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A New Solution for Reconstruction of Deteriorated Pipelines

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Abstract

Pipelines are a major component of the infrastructure that often get damaged by corrosion. In many cases, the repair may require restoring the strength of the pipe to its full original capacity, including the effect of external gravity loads. Access is always a challenge as these structures are buried deep and cutting trenches to replace the damaged pipe can add significant cost and time to the project.

This paper introduces a new type of FRP pipe that utilizes sandwich construction technique to achieve high stiffness for the pipe. The technique received the 2016 ASCE Innovation Award as the world's first green and sustainable pipe. This technology allows the construction of a fully structural pipe below ground, using the host pipe as the formwork.

In addition to the discussing the development of the technique, several recent projects that were successfully completed are presented. These include pipes with diameters ranging from 900-3650 mm (36-144 in.) and include pressure and gravity flow pipes carrying potable water or storm water.

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Introduction

Repair of large-diameter pressure pipes with FRP started in the late 1990s. Using the wet lay-up technique, workers install resin-saturated layers of carbon or glass FRP on the interior surface of the pipe. The FRP serves as a strengthening material to compensate for the loss of strength in the pipe caused by corrosion of steel; it also provides an impervious barrier to keep moisture away from the underlying steel. As an added advantage, the smooth surface of the FRP reduces friction in the pipe and can therefore increase the flow capacity.

The largest reported application of this system is on a 1750m (1.1 mile) concrete pipe with a diameter of 2100mm (83 inch) in a mountainous region of Costa Rica [1]. The penstock at El Encanto Hydroelectric Power Plant was constructed onsite using local concrete and laborers. During the testing phase of the pipe, it was realized that there were millions of holes in the pipe, rendering the penstock useless. The pipe was repaired by applying glass FRP to the interior of the pipe. The project was successfully completed in 3 weeks and it was recognized by two international awards; a video of the project can be seen here: http://tinyurl.com/y332hdnk

Fig. 1. The longest reported penstock repaired with FRP.

In most repair cases, one or two layers of carbon FRP are enough to provide significant hoop strength and pressure rating for a deteriorated pipe. This typically leads to a cost-effective solution. However, in recent years, some pipe owners make the conservative assumption that at some time in the future, the host pipe will be so deteriorated that it will offer no resistance to carrying internal or external loads. In essence they require a repair system that not only takes the internal pressure, but also all external loads from soil, traffic, etc. The latter is controlled by buckling of the liner and requires a thick liner with high stiffness. To achieve this, some FRP contractors have used many layers of carbon FRP to make a 15-20 mm liner in the field; projects where 15 layers of carbon FRP have been applied on larger diameter pipes are not uncommon. But these solutions become extremely costly and time-consuming to install. That is why the writer developed a new repair system that uses the sandwich construction technique as described below.

Development of StifPipe®

The concept of an I-beam and the efficiency in terms of weight to stiffness that it offers has been used extensively in the construction industry. However, the pipeline industry has taken little benefit from this knowledge. Nearly all pipes are made with solid walls of concrete, steel, HDPE, etc. that become very heavy. Some GFRP pipe manufacturers such as Hobas do use glass fibres as the skin for the pipe interior and exterior surface. But they use a mix of mortar and resin as the centre core for the wall of the pipe; this results in a heavy and solid wall for the pipe.

Recently, the concept of a sandwich construction pipe was introduced [2]. In this technique a lightweight core is used to serve as the web in an I-beam; layers of glass or carbon FRP are applied to the core and these serve as the flanges of the I-beam. Figure 2, shows two layers of carbon FRP with a total thickness of “T” bonded together, providing a reference stiffness value of unity. If these two layers are separated from each other using a lower cost material, the stiffness of the new system becomes significantly larger, while the change in weight is negligible.

The construction of StifPipe® begins by building a mandrel that is the same shape and size of the pipe being made. Various layers of glass or carbon FRP and the core material are wrapped around the mandrel. The resin cures in about 18 hours in ambient temperature; heating the mandrel can expedite the curing process. Next, the mandrel is collapsed, and the finished pipe is removed and stored away. This technique allows building in pipe segments in lengths up to approximately 7 m (23 feet) long.

