Reusable Form of Infinite Shape and Size—A Sustainable Product for the Repair Industry

by Mo Ehsani

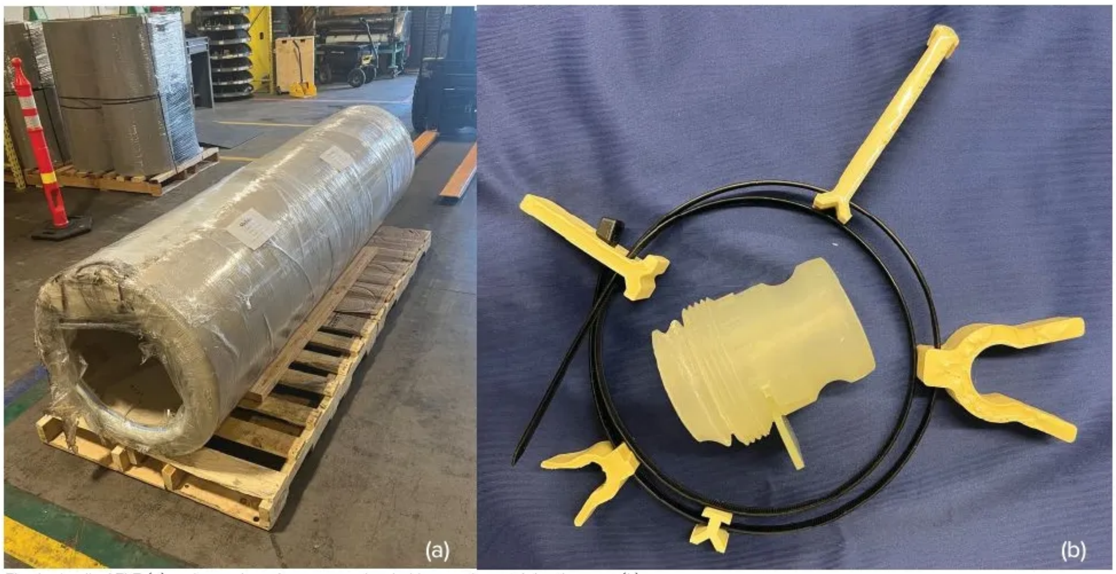

Fig. 1: A roll of FLF (a) and samples of spacers, rebar holders and grout injection port (b)

INTRODUCTION

Repair of columns in existing buildings and bridges is a challenging task. In many structures—such as bridges, parking garages, ports and piers, mines—columns (structural steel or concrete with embedded steel reinforcement) corrode and require repair. In other cases, column jacketing is used as a technique to strengthen existing columns by adding a shell of reinforced concrete around the column. The latter is gaining popularity in seismic upgrade of structures and the ACI Committee 369 on Seismic Repair and Rehabilitation is currently developing guidelines for such applications.

The forming of existing columns is a difficult task. The existing floor and beams above prevent the use of conventional disposable cardboard tubes because they cannot be slipped over the column. The contractor is faced with assembling a form consisting of many segments around the host column. Because these forms offer virtually no resistance to the lateral pressure of the freshly cast concrete, the segments must be tied externally with bolts, clamps and the like. These forms can become very heavy and add significant time and expense to the project. The problem is especially arduous when the columns are not easily accessible.

This paper describes a recently developed application process that can overcome many of the above shortcomings.

FRP LAMINATE FORM

The new application process includes jacketing made of Fiber Reinforced Polymer (FRP). Using specialty equipment, glass fibers are impregnated with vinyl ester resin and subjected to heat and pressure to make very thin laminates. For brevity, the new jacketing system will be referred to as FRP Laminate Form (FLF) in this paper. The laminates have a uniform thickness that varies from 0.045 to 0.075 in. (1.1-1.9 mm) depending on the product style.

FLF is manufactured in rolls up to 102 in. (2,590 mm) wide. A typical roll includes approximately 500 lineal feet (152 m) of FLF (Fig. 1a). The laminates weigh between 0.31 to 0.51 lb/ft² (1.5–2.5 kg/m²). This light weight allows for easy handling. The mechanical properties of the laminates and the applicable ASTM Standards are listed in Table 1. The unique design of the laminate provides a perfect balance between a smooth finish surface and enough friction to prevent sliding/slippage of the surfaces.

