StifPipe™: For Repair of Pipes & Culverts

Break-through technology offers solution to most challenging pipe renovation projects

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Shortcomings of Current Pipe Linings

In recent years, there has been a tendency towards designing liners, assuming that at some point in the future the host pipe will fully disintegrate. Thus the liner must be designed to resists both the internal pressure, *plus* the traffic and soil pressure. While this may pose an extremely conservative view, it essentially requires building a new pipe inside the host pipe that could perform independently of the latter.

The design of such pipes is controlled by buckling of the liner. The compressive strength of FRP products is lower than their tensile strength. That leads to installing several layers of carbon fabric inside a pressure pipe to create a thick enough liner with adequate stiffness. For such repairs, it is common to see designs calling for 10 or more layers of CFRP. Both the *high cost of repair* and the *long time required to accomplish the repair* offered opportunities for innovation. It is emphasized that most of these repairs must be performed under very tight shutdown schedules. So, shortening the repair time is of extreme value to the owners of these pipes.

The other option for repair of pressure pipes is to slip-line them with a new pipe. In this case, a section of the host pipe is removed to allow a segment of a new pipe be inserted into the pipe. Next, an additional segment of pipe is welded in the field to the first segment and the two are pushed together into the pipe, using special rigs to push or pull the heavy pipe assembly. The process continues as long as the pipe is running straight; bends in the pipe must be handled differently and may require cutting a new trench for access. Once the new pipe is in place, the annular space between that and the host pipe is filled with grout. A major shortcoming of this technique is that the new pipe is often one size (e.g. 6 inches in diameter) smaller than the host pipe and this leads to significant loss of capacity compared to the original pipe.

For gravity flow sewer pipes and culverts, there has been little use of the pricy CFRP liners. However, there are several lower cost FRP liners that are supplied as long flexible tubes that are blown or inverted inside the host pipe. Curing is often with steam, hot air or water. These products do make the pipe water tight but in many cases they cannot provide the required strength to carry the loads imposed by traffic and soil. Moreover, the high cost of mobilization for these systems is a disadvantage for repair of shorter pipes and culverts.

The option of slip-lining can also be used for gravity flow pipes. But many of these pipes are non-cylindrical. Slip-lining such pipes with a readily-available cylindrical pipe can easily lead to 30%-40% reduction in cross sectional area and loss of flow capacity.

StifPipe™

In light of the above challenges, we have developed the patent-pending StifPipe™ that takes advantage of honeycomb technology. Honeycomb construction was originally developed by the aerospace industry to achieve strong and light-weight structures. It has also been successfully used in construction of boats, so exposure to water is not a concern. A layer of FRP is used as skin reinforcement that is applied to both faces of a light-weight honeycomb core. The principles of design are simple; similar to the high stiffness offered by an I-beam compared to a solid steel plate, it is recognized that by separating the outer skin layers with a honeycomb core, one can achieve high stiffness at a fraction of the cost of a solid cross section.

Manufacturing can be done onsite or offsite. A mandrel is prepared as a template and the required number of layers of saturated fabric and honeycomb core are applied successively to create a pipe of desired shape, size and strength. Finished sections of StifPipe™ can be tested to verify that they meet the project specifications.

Test Results

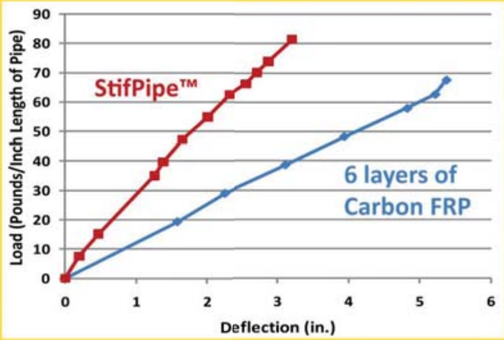
The standard test for determining stiffness of liners is provided by ASTM D2412-02 "Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading". The figure below shows the set up for such tests at the Department of Mining and Geological Engineering, at the University of Arizona.

A project for rehabilitation of a 36-inch diameter PCCP required 2 layers of carbon fabric to resist the internal pressure. However, the client's requirement to design the pipe as a "free-standing" pipe capable of resisting both internal and external (gravity) loads, led to 6 layers of carbon fabric. To compare the effectiveness of StifPipe™, two sections of a 36-inch pipe were constructed. The first sample followed the conventional repair and consisted of 6 layers of unidirectional carbon fabric applied on top of one another; the average thickness for this liner was 0.30 inches. The second sample was constructed of a single layer of honeycomb core with a layer of glass fabric on the outside and inside faces. The StifPipe™ had an average thickness of 0.71 inches. Both samples are shown below.

The load vs. deflection results for both pipe liners are presented. As can be seen, StifPipe™ has a stiffness that is 2.1 times that of the conventional CFRP system with 6 layers of carbon fabric.

