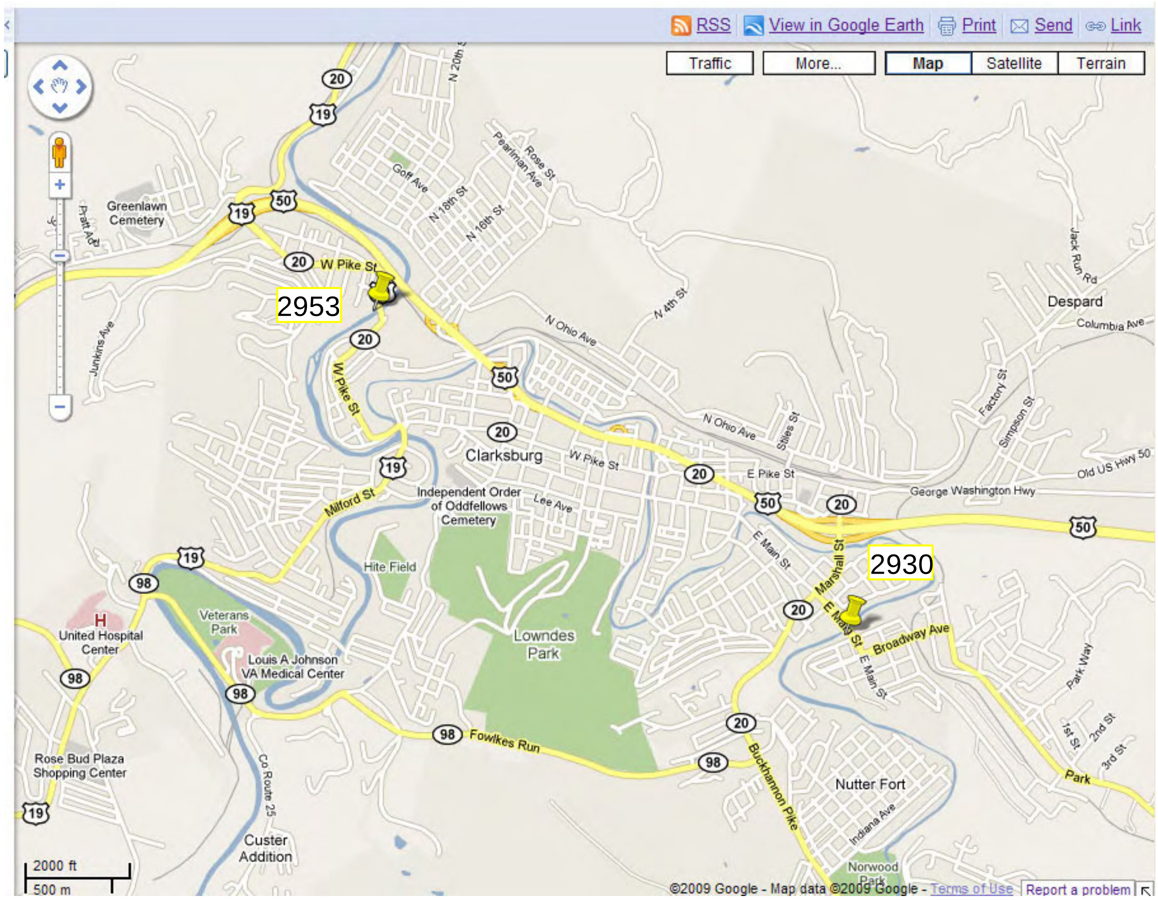
Location of Bridge Nos. 2668N, 2672N, 2672S, 2930, and 2953



Location of Bridge Nos. 2668N, 2672N, and 2672S



Location of Bridge Nos. 2930 and 2953



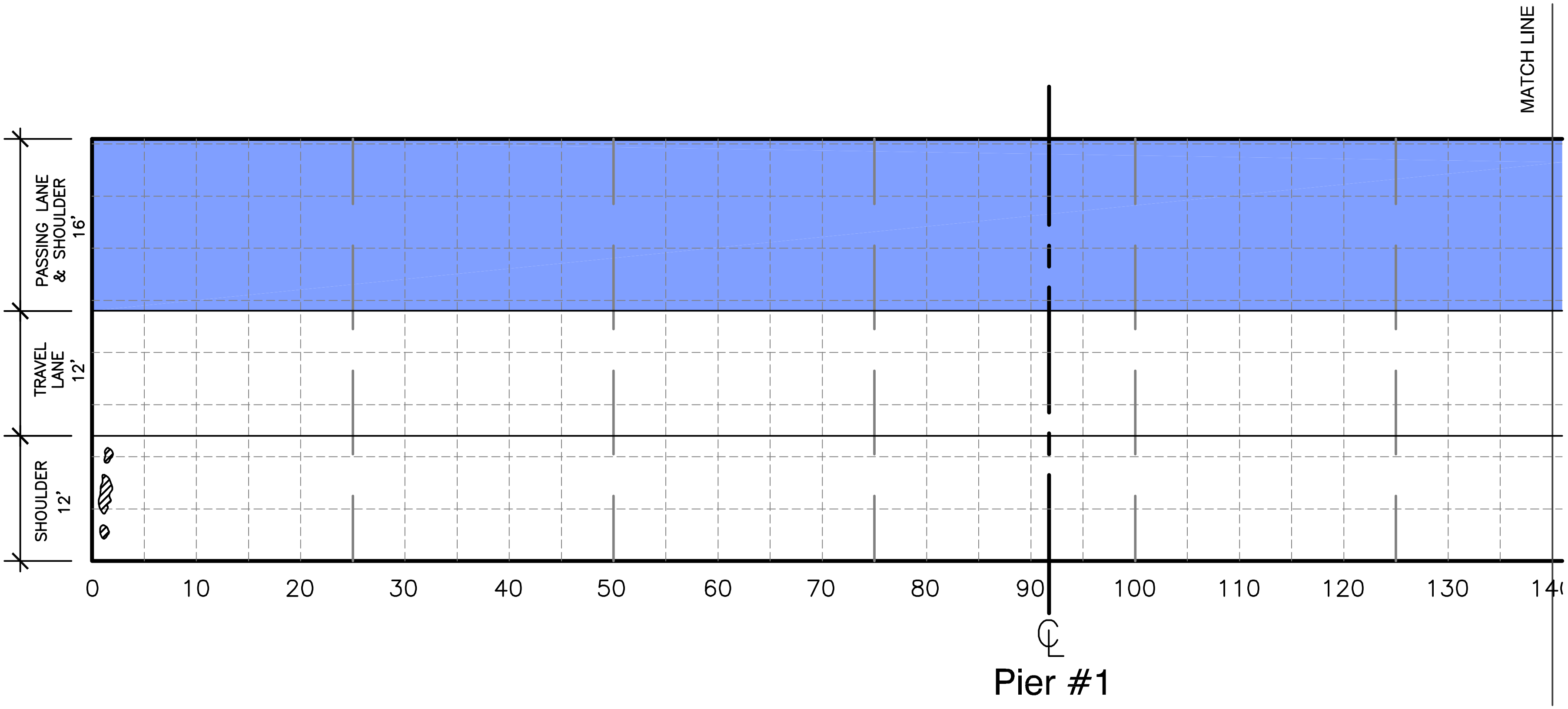
APPENDIX C - CURRENT CONDITION OF WV DECKS SURVEYED IN 1993

WV Bridge No.	WV Project No.	Reinforcing Type (U=Uncoated, ECR=Epoxy Coated)	If ECR, top mat or both?	District	Year Built	Location - feature crossed	Location - RT & milepost	Location - nearest town	Size (length, width, area)	Traffic (ADT)	Repaired/Rehabilitated? (When?/How?/Why?)	Date Repaired	Bridge Age at Repair	NBI Structure No.	Additional Identification Information	Most Recent NBI Inspection Deck Rating	Most Recent NBI Inspection Date	Any other comments?
2669	S320-79-8.48 North	U	N/A	1	1975	Little Sandy /CR 45	I-79 - Mile 8.48	Charleston	420,40,16800	10700	Overlaid in '93 -microsilica concrete - deterioration	1993	18	20A504	20-79-8.48 NB	6	6/22/2007	Two different overlay repairs used because this was part of an evaluation project
2669	S320-79-8.48 South	U	N/A	1	1975	Little Sandy /CR 45	I-79 - Mile 8.48	Charleston	420,40,16800	10700	Overlaid in '93 -microsilica concrete - deterioration	1993	18	20A505	20-79-8.48 SB	6	6/25/2007	Two different overlay repairs used because this was part of an evaluation project
2670	S320-79-9.20 North	U	N/A	1	1975	Little Sandy /CR 45	I-79 - Mile 9.20	Charleston	323,40,12900	10700	Overlaid in '93 -microsilica concrete - deterioration	1993	18	20A506	20-79-9.20 NB	6	7/3/2007	
2670	S320-79-9.20 South	U	N/A	1	1975	Little Sandy /CR 45	I-79 - Mile 9.20	Charleston	323,40,12900	10700	Overlaid in '93 -microsilica concrete - deterioration	1993	18	20A507	20-79-9.20 SB	6	7/5/2007	
2611	S350-37-30.06	U	N/A	2	*	*	*	*	*	*	*	Unknown	NA			Unknown		
2648	S323-119-19.28 North	U	N/A	2	*	*	*	*	*	*	*	Unknown	NA			Unknown		
2648	S323-119-19.28 South	U	N/A	2	*	*	*	*	*	*	*	Unknown	NA			Unknown		
2441	S317-79-115.33 North	U	N/A	4	1973	WV Route 20	M.P. 115.33 on I-79	Quiet Dell	190, 40.5, 7695	19000	LMC overlay & new joints in 1992	1992	19	17A251		5	2008	
2441	S317-79-115.33 South	U	N/A	4	1973	WV Route 20	M.P. 115.33 on I-79	Quiet Dell	190, 40.5, 7695	19000	LMC overlay & new joints in 1992	1992	19	17A252		5	2008	
2445	S317-79-117.30 North	U	N/A	4	1973	Co. Rt. 23/9, Creek	M.P. 117.30 on I-79	Anmoore	270, 40.5, 10935	19000	LMC overlay in 1992, joint repair in 1995	1992	19	17A255		5	2008	
2445	S317-79-117.30 South	U	N/A	4	1973	Co. Rt. 23/9, Creek	M.P. 117.30 on I-79	Anmoore	270, 40.5, 10935	19000	LMC overlay in 1992	1992	19	17A256		5	2008	
2446	S317-79-117.74 South	U	N/A	4	1973	WV Route 58	M.P. 117.74 on I-79	Anmoore	180, 54.4, 9792	19250	LMC overlay & new joints in 1992	1992	19	17A258		5	2008	
2446	S317-79-117.74 North	U	N/A	4	1973	WV Route 58	M.P. 117.74 on I-79	Anmoore	180, 54.4, 9792	19250	LMC overlay & new joints in 1992	1992	19	17A257		5	2008	
2520	S331-79-154.87 North	U	N/A	4	1972	Co. Rt. 19/24	M.P. 154.87 on I-79	Osage	185, 40.5, 7492	23500	LMC overlay in 1993	1993	21	31A219		5	2007	
2520	S331-79-154.87 South	U	N/A	4	1972	Co. Rt. 19/24	M.P. 154.87 on I-79	Osage	185, 54.4, 10064	23500	LMC overlay in 1993	1993	21	31A174		5	2007	
2521	S331-79-155.97 North	U	N/A	4	1972	US 19, Scotts Run	M.P. 155.97 on I-79	Pursglove	400, 40.5, 16200	14750	LMC overlay & new joints in 1992	1992	20	31A221		5	2009	
2521	S331-79-155.97 South	U	N/A	4	1972	US 19, Scotts Run	M.P. 155.97 on I-79	Pursglove	415, 40.5, 16807	14750	LMC overlay & new joints in 1992	1992	20	31A175		5	2009	
2713	S321-79-104.15 North	U	N/A	7	1971	Hackers Creek	I-79 Mile 104.15	Jane Lew	135', 40', 5468	12400	LMC overlay in 1991-Champayne Weber, delaminated	1991	20	21A128	21-79-104.15 NBL	6	12/18/2008	
2713	S321-79-104.15 South	U	N/A	7	1971	Hackers Creek	I-79 Mile 104.15	Jane Lew	135', 40', 5468	12400	LMC overlay in 1991-Champayne Weber, delaminated	1991	20	21A129	21-79-104.15 SBL	7	12/18/2008	

