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Reducing Capital Budgets Through Pipe Segment Replacement Planning and Acoustic Monitoring

Developing an affordable utility capital plan with declining revenues during an economic downturn is like playing the Parker Brothers' game of Jenga, in which players remove a block from a tower and balance it on top, stretching it taller and making it increasingly unstable as the game progresses. Jenga, like capital planning, is a game of physical and mental skill. Jenga means "build" in Swahili. Capital planning for a utility means "infrastructure replacement and sustainability."

Utility managers are being challenged to develop comprehensive capital plans to replace aging infrastructure, then chop out sections and extend the required work over a longer time frame. This project-reprioritizing effort is driven by budget and revenue constraints and supported by asset management criticality analysis. The financial aspects of the pipe replacement game entail estimating how long a pipe can remain in service before rehabilitation or replacement is required, and before a critical failure. Decision-makers must balance the capital and maintenance dollars and the underlying financial bottom line with the overall risk and political exposure of pipe failure. A real challenge is developing and gathering enough information to make the best decision possible.

At many utilities, total pipeline replacement strategies have given way to slip-lining and other rehabilitation remedies (carbon fiber repair, tendon repair) necessary to extend the life of the existing pipeline. Acoustic monitoring is a technology that should be considered to improve the underground infrastructure investment decision-making process. When pipe condition assessments are performed, a snapshot of the baseline pipe condition can be established, but moving quickly from that point to a complete rehabilitation program for the entire pipeline may be premature. The strategy of performing condition assessment activities and then engaging in a long-term monitoring program can provide a substantially lower cost in the earlier years and may provide an overall reduction of replacement costs when failure curves are projected and deterioration is monitored in real time for each pipe segment. Condition assessment and inspections are not enough to prevent catastrophic failure. The combination of advanced condition assessment technology and continuous acoustic monitoring provides a powerful pipe risk management strategy by accurately targeting future inspections and repairing or replacing individual pipe segments before failure without wasting a pipe's remaining life.

PRESTRESSED CONCRETE CYLINDER PIPES

The building blocks. One of the most costly replacement expenses for a water system is the large transmission line that brings water to the treatment plant. Many of these transmission lines are large-diameter prestressed concrete cylinder pipe (PCCP), which are used in water and wastewater systems throughout the United States to convey large volumes of water. The United States has more than $50 billion invested in PCCP. According to the American Concrete Pressure Pipe Association, 90 of the 100 largest US water utilities use PCCP in their water systems, and the use of PCCP is steadily increasing for transmission pipelines. PCCP has also been used for water distribution mains, wastewater gravity sewers, wastewater force mains, dam principal spillways, and treatment plant process lines (ACPPA, 2011).

The primary reasons PCCP has been used so extensively include the fact that it is installed in less time because it is a rigid conduit needing no special bedding or backfilling under normal ground conditions. PCCP also provides corrosion protection. The pipe's concrete and steel wall is prestressed with steel wire to provide strength to withstand water pressure and support the external forces of the surrounding ground.

The tower. PCCP consists of a thin water-tight steel cylinder lined or embedded with concrete before being spirally wrapped with high-strength steel wire under high tension. The prestressing wire ensures that the concrete core will hold up under compression. PCCP is designed in accordance with AWWA design standard C304 and is currently made in diameters ranging from 16 to 144 inches, with straight sections of pipe coming in either 16- or 24-foot lengths (HPP, 2011). PCCP was first manufactured in 1942 and was compliant with AWWA Standard C301. Manufacturing technology for PCCP improved over the years, and the standard evolved with it, being revised in 1964 and 1979. In 1992 C301, which set the manufacturing standard for PCCP, was completely revised to incorporate new and more detailed testing of virtually every aspect of the pipe manufacturing process, including controls on wire, mortar coating mixing, application, performance, and testing (PPIC, 2011).

