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Transportation Research Division

Technical Report 10-03

Culvert Rehabilitation & Invert Lining using Fiber Reinforced Polymer (FRP) Composites

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Transportation Research Division

Culvert Invert Lining with Fiber Reinforced Polymer (FRP) Composites, Route 9, West Branch Half Mile Pond Brook, Amherst, Maine

Introduction

As part of the state of Maine bridge funding initiative, MaineDOT has partnered with the University of Maine's AEWC Advanced Structures and Composite Center and the Maine composites industry to incorporate composite technologies into bridge construction and maintenance activities. The goal of the partnership is to utilize composite technology for bridge construction, bridge component parts, small ferry vessels and a number of other transportation applications, building on the knowledge gained through research projects. The partnership seeks to focus and accelerate the application of fiber reinforced polymer (FRP) composite technology to meet transportation project needs, and to play a role in assisting Maine's composite industry.

Composite materials are a construction technology that may provide an option in certain circumstances. This report concerns a pilot project where composite materials were used to re-line the invert of an existing steel corrugated culvert. The project was unique in that fish ladders and weirs were also designed into the project.

Problem Statement

Corrugated metal plate (CMP) culverts are a common means of spanning streams. Over time the culverts eventually corrode and weaken. The culvert invert is frequently completely eroded due to abrasion and corrosion. Replacement of CMP culverts is expensive, especially for deeply buried spans. Current rehabilitation options such as reinforced concrete liners can extend the life of the culvert, and require significant in-stream work periods. The objective of this project was to develop a composite culvert rehabilitation methodology which could compete favorably with existing rehabilitation techniques, in regard to project costs and environmental impact.

Project Information

In 2009, an 8' diameter x 130' long dual pipe culvert bridge was rehabilitated using FRP composite panels. The site is located about three miles east of the Amherst town line on Route 9. The westerly culvert pipe handles the main flow of the West Branch Brook while the easterly pipe is intended to handle overflow. The MaineDOT Project Identification Number (PIN) is 15642. The field construction period, including mobilization and demobilization occurred from August 31, 2009 until October 2, 2009. The overall project was completed in Phases; Phase 1 included the initial design, laboratory testing, manufacture mock up parts, development of specifications. Phase 1 provided information needed for the contractor to provide a detailed bid for the manufacture and installation of the FRP liner panels & weirs at the demonstration site. Phase 2 of the project was the construction & installation at the project site.

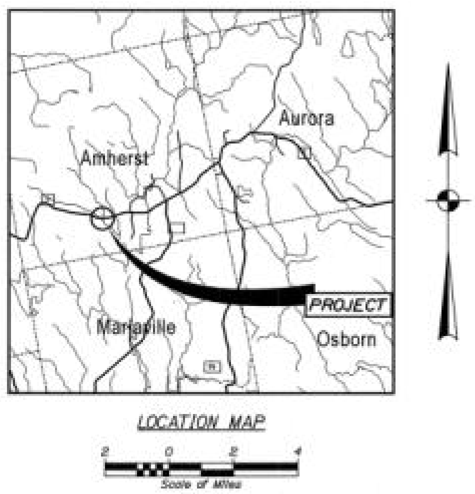

Figure 1. Project Location

Phase I – Design, Analysis, and Testing [1]

The initial design data was developed by a partnership between Kenway Corporation and the University of Maine. Information in this report has been taken from the report footnoted below, and information provided by Kenway Corporation.

Figure 2

AEWC and Kenway designed the FRP panel and connection system specifically for conditions at the Amherst job site. Lessons learned from Phase I of the project were used to identify and incorporate potential improvements to the FRP system into Phase II. These improvements affected the performance, manufacturability, and constructability of the Hybrid System. AEWC developed drawings and performance specifications to support fabrication and installation. Initial analysis & testing resulted in a design recommendation. Factors such as, the existing structure, design loads, environmental concerns, ease of installation, durability, low weight, and improved performance were considered. A panel design was recommended, including fiber reinforcement architecture and resin selection, structural connection system design and candidate options for use in material/component tests. The strength, stiffness, and durability predictions were next validated through

[1] Information taken from, **Concept Development of a Hybrid Composite Bridge Culvert Rehabilitation System, AEWC Report 09 – 43, Project 683, May 15, 2009, University of Maine, Advanced Engineering Wood Composite Center.**

the manufacture and testing of several full scale test panels. This confirmed the performance for the development of the specifications for full size components

AEWC conducted full scale testing of a six foot diameter culvert to demonstrate the performance of a baseline steel plate culvert and the hybrid system. The scale models were approximately 8 feet long with roughly the bottom quadrant replaced with FRP panels. The test fixture simulated soil boundary conditions and applied the equivalent design load using a servo-hydraulic actuator.

