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Pro-Active Knowledge Based PCCP Asset Management Program

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ABSTRACT

The Tarrant Regional Water District (TRWD) oversees over 260 miles of Prestressed Concrete Cylinder Pipe (PCCP) infrastructure used for water transmission to over 30 wholesale customers in the Fort Worth area. Over the years, catastrophic failures in these pipes have driven the development of a proactive, knowledge-based asset management strategy. This study examines phases two and three of an investigation into the loss of preload in 72-inch PCCP using Remote Field Technology (RFT). The research aimed to establish a predictive model that correlates wire breaks, preload loss, and pipeline failure risk. Through detailed analysis and experimentation on both testbeds and buried pipelines, the study developed actionable insights that have significantly reduced failure incidents. This paper discusses the methodology, findings, and implications for long-term infrastructure maintenance.

INTRODUCTION

The Tarrant Regional Water District operates one of the largest PCCP networks in North America, spanning 260 miles and serving over two million people in 11 counties. Historically, several failures in these pipelines were attributed to wire corrosion and hydrogen embrittlement, leading to costly repairs and service disruptions. PCCP is a composite material system comprising a concrete core, a steel cylinder, prestressing wires, and a protective mortar coating. While the concrete core serves as the primary load-bearing component, the steel cylinder acts as a water barrier. The prestressing wires impart a uniform compressive force on the concrete, mitigating tensile stresses during operation. The mortar coating provides additional protection, preventing external physical and chemical damage to the prestressing wires.

Given the age of some sections of this pipeline, particularly those installed in the 1970s, TRWD faced an urgent need to shift from reactive to proactive maintenance. To achieve this, the district partnered with Pipeline Inspection and Condition Analysis Corporation (PICA) to employ advanced Remote Field Technology (RFT). This technique leverages low-frequency electromagnetic fields to assess pipeline integrity, enabling the detection of structural anomalies such as wire breaks, loss of preload, and wall thickness variations. The ultimate goal of this program was to reduce pipeline failures by identifying high-risk sections and implementing timely interventions through the identification of leading indicators to failure such as loss of preload, broken wires and cylinder integrity.

The project results are built off previous work that was conducted by PICA in 2020 to identify changes in integrity of the pipeline over time. This testbed allowed for accessibility to the pipeline internally and externally for modifications and testing. Modifications were made including the thinning and cutting of prestressed wires as well as puncturing the core cylinder of the PCCP pipeline to determine feasibility of RFT data in recognizing loss of preload, wire breaks and cylinder integrity.

This paper presents the results from phases two and three of the preload loss study, focusing on experimental setups, field data, and the development of predictive maintenance models. By integrating findings from testbeds and buried pipelines, this research contributes to a more comprehensive understanding of testing results for PCCP wire breaks, loss of preload and cylinder integrity utilizing RFT data.

METHOD

Inspection Setup

The study was conducted on both controlled testbed environments and operational buried pipelines. At the Ennis Pump Station, testbeds comprised multiple 72-inch diameter PCCP segments designed to replicate field conditions. These testbeds were modified in a controlled manner to simulate various failure scenarios, such as wire breaks and concrete mortar removal. The buried pipelines inspected during this study were located near Midlothian and Mansfield, with inspection segments selected based on historical performance data and suspected distress.

Remote Field Technology (RFT) was central to the data acquisition process. The RFT system uses an exciter to generate a low frequency alternating electromagnetic field, which interacts with the ferrous materials in the pipeline. Detectors placed at strategic intervals measure the resulting signals, providing insights into conductivity, magnetic permeability, and wall thickness as well as broken wires. These parameters are critical for identifying wire breaks, preload loss, and potential corrosion in the steel cylinder.

Figure 1. 54-inch EMIT fully assembled in PICA’s yard for calibration testing.

