

Cracking of Overhead Sign Structures and Their Repair Using Composite Fabric as a Wrap

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This work was sponsored by the Delaware Center for Transportation and was prepared in cooperation with the Delaware Department of Transportation. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Delaware Center for Transportation or the Delaware Department of Transportation at the time of publication. This report does not constitute a standard, specification, or regulation.

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Project Statement

Delaware, like several other states, has encountered cracking of overhead sign structures (OSS). This project seeks to investigate a method of repair, namely the use of composite fiber wraps. NYSDOT has apparently used this technique successfully, and DelDOT is looking for a summary of the technology and a how-to document that can be used by technicians in the field. The primary focus of this work is the repair of cracked secondary sign members.

Background of FRP Use by NYSDOT

The prevalent problem in New York that led to the use of a fiber reinforced polymer (FRP) retrofit was cracking in the connection between diagonal and chord members of OSS. NYSDOT began an inspection program in 2000 that found ten percent of the state's sign structures damaged. Cracks in the diagonal to chord connection were the most common form of damage, and were sometimes completely severed. This connection failure can lead to complete structural failure, which is reported to have happened in some states in the past.

The cause of the damage is not exactly known, although several key factors may play a role. Lack of inspection during shop fabrication can yield poor quality welds, insufficient supervision during construction can lead to unforeseen stresses, and fatigue was not a part of the design codes when the truss designs were done in the 1960's. Wind induced vibrations of the slender diagonal truss members are also believed to have been a large factor in the fatigue damage to poor quality or highly stressed welds.

Air Logistics Corporation was the first composite fiber application company to get involved with NYSDOT and the AASHTO Technology Implementation Group (TIG) for this problem. They noticed that FRP could probably be used to solve the diagonal to chord failure, so they developed a method to test. The procedure that Air Logistics came up with was sent to the University of Utah for evaluation.

Another company, Fyfe Company LLC, has since also developed a FRP repair system for NYSDOT which was tested for ultimate and service strength at NC State University. A second round of testing for fatigue is currently being planned.

The result of these tests is that FRP is a very attractive repair method. It is cheap, fast, and easy relative to other methods and it restores full strength to the connection. Therefore NYSDOT has approved and begun using these methods on their OSS.

Summary of OSS Damage in DE

An investigation of all sign structures and luminaries in Delaware by URS is currently in its fourth year of the five it will take to complete. So far only two real problems have been discovered. The more severe of them involves cracked anchor bolts in four-bolt anchored cantilevered signs. The repair for this involves taking the sign down and altering the design by adding more bolts to further distribute the load.

The other problem has arisen from the re-hot-dip-galvanizing of a few miscellaneous trussing elements on steel sign structures. This problem stems from the fact that when a structure is hot-dip galvanized without big enough weep holes to let the zinc out from inside the sign structure, the trussing members will bend and crack at the welded connection to the pole or chord.

No other problems have been prevalent so far, including the particular case of the diagonal to chord connection that was of much concern to New York and was anticipated to be the focus of this project.

While the Aluminum diagonal to chord connection for which much work has been done to repair in other states has not yet proven to be a problem in Delaware, this does not mean that it should be overlooked. The nature of fatigue is to accumulate damage over time. If it is simply the case that DE has not seen problems to date because their design is more robust, this does not rule out the possibility that damage is developing more slowly and will thus take more time to become evident. With this in mind, it becomes prudent to take a closer look at the repair methods available.

Non-FRP Methods

Currently, DOT's have two options when it comes to damaged OSS connections: re-weld the connection or replace the whole thing. Table 1 outlines the approximate cost of these options according to DelDOT.

<i>Description</i>	<i>Repair Cost</i>	<i>Additional Costs</i> (not included in repair cost)
Minor damage, fixed in-situ	\$1,500	\$1,200/lane shut down/day
Take OSS down to fix, Cantilever	\$3,500	\$1,200/lane shut down/day
Take OSS down to fix, Span	\$6,500	\$1,200/lane shut down/day
Replace OSS	\$65,000-\$80,000 approx.	

Table 1: Non-FRP Repair Figures

The total cost of these options is high, especially if the OSS needs replacement. Aluminum is hard to weld in situ, so the sign will most likely need to be taken down implying that traffic will have to be shut down more than once.

The repairs take time to complete and must be fit into a list of scheduled maintenance. If the damage is serious enough to warrant an emergency situation, extra costs will be associated with the replacement or repair needing to be put at the top of that list.

