Recent Developments in Pipeline Condition Assessment Using Inline Technologies

Aktuelle Entwicklungen bei der Beurteilung des Zustands von Rohrleitungen unter Verwendung von Inline Verfahren

Développements récents dans l'évaluation de l'état des conduites à l'aide de technologies d'inspection interne

Frank J. Mueller
Director Business Development Middle East
Pure Technologies Ltd. - Abu Dhabi
Mobile: +971 50 6416130
Email: frank.mueller@puretechltd.com

ABSTRACT

As water and wastewater networks around the world continue to age and reach the end of their operational life, comprehensive condition assessment is becoming a major priority for utility operators. Owners of “large diameter” water and wastewater pipelines have particular difficulties due to several factors, including environmental, demand and access restrictions. While desktop studies can identify pipelines with a high likelihood and consequence of failure, actual condition assessment data provides actionable information that can be used to estimate the remaining useful life of a pipeline and aid the development of a repair or replacement programs. This paper will outline the recent developments in the non-destructive methods available for evaluating the condition of water and wastewater pipelines. This paper looks at a suite of technologies including inline leak detection systems, robotic surveys (CCTV & Sonar), Magnetic Flux Leakage (MFL) Inline Inspection (ILI), and Electromagnetics (EM); Pure’s tools are helping clients around the world collect actionable information that is critical in making informed decisions regarding any pipeline. Rather than implementing lengthy and expensive replacement programs, Pure’s comprehensive condition assessment approach allows for significant cost savings with targeted repairs, effectively extending the useful life of a pipeline

ZUSAMMENFASSUNG

Wasser- und Abwassernetze weltweit altern immer weiter und erreichen das Ende ihrer Nutzungsdauer. Daher ist eine umfassende Beurteilung ihres Zustands extrem vorrangig für Betreiber von Versorgungsnetzen. Die Eigentümer von Wasser- und Abwasserrohrleitungen haben aufgrund mehrerer Faktoren besondere Schwierigkeiten, unter anderem aufgrund von Umweltauflagen, Nachfragerestriktionen und eingeschränkter Zugänglichkeit. Während Sekundärforschung Rohrleitungen feststellen kann, bei denen Wahrscheinlichkeit und mögliche Folgen von Schäden hoch sind, liefern tatsächliche Daten einer Beurteilung des Zustands entscheidungsrelevante Informationen, die verwendet werden können, um die restliche Nutzungsdauer einer Rohrleitung einzuschätzen und bei der Ausarbeitung eines Reparatur- oder Austauschprogramms zu helfen.

Dieser Beitrag umreißt die aktuellen Entwicklungen bei den zerstörungsfreien Methoden zur Beurteilung des Zustands von Wasser- und Abwasserrohrleitungen. Der umfassende Zustandsbeurteilungsansatz von Pure ermöglicht beträchtliche Kosteneinsparungen mit zielgerichteten Reparaturen, die die Nutzungsdauer einer Rohrleitung effektiv verlängern.

RESUME

Compte tenu du vieillissement et de la fin de vie inéluctable des réseaux de distribution d’eau et de collecte des eaux usées de par le monde, l’évaluation exhaustive de leur état est devenue une priorité fondamentale pour les gestionnaires de ces services. Dans le cas des conduites de distribution d’eau ou de collecte des eaux usées, les propriétaires de canalisations de large diamètre sont en proie à des difficultés spécifiques liées à différents facteurs, tels que des restrictions environnementales, de demande et d’accès. Contrairement aux desktop studies, qui identifient des canalisations avec un risque et un résultat d’échec important, les données d’évaluation de l’état réel d’une conduite fournissent des informations permettant d’estimer sa durée de vie restante et de contribuer au développement de programmes de réparation ou de remplacement.

Cet exposé fera le point sur les développements récents intervenus dans le domaine des méthodes non destructives visant à évaluer l’état des canalisations de distribution d’eau et de collecte des eaux usées. L’évaluation exhaustive de l’état d’une conduite à l’aide des technologies Pure permet de réaliser des économies de coûts substantielles grâce à des réparations ciblées et d’allonger la durée de vie utile d’une canalisation.

