CARBON FIBER-REINFORCED POLYMER REPAIR OF REINFORCED CONCRETE PIPE

BY DARYL A. LITTLE

The U.S. Bureau of Reclamation's Technical Service Center (TSC) recently assisted the Pacific Northwest Regional Office by providing advice and specifications. The center also participated in the QA/QC inspection for a carbon fiber-reinforced polymer (CFRP) installation at the Weber Coulee Siphon in eastern Washington. The new siphon at Weber Coulee is a reinforced cast-in-place concrete pipe with an inside diameter of approximately 15 ft (4.6 m) and sections approximately 25 ft (7.6 m) long.

Fig. 1: Completed CFRP-lined section

FLAWS DISCOVERED DURING CONSTRUCTION

During the pouring of four newly constructed barrel sections, a number of flaws appeared, including full-section rock pockets and voids in and around the reinforcing steel and water stop, because of concrete consolidation problems. The bureau did not feel that the standard concrete repairs could adequately withstand the high pressures the pipe would realize and also assure corrosion protection of the reinforcing steel for the intended life expectancy of the siphon.

Fig. 2: High-pressure hydroblasting

The bureau determined that a CFRP lining would make the sections watertight and provide long-term serviceability despite the large rock pocket repairs that were made. CFRP has good wear and impact resistance; and because it is capable of handling the external and internal loads, the safety factor for the barrel sections was increased. Based on the bureau's suggestion, the contractor agreed to line those sections with CFRP. Figure 1 shows a completed section of the lined siphon.

EXPERIENCE WITH CFRP

Starting in about 1995, the San Diego County Water Authority (SDCWA) and the Metropolitan Water District of Southern California (MWD) began successfully using CFRP for their repairs. In subsequent phone conversations, MWD said the materials and techniques being used today are even better than those used in the initial installations. In 2005, the bureau's Materials Engineering and Research Laboratory (MERL) evaluated the use of

Fig. 3: Hydroblasted surface

Fig. 4: Application of epoxy primer

Fig. 5: Application of saturation epoxy

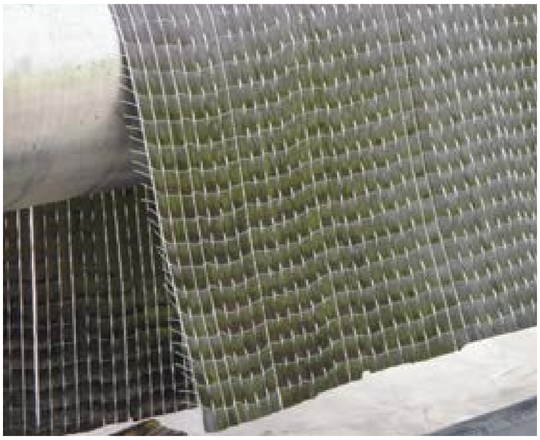

Fig. 6: Unidirectional carbon-fiber fabric

Fig. 7: Saturation of carbon-fiber fabric

CFRP for similar applications and found it to be a practical repair material.

The design of a CFRP system takes into account internal pressure and backpressures and can accommodate a variety of joint and leading-edge details for the repair to function the same as the original pipe sections. Generally, materials are readily available and CFRP rehabilitation can begin soon after repairs to the underlying concrete are completed. Installation time is minimal, and the pipe can be returned to service in approximately 3 days or just after curing of the polymer.

INSTALLATION

The CFRP lining included the design, ventilation, dehumidification, temperature control, surface preparation, and installation of the CFRP liner with an epoxy overcoat. The concrete surface of the pipe was repaired and cured in accordance with the bureau's specifications prior to installing the lining.

The concrete surface was prepared using high-pressure water cleaning, or hydroblasting, in accordance with the ASTM D4258 water cleaning method. This procedure removed the surface laitance and provided a concrete surface profile of Level 3 per ICRI Technical Guideline No. 310.2. Hydroblasting the concrete surface is shown in Fig. 2, whereas Fig. 3 shows the surface of the pipe after the water cleaning work was completed. The lighter areas seen in Fig. 3 are the locations that were repaired prior to hydroblasting. Then, the equipment was set up to dehumidify the pipe, dry the walls, and ventilate the work area.