By adjusting the telescopic arms of the mandrel, various shape pipes including non-circular shapes shown in Fig. 2 can be built easily. Currently, there are no such pipe manufacturers in the U.S., and when a non-circular pipe requires repair, the FRP pipe segments must be purchased from overseas and that adds significant cost and time delay to the project. The versatility of the mandrel also allows customization of the pipe to any size. This feature minimizes the loss of capacity of repair in slip-lining projects when pipe segments are inserted into the host pipe and the annular space is filled with grout or resin. Conventional pipes that are offered in 6-inch (150-mm) diameter increments, often result in significant loss of capacity in the pipe being repaired.

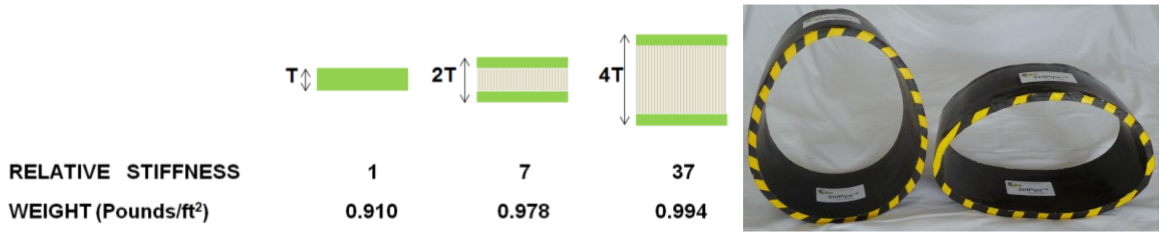

Fig. 2. The efficiency of sandwich construction technique and two non-circular StifPipe®

In designing the pipe, the interior layers are designed to resist the internal pressure of the pipe; carbon FRP is used for pressure pipes while glass FRP offers a good economical solution for gravity flow pipes and culverts. The rigidity of the pipe is provided by the core material. The outer skin is usually made with glass FRP. Various aspects of the pipe such as ring stiffness, impact resistance, overburden pressure, etc. have been tested at the Trenchless Technology Center of the Louisiana Tech University [3]. These studies have concluded that the pipe behaves in much the same way as similar pipes made with fiberglass or HDPE that utilize solid wall construction. The unique features of StifPipe® and its light weight, resulted in the pipe receiving the 2016 Innovation Award as the world's first green and sustainable pipe from the American Society of Civil Engineers (ASCE) [4].

Repair of Pipelines with StifPipe®

The sandwich construction technology described above can be used in two distinct ways to repair damaged and deteriorated pipes and culverts. Each of these techniques and sample case studies are presented here.

Slip Lining Application

In this technique, segments of StifPipe® are manufactured in advance. These segments are shipped to the job site and inserted into the host pipe; then the annular space between the host pipe and the StifPipe® is filled with resin or cementitious grout based on the design requirements. This method of installation is limited to projects where there is enough access to slide segments of completed StifPipe® into the host pipe.

One such application shown in Fig. 3 is repair of pressure pipes in the Aguirre Power Plant, Puerto Rico, where 29 corroded riser pipes were repaired. The riser pipes were 915 mm (36 inches) in diameter and the design pressure for the system was 2.76 MPa (400 psi). The 1200-mm (4-ft) long sandwich pipe segments had an outside diameter of 900 mm (35 inches) and were lowered into position. The small annular space between the host pipe and the liner was filled with a cementitious grout. Two layers of carbon FRP fabric were used on the interior surface of the pipe to resist the internal pressure. The rigidity of the pipe can support the lateral loads from the soil and nearby traffic. The premanufactured pipes reduced the repair time significantly. The project was completed in February 2016 [5].