Some experts have suggested that PCCP has one of the lowest main-break rates per 100 kilometres of any pipe material used in the past 100 years. Additionally, condition assessments have shown that on average just 4–7% of PCCP transmission lines need immediate attention (Mergelas, 2011). The challenge is finding the pipe segments requiring replacement and knowing where to find the next pipe segments needing attention and when that attention will be required.

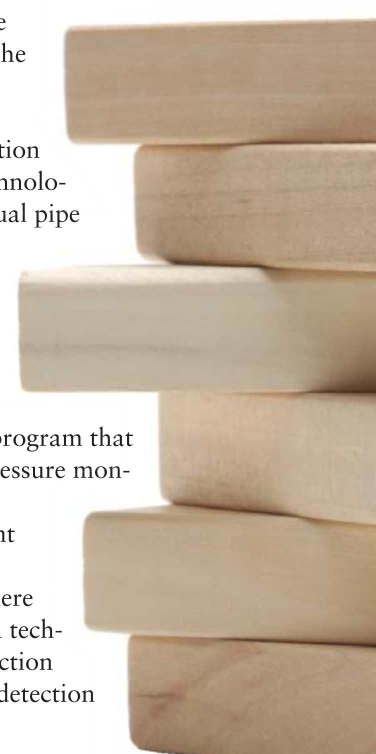
The collapse. Although PCCP is strong and the structural design and performance have improved over the years, the high-strength steel wires are still susceptible to failure caused by stress corrosion, fatigue, and water- and oxygen-induced embrittlement. Failures of PCCPs typically occur when the wires lose their prestress and operating pressures and conditions exceed design limits. A rupture in a single piece of pipe can have a tremendous effect on the entire pipeline system. These types of failures have caused critical economic, safety, public health, and political problems and usually garnered a great amount of media attention. These kinds of catastrophic failures are the most severe (Class III) and are defined as "pipe failures with serious consequences in terms of number of customers losing water supply, damage to surrounding environment and/or other direct, indirect, or social costs. This failure analysis should be conducted on the assumption that it will be reviewed by other interested parties, such as utility managers, local politicians or litigants" (Makar, 2001).

CONDITION ASSESSMENT AND A PIPE RISK MANAGEMENT STRATEGY

In order to prevent such catastrophic failures and ensure the long-term viability and affordability of water transport, advanced risk management strategies should be considered. There are now various levels of decision-making processes that are being used by utilities to minimize their operational risk while also optimizing the investment of their expenditures on repairs to preserve or even enhance the asset value of the water line infrastructure. The development of a pipe risk management strategy is a critical step in effectively managing these major assets (Mergelas, 2011). The basic steps include

- developing a comprehensive inspection program for leak detection that uses location-appropriate technologies (e.g., electromagnetic and visual pipe inspection and forensics to evaluate soil and concrete samples),
- conducting an engineering evaluation to identify and replace or repair pipes that are in danger of failure,
- implementing a monitoring program that includes acoustic and transient pressure monitoring, and
- developing a risk management plan for the entire network.

PCCP inspections techniques. There are three main types of inspection techniques that can be used in conjunction with one another to improve the detection of pipe deterioration.



Electromagnetic inspection. Using electromagnetic inspection can identify wire anomalies and estimate the number of wire breaks on each section of pipe. This allows engineers to establish a baseline condition of the number of wire breaks within a pipe segment at the time of the inspection.

Sonic/ultrasonic inspection. This type of inspection is able to determine whether the concrete in the pipe section is microcracked, delaminated, or not in compression.

Visual and sounding inspection. This technique involves inspectors visually examining the interior of the pipe for signs of physical deterioration, including any corrosion stains or cracks.

Risk management methodology. This methodology involves setting up a database with all the relevant and available data for the pipe, including design data, construction and as-built records, operational criteria, inspection data, and monitoring data. The next step requires development of a deterioration model and establishing a criticality index. This database can be the geographic information system (GIS) geodatabase for a GIS-centric approach; otherwise, a web-based GIS interface must be established.

