Multifaceted Approach Mitigates Corrosion of a New Wastewater System

Modern Sewer Tunnel Network Lies Beneath Historic Charleston

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Charleston, South Carolina is a beautifully preserved architectural and historic treasure with a rich, 300-year heritage. Photo courtesy of Charleston Area Convention & Visitors Bureau, www.charlestoncvb.com.

Historic Charleston, nestled on the tip of a peninsula that lies near the southern half of South Carolina's Atlantic coastline at the junction of the Ashley and Cooper Rivers and the Charleston Harbor, boasts more than three centuries of history that date back to colonial times. Founded in 1670, the city today is a beautifully preserved historic treasure that embraces colonial, antebellum, and Victorian architecture along with formal gardens that adorn much of the town's Historic District.

Early on, city officials had constructed a sewage collection system as Charleston grew, and wastewater practices at that time discharged sanitary sewage directly into the bordering rivers and harbor. In the 1960s, however, alarm over sewage disposal methods prompted city planners to design a system that collected all of the Charleston peninsula sanitary sewage from shallow sewer lines and transported it to a newly constructed wastewater treatment facility located on a small island across the Charleston Harbor. To preserve the city's historic character, city planners opted to construct an underground inverted siphon tunnel system approximately 110 ft (33.5 m) below the city to facilitate the collection of sewage and carry it under the harbor to the Plum Island Wastewater Treatment Facility.

When constructed, the Charleston wastewater deep tunnel system was one of the first tunnel systems built to convey sanitary sewage. According to Larry Drolet, director of construction for Charleston Water System (CWS), the public water and wastewater utility that provides water and wastewater service to the City of Charleston, West Ashley, Daniel Island, and James Island, the original tunnel system was an eight-mile (13-km) network consisting of two tunnels; one that followed the perimeter of the peninsula and one that carried waste water from West Ashley to the Plum Island plant. The tunnels were constructed of vertical, arch-shaped steel rib supports, spaced approximately 6 ft (1.8 m) apart, with wooden planks (known as lagging) lining the walls of the tunnels.


An intact section of the original tunnel. Photo courtesy of Charleston Water System.


Waste water from breached carrier pipes escaped into the tunnels' annular space and created conditions that corroded the steel ribs. Eventually the wood lagging came loose and caused the marl behind it to spall. Photo courtesy of Charleston Water System.

Inside the tunnels, a reinforced concrete carrier pipe was blocked into position with timber wedges, and the annular space around the carrier pipe was filled with water. The tunnels were excavated in a geologic formation known as Cooper marl, a stiff, non-permeable material that is similar in look and feel to modeling clay. The calcareous material was easy to excavate but strong enough to require only modest support.

Standard vortex drop pipes and 6-in (152-mm) ventilation pipes, commonly used for stormwater systems, were designed to channel the flow of sewage from the shallow sewer lines into the subterranean carrier pipes. At the Plum Island Wastewater Treatment Facility, a deep pump station lifted flows of waste water from the carrier pipes to the plant for treatment and subsequent discharge of the treated waste water into the Charleston Harbor.

Over the years, however, the tunnel structures and the carrier pipes inside

Shown is the installation of the next to last section of a precast polymer concrete pipe shaft liner. Photo courtesy of Black & Veatch.

were slowly compromised by the corrosive gas that forms when waste water reacts with air. Limited engineering experience with subterranean tunnels designed specifically to convey waste water and the types of materials and technology available at the time were contributing factors.

"The original system didn't work quite as well as had been planned," says Drolet. "The original carrier pipes were not lined, and the vortex drop pipe allowed air to enter the system. Air became trapped in the carrier pipes when the small-diameter ventilation pipes became blocked, and caused the formation of sulfuric acid (H_2SO_4) from the hydrogen sulfide (H_2S) in the wastewater stream. This contributed to the corrosion of the top of the carrier pipes. Once the carrier pipes were breached, waste water escaped into the tunnels' annular space and created conditions that corroded the steel ribs. Eventually the wood lagging came loose and caused the marl behind it to spall."

The corrosion caused cave-ins that restricted flows, caused partial blockages, and threatened to create a complete flow blockage in the tunnels that could trigger sewer overflows. Although repairs were made, subsequent diving inspections of the tunnels in ensuing years revealed additional damage—particularly in the Harbor Tunnel section that ran under Charleston Harbor to the wastewater treatment plant—with corrosion most prevalent in the carrier pipes closest to the drop shafts. Because repairs to the existing tunnels would require slow, dangerous work that was cost prohibitive, CWS officials decided to replace the existing tunnel system with a network of new tunnels.

Designing to Combat Corrosion

The design team—which included engineers from the Charleston office of Black & Veatch Corp., a global engineering, consulting, and construction company, and Hussey, Gay, Bell, and DeYoung, a local consultant—used a multifaceted approach for constructing the new tunnel system that addressed all the issues that led to the corrosion of the carrier pipes and, ultimately, the steel rib tunnel supports.