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1. Introduction

Water is our most precious resource; its availability transcends political borders. To meet future demand, trillions of dollars will be needed globally to upgrade aging infrastructure and expand water related assets (Leigh 2012).

Utilities face significant challenges managing their aging infrastructure. Pipeline failures are increasing in frequency and severity, leaving utilities with difficult decisions on whether to maintain or replace these assets. The U.S. Environmental Protection Agency (EPA) and the American Society of Civil Engineers (ASCE) estimate the funding gap associated with buried infrastructure ranges from more than $200 billion to $1 trillion over the next two decades.

Corrosion in water mains is an increasing and costly problem worldwide. This is complicated by the fact that the condition varies significantly not only from one pipeline to another but often from one pipe segment to the next. Until now, visual assessment of a pipeline's condition has been difficult to perform and has revealed limited information. Without proper information this may lead to non-optimal rehabilitation projects with respect to costs, timing and also rehabilitation method.

Conventional pipeline management allowed a pipeline to fail multiple times before replacing it. This "three strikes and you're out" approach may work well for small-diameter distribution pipelines, but for large-diameter pipelines it is wasteful (Kloostermann, 2009).

A complete capital replacement program for a system's large-diameter pressure pipelines not only carries a high price, but also poses significant logistical challenges. Through the assessment of more than 12,800 kilometers of large-diameter pipelines, it is clear that even problematic transmission mains can be managed. In fact, roughly 96 percent of pipe sections do not have any deterioration at all and are in good condition. Less than 1 percent of pipe sections actually requires immediate attention or repair. Hence, it can be acknowledged that there is a better way to maintain pressure pipelines other than replacement or slip lining; assess the pipeline and address the problems. Return on investment studies and found that while many variables impact pricing, on average, an Assess & Address™ program can be implemented for about only 4 percent of the capital replacement cost.

Pure Technologies is helping utilities address their buried infrastructure through its Assess & Address™ pipeline management approach utilizing its large suite of technologies such SmartBall® and Sahara® leak detection systems, Robotic surveys (CCTV & Sonar), MFL ILI, and Electromagnetics (EM).

2. Pipeline Risk Management

When evaluating how to safely renew or extend the life of a pipeline, inspection data, structural assessment, and a comprehensive risk evaluation should be considered to make sound engineering recommendations. The risk evaluation considers not only the likelihood of failure (condition) of the pipe based on the inspection data and structural modeling, but also the consequence of a failure.

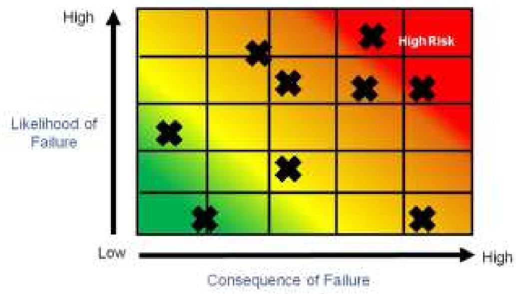
In general individual pipes or areas of a pipeline can be classified into one of four categories based on their likelihood of failure:

- Near Incipient Failure,
- Moderate Risk,

- Minor Risk, and
- No Damage

A solid risk management (RM) analysis will include re-inspection plans or ongoing monitoring of a pipeline using suitable technologies applicable for the pipe material and operational parameters. In any case, the inspection limitations and the rate, as well as type of damage, has to be considered when choosing an inspection technology and frequency. This risk management method can be used to cost effectively extend the life of pipelines with moderate damage, while ensuring its safety.

In order to fully evaluate the risk associated with areas found to have damage based on the pipeline inspection, a risk matrix should be developed to provide a decision making tool for rehabilitation or replacement planning. Such RM typically establishes a likelihood and consequence of failure rating system in close coordination with the operator's staff. Repair/replacement recommendations as well as long term management strategies will be developed using the risk based assessment in order to provide a cost effective, comprehensive pipeline management protocol for the asset. Risk tolerance is unique for each utility operator, and it is important to establish clear criteria throughout the data evaluation process in order to establish an effective management strategy. It is also important to consider any asset management or strategic planning that the operator has undertaken so the assessment work conducted will fall within established guidelines. This is critical when considering capital budget planning as well as operational and maintenance budgets.



