Municipal Aqueduct System Uses

Fiber-Reinforced Polymer Technology
for Repair and Strengthening

By Jay Thomas and Robert St. John

One of the worst scenarios for any municipal waterworks is a failure in one of its pipelines. If a blowout occurs, the cost of repairs is only the beginning. Other problems include snarled traffic and a disruption of neighborhoods, not to mention the community ill will generated by the protracted repair process. With these headaches it is easy to see why this is a situation municipalities try to avoid at all possible cost.

The Providence Water Supply Board faced such a dilemma in 1998 when a major section of a 102″-diameter water line in Cranston, R.I., failed completely. The ruptured precast concrete cylinder pipe failed due to corroded prestressing wires that were the primary reinforcement in place to contain 120-psi water pressure as well as the overburden and live loads.

The Providence water line failure raised valid concerns that other sections of the aqueduct also could be prone to failure, since the pipes originally had been installed as long as 50 years ago. Ultrasonic (pulse echo) and acoustic (hammer sounding) testing identified other areas of potential concern where exterior delaminations could be occurring.

An inspection of the entire water line system confirmed these suspicions. This inspection revealed vulnerabilities in twenty nonconsecutive 16-foot-long sections within a five-mile stretch of the pipeline. Strengthening these sections was deemed important to the long-term durability of the system. SPS, a national concrete repair contractor headquartered in Maryland, was invited to submit a proposal on the repair and strengthening of the sections.

Designing a Better Repair Approach

Preventive aqueduct pipe repairs often are made by inserting a steel liner in sections, welding them together, and then grouting the annular space between the new and old sections. This approach requires a significant amount of excavation, coupled with long periods of downtime. In the case of the Providence Aqueduct, the individual repairs were scattered along a five-mile stretch of line, which meant that the steel liner approach would be both costly and overly intrusive. For this reason, SPS believed that the installation of a carbon fiber-reinforced polymer (FRP) sheet lining would be the fastest, least disruptive and most cost-effective repair solution.

This carbon fiber strengthening design assumed that the existing prestressing wire was no longer effective. Thus, a multi-system was designed to carry the 125-psi internal service loads, the live and dead loads of the soil, plus additional safety factors. Layers were internally wrapped around the circumference of the pipe, as well as longitudinally. The design called for surface areas to be completely covered with carbon fiber – essentially creating a “pipe within a pipe.” In order to eliminate the possibility of water infiltrating behind the FRP system, a waterstop-type termination detail was designed for the end of each 16-foot section of pipe.
Testing the Design

Once the design was finalized, full-scale testing on three pipe sections was conducted to validate its effectiveness. Testing multiple sections as opposed to just a single pipe section provided the chance to test a complete waterstop termination detail at both the spigot and bell ends of a pipe section. After the FRP liner was installed, the prestressing strands at the center of the strengthened section were cut to guarantee a full test of the FRP. The pipe assembly was sealed with large steel bulkheads and then filled with water. Next, the test pipe was pressurized at steadily increasing rates until failure. This occurred at almost 300 psi, which is 2½ times the service and surge pressures and within 5 percent of the capacity of a new pipe.

Winter in New England

The actual repairs began in January 2000 in typical New England winter weather conditions. The pipe sections to be strengthened were buried 10 to 15 feet underground, and some were situated miles from one another. Access points were limited and, predictably, not always near the areas to be repaired. Ladders were placed in the 30″-diameter service holes to provide access to the repair areas. A tripod and winch pulley system was used to raise and lower materials into the work area. Since this was a confined work environment, special safety measures were enacted.

In addition, because the pipe sections had not been dry in years, high levels of humidity coupled with cold working temperatures required constant monitoring to ensure ambient conditions for the FRP installation. Blowers, dehumidifiers and heaters kept the relative humidity level between 40 and 50 percent and the ambient temperature between 55° and 60° F.

A Meticulous Process

Before the FRP was applied, SPS conducted pull tests to verify the potential bond strength of the actual pipe surfaces. These tests revealed that failure occurred in the subsurface at an average of 300 psi. This strength was well over the 200 psi necessary for the carbon fiber application per the American Concrete Institute and the manufacturer’s guidelines.

Next, high-pressure waterblasting removed sediment from the pipe’s interior to prepare the surface for the carbon fiber application. Scaffolding was erected to allow the technicians to reach the top of the pipe and to prevent walking on the bottom. The surface was prepared by applying an epoxy primer followed by a trowel-applied epoxy putty material to fill voids and level imperfections. The surfaces now were ready for the FRP installation.

Prior to installation, the FRP sheets were cut to a predetermined length in an aboveground staging area. Once the sheets were lowered into the work area, they were saturated with an epoxy. Each FRP sheet then was applied to the pipe’s circumference in three sections with a 4″ overlap. Metal rib rollers were used to push out any air bubbles and to press the FRP sheets into the saturant. A second layer of the saturant then was applied to form a complete fiber/laminate matrix.

This process was repeated for the subsequent layers of carbon fiber. Finally, an epoxy topcoat approved for potable water applications was applied to protect the FRP and provide a safe, sealed passageway for the water.

Success on Many Levels

Using lightweight, flexible carbon fiber material for strengthening the Providence Aqueduct turned out to be an innovative, cost-effective solution. In fact, the total project cost came in on budget, and its success earned the International Concrete Repair Industry’s ICRI Award of Excellence in the Water Systems category.

The Providence Aqueduct project now serves as a model for water utilities facing similar repair situations where the excavation of pipes is neither cost-effective nor desirable. By using FRP, Providence Water Supply did not have to dig, replace or line long pipe segments. This also was one of the first times on-site installation of FRP sheeting in potable water pipes for strengthening purposes took place.

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