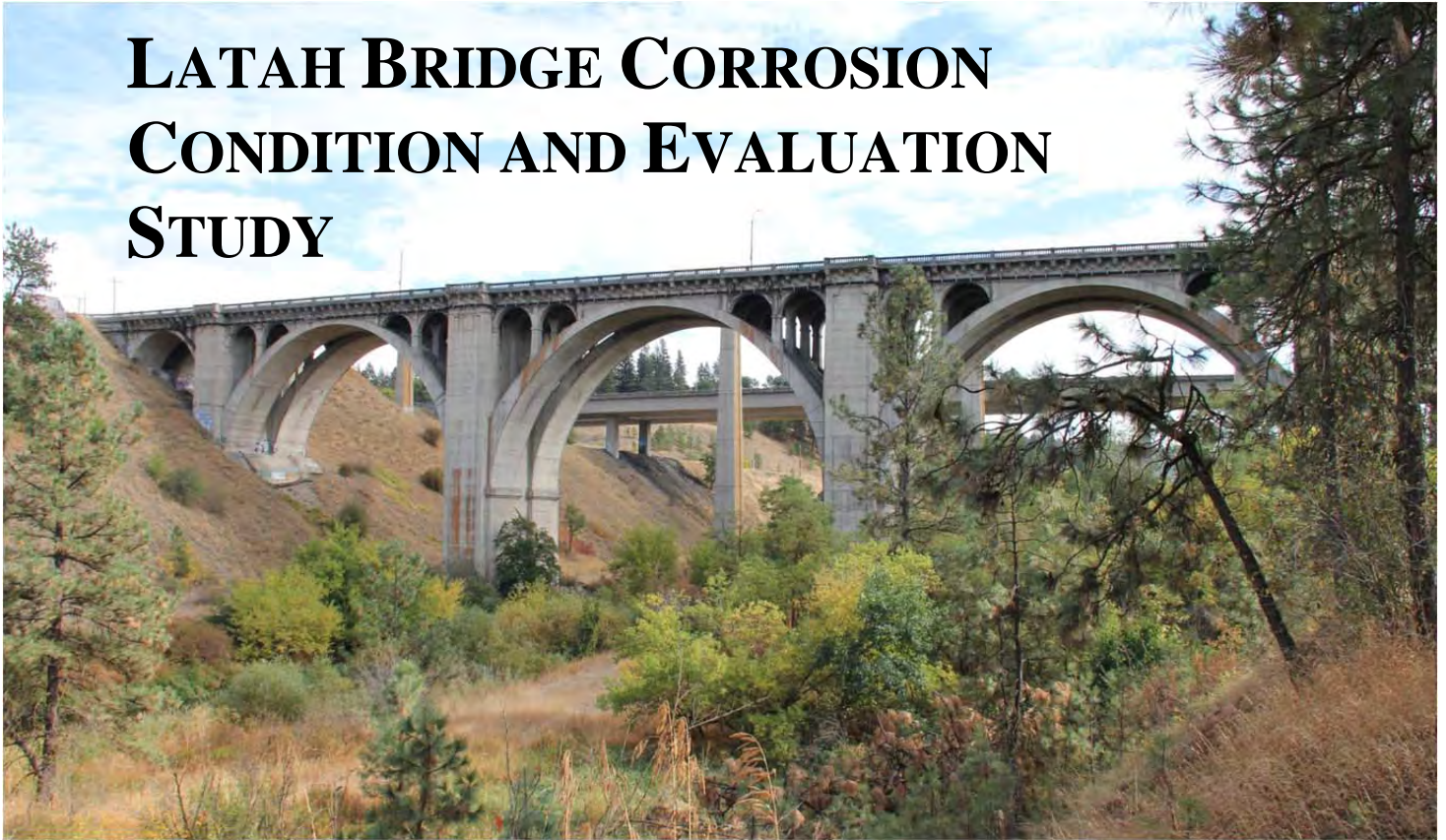


Appendix D

Corrosion Testing and Analysis Results

CITY OF SPOKANE, WASHINGTON

LATAH BRIDGE CORROSION CONDITION AND EVALUATION STUDY



Prepared for:



P. O. Box 8748 ♦ Boise, Idaho 83707-2748

Prepared by:



7821 South 700 East ♦ Sandy, Utah 84092

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Executive Summary

Rehabilitation and preservation of the Latah Bridge is recommended to assure public safety and extend the life of this historic and aesthetic bridge. Corrosion mitigation alternatives for rehabilitation can preserve the appearance of Latah Bridge, while minimizing maintenance.

A field survey was performed to assess the extent and degree of reinforcement corrosion activity, identify specific areas of concern. Based on the field condition assessment, a majority of the exposed bridge substructure is in good to fair condition, while sheltered areas of the bridge substructure were in good to very good condition.

Exposed areas in fair condition were subject to water runoff that primarily affected the corbels, spandrel wall columns, spandrel columns, and pier faces. Water runoff from the spandrel columns also affected the arch ribs resulting in highly localized corrosion activity, but very limited concrete disbondment. The arch ribs would be classified as good to very good condition, with the top and exterior surfaces of the arch rib having a slightly greater corrosion risk than the sheltered portions of the arch rib.

The most significant corrosion activity was observed on the deck rails, exterior corbels and walls, and spandrel columns. These locations were exposed to wetting and drying conditions from frequent water runoff, sometimes with chlorides present. Under wetting and dry conditions, carbonation of the concrete and chloride penetration is increased both in rate and depth.

Chloride and concrete disbondment testing on Latah Bridge was performed by others and their reports were reviewed for this corrosion condition assessment. A significant observation on the chloride content of the structure was that corrosive thresholds of chlorides had penetrated to the reinforcement level at only 25 percent of the powder sample locations. Areas of high chlorides at the reinforcement level were identified on the Spandrel columns, spandrel wall, and pier, which corresponds with areas of water runoff previously described. Of the twelve powder sample locations, five exhibited corrosive levels of chlorides at the 0.5 inch depth and only three at the 1.5 inch depth for concrete reinforcement cover.