HOW TO INSTALL FLF

The behavior of FLF is based on principles of belt friction. Various shape and size spacers are available from the manufacturer, as shown in Fig. 1b. To repair a column, these spacers can be threaded through via a zip-tie and secured tightly around the column. They serve to hold the reinforcing bars in place, and to provide the desired standoff distance, i.e., the annular space, between the FLF and the existing exterior face of the column (Fig. 2a, 2b).

The process begins with cutting a piece of the laminate long enough to wrap 2–3 times around the column. The laminate is tightly wrapped around the structure. Duct tape or double-sided tape can be used to secure the interior edge of the laminate to itself so as to minimize cement paste getting between the layers. The free exterior end of the laminate can be secured with a few pieces of duct tape. Alternatively, rope can be tied around the tube (Fig. 3a) to maintain the size of the tube. Note, the duct tape or rope is not required to resist any loads from the internal pressure of the freshly placed concrete.

Once the FLF is in place, the concrete can be placed using a hose and tremie method or by pumping it using the grout ports shown in Fig. 1. The latter will create a hole in the laminate that must be patched later and will ultimately limit the number of times the laminate can be reused.

Table 1: Typical Physical Properties of FLF

Property	US Customary
Flexural strength (ASTM-D790)	1.91×10^4 psi
Flexural modulus (ASTM-D790)	6.0×10^6 psi
Tensile strength (ASTM-D638)	1.0×10^4 psi
Tensile modulus (ASTM-D638)	5.2×10^5 psi
Izod impact (ASTM-D256)	4.5 ft-lb/in. notched
Coeff. of Linear Thermal Expansion (ASTM-D696)	1.7×10^{-5} in./in./°F
Water absorption / 24 hours (ASTM-D570)	0.3% @77°F
Coefficient of Static Friction	0.18

Fig 2: Spacers being installed (a) and the FLF laminate being wrapped around a deteriorated column (b)

Fig. 3. Field application: (a) FLF placed and filled with concrete, (b) removing the laminate after concrete hardens, (c) cleaning and saving the laminate for future use, and (d) smooth concrete finish with no spiral marks

After the concrete hardens, the rope is untied, and the laminate is removed (Fig. 3b). The laminate can be cleaned, washed, and dried (Fig. 3c) before it is coiled and stored away for future use to build a form of the same or different shape and size. Note, the finished surface of the cast concrete that is very smooth (Fig. 3d) and free from unsightly spiral marks that are commonly left behind when cardboard tubes are used for forming. Thus, eliminating the need for grinding of the new exterior surface.

As stated earlier, the behavior of this laminate is unique in that instead of using external clamps to hold the form together, the layers get pressed against one another due to the internal pressure of the concrete. Referring to Fig. 4a, if a tube of height H is filled with concrete and has a density γ, an internal hydrostatic pressure $p = \gamma H$ is developed at the base of the form. This internal pressure, shown with red arrows in Fig. 4b, results in a friction force between all layers of the laminate that is shown with smaller blue arrows in that figure. The higher the pressure of the concrete, the larger the friction force between the layers of the laminate. If the laminate is wrapped 3 times around itself, the external ties carry zero load. Alternatively, it is possible to use 2 layers of laminate. However, in that case stronger external ties such as ratchet straps must be used to resist some of the hydrostatic pressure of the freshly placed concrete.

The laminates themselves are very strong and for most applications, a layer can resist the hoop stresses generated in the form. In such cases, a minimum overlap length of 8 inches (200 mm) is recommended. For example, assuming an 8-ft (2.4 m) high concrete placement with a unit weight of 145 lb/ft³ (23 kN/m³), the hydrostatic pressure at the base of the form will be 1160 psf (55.5 kPa). Assuming the diameter of the form is D=36 in. (914 mm), the tension force in a single layer of laminate will be T=145 lb (645 N). The 0.060 in. (1.5 mm) thick laminate shown in Fig. 3 has a breaking strength of 600 lb/in. (105 N/mm) width of laminate that is significantly larger than the force T calculated above. The safety factor in this case is 4.1—considerably larger than that required for live loads. This demonstrates that the construction of FLF with 2 or 3 layers of laminate is primarily to enhance the rigidity and stiffness of the tube. Again, the tensile strength of a single layer of laminate is greater than what is needed to confine the hydrostatic pressure of the freshly placed concrete.

