Fiber-Reinforced Polymer Pipe Lining

Emergency repair to penstock allows power plant to enter service

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Fiber-reinforced polymer (FRP) linings have long been accepted for the rehabilitation of pipelines that have deteriorated through decades of service, but they can also be used to correct design or construction deficiencies in new pipelines. Such was the case of the low-pressure penstock at the El Encanto Hydroelectric Power Plant, located 75 miles (120 km) northwest of San José, Costa Rica. We believe this project, which required the installation of about 150,000 ft.^{2} (14,000 m^2) of FRP lining in a single phase, is the largest such project in history.

Fig. 1: Above ground segment of the El Encanto penstock

PRESSURE TEST

The low-pressure penstock at the El Encanto plant conveys river water from an upstream dam to the plant's turbine complex. The cast-in-place reinforced concrete pipeline (Fig. 1) has an inside diameter of 7 ft. (2.1 m) and a total length of 5,742 ft. (1,750 m). The water flows by gravity, but it is also pressurized.

Before it was placed in service, a pressure test showed that the pipe had significant longitudinal and transverse cracking. As a result, as much as 20% of the flow was lost due to leaks. The penstock was drained and all visible cracks were sealed using locally available repair materials; but when it was pressurized for a second time, the repaired cracks continued to leak (Fig. 2).

We were then contacted to engineer repairs. After inspection of the cracks (Fig. 3), review of the structural plans, and consideration of the engineering reports pertinent to the leak issues, we determined that an FRP lining would provide a solution.

RAPID RESPONSE

Design

The FRP lining was designed to bridge cracks in the concrete, provide a moisture barrier, and supply additional hoop strength to compensate for future loss of circumferential steel due to corrosion. We designed the adhered FRP laminate to achieve full deformation compatibility with the pipe during pressurization, and we specified bidirectional glass fibers in the fabric to ensure that existing or future cracks are intercepted in orthogonal directions. It should be noted, however, that although the laminate will prevent water from leaking from or into the pipe, corrosion of the steel reinforcement will not be slowed significantly in this case due to the constant presence of seepage water in the cracks.

The time urgency associated with the power plant's imminent start of operations required placing the entire design and manufacturing process on a very tight 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 of two structural engineers and three field supervisors traveled to Costa Rica to oversee the project and train the local installation crews. A technical team fluent in Spanish was required for the job to run smoothly.

Fig. 2: After conventional crack sealing, the penstock failed to pass a second pressure test.

"more than 1 mile of a 7 ft. diameter penstock was successfully retrofitted in 2 weeks"

Preparation and installation

Before an FRP lining can be applied, the substrate must be prepared to maximize contact and bond strength. The inside of the pipe was pressure washed with 7,000 psi (50 MPa) machines to remove scour, sediment, curing compounds, and any other substance that could hinder the bond between the FRP and the pipe surface; surface irregularities (such as roughness at construction joints and fins at formwork joints) were ground smooth (Fig. 4).

Crews were able to access the penstock at four relief valves. The valves, which were spaced from 1,000 to 1,500 ft. (300 to 450 m), provided 24 in. (600 mm) square access ports for workers, materials, and equipment. A five-person crew prepared and cut the FRP rolls at an outside station adjacent to the access point. The prepared rolls were then transported from the access point to the installation point, where a second five-person crew did the actual installation.

To help prevent the joints in the lining from being lifted by the water flow, the installation direction was opposite to the flow direction. An installation crew initially applied an epoxy paste to the top half of the penstock. This not only sealed the surface of the concrete to prevent the dry concrete from absorbing excessive resin from the saturated fabric but also prevented peeling of the saturated FRP fabric before the resin cured. Figure 5 shows the installation of the first roll of FRP lining material at one of the installation stations. After they were saturated with resin, 50 in. (1,270 mm) wide bands of fabric were rolled onto the prepared surface—much as one would install wallpaper.

Because gravity helped to hold the FRP fabric in place, only a seal coat of epoxy resin was used to prevent the dry concrete from absorbing excessive resin from the fabric in the lower half of the pipe. The edges of the fabric bands were lapped in the circumferential and longitudinal directions to achieve full continuity of the FRP. To help prevent delamination, the edges of the laps were feathered with epoxy paste or resin.

Construction joints were prepared at the starting point of each installation run, which later became the end point of the installation front that had started at a downstream access point. This joint was later sealed with an epoxy paste. No FRP lining edges were left exposed to peeling from water flow, maximizing the water tightness of the installation.

Fig. 3: A typical crack in the pipe wall

The final step involved installation of an epoxy top coat as a cover for all the installed FRP. This coat was designed to protect the laminate against abrasion caused by sediment carried by the river water as well as to cover possible pinholes in the FRP lining. The coating has a concrete gray color to facilitate quality control by providing a visual indication that the light green-colored FRP lining was fully covered. The top coat application took place before the lining was fully cured (the lining surface was tacky on contact) to ensure maximum bond.

Fig. 4: Prior to installation of the FRP lining, surface preparation included grinding

Fig. 5: Installation of FRP sheets on the interior surface of the pipe. An access point is visible at the lower left

Fig. 6: Completed lining, including gray top coat, prior to testing

The average rate of production of each of the four installation stations was 2,500 ft.² (230 m²) of FRP lining installed in an average 8-hour work day. The operation continued 7 days a week, allowing the complete installation of approximately 150,000 ft.² (14,000 m²) of the FRP lining system in 15 calendar days. This time included the application of the epoxy top coat. The FRP lining installation was completed on July 8, 2009 (Fig. 6), and pressurized test runs were successfully completed on July 15.

SERVICE

Unique challenges of this project included extensive prep work needed to smooth irregularities caused by the cast-in-place construction procedure, the need to accommodate changes in the vertical and horizontal alignment of the pipeline due to the mountainous topography, the training of local installation crews with no previous experience with FRP, and the urgent need to minimize downtime of the power plant. In spite of these unique challenges, the project was completed ahead of schedule, making it an outstanding achievement in civil engineering.

With no excavation, more than 1 mile (1.6 km) of a 7 ft. (2.1 m) diameter penstock was successfully retrofitted in 3 weeks (1 week of prep work and 2 weeks of FRP lining installation). The FRP lining is expected to require no maintenance over the penstock's operational lifetime.

Selected for reader interest by the editors.

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CIRCLE 51

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