Concrete disbondment was very limited considering the quantity of area impacted by water runoff. Most of the concrete disbondment was associated with limited depth of cover over the reinforcement, areas of honeycombing, and chamfered corners with reduced concrete cover. Bottom of floor beams were also found to have extensive disbondment, especially where water leakage was occurring, such as inside the piers at manholes and drains. Sheltered areas under the bridge were in very good condition with limited disbondment because of protection from water leakage and runoff.

Introduction

The Latah Bridge is a 1,024-foot long, four-lane arch bridge built in 1913. The bridge is located over Latah Creek on Sunset Boulevard in Spokane, Washington and is listed on the National Register of Historic Places.

The structure consists of seven deck spans with two abutments and six piers. Each deck span is supported by two pairs of arch ribs with intermediate arches and spandrel columns. The deck is asphalt paved between the concrete sidewalks. Therefore, concrete deck inspection was not included in this study.

The objective of the corrosion condition and evaluation was to assess the substructure condition for corrosion activity and to ascertain the cause of the corrosion activity. A field study was conducted on the bridge September 28 through 30, 2011, in coordination with the delamination and chloride sampling evaluation completed by others. The City of Spokane provided a snooper truck to provide access to the substructure for the evaluation.

The evaluation was predominately visual inspection and corrosion potential measurements on selected areas of the substructure between Pier 2 and 3. Corrosion potential measurement locations were selected based on visual assessments of the potential for corrosion and delaminations identified. The corrosion potentials measurements were taken on the following locations:

- Spandrel Wall Column, South Side, East End
- Spandrel Column, South Side, East End
- North Arch Rib, East End
- North Arch Rib, West End

The result of the delamination survey, chloride testing, and corrosion potential testing are discussed within this report and conclusions presented on the condition of the substructure.

Methodology

Corrosion Factors

Reinforced concrete structures can be subjected to a number of factors that affect corrosion activity of the reinforcement. Chlorides and carbonation have been identified as a primary cause of corrosion on reinforced concrete structures. Chlorides are identified to cause breakdown of the passivity of the steel caused by the strongly alkaline concrete. In contrast, carbonation is a chemical reaction between dissolved carbon dioxide (carbonic acid) and the cement paste, which results in a decline in pH of the concrete.

Chlorides are the most notable cause of corrosion because they can be introduced into concrete from concrete additives or environmental sources, also referred to as “domestic” and “foreign” chloride, respectively. Domestic sources include concrete batch water, set or water reducing admixtures, or cementitious materials. Foreign chlorides can be introduced into the concrete from wetting and drying cycles in marine environments or from road or de-icing salt application.

Penetration rate of chlorides from external sources is controlled by the porosity of the concrete and the frequency of wetting and drying cycles. Fewer wetting and drying cycles minimize the rate of chloride migration while more frequent cycles, typically associated with tidal zones or freezing and thawing, increases migration rate.

In a similar fashion carbonation causes carbonic acid to attack the cement paste. Water saturation of the concrete is a significant factor and will increase the rate of carbonation. For reasons similar to that stated for chlorides, wetting and drying cycles will increase the rate and depth of carbonation.

Because of the heterogeneous properties of concrete, porosity will vary significantly over the structure and even in the same area on a structure. This variation can result in localized corrosion activity and concrete delamination in one area while another area does not corrode. Porosity is affected by water cement ratio and concrete placement. Honeycombing is a common placement issue that causes porosity and will allow chlorides and/or carbonation to occur at reinforcement depths.

Bridge design elements also affect the chloride penetration rate. Penetration from wetting and drying is typically the result of improper water drainage from the deck. The water runoff can contain high concentrations of chlorides from de-icing applications, which are continuously deposited at the same location of the concrete substructure. Even if chlorides are not present, water runoff will increase water saturation of the concrete and increase carbonation.

Reinforcement corrosion will occur from high chloride concentrations when oxygen is present from wetting and drying cycles. Increased depth of concrete cover over the reinforcement extends the time to until corrosion activity will occur.

Concrete repair areas are other locations where accelerated corrosion can occur between the existing chloride containing concrete and new chloride-free patch material. The reinforcement located outside of the patch area will corrode to protect the reinforcement with the patch area.

Electrical Continuity Testing

Prior to commencing with potential testing for corrosion activity, electrical continuity was tested between different components of the bridge. Electrical continuity of the reinforcement can be impacted by corrosion activity and poor or no physical contact between reinforcement.

Electrical continuity is necessary in order to perform the corrosion potential mapping survey and evaluate possible alternatives for preservation and rehabilitation.

Electrical continuity testing was performed by measuring the voltage drop between two locations and by measuring reinforcement potentials using a stationary reference cell. Contact was made to the reinforcement at locations where rebar was exposed because of spalled concrete.

Electrical continuity was verified between the spandrel columns, arch ribs, and spandrel wall columns.

Corrosion Potential Survey

Corrosion of the steel reinforcement in concrete structures occurs with the presence of chlorides and oxygen. When the steel reinforcement begins to corrode the potential of the reinforcement begins to shift more negative with increasing degrees of corrosion activity and associated metal losses.

To evaluate the reinforced concrete for corrosion activity, one spandrel wall column, one spandrel column and the upper half of the north arch rib were selected for grid potential surveys. Because of the symmetrical construction of the bridge and similar exposures, the potential survey was conducted on the western and eastern half of the arch rib between Piers 2 and 3. Spandrel columns were tested on all four sides, except for the wall column. The arch ribs were surveyed on the sides and top to identify areas of varied corrosion activity.