WV Bridge No.	WV Project No.	Reinforcing Type (U=Uncoated, ECR=Epoxy Coated)	If ECR, top mat or both?	District	Year Built	Location - feature crossed	Location - RT & milepost	Location - nearest town	Size (length, width, area)	Traffic (ADT)	Repaired/Rehabilitated? (When?/How?/Why?)	Date Repaired	Bridge Age at Repair	NBI Structure No.	Additional Identification Information	Most Recent NBI Inspection Deck Rating	Most Recent NBI Inspection Date	Any other comments?
2668	I-79-1(39)7 North	ECR	Both	1	1976	Little Sandy/CR 45	I-79 - Mile 7.38	Charleston	980, 40, 39200	10700	Overlaid in '08 -Safelane - safety concerns	2008	32	20A502	20-79-7.38 NB	5	7/25/2007	
2668	I-79-1(39)7 South	ECR	Both	1	1976	Little Sandy/CR 45	I-79 - Mile 7.38	Charleston	980, 40, 39200	10700	Overlaid in '08 -Polycard Flexgrid - safety concerns	2008	32	20A503	20-79-7.38 SB	6	4/5/2009	
2672	I-79-(38)10 North	ECR	Top	1	1976	Kan CR 53	I-79 - Mile 10.64	Charleston	175, 40, 7000	10000	No rehab thru '09	-	NA	20A508	20-79-10.64 NB	6	6/20/2007	
2672	I-79-1(38)10 South	ECR	Top	1	1976	Kan CR 53	I-79 - Mile 10.64	Charleston	175, 40, 7000	10000	No rehab thru '09	-	NA	20A509	20-79-10.64 SB	6	6/17/2007	
2673	I-79-1(38) 10 Ovrhd	ECR	Top	1	1975	I-79	Kan CR 53 - Mile 2.52	Charleston	400, 42, 17000	500	No rehab thru '09	-	NA	20A332	20-53-2.52	7	11/26/2008	
2655	RF284(12)	ECR	?	2	1976		US 52 -?	Kermit	445, 38, 17000			Unknown	NA			Unknown		
2665	BRF-0312(019)	ECR	?	2	1976		Rt 2 - ?	Huntington	584, 36, 21000			Unknown	NA			Unknown		
2768	ER-277(1) C-7	ECR	?	2	1976	Buffalo Creek	Co. 37 - ?		116, 46, 5300			Unknown	NA			Unknown		
2776	ER-277(1)C-4	ECR	?	2	1975	Buffalo Creek	Co. 37 - ?		136, 46, 6200			Unknown	NA			Unknown		
2975	BRS-0754(002)	ECR	?	2	1976		WV 37 -?	East Lynn?	172, 30, 5160			Unknown	NA			Unknown		
2930	APD 282(70)	ECR	Both	4	1974	Elk Creek, City St.	East Main Street	Clarksburg	557, 32, 17800	7000	Repaired exp. jt. & patched deck spalls in 1998	1998	24	17A912		5	2007	
2953	HRR-19-16-3657	ECR	Both	4	1975	West Fork River	US 19 - Adamson St.	Clarksburg	300, 30, 9000	6000	No deck maintenance performed to date	-	NA	17A076		5	2008	
2771	736(1)C-2	ECR	?	9	1976	New River & CSX R/R	WV 20 - 14.35	Hinton	1300, 32, 41600	8300	Deck was sealed in 1995 using Dural 335 (Ultra Low Viscosity, Penetrating Epoxy Crack Healer-Sealer)	1995	19	45A061	45-20-14.35	7	4/8/2009	No deck repairs has been done other than sealing in 1995; Dural 335 is epoxy healer-sealer
2847	BRF-0824(011)	ECR	Top	10	1976	Elkhorn Creek	US 52 - Mile 30.78	McDowell County	130, 32, 4100	5200	Overlaid in 1999 - Epoxy Urethane Copolymer O/L - ???	1999	23	24A133	24-52-30.78	7	10/6/2008	Overlay in 1999 possibly a pilot/evaluation project….can not find info in file for reason.

* District 2 survey not returned.

APPENDIX D - DELAMINATION MAPS FROM 2009 SURVEY



PLAN

SCALE: 1/16" = 1'-0"

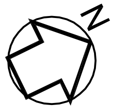
Delamination/Spall

Repair

Crack

Core

Did not survey

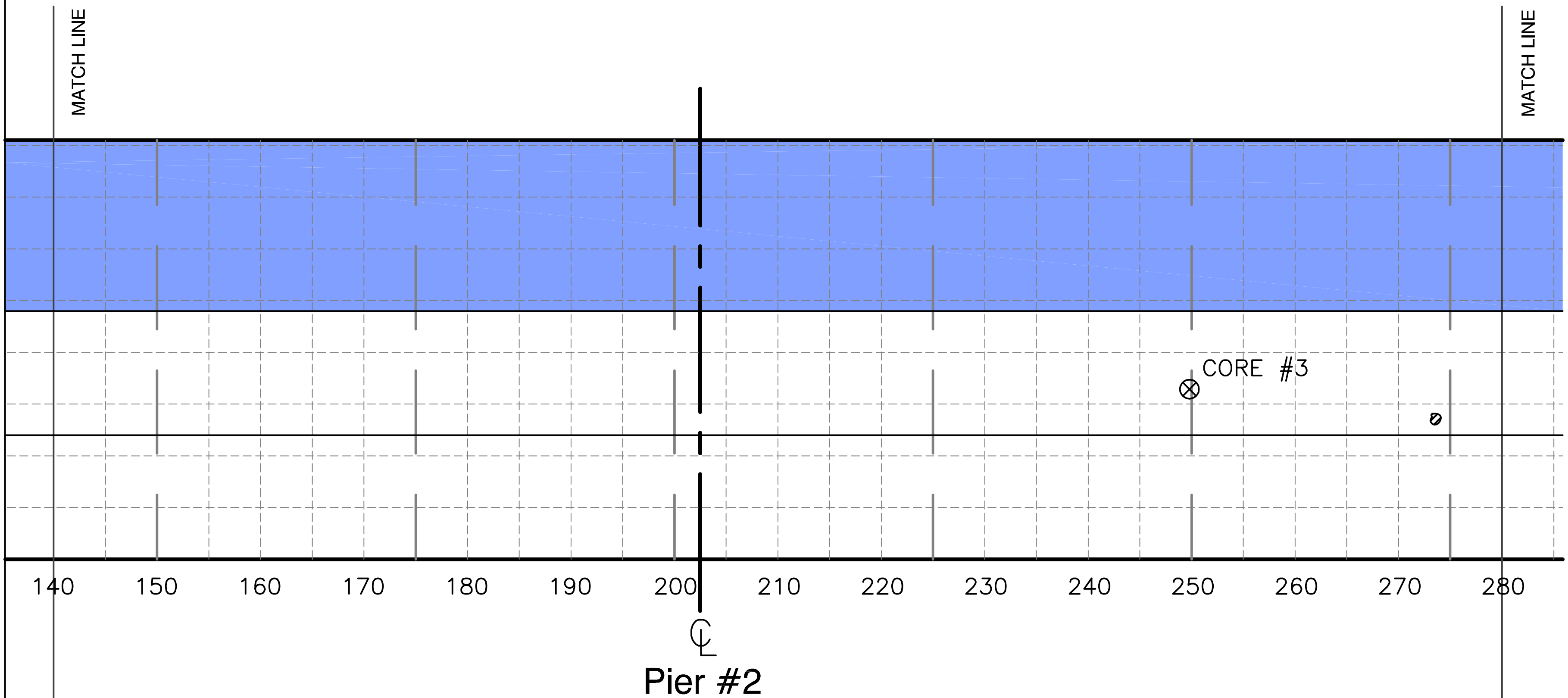


West Virginia Bridge Deck Evaluation

WV No. 2668 North Bound NBI No. 20A502

WJE
WISS, JANNEY, ELSTNER ASSOCIATES, INC.
Engineers, Architects, Material Scientists
330 PFINGSTEN ROAD
NORTHBROOK, ILLINOIS 60062
(847) 272-7400 FAX: (847) 291-4813

WJE Job No. 2007.1402
Date: 8/31/09
Recorded by: JSL
Sheet No: 1 of 8



PLAN

SCALE: 1/16" = 1'-0"

Delamination/Spall

Repair

Crack

Core

Did Not Survey

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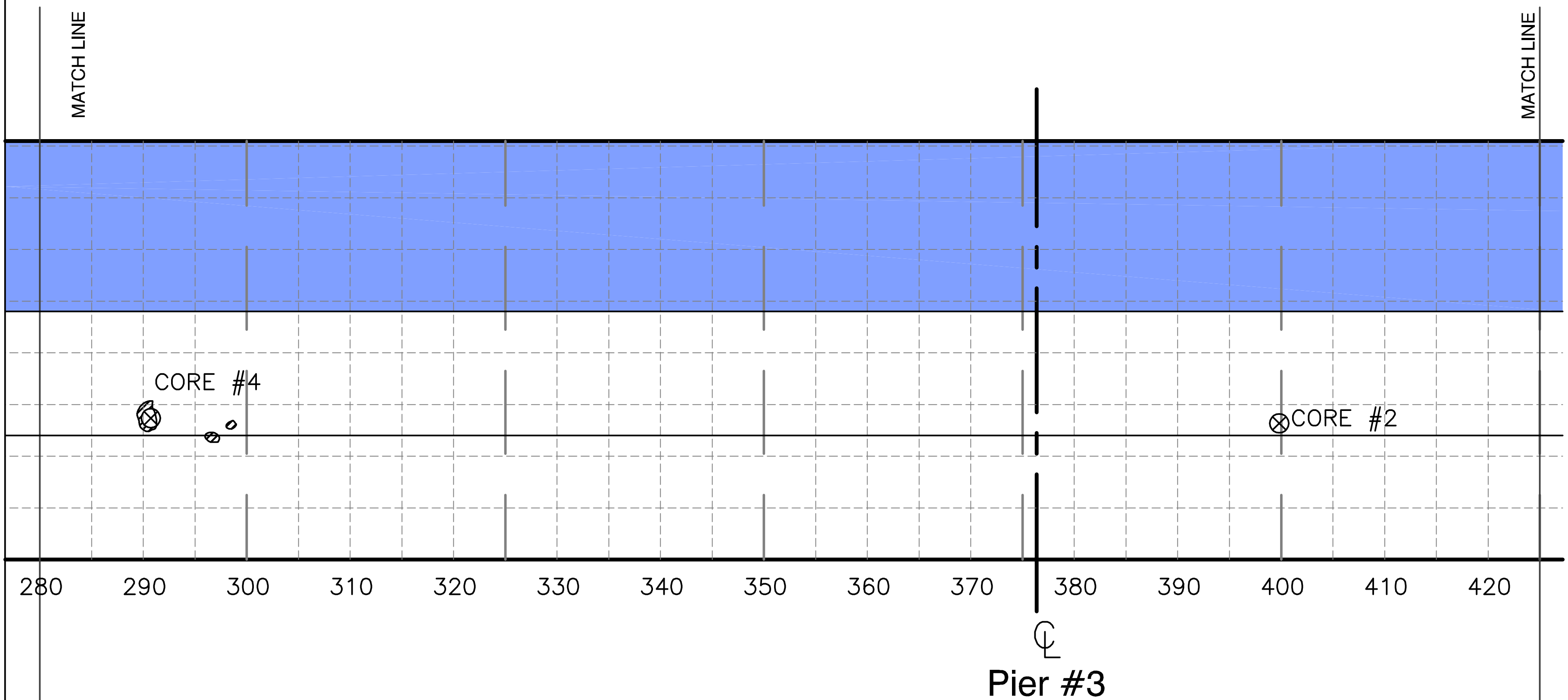


PLAN

SCALE: 1/16" = 1'-0"