The need for personal respirators was eliminated because all of the epoxies used in the application of the carbon fiber were 100% solids and contained no solvents or volatile organic compounds (VOCs). All epoxies were mixed outside (in the open air) prior to transport into the pipe, and an epoxy primer was applied using paint rollers, as shown in Fig. 4. After the primer was rolled on, saturation epoxy was applied to the surface using trowels (Fig. 5).

The carbon-fiber fabric is shown in Fig. 6 and had a unidirectional carbon-fiber weave. Large rolls of fabric were saturated with epoxy using a saturation machine (Fig. 7) and rolled onto plastic pipes. As the fabric was being rolled onto the pipe, it was also cut to the appropriate length for installation. The saturated fabric rolls were then wrapped in

Fig. 8: Longitudinal application of fabric

Fig. 10: Smoothing out fabric

Fig. 9: Applying fabric in hoop direction

Fig. 11: Application of saturation epoxy

plastic wrap and transported to the pipe section being repaired.

The design of the proposed liner specified three layers of fabric for the installation. The CFRP was installed by first unrolling fabric in the longitudinal direction, as shown in Fig. 8. The second and third layers were then applied by unrolling the fabric in the hoop direction (shown in Fig. 9). The number of hoop layers required is dependent on the structural requirements of the CFRP repair. Air pockets and wrinkles were smoothed out of the fabric using putty knives and hands, as shown in Fig. 10. After each layer of fabric was applied, the saturation epoxy was troweled onto the surface (Fig. 11).

After the CFRP had cured for 24 hours, it was inspected for bubbles, delaminated areas, and fabric tears using a sounding method. Repair areas (Fig. 12) were identified and repair methods selected based on the size of the defect. Defects smaller than 2 to 3 in. (50 to 76 mm) were repaired by drilling a hole in the defect (Fig. 13) and injecting saturation epoxy (Fig. 14). For defects larger than 2 to 3 in. (50 to 76 mm), the delaminated layers of CFRP material were removed as shown in Fig. 15, and squares of saturated fabric for each layer removed were applied to the surface (Fig. 16).

Fig. 12: Delaminated areas identified for repair

The patch applied was larger than the defect with a 4 in. (102 mm) overlap, and each additional layer of fabric applied had a 4 in. (102 mm) overlap onto the previous layer. The CFRP will be inspected after 1 year of service and then every 5 years during the required pipe inspection.

CFRP ADVANTAGES AND PROJECT DATA

Installation of a CFRP liner was accepted instead of removing and replacing the defective siphon sections. CFRP repairs are new to the Bureau of

Reclamation but have been used successfully by large municipal water authorities.

CFRP lining is a cost-effective repair solution for in-place repairs of concrete pipe. The method does not require the excavation normally needed to replace a pipe section, resulting in significantly less downtime. Some specific key elements of this project included:

- The CFRP lining was completed in about 2 weeks but after the extensive concrete repair work was completed;
- The installed CFRP liner, with a bond of 400 psi (2.75 N/mm^2) to the host pipe's interior concrete surface, is fully capable of resisting pressure from the water table, which is 25 ft (7.6 m) above the pipe's spring line;
- Inclusion of three layers of CFRP material will allow the CFRP liner to act as a long-term impermeable barrier to ensure the water tightness of the barrel sections;
- The CFRP was designed primarily as a water barrier and not for strength purposes; however, the addition of the CFRP liner increases the factor of safety for internal pressure resistance by at least 10%; and
- The source of water for the siphon is a canal that could potentially have large objects flowing with the water and impacting the liner. The CFRP lining has wearing and impact-resistance properties that are better than the unlined concrete pipe sections and can handle the impact from a car-sized object floating down the siphon.

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Fig. 13: Hole being drilled for epoxy injection

Fig. 14: Epoxy being injected

Fig. 15: Cutting out delaminated layers

Fig. 16: Patch repair of delaminated area