Upon the satisfactory completion and acceptance by MaineDOT of Phase 1 results, Kenway Corporation developed and then provided a detailed price quote for the manufacture and installation of a complete FRP rehabilitation system defined as Phase II.

Phase 2- FRP Installation, Re-lining of Culvert & the Construction of Weirs

Liner panels

Kenway Corporation manufactured and installed the FRP hybrid liner system in both culverts of the dual pipe system. The FRP panels were made of a fiber reinforcement and vinyl ester resin, that was chosen as an economic solution for abrasion and corrosion resistance. The nominal thickness of the panels is ¼" (0.250"). The panels were anchored into position using a powder actuated system utilizing special fasteners, together with steel washers. The space between the FRP panel and the culvert was filled with a Portland cement based grout mix.

Internal Weirs and Stilling Pools

The project utilizes fish passage stilling pools and weirs. The entire system is a hybrid design of FRP, rebar and concrete. Concrete for the stilling pools was Class A concrete. In addition nine internal FRP weirs were placed in the West culvert. Each weir incorporates an adjustable notched weir plate. A fixed weir with no notch was installed at the upstream invert of the East culvert. The external FRP weir system consisting of seven round stilling pools connected together with FRP spouts. Each spout has a curved, notched weir plate that is fully adjustable. Each pool has a minimum depth of 3'-0"of water to allow for the energy dissipation required for fish passage. The external weirs were installed at specified water and spout elevations.

Repair of Overhead Damage in East Culvert

Two FRP panels and grout were placed covering the affected area inside of the East culvert. The panels, attachment and grouting was the same as on the invert reline.

Supporting Work by MaineDOT

MaineDOT provided labor, equipment and materials for the associated construction tasks such as:

- Excavation required for the installation of the external weir system
- Assistance in placement of concrete, stone and backfill in the external weir system.
- Removal and proper disposal of all vegetation and trees
- Removal and re-installation of guard rail to allow for access
- Install of all environmental controls required in keeping with the Environmental Best Management Practices.
- Installation of temporary coffer dams required to divert flow from the stream
- Installation of all equipment and piping required to divert flows and keep the culvert areas free of water.
- Purchase and placement of approximately 182 yards of heavy rip rap
- Traffic control as required by the activities of this scope of work.

- Reseeding and planting necessary to restore the work site.

