Using FRP for Large Diameter Sewer Rehabilitation

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Carbon and glass fiber reinforced polymer (FRP) have been used for infrastructure for more than three decades, and applications in pipeline rehabilitation have gained momentum in recent years. The advantages these systems can provide include high strength, light weight, and ability to be installed on essentially any type of pipe material, size, and geometry.

The common practice for an FRP system design entails accounting for carbon layers only. While carbon fiber is extremely strong in tension (200,000 psi ultimate tensile strength and above), it is not as strong in compression (typically about 50 percent of tensile strength or less). As such, if the external load on a pipe is significant, such as with deep gravity sewers, then a stand-alone design carbon FRP (CFRP) system will result in too many layers of carbon, along with a price much greater than other alternatives. This has been the primary reason for FRP systems not being able to find many applications in wastewater and stormwater infrastructure rehabilitation.

The situation is changing with the latest advents in the FRP industry, however. One example is a sandwich structure system originally developed by Prof. Mo Ehsani, a pioneer in the application of FRP for large structural repair. Ehsani utilized the I-beam concept for the FRP liner profile to increase ring stiffness without using excessive layers of carbon fiber laminae. This concept was developed into a pipe (StifPipe®) and has been used in a number of applications over the years.

The first tier of StifPipe applications were made using a "mini I-beam" fabric sandwiched between glass and carbon fiber polymer layers. Then, after much testing and evaluation, the manufacturer (QuakeWrap, Inc.) moved to a proprietary 3D fabric that has the capability to absorb more epoxy resin, thereby giving it more ring stiffness without a significant increase in weight (Figure 1).

Depending on the design, a typical pipe stiffness (PS) value for StifPipe would be 75, but it can be made stronger by adding more

Figure 1. Graphical depiction of StifPipe® with carbon (black), glass (yellow) fiber and the proprietary 3D-core layer (white) in between.

Figure 2. A post-installation picture from the first application of StifPipe® by sliplining. Note the grout injection port used to fill the annular space.

layers. StifPipe weighs about a tenth of a reinforced concrete pipe (RCP) of equivalent strength. This enables installation of StifPipe without any jacking equipment for diameters up to 72-inch. Design considerations include factoring in any excessive axial forces, which could require additional layers to prevent axial buckling in a pipe that otherwise has a small wall thickness to withstand external and internal pressure (for force mains and surcharge conditions).

The first installation of StifPipe with the sliplining method dates back to 2012 for a 48-inch wastewater pump station discharge line in Avalon, California. The outside diameter (OD) of the StifPipe segments used was 47 inches, and the one-inch annular space was filled with non-shrink grout (Figure 2). This first installation was followed by multiple other sliplining applications, mostly in stormwater lines and culverts up to 70-inches in diameter.

NEW INSTALLATION CHALLENGES

In 2018, QuakeWrap started exploring the idea of building a StifPipe inside an existing pipe as a cured-in-place installation. In other words, this would be applying the conventional FRP installation technique (wet layup) with the resin rich 3D core fabric. The main installation challenge for the wet layup application of StifPipe is making sure the surface prep is done properly. This applies to all types of FRP installation.

A unique challenge for the new StifPipe installation is making sure the thick and heavy 3D core layer is saturated with epoxy

Figure 3. Installation of StifPipe® with the wet layup method in a 66-inch RCP storm sewer.

completely, and applied properly on the preceding layer. There is no saturating machine produced for this type of thick fabric; therefore, the current practice is infusing the resin with ribbed rollers. Quality assurance is performed by weighing the saturated fabric.

Following several successful mock installations at QuakeWrap's R&D facility, the first project with the wet layup was carried out in New Jersey (for Middlesex County) to repair a 66-inch storm sewer pipe (Figure 3).

The installation went smoothly and QuakeWrap has completed several projects ever since with this method, including a 12-ft diameter, 100-120 ft. deep stormwater tunnel under I-35 in Minneapolis, Minnesota.

CASE STUDY: ERODED STORM TUNNEL

The I-35W/I-94 tunnel system in Minneapolis ranges in size from 8 to 14 feet (2.4 m to 4 m) in diameter and varies from 50 to 130 feet (15.2 m to 40 m) underground. Cycles of pressurization and depressurization have led to structural distress of the liner and subsequently caused erosion of the friable St. Peter sandstone in which the tunnel was constructed.

To temporarily restore structural integrity, an external void grouting and crack sealing program was enacted by officials to prevent further structural damage to the tunnel. This grouting program was successful for the most of the tunnel system, except for a segment that was experiencing high groundwater pressure, inflow and a noticeable decrease in effective liner thickness. As such, this segment of 12-foot diameter, at approximately 100 feet below grade level, needed a structural repair. StifPipe was selected by the project engineer (Brierley Associates) for this repair with high loads and limited access.

The proposed design called for a structural rehabilitation system that can be conveniently conveyed to the repair point, which is more than 100 feet below ground with the nearest access hole 3,250 ft away. As such, an FRP solution was an ideal fit with components delivered to the location of repair in boxes (fabrics) and drums (resins). Due to the high external loads, a conventional FRP system would require excessive layers of carbon fiber laminae to meet those loads for a stand-along design. As such, the more economical FRP composite StifPipe was proposed in lieu of a conventional carbon fiber only design. Despite the high design loads, the total thickness required for the StifPipe system was only 1.47 inches.

