STIFPIPE™: INTRODUCING A NEW HONEYCOMB-FRP PIPE

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ABSTRACT

Retrofit of pipes subjected to combined internal pressure and external loads results in designs that require installation of many layers of carbon fabric. Such repairs are very time-consuming and expensive. To overcome these shortcomings, the author has developed a new honeycomb-FRP pipe that is presented here. This method of construction uses the lower cost honeycomb to provide stiffness for the pipe. The costly carbon fabric is used only as skin reinforcement to resist the internal pressure of the pipe. The result is a higher-quality product that can save significant time and money in many pipe renovation projects.

BACKGROUND

In the late 1980s, researchers at the University of Arizona were among the first to introduce the concept of repair and retrofit of bridges and buildings with FRP to the construction industry (Ehsani and Saadatmanesh, 1990). Fiber Reinforced Polymer (FRP) is comprised 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 or column; 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 and retrofit projects.

The use of wet layup FRP to strengthen pipes (Figure 1) began in the late 1990s for Prestressed Concrete Cylinder Pipes (PCCP) and the technique has gradually extended to cover pipes made with steel and fiberglass. Wet layup is an efficient method to retrofit weak segments of pipes. In this trenchless repair technique, the crew can enter the pipe through access ports and apply carbon or glass fabric to the interior surface of the pipe. Once the fabric cures, it creates a pressure vessel that can relieve the host pipe from carrying all or part of the internal pressure. This technique is fairly well accepted and recognized by the industry (ICRI 2008). The efficiency of this repair technique is further demonstrated in a recent project where 1.1 mile of an 84-inch pipe in a remote mountainous site in Costa Rica was repaired in only 15 days (Ehsani and Pena 2009).

Figure 1. Repair of pipes with wet layup FRP

SHORTCOMINGS OF CURRENT REPAIR TECHNIQUES

In recent years, there has been a tendency towards designing liners where the liner not only resists the internal pressure of the pipe, but also the traffic and soil pressure. The latter assumes that at some point in the future the host pipe will fully disintegrate. While this may pose an extremely conservative view, it essentially requires building a new pipe inside the old pipe that could resist all internal and external loads 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 and the thin FRP sheets have little stiffness. That leads to installing layer after layer 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 installation time required to accomplish the repair are major shortcomings of this system. It is emphasized that many 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 steel pipe. In this case, a section of the host pipe is removed to allow a segment of a new pipe to 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 assemblies. 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. The new steel liner must also be protected against corrosion.

For gravity flow 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 achieved with UV light, 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 cost of mobilization for these systems is a disadvantage for spot repair or 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.

The above shortcomings led to the development of the new honeycomb-FRP pipe described below.

CONSTRUCTION OF PIPE

Honeycomb construction has been successfully used in aerospace and other industries for decades. A layer of FRP is bonded as skin reinforcement to the exterior faces of the lightweight honeycomb (Figure 2). This results in a very efficient structure that is much stronger and stiffer than the sum of its constituent components. Many parts in ship-building and automotive industries, as well as the floors of most commercial airplanes are constructed with honeycomb FRP.

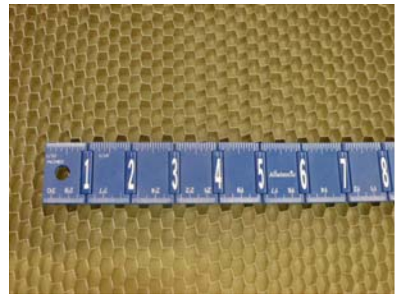


Figure 2. Honeycomb panel

In its simplest form, the construction of *StifPipe*™ begins by building a mandrel of the same size and shape as the pipe; in Figure 3, a corrugated metal pipe is used as the mandrel. In other applications, a collapsible mandrel can be designed to allow easy removal of the finished pipe. The mandrel is covered with a non-bonding release material (Figure 3a). Depending on the design requirements for the internal pressure rating of the pipe, one or more layers of carbon fabric saturated with resin is wrapped around the mandrel (Figure 3b). These fabrics typically have a thickness of less than 0.05 inches per layer. Next, the honeycomb sheet is coated with epoxy and it is wrapped around the carbon fabric; the thickness of the honeycomb typically varies between ½ -1½ inch and it is determined based on the overall stiffness requirements for the pipe. Additional layers of carbon or glass fabric saturated with epoxy are wrapped on the outside of the honeycomb. The pipe section is cured in ambient condition before it is removed from the mandrel (Figure 3c). If necessary, the curing process can be accelerated by heating the assembly to a moderate temperature, e.g. 150 ºF.

