Investigating Critical Infrastructure With Limited Access

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Communities across Florida continue to be challenged with degrading infrastructure, including leaks and breaks in their large-diameter water mains. In 2010, the City of Miami Beach (City) experienced a rupture of one of its water mains near the 63rd Street Bridge. This prompted the City to evaluate the structural integrity of a nearby primary transmission water main from the mainland: the 36-in.-diameter water main that crosses the Julia Tuttle Causeway (Figure 1). The City began to develop a condition assessment and rehabilitation strategy to minimize the potential of this primary transmission main experiencing a similar rupture.

This article presents the available and innovative assessment approaches utilized to evaluate the structural integrity of underground and subaqueous pressure pipelines with minimal surface impacts and service interruptions. The approaches utilize acoustics and electromagnetics to detect active leaks, gas pockets, and structural integrity of the pipelines, respectively, while recognizing that it was not feasible to take the transmission main out of service.

The approach was executed within the City on approximately 3 mi of 36-in.-diameter pipe comprised of prestressed concrete cylinder pipe (PCCP), cast iron (CI), and high-density polyethylene (HDPE). The transmission main traverses a subaqueous route under environmentally sensitive Biscayne Bay and an active Florida Department of Transportation (FDOT) traffic corridor in a densely populated zone from the intersection of NE 35th Terrace and NE 5th Avenue in Miami and along Julia Tuttle Causeway and Arthur Godfrey Road (West 41st Street).

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Condition Assessment Tools

To evaluate the Julia Tuttle Transmission Main, two specific condition assessment techniques were employed: acoustic-based leak detection and gas pocket inspection and electromagnetics. More detailed explanations of each technique are provided in the following sections.

Acoustic-Based Leak Detection and Gas Pocket Assessment

The inspection also included an acoustic-based leak and gas pocket inspection using an inspection unit (Figure 2). The equipment used is a free-swimming, acoustic-based technology that detects anomalous acoustic activity associated with leaks or gas pockets in pressurized pipelines. The unit is comprised of a water-tight aluminum alloy core that contains a power source, electronic components, and instrumentation, including an acoustic sensor, triaxial accelerometer, triaxial magnetometer, global positioning system (GPS) synchronized ultrasonic transmitter, and temperature sensor.

The aluminum core is encapsulated by a compressible protective foam outer shell, which provides a larger surface area by which the device is pushed along by the hydraulic flow of the water, while reducing low-frequency ambient noise that is typically present in the pipeline. The assembly is deployed into the flow of a pipeline, traverses the pipeline, and is captured and extracted at a predetermined point downstream that will also be utilized for the electromagnetic assessment. During the inspection, the free-swimming, acoustic-based technology's location is tracked at predetermined points, typically air release valves or exposed sections of the pipeline, to correlate the inspection data with inspected distance.

Electromagnetic Testing

An electromagnetic inspection provides a nondestructive method of evaluating the baseline

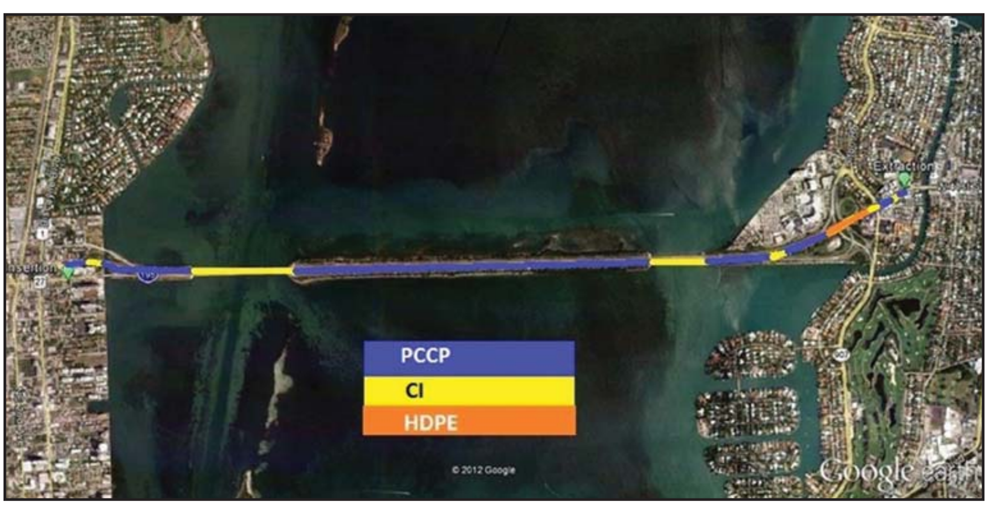

Figure 1. 36-In.-Diameter Julia Tuttle Transmission Water Main

Figure 2. Acoustic-Based Leak and Gas Pocket Detection Equipment

condition of the prestressing wire in PCCP, and wall loss in metallic pipe. Electromagnetic inspections ascertain a magnetic signature for each pipe to identify anomalies that are produced by zones of broken wire wraps and changes in pipe properties, such as material change and wall thickness. Various characteristics associated with an anomaly are evaluated to provide an estimate of the number of broken wire wraps or broad corrosion zones, and areas of wall loss. This inspection method is able to quantify the amount of wire wrap damage.