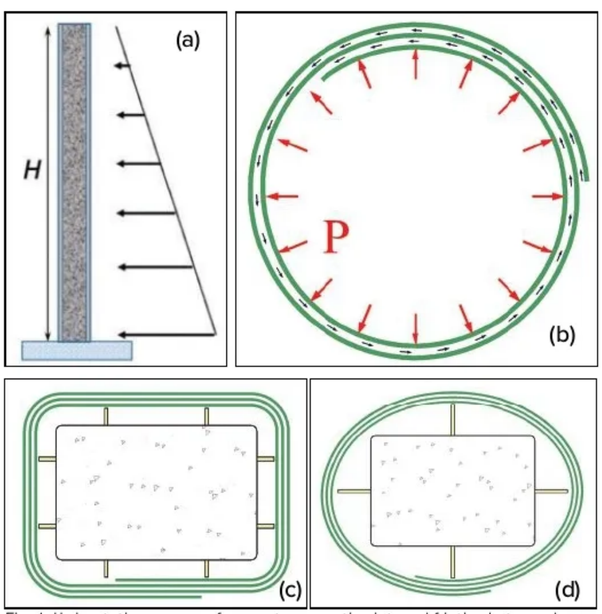

Fig. 4: Hydrostatic pressure of concrete generating internal friction between layers FLF; Spacer sizes allow making different FLF sizes around the same rectangular column

In this example, a circular column was formed around a damaged circular column. A major advantage of FLF is that by changing the size of the spacers, the flexible laminates allow construction of nearly any shape and size form in the field. Fig. 4c shows a rectangular column cross section that can be enlarged to a larger rectangular column or an oval shape column, for example. The only limitation is that the radius of bend at the corners of a rectangular form must be larger than the allowable limit for the laminate. This radius is a function of the thickness of the laminate and is approximately 1 in. (25 mm).

PRESSURE TEST

To determine the adequacy of this system in resisting internal pressures, the following test was conducted. A 9.5-ft (2880 mm) long piece of a 0.06 in. (1.5 mm) thick laminate was cut from the roll. This laminate was coiled to create a 3-ply tube with a diameter of 12 in. (305 mm) and a length of 102 in. (2590 mm). The free end of the laminate was secured to itself with a few short pieces of duct tape to maintain the tube diameter.

An elongated balloon that is frequently used in internal repair of pipes was inserted inside the FLF. The balloon was connected to an air hose and gradually inflated to a pres-

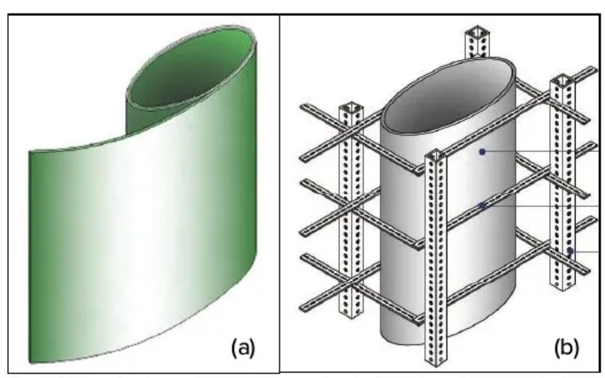

Fig 5: FLF can also be used to produce non-circular forms in a wide range of shapes and sizes for construction of new columns

sure of 3,300 psf (158 kPa). This is nearly 3 times higher than the pressure calculated in the above example. It is also significantly higher than any anticipated pressure that would be encountered in the field. The test was stopped at 3,300 psf due to the limitations of the balloon. There were no signs of any damage to the FLF at the conclusion of this test.

SUSTAINABILITY

The FLF presented here has several unique features making it an environmentally friendly alternative to a project's forming needs.

- The size of a single roll of laminate allows for virtually any size form to be built on site.
- The laminate can easily conform to the shape required. As demonstrated in Fig. 4d, the form can be shaped in rectangular, circular, and an endless range of geometries in between.
- The light weight of FLF eliminates the need for heavy lifting equipment on site that may be required for bulkier steel or timber forms.
- FLF is fully water resistant, making its storage easier and allowing for challenging forming of submerged columns and piles.
- The FLF can be used numerous times, thus reducing landfill waste.

These versatilities can help reduce forming costs on numerous projects.

SUMMARY

A new material, FRP Laminate Form (FLF) has been presented. The material can be used to form repair of existing columns or to form new columns (Fig. 5a, 5b). The advantages of this material are its ability to be used multiple times and to create forms of nearly any shape and size. FLF reduces storage space, transportation cost, and landfill costs significantly. It is fully water and rain resistant. The result in an environmentally friendly, sustainable solution.

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