FRP Super Laminates

Transforming the future of repair and retrofit with FRP

BY MO EHSANI

Twenty years ago, I presented the findings of a study on strengthening concrete beams with external bonding of fiber-reinforced polymer (FRP) laminates in the pages of *Concrete International*.[1] In the aftermath of the 1989 Loma Prieta earthquake, I proposed an extension of my earlier research to retrofit deficient bridge piers by lateral confinement with FRP.[2] What appeared to be unusual approaches at the time have since become mainstream techniques for the repair and retrofit of structures worldwide.

The high tensile strength, light weight, durability, and versatility of FRPs have made them the material of choice for many repair and rehabilitation projects. To date, numerous bridges, buildings, pipelines, and other structures have been retrofitted with these products worldwide. With the publication of design guidelines,[3] it is fair to say that FRP is no longer an experimental product but rather a well-accepted construction material.

FRP products come in two categories: fabrics and pre-cured laminates. Fabrics offer the widest versatility in the field and are installed with what is commonly referred to as the wet layup method. This technique requires properly trained technicians to prepare the resin in the field, saturate the fabric, and apply it to the structural member. Care must be taken to ensure that the fibers are aligned in proper directions and that all air bubbles are removed before the fabric is cured.

Pre-cured laminates are manufactured in a plant, eliminating many of the field errors possible with the wet layup method. They are available in the shape of reinforcing rods or tendons as well as narrow unidirectional laminate strips typically produced in the range of 3 to 4 in. (75 to 100 mm) wide and 0.05 in. (1.3 mm) thick. In the field, these laminate strips are bonded to the exterior surface of the structural element using epoxy putty. In a variation of this approach, known as near-surface mounted reinforcement, laminate strips or rods are adhesively anchored within narrow grooves that have been cut in the structural member.

While the laminate strips offer ease of installation and higher strength than the wet layup system, their use has been relatively limited. The unidirectional reinforcement in laminates makes them primarily suitable only for flexural reinforcement of beams and slabs, with some applications for shear strengthening of beams. Other applications (for example, for pipe or column repairs) are practically impossible. The stiffness of a typical laminate prevents coiling it into a circle smaller than about 30 in. (750 mm) in diameter, and the maximum width of available products (about 10 in. [254 mm]) renders them impractical for use as pipe linings.

SUPER LAMINATES

Super laminates represent a huge advance in FRP manufacturing technology. Sheets of carbon or glass fabric up to 60 in. (1524 mm) wide (Fig. 1) are saturated with resin and passed through a press that applies uniform heat and pressure to produce the laminates. Super laminates offer three major advantages:

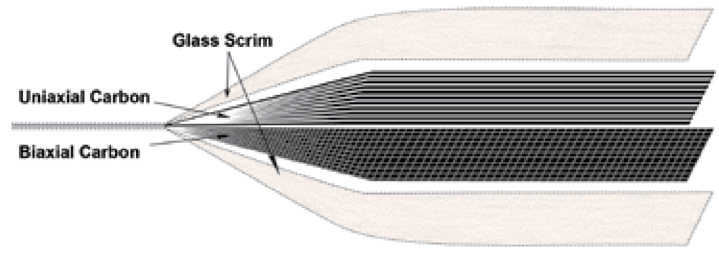

Fig. 1: Super laminates can be constructed with multiple layers of unidirectional or biaxial fabrics

- By combining unidirectional and/or biaxial fabrics, the laminates offer strength in both longitudinal and transverse directions, opening the door to many new applications;
- They are much thinner than conventional laminates. With a typical thickness of 0.025 in. (0.66 mm), they can fit into a cylinder with a diameter as small as 8 in. (200 mm); and
- The number and design of the layers of fabrics can be adjusted to produce an endless array of products that can save time and money.

Super laminates are produced under ISO 9000 certification, ensuring the highest standards of quality control. Also, when rolls of super laminates are delivered to a construction site, samples can be tested before the material is installed. This contrasts with wet layup applications, where samples are prepared daily but tested too late to easily correct defective installations. Furthermore, super laminates can easily address many construction challenges.