Potentials were measured using a copper/copper sulfate reference electrode and an Juniper Allegro field computer with a National Instruments digital voltmeter card. The Allegro is a datalogger and voltmeter that can electronically record the reinforcement potential at each test point based on a gridded area. The grid spacing varied depending on the surface size and configuration from 1 to 3 feet on center. Most of the grid intervals were 1.0 to 2 feet on center.

The positive voltmeter lead was connected to exposed rebar that had been verified to be electrically continuous with other rebar in the test area. The negative test lead was attached to the reference cell. A water saturated sponge was fitted around the end of the electrode for electrical contact with the concrete. The sponge was kept saturated during the survey. The voltmeter used for the measurements has high input impedance which minimizes contact resistance errors.

Evaluation of the data was completed through a software program that plots the data as a set of equipotential contours over the concrete surface. The contours are colored to represent the level of corrosion activity that could be occurring. The criterion for establishing relative corrosion activity was based on the criteria provided in Table 1.

Table 1
Corrosion Activity Criteria

Relative Corrosion Activity	Potential Range	Approximate Structure Condition
No Corrosion	+0.20 to -0.30 V	<ul style="list-style-type: none"> • No metal losses on the reinforcement, • No cracking or delamination of the concrete
Initial	-0.30 to -0.35 V	<ul style="list-style-type: none"> • Insignificant metal losses on the reinforcement, • Initial cracking or delamination of concrete, • Some spot corrosion on reinforcement.
Active	-0.35 to -0.40 V	<ul style="list-style-type: none"> • Metal losses minor • Some pitting corrosion occurring • Surface cracking • Areas of delamination
Advanced	-0.40 to -0.45 V	<ul style="list-style-type: none"> • Significant and measurable metal losses, • Deep pitting corrosion on the reinforcement • Surface cracks visible • Concrete delamination at the reinforcement level
Severe	More than -0.45 V	<ul style="list-style-type: none"> • Possible structurally significant metal losses • Cracks on the concrete surface • Large delaminations at the reinforcement level

Potential measurements provide a good indication of the corrosion activity occurring on a structure. However, the corrosion activity criteria are based on correlating the specific site observations to the potential values and may not be applicable to other structures. The variation between different structures is caused by variations in concrete composition, strength, porosity, cure, and reinforcement depth of cover. High strength concrete can exhibit smaller and fewer delaminations than lower strength concrete, even with corrosion activity equal.

Progression of corrosion does not occur in incremental steps as outlined in Table 1. Corrosion activity increases as potentials become more negative, however delamination formation may occur earlier or later on different structures. Corrosion activity will begin long before concrete delaminations can be detected on a structure.

Delamination Surveys

Delamination surveys were conducted by others over the substructure surfaces between Piers 2 and 3. The purpose of the delamination survey is to identify areas where corrosion of the reinforcement has exerted stresses on the concrete greater than the tensile strength of the concrete resulting in delamination from the reinforcement.

The delamination survey was conducted using hammers, to audibly define the limits of the delaminations. The limits of the delamination were marked in chalk on the structure surface for photo identification and structure mapping. Maps of identified delaminations were not available.

Laboratory Testing and Results

Chloride Testing

Powder samples for laboratory analysis for chlorides levels were collected by others. Powder samples were collected at depths of approximately 0.5, 1.5, and 3.0 inches. A rotary hammer drill was used to collect the samples. The samples were analyzed by CTL Group for total acid-soluble chloride concentration per ASTM C1152 and reported in parts per million. The laboratory testing report was reviewed as part of this evaluation and chloride results are summarized in Table 2. Deck core chloride results are not included.

Table 2
Summary of Chloride Laboratory Results

Sample	Location	0.5 inch depth	1.5 inch depth	3.0 inch depth
Powder 1	Spandrel Column A-4	2,800	910	110
Powder 2	Spandrel Column A-4	100	10	<10
Powder 3	Spandrel Wall Column A-8	<10	10	10
Powder 4	Spandrel Wall Column A-8	1,750	1,350	100
Powder 5	Floor beam 2, between B and C Arch rib lines	10	<10	<10
Powder 6	Floor beam 2, between spandrel arch wall A	<10	<10	10
Powder 7	Pier 2, exterior wall, south face	2,210	280	60
Powder 8	Pier 2, interior of south wall, mid-height between ceiling and floor	370	50	<10
Powder 9	Pier 2, interior beam 1, 1.5 foot from west end of beam on south side of beam.	220	180	100
Powder 10	Pier 2 Exterior north face	20	<10	<10
Powder 11	Floor beam 2, between C and D spandrel walls, adjacent to wall D	10	20	<10
Powder 12	North Arch rib, exterior side, 4" east and 1.5 foot down from end of spandrel arch wall at floor beam line 8	1,010	570	10
Note: Chloride testing performed by CTL Group, laboratory report dated November 1, 2011.				

The threshold for chloride corrosion in ACI 222R is 0.20 percent based on cement weight for acid soluble chlorides. This equates to approximately 1.2 pounds per cubic yard of concrete or 310 ppm using an assumed cement content of 7 bags per cubic yard of concrete. The 310 ppm criterion is an approximate value as the actual cement weight in the concrete used for the Latah Bridge is not known. Results that exceeded the threshold for chloride corrosion are highlighted in Table 2. Reinforcement depth of cover is commonly 1.5 inches or more, but was observed to be less than 1 inch at many delaminations and spalls on the Latah Bridge substructure.

Overtime, chlorides penetrate the concrete and increases in concentration at the reinforcement. The degree of corrosion activity is also influenced by oxygen availability at the reinforcement depth. Higher oxygen levels typically increase corrosion activity. Oxygen levels are affected by concrete porosity and wetting and drying cycles. The chloride threshold level must be exceeded at the steel reinforcement level for corrosion activity to be initiated.