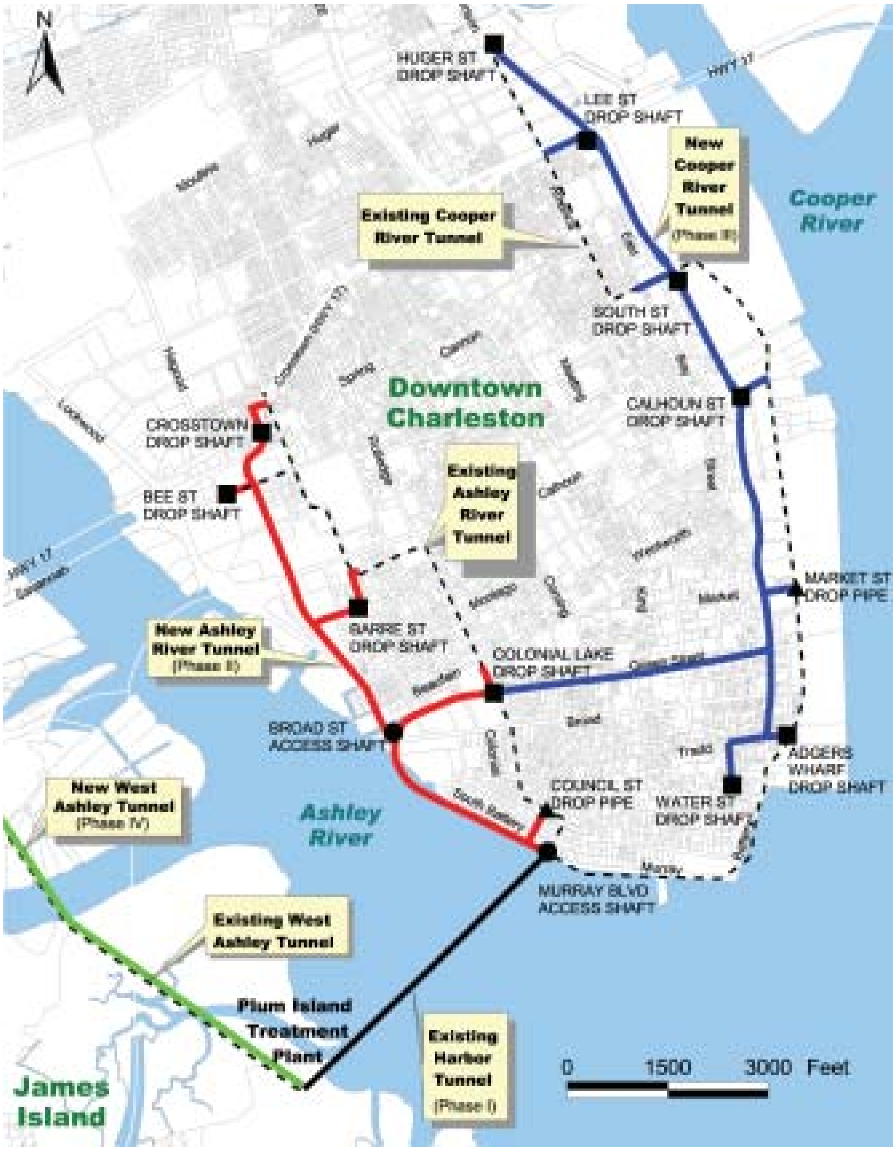
Since oxygen in the wastewater stream was a concern, it was crucial to reduce the amount of air swept into the downstream sections of the tunnel when the fluid stream entered the drop shaft. According to Paul Smith, resident engineer with Black & Veatch, the team developed a new, larger vortex drop shaft design, with a scroll-type inlet device that forces the influent to the outside of the drop pipe in a downward spiral path. An air core, formed in the center of the pipe, carries air released from the fluid stream upward to the top of the inlet, and trapped air is minimized.

"The vortex gets the waste stream moving, which forces the air out of the fluid," Smith says. In addition, the drop pipes were terminated below the water surface but 20 ft above the carrier pipes, so any small air bubbles will rise to the surface of the water rather than be drawn into the tunnels. A physical model was constructed by Northwest Hydraulic Consultants, Inc. (Seattle, Washington) to test the efficiency of the new design.

To reduce future operating and maintenance costs, corrosion-resistant materials and coatings were used in the new 10-ft (3-m)-diameter vortex drop shafts. The shafts' 30-in (762-mm)-diameter drop pipe consists of a high-density polyethylene (HDPE) body with a stainless steel (SS) wall pipe that sits on top to form the base of the scroll inlet. Two types of shaft liners were used in the project. Precast reinforced concrete pipe shaft liners made with Portland cement feature a 100% solids epoxy coating, 120 mils thick, that is sprayed on the interior of the shaft, Smith notes. The team also utilized precast shaft liners made of polymer concrete pipe. *(See sidebar, p. 34.)*

For the subterranean carrier pipes, instead of using reinforced concrete pipe, Smith says the team selected 24- to 48-in (0.61- to 1.22-m)-diameter centrifugally cast fiberglass reinforced polymer mortar pipe (CCFRPM), which consists primarily of thermosetting polyester and glass-fiber reinforcement, and has a history of long operation in an acidic environment.