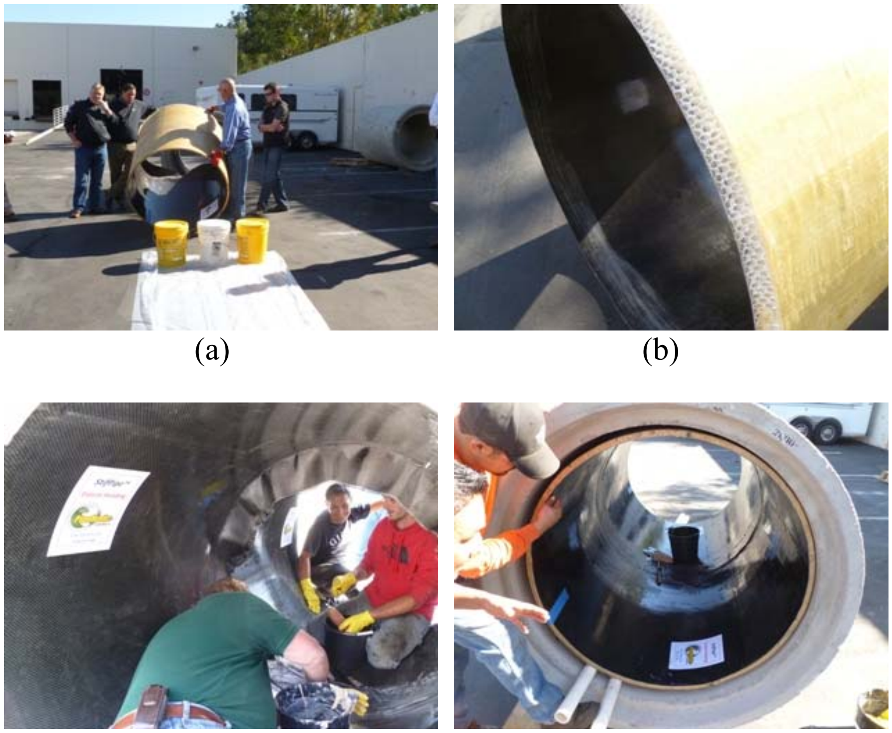
(a) (b) (c)

Figure 3. Steps in construction of *StifPipe*™

INSTALLATION METHODS

Honeycomb-FRP pipes can be installed in several ways as described in more detail below. The first two methods are applicable to larger diameter pipes that allow man entry; the third method can be used for both large and small diameter pipes.

Conventional Slip-Lining -- The pipe segments will be constructed offsite and delivered to the job-site. The segments will be as long as the access pit size allows and they will have a custom cross section that is slightly smaller than the host pipe. As shown in Figure 4a, a 4-ft long 46-inch diameter pipes section weighs only 50 pounds and can be easily lifted by hand and carried into the host pipe. The segments will be positioned sequentially along the pipe (Figure 4c) and adjacent segments will be connected together with a special detail (described in the following section) to create a long continuous pipe (Figure 4d). The small annular space between the liner and the host pipe will be filled with resin or grout to join the two pipes together.



(a) (b)

(c) (d)

Figure 4. Installation steps: (a) lightweight pipe is hand-carried into host pipe; (b) beveled end; (c) fabric band is saturated to complete the joint; (d) small annular space between the liner and host pipe can be grouted.