The electromagnetic system used generates eddy currents in the wire wraps, and detected where the field was altered by the presence of breaks in the prestressing wires; if there are no breaks, the current will flow uniformly along the wire. However, where a broken wire wrap exists, a discontinuity in the current forms. Analyzing and interpreting this phenomenon allows for estimates of the number of broken wire wraps, and the approximate location of the broken wraps along the length of the pipe.

For metallic pipe, the electromagnetic system generates a magnetic field that is able to provide detection of variance in wall thickness, material change, and regions of broad corrosion.

The pipeline was inspected by a specialty consultant using an inserted robotic condition assessment tool to provide data for condition assessment of the PCCP and CI sections of the transmission main. Analysis of impacts to the HDPE section were limited to evaluation by acoustic-based leak and gas pocket detection. The electromagnetic assessment tool is an innovative free-swimming tool that is neutrally buoyant, with flexible fins that are used to center the tool within the flow of the pipe and provide propulsion with the active flow in the pipeline. Its flexible design allows for navigation through inline valves (like butterfly valves) and bends in the pipeline, while traveling long distances. Data is downloaded and interpreted by the

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Figure 3. Assessment Tool Prior to Installation and With Insertion Tube

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specialty consultant, upon completion of the inspection, to identify and quantify locations of structural changes from the original design and construction.

The electromagnetic assessment tool was inserted into the live pipeline via a hot tap connection and insertion tube (Figure 3). Once inside the line, the tool traveled with the flow of the water until it reached the predetermined extraction point. The tool's movement and distance traveled is tracked from aboveground via tracking locations, typically at air release valves or exposed sections of the transmission main.

Results Summary

The objective of this analysis was to determine the location of any water main sections that may require rehabilitation, and prioritize these sections based on the severity of conditions. The Julia Tuttle Transmission Water Main had 42 (4.8 percent) pipe segments with indications of structural impacts along the approximate 3-mi, 837-segment pipeline. This percentage of distress is above average when compared to what has been observed globally and historically (3.9 percent) by the specialty consultant through electromagnetic inspection.

One pipe segment was analyzed to have 45 broken wire wraps, which exceeded the yield limit state based on the original design parameters of the pipeline. Six other pipe segments were determined to be at or near 50 percent of the yield limit state, 35 pipe segments were found to have a small number of broken wire wraps, and the balance (over 95 percent of the total pipeline) showed no sign of wire wrap breakage.

Eight anomalies were identified by the leak and gas pocket inspection, many coinciding with the location of wire-wrap breakage.

Recommendations

The following recommendations are based on the inspection of the pipeline and a review of one month's data on transient pressure surges in the line.

Emergency Action Plan

a. Order and store standby materials to be used in a near-term emergency repair, if required. Replace 36-in. ductile iron pipe water main (three segments minimum in case the upstream or downstream pipes from a break are also damaged), pipe sleeves, adapter/transition couplings (both male and female for bell and spigot ends), gaskets, restraints, pipe saddles, and an air release valve.
b. As this condition will require a shutdown of the pipeline for up to a week, depending on accessibility of the break location and contractor mobilization, the pipes' isolation valves should be located and exercised regularly in preparation for a shutdown.
c. An operations plan should be in place to provide supplemental feed and maintain flow and pressure to the City's system from interconnects and the other mainland crossings.

Repair/Reinforce Implementation Plan

a. Develop an implementation plan to replace or repair/reinforce the section in excess of the yield limit state.
b. A cost–benefit analysis can be performed to evaluate different options for repair and to aid in the selection of the optimum solution.
c. The six pipe segments listed in the moderate limit state should be rehabilitated with, or soon after, repairs to the pipe segment, in excess of the yield limit state.

Re-evaluate or Monitor

a. Schedule a periodic re-evaluation of the pipeline or implement a continuous monitoring plan. With only one snapshot of the status of wire breaks, a trend or rate of deterioration cannot be determined. This data may influence the decisions of the timing and type of rehabilitation. The taps installed for the initial evaluation can serve in the same capacity for subsequent evaluations. Continuous monitoring could include inserting an acoustic fiber optic cable throughout the PCCP portions of the pipeline. Performing two additional subsequent evaluations at regular intervals (say, three and five years) can be done using the same procedures as the initial evaluation.
b. Continue to monitor the transient pressure condition (pressure spikes) in the pipeline to confirm that it remains below the American Water Works Association (AWWA) C304 transient design pressure. The peak pressures recorded during the one-month evaluation period were between 75 and 80 pounds per sq in. (psi); the system working pressure is about 65 psi. The worst-case transient design pressure is 140 percent of working pressure, or working pressure plus 40 psi, per AWWA C304. Therefore, the serviceability conditions of the pipeline were based on a transient pressure of 105 psi. If system pressures rise, any conservatism built into the higher AWWA pressure will be diminished.

Conclusion

Maintaining and effectively managing good-quality underground infrastructure is critical to minimize emergency replacement and repair costs, provide continued service to customers, reduce capital investments, and alleviate the impact to public health and safety, as well as the environment. By having a better understanding of the condition of their pipeline assets, utilities can benefit by better prioritizing repair and replacement projects to enable them to solve the most critical issues first, as well as develop a plan for additional improvements needed as resources become available.