ABSTRACT

Water utilities in Texas have a long and enviable record of establishing the best practices in operating – and maintaining – water transmission systems. As a result, condition assessment of pipeline assets is an accepted practice. However, historically, condition assessment methodologies have been somewhat primitive – usually consisting of “walking the pipe” or random couponing from selected pipe. Unfortunately, these types of inspections provide information that is too general to result in an effective use of limited capital resources.

Today, a broad array of proven “bottom-up” condition assessment techniques is available. Several condition assessment techniques that can pinpoint individual pipe that are suffering from distress are commercially available. By utilizing the information that these techniques provide, an operator can establish a cost-effective long-term maintenance and management plan for their pipeline assets.

This type of program demands the best available information and includes the following four steps:

1) Establish the Asset’s Baseline Condition
2) Determine Action on an Individual Pipe Basis
3) Implement Necessary Rehabilitation Measures
4) Perform Preventative Maintenance

Adoption of such a condition based asset management approach represents current best practices in the condition assessment of water transmission mains in Texas. It has the potential to save the industry billions of dollars.

INTRODUCTION

As little as ten years ago, there was little consensus as to the best practices approach for assessing the condition of a water transmission system. Five years ago, as quantitative tools for assessing the condition of each pipe within a system gained acceptance, innovative water utilities in Texas began to adopt a “bottom-up” condition assessment approach. Today, operators are beginning to standardize on this method, known as condition based asset management.
Adoption of condition based asset management is being driven by both technological and economic factors. Firstly, proven technologies exist that allow pipeline distress to be accurately identified and quantified. Secondly, the cost of conducting such an assessment is a fraction of the replacement value of those critical assets. Given that maintenance costs comprise a high percentage of a pipeline operator’s entire budget, utilities that follow a best practices model are finding that it is less expensive to run proactive and predictive maintenance programs than to replace entire suspect pipelines. In fact, after implementing a condition based asset management program that emphasized proactive and preventative maintenance measures, Marshall et al found that “summing all the mitigation costs (repairs, cathodic protection, consulting) [Tarrant Regional Water District, of Forth Worth, Texas, spent] about 4% of the replacement cost of the two lines.”

By following the best practices model outlined in this paper, other water utilities in Texas can achieve this type of success. However, the most important element of a successful condition based asset management program is to ensure that it is run like a business – and businesses demand that objective and informed decisions are made on the best possible information. For water transmission pipeline operators, this information is derived from condition assessment. The data provided by condition assessment inspections allow informed decisions to be made that help dictate what levels, and types, of maintenance are performed on each individual pipe in a pipeline. In combination with continued preventative maintenance, this then maximizes both the safe life of the pipeline and the effectiveness of the budget spend.

**STEP 1: ESTABLISH THE ASSET’S BASELINE CONDITION**

The first step in establishing a condition based asset management program is to conduct a proactive maintenance program that establishes the condition of the assets – rather than simply waiting for the asset to fail. There are several commercially available systems that can be employed to determine the actual condition of each pipe within a water transmission system. The methodology selected depends upon many factors including: the ease of access; the type of pipe; the diameter of pipe; the nature of the information the operator wants to obtain and the suspected deterioration mode. The following table illustrates which pipeline evaluation tools are appropriate for a broad range of pipe types and diameters.
### Table 1 – Condition based asset management techniques and their applicability to the evaluation of Concrete Pressure Pipe (CPP) subtypes

