Carbon Fiber Composites for Concrete Repair

UNIQUE FRP TECHNOLOGY
USED TO REPAIR AND STRENGTHEN
MUNICIPAL AQUEDUCT SYSTEM

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One of the first-ever on-site application of FRP strengthening technology to water pipelines enabled the Providence Water Supply Board to repair rather than replace 50-year-old pipes in its aqueduct system. This presentation will discuss CFRP Strengthening systems for the structural upgrade of PCCP Aqueducts . Topic covered are material properties, design strategies, installation techniques and QC.

One of the worst nightmare scenarios for any municipal waterworks is the failure in its pipelines. If a blowout occurs, the cost of repairs is only the beginning. Add to this snarled traffic and disruption of neighborhoods — not to mention the community ill will generated by the protracted repair process — and it's easy to see why this is a scenario 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 PCCP water line in Cranston, Rhode Island, failed completely. The ruptured precast concrete cylinder pipe failed due to corroded prestressing wires, which 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 could also be prone to failure, since the pipes had originally been installed as long ago as 50 years. Ultrasonic (pulse echo) and acoustic (hammer sounding) testing identified other areas of potential concern where exterior delaminations could be occurring. Other forms of condition analysis techniques such as Eddy current testing have since been developed and accurately used on pipe testing.

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 propose on the repair and strengthening of the section

Designing a Better Repair Approach

Preventive aqueduct pipe repairs are often made by inserting a steel liner in sections, welding them together, then grouting the annular space between the new and old sections. But this approach requires long , continuous sections of repair to make it a viable option based on the fact that a significant degree of excavation, coupled with long periods of downtime is required. 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, SPS designed a multi-ply system 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, thus bypassing the strengthening system and making it ineffective, 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 by SPS to validate its effectiveness. Testing multiple sections as opposed to 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 so as 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 – almost 300 psi, which is 2-1/2 times the service and surge pressures, and within 5% of the capacity of a new pipe.

Welcome to 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 apart from one another. Access points were limited and, predictably, not always near the areas to be repaired. Ladders were placed in the 30-inch diameter service holes to provide access to the repair areas, and a tripod and winch pulley system was used to raise and lower materials into the work area. Because of the confined work environment, special safety measures needed to be enacted.

Because the pipe sections had not been dry in years, high levels of humidity coupled with working temperatures required constant monitoring to ensure the required ambient conditions for the FRP installation. Blowers, dehumidifiers and heaters kept the relative humidity level between 40% and 50%, 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 — well over the 200 psi necessary for the carbon fiber application per the American Concrete Institute 440 (FRP) and 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. To prepare the surface, an epoxy primer was applied, followed by a trowel-applied epoxy putty material to fill voids and level imperfections. The surfaces were now ready for the FRP installation.

Prior to installation, the FRP sheets were cut to a predetermined length in an above-ground staging area. Once the sheets were lowered into the work area, they were saturated with an epoxy saturant. Each layer of FRP sheet was then applied to the pipe's circumference in three sections, with a 4-inch 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 was then applied to form a complete fiber/laminate matrix.

This process was repeated for the subsequent layers of carbon fiber. Lastly, 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 a proactive condition survey and preventative repairs avoided disastrous failures or where 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 represents one of the first-time-ever on-site installation of FRP sheeting in potable water pipes for strengthening purposes. But based on the success of this project, FRP is likely to be adopted as a choice repair technique for future municipal waterworks projects throughout the United States involving isolated pipe section repairs.

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