Strengthening of large-diameter pipes

In the U.S. alone, more than 7 billion gal. (26.5 million L) of water are lost daily due to leaking pipes.[4] Additionally, a large number of pipes in water distribution networks and oil and power industries are badly deteriorated and require repair or strengthening. These pipes are usually pressurized and deteriorated reinforcement can result in the hoop stresses exceeding the capacity of the pipe. When unattended, the consequences of such failures are grave and can leave entire neighborhoods under water[5] or force emergency shutdown of plants. A common strengthening approach in the last decade has been to apply at least one layer of carbon fabric inside the pipe. The fabrics provide adequate strength in the hoop and longitudinal directions. While very effective, the time associated with the wet layup method has been a major drawback to this system. Contractors have tried to overcome this shortcoming by using 10 in. (254 mm) wide laminate strips to repair pipelines, but the efforts have been unsuccessful.[6]

Super laminates significantly reduce construction time. The laminates' flexibility allows them to be wrapped around 12 in. (300 mm) diameter cores that can be easily transported into pipes through manholes (Fig. 2). Super laminates can conform to any pipe diameter—a major time- and money-saving attribute.

Installation involves applying a thin layer of epoxy putty to the back of the super laminate and pressing it against the pipe surface. No effort is required to remove the air bubbles as the super laminates are pre-cured. In fact, depending on the diameter of the pipe, the elastic memory of the coiled super laminate may cause it to expand inside the pipe like a loaded spring and snap against the host pipe with little effort. Continuity of the super laminate rings is achieved by adequate overlap lengths in the hoop and longitudinal directions. Thus, unlike ordinary laminates that are unidirectional, super laminates strengthen the pipe in both hoop and longitudinal directions with a single application.

It's possible to include multiple layers of fabric into a single laminate, further reducing construction time by up to 80%. To avoid galvanic corrosion when steel pipes require strengthening, a layer of glass fabric is typically applied to the surface of the pipe before any carbon fabric is applied.[3] This protective layer can also be included in the super laminate, saving even more time. Such a significant reduction in repair time makes possible many larger retrofit projects that could not afford the long shutdown time required for conventional repairs.

Repair of small-diameter pipes

Pipes that are too small to facilitate human entry can be repaired using a packer, a cylindrical frame that houses a closed bladder on the outer surface (Fig. 3). An appropriate length of super laminate is cut and coated

Fig. 2: Super laminate being taken into the pipe and installed; one size fits all pipe diameters

with epoxy putty. The laminate is then wrapped around the packer and held in position with the aid of strings. The assembly is lowered into the pipe through access ports and pulled to the desired location with the help of closed-circuit TV cameras. The packer is then inflated, allowing the super laminate to adhere to the host pipe. After a few minutes, the packer is deflated and removed from the pipe. Additional pieces can be similarly installed with a small overlapping length to repair or strengthen a larger length of the pipe.

A major cost associated with pipeline repairs is the traffic control required to accommodate bypass pipes that are laid at the street level. Most repair systems require inserting a flexible pipe or liner between adjacent manholes and curing it using steam or hot water—such systems require the repair area between the manholes to be clear of any obstacles. Using plugs at ends, water or sewer is pumped to the ground level to bypass the repair area (Fig. 4(a)).

In contrast, repairs with super laminates do not have this restriction. Using flow-through packers (Fig. 3), a smaller diameter flexible hose or pipe can be used to bypass the fluids inside the pipe (Fig. 4(b)). The super laminate can be applied on a third flow-through packer that rides on top of the flexible hose (Fig. 4(b)) and can deliver the repair materials to the damaged area (Fig. 4(c)).