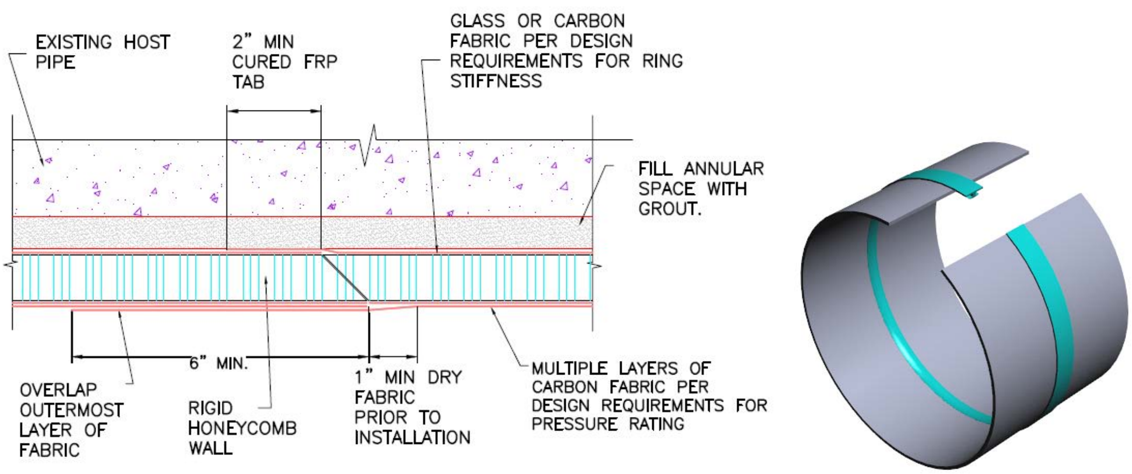
***Cured-In-Place* Liner –** This approach is ideal for larger pipes with relatively smooth surfaces. Once the pipe surface has been prepared and cleaned, a layer of carbon or glass fabric is applied on the pipe surface. Next, the honeycomb core is applied on top of the fabric; the thickness of this hollow core can be ¼ inch or more depending on the design strength requirements. Additional layers of carbon fabric will be applied on the honeycomb core; these layers will be designed to resist the internal pressure of the pipe

***Continuous On-Site* –** This technique is ideal when there is a relatively large open space at least at one end of pipe such as a culvert buried under a roadway. A long mandrel with a cross section the same shape but slightly smaller than the 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. A portion of *StifPipe*™ several feet long is constructed on the mandrel and is partially cured; the partially-cured portion is slipped a few feet into the host pipe. Additional segments are continuously made on the mandrel, cured and pulled or pushed into the host pipe. This results in a long pipe with no joints. Once the entire pipe is lined, the annular space between the host pipe and the liner is filled with a low-viscosity resin or grout.

CONNECTION DETAILS

The ends of the pipe sections can be connected in a number of ways. One such detail includes a beveled edge shown in Figures 4b and 5a. One end of the pipe has a 2-inch cured FRP tab on the exterior face and a 6-inch dry carbon fabric on the interior face (Figure 3c). Once the two beveled ends of the pipe are mated together in the field, the dry fabric is saturated with resin and bonded to the adjacent pipe section to create a smooth overlapping joint in the direction of the flow (Figures 4c and 4d). The 2-inch cured FRP tab on the outside prevents the grout from getting into the pipe.

This connection is good for pipes large enough to allow man entry. Other gasket connections (Fig. 5b) can be used for smaller diameter pipes or when man entry is not desirable.



(a) Wet layup (b) Rubber gasket

Figure 5. Connection details at ends of *StifPipe*™.

CASE STUDY

A recent project for rehabilitation of over a mile 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 liner as a "stand-alone" Class IV liner capable of resisting both internal and external (gravity) loads, resulted in 6 layers of carbon fabric.   To compare the effectiveness of *StifPipe*™, two samples 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, resulting in a liner thickness of 0.30 inches. The *StifPipe*™ sample consisted of a single layer of honeycomb core sandwiched between two layers of glass fabric, one on each face.

