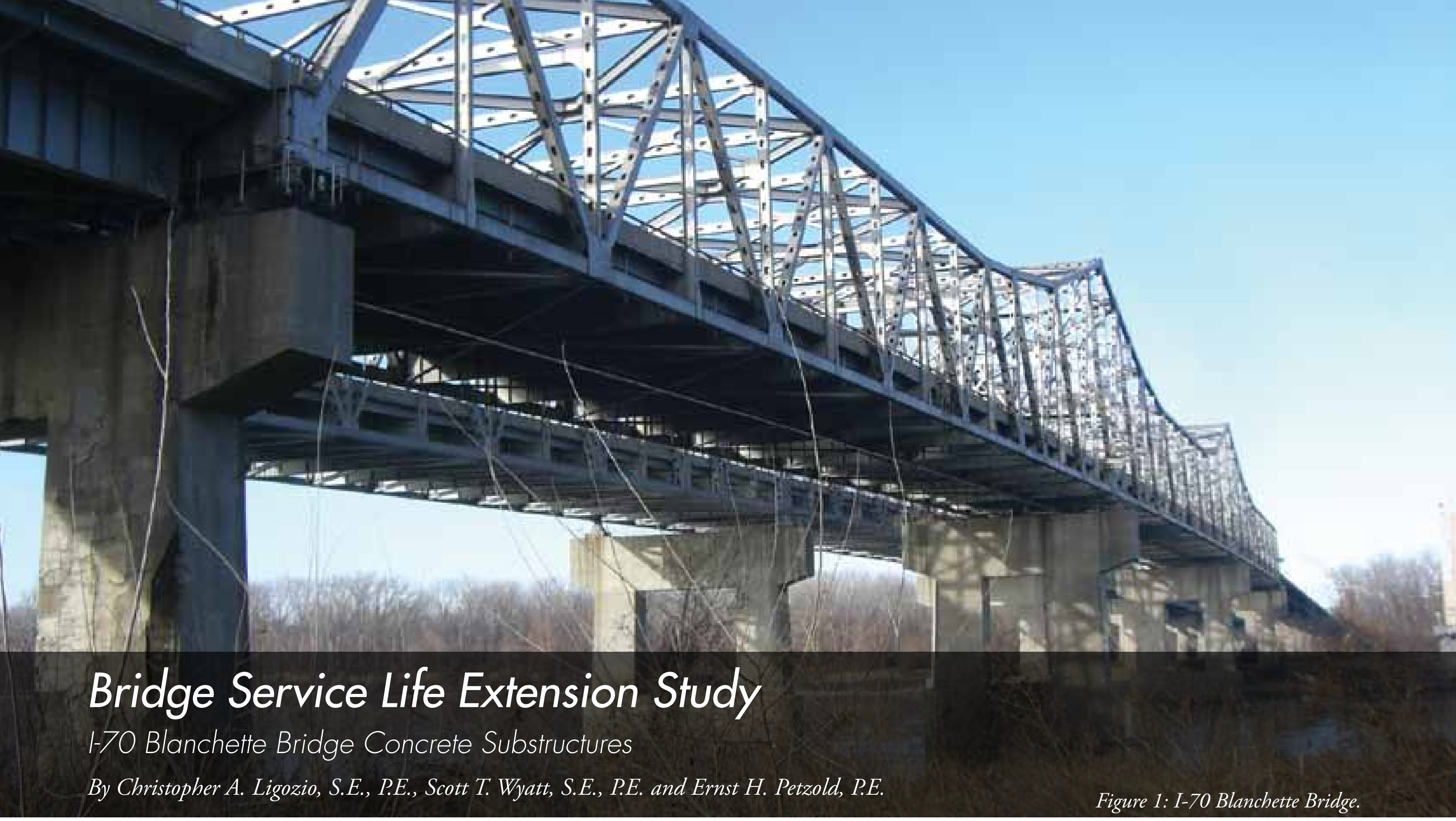

Bridge Service Life Extension Study

I-70 Blanchette Bridge Concrete Substructures

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Figure 1: I-70 Blanchette Bridge.

Bridge rehabilitation vs. replacement decisions are more challenging when highway funding is scarce. For older, critical highway corridors, decisions are influenced by structural condition and capacity, durability of components, safety standards, future traffic projections, effects on environment, construction-related traffic disruption, and economic considerations. Service life evaluation methodology and diagnostic tools were applied to the 50-year-old concrete substructures of the westbound Blanchette Bridge, carrying I-70 across the Missouri River in St. Charles, Missouri.

This article summarizes the substructure service life model and rehabilitation plan developed through a program of hands-on inspection, nondestructive testing, and methodical material sampling and testing. The plan provided a basis for achieving adequate performance for the rehabilitated westbound bridge over an additional 50 years of service life, meeting Missouri DOT project objectives.

