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Rehabilitate Pipelines With Minimal Downtime

More than one mile of a large-diameter pipeline was retrofitted to its original condition with minimal downtime and no excavation, underlining the versatility and effectiveness of fiber-reinforced polymer technology and the experience of the project team. **BY MO EHSANI AND CARLOS PEÑA**

THE USE OF fiber-reinforced polymer (FRP) structural linings to strengthen and rehabilitate existing pipelines is gaining widespread acceptance among utility managers. The linings can conform to a wide range of diameters and lengths, and they offer high strength, light weight, impermeability, thinness, and quick application and installation. However, some managers may have the misconception that installing FRP linings requires significant downtime. Recent advances in FRP technology, as well as improved installation methods, have significantly decreased installation time. These improved methods had a dramatic impact on the world's largest FRP pipeline structural rehabilitation job ever performed in a single phase—a low-pressure pipeline at the El Encanto Hydroelectric Power Plant, which is located 75 mi northwest of San José, Costa Rica. The project included the installation of about 150,000 ft^2 of FRP lining.

FRP DETAILS

FRP linings typically consist of fabrics made with high-strength fibers that are soaked in an adhesive resin and applied like wallpaper to a pipe's interior or exterior surface. The high-strength fibers are typically composed of bundles of thin strands of glass, carbon, aramid, or para-aramid synthetic fibers. When the resin cures, the fabric turns into a thin (typically about 0.05-in. thick) composite laminate. The density and orientation of the high-strength fibers, as well as the fiber type, can vary to create customized FRP linings to meet specific project criteria.

When applied to a pipeline's inner surface, the FRP lining becomes a trenchless structural rehabilitation alternative in which all labor, equipment, and materials are introduced into the pipeline through service access points, thus avoiding excavation. Many major pipelines can't be excavated without disrupting traffic, production, and other normal operations because they lie under freeways and urban or industrial developments. The economic impact of such disruptions, coupled with the significant investment required to replace deteriorated pipelines, increases the appeal of trenchless retrofit.

Although the use of FRP linings has focused on rehabilitating deteriorated pipelines that have been in service for decades,

Several leaks occurred along the length of the pipeline during tests conducted at maximum operational pressure.

FRP was an effective trenchless structural rehabilitation solution for the El Encanto pipeline, which exhibited significant longitudinal and transverse cracking during pressure tests.

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they can also be used to correct design and construction errors of new pipelines. Such was the case for El Encanto power plant's low-pressure pipeline.

PROJECT DESCRIPTION

The low-pressure pipeline at the El Encanto power plant conveys river water from an upstream dam to a turbine complex downstream. The pipeline is built of cast-in-place reinforced concrete, with a 7-ft inner diameter and a total length of 5,742 ft. The water flows by gravity. The flow is pressurized, however, because of the elevation difference between the dam and turbine complex and the continuous changes in the vertical and horizontal alignment of the pipeline required to conform to the mountainous topography.

Although the structural design had properly addressed the pipeline's strength requirements and accounted for design pressure and hydrodynamic loads, the pipeline's serviceability requirements were overlooked. During a pressurized test, the pipeline exhibited significant longitudinal and transverse cracking, which caused leaks that accounted for as much as 20 percent of lost flow.

The pipeline was drained, and all visible cracks were sealed using locally available repair materials. The repaired cracks leaked again when the pipeline was pressurized for a second time—probably because of increased crack width caused by pipeline deformations resulting from increased internal pressure. The relative rigidity of most crack-sealing materials made it impossible to achieve full deformation compatibility between the repair material and the surrounding concrete, degrading the integrity of the seal and allowing leaks to recur.

Moreover, the cracks generated multiple paths for humidity intrusion that reached the pipeline's steel reinforcement, allowing for corrosion problems that, if not properly addressed, could compromise the pipeline's structural integrity in the future. Complicating the problem even further was the combination of mountainous topography and frequent tropical rains. Because most of the pipeline is underground, water draining down the mountainside keeps the surrounding soil saturated, which generates seepage pressures. With the pipeline empty, seepage water was observed to drain through some of the longitudinal cracks.

To arrive at an optimal engineering solution, all of these problems needed to be properly and simultaneously addressed. An additional consideration was the urgency of minimizing repair time, because the power plant couldn't produce electricity while the pipeline was shut down.

AN EFFECTIVE SOLUTION

Applying the FRP linings requires some preliminary work to the pipe surface to maximize contact and bond strength between the substrate and the FRP. Therefore, pressure washing and/or sandblasting, as well as some patching and grinding, must take place in the areas targeted for FRP lining. In the case of the El Encanto pipeline, the amount of preliminary work was atypically large, because

As a result of constant tropical rains, water seeped into the pipeline from the surrounding soil (inset). Prep work prior to installing the FRP lining included grinding protrusions on the pipeline's interior surface.

the cast-in-place construction process caused significantly more surface irregularities than those associated with more traditional precast pipes. Evidence of cast-in-place procedures, such as construction joints, formwork fins, etc., was visible in the pipeline. The pipeline was pressure washed with 7,000 psi machines to remove any scour, sediment, curing compounds, and any other substance that could hinder the bond between the FRP and the pipe surface.