The wet layup method was used for installation (Figure 4), and the space inside the concrete tunnel was sealed-off with plastic sheets to obtain a humidity- and temperature-controlled environment. Water (groundwater and small amount of snow melt) that gathered upstream at a bulkhead was pumped through the scaffolding in the repair area using bypass pipes. Moisture and temperature readings along with pull-off tests were continuously recorded during the installation process, and work was overseen by inspectors from the engineering firm (Brierley) and the owner, Minnesota Department of Transportation (MnDOT).

Figure 4. Installation of composite FRP system in a 12-ft tunnel in Minnesota.

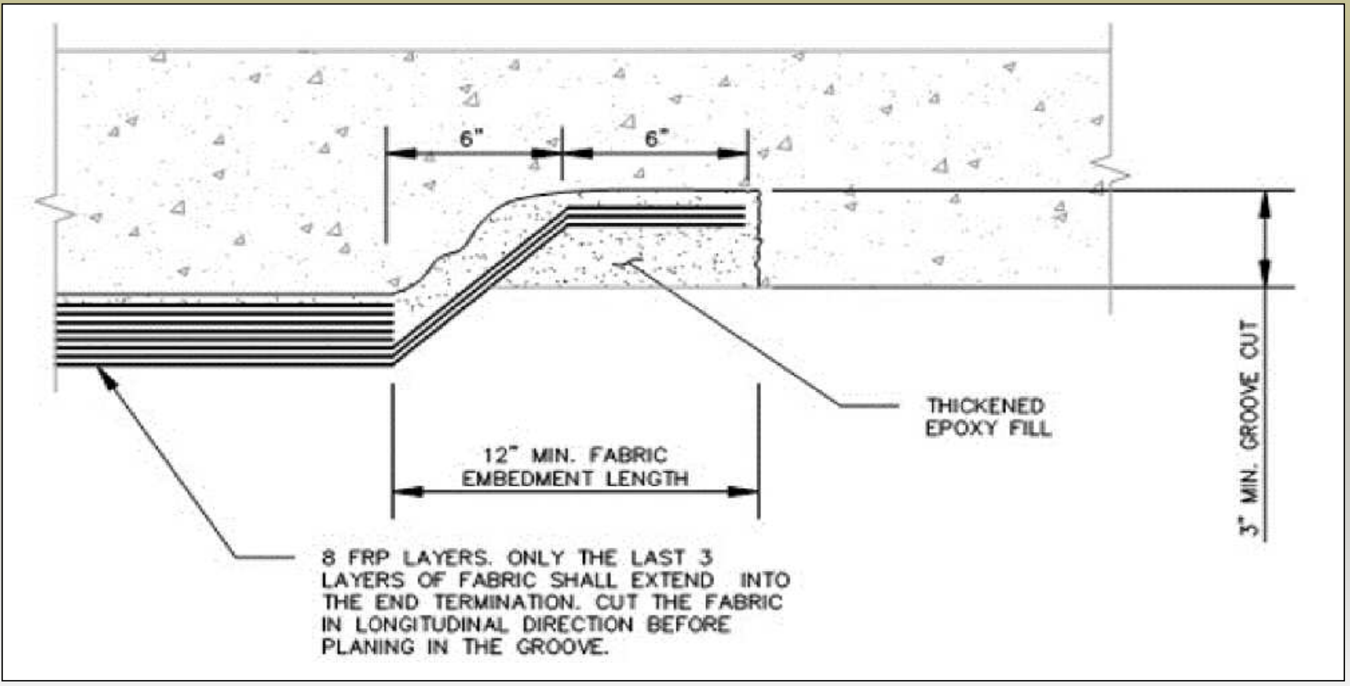

Figure 5. Termination detail for the 8-layer StifPipe® used for the I-35 tunnel repair.

The installation company, FRP Construction LLC, first implemented surface prep by applying a primer, then installing the StifPipe fiber reinforced polymer (FRP) system comprising eight layers including carbon fiber, glass fiber, and the proprietary 3D fabric for increased stiffness. Three layers of FRP were tucked into the groove cuts into the concrete tunnel liner and filled with thickened epoxy at the termination points to ensure no water would seep behind the FRP linings system (Figure 5).

MINIMAL SERVICE INTERRUPTION

One challenge the project team faced was to complete the installation in the short time period before the snow above ground melted and substantially increased the flows and pumping costs. The ambient temperature was 63° Fahrenheit; heaters were deployed to increase the temperature to 75° for accelerated cure. Under these circumstances, the epoxy resin used to saturate the FRP layers were dry to the touch within a couple of hours and the storm tunnel was ready to be returned to the service the next day.

The installation was completed ahead of the schedule for spring rain and melting snow. The project was completed with success and without any significant issues encountered at the site. The I-35 tunnel repair project marks a record as the deepest application of an FRP system for fully structural pipe/tunnel rehabilitation. The StifPipe design enabled a feasible and economical solution for such high external loads and a limited access to the repair site.

FRP systems are continuing to provide a viable alternative for pipeline rehabilitation, and the use of FRP systems for particularly large diameter pipelines is growing. Nevertheless, better design practices and education of the end users are needed to get the best out of these high-tech materials in achieving cost competitiveness. Consequently, National Association of Sewer Service Companies (NASSCO) is in the process of publishing a Guideline Specification for rehabilitation of sewers with FRP. With such initiatives to improve design and installation practices, it is fair to assume that the use of these materials will also grow in the gravity flow pipe systems (mainly storm and sanitary sewers) given the advantages they provide.

Dr. Firat Sever, a Professional Engineer licensed in several states, joined QuakeWrap in 2018 as head of its expanding Pipeline Division. More information on StifPipe can be found at www.pipemedic.com.