Detailed Views

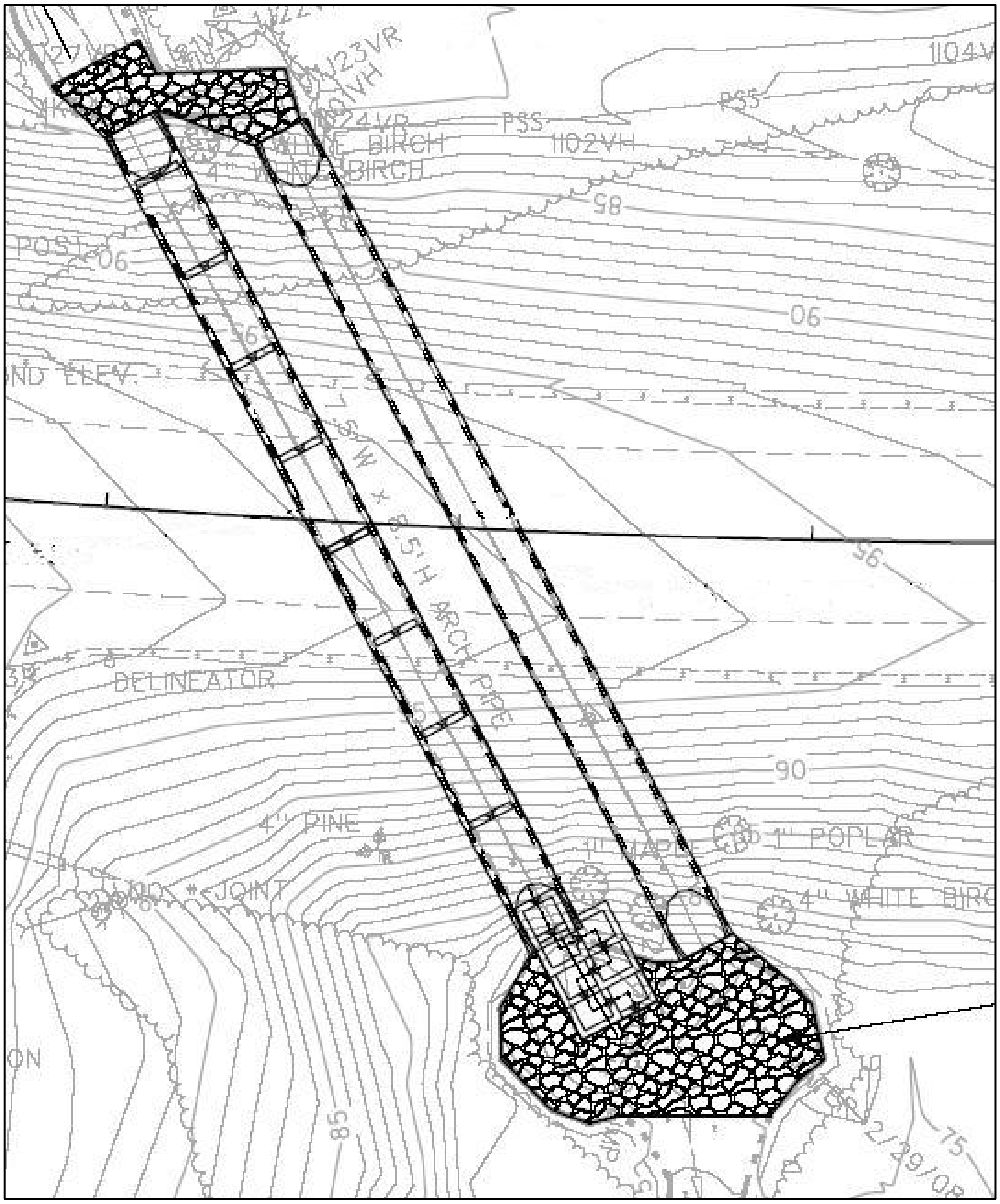

Figure 3- Plan View

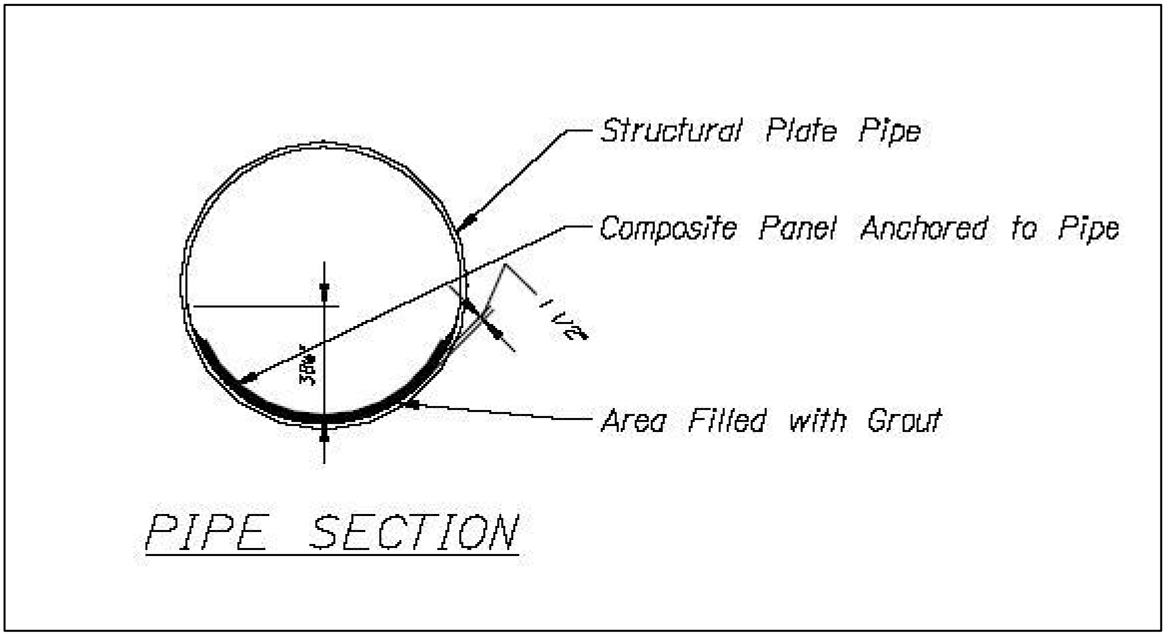

Figure 4

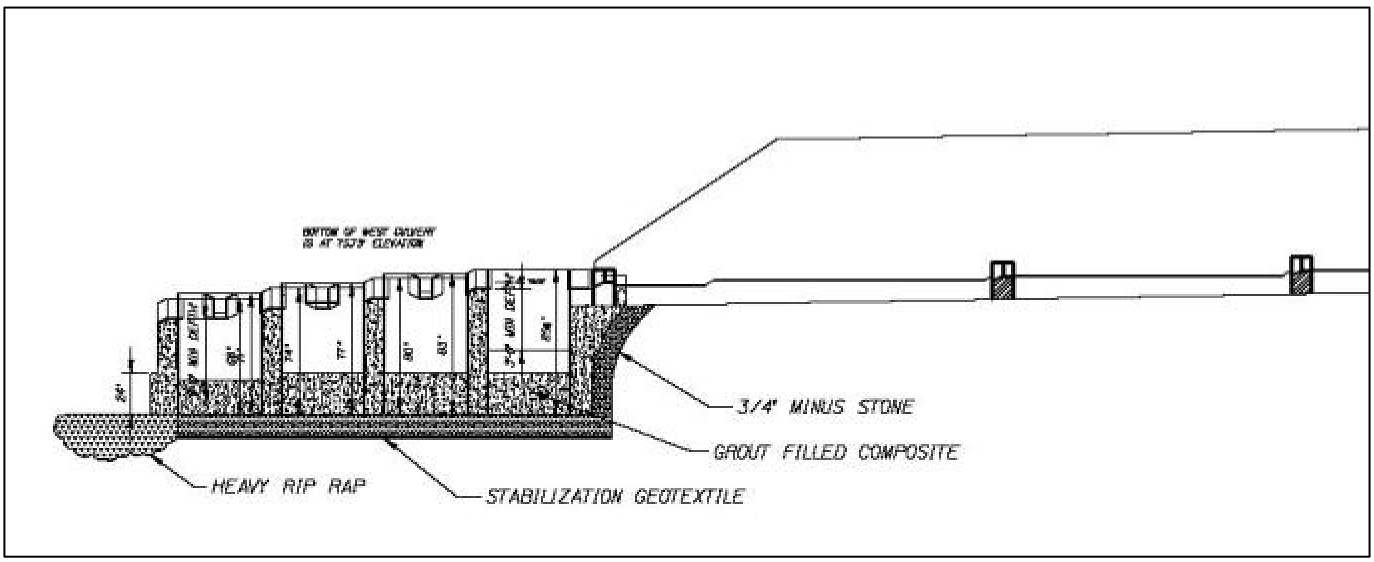

Figure 5- Elevation View at Outlet End

Project Evaluation

Overall the project proceeded quickly. Several lessons were learned from specific problem areas as discussed below.

Panels

A wheeled lift was used to transport the panels from the highway to the culvert ends. From there the panels were carried into place manually. Manual positioning of these panels inside the culvert was a little awkward. This problem was solved by using a wheeled dolly so that the panel could be rolled into position. As a result of initial difficulties, only three panels were installed on the first day, however this daily production increased to five. Panels were installed as they were delivered from the plant without stockpiling many panels on-site. Panel production at the plant was not optimum due to the uncertainty that last minute adjustments to panels might have to be made based on installation difficulties. No major problems occurred, however, and the confidence gained by doing this project might lead to a faster installation on a future project.