Petrographic Analysis

Petrographic analysis of a single concrete core was performed by CTL Group and the results presented in a report dated November 16, 2011. Core B6 from the bridge deck was selected for Petrographic analysis.

The analysis completed and associated with the corrosion of the structure included carbonation depth and air content. Carbonation of the concrete from the deck did not show that the carbonation has progressed more than 1/8 inch. The test was based on phenolphthalein pH indicator.

Results and Observations

This section summarizes the findings during the fieldwork performed on the bridge for each of the bridge components. Testing was performed on the structures associated with the down station half of the right (downstream) arch. Visual examination prior to testing indicated that similar construction, physical concrete condition, and exposures were occurring on each of the six arch ribs, piers, and spandrel columns and intermediate arches.

The following figure summarizes the areas where potential measurements were taken on the substructure. Testing of the deck was not possible because of asphalt pavement. Because of lift equipment availability and traffic control limitations, spandrel columns were tested on the south side of the bridge and arches were tested on the north side. The areas tested for corrosion activity were selected because their locations were subject to water runoff as shown in Photograph No. 1. Water runoff can be identified by the dark staining of the concrete surface.

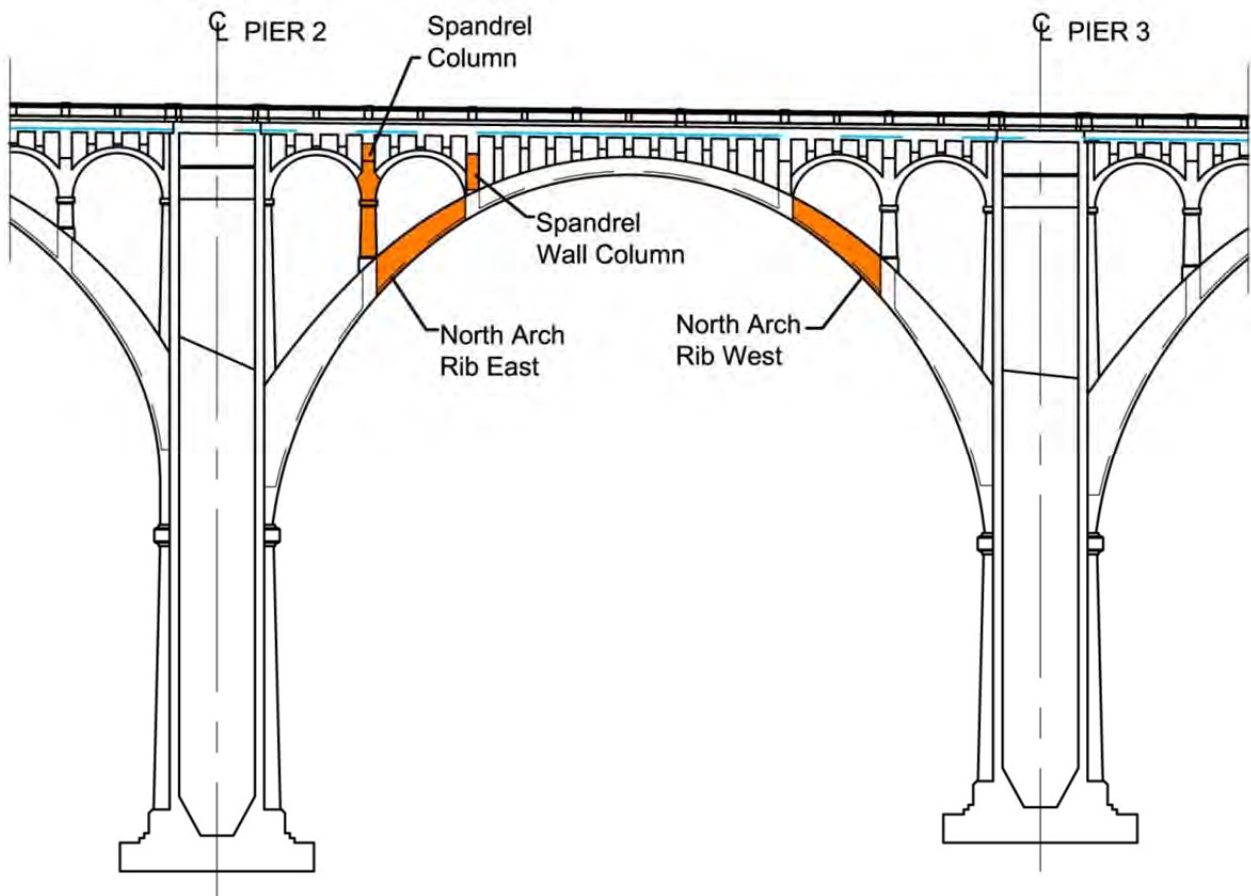


Figure 1 - Potential Test Measurement Locations



Photograph 1 –Water runoff areas between spandrel wall column and pier.

Deck Condition

The asphalt overlay applied over deck in was in good condition and prevented evaluation of the concrete decking. Therefore, assessment of the deck condition was not performed as part of this study.

Rail and Curb Condition

The deck rails and curbs were visually inspected and exhibited the most extensive deterioration on the bridge. The deterioration is likely attributed to the poor performance of non air-entrained concrete and its exposure to freeze/thaw cycles.

The rails and sidewalks are directly affected from freezing and thawing and chloride contamination caused by wetting and drying from vehicle splash and spray and snow removal. Some of the rails have been replaced over the years, but continued to show excessive deterioration from freeze thaw cycles.

The rail and curb are exhibiting extensive concrete spalling and some metal loss. The rails and curbs do not provide structural support to the bridge however; their deterioration poses safety concerns in the railing's ability to withstand vehicle impact and spalled concrete falling into the creek. The

extent of concrete deterioration on the rails was significant and does not appear to be suitable for preservation.

