PHM Technology Applied to Water Utility Pipelines to Prevent and Predict Breaks

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Introduction

On February 5, 1999, in the City of Tucson, Arizona, a 96-inch diameter water utility pipeline failed catastrophically, funneling 38 million gallons of water through a half-mile square residential area in just 90 minutes. This pipeline rupture caused extensive private and public property damage, which resulted in 12 homes being condemned and costing the City of Tucson $5 million. The City of Tucson vowed to the community to prevent future occurrences by performing annual inspections of large diameter water pipelines. Tucson began networking with other agencies, which operated and maintained similar pipeline infrastructure, several months following the pipeline break. By February 2000, Tucson implemented a comprehensive condition assessment program named the Pipeline Protection Program (PPP).
Tucson contacted members of the users' group, such as Central Arizona Project (CAP), Arizona Public Service (APS) and San Diego County Water Authority (SDCWA) for assistance. San Diego had just shut down one of its pipelines and invited a group of Tucson Water maintenance employees out to learn and experience firsthand what some of the elements were to condition assessment of PCCP. It was an invaluable experience that became the impetus for Tucson's own condition assessment program - the Pipeline Protection Program - modeled after San Diego's own Aqueduct Protection Program (APP). The PPP condition assessment methodologies are similar to the prognostics and health monitoring methodologies used in the electro-mechanical systems industry. The PPP became an advanced predictive and preventive maintenance program for Prestressed Concrete Cylinder Pipes (PCCPs). The PPP included routine internal visual pipeline inspections, internal electromagnetic surveys, hydrophone arrays, and acoustic fiber optics (AFO).

Since implementing the PPP, Tucson has avoided catastrophic failures, which includes a close call in August 2012. This close call occurred when the City Water maintenance staff was alerted by an incipient wearout mechanism within a 96-inch water pipeline. This pipeline wearout mechanism represented an imminent failure mode that could result in a catastrophic failure occurrence with expensive and dangerous failure effects. Thanks to Tucson's AFO system employing prognostics and health monitoring capabilities, a break in a 96-inch pipeline, which had the potential to surpass the damage and destruction experienced in the $5 million 1999 failure was averted.

Strategies to Prevent and Predict Breaks

Corrosion control is one means to prevent and predict pipeline breaks. Tucson's corrosion control program, which includes both impressed cathodic protection (CP) systems and sacrificial systems, was assessed and improvements were implemented. One of Tucson's biggest challenges it faced when redesigning its corrosion control program was the need to locate and confirm the integrity of more than 1500 corrosion test stations (CTS), many of which were buried and damaged. By 2001, Tucson had established an inventory of its corrosion test stations (CTS) and rectifiers and began moving toward a more viable corrosion control program. External electromagnetic conductivity surveys were performed over critical pipelines in an effort to identify soil conductivity to calculate soil resistivity. The soil conductivity survey is useful when establishing high corrosive soil conditions at the onset of a corrosion control and monitoring program. During the past 13 years, Tucson has invested nearly $2 million in its corrosion control program and maintains an inventory of 1996 test stations and 65 rectifiers.

Remote Field Eddy Current/Transformer Coupling (RFEC/TC)

The RFEC/TC inspection was the first commercial, nondestructive testing of PCCP using electromagnetics. The technology is used to identify broken wires and damaged areas in concrete cylinder pipe (CCP) and PCCP. RFEC/TC is a form of Prognostics and Health Management (PHM) health monitoring, which is conducted by electromagnetic (EM) survey or inspection. Tucson performed its first RFEC/TC inspection in 2001 and uses the technology as a standard to update its baseline of broken wires or “distressed” regions in the pipeline wall. Tucson will perform an EM inspection whenever a pipeline has been taken out of service for scheduled maintenance. Pipeline modifications, valve repair, and planned inspections, are examples of scheduled maintenance actions. The minimum length of pipeline scheduled for an EM inspection is largely dependent on Tucson’s ability to meet water demands when the targeted lines are out of service. The length of pipeline inspected on a daily basis depends on many variables. These variables include available ingress and egress, pipe diameter, number of inline butterfly valves and water hindrances. The EM inspection data is analyzed by experts and a report furnished within two weeks of the inspection. Areas of concern discovered during the EM inspections are immediately brought to the attention of the owner in the event immediate action must be taken.