FRP Methods

The benefits of FRP repair methods include:

- Low cost (see table 2)
- Quick completion
- Less traffic disruption: only lanes directly beneath the repair need to be blocked, and the duration is shorter
- Easier than re-welding aluminum or rebuilding the sign

To date, only two methods of FRP repair have been developed and tested: one by Air Logistics and the other by Fyfe Co. Each of these methods has been designed and successfully tested to restore the connection to full strength, full strength being defined as the strength of an undamaged weld (see appendix for test reports and product brochures). However, of these two methods, only Air Logistics has completed a second round of testing for fatigue for which the results showed the FRP wrap holding up well over time. Fyfe Co. plans to conduct this second round of testing for fatigue soon. Table 2 outlines the costs and basic labor characteristics of these methods.

<i>Description</i>	<i>Repair Cost</i> <i>(Total, assuming just one lane shut down)</i>	<i>No. of Workers</i>	<i>Time to complete</i>
FRP repair, in situ			
Air Logistics	\$3,000	3	~2-3 hrs
Fyfe Co.	\$2,500	2	~2-3 hrs

Table 2: FRP Repair Figures

The approximate cost figures above include materials, labor, equipment, and traffic maintenance and protection (assuming just one lane is shut down). The work is done in-situ, and only the lane(s) directly beneath the damage need to be shut down. In fact, the cost of the actual repair is no more than the cost of shutting down the lane for the time it takes to complete.

Each company sells their product differently. Air Logistics sells the wrap material per-joint for \$395 and the chemicals for several joints for \$325. Fyfe Co. sells their product with wrap material and chemicals together for one joint for about \$200. Again, it is the labor and lane shut-downs that make up the bulk of the repair cost in each case, which make the above figures approximate since they are based more on soft costs than hard costs.

A Comparative Look

The basic characteristics of each product are outlined below.

Air Logistics Corporation

- 4 different types of *Glass* FRP weave in each joint
- Systematic application procedure involving spraying individual pieces with water and then applying them to the connection (pre-impregnated with epoxy)
- Wrap material available per-joint, chemicals available in bulk
- Employee training completed within one day by the company for minimal cost
- Minimum application temperature: ___°F (_°C)

Fyfe Company, LLC

- 1 weave of *Carbon* FRP used throughout
- Epoxy is rolled onto Aluminum, CFRP is applied and impregnation occurs with the use of rollers
- Wrap material and chemicals all available on a per-joint basis
- Employee training completed within one day by the company for minimal cost
- Minimum application temperature: 35°F (2°C)

As stated earlier, each company's method restores full strength to the connection. However, only Air Logistics has yet proven to be able to handle the stress fluctuations at service levels. This testing and its so-far-successful service has given the Air Log method a projected life of 5 years, which can only increase with continued successful service. The expected life of Fyfe Co.'s repair cannot yet be determined.

Conclusions

As of right now, if this repair needed to be done the Air Logistics method looks the most attractive. It is currently the only one with proven fatigue resistance, and according to NYSDOT officials its more systematic application procedure leads to more consistent results.

Once Fyfe Co. completes their testing, assuming it produces favorable results, the decision should be based on whichever method/procedure DelDOT feels more comfortable with. Although the Fyfe Co. materials run slightly cheaper, the overall cost is so low that it should not be the driving factor. The workers should be using whichever method they can most easily apply.

The AASHTO TIG offers demonstrations of each method to DOT's that I would recommend DelDOT take a look at. This would be a good way to determine which system is more comfortable for your workers to use. More information on the demonstrations or the TIG can be found at tig.transportation.org or by contacting Mr. Harry White of NYSDOT (hwhite@dot.state.ny.us). Also, please reference the brochures and reports included in the appendix and outlined below.

SSpecial thanks to Jason Arndt of DelDOT, Harry White of NYSDOT, and Sarah Witt of Fyfe Co. for providing the information and patience to complete this project. Also thanks to Dr. Bhattacharya of the University of Delaware for guidance beginning before the start and continuing beyond the finish.

Overview of Appendices

Appendix A: Air Logistics Corporation; www.airlog.com

- A1: Page from their website briefly outlining their product.
- A2: Repair Method Manual. This is the materials list and detailed set of instructions for their product.
- A3: “Repair of Cracked Aluminum Overhead Sign Structures with Glass Fiber Reinforced Polymers” Chris P. Pantelides, M.ASCE, Justin Nadauld, and Larry Cercone. This is the report for the first round of testing done on the Air Log wrap at the University of Utah. It describes the experimental setup and tabulates the resulting strength measurements for various repaired connections.
- A4: “Fatigue Tests of Cracked and GFRP-Repaired Aluminum Overhead Sign Structures” Chris P. Pantelides, Justin Nadauld. This is the report for the second round of testing at the University of Utah. It describes the experimental setup and tabulates the resulting fatigue resistance measurements for various connections under different loading conditions.