Fig. 3: Flow-through packer

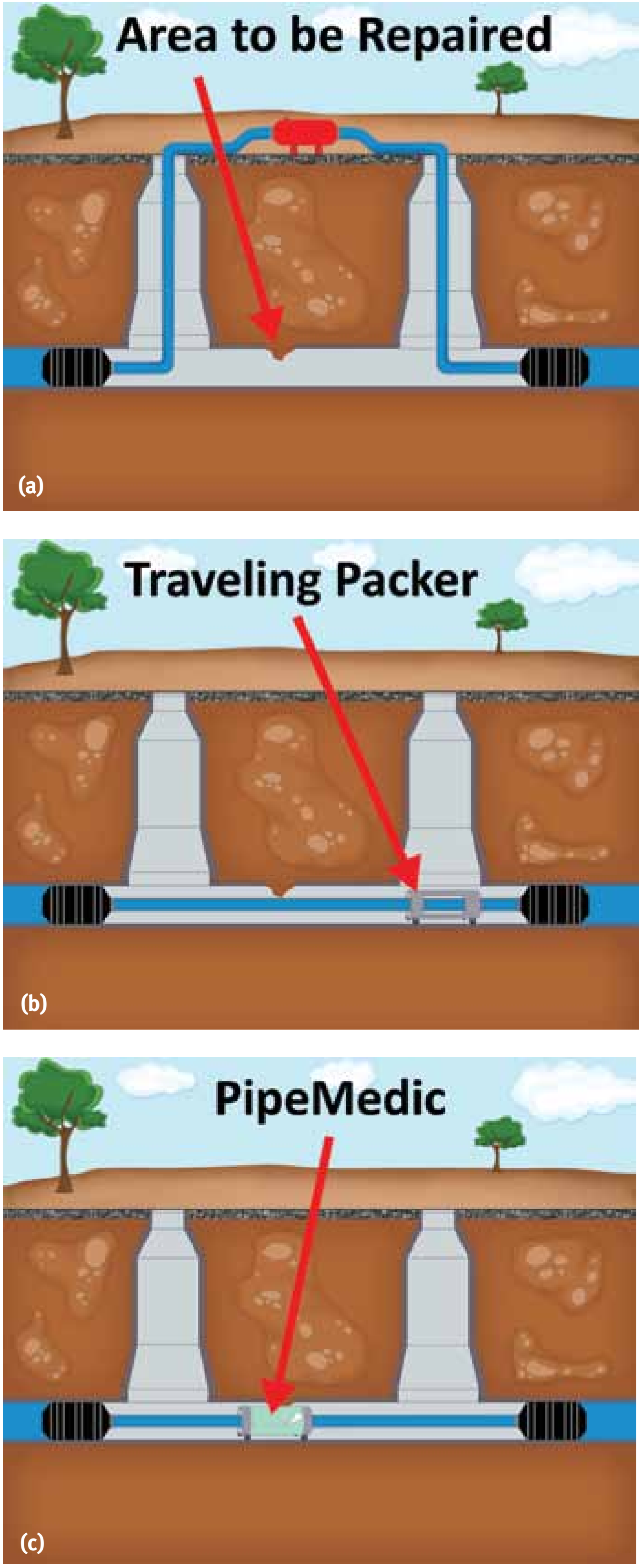

Fig. 4: Repair of pipes: (a) conventional method requiring above ground bypass; and (b) and (c) using super laminates with bypass through the pipe

Seamless shell around existing columns

A long-standing challenge to the engineering community has been how to construct a seamless structural shell around an existing column. Two half shells can be bolted together in the field to form a shell around the column. But this introduces two limitations: the shell has to be custom-made to fit the column size and the vertical seams along the sides of the shell introduce planes of weakness that prohibit pressurization of the grout in the annular space.

Super laminates make this task very easy. Starting at the bottom of the column, a laminate strip is wrapped helically in a continuous manner, moving toward the top of the column while applying resin on the overlapping surfaces to construct a seamless, solid, cylindrical shell. To prevent the top end of the super laminate from opening (due to its elastic memory), a band of fabric saturated with resin can be wrapped around the jacket near the top.

A jacket formed in this manner has no seams along the sides. Based on the design of the super laminate, the end result can be a jacket that has continuous fibers in both hoop and longitudinal directions. The annular space can be filled with expansive grout or resin and, if desired, the grout can be pressurized for improved confinement of the column.

Retrofit of square columns

External confinement of square columns is often not efficient—either the corners of the column are properly confined while the sides remain relatively unconfined or additional concrete is cast to transform the square column to a circular one. The flexibility of super laminates allows them to be easily wrapped around square columns to create a tightly fitting circular column; the resulting annular space can be filled with grout.