Overview

Traditional bridge management practice is often reactive to the needs of aging bridges. When routine inspection identifies that structural and durability conditions have degraded sufficiently, a more detailed inspection and study is sought and performed, to correct observed deficiencies.

This reactive inspection/maintenance approach rarely addresses latent durability issues in a rational, cost-effective manner, and when applied in a rehabilitation context, tends to favor lower initial capital investment over lower life cycle cost options. When durability concerns are addressed, the method tends to favor full replacement over rehabilitation following extended periods of neglect.

The 4,083-foot long, westbound I-70 Blanchette Bridge (*Figure 1*), consists of 23 steel girder and truss spans, supported on reinforced concrete piers. The structure was originally constructed in 1958 and underwent a significant rehabilitation in the 1980s, including deck replacement, substructure repairs, and strengthening. The bridge presently carries 70,000 vehicles daily.

The reinforced concrete piers are comprised of a cap beam supported on two columns. Pier geometry varies along the length of the bridge.

The substructure service life extension study was conducted by the authors, under contract with Jacobs Engineering Group, Inc. of St. Louis, MO, from July 2009 to March 2010. The Jacobs' scope of work included inspection, preliminary and final design, and consultation during construction. The project will restore the condition of the older westbound bridge and develop a maintenance plan to provide a 50-year extension to its service life.

Inspection & Testing

The field investigation consisted of a hands-on detailed inspection, nondestructive testing, concrete cover profiling, and concrete sampling and testing to document the condition of the concrete piers above ground, and above water. Inspection access to the piers was provided using a combination of aerial lifts, under-bridge inspection vehicles and work boats.

Inspection revealed the condition of the piers was highly dependent on their location with respect to deck joints. Piers beneath continuous deck sections were generally in good condition, with minor, localized deterioration and isolated areas of delaminated concrete. Piers beneath or adjacent to deck joints had been subjected to deck runoff and were in poor condition (*Figure 2*). Significant cracking, localized to widespread spalling, and widespread areas of delaminated concrete (as much as 50% of area) were evident in these latter piers.

Corrosion potential measurements were used to evaluate the likelihood of active corrosion (*Figure 3*). Measured potential values were in general agreement with the inspection results: piers away from deck joints indicated a high probability that no corrosion was occurring at the time of testing; measurements of sound areas of piers under or adjacent to deck joints indicated significant areas of active corrosion, signifying a strong potential for additional delaminations and accelerated deterioration in these piers.

Figure 2: Pier Deterioration beneath deck joint.

During inspections, concrete cores were extracted from areas representative of sound concrete. In the laboratory, chloride ion concentration analyses of concrete samples indicated that in piers under or adjacent to deck joints, chloride ion levels at the depth of the reinforcing steel were higher than the threshold at which corrosion of embedded steel is known to initiate.

Petrographic examination and compressive strength testing of the concrete cores demonstrated that outside of areas of observed damage, the concrete appeared sound and generally of good quality, with no additional durability concerns.

Service Life Evaluation

Based on the project scope and plan, bridge operating environment and results of the inspection and testing program, the following parameters were candidates to pose potential vulnerabilities, which could impair the piers' remaining service life (these were addressed during the service life study):

- Concrete deterioration due to expansive reaction of siliceous aggregate with cement paste in concrete (ASR).
- Concrete deterioration due to repeated cycles of freezing and thawing while concrete is wet.
- Corrosion of steel reinforcement due to carbonation of concrete, which alters the protective qualities of concrete paste.
- Corrosion of steel reinforcement due to the presence of chlorides.

Of these factors, corrosion of steel reinforcement due to the presence of chlorides was found to be the controlling vulnerability. Remaining service life was estimated based on a statistical evaluation of measured cover depth and chloride content profiles.

Figure 3: Measuring corrosion potential.

High levels of chloride ion, in the presence of moisture and oxygen, result in corrosion of reinforcement, even in the highly alkaline conditions of non-carbonated concrete. The American Concrete Institute (ACI) Committee 201 specifies that water soluble chloride contents greater than 0.15% by weight of cement are likely to result in corrosion of reinforcement.

Due to the observed differences in environmental exposure among substructure elements and variation in concrete cover, chloride content and reinforcement cover data were subdivided into 4 categories, based on statistical evaluation of results.

Chloride content was evaluated for piers under joints separately from piers without joints, since chloride levels were an order of magnitude greater for piers under joints. Within each group of piers, critical cover depth (*Figure 4, page 24*) was determined separately for the cap beams and columns, as average cover in the columns was generally an inch greater than in the cap beams.