Spandrel Columns and Spandrel Wall Columns

Visual Observations

The deck corbels, spandrel columns, and intermediate arches exhibited staining from water runoff off the deck. These areas of the substructure showed the most delaminations and corrosion activity on the substructure.

Photograph No. 1 shows the concrete staining that has occurred from deck water runoff or leakage. The majority of the water appears to be leaking from the deck at the spandrel wall column on the left. The intermediate arches tend to concentrate the water at the spandrel wall columns and spandrel columns. The upper part of the arch rib also shows staining that result from water running over the arch and its dissipation as it moves from the upper half of the arch to the lower half. Concrete disbondment is generally occurring at the spandrel wall columns, corbels, and intermediate arches as shown in Photograph No. 3.



Photograph 2 - Spandrel Columns and Intermediate Arches



Photograph 3 - North Spandrel Wall Column Delaminations on Intermediate Arch Corners

the delaminations of the concrete on the interior corner of the arch. This area of the arch is protected from water runoff and yet corrosion was occurring. Depth of concrete cover was less than 1.5 inches and may have been further reduced by the chamfered corner. Corrosion was also observed at honeycomb areas in the concrete that may be associated with carbonation.

Electrical Continuity

Electrical continuity was tested and verified between exposed reinforcement on the various surfaces of the spandrel columns and intermediate arches as described in the Methodology

Chlorides

Chloride testing was performed on powder samples from spandrel column A4 and spandrel wall column A8. The chloride samples results were reported by CTL Group at three depths; 0.5, 1.5, and 3.0 inches and were summarized in Table 2 previously.

The chlorides levels in the spandrel columns ranged from 2,800 ppm at 0.5 inches to less than 10 ppm at 3 inch depth. One of two samples from the column and one of two samples from the wall column showed corrosive levels of chlorides at the reinforcement depth.

Delaminations

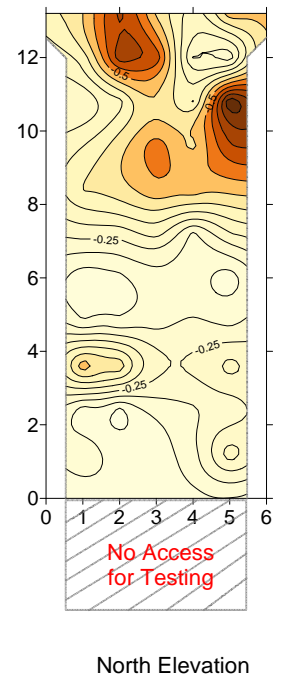
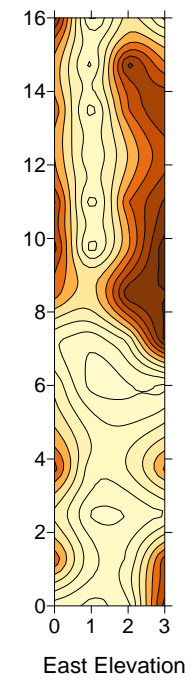
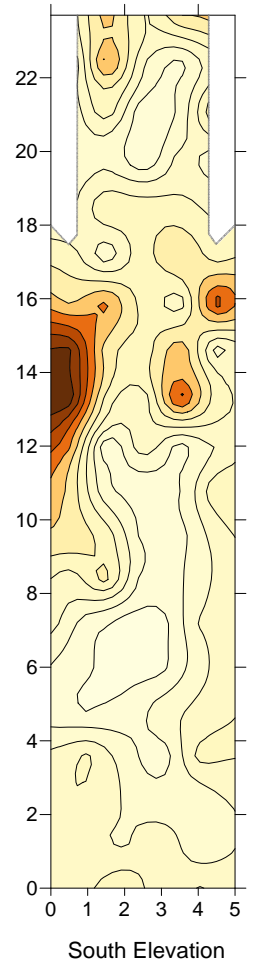
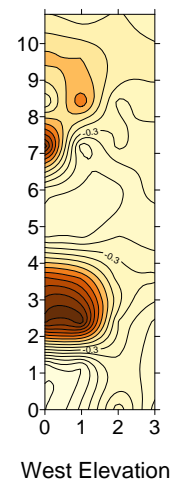
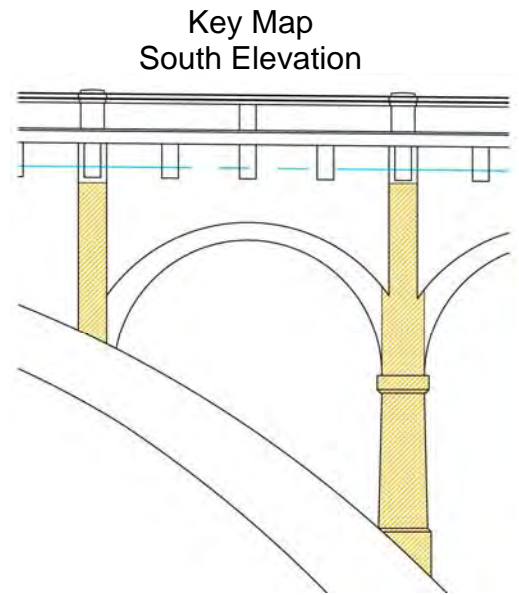
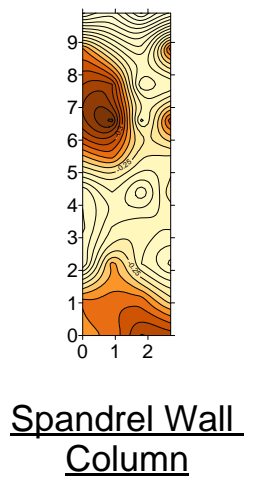
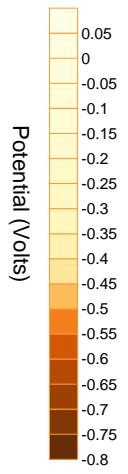
The delaminations shown in Photograph No. 3 illustrate a common observation throughout the substructure. Spalling of chamfered concrete edges where concrete cover is reduced over the stirrup reinforcement.