Pipe Risk Plot

Understanding the condition of a pipeline and remaining useful life of a pipeline allows the utility operator to plan for appropriate repairs in a proactive and cost-effective manner. Estimations on rates of deterioration and condition allow for the remaining useful life to be maximized, therefore utilizing the maximum value of the asset while ensuring the safety of the pipeline (PTL Technical Bulletin, 2011).

3. Effective Management of Buried Infrastructure

Buried infrastructure has a limited life span. It has been documented that the service life of a pipe is often shorter than the design life that was originally anticipated. In addition, not all pipe installed in the same year or will expire in the same year (Livingston, 2008). The service life of a pipeline is affected by corrosion (both internally and externally), manufacturing processes and material, poor installation practices, third-party damage as well as intentional or un-intentional operational impacts during the lifetime of the system (i.e. uncontrolled drainage and recharge, transient pressure surges etc.). Large-diameter pipelines will fail when the pipe cannot withstand the applied internal and external forces anymore. The failure mechanism of large-diameter pipelines is, however, multi-faceted and complex to accurately predict. While catastrophic failures of large-diameter pipelines are rare, the cost and risk of reactively repairing a large-diameter pipeline failure could be significantly higher than proactively assessing and refurbishing or replacing select pipe sections. This is an important consideration in deciding whether to pro-actively inspect, rehabilitate or replace a pipeline (Gaewski, 2007).

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 (Baird, 2011). 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 expenditure on repairs to preserve or even enhance the asset value of their pipeline infrastructure. The development of a pipe risk management strategy is a critical step in effectively managing major assets. The basic steps include:

- Implement comprehensive inspection programs to accurately assess the condition of pipelines using appropriate technologies.
- Conduct an engineering evaluation to identify and prioritize pipe sections in need of repair or replacement
- Implement monitoring programs to track the active deterioration of assets
- Develop risk management plans for the entire network to proactively allocate funds to where they are most needed.

Knowing the condition of existing pipeline assets forms the basis of a sound risk management strategy. Tools and technologies available to assess the condition of pipelines are constantly evolving. Selecting the most appropriate technology is determined by the level of accuracy and pipeline coverage required. This in turn, is guided by the risk profile of the asset and the risk tolerance of the utility as well as availability of funding (Wrigglesworth, 2011). A toolbox of advanced inspection technologies that can be applied are identified in clause 5 below.

4. Selecting Technologies

An asset manager needs information on the actual condition of the assets in order to choose the appropriate and most economical rehabilitation method. Information on the actual condition of the pipelines will strongly improve the quality of lifecycle cost analyses and risk assessments.

While there are dozens of destructive and non-destructive pipeline inspection technologies available today, many are external tools that require regular access to the pipeline. Inline tools provide owners with the most accurate and useful information on the actual condition of their assets. Regardless of the technique used, collecting information is critical to making informed decisions regarding the condition of any pipeline. Rather than embark on lengthy and expensive replacement programs, pipeline management programs that utilize various inspection techniques enable significant cost savings with targeted repairs.

5. Inspection Technologies

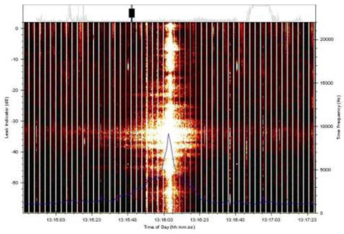
A holistic and multi-disciplinary ‘toolbox’ is the most suitable approach to ensure that relevant and appropriate information is gathered enabling an accurate assessment of a pipelines condition. Different pipe materials, type, level, and accuracy of information which is required will determine the type of survey methods and techniques. Available inline inspection technologies are:

5.1. SmartBall®

The SmartBall® device departs from the traditional full bore, cylindrical shape of inline tools or “pigs”. The spherical shape, sized to be slightly less than the pipeline diameter, greatly reduces the noise produced by the device as it passes through the pipe, thus permitting the sensitive acoustic sensor to operate free of acoustical interference. The net result is a tool that is sensitive to very small acoustic events and therefore, very small leaks.

