A Novel Solution for Restoration of Deteriorated Piles - Part 1

Missouri DOT Pioneers the Implementation of the Next Generation of FRP Products

By Mo Ehsani and Mark Croarkin

This is part one of a two-part article on the restoration of deteriorated piles. Next month's issue will focus on the project completed by the Missouri Department of Transportation (MoDOT) in St. Louis.

One of the 49 corrosion-damaged piles in the I-70/I-270 interchange (St. Louis, Missouri) that was repaired with this technique.

Loss of load-carrying capacity in columns and piles is a major concern in many structures. In coastal regions, the dry-wet cycles lead to corrosion of reinforcing steel in concrete piles and bridge piers. In industrial facilities such as mines, aggressive chemicals cause premature corrosion of steel columns.

Thousands of utility poles are weakened due to deterioration of wood and break each year during hurricanes and storms.

These scenarios all require efficient techniques for in-situ repair and retrofit of the structures. The ideal method will not only replace the decaying materials, but will result in a stronger and more durable structural element. Many bridges constructed in Missouri over the last 70 years utilize exposed steel H piles as part of their substructure. From time to time, these exposed piling corrode for various reasons such as a shift in a stream channel that allows water flow directly around the piling, repetitive cycles of condensation at a connection to the concrete, or in the case of the bridge recently repaired with FRP, the drainage from the deck onto the concrete slope protection allowing anti-icing chlorides around some of the piling. The damage is typically concentrated at the base of the pile above and below the soil.

WET LAYUP FRP

Among the techniques gaining popularity in recent years is the use of Fiber Reinforced Polymer (FRP) products. Repair and strengthening of structures by external bonding of FRP was introduced by the first author in the late 1980s. The technique, known as wet layup, includes saturating fabrics of carbon or glass with resin in the field and applying them to the surface of beams, columns, walls, slabs, etc. By the next day when the FRP is cured, it forms an impervious sheet that is two to three times stronger than steel. This technique has seen worldwide acceptance for repair of buildings and bridges and its use has grown in the last 2 decades.

Many concrete bridge columns have been retrofitted with this technique for improved seismic performance. In all cases, the surface of the column must first be repaired and made smooth to allow proper bonding of the FRP fabric. It is well recognized that confinement of square or rectangular columns is not as efficient as that of circular sections. However, due to difficulty and expense of enlarging a rectangular column to a circular or oval shape, this step is often avoided and the original shape of the column is kept.

Retrofit of steel columns with wet layup FRP is not effective because: a) there is limited surface area available for bonding of FRP fabrics, and b) FRP is weaker in compression compared to tension and its contributions to the overall strength of the column will be minimal. Similarly, strengthening of wooden piles with wet layup FRP is not feasible. The uneven surface and porous nature of wooden piles make the installation of wet layup systems very difficult.

PILEMEDIC™

As a result of several years of research and development, the

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author has recently developed a new form of FRP called PileMedic™, which for certain applications offers great advantages over the earlier generation wet layup system. PileMedic™ allows transfer of a great portion of the activity from the construction site to the manufacturing plant. This results in higher quality products that can be installed much faster in the field and with significantly less manpower. It also allows certain unique solutions that are *impossible to implement* with the wet layup system.

Manufacturing of PileMedic™ uses specially-developed equipment. Rolls of carbon or glass fabric are impregnated with resin and they are pressed together under heat and pressure to produce very strong thin laminates. The laminates have tensile strength in excess of 150,000 psi and are produced in a continuous process in sheets up to 5-feet wide by 300-feet long. The large laminate sheets are coiled and packaged in a box for easy shipment; they can be cut to any width and length in the field with ordinary scissors. With a thickness below 0.025 inches, the thin laminates are flexible enough to create a cylindrical shell as small as 8 inches in diameter in the field. There is no upper limit for the diameter of the shell for such applications. By wrapping and epoxy bonding the laminate around itself, a multi-layer strong shell can be quickly created around the pile that can be filled with grout or resin.

PileMedic™ is compatible for repair or strengthening of structural elements made with wood, concrete, and steel. It also offers solutions for repair of utility poles and underwater piles. This article focuses on only one of these applications, namely restoration of corroded steel piles in bridges.

FIELD APPLICATION

The first installation of this product on a highway project was recently completed in St. Louis, Missouri, on four bridges at the I-70 and I-270 interchange. The four structures are five span bridges that carry I-270 traffic and two of the intermediate bents are constructed of exposed H piling. The H piling bents allow for expansion between the cap and the deck, while the other two intermediate bents on these bridges are constructed of concrete columns that are integral with the deck. The H piling bents had 26 to 32 steel 10X42 steel piles that are located behind the barrier wall on a 3:1 concrete slope with limited overhead space, so all work had to be performed by hand. The pile lengths in place varied between 30 and 46 feet. A total of 49 piles near the edges of the bridges were severely corroded with the section loss of the piling to be repaired varying from 20 to 80 percent and were repaired. The damage caused by polluted rain runoff was concentrated over a 1-foot-high section at the base of the piles. ■

Stay tuned for next month's conclusion to the MoDOT project in St. Louis. Please note the PileMedic™ products and the applications described in this article are subject to several pending U.S. and international patent applications.