The actual StifPipe™ for this project will include a single layer of glass or carbon on the outside. However, on the inside, we will use two layers of carbon fabric to meet the design requirements for resisting the internal pressure of the pipe. This will increase the stiffness of the StifPipe™ even beyond what is shown in these tests.

StifPipe™ will reduce the pipe diameter by a slight amount over the CFRP liner. However, considering all the other significant advantages that are detailed in the following pages, it is clear that StifPipe™ will be the preferred method for repair of most pressurized pipes.



Installation

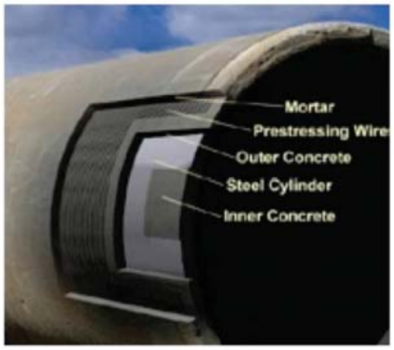
There are many ways to install StifPipe™ including the three installation approaches described below.

Method A: Cast-In-Place – This approach is ideal for pipes with relatively smooth surfaces. Installation steps (after the pipe surface has been prepared and cleaned) include the following:

1. A first layer of carbon or glass fabric is applied on the pipe surface
2. The special honeycomb core is applied on top of the first layer of carbon fabric; the thickness of this hollow core can be 1/4 inch or more depending on the diameter of the pipe being repaired and the applied loads
3. Additional layers of carbon fabric will be applied on the honeycomb core; these layers will be designed to resist the full internal pressure of the pipe

Method B: Precast Segmental Construction – This approach is ideal for sewer pipes and corroded and/or collapsing culverts that are made with corrugated metal pipe (CMP) and have a non-uniform interior surface. The technique is similar to the segmental construction method that has been successfully used in construction of long span bridges for decades. Based on consideration of the diameter and shape of the pipe (i.e. circular, oval or egg-shaped cross section) as well as the size and number of access points, the pipe segments will be constructed offsite. These segments will be a few feet long and will have a cross section that is slightly smaller than the pipe. The field installation sequence consists of the following steps:

1. The pre-manufactured StifPipe™ segments will be delivered to the job site
2. Client will have the opportunity to inspect & validate the strength of each pipe segments prior to installation
3. The crew will hand carry the lightweight StifPipe™ segments into the host pipe
4. The segments will be positioned sequentially along the pipe
5. Adjacent segments will be connected together with a special detail to create a long continuous pipe
6. The small annular space between StifPipe™ segments and the host pipe will be filled with resin or grout to join the StifPipe™ and the host pipe together



Prestressed Concrete Cylinder Pipe (PCCP) is widely used as water transmission lines: Components of PCCP, catastrophic failure of a 96-in. pipe, and retrofit of such pipes with wet layup carbon FRP application (2). StifPipe™ allows faster repair of PCCP at much lower costs than conventional CFRP liners shown here.

Method C: Continuous Precast – This technique is ideal when there is a relatively large open space at least at one end of the pipe; this could, for example, be the case for a culvert buried under a roadway. The construction sequence could be as described below:

1. A mandrel several feet long with a cross section the same shape but slightly smaller than the host pipe cross section is built in advance and is placed outside the pipe such that its axis is aligned with that of the host pipe
2. A portion of StifPipe™ several feet long is constructed on the mandrel and is partially cured
3. The partially-cured portion is slipped away from the mandrel and is pushed into the host pipe
4. Additional portion of StifPipe™ a few feet long will be constructed on the mandrel such that it will be continuous with the previously constructed segments; this new portion will also be partially cured
5. The new longer piece is moved a few feet into the pipe
6. The above steps 2) through 5) will continue until the desired length of StifPipe™ has been manufactured
7. The annular space between StifPipe™ and the host pipe is filled with grout or resin

History of the Development

In the late 1980s, Prof. Ehsani and his associates at the Univ. of Arizona were the first to introduce the concept of repair and retrofit of bridges and buildings with FRP to the construction industry (1). Fiber Reinforced Polymer (FRP) is made of fabrics of carbon or glass that are saturated with epoxy resins. In a process known as wet layup, the fabric is saturated with resin in the field and is bonded to the exterior surface of beam, column or wall; upon curing in several hours, it becomes 2-3 times stronger than steel! The high tensile strength, light weight, durability and ease of installation have made these products very popular in repair & retrofit projects.

The use of wet layup carbon FRP to strengthen Prestressed Concrete Cylinder Pipe (PCCP) began in the late 1990s. As shown in Fig. 1, these pipes consist of a steel cylinder that is sandwiched between layers of concrete and wrapped on the outside with prestressed wires. PCCPs have been used extensively worldwide as water transmission lines. Improper design and poor construction practices have resulted in breaking of the stressed wires and catastrophic failure of many of the older pipes. Once the pipe fails large volumes of water under high pressure can create rivers running down streets and city blocks in seconds.