An FRP lining consisting of one layer of bidirectional glass fabric was designed to provide a humidity barrier, offer an effective crack-control mechanism, and supply additional hoop strength to account for future losses of hoop steel from corrosion. As the corrosion process at the reinforcing steel had already started because of the two-way humidity paths generated by the existing cracks, the additional strength that FRP provided assured effective increase of the pipeline's useful life. The humidity barrier is effective against water leaking into and out of the pipe from seepage or internal pressure effects, respectively; however, the corrosion of the steel reinforcement won't be slowed significantly as a result of the humidity barrier, as seepage water will allow the process to continue. Although nonstructural linings can also provide two-way humidity barriers, nonstructural linings can't account for the loss of structural integrity caused by ongoing corrosion due to the presence of seepage water.

Moreover, the adhered FRP laminate was designed to achieve full deformation compatibility with the pipe as the pipe expands from pressurization, and the bidirectional orientation of the high-strength glass fibers in the fabric guarantees existing and future cracks are intercepted in orthogonal directions to provide superior crack control. Nonstructural linings, on the other hand, can't serve as an effective crack-control mechanism.

Finally, an epoxy top coat was applied as a cover for all the installed FRP. The coating resists abrasion caused by sediment carried by river water and provides additional leakproofing by covering any pinholes remaining in the FRP lining. The coating has a concrete gray color, which facilitates quality control by providing visual verification that the entire light-green FRP lining is covered.

The urgency of starting operations at the power plant required placing the entire design and manufacturing process on a short schedule. Epoxy and fabric manufacturing plants were placed on accelerated production runs, and part of the production was prepared for air cargo transport.

A technical team comprising two structural engineers and three field supervisors traveled to Costa Rica to oversee the project and train local installation crews. A technical team fluent in Spanish was required for the job to run smoothly.

INSTALLATION PROCEDURE

The 5,742-ft-long pipeline had four lateral access points at the locations of relief valves, with spacing ranging from 1,000 ft to 1,500 ft. These 24 x 24-in. access points were used by the crew to supply FRP materials, tools, and equipment to four installation stations inside the pipeline.

The FRP lining is expected to require no maintenance and to have a useful life that will at least match the pipeline's operational lifetime.

A completed segment of the pipeline is shown prior to pressure tests (inset). Approximately 150,000 ft^2 of the FRP lining was installed in 15 days, and the tests were successfully completed a week later.

The installation direction was opposite to the flow direction to prevent the joints in the FRP lining from being lifted by the water flow. Each installation station consisted of a five-person crew applying the FRP lining to the pipeline's interior walls and another five workers performing support activities, such as transporting rolls of lining material from the access point to the installation point and cutting and preparing the FRP rolls.

An epoxy paste was applied to the top half of the pipeline to prevent peeling caused by self weight of the saturated FRP fabric and to seal the surface to prevent excessive absorption by the dry concrete surface of the epoxy resin from the saturated FRP fabric. No epoxy paste was used in the lower half of the pipe. Because gravitational forces in this area tend to hold the FRP fabric in place, only a seal coat of epoxy resin was used to prevent excessive absorption by the dry concrete surface of epoxy resin from the saturated FRP fabric. The edges of the 50-in.-wide bands of fabric were adequately overlapped in the hoop and longitudinal directions to achieve the FRP's full continuity. Overlap edges were feathered with epoxy paste and/or epoxy resin to secure the overlaps in the lining.

Specially designed construction joints were prepared at the starting point of each installation run, which also became end points of the installation front that started at a downstream access point. The joint was later sealed with an epoxy paste. Nowhere in the 5,742-ft length of pipeline were FRP lining edges left exposed to peeling from water flow, maximizing the installation's watertightness.

The average production rate of each of the four installation stations was 2,500 ft^2 of FRP lining installed in an average eight-hour workday. The operation continued seven days a week, and complete installation of the approximately 150,000 ft^2 of FRP lining system was accomplished in 15 days. This included applying the epoxy top coat. To ensure maximum bond, the application took place before the lining was fully cured—i.e., the surface was still tacky on contact.

The FRP lining installation was completed July 8, 2009, and pressurized test runs were successfully completed on July 15. More than one mile of a 7-ft-diameter pipeline was successfully retrofitted to its original condition in three weeks (one week of prep work and two weeks of FRP lining installation). The FRP lining is expected to require no maintenance and to have a useful life that will at least match the pipeline's operational lifetime.

PLANNING AHEAD

Because retrofitting pipelines inside power plants, water/wastewater plants, or other industrial facilities usually is scheduled during programmed maintenance shutdowns, the amount of retrofit that can be done depends on the time allocated for the shutdown. However, considering the production rates that can be achieved with FRP lining installation, it may now be feasible to schedule structural rehabilitation of complete pipelines during a typical shutdown period. Moreover, FRP is a viable alternative for emergency pipeline repairs in which pipeline segments can't be excavated.