A Novel Solution for Restoration of Deteriorated Piles - Part 2

Missouri DOT Pioneers the Implementation of the Next Generation of FRP Products

By Mo Ehsani and Mark Croarkin

This article concludes the two-part series on the restoration of deteriorated piles. Please note the PileMedic™ products and the applications described in this article are subject to several pending U.S. and international patent applications.

Steps in installation of PileMedic™ clockwise from upper left: application of epoxy to laminate, creating the shell around the pile, positioning the shell, filling with grout and vibrating, finished painted shell.

The Missouri DOT (MoDOT) determined that it would be sufficient to repair a 2-foot-high length of the pile in the corroded area. A section of the concrete slab approximately 2.5 feet by 2.5 feet was cut and removed to expose the pile. The corroded area was cleaned by sandblasting; mechanical grinders can also be used to remove rust from the surface of the steel. As added protection, a corrosion-inhibiting paint was used to coat the repair area of the steel pile.

A piece of PileMedic™ 2-feet wide by 9-feet long was used for each pile. A special two-component epoxy was mixed in the field and applied to an approximately 2-foot by 5-foot section of the laminate. The mixed epoxy has a paste-like consistency and is applied with a trowel to a thickness of 30 to 40 mil. The laminate is then wrapped loosely around the pile to create a two-ply shell. The 9-foot length of the laminate allows creation of a two-ply, 16-inch-diameter shell with 8 inches of overlap beyond the starting point.

At this stage, before the epoxy cures, ratchet straps must be used to hold the shell in a cylindrical shape to maintain the diameter of the shell. The shell can be moved up or down to be centered around the damaged portion of the pile. In this project, the soil below the slab formed the seal at the bottom of the shell.

The annular space between the shell and the pile was filled with a high-strength, non-shrink cementitious grout. The grout was mixed in a 5-gallon pail with a hand-held jiffy mixer and required no special heavy equipment. Consolidation of the grout was completed with a small vibrator and the top of the grout was finished with a trowel. Before the grout sets, the hydrostatic pressure from the grout pushes the inner layer of the shell outward against the outer layer and forces the two plies of the PileMedic™ laminate to be tightly pressed against each other. After several hours, the ratchet straps are removed, and if desired, the exterior of the shell can be painted. The entire repair operation, excluding the painting, was completed in about 2 hours.

If desired, steel reinforcing bars can also be positioned in the annular space before the placement of grout. This will provide significant flexural capacity to the column. In those cases, a taller jacket may be required to ensure there is sufficient development length for the steel to develop its full capacity.

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ADVANTAGES OF NEW SYSTEM

The laminates described offer several advantages over conventional methods and materials used for repair of piles. From a structural behavior point of view, the combination of the high tensile strength of the laminates and the creation of a seamless shell results in a tube that offers high confining pressure for the grout and pile. The magnitude of this confining pressure depends on the strength of the laminates and the number of plies that are incorporated in forming the shell in the field. For example, in the above application the shell provided a confining pressure of 650 psi and the compressive strength of the grout was 6,700 psi. However, due to the confinement provided by PileMedic™, the compressive strength of the grout increased to more than 9,000 psi.

In wet layup FRP systems, it is customary to prepare coupons (witness panel) of the installed fabrics each day. These coupons are later shipped to a qualified laboratory for strength verification. However, by the time the results become available, the project is most likely completed, making any remedial measures difficult to implement. In contrast, the PileMedic™ laminates can be tested in advance and any substandard roll can be rejected.

From a construction point of view, the laminates can be made into a cylinder of any diameter in the field; this eliminates time and expense of ordering customized jackets in advance, reduces the amount of excavation required, and speeds up the repair process. Similarly shipping and storage costs are reduced. The light-weight laminates require no heavy equipment for handling, and the entire repair kit and necessary tools fit on a typical pickup truck. This eliminates traffic controls, reduces labor and equipment, and associated delays and expenses in most situations.

The laminates also serve as a moisture barrier and protect the grout and steel column from future deterioration. Even in cases where reinforcing steel is placed within the annular space, there is no need to provide substantial concrete cover for the reinforcing bars. This, combined with the fact that the jackets are not supplied in pre-made sizes, allows construction of snug-fitting jackets in the field that minimize the volume of grout needed for repair.

FRP laminates are non-metallic and will not corrode. They offer a long service life with little maintenance. With a special epoxy that cures under water, PileMedic™ can be used to repair piles in water. Likewise, the laminates are ideal for repair of deteriorated concrete or wooden piles and utility poles. In such applications, it is best to inject a low viscosity resin in the annular space. Such resins can be pressurized to penetrate into the voids and crevices of the concrete or wood for enhanced structural performance and elimination of decay from the environment and insects. ■

Editor's Note: *Two months prior to the PileMedic™ repairs, routine inspections had lowered the substructure condition rating to poor (NBI rating of 4 on a 9-point scale). This meant these bridges were considered structurally deficient due to the number of piling with significant section loss. The FRP repairs were completed in just 2 weeks, improving all four bridges to a satisfactory condition rating (NBI rating of 6). All of this was affordable enough to be funded with the region's operations budget and happened on one of the busiest highways in Missouri without causing any delays or distractions to the traveling public.*