<table>
<thead>
<tr>
<th>Pipe Type</th>
<th>Condition Assessment Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concrete Pressure Pipe Subtype</strong></td>
<td>RFEC/TC*</td>
</tr>
<tr>
<td>Embedded Cylinder Pipe (ECP)</td>
<td>&gt; 36” All diameters</td>
</tr>
<tr>
<td>Lined Cylinder Pipe (LCP)</td>
<td>&gt; 24” All diameters</td>
</tr>
<tr>
<td>Non Cylinder Pipe (NCP)</td>
<td>&gt; 24” All diameters</td>
</tr>
<tr>
<td><strong>C303 (Bar-Wrapped)</strong></td>
<td>&gt; 24” N/A All diameters</td>
</tr>
<tr>
<td>* Unmanned Inspection required for diameters under 36&quot;</td>
<td></td>
</tr>
<tr>
<td>** RFEC/TC detects broken prestressing bars only</td>
<td></td>
</tr>
<tr>
<td>*** Requires a 2” insertion tap regardless of pipe diameter</td>
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</tbody>
</table>

### Table 2 – Condition based asset management techniques and their applicability to the evaluation of non-CPP subtypes

<table>
<thead>
<tr>
<th>Pipe Type</th>
<th>Condition Assessment Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non CPP Subtypes</strong></td>
<td>RFEC/TC AET Sahara*</td>
</tr>
<tr>
<td>Metallic</td>
<td>N/A N/A &gt; 10”</td>
</tr>
<tr>
<td>Plastic</td>
<td>N/A N/A &gt; 10”</td>
</tr>
<tr>
<td>Reinforced Concrete</td>
<td>N/A N/A &gt; 10”</td>
</tr>
<tr>
<td>* Requires a 2” insertion tap regardless of pipe diameter</td>
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</tbody>
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In the following pages, the above techniques are categorized according to their applicability to the condition assessment of Concrete Pressure Pipe and all other types of pipe.

**Concrete Pressure Pipe (CPP)**

CPP contains pretensioning wires, in the case of Lined Cylinder Pipe (LCP), Embedded Cylinder Pipe (ECP), and Non-Cylinder Pipe (NCP) or bars, in the case of Bar Wrapped Pipe, that provide structural support to the pipe. If sufficient numbers of these pretensioning wires/bars are broken, the structural integrity of the pipe becomes compromised.
RFEC/TC

Texan CPP pipeline operators who have established proactive maintenance programs use a technology known as Remote Field Eddy Current / Transformer Coupling (RFEC/TC) to establish the baseline condition of this type of pipe. RFEC/TC determines the location, distribution and number of broken wires/bars anywhere along the length or around the circumference of ECP, LCP, NCP and Bar-Wrapped Pipe.

Figure 1: RFEC/TC Tool

RFEC/TC has been used to establish the baseline condition of over 400 miles of CPP in Texas. As an example, PPIC originally inspected about 15 miles of PCCP for a Texan water utility.

Figure 2: Broken Wires discovered using RFEC/TC
Analysis of the data obtained during this inspection determined that a high percentage (approximately 10%) of the pipeline showed clear evidence of distress.

As a result of this evaluation, the utility took several actions. It verified the accuracy of PPIC’s evaluation. It began an emergency selective rehabilitation program and it contracted with PPIC to evaluate the condition of additional portions of its lines. Accordingly, PPIC inspected another 30 miles. Analysis of the data obtained during these inspections determined that approximately 5% of pipe in this portion of the line displayed evidence of wire breaks.

As a result of these investigations, the client has been able to re-establish the integrity of a critical part of its water supply system. This utility continues to work with PPIC and plans to evaluate the condition of the balance of its water transmission system, utilizing a combination of techniques.

AET

Another system that can be used to locate prestressing wire breaks is Acoustic Emission Testing (AET). Unlike the leak detection system described below or the RFEC/TC system discussed above, acoustics is most useful as a monitoring tool. Like other monitoring tools it should be used in conjunction with other data to be most effective. Specifically, if the baseline condition of a pipeline is established using RFEC/TC, acoustics offers a powerful view into the ongoing health of the line as it can be used to identify and quantify the level of active distress in individual pipe. This can impact decisions on what level, and type, of pipe rehabilitation is necessary.