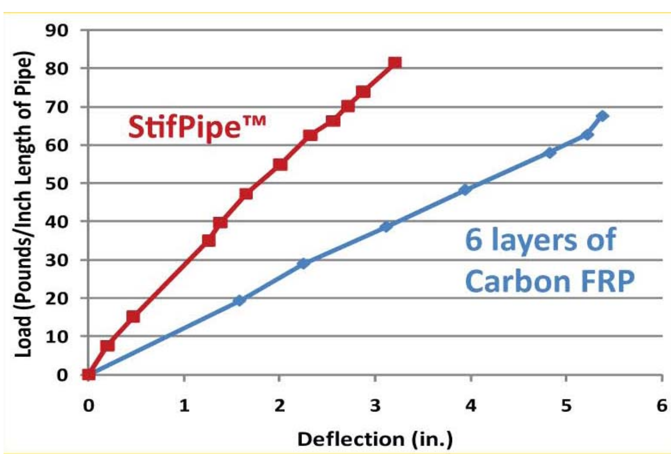
This liner had an average thickness of 0.71 inches (Fig. 6a). The honeycomb pipe was conservatively constructed with glass fabric that has a stiffness nearly ⅓ that of the carbon fabric.

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”. Figure 6b shows the set up for such tests at the University of Arizona. The load vs. deflection results for both pipe liners are presented in Figure 6c. As can be seen, the *StifPipe*™ sample has a stiffness that is 2.1 times that of the conventional CFRP system with 6 layers of carbon fabric.

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

(a)

(b)



(c)

Figure 6. Comparison of 36-inch diameter carbon FRP pipe with *StifPipe*™: (a) samples; (b) test setup; (c) load vs. deflection

The honeycomb-FRP pipe will reduce the pipe diameter by a slight amount over the CFRP system. However, considering all the other significant advantages that are detailed below, *StifPipe™* can be the preferred method for repair of many pressurized pipes.

ADVANTAGES

The main advantage of the new *StifPipe™* for *gravity flow* applications is the fact that the pipe can be manufactured to virtually any size and shape (Figure 7). This will minimize flow loss and grouting requirements during installation. But by far the biggest advantage of the new pipe is in repair of *pressure pipes* as summarized below:

Materials – *StifPipe™* requires considerably fewer layers of carbon fabric; the savings in materials cost alone will be more than 50% on most projects.

Labor – *StifPipe™* has fewer layers of materials and thus takes less time to construct. In addition, the workers' productivity is much higher for *StifPipe™* that is made in a manufacturing setting; in contrast, the conventional repairs requiring installation of multiple layer of FRP inside a pipe are very time-consuming. Typical savings in labor on larger projects can be over 60%.

Quality – The adverse working conditions for installing many layers of FRP inside a pipe lead to lower quality; in contrast, *StifPipe™* sections are constructed under more favorable conditions that improve quality. The owners also have the opportunity to verify the quality by testing finished segments of the pipe *prior* to installation.

Time – Most pipe repair projects must be completed in a short schedule; the fact that the majority of the activity in building the *StifPipe™* segments can be performed offsite, reduces the onsite repair time significantly. The savings frequently exceed the additional time that may be required to cut an access pit for insertion of honeycomb-FRP pipes.

Cost – Labor fees for construction of *StifPipe™* segments that are manufactured offsite are typically much lower than those on the job site. This combined with other savings in labor time and materials results in savings well over 50% in many pressure pipe rehabilitation projects. For the case study discussed earlier, for example, application of 6 layers of carbon would cost about $6.5 million and it will require 20,000 man-hours onsite; the *StifPipe™* alternative would cost less than $3 million and requires only 3,000 man-hours onsite.

NSF Certified – The new pipe is constructed with materials that are certified for repair of potable water pipes.

SUMMARY AND CONCLUSIONS

This paper describes the development of a new form of pipe constructed of a lightweight honeycomb core and carbon or glass fabric as skin reinforcement. The pipe offers high strength and stiffness at a fraction of the cost of a similar pipe constructed solely with carbon FRP. In addition to lower costs and higher quality, the newly developed *StifPipe™* can significantly reduce onsite repair time on most projects. The quality of the installation is enhanced since the pipe segments can be tested before they are inserted in the host pipe.

Figure 7. Samples of honeycomb-FRP pipe for repair of oval-shaped culverts and egg-shaped sewer pipes.

ACKNOWLEDGEMENT

The honeycomb-FRP pipe system described in this paper is available under the trademark ***StifPipe™***. The methods of manufacturing and repair of pipes described above are subject to pending U.S. and international patents by the author.

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