To mitigate corrosion of the new tunnels' 60- to 96-in (1.5- to 2.4-m) circular steel ribs and 3- by 6-in (76-mm by 152-mm) hardwood lagging, the team



The map shows the placement of existing and newly constructed tunnels. Image courtesy of Charleston Water System.

Workers construct a precast concrete pipe vortex drop shaft. This type of shaft consists of a HDPE drop pipe (center), and a SS wall pipe (the top portion of the center pipe) that forms the base of the scroll inlet. A 100% solids epoxy coating, 120 mils thick, is sprayed on the concrete interior of the shaft. Photo courtesy of Black & Veatch.

decided to backfill the annular space with low-density cellular concrete (LDCC)—a cementitious grout consisting of cement, fly ash, water, and admixtures in a closed-structure foam. The LDCC forms a barrier between the carrier pipe and the tunnel support system and provides protection in the event of a limited breach of a section of carrier pipe.

The tunnel system was replaced in several phases that were prioritized according to the extent of the deterioration in sections of the original tunnel. The first and second phases—the Harbor Tunnel, and the Ashley River Tunnel on the west side of the peninsula—were completed in 2002 and 2006 respectively. Phase three, the Cooper River Tunnel on the east side of the peninsula, was completed around the beginning of March 2008. At press time, phase four of the project, the Daniel Island Extension Tunnel, was being finalized.

The tunnel construction contracts were awarded individually to Affholder, Inc. (Chesterfield, Missouri). Most of the work took place more than 100 ft underground, with aboveground construction performed in and around the drop shafts. As the new tunnels were completed, crews diverted the flow of waste water from the existing drop pipes to the new drop shafts. According to CWS, estimated cost for the entire project is $212 million.

"Quite a bit of effort was spent in the design and material specification stage of this project," Drolet says, "and we feel confident that the design and materials will ensure the tunnel system lasts a long time. It was a very good project, resulting from a great team effort."

More information on the project can be found on the CWS Web site, www.charlestoncpw.com.

Bibliography

Haynes C., J. McKelvey, and M. Cline. "Corrosion Failure in Deep Wastewater Tunnels: Lessons and Solutions." WEFTEC 2007, Chicago, Illinois. Alexandria, VA: Water Environment Federation, 2007.

A 12-ft (3.6-m)-high, 10-ft (3-m)-diameter cast polymer composite section of a vortex drop shaft liner is lowered into place. Photo courtesy of U.S. Composite Pipe.

MATERIALS REVIEW

Mitigating Corrosion with Cast Polymer Composite Pipe

One of the key corrosion-mitigation components of the Charleston Water System's (CWS) new wastewater tunnel system was the specification of materials that would resist the corrosive nature of hydrogen sulfide (H_2S) found in the wastewater stream. For three of the new vortex drop shafts that were constructed as part of the Cooper River Tunnel, the design team approved precast polymer composite drop shaft liners manufactured by U.S. Composite Pipe (Alvarado, Texas). The use of precast polymer concrete pipe was recommended by Affholder, Inc. as a cost-reduction proposal. The structures combine the strength of steel reinforcing rod with a special polymer concrete formulated with Vipel† corrosion-resistant resin from AOC (Collierville, Tennessee).

The polymer concrete offered several advantages, says Paul Smith, resident engineer with Black & Veatch, the engineering consulting firm that worked with CWS to design the new tunnel system project. Because H_2S doesn't affect the polymer, corrosion protection is inherent throughout the entire composite material due to the special resin used in place of traditional cementitious binder. Unlike the precast concrete liners made with Portland cement, the precast polymer concrete doesn't require an epoxy coating.

Another advantage to using polymer composite is its higher compressive strength—two to three times the strength of concrete made with Portland cement, Smith adds. This facilitated thinner and significantly lighter structural members with equivalent design strength. Lower weight can lower the overall cost of the finished product, the cost of shipping it to the job site, and the cost of a larger crane.

"We took the original design from Black & Veatch and were able to reduce the wall thickness by 40% or more through our own in-house engineering," says Eric H. Davidson, P.E., vice president of U.S. Composite Pipe.

Casting procedures for both conventional and polymer concrete are similar. U.S. Composite Pipe components are manufactured by first placing a steel reinforcement cage into a formwork. Like conventional pipe, the steel reinforcing gives the finished product the ability to handle severe loading. The polymer concrete is then vertically cast into the formwork and vibrated for optimal compaction.

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†Trade name.