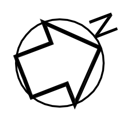
Delamination/Spall

Repair

Crack

Core

Did Not Survey



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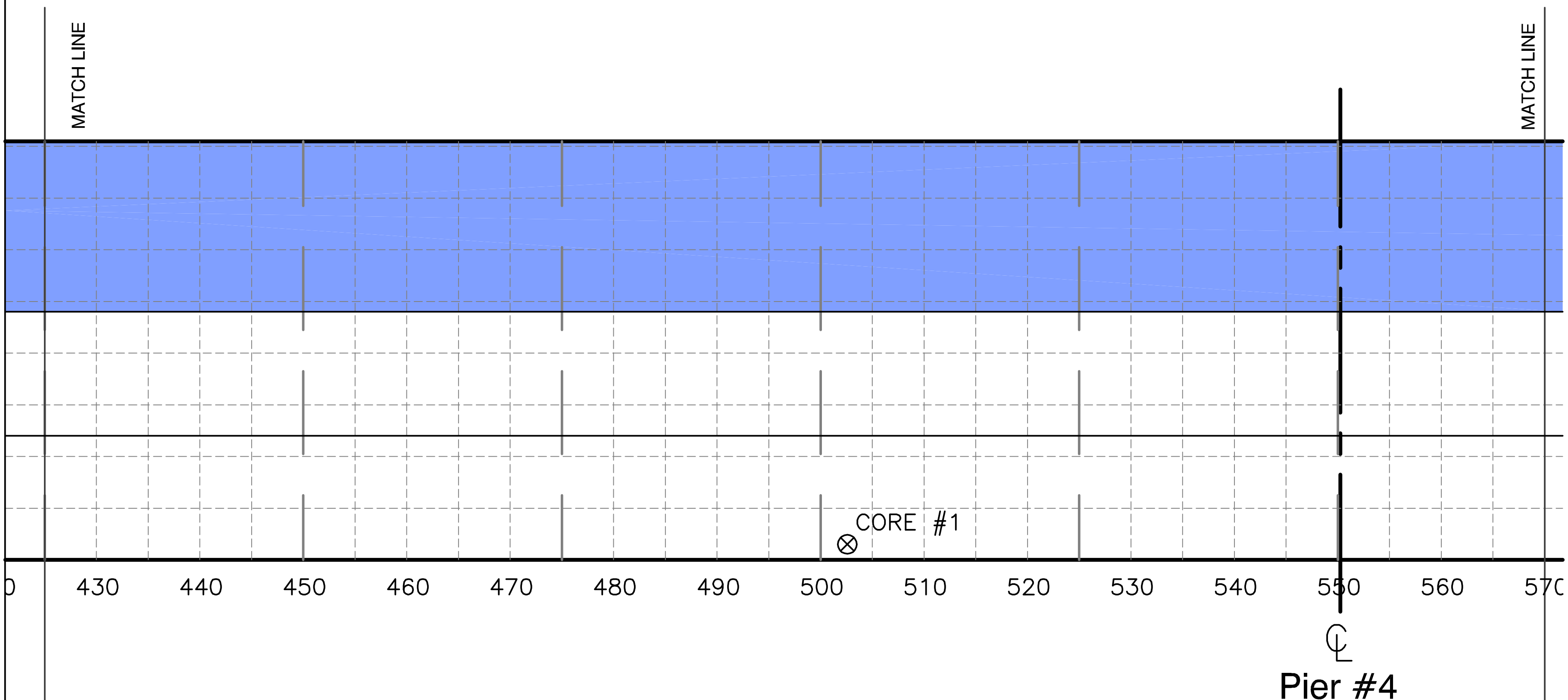

PLAN

SCALE: 1/16" = 1'-0"

Delamination/Spall

Repair

Crack

Core

Did Not Survey

West Virginia Bridge Deck Evaluation

WV No. 2668 North Bound NBI No. 20A502

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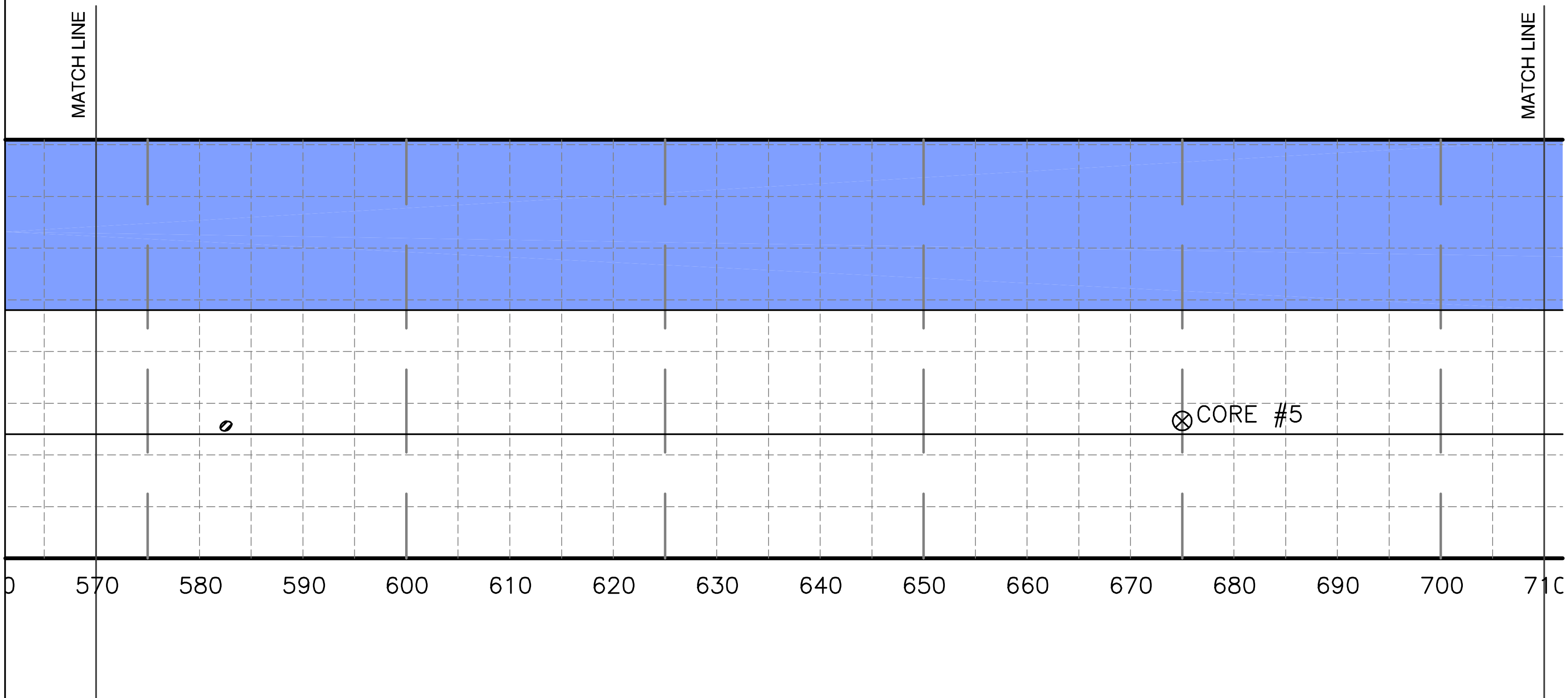
Sheet No: 4 of 8



PLAN

SCALE: 1/16" = 1'-0"

- Delamination/Spall
- Repair
- Crack
- Core
- Did Not Survey

West Virginia Bridge Deck Evaluation

WV No. 2668 North Bound NBI No. 20A502

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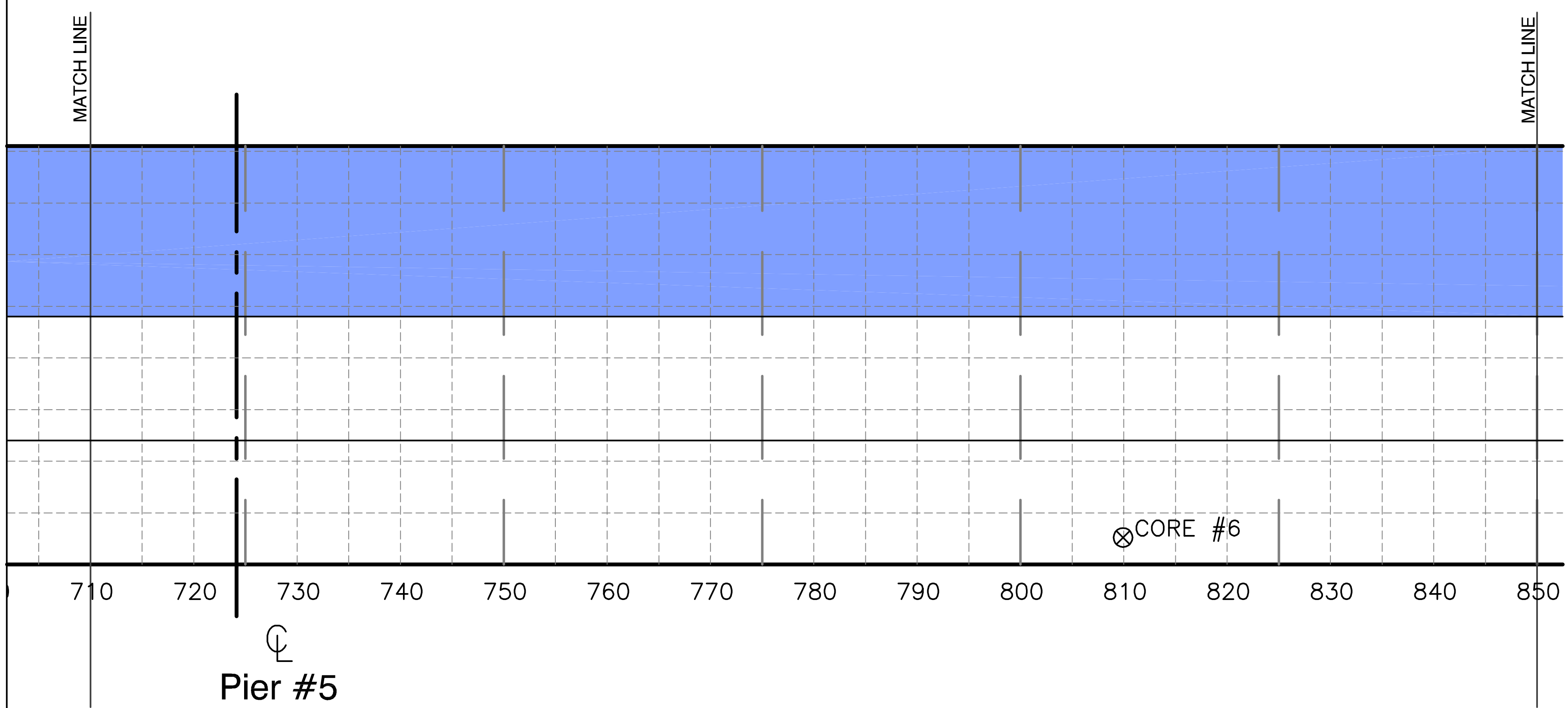

PLAN

SCALE: 1/16" = 1'-0"

Delamination/Spall

Repair

Crack

Core

Did Not Survey

West Virginia Bridge Deck Evaluation

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WJE Job No. 2007.1402
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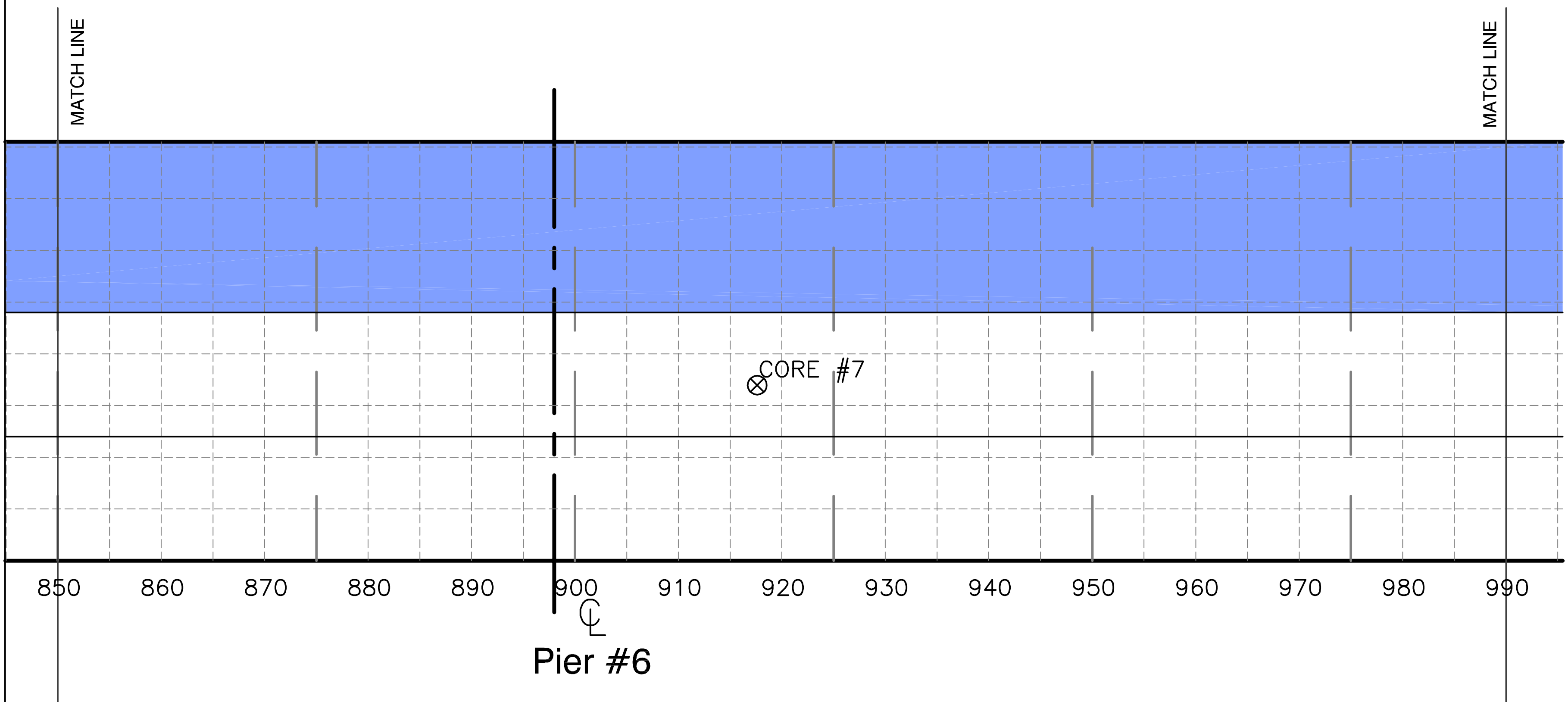
Sheet No: 6 of 8