In operation, AET takes advantage of the fact that when a prestressing wire breaks, or resettles itself in the pipe wall, it generates a sudden release of energy. Much of this energy is in the form of sound energy, which propagates through the pipe core, inducing vibration in the pipe wall, and into the column of water within the pipe. In general this energy travels for over a thousand feet before dissipating, although it is attenuated by such factors as: pipeline diameter; pipeline design (horizontal or vertical bends in the pipe); internal pipeline features etc.

Two types of sensors are commonly utilized to record this activity. Typically very sensitive hydrophones, inserted into operating pipelines, have been used to detect and record these wire related events. However, recent advances in instrumentation and sensor technology have resulted in the use of non-intrusive, surface mounted accelerometers in cases where installation of hydrophones is impractical (hydrophones require a ¾” tap). The use of these sensors mounted on the surface of prestressed concrete pipe has negated the need to tap the pipelines to allow the insertion of hydrophones. Accelerometers also allow greater flexibility in selecting sensor spacing and virtually guarantee 100% coverage of the pipeline that is being monitored.
AET has been used to detect evidence of active distress in a variety of PCCP lines operated by a water utility in Texas. In the first case, AET was strategically used as part of a condition based asset management program to provide a general indication of which areas of a line, if any, were experiencing active distress. Accordingly, the hydrophones that were used to monitor the condition of 3 miles of this line were spaced far apart. Upon analysis of the data, it was found that the majority of the pipeline exhibited little or no active distress.

The utility continued its proactive maintenance approach and conducted a focused condition monitoring program (using sensors spaced more closely together than in the example above) on a pipeline that had experienced a catastrophic failure. Initially, as with the previous monitoring program, PPIC planned to conduct the test using a series of hydrophones. After the testing commenced, it became apparent that additional testing locations would be necessary. Accelerometers were used to eliminate the need to hot tap the pipeline allowing 100% testing coverage of the pipe. Upon analysis of the data, PPIC was able to identify a number of acoustically active pipe. The utility is using the information derived from this condition based asset management program to prioritize its capital expenditures and selectively rehabilitate individual pipes.

**LEAK DETECTION**

Pipe greater than 12” in diameter may be assessed using the Sahara® water transmission main leak location system - which pinpoints the location and estimates the magnitude of leaks in water transmission mains of any construction type.

In operation, a sensor head attached to an umbilical cable is inserted into a live pipeline. Carried through the pipe by the flow of water, the sensor pinpoints the exact location of a leak through identification of its distinctive acoustic signal. The leak is then localized and its magnitude is
estimated. The position of the sensor head is marked on the surface, ensuring the ease of any subsequent repairs.

Figure 4: Schematic of the Sahara system in operation

While this technique is most commonly used to assess the condition of non-CPP pipe, and is discussed further below, examination of several Lined Cylinder Pipe failures have shown clear evidence of perforated or leaking cylinders in conjunction with broken prestressing wires (Figure 5). Recent inspection work has found very clear evidence of leaking cylinders in areas where broken prestressing wires were found (Figure 6). It seems reasonable to infer that in lined cylinder pipe, breaks in the prestressing wire may precede leakage of the cylinder however, leakage of the cylinder may precede catastrophic failure.

Figure 5: Perforated Cylinder on a Failed 36” Lined Cylinder Pipe
In addition, observations of bar wrapped pipe have found electrically continuous bars in areas where through holes had appeared in the steel cylinder. This suggests that, at least in some cases, cylinders in bar wrapped pipe may leak in advance of prestressing bars breaking. While corrosion of both the cylinder and the bars may be taking place simultaneously, there is no way to know for certain. It is likely that, in some cases the cylinder will begin to leak before there are any broken bars, while in other cases bar breaks will be a precursor to any cylinder leaks.

When used in conjunction with RFEC/TC, Sahara helps provide a complete picture of the structural integrity of Concrete Pressure Pipe as it gives a direct measure of leak activity at the joints. Occasional leakage at the joints of CPP has been noted due to the presence of rolled gaskets. While these leaks may be small in volume, the accumulation of ground moisture may actually accelerate the corrosion process especially in the presence of aggressive soils. Thus joint leakage may actually be a precursor to future structural problems.