The loss of preload study was performed using PICA’s Electromagnetic Inspection Tool (EMIT) shown in Figure 1 below. With the EMIT tool shown in Figure 1, there is one exciter coil and one detector coil where both coils are wound co-axially to the examined pipe and are separated by a distance greater than two times the pipe diameter. The actual separation depends on the application but will always be a minimum of two pipe diameters. The EMIT tool works by measuring the “time of flight” (phase shift) and the signal strength (amplitude) of a signal emitted by an exciter coil and detected by an array of receivers. The receivers are positioned circumferentially so that each one is sensitive to one of the many clock locations of the pipe circumference.

When the RFT setup is introduced to PCCP pipe the external electromagnetic coupling path also interacts with the external pre-tensioning wires as such the RFT detector signal contains information on both the cylinder and helical wire wrap as shown in Figure 2 below. Because of its electromagnetic fundamentals, an RFT tool has the advantage that intimate contact with the pipe wall is not required, and the technique is therefore ideally suited to inspect the steel cylinder for metal loss and wire breaks through (thick) internal cement liners.

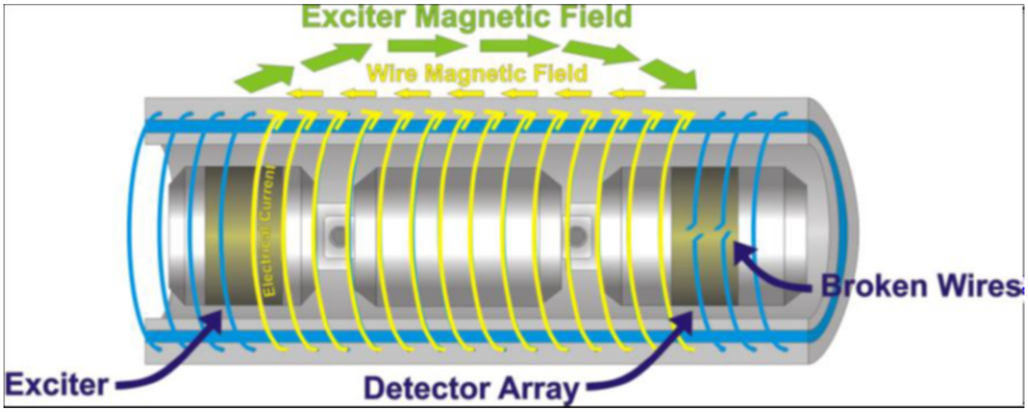

Figure 2. Magnetic Field

Supplementary inspection tools enhanced the accuracy and scope of the analysis. Closed-circuit television (CCTV) and Light Detection and Ranging (LiDAR) systems were deployed to capture visual and geometric data, while strain gauges were installed directly on exposed steel cylinders to measure stress changes in real time. The combination of these tools enabled a holistic evaluation of pipeline integrity, correlating physical modifications with electromagnetic signal changes.

Experimental Modifications

In the testbed environment, a series of deliberate modifications were made to simulate different failure mechanisms. Concrete mortar was removed incrementally to expose prestressing wires, which were then selectively cut to represent localized and distributed breaks. These controlled interventions allowed researchers to observe the impact of specific damage types on preload loss and electromagnetic signals. The testbed experiments also included attempts to restore preload using hydraulic tensioning straps. By applying controlled forces to the exposed steel cylinder, the study explored the feasibility of reintroducing structural integrity to compromised sections.

Figure 3. PICA technicians removing an outer concrete window

In the buried pipeline segments, inspections focused on identifying anomalies indicative of wire breaks and preload loss. Data collected from these sections were analyzed using an algorithm developed during earlier phases of the study. This algorithm interpreted RFT signals to differentiate between hydrogen embrittlement-induced wire breaks, which typically do not result in preload loss, and corrosion-induced breaks, which often compromise the structural integrity of the pipeline.