The system also simplifies the repair of corrosion-damaged columns. Currently, once the corroded steel in such columns has been repaired, the column must be coated with concrete to bring it back to its original shape before it can be wrapped with FRP fabrics. Super laminates will eliminate this step, as they can be used to create a smooth cylindrical column jacket around the uneven surface; the annular space can then be filled with grout. A similar approach can also be used on circular columns.

Repair of underwater piles

Various systems have been developed to repair piles located underwater and in splash zones. Typically, these systems require two half shells that are customized to fit the specific pile size. However, ordering custom-fit jackets can add long lead times to a project. These systems also require the assistance of divers to install the underwater portions, an additional expense.

Similar to the method for creating column jackets, a "seamless" jacket can be made in the field around the existing pile (Fig. 5). A single roll of super laminate can be used for a wide range of shapes and sizes, producing a cylindrical jacket around the pile. When field conditions permit, the jacket can be started above the waterline on the dry portion of the pile. Once a few turns are completed, the finished portion of the jacket can be gradually lowered into the water while workers complete the remaining portion of the jacket above the waterline. Moisture-insensitive epoxy putties that can be applied and cured in water are available for use in marine environments.

Once completed, the ends of the annular space between the jacket and pile are sealed, a task that may require minimal assistance from divers. The annular space is then filled and pressurized if necessary, something that can't be done with traditional jackets because of their vertical seams. The pressurization of the annular space ensures that the grout or resin fills all the voids and crevices in the deteriorated pile. The pressurization also causes active lateral confinement of the pile, thereby increasing its axial load-carrying capacity.

Repair of tanks and silos

Many structures, such as silos and water or oil storage tanks, are designed as cylinders. The hydrostatic pressure from the stored grains or liquid produces hoop stresses in the side walls of these structures. The stresses are highest at the base and gradually reduce along the height of the wall. Corrosion results in reduced cross-sectional reinforcement in concrete structures, compromising the hoop strength.

Super laminates can be bonded as rings on the inner surface of these structures, with the laminates designed as primarily uniaxial products providing significant hoop strength. Continuity of the rings in the horizontal direction can be achieved by overlapping the ends of the rings. The super laminates used in the lower portions of the wall can be constructed with more layers of reinforcing fabrics, and the thickness of the super laminate can be reduced for subsequent layers installed farther from the base of the tank or silo. Along the height of the wall, super laminates can be overlapped slightly to prevent any fluids stored in the tank from reaching the host structure.

Fig. 5: Retrofit of underwater piles, from top to bottom: construction of a seamless jacket with super laminates; filling the annular space; and completed pile jacket

CONCLUSIONS

Super laminates comprise a major advancement for the repair and retrofit industry, offering solutions to repair and retrofit problems that can't be solved with wet layup systems or conventional laminates. Several applications of super laminates have been detailed in this article. More are likely to follow, as this new product will be a catalyst for new concepts and wider acceptance of FRP products in repair and retrofit projects.

References

1. Saadatmanesh, H., and Ehsani, M.R., "Fiber Composite Plates Can Strengthen Concrete Beams," *Concrete International*, V. 12, No. 3, Mar. 1990, pp. 65-71.

2. "Engineer Says Agency Leaked Idea," *Engineering News-Record*, Aug. 9, 1990, p. 16.

3. ACI Committee 440, "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures (440.2R-08)," American Concrete Institute, Farmington Hills, MI, 2008, 80 pp.

4. "2009 Report Card for America's Infrastructure," American Society of Civil Engineers, 2009, 153 pp.

5. Johnson, B., and Shenkiryk, M., "The Genesis of a Condition-Based Asset Management Program for Critical Water Pipelines," *Western Regional Trenchless Review*, 2006, pp. 31-35.

6. Carr, H., "Repair of Prestressed Concrete Cylinder Pipes with Carbon FRP," presented at ASCE Pipelines, San Diego, CA, Aug. 15-19, 2009.

Selected for reader interest by the editors.

Mo Ehsani, FACI, has been a Professor of Civil Engineering at the University of Arizona since 1982. In 1994, he founded QuakeWrap, Inc., a company offering turnkey solutions for repair and retrofit of structures with FRP products. Ehsani has been featured on major media such as CNN, National Public Radio, and the History Channel for his expertise on strengthening of structures, particularly related to earthquakes, terrorist attacks, and other potential structural disasters.