Other Types of Pipe
Due to the introduction of the Sahara system into the North American marketplace, condition based asset management programs can now also be conducted on non-CCP transmission mains. While different pipe types have different failure modes, leakage is a common characteristic of pipe whose structural or mechanical integrity has been compromised. For large diameter cast iron pipe, longitudinal breaks and bell shear lead to pinhole leaks, as does corrosion through pitting and casting flaws. Ductile Iron can experience corrosion through holes. Corrosion through holes in large diameter steel pipelines can be detected, as well as imperfections in welded joints. Large diameter PVC can experience longitudinal breaks due to excessive mechanical stress and also suffer from mechanical joint installation failure such as rolled or pinched gaskets. HDPE, on the other hand, can exhibit leaks due to joint imperfections. All of these mentioned structural or mechanical failure modes can be detected by using a Sahara leak inspection.

As a result, Sahara is the condition assessment technique of choice for operators conducting proactive maintenance programs. The system has been used to precisely locate leaks, reduce
non-revenue water, identify leaks causing pipeline commissioning delays, and as a condition assessment / risk management / asset validation tool that forms the basis of future asset management strategies.

**LEAK LOCATION**

Leak location is of special importance to water utilities in Texas. Rule 288.2 of the Texas Administrative Code, recently brought into place, demands “a program of leak detection, repair, and water loss accounting for the water transmission, delivery, and distribution system in order to control unaccounted-for uses of water.” As a result, many water utilities in Texas have adopted Sahara – which is the only reliable and proven technique of identifying leaks in water transmission mains greater than 12” in diameter. In fact, over 1,000 surveys have been conducted using the system, which has pinpointed leaks as small as 0.25 gallons/hr in PCCP, Ductile & Cast Iron, Steel and PVC C905 - while the have lines remained in service.

As an example, a water utility in West Texas used Sahara to inspect portions of 30” SCCP, 16” PVC, 20” PVC, 24” Steel, 16” Cast Iron, 24” SCCP and 16” Cast Iron pipelines. The total distance surveyed was 29,837 ft or 5.65 miles.

During the course of the inspection, a major leak was detected on the 30” SCCP line. The utility had suspected that there was a leak in the area, due to the presence of an unaccounted for pond, but had been unable to locate the source of the leak. Once the leak was identified, the system was temporarily halted at the leak point. The sensor head was detected within the main from the surface using the locator unit. PPIC staff then marked the position of the leak on the surface. City staff promptly excavated the pipe and verified the presence of the leak.

**REDUCTION OF NON-REVENUE WATER**

Sahara is primarily used as a condition assessment tool. However, given the costs associated with water acquisition, treatment, and distribution, it’s ability to reduce non-revenue water has, on occasion, reduced the pay-back period for using the service to less than a year. As an example, a utility in North Africa used the system to reduce their entire water importation by 3.5%. The savings afforded paid for the inspection in just eight months.

**IDENTIFY LEAKS IN PRE-COMMISSIONED PIPELINES**

On most occasions, when a new pipeline is built it passes its hydrostatic pressure test and is handed over to its operator without issue. On occasion, however, it does not pass this test and the contractor is obligated to try and identify the source of the leak(s). This can be an extensive, expensive and time consuming, process.

In the past, operators have attempted to locate leaks using a variety of methods including: visual inspection (internal and external), leak-noise correlators and excavation. None of these methods have proved universally effective.

In order to detect leaks in pre-commissioned lines, Sahara must be modified, as the requisite flow required to perform a typical under pressure insertion does not exist. During the
modification process, the pipeline is dewatered, a dragline is installed inside the pipe, and the line is repressurized. Operators at either end of the section to be surveyed synchronize the deployment and retrieval of the cable to ensure optimal performance.