PLAN

SCALE: 1/16" = 1'-0"

- Delamination/Spall
- Repair
- Crack
- Core
- Did Not Survey

N

West Virginia Bridge Deck Evaluation

WV No. 2668 North Bound NBI No. 20A502

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WJE Job No. 2007.1402
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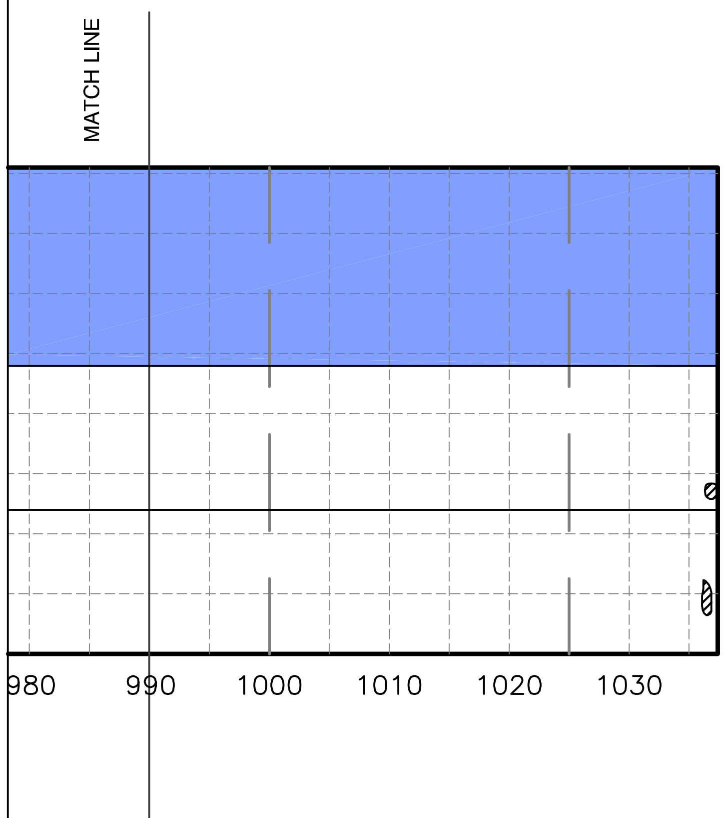
Recorded by: JSL
Sheet No: 7 of 8



PLAN

SCALE: 1/16" = 1'-0"

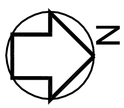
Delamination/Spall

Repair

Crack

Core

Did Not Survey



West Virginia Bridge Deck Evaluation

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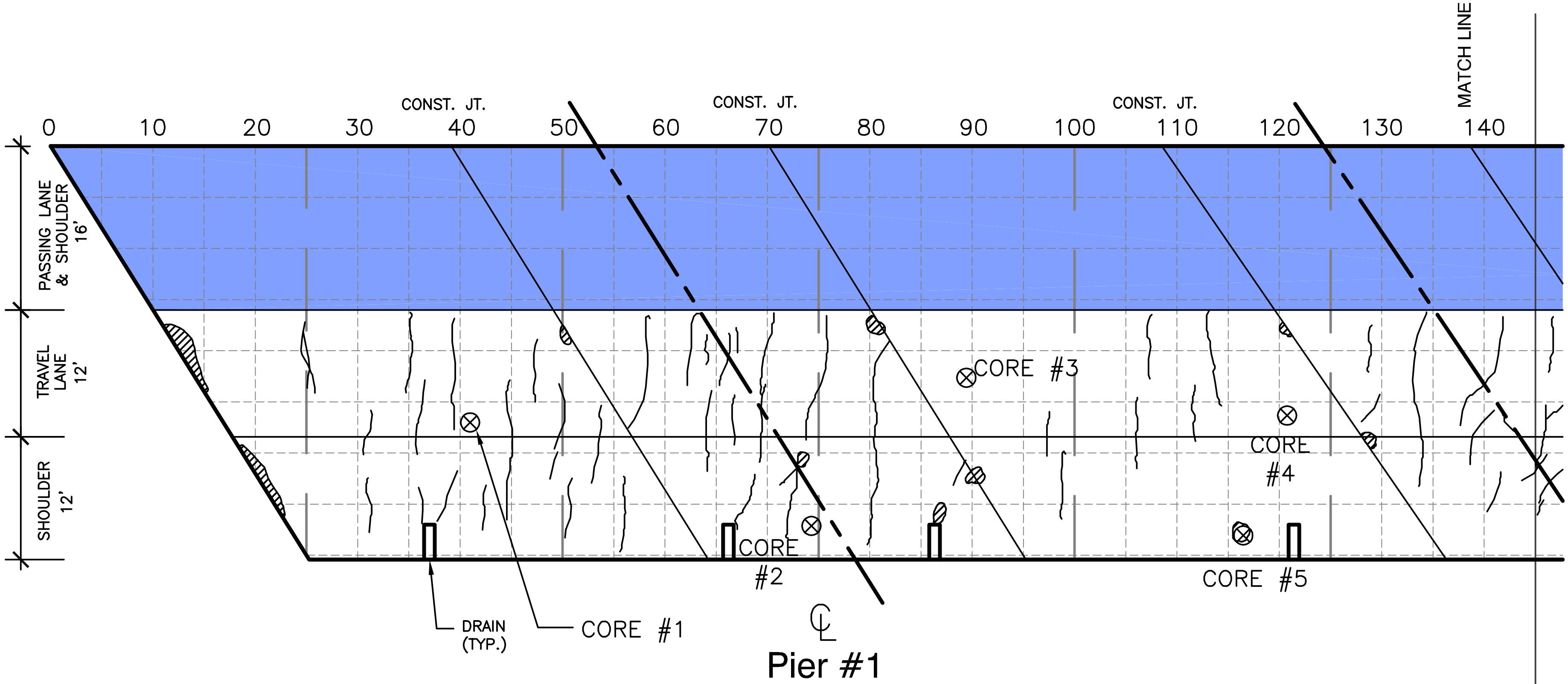
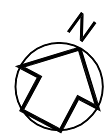


PLAN

SCALE: 1/16" = 1'-0"



Delamination/Spall

Repair

Crack

Core

Did Not Survey

West Virginia Bridge Deck Evaluation

WV No. 2672 North Bound NBI No. 20A508

WJE
WISS, JANNEY, ELSTNER ASSOCIATES, INC.
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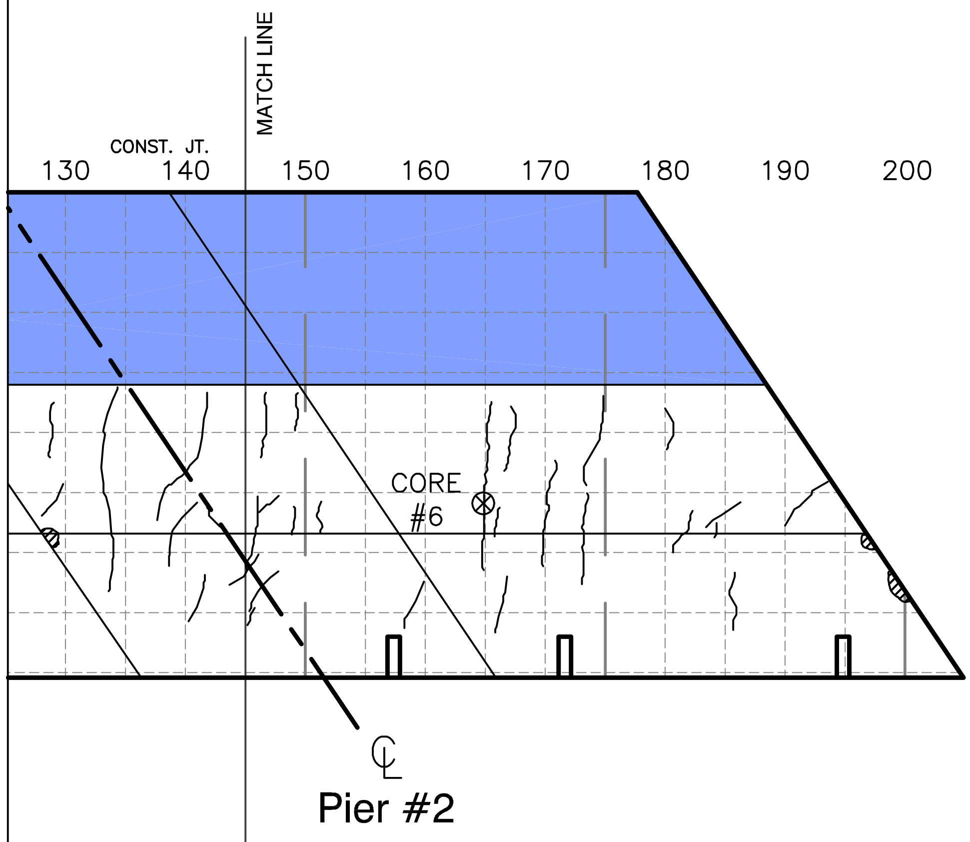
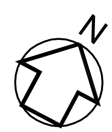
WJE Job No. 2007.1402
Date: 9/1/09
Recorded by: JSL
Sheet No: 1 of 2



PLAN

SCALE: 1/16" = 1'-0"



- Delamination/Spall
- Repair
- Crack
- Core
- Did Not Survey

West Virginia Bridge Deck Evaluation

WV No. 2672 North Bound NBI No. 20A508

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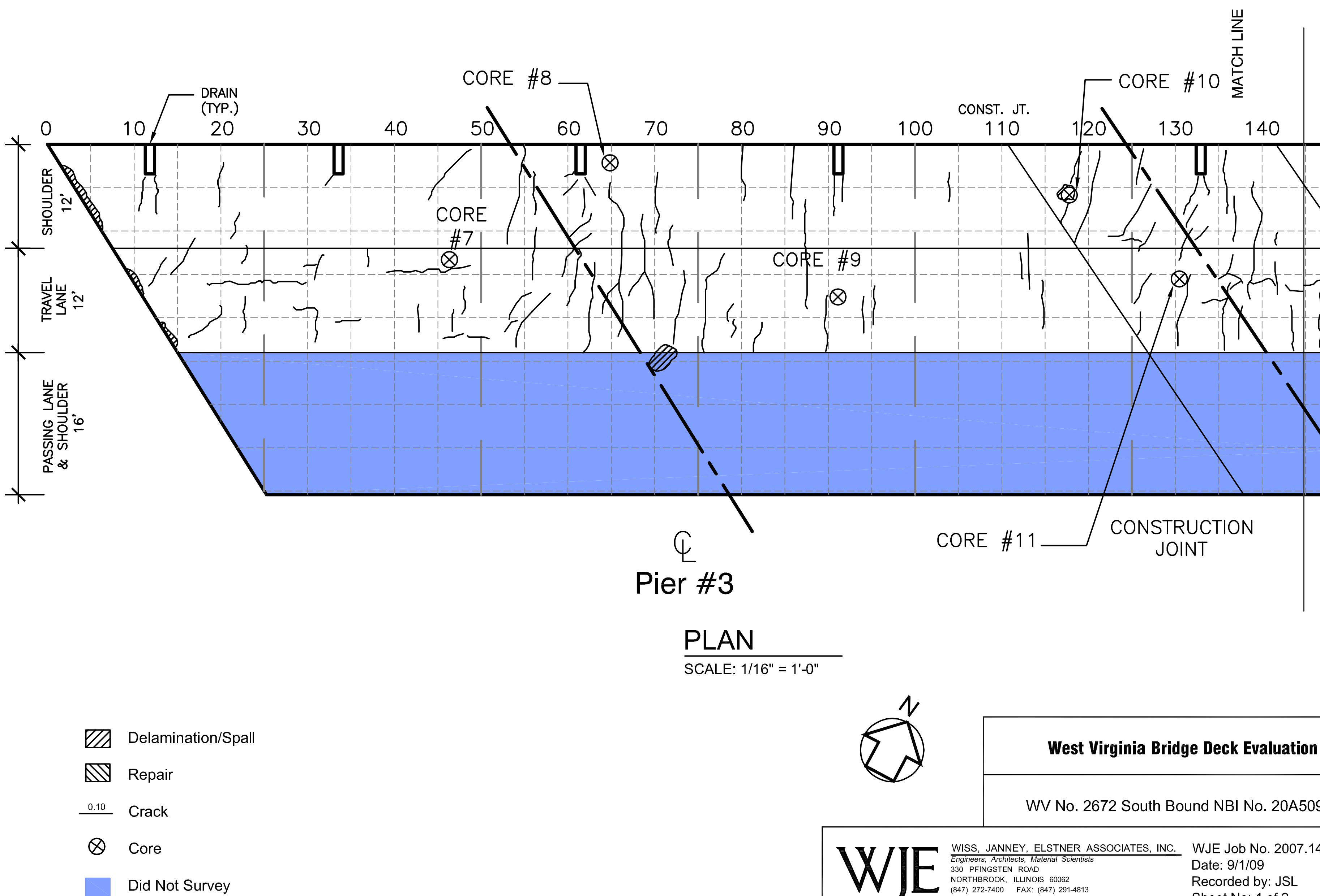
WJE Job No. 2007.1402
Date: 9/1/09
Recorded by: JSL
Sheet No: 2 of 2