Grout & grout placement

The first attempt at pumping grout failed because the rotor stator pump supplied by a subcontractor would not pump the grout mix. A second subcontractor supplied a piston pump that was able to do the job. Another problem arose because the grout supplier sent an out-of-spec mix that included stone aggregate. The stone caused problems in both the pump and the lines. The grout supply line was prone to plugging at pipe reductions. The contractor improvised a piece of perforated steel plate to screen out the aggregate that was too large to pump. In the future, grout supply lines of uniform diameter should be used.

Concrete & Concrete Placement

The pump supplied by MaineDOT to get the concrete into the forms (for the stilling pools) did not function properly. The hose continually plugged. Concrete had to be carried to the forms with the excavator bucket until a concrete bucket could be obtained. In placing concrete with an excavator there is some risk of aggregate segregation, however this temporary measure worked satisfactorily.

Flooded worksite

Heavy rainstorm events caused a large increase in stream flow. A 4 inch pump used to de-water the stilling pool site was inadequate. In fact, at one point even two 6 inch pumps had difficulty keeping up with the storm flow. The amount of runoff and the storm events were underestimated. The worksite also flooded on another occasion due to overnight pump failure.

Environmental Considerations

One of the benefits of using FRP panels is the resulting small increase in invert elevation. The final invert height is only a few inches above the existing culvert elevation. If fish passage considerations dictate a minimal invert increase, then this FRP reline technique could be considered. Fish passage concerns may dictate future replacement options in some locations. This consideration may limit increases in invert heights above the natural stream bed elevation.

Service Life

The exact service life of concrete culvert rehabilitation depends on many factors. It is believed that a concrete culvert rehab may give a service life of a few decades. The composite industry estimates that the life of composite materials will exceed that of concrete. Given the limited data on this technique, no conclusions can be made at this time. Projects like this one will yield performance data on which to evaluate future performance. The FRP reline was a relatively faster process than using concrete, with less risk of washout during storm events. These factors must be evaluated on a case by case basis for potential applications of this type.

Costs

This project was a “first-of-it’s-kind” project, therefore a cost comparison with a conventional culvert rehabilitation project is difficult. Future costs for this type of treatment might be less, given the experience gained on this installation and increased production volume.

The total cost for this project was $325,000. The cost, excluding the initial research & associated work was around $276,000. The relining portion of the project by itself was about $157,000 excluding the weir system, for both culverts, or about $600 per lineal foot per individual culvert, excluding any additional overhead patching or external pools. These costs are favorable given the environmental challenges of providing fish passage together with the limitations on invert elevation increase.

Construction Photos

Figure 6- Existing Outlet before Project

Figure 7- Westerly Outlet prior to Construction

Figure 8- Existing Downstream Pool below the Outlet

Figure 9- Corrosion of Corrugated Culvert

Figure 10- Excavation for the Stilling Pools at the Outlet End

Figure 11- Limits of Excavation for Pools

Figure 12- Holes in Bottom of Culvert; Stones and Sub Soil Visible

Figure 13- Corrosion on Culvert Walls & Top

Figure 14- Patching Applied to Corroded Areas in the Invert

Figure15- Stack of FRP Panels as Delivered from the Plant

Figure 16- FRP Baffles with Notched Weirs

Figure 17- Lowering a Panel into Culvert Opening

Figure 18- A Wheeled Lift Used to Move Panels to Mouth of Culvert

Figure 19- Manually Carrying A Panel into Culvert

Figure 20- Fastening Panels to the Steel. (The Type of Fastener is shown below)

Figure 21- Progression of Panel Placement

Figure 22- Application of Final Topcoat on the Internal Weirs (Baffles)

Figure 23- Completed Installation

Figure 24- Initial Water Flow after Completion

Figure 25- Base & Forms for Pool System

Figure 26- Pool System after Being Lowered onto Concrete Base

Figure 27- Placing Concrete around the Pool System

Figure 28- Perspective of Completed Culverts & Pool System

Figure 29- Stream Flow Restored

Conclusions

Inspection of the project after the first winter and spring runoff shows the system to be in excellent condition. These culverts are inspected by MaineDOT Bridge Maintenance on a two year cycle. Performance of the liner and weir system will be evaluated and any problems or concerns noted. This project demonstrated the feasibility of FRP for culvert relining. The cost analysis shows that depending on the location, environmental factors, and condition of the culvert, the FRP process can compete with conventional culvert rehabilitation methods.

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Credits

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