SmartBall® is a technology based on acoustics sensors that detects audible activities associated with leaks in pressurized pipelines at the time of inspection. The SmartBall® assembly is deployed into a pipeline and traverses the pipeline – propelled by the hydraulic flow - and is eventually captured at a receptor downstream.

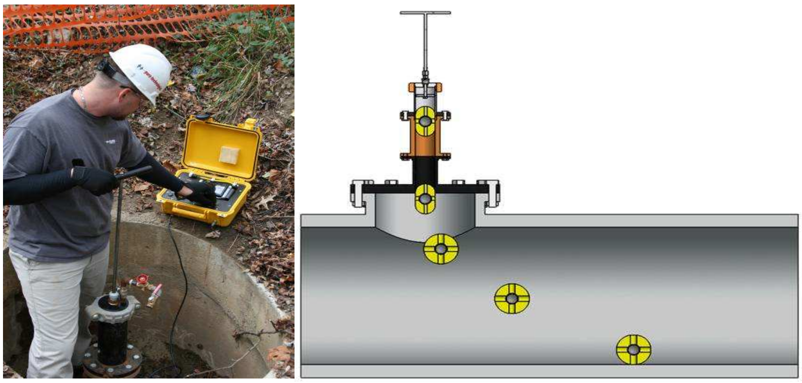
While traversing the pipeline, it acquires high-quality acoustic data which is evaluated to identify any leaks. Since the SmartBall® acoustic sensor passes no further than a pipe diameter from an acoustic anomaly of interest, three significant advantages are recognized:



- SmartBall® can be used to detect leaks on medium and large diameter pipe (>4").
- SmartBall® can be used on any pipe material
- SmartBall® is very sensitive to small leaks

The tool is tracked as it traverses the pipeline via SmartBall® Receivers (SBR's) which are positioned periodically along the pipeline. This tracking is used to calculate the location of the ball, and more importantly it provides accurate information of the location of the ball at any point in time.

To provide an accurate plot of tool position, the device has an on-board three dimensional accelerometer. The accelerometer data and GPS time is used to best fit a curve between position reference points where the ball passed an SBR. This provides an accurate plot of position versus time that is used to report the location of leaks. (Ariaratnam 2009)



SmartBall® insertion under live operating conditions

SmartBall® is available for application in water, waste water, oil and gas pressure pipelines

5.2. Sahara® Tethered Leak detection & CCTV

Tethered inline leak location is a non-destructive and non-intrusive condition assessment technology that pinpoints the location and estimates the magnitude of leaks and air pockets in bulk water pipelines of all material types with a diameter of at least 300mm. Leaks are located in real-time and their surface locations are typically marked to an accuracy of less than 1-meter. As illustrated below, the system can be inserted into a live pipeline through any tap of 50-mm or more in diameter. Carried by the flow of water, the tethered sensor head can then travel through the pipe for distances up to 2,000-m per survey. The leak's position is located and marked on the surface in real-time, facilitating subsequent repairs.

The latest development of the Sahara® system incorporates the ability to perform simultaneous acoustic leak detection and live Closed Circuit Television (CCTV) inspection on potable water mains. It is now possible to pinpoint the location of leaks while at the same time inspecting the internal condition of the pipeline using a combined acoustic hydrophone with integrated CCTV camera. The system uses the same Sahara® insertion platform and is capable of being inserted into live pipelines.

Principle of tethered inline leak detection Sahara®

5.3. PipeDiver®

Versatile and reliable, the PipeDiver® system was designed for use in prestressed concrete pipelines (PCP) that are live or can't be taken out of service due to a lack of redundancy or operational constraints. The tool provides accurate condition assessment of critical infrastructure, specifically detecting problems that could lead to pipe ruptures. Compared to alternative methods of condition assessment, the PipeDiver® solution offers significant cost savings as the pipeline remains in service, eliminating the need for de-watering and service shutdown. In addition PipeDiver® outfitted with electromagnetic sensors is capable of detecting broken bars in BWP, as well as areas of corrosion on BWP and other metallic pipes.

