Cost-Effective Rehabilitation of Two Aluminum Bridges on Long Island, New York

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Abstract: After testing of a full-scale model semimonocoque airframe aluminum bridge at Lehigh University in 1960, New York State built two similar four-span aluminum structures on Long Island, which were opened to traffic in 1965. During an inspection in 1996, galvanic corrosion of the aluminum superstructure at contact surfaces with the steel bearings in presence of moisture, limited distortion or buckling of members at some of these locations, and damage to the bridge underside when struck by a vehicle taller than available clearance were noticed. Otherwise, the rest of the structure appeared to be in good condition. Due to the unique structural configuration, an investigation of viable procedures for repair and maintenance of these structures was conducted. This investigation resulted in the cost-effective rehabilitation procedure described in this paper.

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Introduction

In the late 1950s, the Fairchild Kinetics Division of the Fairchild Engine and Airplane Corporation investigated the use of semimonocoque airframe aluminum structures for composite bridge construction. (Monocoque refers to a metal structure, in which the skin absorbs all or most of the stresses to which the body is subjected.) Subsequently, a full-scale 50 ft (15.24 m) long bridge with a composite concrete deck (Fig. 1) was designed, fabricated, and tested by the Fritz Engineering Laboratory at Lehigh University in Bethlehem, Pennsylvania (Mindlin and Errara 1959). The testing indicated close correlation between theoretical and experimental stresses and confirmed satisfactory performance under fatigue-, service-, and ultimate-load conditions. Semimonocoque composite aluminum construction for bridges was claimed to promise lower dead-load stresses, lighter substructures, and lower costs for transportation and erection of components and for future maintenance. Following this study, in 1960 the former New York State Department of Public Works (predecessor of the Department of Transportation) contracted for construction of two similar four-span structures (opened to traffic in 1965) in Suffolk County on Long Island, each carrying both northbound and southbound traffic over Route 27 (the Sunrise Highway):

1. BIN 1018259, carrying Wellwood Avenue (County Rte 3) in the Town of Lindenhurst, and
2. BIN 1019119, carrying Broadway (State Rte 110) in the Town of Amityville (Fig. 2).

Based on recent inspections, both bridges are now yellow-flagged (defined by the Department as indicating a potentially hazardous condition, which if left unattended would likely become a clear and present danger, or the actual or imminent failure of a non-critical structural member, possibly reducing the bridge’s reserve capacity or redundancy), but open to traffic with no posted weight-limit restrictions. The rehabilitation of these two bridges is the subject of this paper.

Bridge Condition

In the summer of 1996, viable procedures for repair and maintenance of these two aluminum bridges were investigated. During the field inspection of the actual condition, the following observations were made: (1) galvanic corrosion of the aluminum superstructure at contact surfaces with the steel bearings in presence of moisture; (2) limited distortion or buckling of members at some of these locations; (3) damage to the bridge underside when struck by a vehicle taller than available clearance; and (4) that, otherwise, the rest of the structure, appeared to be in good condition, including localized aluminum skin patches to repair minor damage to the bridge underside. Based on these observations, a conventional preliminary procedure was proposed for the repair of bridge areas affected by galvanic corrosion. Bridge-bearing details in as-built and typical current conditions are shown in Figs. 3 and 4, respectively.

Preliminary Repair Procedure

This procedure (NYDOT 1996) for repair of corroded aluminum skin at bearing locations included: (1) raising the spans by lifting them from above or jacking them from below; (2) repairing aluminum members by riveting or lock-bolting patches in needed locations to replace the corroded cross-section of the aluminum sheet and/or extrusions; and (3) replacing material isolating alu-
minum from steel members with stainless-steel plates or elastomeric pads. Details for the proposed stainless-steel shim plates are shown in Fig. 5. For each end of each span, the procedure proposed for replacing existing bearing shims would repeat the following steps:

1. Remove any dirt or other foreign material from inside the aluminum girders;
2. Close one side of the bridge (northbound or southbound) to traffic;
3. At one end of the span, position a jack near each bearing, placed so that it is centered on a web stiffener in an aluminum girder and bears on an area of at least 9 by 10 in.² (230 by 254 mm²). With this bearing area and with traffic off the lanes being repaired, load on the span should be less than the design load and the jacking procedure should be safe;
4. Uniformly raise the jacks enough to remove the 4 1/2 in. (11.43 cm) stainless-steel bolts attaching each sole plate to the bottom of the aluminum girder;
5. Remove and discard any shims between the steel sole plate and aluminum girder. Remove any corrosion product or dirt, and inspect to evaluate need for replacement of any aluminum parts;
6. Insert a 1/4 in. (6 mm) thick stainless-steel plate (dimensioned as shown in Fig. 5) between the aluminum girder and steel sole plate at each bearing. This plate must be larger in plan than the bearing contact area to prevent galvanic corrosion (Additional steel plates may be inserted, if needed, to adjust elevation of the deck);
7. Reinstall the stainless-steel bolts to attach the steel sole plates to the aluminum girder; and
8. Uniformly lower and remove the jacks.