West Virginia Bridge Deck Evaluation

WV No. 2672 South Bound NBI No. 20A509

WJE

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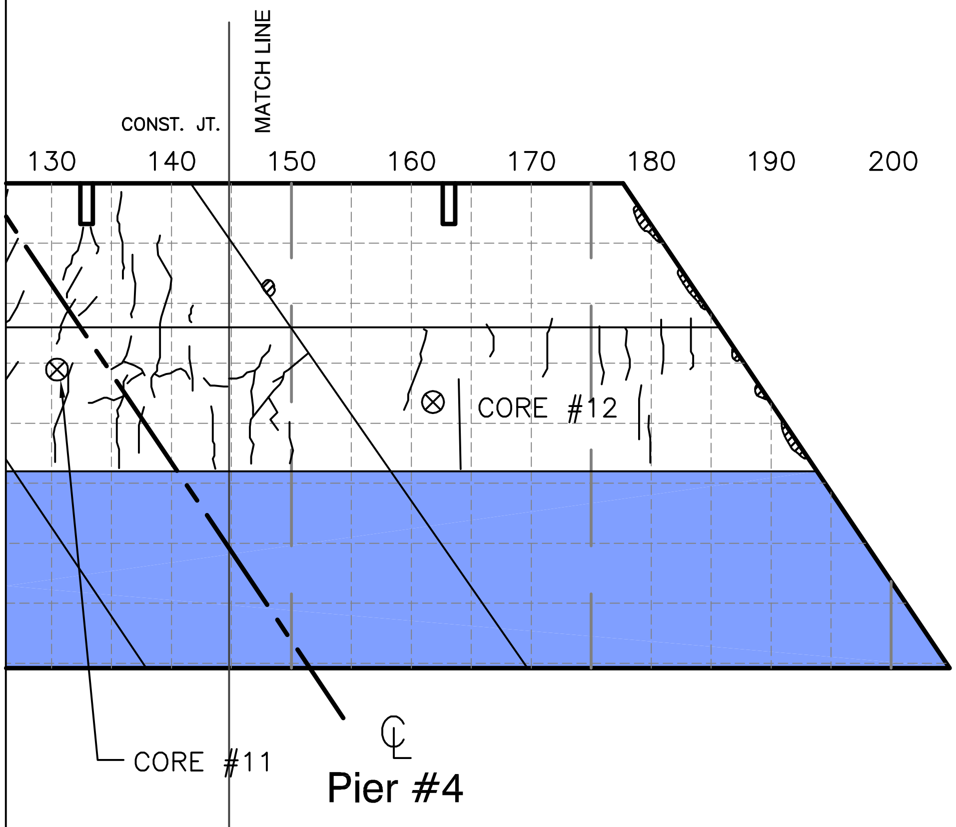
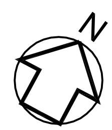


PLAN

SCALE: 1/16" = 1'-0"



	Delamination/Spall
	Repair
0.10	Crack
⊗	Core
	Did Not Survey

West Virginia Bridge Deck Evaluation

WV No. 2672 South Bound NBI No. 20A509

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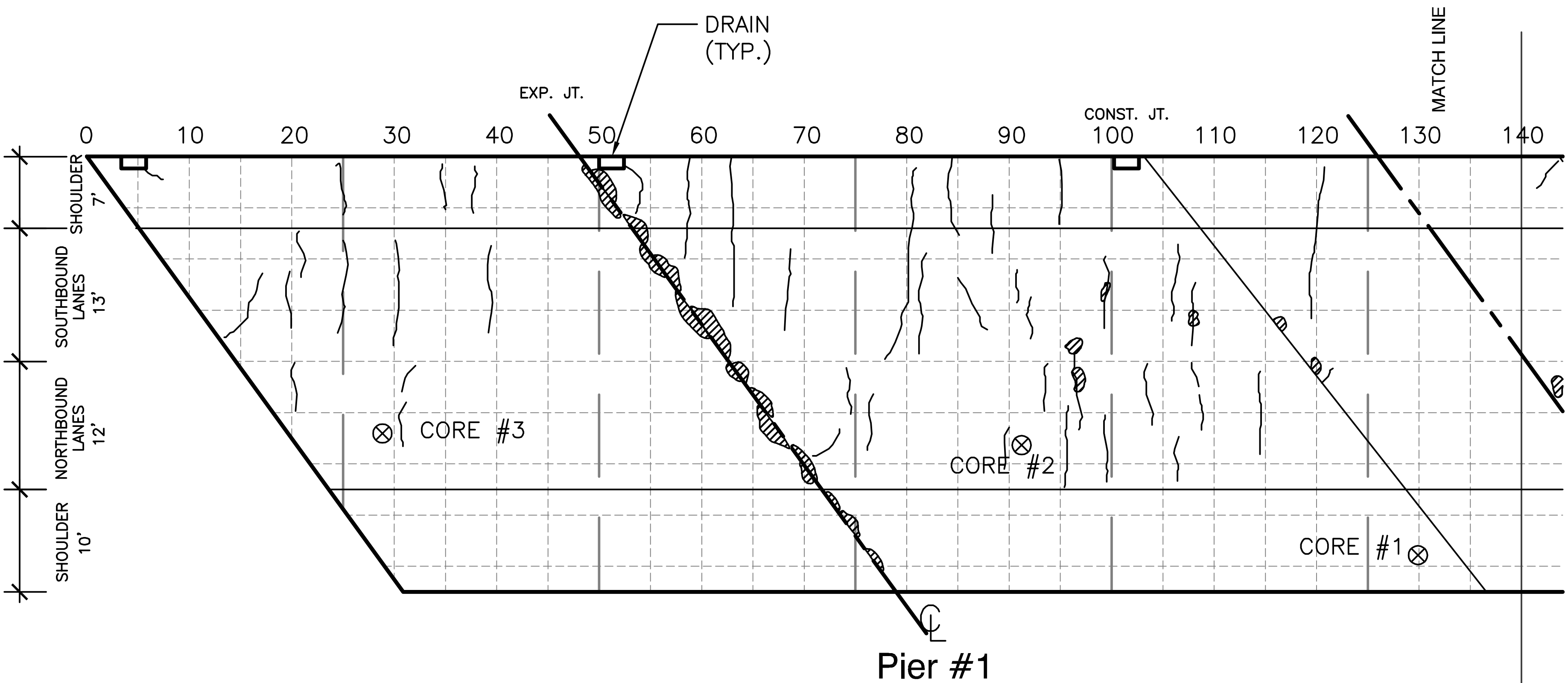
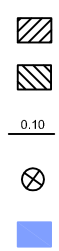
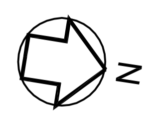


PLAN

SCALE: 1/16" = 1'-0"





West Virginia Bridge Deck Evaluation

WV No. 2673 Overhead NBI No. 20A332

WJE

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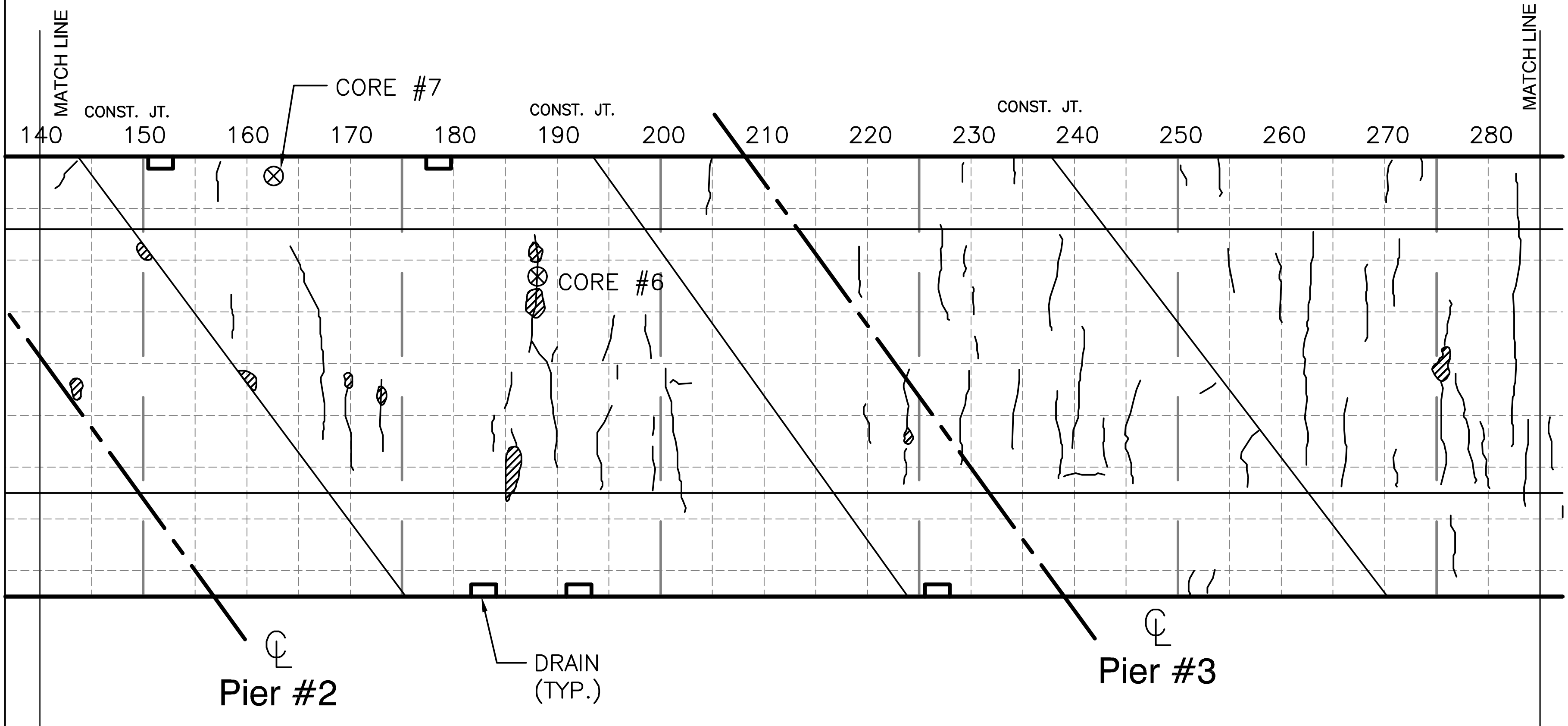
WJE Job No. 2007.1402
Date: 9/2/09
Recorded by: JSL
Sheet No: 1 of 3



PLAN

SCALE: 1/16" = 1'-0"