PipeDiver® is an innovative free-swimming tool that consists of a battery module, electromagnetic module and a tracking module. The system is neutrally buoyant and has flexible fins that are used to center the tool within the pipe and provide propulsion. Its flexible design ensures that PipeDiver can navigate butterfly valves and bends in the pipeline, while travelling long distances. Data is recorded and interpreted by an experienced analyst to pinpoint and quantify locations of distress.

PipeDiver® carried to insertion point **PipeDiver® at receiving point**

PipeDiver® can be inserted into a live pipeline via a simple hot tap connection and insertion sleeve, an existing access or a submerged tank. Once inside the line, PipeDiver will travel with the flow of the water until it reaches a predetermined extraction point. PipeDiver movement and distance travelled is tracked above ground via check points. The system has been engineered to overcome the challenge of insertion and retrieval from a live pressured main.

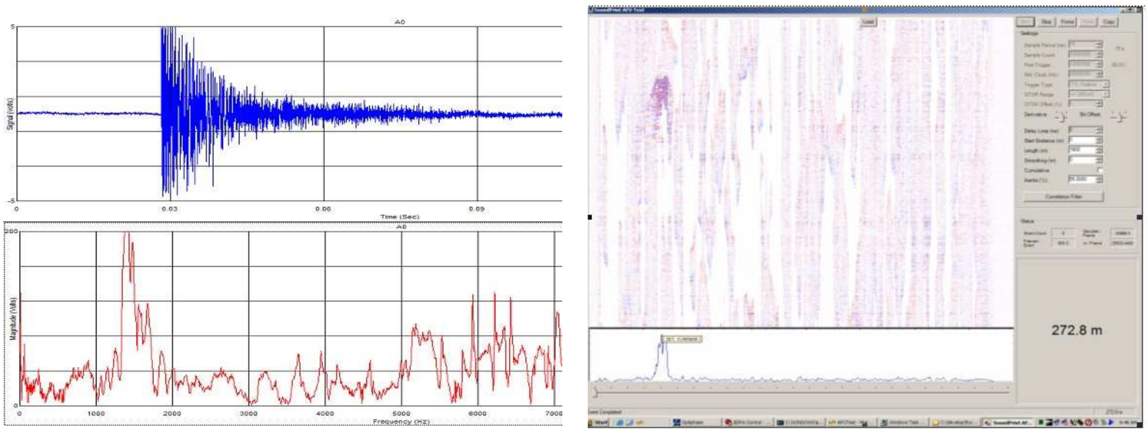
5.4. Acoustic Fiber Optic Monitoring (AFO)

The outcome of any inspection will provide a 'snapshot' of the condition of the pipeline. With the baseline condition known, the next step is to continuously monitor the pipeline to track active deterioration.

Acoustic monitoring has been used since 1997 and is a proven technology for assessing the condition of PCP; it has been used in both short and long-term monitoring programs. The major advantage of acoustic monitoring over other methods is the availability of real-time information on the deterioration rate of the pipe.

The latest innovation in acoustic monitoring uses acoustically sensitive fiber optic sensors. Acoustic Fiber Optic (AFO) systems enable cost-effective monitoring of long lengths of pipeline. The AFO system is comprised of a specially designed fiber optic cable that is deployed inside a pipeline. The cable is typically deployed in dewatered pipelines but can also be installed in live pipelines if hydraulic conditions permit.

As with other acoustic monitoring systems, the fiber sensor is attached to a Data Acquisition (DAQ) system that is continuously acquiring acoustic data from the fiber. The DAQ processes the data and rejects any events that are outside of the parameters established for an event of interest (e.g., wire break). A high-speed internet connection transmits the remaining data to a central processing facility. Acoustic events that meet the criteria for a wire break are classified as such and accurately located. Histograms are generated for each pipe stick showing the quantity of both electromagnetic and acoustic wire breaks which allows the utility to determine when the pipe should be repaired or replaced (Galleher, 2009)



PCCP wire break detected, classified & accurately located by AFO monitoring system

AFO monitoring programs are used worldwide to actively monitor PCP pipelines and provide Water Authorities with accurate and real time information on the condition of their infrastructure and its rate of deterioration. It is therefore an effective way of determining the remaining useful life of the infrastructure and guide rehabilitation and refurbishment programs.