Appendix B: Fyfe Company, LLC; www.fyfeco.com

- B1: Product brochure containing both written and illustrated instructions for application.
- B2: “Experimental Testing of Aluminum Truss Joint Using CFRP Sheets” Dr. Amir Z. Fam, Dr. Sami H. Rizkalla. This is the report for the first round of testing done on the Fyfe Co. wrap at NC State University. It describes the experimental setup and gives resulting strength measurements.

Appendix C: AASHTO TIG

- C1: Fiber-Reinforced Polymer brochure outlining the benefits of FRP use for repairs.

Appendix D: Correspondence

- Included printouts of emails in which included information was provided but not found in reports

Appendix A

Appendix B

Appendix C

Appendix D

Appendix A

Appendix B

Appendix C

Appendix D

Appendix A

**NYS-DOT
AQUAWRAP[®] COMPOSITE
REPAIR METHOD MANUAL
FOR
HIGHWAY SIGN
ALUMINUM TUBE STRUCTURES**

CHECKLIST

Note: The numbers preceding items on this checklist correspond to the more detailed item's numbers, beginning on page 4.

WARNING: Harsh chemicals. At least

- Safety Glasses
- Chemical Gloves
- Tyvek Coveralls

are mandatory.

1. Drill crack ends.
2. Install absorbent pads
3. Scrub with Loyal 3020.
4. Rinse.
5. Acid etch with Alumiprep 33.
6. Rinse.
7. Abrade with 60-grit "emery paper" tape.
8. Rewet with fresh Alumiprep.
9. Rinse.
10. Air dry.
11. Apply 5/20 Epoxy Putty Stick.
12. Apply Alodine 1201.
13. Very thorough rinse.
14. Air dry.
15. Apply Primer.
16. Let Primer cure to tacky.
17. Open one Package A and dunk contents.
18. Wrap bonding areas of the small tube.
19. Open one Package B and dunk 2 short pieces.
20. Apply these Bear™ segments to both acute tube angles.
21. Open one Package C and dunk 1 long piece.
22. Apply this Bear™ segment between the branch tubes.
23. Open Package D, and dunk contents.

24. Apply these Backbone™ segments.
25. Tack down the Backbone™ with wraps from Package A remainder.
26. Dunk remaining 2 segments from Package B.
27. Apply over previous Bear™ like-segments, enclosing the Backbone™.
28. Do the same with the remaining segment from Package C.
29. Open Package E and dunk.
30. Completely wrap-encapsulate the repair.
31. Apply Stricture Banding™.
32. Apply backer rod and secure with Stricture Banding™.
33. Compress the backer rod with Stricture Banding™.
34. Ventilate the Stricture Banding™.
35. Allow to cure at least 1 hour.
36. Cut away or unwrap Stricture Banding™ and remove backer rod.

Allow composite to air dry and paint.

DETAILED PROCEDURE

1. Locate one end of the weld-crack. Center punch about 1/16" beyond that point, in the sound region of the weld metal. From the center punch mark, drill out the end of the crack, all the way through the weld with 3/16" drill bit. Find the other end of crack. Repeat.¹
2. Install the large 3 x 5-ft absorbent mat (fuzzy side up) in a way so that it will catch all drips and runoff from the following steps. Extra absorbent loose pads should be placed on top of the absorbent pad; and, if required, wrapped around the structure chord or struts to block any liquids that might run off that way.
3. Scrub the bonding surfaces² with Loyal 3020 (128:4 dilution with water:3020) using Scotch-Brite 420/425 scrub sponges and Norton Bear-TEX 74000 scrubbing pads. This is continued until no more oxides seem to be coming up.
4. Thoroughly water-rinse. Change to a new pair of (outer) gloves.
5. Acid etch the bonding surfaces with Henkel Alumiprep 33 (2:1 dilution with water:33) using a clean Scotch-Brite sponge scrubber-side and a clean Bear-TEX pad. Scrub the bonding surfaces well while wet with the Alumiprep. Dwell time 3 minutes. Keep rewetting with Alumiprep if drying occurs during the dwell time.
6. Thoroughly water-rinse.³
7. Abrade the bonding surfaces with Norton 2" E-Z Flex Metalite 60-grit "emery paper" tape, P/N 27733, until all bonding surfaces have thorough scratching, transverse to the load axis⁴, and until there is no remaining oxide discoloration anywhere (except possibly in the deepest weld bead grooves and any cracks.)
8. Rewet with fresh Alumiprep, using a clean sponge. Dwell 3 minutes.
9. Thorough water rinse. Change to a new pair of (outer) gloves.
10. Air dry. Check any deep weld bead grooves and cracks for trapped water. The corner of a clean towel may be needed to pull excess water from these areas. The following step will fail if the tubes are not dry.