Given these data and by combining the number of wire breaks with operating characteristics and conditions, a level of failure risk can be calculated using a finite element analysis. The factors surrounding the pipe location and operating conditions—for example, pressure—must be used in conjunction with the number of wire breaks to determine a possible repair plan; however, the process should not stop there.

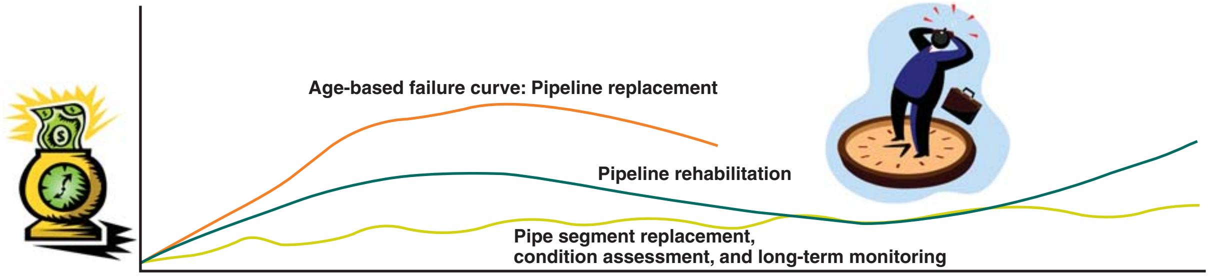
Monitoring. Acoustic monitoring relies on placing equipment on or in a pipe that continuously monitors the acoustic activity in the pipeline to detect the energy release (snapping sound) associated with the breakage of an individual prestressing wire wrap. This continual monitoring provides data by which it can be determined when acceptable risk crosses the threshold necessitating repair or replacement of a section of pipe. After an internal inspection, a ⅜-inch cable can be installed in the pipeline to detect wire breaks acoustically, allowing near-real-time assessment of the deterioration by providing wire-break data as they occur when the pipeline is in service.

An important part of a condition-assessment program is establishing the baseline condition of the pipes and then monitoring them long term to provide accurate information on the overall serviceability of the mains and to allow the utility to plan for funding for capital improvements. Additionally, the combination of detailed inspection and long-term monitoring has allowed for more efficient operation, optimized the frequency of inspections, and increased repair and rehabilitation efforts (Rush, 2009).The current condition assessment technologies can also offer nondewatering solutions in order to maintain service, and the monitoring cable can be installed while maintaining water service.

Bringing it all together. The final steps of the methodology include combining the deterioration model and the interface in a comprehensive software system to provide on-demand management information. This system can have an ongoing feed and adjust the model with data from the continued acoustic monitoring. Integrated correctly, automatic e-mails can be sent to key personnel to inform them of wire-break activity with pipe-segment locations and history. GIS-based maps can also be used to show the location of this pipe activity. Long-term maintenance programs can be developed based on the criticality assigned by the model to each pipe segment (Mergelas, 2011). A monitoring program is important for areas with frequent seismic activity and for water wholesalers who have concerns and complaints from their customers because of unplanned service disruptions.

To best manage large-diameter pipelines, it is important to understand whether and to what extent the condition of the pipe can change after an inspection. If a pipe is damaged, the condition of the structure can change as soon as it is repressurized. As time progresses, the condition of the structure can change significantly.

With the permanent application of acoustic monitoring, the structural condition of pipes can be tracked. If problems develop, flags can be raised to call attention to potential problems, and repairs can be implemented, thereby avoiding a rupture of the pipe (Pure Technologies, 2011).



Graphical Representation of Mitigating Capital Budget Versus Risk of Failure

A proactive asset management strategy for PCCP should include a monitoring program. Continuous acoustic monitoring is critical to the long-term sustainability and reliability of water and wastewater networks. This type of comprehensive risk management program can ensure that catastrophic failure for PCCP and excessive and premature debt can be avoided. These types of monitoring technologies will continue to be developed and deployed for accurate evaluation and monitoring of the lifelines of our water systems and allow utilities to manage underground infrastructure in a more cost-effective manner.

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