While the delaminations are caused by corrosion of the steel reinforcement, in some cases the cause does not appear to be chloride related corrosion. Lack of concrete cover was also a factor in

Corrosion Potentials

Reinforcement corrosion potentials were measured on the spandrel wall column and spandrel column on the south side of the bridge. Figure 2 shows the resulting corrosion activity on the surfaces measured. Potential measurements were obtained on all four sides of the spandrel column, but only on the south elevation of the spandrel wall column.

While some localized corrosion activity was detected with the potential measurements, a majority of the spandrel column and spandrel wall column were not corroding. Where corrosion was detected, it was located on the corners of the columns where concrete cover over the reinforcement appears to be less than 1.5 inches as recommended by ACI. Where cracking and delaminations were observed on the column, they corresponded with corrosion activity indicated by the potential measurements.



Spandrel Column

Figure 2
Latah Bridge
Spandrel Wall and Column
Corrosion Potentials

Arch Rib Condition

Visual Observations

Overall, the arches were in good to very good condition with little or no delamination observed. While the exterior surfaces of the arches showed staining from water runoff, no corrosion staining or delamination was observed.

Electrical Continuity

Electrical continuity of the steel reinforcement within the arches was verified at a few locations using the test methods outlined in the Methodology section. Both the left and right arch ribs were found electrically continuous within themselves. However; continuity between the two arch ribs was not tested because of access issues during the study.

Delaminations

Delaminations were very limited on the arch ribs. Generally, the arch ribs were not exhibiting any corrosion activity, except at localized areas. Corrosion potential survey data confirmed that corrosion activity, while present, was not sufficiently active to cause delamination of the arch ribs.

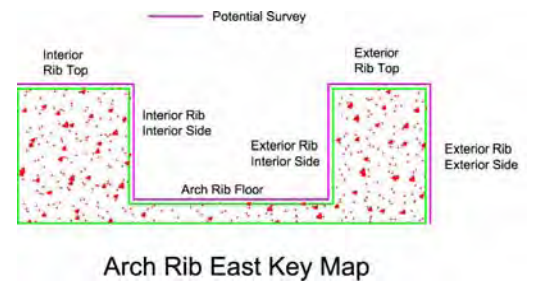
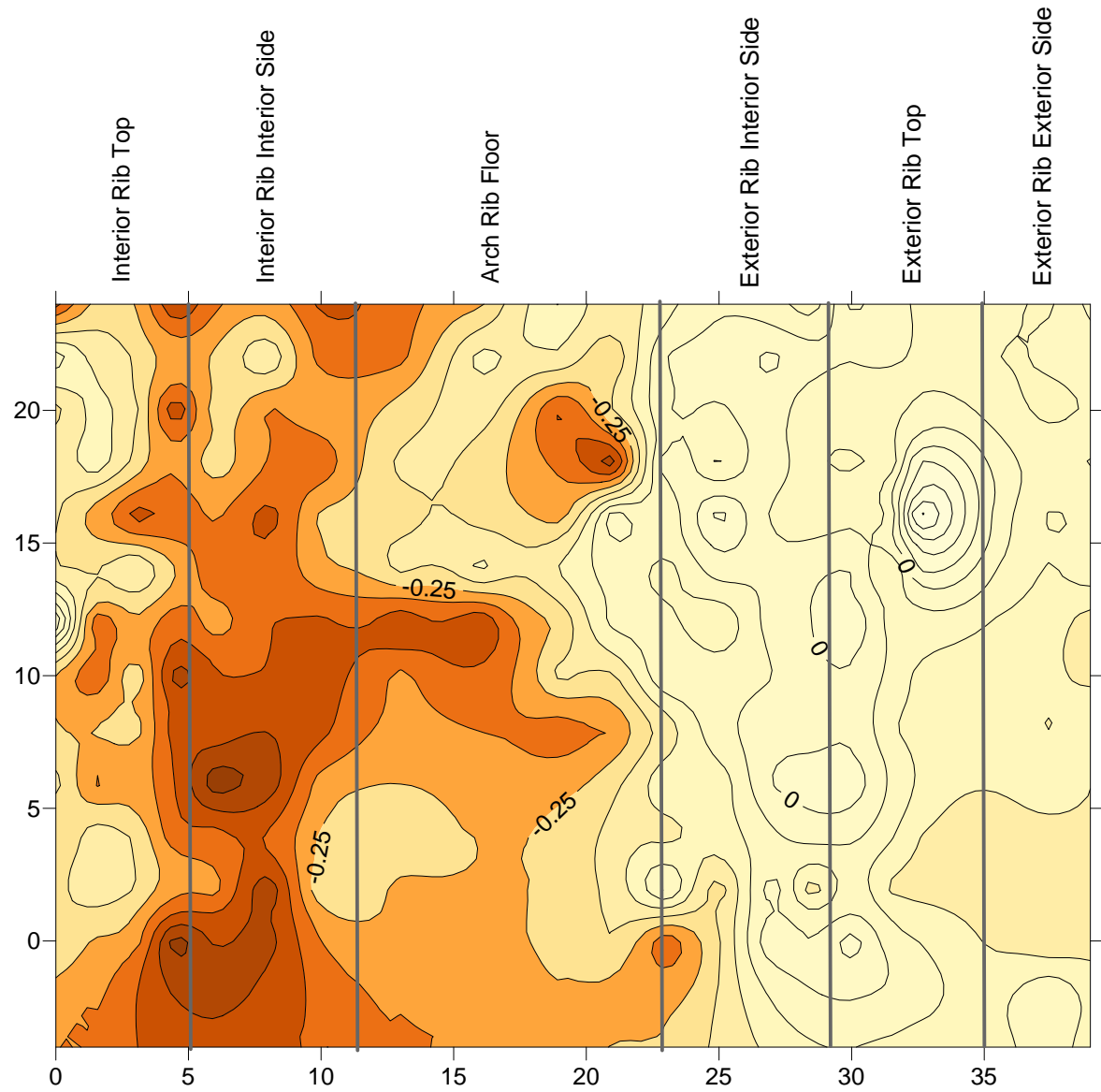
Corrosion Potentials