Another application was for repair of a corroded corrugated metal pipe culvert in Australia. A 78-ft (28.3 m) long, 72-inch (1830 mm) diameter culvert in a remote site more than 1000 miles north of Brisbane had deteriorated and partially collapsed to a diameter of 55 inches (1400 mm). The four custom-made pipes manufactured in Australia were twenty feet long each, less than 1 inch (25 mm) thick and had an outside diameter of 51 inches (1295 mm). The lightweight pipes could be pushed by hand into the culvert, eliminating the need for jacking equipment on site. The annular space was filled with cementitious grout. The repairs were successfully completed in 4 days in July 2015 with no traffic disruption.

(a) (b)

Fig. 3. Repair of (a) pressure pipe in Puerto Rico and (b) culvert in Australia with StifPipe®

Wet Layup Application

This technique that has been perfected in the last six months, allows construction of a fully structural pipe inside an existing pipe and it is ideal for projects where due to access limitations slip lining a pre-manufactured StifPipe® is not possible.

One such case is the 3.6-m (12-ft) diameter concrete tunnel that is buried at a depth of 46 m (150 ft) in the central parts of Minneapolis, MN. A portion of the tunnel, 6.1-m (20-ft) long was deteriorated such that it had caused significant infiltration of water into the tunnel. Access to this portion of the tunnel was very challenging. The crew and materials had to be lowered in a 3-person bucket through a 3.6-m (12-ft) diameter by 46-m (150-ft) tall shaft into the tunnel. The actual repair location was 1200-m (4000-ft) away from the base of the shaft. A skid-steer loader was used inside the tunnel to transport the crew and materials for the 15-minute ride from the base of the shaft to the repair area. Clearly, in such conditions the slip lining technique described above cannot be implemented.

The first step of the repair was to stop the flow of water into the tunnel through the cracks. The tunnel was used as the mould and various layers of resin-saturated fabrics were applied in bands to the surface of the tunnel. These included 4 layers of carbon FRP and a core material with a total thickness of 20 mm (0.78 in.) was applied between the glass and carbon FRP layers to provide the required stiffness for the StifPipe®. The project was successfully completed in February 2019 during one of the harshest winter seasons experienced in the area.


Fig. 4. Repair of 3.65-m (12-ft) diameter concrete tunnel in Minneapolis, MN using wet layup StifPipe®

Two additional projects for repair of concrete pipes have also been completed in the last six months; one was for repair of 1675-mm (66-in.) diameter storm water pipe in New Jersey. The other was an 1830-mm (72-in.) diameter pipe in Amarillo, TX that carries potable water and operates at a pressure of 0.70 MPa (100 psi). Several other major projects are in the design phase based on the technologies presented here. The fast adoption of these techniques attests to the advantages the systems offer and the needs of the pipeline repair industry for such innovative solutions.

Acknowledgements

The design concepts, materials, and construction techniques presented in this paper are subject to several pending U.S. and international patent applications by the author.

References

[1] Ehsani, M., and C. Peña. 2010. "FRP Repair of a Large-Diameter, Mile-Long Pipeline with Minimum Downtime," *Proceedings*, ASCE Pipelines Conference, Keystone, CO, August 2010

[2] Ehsani, M. (2012). "Introducing a New Honeycomb-FRP Pipe," *Proceedings*, ASCE Pipelines Conference, Miami, FL, August 2012, 1084-1091.

[3] Alam, S., Ehsani, M. and Allouche, E. (2016). "Evaluation of Mechanical properties of Sandwich Construction FRP Pipe," *Proceedings*, North American Society for Trenchless Technology (NASTT) No Dig Show, Dallas, TX, March 2016, Paper WM-T2-02, 10 pp.

[4] ASCE Grand Challenge Innovation Award, StifPipe®: A Green-Sustainable Solution for Repair and Construction of Pipelines, ASCE, May 2016 http://goo.gl/MFfOuh

[5] Ehsani, M., and Cortes, M. (2017). "Puerto Rico Ushers in a "Green" Class IV Carbon FRP Liner," *Proceedings*, North American Society for Trenchless Technology (NASTT) No Dig Show, Washington, DC, April 2017, Paper TA-T6-04, 10 pp.