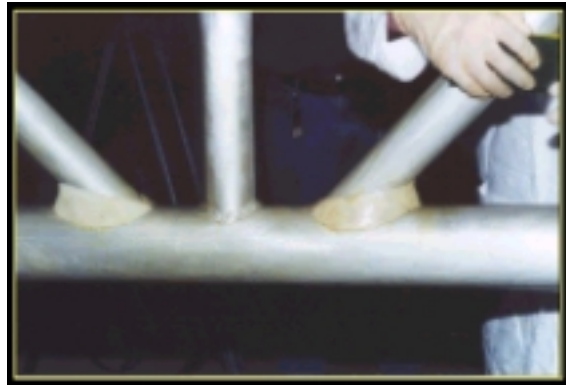
¹ From this point forward it is important to constantly wear clean chemical-resistant gloves. Always change to new clean gloves between the various chemical application steps so that cross-contamination does not occur. Although the same glove set can be used for the entire Aquawrap® layup, change them if there is any sign of dirtiness or if they hole through at any point.

² For most applications, the "bonding area" to be cleaned extends 18-in out from the welds, and the area between the tubes.

³ From this point forward, any accidental touching with bare hands, dirty gloves, etc., will require an acetone wipe of the contaminated area.

⁴ Generally this means to abrade so that the scratch marks go around and around the tubes, as opposed to along their long axis.

11. Apply a coving into both of the acute-angle joints of the small aluminum tubes, using one 7" long 5/20 Epoxy Putty Stick per joint. Smooth and feather edges. Let cure to "finger nail indentation hard" (about 10 minutes at room temp.) This procedure is best done mixing only a half of the Epoxy Stick at a time and only addressing one joint angle at a time.



12. Wet out bonding surfaces with Henkel Alodine 1201 (full strength) using a new, clean sponge (no abrading at all.) Dwell time 2 minutes with constant rewetting.
13. Very thoroughly water-rinse. Wipe down with clean white towels until no more color runs off or lifts from the bonding surfaces. Rinse again. Change to a new pair of (outer) gloves.
14. Air dry. (Check any deep weld bead grooves and cracks for trapped water. The corner of a clean towel may be needed to pull excess water from these areas.)
15. Apply thoroughly mixed⁵ Air Log Base Primer #1 to bonding surfaces with hand paint brushes. Lay down a general thin coat with extra heaviness dabbed in around the welds/epoxy putty areas.
16. Let Primer cure until just beginning to get tacky – usually 5 to 10 minutes.
17. Open one Package A of the 3" wide, 11 oz. standard Aquawrap® and water-submerge the contents for 1 minute. {3 x 10} (You will not use all of this roll for the next step. Save the remainder for Step 25.)

18. Use this roll to tightly wrap the bonding areas of the small tube(s) with a single layer. Starting from the epoxy putty line, use a helical (bandage) wrapping method with no edge overlap, thereby creating as smooth and flat a first composite layer as possible. Cover 1-foot. Save the balance of this roll for use later in this procedure.



19. Open one Package B of the segments of 4" Bear™ Aquawrap®. Take out two pieces and water-submerge them for 1 minute. Leave the remaining pieces inside the foil bag and roll the top down on the bag to protect from moisture.

⁵ It is very important to mix the individual containers of Part A and Part B before combining them, and mixing them together. Try to avoid "whipping" the mix when stirring. During application, if the primer starts to foam up, "swizzle" the paint brush in the mix. That will break up the foam and allow you to quickly complete the application.

20. Apply these activated Bear™ segments in both acute angles of each branch tube, in line with the centerline of the main header tube. “Saddle in” these Bear™ segments so that they lay down smoothly and so that they fully cover a bit more than half the small tube.