Delamination/Spall

Repair

Crack

Core

Did Not Survey

N

West Virginia Bridge Deck Evaluation

WV No. 2673 Overhead NBI No. 20A332

WJE

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WJE Job No. 2007.1402
Date: 9/2/09
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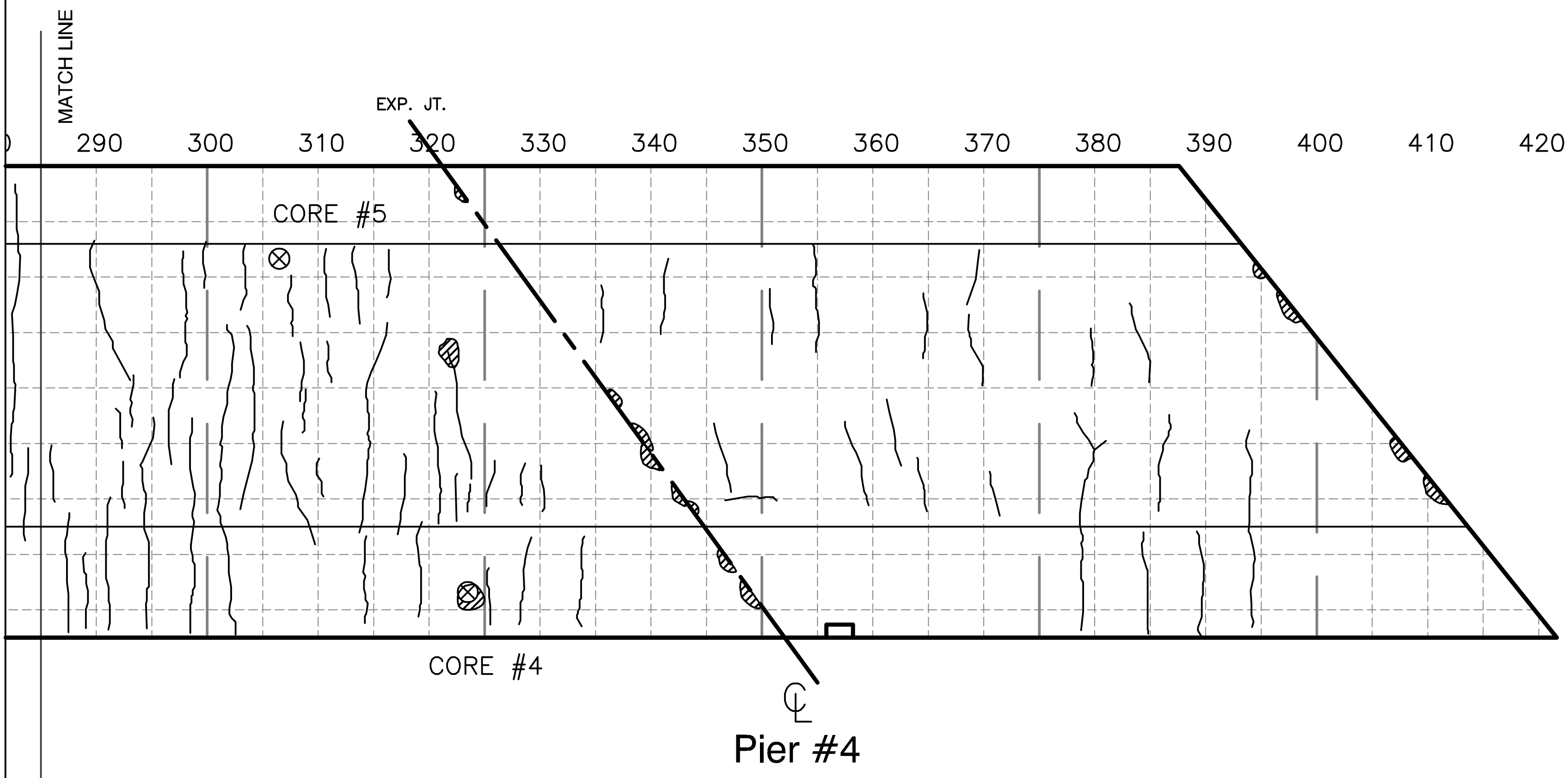
Sheet No: 2 of 3



PLAN

SCALE: 1/16" = 1'-0"

Delamination/Span

Repair

Crack

Core

Did Not Survey

West Virginia Bridge Deck Evaluation

WV No. 2673 Overhead NBI No. 20A332

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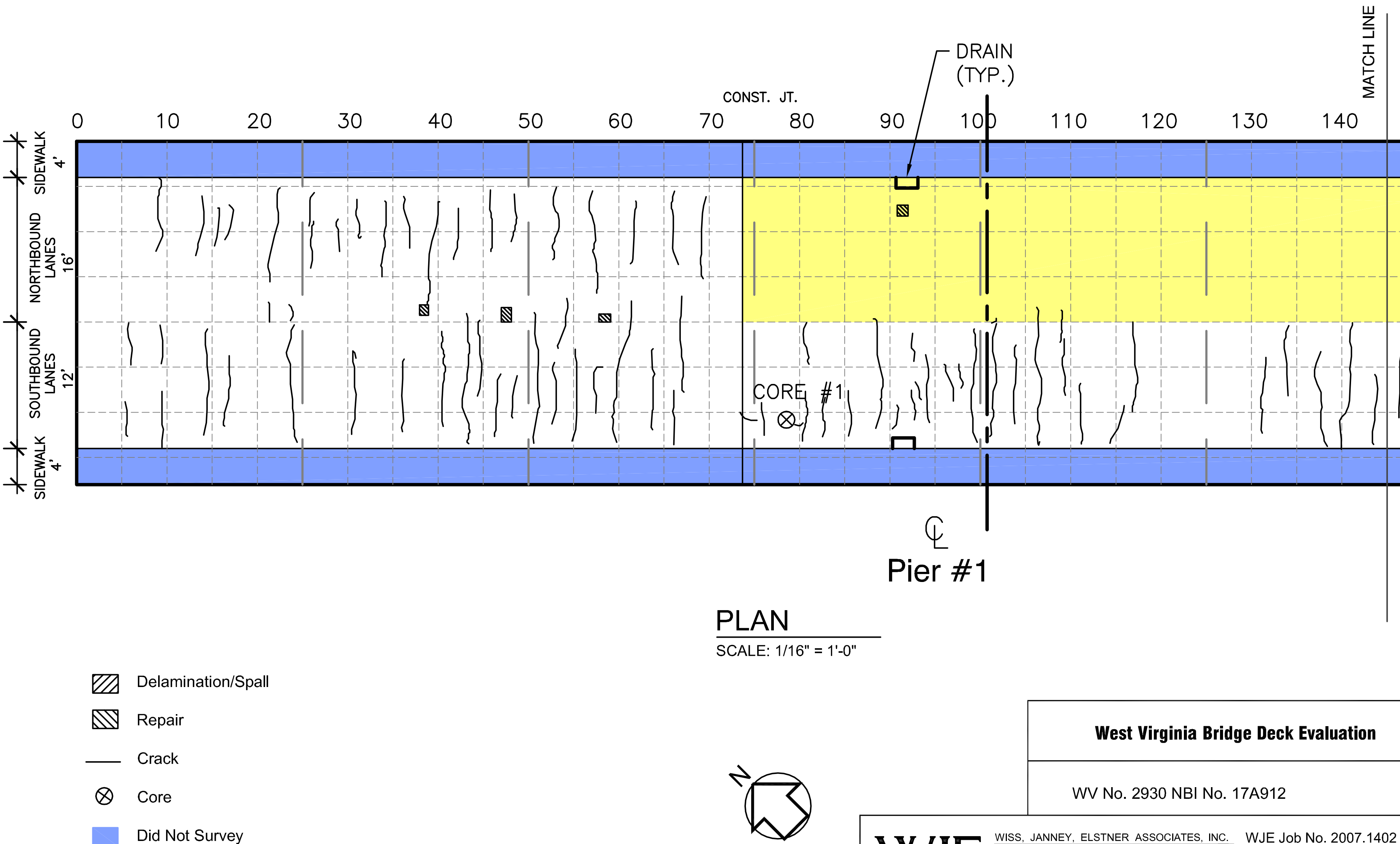
Sheet No: 3 of 3



PLAN

SCALE: 1/16" = 1'-0"

West Virginia Bridge Deck Evaluation

WV No. 2930 NBI No. 17A912

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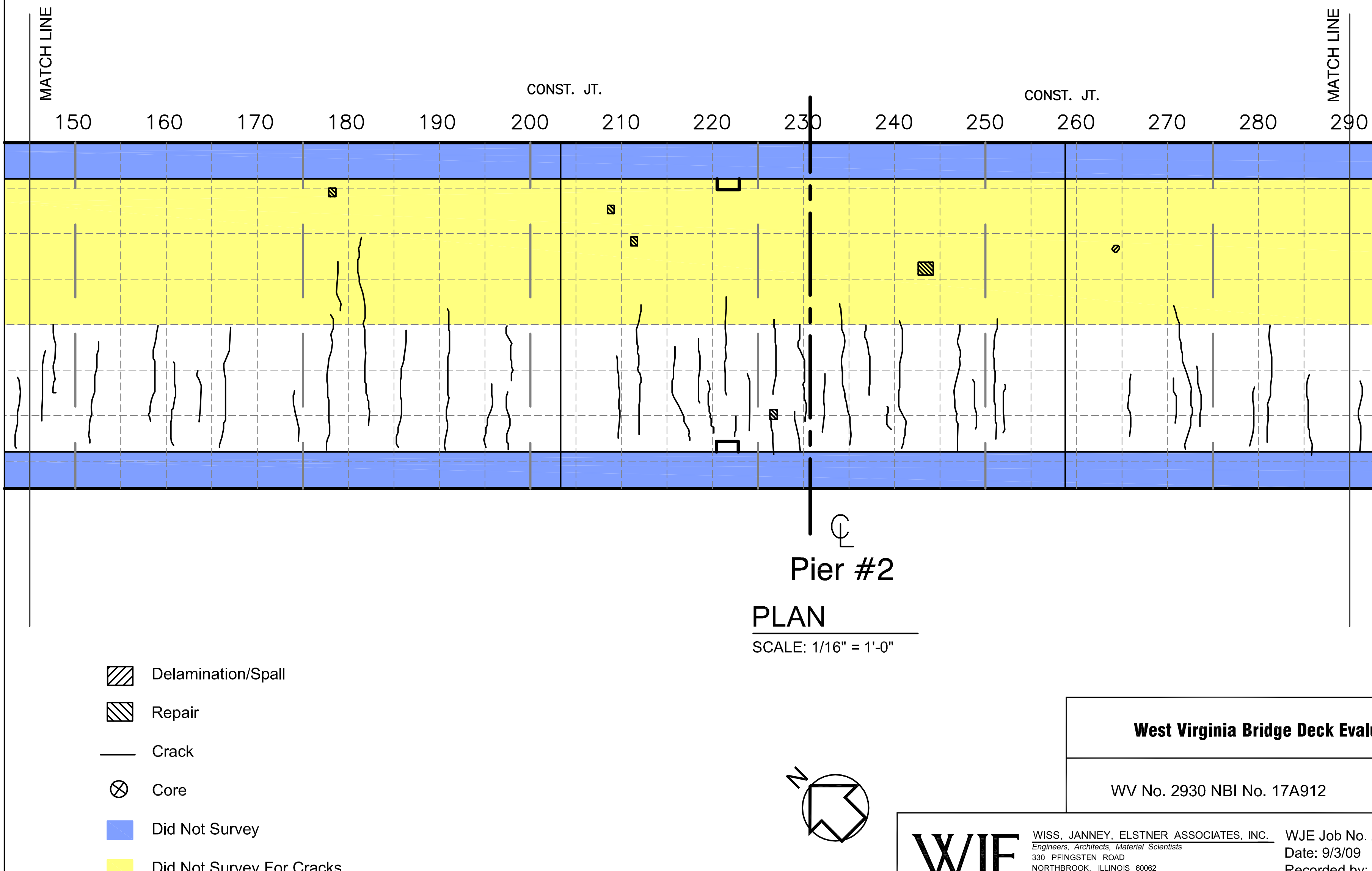
WJE Job No. 2007.1402
Date: 9/3/09
Recorded by: JSL
Sheet No: 1 of 4



PLAN

SCALE: 1/16" = 1'-0"

