Inflatable Plug Protects Subway Tunnels from Floodwaters

SOME OF THE most memorable pictures of the damage caused by Hurricane Sandy as it overwhelmed New York City in the fall of 2012 are of inundated subway stations. Some, such as the two-year-old South Ferry station, located at the foot of Manhattan adjacent to the harbor, received significant amounts of salt water. Well before Sandy hit the East Coast, however, scientists and engineers within the U.S. Department of Homeland Security's Science and Technology Directorate had spearheaded a project aimed at protecting tunnels and subways from extreme flooding. The directorate was working with ILC Dover, a designer of high-performance engineered fabric systems based in Frederica, Delaware; the U.S. Department of Energy's Pacific Northwest National Laboratory, in Richland, Washington; and West Virginia University. Their decade-long effort to develop a plug that would be capable of stopping floodwaters from entering subway tunnels and could be stored at its point of use, deployed immediately, and then reused has borne fruit.

"While we began this whole project before Sandy hit, it was this type of scenario that we were envisioning," says John Fortune, Ph.D., the project manager for the Science and Technology Directorate. The research team wanted to prevent flood damage to train tunnels by deploying inflatable plugs so as to limit damage to the interconnected transportation system. The Department of Homeland Security is charged with helping protect the nation's critical infrastructure, and its Science and Technology Directorate is responsible for developing high-risk, outside-the-box ideas, Fortune explains. "We are allowed to invest a small amount of our budget for the use of [what could be termed] they probably aren't going to work ideas," he says. "A lot of people didn't think this was going to work, including some of our transit partners."

An early prototype of the concept was designed by a team from West Virginia University and tested in the Washington, D.C., subway system in 2008, according to Fortune. The test sought to determine whether a lightweight fabric plug could be folded to fit into a space no more than a few inches deep and then inflated to fill a tunnel, Fortune explains.

When success was achieved in the test, ILC Dover was brought on board because of its expertise in high-tech, high-strength inflatable textile manufacturing. The company has created experimental habitats and space suits for the National Aeronautics and Space Administration, among other products, according to Fortune. The team then experimented with different fabrics and inflation systems to ensure that the plug would be able to withstand floodwater pressures and debris impacts while lending itself to storage in a streamlined container that could be placed either on the side or the ceiling of a subway tunnel. The plug would also need to be reusable so that replacements after each event would not be necessary.

The final design of the system, known as the Resilient Tunnel Plug (RTP), includes three elements: a plug, its container, and a pressurization system. "The RTP functions similarly to an automotive air bag system in that it resides in a small container and is pressurized to shape when an event occurs," explained Dave Cadogan, the director of engineering and product development for ILC Dover, who wrote in response to questions posed by *Civil Engineering*. "Internal pressure exceeds the external water pressure to create the barrier, and the plug is held in place with friction," Cadogan said.

The Resilient Tunnel Plug is stored in a container just a few inches in depth. When needed, it can be deployed remotely and will inflate in just 10 to 12 minutes.

ILC DOVER, LP, ALL

The plug comprises an exterior structural layer, a central protective layer, and an interior layer that is a urethane-coated polyester bladder. The layers are attached to one another in such a way that they can deploy monolithically. The exterior and central layers are made from a fabric woven from high-strength Vectran liquid crystal polymer yarns, produced by the Japanese firm Kuraray, Inc. "Vectran is a high-strength fiber that is similar to Kevlar but more robust for an application like this," Cadogan noted. The structural layer uses Vectran webbing that has a breaking strength of 24,000 lb, he said. The layer is "woven in a square weave for damage tolerance and structural resiliency," he explained. "Even if you cut a webbing, the structure remains intact because of the friction in the weave."

The plug could also be used for flood protection in mines, during tunnel construction, for site dewatering projects, and for dam testing.

The system, which can be operated remotely, can inflate to full pressure in just 10 to 12 minutes. Before the plug system is installed, the tunnel will need to be "modestly" modified, according to Fortune. While the plug can fill tunnels of almost any shape, it works best where rails similar to those at railroad crossings have been installed to fill any gaps between the rails on the floor and where any sharp corners at ceilings and floors have been rounded, he notes. Recessing or sealing pipes, conduits, and anything else that would impede the inflating fabric would be advisable, Fortune says.

Other potential tunnel conditions were taken into consideration and should not pose a problem, Cadogan said. Friction assessments were conducted to test the plugs against many types of tunnel wall finishes, including those coated with such contaminants as oils and brake dust, "to verify performance in every application imaginable," Cadogan explained.

A successful, 21-day test performed earlier this year involved a plug approximately 16.5 ft in diameter and 32 ft long. The plug was deployed, used, repacked, and retested more than two dozen times in a replica subway tunnel, according to Cadogan. The plug was filled with air pressurized to 17.3 psi so that it could withstand the pressure created by water at a depth of 26 ft, which equated to 11.56 psi in the test, he explained. The plug has an expansion ratio of 45:1 from its deployed to its packed shape, and it can be made in a variety of sizes to fit each project perfectly.

The 21-day test was undertaken to prove that the system could operate while water levels outside the subway receded and cleanup began. "It was a beautiful test from my perspective because the plug sat there for three weeks and did exactly what it was designed to do," Fortune says.

The plug could also be used for flood protection in mines, during tunnel construction, for site dewatering projects, and for dam testing, among other applications, according to Cadogan. It could even be used to prevent the movement of smoke, chemical or biological agents, or people, he noted.

Such a system comes at a cost, however. "It's not an inexpensive system," Fortune says. "[But] when you look at those Sandy numbers, the costs [of an RTP system] are very low compared to the potential impacts of losing tunnels and stations and other parts of the system to a major flood." The system can also be installed without shutting down the mass transit system, according to Cadogan, which is not the case with such other solutions as floodgates.

ILC Dover has applied what it learned in developing the plug system to its work on other solutions to flooding in subway and vehicular tunnels, including flexible wall- and gate-barrier systems. A number of these barriers have already been installed in New York City as part of the post-Sandy repair work, according to Cadogan. "In Sandy you had leakage through stairwells, ventilation shafts, elevator shafts, and through rail yard portals," Fortune says. The barriers developed by ILC Dover are stored discreetly at such openings and can be deployed immediately when necessary. "These are the systems that will become the workhorses of the flood protection market over time because of their ability to be stored at the point of use, and their technology stems from the RTP," Cadogan noted.

—CATHERINE A. CARDNO, PH.D.