To evaluate the effect of non-sequential wire breaks, varying distributions of wires were cut along the pipe, but at the same circumferential position. These new modifications were installed in the testbed piping segment in a region adjacent to pre-existing modifications. The sequence of modifications was as follows:

1. The outer concrete was removed, and the region was scanned to establish a baseline that included the slight loss of preload from missing concrete.
2. Five wires were cut, distributed in such a fashion as to maintain three intact wires between the cut ones. The affected region was re-scanned.
3. Next ten wires were cut, distributed such that a sequence of one cut then one intact wire was formed. The affected region was re-scanned.
4. Next fifteen wires were cut, distributed such that a sequence of three cut then one intact wire was formed. The affected region was re-scanned.
5. Finally, twenty sequential wires were cut, and the affected region was re-scanned.

Figure 4 depicts RFT data from the region where different distributions of wires were cut. The blue shaded region highlights the signal response as the wire cut quantity and cut density increases. Even as few as five cut wires, where each cut wire is separated by three intact wires, is detectable when compared against baseline. After cutting ten wires and leaving one intact wire between the cuts, the signal perturbation is prominent and distinguishable even in the absence of baseline data. The perturbation grows at fifteen cut wires and is larger again at twenty sequential cut wires. The growing perturbation on the left-hand-side of panes four and five is the result of pipe modifications unrelated to this experiment.

Figure 5 depicts the progression of wire cuts where each red dot signifies a wire modification.

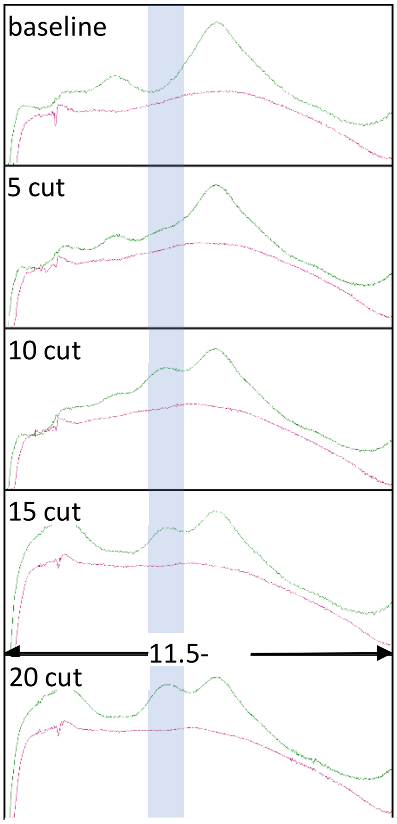

Figure 4. RFT data progression of cut wires (blue highlighted signal)

Figure 5. Exposed pre-tensioning wires

RESULTS AND DISCUSSION

Testbed Analysis

The controlled environment of the testbed experiments provided valuable insights into the behavior of PCCP under simulated failure conditions. Initial baseline scans established the unmodified state of the test pipes, serving as a reference for subsequent modifications. Data from these scans confirmed the stability of well-bonded pipes, even when minor wire breaks were introduced. This finding suggests that the bond between the concrete and the wires can mitigate the immediate effects of isolated breaks.

However, as the number of wire breaks increased, significant changes in preload were detected. RFT data revealed distinct perturbations in magnetic permeability, correlating with the extent of wire loss. The application of hydraulic tensioning straps demonstrated partial success in restoring preload. While strain gauge readings indicated localized recovery, the RFT data showed that the restoration was not uniformly effective around the pipe circumference. This discrepancy highlights the need for further refinement of preload restoration techniques.

Buried Pipeline Findings

Field inspections of the buried pipelines revealed a diverse range of anomalies, underscoring the complexity of real-world conditions. In many cases, wire breaks were detected without accompanying preload loss, suggesting that these breaks were caused by hydrogen embrittlement. Such pipes were deemed structurally stable but flagged for monitoring to prevent further degradation.

Remote Field Technology (RFT) measures three variables in PCCP pipe: Conductivity, relative magnetic permeability, and wall thickness. To understand the effects of these variables on the RFT signals it is worth considering the possible combinations of them:

Conductivity: This is a variable that is almost exclusively coming from the "transformer coupling effect". That is, the helically wound pre-stress wires. When they break or are cut, the conductivity of the pipe changes noticeably.