Wet layup carbon FRP (CFRP) is a cost-effective method to retrofit the weak segments of a PCCP prior to failure. In this trenchless repair technique, the crew can enter the pipe through access ports and apply carbon fabric to the interior surface of the pipe. Once the fabric cures, it creates a pressure vessel that can relieve the PCCP from carrying all or part of the internal pressure. This technique is fairly well accepted and recognized by the industry. We have been a leader in this field and have been recognized by Awards of Excellence for PCCP repair projects (2). Our past experience also includes the world's largest pipeline repair project using FRP (1.1 mile of an 84-inch pipe) (3, 4).

Because the tensile strength of CFRP is 2-3 times that of steel, the application of a few (typically 2-4) layers of carbon fabric is sufficient to restore the integrity of the pipe. This makes the technique cost-competitive, especially in cases where digging and replacement of the pipe is not easy. But when the liner is expected to carry internal and external loads, the use of CFRP leads to many layers of carbon that make the projects *too expensive* and *time-consuming*. It was the combination of these problems and our 25 years of R&D on FRP and pipe rehabilitation that led to the development of StifPipe™.

1. Ehsani, M.R. and Saadatmanesh, H. "Fiber Composite Plates for Strengthening Bridge Beams," *Composite Structures*, 1990, 15(4), 343-355.
2. "Restoration of Large Diameter Prestressed Concrete Cylinder Pipelines," 2008 Awards of Excellence, *Concrete Repair Bulletin*, International Concrete Repair Institute, November/December 2008, 45-47.
3. Ehsani, M. and Pena, C. "World's Largest Project on Pipe Renovation with FRP Completed Ahead of Schedule," *Trenchless Review*, Western Society of Trenchless Technology, 2009, 29-33.
4. Ehsani, M.R. and Pena, C. "Rehabilitate Pipelines with Minimal Downtime." *Opflow, American Water Works Association*, December 2009, 22-25.

Advantages of StifPipe™

Some of the unique attributes of StifPipe™ are listed below:

1. Manufactured to *any size*; unlike conventional pipes, we are not limited to available "round" pipe diameter sizes only. For example, it is possible to line a 60 inch diameter pipe with a StifPipe™ having an inside diameter of 58 inches, thereby maximizing the flow capacity.
2. Made to *any profile* for maximum capacity; For repair of non-circular pipes, StifPipe™ can be constructed to match the existing pipe profile, reduce the loss of cross section and thus maximize the flow capacity. Conventional slip-lining of these pipes with commonly available cylindrical pipes leads to significant loss of capacity.
3. *No lifting equipment needed*; StifPipe™ is so light that it can be hand-carried to its final position.
4. *Shorter repair time*; Manufacturing the pipe sections offsite before repairs begin will significantly reduce the onsite repair time. The time savings are enormous when compared to installing many layers of carbon fabric inside the confined space of a pipe and delivering the raw materials to the workers under those adverse conditions at locations that could be hundreds of feet away from the access points.
5. *Less volume to grout*; By constructing the pipe profile to closely fit that of the existing pipe, little volume will be left to be grouted or filled with resin. This results in materials and time savings during the installation.
6. Virtually *no lead time required*; For emergency repairs, unlike conventional pipes, no time is lost waiting for the manufacturing of pipes; the raw materials are always available and pipe sections can be ready in 24 hours!
7. Non-corroding materials; FRP products do not corrode and have excellent chemical resistance, e.g. H_2S gas.
8. *Quality Assurance*; StifPipe™ sections can be tested before they are installed to ensure that they meet the design specifications. In contrast, for wet layup CFRP liners, only the witness panels of the fabric that are made daily can be tested at a later date. There is a high possibility of substandard installation when so many layers of fabric are to be installed under such adverse working conditions.
9. *Lower Cost*; StifPipe™ costs less than conventional carbon FRP liners.

ASCE Fellow Mo Ehsani is President of PipeMedic, LLC, and Professor Emeritus of Civil Engineering at the University of Arizona. He was a pioneer in the development of structural applications of FRP technology and is internationally recognized as an expert on the subject. He has been featured on major media such as CNN, NPR and ENR for his expertise on strengthening of structures related to earthuakes, etc.

Corroded oval-shaped CMP culvert, and an egg-shaped brick sewer with pending collapse of the crown are ideal examples of gravity flow pipes that can be fixed economically with StifPipe™.

Conventional slip-lining of non-circular pipes results in a large annular space & loss of flow capacity; these are just a few of the problems that will be eliminated when StifPipe™ is used!

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.