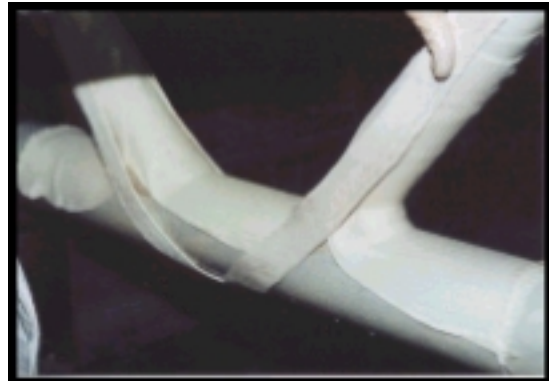


21. Open one Package C of the segments of 4” Bear™ Aquawrap®. Take out one piece and water-submerge it for 1 minute. Leave the remaining piece inside the foil bag and roll the top down on the bag, as above .

22. Apply this activated Bear™ segment into the obtuse angle between the branch tubes. “Saddle in” this segment also, and overlap the previously applied Bear™ slightly.⁶

23. Open Package D, containing the 1” Backbone™ Aquawrap® tendon segments and water-submerge them for 1 minute.

24. Starting at the end of the bonding area of the small tube, lay on a Backbone™ segment down a face-side of the small tube, crossing under the header tube and continuing up the other face-side of the small tube. For adjacent small tubes, use two Backbone™ segments and have one end of a segment layed up onto a face-side of one small tubes, crossing around the header tube backside midpoint (opposite where the small tubes join the header), then continuing up the face-side of the opposite side of the adjacent tube. Repeat with a second segment, starting and ending on the unoccupied faces of both tubes. The segments will form an “X” crossing on the backside of the header.



25. Using the remainder of the roll from Step 17, secure the ends of the Backbone™ to the sides of the small tubes with a wrap of 3” 11 oz. Aquawrap®. On some sign configurations you may have to open a new Package A. Note: Packages F also contain 3” x 10-foot rolls of 11 oz. Aquawrap®. These are “spares” which may be necessary to finish off certain configurations of tube intersections.



26. Take the two remaining pieces of 4” Bear™

⁶ If necessary to “hold things in place” a band of the Package A material can be wrapped around any Bear™ or Backbone™ layers to keep them positioned properly while the layup continues.

Aquawrap® from the previously opened Package B and water-submerge them for 1 minute.

27. Lay down these activated segments of 4" Bear™ over the top of the previous Bear™, and saddle in these segments so that they enclose the Backbone™ tendons and slightly overlap each other.
28. Do the same with the remaining long strip of 4" Bear™ from the previously opened Package C.
29. Open Package E of the 3" 11 oz. Aquawrap® and water-submerge the contents for 1 minute. {3x25}

30. Starting at the joint crotches, completely wrap-encapsulate all of the composite layup with this 11 oz. Aquawrap®. You may have to use the Packages F or the second Package E to finish off this step. Be sure to water-submerge them prior to use.



31. Tightly stretch and apply Stricture Banding™ on all Aquawrap® straight tube surfaces, covering these areas with at least two Stricture layers. Stricture applies best if it is wound over the Aquawrap® in the same direction as the Aquawrap® was wound. The purpose of the Stricture Banding™ is to be stretched and tightly compress the layup. It is not to be just unrolled and laid down onto the composite surface as a no-stress covering.

32. Wrap the weld joints with 1" Mile High Foam backer rod and secure with a loop of Stricture Banding™.



33. Tightly overwrap the backer rod with Stricture Banding™ so that the backer rod is loaded downward into the Aquawrap®, pressing it into the surfaces at the crotches of the welded joint(s). This requires at least two layers of Stricture Banding™.

34. Ventilate the Stricture Banding™ at several locations by poking holes in it, using the point of a sharp knife. This allows curing bubbles and excess water to escape.

35. Allow to cure at least 30 minutes or until hardened.

36. Cut away or unwrap Stricture Banding™ and remove backer rod.⁷

Allow composite to air dry and paint if desired.

⁷ If cutting away Stricture Banding™, do not nick or cut the composite surfaces. Use of "EMT bandage-cutting safety shears" is recommended for any cutting of Stricture Banding™.

Appendix B

Appendix C

Appendix D

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AN EQUAL OPPORTUNITY/AFFIRMATIVE ACTION EMPLOYER

The University of Delaware is committed to assuring equal opportunity to all persons and does not discriminate on the basis of race, color, gender, religion, ancestry, national origin, sexual orientation, veteran statutes, age, or disability in its educational programs, activities, admissions, or employment practices as required by the Title IX of the Education Amendments of 1972, Title VI of the Civil Rights Act of 1964, the Rehabilitation Act of 1973, the Americans with Disabilities Act, other applicable statutes and University policy. Inquiries concerning these statutes and information regarding campus accessibility should be referred to the Affirmative Action Officer, 305 Hullihen Hall, (302) 831-2835 (voice), (302) 831-4563 (TTD)