As an example, a water utility had contracted the design and construction of approximately 30 miles of a 108 inch diameter PCCP raw water force main. Phase I, which consisted of 7 miles of pipe, had failed a series of hydrostatic pressure tests when its test pressure was increased above 190psi. This suggested the presence of high-pressure leakage. Attempts were made to locate the leaks utilizing both visual inspections (internal and external) and correlators. Neither of these methods proved universally effective.

In a further attempt to locate the leaks, a contractor was hired by the bonding company to excavate and repair several areas of the pipeline. When the line continued to fail its pressure tests, the forensic engineers, contracted to assist in the remediation of the pipeline, contracted with PPIC to inspect Phase I of the main using a modified version of the Sahara system.

Two leaks were successfully located. After the inspection was completed, the presence of the leaks was verified and the line was repaired. The rehabilitated line passed its hydrostatic test and was handed over to the City.

CONDITION ASSESSMENT / ASSET MANAGEMENT

As leakage is a common characteristic of pipe whose structural or mechanical integrity has been compromised, the Sahara system provides invaluable information to pipeline operators that are conducting proactive maintenance programs. As the system pinpoints the location and estimates the magnitude of leaks, operators can use this information to make informed decisions that are based on the actual condition of the asset. This can involve selective replacement and strategic rehabilitation of individual pipe sections, if an unacceptably large leak is located, and/or preventative maintenance programs that monitor leak growth, where no direct action is taken until the leak reaches a certain threshold level.

Sahara can also be used as an asset validation tool that proves that a line is leak-free. As an example, a water utility in Texas was interested in determining the integrity of a pipeline adjacent to a municipal solid waste landfill. This site had had a dramatic increase in the volume of leachate and its management suspected that the City’s line was leaking. PPIC used Sahara to assess the condition of this line and determined that it was leak-free.
STEP 2: DETERMINE ACTION ON AN INDIVIDUAL PIPE BASIS

Once the baseline condition of each pipe within a system has been established, operators have information they can use to make informed decisions. By identifying individual pipe that have either an unacceptable number of wire breaks or an unacceptably large leak, operators can prioritize capital expenditures by enacting a selective repair and strategic replacement program that is based on the actual condition of individual pipe.

If other data sets are available, the data can be combined in a risk management system. This type of decision facilitation tool has the ability to note simple and complex interrelationships among data sets and allows an operator to compare data sets over time. At its simplest level, this allows operators to enter the number of main breaks per year, determine the number of new breaks, and note the percentage increase or decrease. At its most complex, it allows operators to fully exploit this data through the development of custom criticality indices that ascribe weighting to individual variables. As a result, operators can model the results of a variety of scenarios to arrive at rehabilitation decisions that make use of all available data.

As an example, a proactive water utility in Texas had implemented a number of condition assessment and risk mitigation measures that resulted in an improvement in the reliability of the pipeline. Through examination of the results presented by the condition assessment program, the engineers at the utility noted that their original construction plans did not accurately reflect the existing current environment around their pipelines. As the utility’s original construction drawings did not incorporate new land use or surface infrastructure information nor integrate condition assessment or pipeline rehabilitation data, the utility’s engineers were having difficulty modeling, analyzing, reviewing or recording changes to their pipeline infrastructure. This led to challenges in planning and executing infrastructure repairs.

The utility, moreover, needed a decision facilitation tool that would help the engineers decide which pipes to repair; discover why specific pipes were corroding; and predict which pipes were going to fail. Accordingly, the utility had PPIC develop an Asset Management System (AMS). Though the system has not yet been fully implemented, the utility had the following goals in mind for the AMS:

1. Development of an Accurate System Map

The utility’s as-builts and lay sheets have proven to be unreliable for displaying pipe details, such as segment length and the position of bends. The AMS will display these details accurately. As an example, use of the RFEC/TC condition assessment tool revealed inaccuracies in the utility’s as-builts. The utility originally thought that the two lines, shown in Figure 7 below, ran close to parallel.
2. Location of Distressed Pipe Segments
Since the utility’s as-builds are only approximations, accurately locating a damaged segment that was identified through condition assessment proved difficult. With an accurate map of the system, and by counting segments from appurtenants on each side of the damaged segment, the utility can verify that it has chosen the proper pipe segment for replacement.