Later in-depth study of the bridge plans (New York State 1961), three reports (Mindlin and Errara 1959; Evans 1960; Kahn 1962) documenting the research preceding design and construction of these two bridges, and subsequent visits to the two bridge sites for closer inspection of specific details revealed the follow-
ing problems regarding the proposed preliminary repair procedure. These problems are mainly related to the procedure’s requirement for lifting or jacking the bridge structure at span ends, which may not be feasible due to the following geometric restrictions:

1. Adjacent northbound and southbound spans are keyed at transverse joints, as shown in Fig. 6, so simultaneous, multiple jacking of spans would be required at some span ends.

2. Each bridge consists of two parallel adjoining structures carrying traffic in opposing directions, keyed along a longitudinal joint as shown in Fig. 7. This creates additional need for simultaneous, multiple jacking of spans in both structures for work on span ends of one structure.

Additionally, even if these two problems were surmountable, further practical limitations remain:

1. Based on previous experience, multiple-point jacking of span ends of skewed bridges may cause the spans to rotate and misalign at the original bearing locations.

2. Preliminary investigation showed that jacking of span ends to their maximum permissible height (as calculated based on available transverse joint length) may not provide the required work space to install the proposed shim plates or to replace aluminum parts.

3. The proposed procedure requires closing down traffic in at least one direction at a time, thus disrupting and delaying normal flow and adding to the cost of channeling traffic onto the accessible half of the bridge.

4. Using stainless-steel plates may add significantly to repair cost, because a total of 192 plates will be required for the two bridges.

5. Repairing aluminum members by lock-bolting or riveting assumes ready access to the structure’s interior, but half these compartments can be reached only with considerable inconvenience and the other half with extreme difficulty.

The above limitations prompted development of an alternative repair plan, which is presented in this paper.

**Proposed Alternative Procedure**

In view of the difficulties just summarized in the previous section, an alternative procedure is now proposed for repair of the corroded aluminum skin at bearing locations. The major difference is that this alternative does not require lifting or jacking the bridge structure, which has many advantages. At each bearing location, repeat the following steps:

1. Support the span at bearing locations using wooden scaffolding and steel shims designed for an estimated reaction of 80 kips (356 kN). Use a wooden block 12 by 12 in. (305 by 305 mm) and 4 1/2 ft (1.37 m) long @ length estimated based on load-buckling analysis of web stiffeners (Aluminum 1994; Hag-Elsafi and Alampalli 1999), centered along each bearing’s centerline as close as possible to that bearing, as shown in Fig. 8(b). Wooden scaffolding is recommended to allow for limited rotational flexibility, thus reducing stresses at the supported locations. The 4 1/2 ft (1.37 m) block adequately supports an area of equivalent stiffness to that existing at the beam ends, noting the small-size web stiffeners and their wide spacing outside the bearing area.

2. Remove the top part of the concrete pedestal as needed to free the bearing sole and masonry plates, and to provide adequate work space to attach the new stiffening steel sole plate and elastomeric insulating pads, dimensioned as shown in Fig. 9.

3. Remove the existing bearing and stainless-steel bolts. Clean the surfaces of the sole and masonry plates, removing rust and dirt. Inspect them for damage and assess the need for replacement. Set them aside for later reinstallation.

4. Remove and discard any shims between the steel sole plate and aluminum girder. Remove any corrosion product or dirt and assess the need for replacement of any aluminum skin—using lock-bolting or riveting, replace the skin only if the affected area is greater than that of the stiffening steel sole plate (Fig. 9). Otherwise, use aluminum shim plates cut to fit the affected area.

5. Temporarily position and support the new stiffening steel...
sole plate and elastomeric insulating pad over the affected area at the bearing location. Pad area should be slightly larger than that of the stiffening sole plate, with its sides 1/8 to 1/4 in. (3 to 6 mm) longer. At the locations shown in Fig. 9, thread four 9/16 in. (14 mm) diameter holes through the stiffening steel sole plate, elastomeric bearing pad, and aluminum skin. Use countersunk stainless-steel bolts to attach the stiffening sole plate permanently to the bridge structure.