West Virginia Bridge Deck Evaluation

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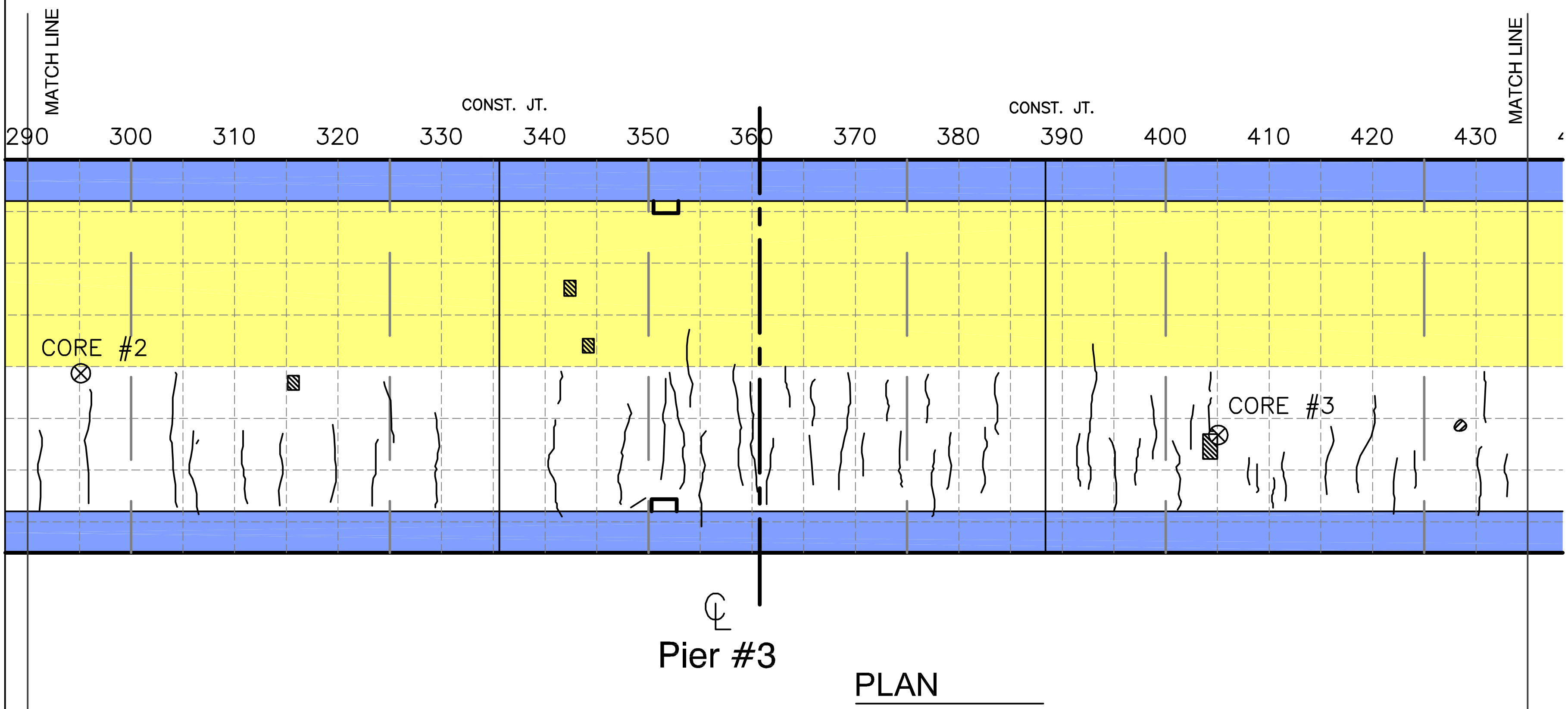

PLAN

SCALE: 1/16" = 1'-0"

- Delamination/Spall
- Repair
- Crack
- Core
- Did Not Survey
- Did Not Survey For Cracks

West Virginia Bridge Deck Evaluation

WV No. 2930 NBI No. 17A912

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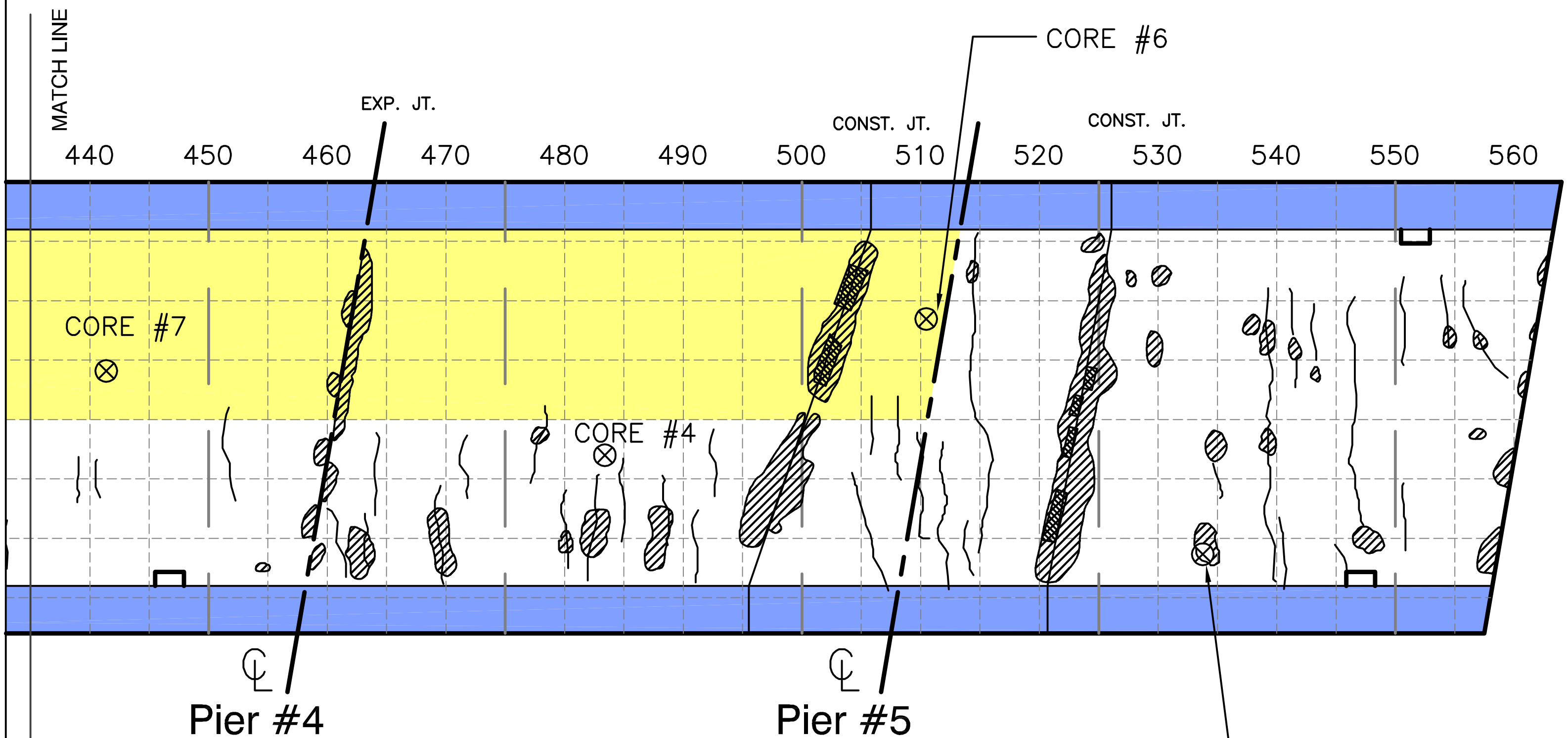

PLAN

SCALE: 1/16" = 1'-0"

- Delamination/Spall
- Repair
- Crack
- Core
- Did Not Survey
- Did Not Survey For Cracks

West Virginia Bridge Deck Evaluation

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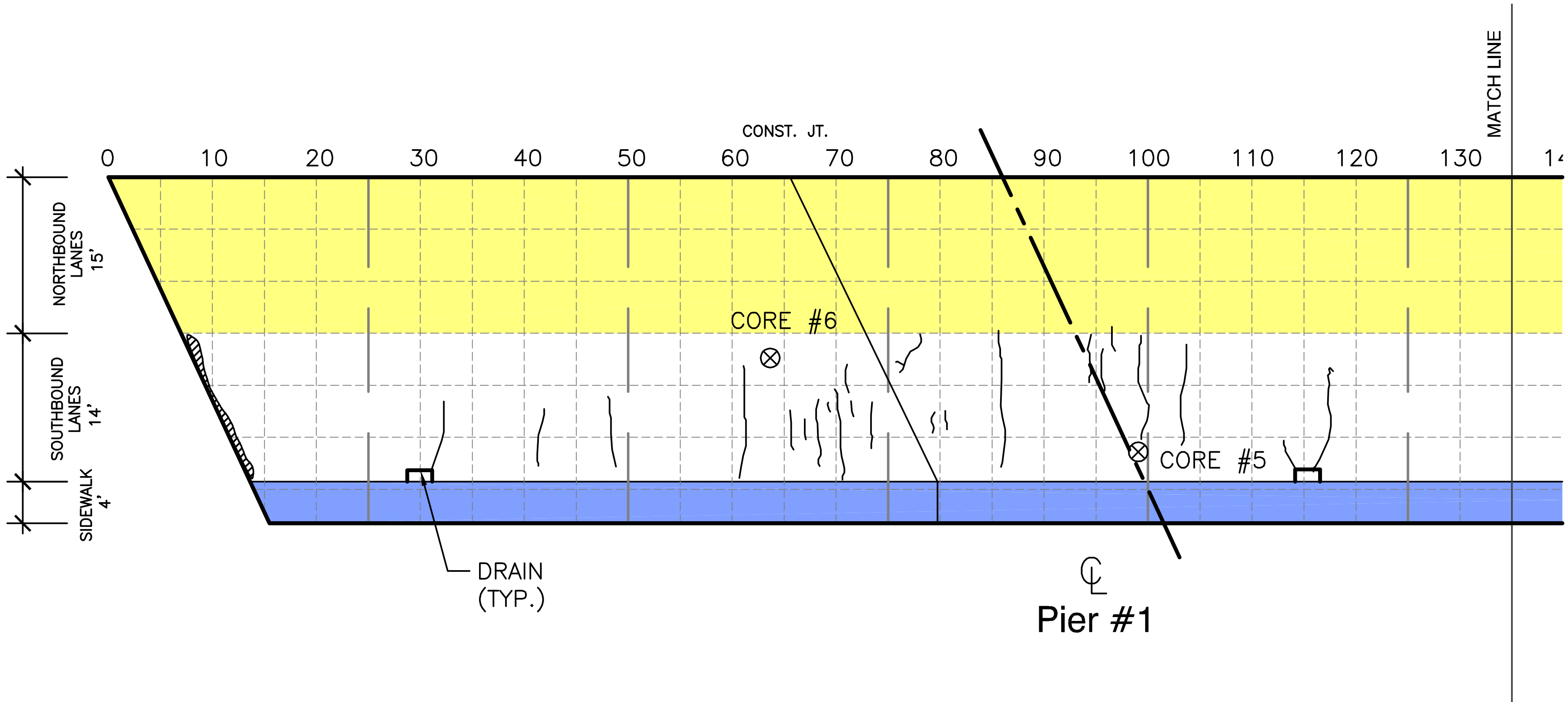
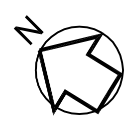


PLAN

SCALE: 1/16" = 1'-0"

- Delamination/Spall
- Repair
- Crack
- Core
- Did Not Survey
- Did Not Survey For Cracks



West Virginia Bridge Deck Evaluation

WV No. 2953 NBI No. 17A076

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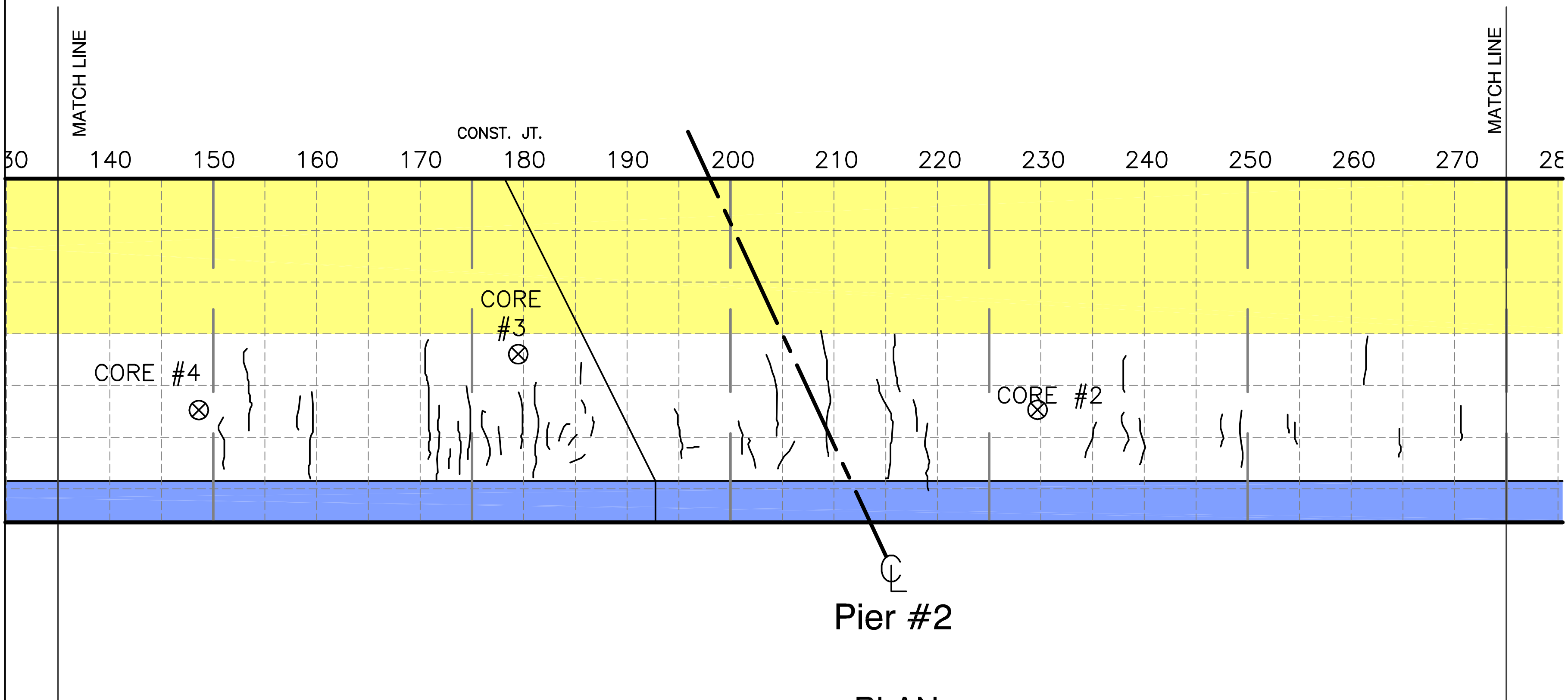
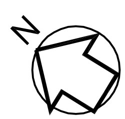
WJE Job No. 2007.1402
Date: 9/3/09
Recorded by: JSL
Sheet No: 1 of 3