Relative Magnetic Permeability: This is the measurement of the pre-load, or the stress imputed on the wires and steel cylinder by the tension applied to the wires when they are wound onto the cylinder/cement pipe. It is distinct from the conductivity, but only affects the RFT signals when enough wires are broken to release the pre-load. It is well known that the pre-load is back at full strength within a few axial inches of a broken wire.

Wall thickness: The wall thickness of the wires does not contribute to the overall measurement of wall thickness because of the relatively large gap between wires (compared to the wire width). Wall loss is therefore related to wall loss of the cylinder which can only occur through corrosion of the cylinder. Corrosion of the cylinder is highly likely to be present when many wires have corroded through and the concrete has degraded, allowing ground water to corrode the cylinder. This is also highly likely to be isolated to a small portion of the circumference which "clock position" is detectable by the RFT technique.

Conversely, segments exhibiting both wire breaks and preload loss including a change in wall thickness were classified as high-risk and prioritized for immediate repair. These segments often showed additional signs of wall corrosion, indicating advanced deterioration. The RFT signals from these sections displayed clear deviations in conductivity and wall thickness, enabling precise localization of the affected areas. These findings lead to the creation of the prioritized model for action based on RFT findings.

1. *Change in conductivity due to broken wires without a change in magnetic permeability*:
    a. The conclusion in this case is that the wire breaks are due to H.E. because there is no wall loss and no loss of preload.
    b. *Suggested action*: monitor the pipe for worsening condition over time
2. *Change in conductivity together with a change in permeability but no change in wall thickness:*
    a. The conclusion in this case is that the wire breaks are due to corrosion because enough wires have broken to release pre-load on the cylinder.
    b. *Suggested action*: repair at earliest convenience
3. *Change in conductivity together with a change in permeability AND a change in wall thickness:*
    a. The conclusion in this case is that enough wires have broken to release pre-load AND the cylinder is corroded. The RFT signal will indicate a clear clock location.
    b. *Suggested action*: emergency repair or re-enforcement of the pipe depending on the length of affected area or number of broken wires estimated.

The study also identified segments with distributed wire breaks spanning the entire length of the pipe. These cases presented unique challenges, as the cumulative impact of distributed breaks could not be easily mitigated through localized interventions. Instead, these pipes required comprehensive replacement to ensure long-term reliability.

CONCLUSIONS

The findings from this study demonstrate the effectiveness of Remote Field Technology in assessing PCCP integrity and guiding proactive maintenance strategies. Specifically, the study identified two key outcomes: first, the ability to distinguish between wire breaks with and without preload loss, structural integrity of the cylinder and second, the integration of field data and modeling to prioritize repair efforts effectively.

For utilities managing extensive pipeline networks, these findings offer significant benefits. The models developed during this study enable operators to move from reactive to proactive maintenance, identifying high-risk sections before failures occur. By understanding the relationship between wire breaks, preload loss, and structural integrity of the internal cylinder, utilities can allocate resources more efficiently, focusing on pipeline segments that pose the greatest risk to service continuity and public safety.

Additionally, the study highlights the practical applications of RFT in real-world scenarios, demonstrating its capability to detect not only immediate threats but also long-term degradation trends. This allows for the development of tailored maintenance schedules that extend the lifespan of pipeline infrastructure and reduce overall capital and operations costs.

Future work will focus on refining the calibration models and exploring advanced techniques for preload restoration. Additionally, expanding the dataset to include a broader range of pipeline conditions will further validate the applicability of these models across different infrastructure systems. Through continued innovation and collaboration, TRWD aims to achieve zero pipeline failures while optimizing maintenance efficiency.

REFERENCES

ASCE. "Minimum Design Loads for Buildings and Other Structures." Reston, VA: ASCE, 2014.
PICA Corporation. "Remote Field Technology and PCCP Inspection Techniques." Internal Report, 2021.
"Water Main Break Rates in the USA and Canada: A Comprehensive Study." AWWA, 2023.