6. Attach the sole plate to the newly attached stiffening steel plate and elastomeric insulating pad, using 9/16 in. (14 mm) diameter stainless-steel countersunk bolts at the prethreaded holes shown in Fig. 9.

7. Position and support the masonry plate to the newly attached sole plate, maintaining positive contact between these plates as in standard construction. The masonry plate may be supported by steel chairs connected to the pedestal reinforcement.

Fig. 3. As-built bearing detail from bridge plans

Fig. 4. Two views of corroded bearing

Fig. 5. Stainless-steel 1/4 in. shim plate (not to scale)
8. Place anchor bolts, attaching them to the supported masonry plate in the normal position, and cast concrete to replace the removed top portion of the pedestal.

9. Allow the concrete to harden and remove the supporting scaffolding.

In Step 1, jacking the bridge at the supported locations up to their as-built elevations is not recommended, because this could significantly increase stresses at these locations. For safety, work on any span should be limited to no more than four locations, spread out in a manner ensuring sufficient redundancy in the unsupported bridge system. For example, simultaneous work should be avoided at two locations along the same bearing centerline or at two adjacent locations. The stiffening steel sole plate used in this procedure spans over relatively small corroded skin areas (most of which are now covered with aluminum shim plates), thus eliminating the need for costly replacement of damaged skin. Countersunk bolts are proposed because they do not require access to the bridge interior, but if for any reason these bolts cannot be used, access is possible for bolting or riveting the sole plates and insulating pads through such compartments as 1B2 or 3D4 in Fig. 10. If visual inspection indicates damage to existing web stiffeners at support locations, stiffening aluminum plates of similar thickness can be attached atop the existing doubler plates, shown in Fig. 8, using countersunk bolts. Access to install these plates is possible through compartments similar to 1B2 and 3D4. However, damage to web stiffeners is highly unlikely because of their proximity to the steel sole plates [at least 3 in. higher in elevation, as shown in Fig. 8(a)], and water is generally not retained in the bearing area. To prevent any future corrosion, all transverse joints overhead in the deck should be sealed immediately.

**Cost Analysis**

Based on the 1995 inspection reports for the two bridges, it is estimated that 20% of existing bearing locations need immediate repair. Costs for immediate and long-term repairs using this proposed procedure have been estimated as listed in Table 1, using the assumed unit prices for installed materials. (Sources for these costs are the Department’s "Weighted Average Bid Prices" and manufacturers’ estimates.) Using these figures, itemized costs per bearing location are shown in Fig. 11. Those associated with sole and masonry plates are estimated as half the cost of the stiffening.
steel sole plates and are meant to cover removal, cleaning, and reinstallation. From Fig. 11, total cost using the proposed procedure is estimated as $206 per bearing location. Additional cost for sealing transverse joints \([85 \text{ ft (25.9 m)}]\) long is estimated as $1,275 per joint.

**Recommendations**

It is recommended that the proposed procedure first be tried by regional maintenance workers to assess its practicality and identify any necessary modifications. Repair is recommended, by contract or maintenance forces, to proceed in two phases according to urgency and budget:

1. In the first phase, badly corroded locations (about 20% of all bearing locations) should be repaired immediately, including treating/sealing of all deck transverse joints to keep dirt and moisture out of the bridge interior. Based on the unit costs given here, total expense for this phase is estimated as $18,400 ($8,200 for bearing locations plus $10,200 for the joints).

2. In the second phase, repair at the remaining bearing locations can proceed over a longer period. If no serious damage is observed there, only existing shims need be replaced with insulating elastomeric pads. Again using these unit costs, total expense for this second phase is estimated at $33,000, assuming that all remaining bearing locations are completely repaired. Thus, total cost for both phases is estimated at $51,000, which may be contrasted with $1.7 million—the replacement-option cost for two six-lane, 250 ft (76.2 m) long, steel/concrete bridges, each estimated at $40/ft\(^2\) ($430/m\(^2\)).

**Summary**

This paper presented a cost-effective procedure for repair of corroded skin at bearing locations on the two aluminum bridges with a unique configuration, providing the following advantages: (1) it does not require closing bridges to traffic; (2) it uses less expensive regular steel (as opposed to stainless) stiffening sole plates and elastomeric insulating pads; (3) it eliminates the need for simultaneous, multiple jacking of spans of both structures; (4) repairs can be completed easily and efficiently, consisting primarily of replacing corroded skin with aluminum shims and using countersunk bolts; (5) repairs can be performed by regular Department maintenance crews; (6) repairs can be scheduled over an extended period based on bridge condition and budgeting constraints; and (7) it results in long-term savings because of the low life-cycle costs generally associated with well maintained aluminum structures.
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