Corrosion activity on the arch ribs was limited to the interior arch rib on the east half of the bridge between Pier 2 and 3 as shown in Figure 3. Corrosion activity is classified as initial to active corrosion, with localized areas of advanced corrosion. Although corrosion activity was detected through the potential survey, no delaminations were associated with the corrosion activity.

Most of the corrosion was located on the interior rib top corner and the interior rib north side. While a depth of cover survey was not performed, it would appear based on the sheltered protection provided to the interior rib that corrosion activity may be due to insufficient cover and carbonation of the concrete.

A single chloride test was conducted on the north arch east end as Powder Sample No. 12. Chloride results indicated that chlorides were at corrosive levels below the spandrel wall column on the exterior surface of the arch. This is an area where water runoff from the deck would affect the arch condition. While the chloride levels exceeded corrosion thresholds, the corrosion potentials did not indicate that corrosion activity was occurring.

The west end of the north arch rib did not show any corrosion activity as shown in Figure 4. Visual observations showed no evidence that corrosion activity was occurring. Chloride testing was not performed on the west half of the north arch rib.



Potential (Volts)

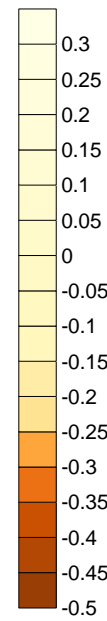
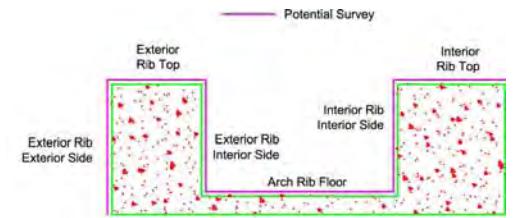
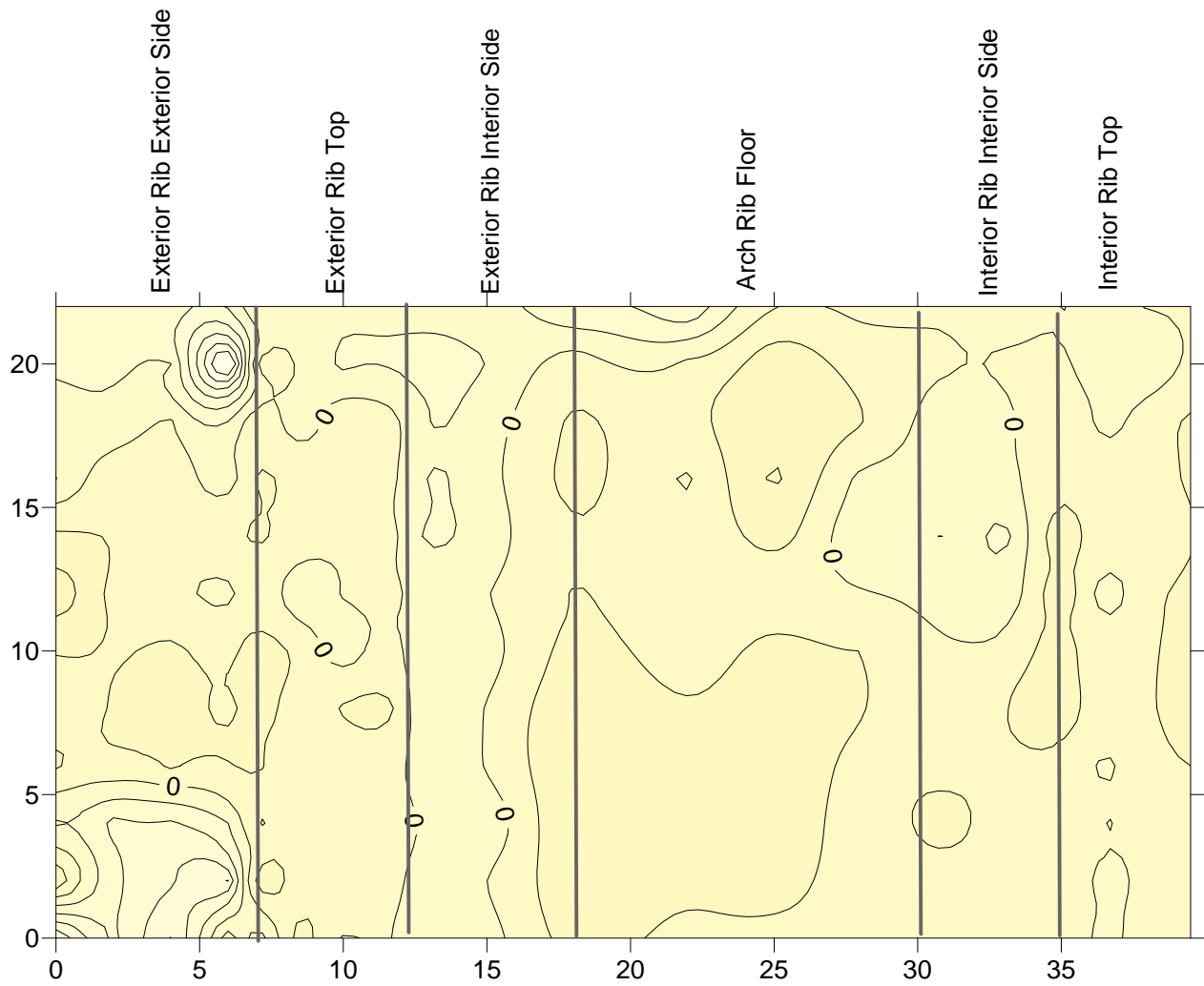