3. Development of Custom Criticality Indexes
Once the utility has inspected the entire system, it will use the AMS as a tool to prioritize segment replacement. It will combine attributes such as: residual remaining strength; rate of deterioration; operating pressure; transient pressure; adjacent land use; pipe polarization (from the cathodic protection system); and the number of wire breaks into a risk model. This decision facilitation tool will help prioritize pipe replacement and function as the cornerstone for the utility’s capital planning programs. Figure 8, below, shows how PPIC’s custom criticality index incorporates a variety of man made structure buffers, land use data, soil resistivity data and condition assessment information.
STEP 3: IMPLEMENT NECESSARY REHABILITATION

Should a condition assessment tool locate pipe suffering from distress, and should the decision be made that selected individual pipe require rehabilitation, there are a number of risk management options available. Rehabilitation and replacement technologies for large diameter water pipelines are chronicled in organizations such as AWWA, WEF, NASTT, and others. Selection of an appropriate method depends on a number of factors – including budget and an individual utility’s risk tolerance.
**STEP 4: PREVENTATIVE MAINTENANCE**

Once all rehabilitation procedures have been undertaken and the pipeline has been returned to its baseline operating condition, operators can control the costs required to keep a system in operation through preventative maintenance. Best practices in preventative maintenance dictate that an asset is inspected on a periodic basis, regardless of its condition. This type of predictive maintenance continues until condition assessment reveals that more frequent measurements are needed.

In addition, by periodically re-inspecting a given pipeline, the residual life expectancy of individual sections of pipe can be calculated through analysis of trends in the data. For example, in year one a given PCCP pipe may have 10 wire breaks. In year three it may still have 10. In year 6 it may have 20. If a pipeline distress growth curve, as shown in Figure 9, is plotted, this type of information allows operators to estimate the costs required to keep the system in operation in the future and optimize the spend required to keep the system in operation today. The same tool suite that is used to establish the baseline condition of the pipe can be used to gather this trending data.

**Figure 9: Growth in pipeline distress**

![Graph showing growth in pipeline distress](image)

Particular lengths of PCCP can also be monitored using AET. Operators, who have established the baseline condition of each pipe in their PCCP lines, use AET to determine which of these pipe are actively deteriorating. This information helps prioritize the replacement of these pipe.
CONCLUSION
The bottom-up condition based asset management approach to managing water transmission mains is fast becoming entrenched as the best practices standard in Texas. This trend is driven by both technological and economic factors. Firstly, proven technologies exist that allow pipeline distress to be accurately identified and quantified. Secondly, the cost of conducting such an assessment is a fraction of the replacement value of those critical assets.

In summary, this approach entails: determining the baseline condition of the asset; using this information to make decisions on what to do with each individual pipe within the system; implementing any necessary rehabilitation steps and maintaining the system in a baseline operating condition through continued preventative maintenance.

As a first step, the selection of one or more condition assessment methods will depend on many factors including: the ease of access; the type of pipe; the diameter of pipe; the nature of the information the operator wants to obtain and the suspected deterioration mode. By establishing the condition of each pipe within a water transmission system, areas of local distress can be identified. This allows operators to make informed decisions on the selective rehabilitation and strategic replacement of individual pipe. This can lead to significant savings by eliminating unnecessary replacement of large lengths of transmission mains, which maximizes the safe life of the asset and the effectiveness of the budget spend.

By establishing and optimizing proactive and preventative maintenance programs, operators can thus obtain the highest levels of performance from the assets in their charge, while reducing the risk of operating those assets.

REFERENCES