Acoustic Fiber Optics (AFO) as a PHM Strategy

In 2005, Tucson was in the midst of expanding its hydrophone array inventory in all reaches of its PCCP when Acoustic Fiber Optic (AFO) was introduced to the industry. The proposed cost was nearly half the cost of hydrophone arrays and appeared to be less cumbersome to install and maintain. Tucson quickly recognized AFO as an important prognostics and health monitoring technology for incorporation into the Pipeline Protection Program. Tucson became an early adopter of the AFO technology for PHM and health monitoring. Beginning in 2006 and ending in 2007, Tucson installed the AFO system in all 20 miles of its 48-inch, 54-inch, 66-inch, 78-inch, 84-inch and 96-inch pipelines and began “listening” to wire break events, in near real-time. Wire break events are recorded, confirmed and sent to select Tucson staff cell phones, “smart” phones and personal computers. When pipe segments are distressed and categorized as “high priority”, a request is made to have these particular pipe segments monitored 24/7 in an effort to closely monitor and avert incipient failures.

Realizing the Value-Added Benefits of PHM

On August 21, 2012, Tucson was beginning to experience the relief from a long, hot summer. Monsoon rains were just starting to bring relief to the thirsty desert city. Tucson Water was hoping to realize a slight decrease in the water demands, which the summer routinely places on the water system. Around midmorning, the AFO system that Tucson invested in six years earlier began sending text alerts to employees in the water department, alerting them to wire break events. It is common to receive one or two wire break event notices on a 20 mile segment of pipe monitored by AFO, but it is uncommon to receive more than four wire break event notices on any particular segment, within a 24-hour period.

By late morning August 21, 2012, the number of wire breaks increased to eight and the astute project manager began to take immediate action. He directed his staff to immediately contact the operators of the system as he alerted the maintenance division administrator. Before the pipeline was completely isolated, the number of wire breaks had climbed to 18 and the water department was on high alert, scrambling to shut down its largest, most critical water transmission line and avoid a repeat of the infamous 1999 catastrophic failure. Unlike the circumstances preceding the 1999 catastrophic failure, this time the two SCADA-controlled 72-inch butterfly valves at the 60 million gallon reservoir were functioning. Simultaneous to the system operators closing the two 72-inch valves feeding the pipeline, crews began manipulating other distribution system valves and rerouting water to feed the affected neighborhoods. Simultaneous to crews rerouting water to neighborhoods, other crews began to drain the 96-inch pipeline to relieve the head pressure that remained on the distressed 96-inch pipe segment.

Emergency operations were immediately implemented and a pipeline contractor was called to begin excavating the suspect pipe. Once the pipeline was exposed, it was alarming to realize how close the pipeline was to catastrophic failure. Wires were unraveling and mortar spawling off. The steel pipe cylinder was bulged out and the inner and outer concrete cores were yielding to the internal pressures of the pipe. Tucson Water had averted a catastrophic failure of a 96-inch pipeline that was adjacent a residential area just 50 feet away from the failing pipe. The homes adjacent to this incipient failure were down slope, just outside of the pipeline easement, making the risk of property damage and threat to life greater than the February 1999 catastrophic failure that occurred 1/2 mile downstream from this location and cost the City nearly $5 million in collateral and property damages.

Conclusion

In February of 1999, Tucson Water suffered a catastrophic failure of its largest, most critical potable water transmission line. This one catastrophic failure had cost the City of Tucson nearly $5 million in property and collateral damages, and a loss of credibility. Through immediate networking with experienced agencies, continued support from the PCCP Users' Group, and sound investment in technologies leading up to its Acoustic Fiber Optics (AFO) program, Tucson was able to avert an incipient failure of its largest most critical water transmission line and win additional internal and external support from its stakeholders.

Reference: Tucson Water's Homegrown Condition Assessment of PCCP, by Myron Shenkiryk1, Britt Klein2, Allison Stroebele3 and Sheldon Franchuk [4]

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