PLAN

SCALE: 1/16" = 1'-0"

- Delamination/Spall
- Repair
- Crack
- Core
- Did Not Survey
- Did Not Survey For Cracks



West Virginia Bridge Deck Evaluation

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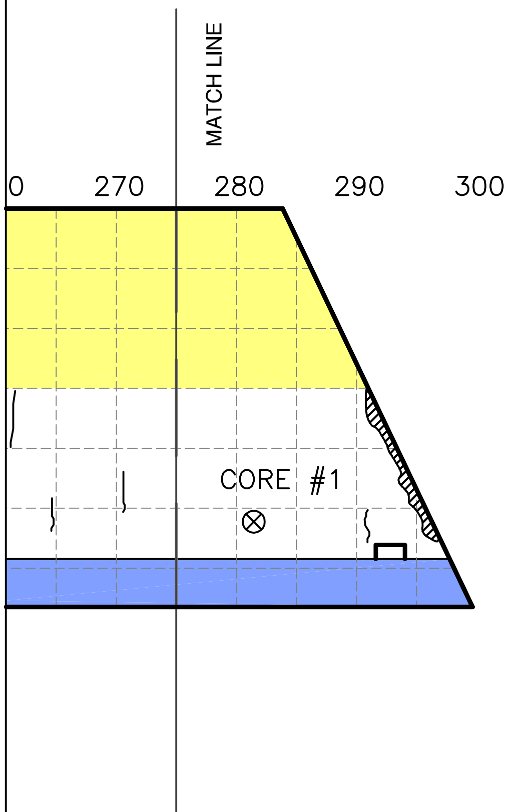

PLAN

SCALE: 1/16" = 1'-0"

- Delamination/Spall
- Repair
- Crack
- Core
- Did Not Survey
- Did Not Survey For Cracks

West Virginia Bridge Deck Evaluation

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Date: 9/3/09
Recorded by: JSL
Sheet No: 3 of 3

APPENDIX E - COVER SURVEY MADE WITH COVERMETER

Measured Cover for Bridge No. 2668N

Station from South (ft)	Distance from Outside East(ft)		
	1	9	17
1	2.7	2.6	2.3
25	2.5	2.5	2.7
50	3.0	2.9	2.8
75	2.8	2.8	2.6
100	2.9	2.8	2.7
125	3.5	2.9	2.7
150	2.7	2.5	2.9
175	3.2	2.8	2.9
200	2.8	3.2	2.7
225	3.1	2.9	2.7
250	4.2	2.7	3.1
275	3.1	2.7	2.8
300	3.0	2.1	2.2
325	3.1	2.7	2.9
350	2.9	2.3	2.5
375	2.7	2.9	2.6
400	3.0	2.8	2.5
425	3.3	3.1	2.9
450	3.2	2.6	2.9
475	3.3	2.8	2.7
500	2.8	2.8	2.8
525	3.2	2.8	2.7
550	3.2	3.1	2.9
575	3.0	2.6	2.9
600	3.0	2.8	2.9
625	3.0	2.6	2.6
650	2.9	2.3	2.8
675	2.8	2.5	2.6
700	3.7	2.4	2.8
725	2.8	2.4	2.7
750	3.0	2.4	2.8
775	2.8	2.2	2.1
800	2.6	2.3	2.5
825	2.6	2.0	2.1
850	2.3	2.2	2.3
875	2.4	2.1	1.9
900	2.1	1.7	1.8
925	2.0	2.3	2.6
950	3.2	2.9	3.0
975	2.6	2.6	2.7
1000	2.7	2.3	2.4
1025	3.0	2.4	2.6

Measured Cover for Bridge No. 2672N

Station from South (ft)	Distance from East Edge(ft)		
	1	9	17
20		1.7	2.5
40	2.7	2.5	2.8
60	2.6	2.1	2.5
80	2.4	2.8	2.7
100	2.4	2.3	2.4
120	1.9	2.5	2.0
140	2.5	2.2	2.5
160	2.7	2.2	2.5
180	2.3	2.4	2.3
200	2.5		

Measured Cover for Bridge No. 2672S

Station from South (ft)	Distance from West Edge(ft)		
	1	9	17
20	2.1	2.5	2.4
40	2.2	2.8	2.5
60	2.1	2.5	2.6
80	2.5	2.1	2.5
100	2.7	2.6	2.3
120	2.6	2.2	2.6
140	2.5	2.7	2.3
160	2.2	2.2	2.7
180	2.2	2.3	2.6

Measured Cover for Bridge No. 2673

Station from South (ft)	Distance from West Edge(ft)					
	1	9	17	25	33	41
0	2.9					
25	2.3	2.2	2.3	2.0	2.7	
50	2.1	2.4	2.2	2.4	2.3	2.4
75	2.2	2.0	1.8	2.1	1.7	3.0
100	2.2	2.0	1.8	2.0	2.1	2.2
125	2.5	2.2	2.2	1.8	2.2	2.5
150	2.1	2.1	2.0	2.0	2.1	2.2
175	2.3	2.2	2.3	2.4	2.4	2.6
200	2.9	2.0	2.0	1.9	2.1	2.9
225	3.0	2.2	2.4	2.1	2.1	2.0
250	2.7	2.2	2.1	2.4	2.5	2.8
275	2.5	2.5	2.5	2.5	2.2	2.2
300	2.6	2.2	2.2	2.5	2.3	2.5
325	2.4	2.0	2.2	2.3	2.1	2.2
350	2.9	2.1	1.7	2.0	2.2	2.2
375	2.7	2.4	2.1	2.3	2.2	2.3
400				2.4	2.0	2.2

Measured Cover for Bridge No. 2930

Station from North (ft)	Distance from West Edge(ft)	
	3	10
1	2.4	2.4
25	2.2	2.5
50	2.3	2.6
75	2.0	1.9
100	2.6	2.2
125	2.3	2.2
150	3.0	2.2
175	2.8	2.8
200	2.6	2.4
225	2.5	2.4
250	2.3	2.5
275	2.1	2.2
300	2.6	2.6
325	2.3	2.3
350	2.5	2.5
375	2.5	2.4
400	2.7	2.6
425	2.9	2.8
450	2.2	2.6
475	2.9	2.5
500	2.6	1.9
525	2.2	1.7
550	2.1	2.4

Measured Cover for Bridge No. 2953

Station from North (ft)	Distance from West Edge(ft)	
	3	10
20	2.4	1.5
40	2.3	1.9
60	2.3	1.7
80	2.6	2.2
100	1.8	1.8
120	2.1	2.2
140	2.3	2.0
160	2.2	1.8
180	2.4	2.2
200	2.2	2.1
220	2.0	1.9
240	2.1	2.3
260	2.1	2.3
280	2.0	2.1
300	2.3	

APPENDIX F - CHLORIDE PROFILES IN CORES

Acid-soluble chloride in nominally ¼-in. slices from cores from Bridge No. 2668

Core ID	**1**		**2**		**3**		**5**		**6**		**7**	
Property	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)
Slice 1	0.421	0.342	0.294	0.436	0.381	0.380	0.419	0.440	0.301	0.345	0.331	0.256
Slice 2	1.194	0.154	1.086	0.246	1.239	0.213	0.799	0.343	1.101	0.223	1.159	0.202
Slice 3	1.909	0.067	2.216	0.010	2.416	0.032	1.224	0.215	1.501	0.148	1.549	0.151
Slice 4	3.599	0.060	3.611	0.004	3.844	0.006	2.186	0.007	3.539	0.005	3.819	0.004
Slice 5	4.879	0.034	4.984	0.004							4.949	0.003

Acid-soluble chloride in nominally ¼-in. slices from cores from Bridge No. 2672N

Core ID	**1**		**2**		**3**		**4**		**5**		**6**	
Property	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)
Slice 1	0.501	0.289	0.426	0.281	0.446	0.296	0.496	0.314	0.431	0.340	0.426	0.304
Slice 2	1.281	0.051	1.131	0.146	1.259	0.154	1.274	0.213	0.826	0.379	1.226	0.204
Slice 3	2.184	0.006	2.616	0.008	2.026	0.055	1.964	0.156	1.234	0.227	1.644	0.181
Slice 4	3.634	0.007	3.996	0.004	3.381	0.008	3.339	0.059	3.456	0.059	3.246	0.065
Slice 5	5.384	0.008			5.239	0.007			5.289	0.013		

Acid-soluble chloride in nominally ¼-in. slices from cores from Bridge No. 2672S

Core ID	7		8		9		10		11		12	
Property	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)
Slice 1	0.381	0.365	0.481	0.225	0.466	0.328	0.471	0.521	0.501	0.276	0.391	0.301
Slice 2	1.109	0.225	1.214	0.164	1.196	0.168	1.226	0.324	1.216	0.160	1.154	0.145
Slice 3	2.529	0.022	2.066	0.121	2.049	0.053	1.859	0.254	1.571	0.161	2.329	0.029
Slice 4	3.836	0.005	3.436	0.073	3.499	0.005	3.511	0.169	3.821	0.021	3.929	0.006
Slice 5	5.394	0.004			5.299	0.004			5.049	0.005		

Acid-soluble chloride in nominally ¼-in. slices from cores from Bridge No. 2673

Core ID	1		2		3		5		6		7	
Property	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)
Slice 1	0.529	0.082	0.454	0.252	0.454	0.226	0.466	0.183	0.454	0.287	0.529	0.159
Slice 2	1.336	0.007	1.249	0.094	1.211	0.127	1.166	0.084	1.261	0.230	1.299	0.101
Slice 3	2.221	0.003	1.624	0.038	1.581	0.071	1.534	0.037	1.739	0.199	2.181	0.033
Slice 4	3.811	0.003	3.944	0.006	3.141	0.002	3.111	0.003	3.416	0.099	3.781	0.005
Slice 5	4.979	0.003			5.059	0.003	5.249	0.003	4.944	0.036		

Acid-soluble chloride in nominally ¼-in. slices from cores from Bridge No. 2930

Core ID	1		2		4		5		6		7	
Property	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)
Slice 1	0.508	0.392	0.433	0.406	0.546	0.324	0.544	0.414	0.474	0.385	0.639	0.472
Slice 2	1.476	0.187	1.359	0.227	1.791	0.052	1.461	0.298	1.289	0.276	1.454	0.281
Slice 3	1.984	0.145	2.034	0.144	2.440	0.005	2.239	0.231	1.994	0.209	2.151	0.237
Slice 4	3.911	0.014	3.972	0.032	3.906	0.005	3.656	0.142	4.144	0.005	3.889	0.074
Slice 5	5.051	0.004			5.213	0.003					5.234	0.011

Acid-soluble chloride in nominally ¼-in. slices from cores from Bridge No. 2953

Core ID	1		2		3		4		5		6	
Property	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)	Mid-depth (in.)	Chloride (% by wt. conc.)
Slice 1	0.376	0.355	0.431	0.380	0.476	0.399	0.666	0.385	0.441	0.476	0.446	0.383
Slice 2	1.141	0.240	1.214	0.259	1.204	0.257	0.911	0.334	1.214	0.392	1.249	0.254
Slice 3	1.489	0.151	1.646	0.206	1.764	0.180	1.306	0.285	1.581	0.305	1.601	0.204
Slice 4	3.394	0.004	3.964	0.027	3.551	0.027	3.066	0.093	3.386	0.097	3.166	0.021
Slice 5					5.039	0.003			4.654	0.033	4.959	0.004