Chloride migration and resulting service life was modeled from the normalized data using Fick's second law of diffusion. Measured chloride profiles were used to calculate the diffusion coefficient, D, for each substructure element evaluated. The element-specific D value was used to calculate the time needed for chloride ions to reach the corrosion initiation threshold for the assumed concrete cover.

Results of the evaluation demonstrated that chloride levels have reached critical values at the level of the reinforcement for both columns and cap beams of piers under joints. In these areas, it was inferred that the resulting corrosion of the reinforcement has reached critical levels. These piers had reached the end of their service life and require a significant rehabilitation to extend service life and maintain structural capacity.

Estimated remaining service life of piers away from deck joints was better, requiring only minor to moderate rehabilitation, to achieve an additional 50 years of service life.

Rehabilitation Options

Given the difficulty and cost of full pier replacement and the adequate strength and durability qualities of core concrete, rehabilitation was recommended.

For piers under continuous deck sections, rehabilitation recommendations include repair of observed damage, sealing of cracks, and application of a penetrating sealer to the full surface of the piers.

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Figure 4: Collecting concrete cover profile data.

This approach would slow chloride contamination and result in an additional 50 years of service life for all elements.

To achieve an additional 50 years of service life in piers under deck joints, a more extensive rehabilitation was necessary. Two rehabilitation options were evaluated, based on cost, constructability, and risk.

Option 1–This alternative included removing all delaminated and chloride contaminated concrete to a specified depth behind the innermost bar level, replacing corroded reinforcement, and repairing with low permeability concrete. Chloride diffusion models were used to determine the required depth of removal beneath the innermost bar to protect reinforcement from the potential for migration of chlorides remaining in core concrete.

The benefits of this approach are its practicality within the context of standard bridge concrete construction procedures, i.e., no need for advanced concrete additives, including corrosion inhibitors, resulting in low permeable concrete that is known to reliably provide good protection.

This alternative's principal drawback is the difficulty/cost of removing concrete below the innermost reinforcing bar level.

Option 2–This alternative was developed as a lower initial cost option and involved removal and replacement of all delaminated concrete followed by implementation of an impressed current cathodic protection system. Cathodic protection can prevent corrosion in the presence of chloride contaminated concrete. This option provided a 50% reduction in the volume of concrete to be removed and replaced, but some chloride contaminated concrete would remain. Unfortunately, this option requires continuous maintenance of the active cathodic protection system for the life of the structure, to provide ongoing corrosion protection.

Value Engineering Study Alternatives

Following review of the proposed alternatives, the DOT commissioned a value engineering study of the project, which identified passive cathodic protection (PCP) as a means to reduce costs by providing corrosion protection to the reinforcement in sound but chloride contaminated areas thus allowing this concrete to remain and reducing the amount of concrete to be removed and replaced by approximately 50%, compared to option 1.

The authors conducted a study and identified several PCP systems suitable for protection of reinforcement in existing structures. The team recommended use of a thermal spray zinc anode, applied to the full surface of the piers following repair of delaminated areas. It was determined that this PCP system could be used to save sound, but chloride contaminated concrete, with approximately $2 or 3 million in initial cost savings when compared to Option 1. The savings were offset by a reduction in likely service life, to approximately 20 years before the next rehabilitation.

Selected Alternative

The DOT selected a combination rehabilitation approach that included both removal and replacement of the full concrete surface of chloride contaminated piers, including all chloride contaminated and deteriorated concrete to a depth of 1 inch below the rebar (consistent with DOT standards), along with the use of PCP consisting of anodes embedded in repaired concrete to provide added protection. Primary protection will be provided by the high-performance, low permeability concrete specified for replacement concrete.

The use of PCP with a low permeability replacement concrete will result in low initial anode consumption rates as the concrete has a high electrical resistance. As chloride content increase over time, due to ongoing exposure to deicing solutions, the electrical resistance of the concrete will be reduced, resulting in increased effectiveness of the PCP. It is anticipated that the rehabilitated piers will provide an additional 50 years of service life, with minimal maintenance, exceeding the target established by the DOT.

Conclusion

With proper modeling and application of statistical principles, service life-based evaluation techniques permit engineers to perform life cycle cost analysis, and reduce the cost of repairs and the overall life cycle cost of a structure.

For the Blanchette Bridge, the service life evaluation resulted in a forecast of performance for the re-habilitated structure, looking ahead 50 years. By evaluating particular vulnerabilities in conjunction with potential rehabilitation alternatives, it was possible to more confidently project additional service life and tailor the rehabilitation to the needs of the piers, based on observed conditions.

For piers in good condition, the team was able to justify minor rehabilitation. For piers at joints with significant levels of existing deterioration, the ability to evaluate the durability of rehabilitation options provided the State with critical information for selecting a rehabilitation scheme. This helped the owner effectively reuse the substructure, accumulating considerable bridge life cycle savings.▪

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