Figure 3

Latah Bridge
North Arch Rib East End
Corrosion Potentials



Arch Rib West Key Map

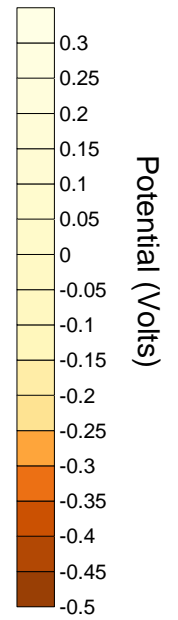


Figure 4

Latah Bridge
North Arch Rib West End

Pier Condition

Evaluation of the pier condition was achieved by visual observations only because of access difficulties. The exterior of the piers were evaluated by photographing the exterior surfaces of the piers with telephoto lens and high resolution camera and then reviewing the resulting photographs for evidence of corrosion activity.

The primary issue observed at the piers, is deck runoff leaks onto the exterior surfaces of the piers. This was readily observed following a rainstorm on the first day of the study. The source of the leaks could not be determined, but it was reported that the asphalt paving covered expansion joints in the deck. However, expansion joints in the deck were not visible from underneath the bridge.

Interior inspection showed leakage from the manholes and drain piping was causing corrosion of the floor beams. Chloride testing showed that the corrosion was not caused to chlorides. However, the magnitude and extent of corrosion would indicate that chlorides had an effect on the corrosion in combination with limited concrete cover. Photograph No. 4 shows the floor beam corrosion observed inside Pier No. 2.



Photograph 4 - Pier 2 Interior Floor Beam Corrosion



Photograph 5 - Corrosion in Pier 2 at drain pipe leakage



Photograph 6 - Corrosion and Delamination at honeycombed concrete

Notice in Photographs 4, 6 and 7 that the stirrups have less than ½ inch of concrete cover. Corrosion of the stirrups and the resulting cracking would allow water and salt to more readily attack the longitudinal bars and cause delamination of the concrete on the bottom of the floor beams.



Photograph 7 - Delamination on bottom of floor beam

Conclusions

The conclusions of the corrosion condition and evaluation study is that the substructure of the Latah Bridge is in good to very good condition with localized corrosion activity occurring. While the tendency is to conclude that chloride corrosion from deicing salt is a primary factor, the chloride testing and water runoff protection provided by the deck to the interior substructure components does not support this conclusion.

On a localized basis some evidence for chloride corrosion of the reinforcement is present, specifically on the spandrel columns, spandrel wall columns, and intermediate arches. But concrete depth of cover and poor concrete placement (honeycombing) at corners were significant factors. With low concrete cover, carbonation of the concrete becomes a secondary affect that would be increased in rate and depth with the wetting and drying cycles from deck water runoff. Carbonation is supported by the quantity of delaminations observed within the interior of the substructure where water runoff was not an occurrence.

The key issue behind reinforcement corrosion is that the concrete pH must be less than pH 10 for corrosion of the steel to occur. Factors that support the degradation of concrete pH are wetting and drying cycles and carbonation; a chemical reaction between dissolved carbon dioxide and cement. Carbonation can occur without wetting and drying cycles, but the depth of pH loss would be slower. At 50 percent water saturation, carbonation occurs more rapidly and to a greater depth. Since the structure is nearly 100 years old, concrete carbonation could still be a factor.

Carbonation was evaluated on one concrete core from an interior arch rib with a result indicating carbonation was only 1/8 inch deep. The test for carbonation was conducted using phenolphthalein pH indicator on the cut surface of a concrete core. The problem with this test is that phenolphthalein changes from clear to pink at between pH 8 and 9. Carbonation can cause corrosion at a pH less than 10. Therefore, the CTL Group conclusion that carbonation had not progressed to any significant depth remains unproven.

While the phenolphthalein test would limit the conclusion of carbonation, there are no other explanations observed or verified by testing to indicate why corrosion was occurring on corners and other areas where water runoff was not occurring. Chloride testing indicated that over 75 percent of the locations tested on the substructure did not exceed the chloride corrosion threshold at the normal reinforcement depth of 1.5 inches.

Regardless of the cause of corrosion, either chloride corrosion or carbonation, the method of corrosion mitigation that extracts chlorides will also restore concrete pH through a process call realkalization. While much of the structure is in very good condition, concrete pH restoration will be a necessary part of the rehabilitation to insure the structure can continue to provide service into the future.

In addition, the source of the deck runoff needs to be located and resolved. Even with pH restoration technology, water runoff from the deck must be contained and properly drained from the structure with runoff onto the substructure mitigated.

The structural components that appear to be in the worst condition are the exterior spandrel columns, spandrel wall columns, and corbels. These areas were subject to deck water runoff and have localized levels of chlorides that would cause reinforcement corrosion. However, interior spandrel columns arches did not exhibit the degree of degradation observed on the exterior of the bridge and would not need replacement, but could be protected with proper concrete patching and realkalization of the concrete.

Corrosion on with the floor beams appeared to be isolated to the leakage areas within the piers at drains and manholes. The recommended method for rehabilitation of the deck would also resolve the pier floor beams.

The piers appear to be in good condition, except in areas of water leakage. In leakage area, delamination of the concrete was occurring. The cause of the delamination is not known as inspection was not possible. Whether from chloride corrosion or low concrete cover, protection or the reinforcement could be resolved with chloride extraction and realkalization technology.