5.5. Robotics

Robotics tools are powerful pipeline inspection platform that can be configured to inspect virtually any pipe application from DN300mm and larger. Umbilical systems are capable of performing multi-sensor inspections in dry pipe or while submerged. PureRobotics pipeline inspection system for example has a range of up to 5-kilometers from a single access point and is capable of traversing through long radius bends. The advantage is the online monitoring allowing instant understanding of the condition and accurate data collection.

Robotics pipeline inspection systems are remotely-operated tracked vehicles tethered by copper or a fiber optic cable. The inspection system consists of a modular, long-range, multi-sensor vehicle that is capable of providing a wide variety of high quality data, including:

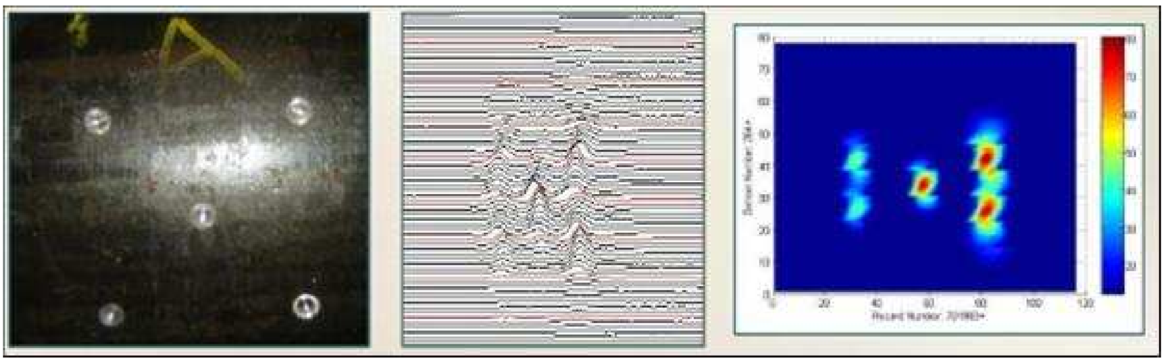
- High definition digital pan-tilt-zoom closed circuit television (CCTV)
- High speed profiling SONAR designed specifically for pipeline inspection
- Laser profiling with 3D reporting capabilities
- Electromagnetic sensors for assessing the structural integrity of PCP and other materials

5.6. Magnetic Flux Leakage Inline Inspection

Magnetic Flux Leakage (MFL) is the most commonly used inspection technology for oil and gas pipeline inspection. Numerous inspection companies provide services, but generally these tools are not suited to "pigging" of water mains. Pure Technologies developed an extra high resolution magnetic flux leakage inline inspection tool (XHR MFL ILI) capable of inspecting through ½" cement mortar lining for application in water mains. The tool can either be pulled through pipelines which are out of service or self-propelled through lines which have a suitable access and retrieval spools or stations.

MFL is the most accurate method of metallic pipeline inspection using advanced nondestructive testing methods. Inline MFL is used to scan the full circumference and length of a pipeline at an extra-high resolution. MFL scans the pipe through linings to measure remaining wall thickness and provides depth and location of metal wall loss. MFL tools detect and characterize metal loss from corrosion, one of the most common causes of ferrous pipeline failures.

New developments in this technique confirm that contact with the pipe wall is not an absolute requirement to accurately detect flaws. This development now allows for cement mortar or epoxy lined ferrous pipes to be assessed with great accuracy.



Both shop tests and field trials have been completed successfully with MFL inspection tools (Hannaford, 2010). The inspections yielded very accurate results and confirmed that MFL is setting the new benchmark in the field of ferrous metal pipe wall assessment. MFL inspection tools have subsequently been developed for the commercial market and are available for use.

6. Future Developments

6.1. Acoustic Pipe Wall Assessment (PWA)

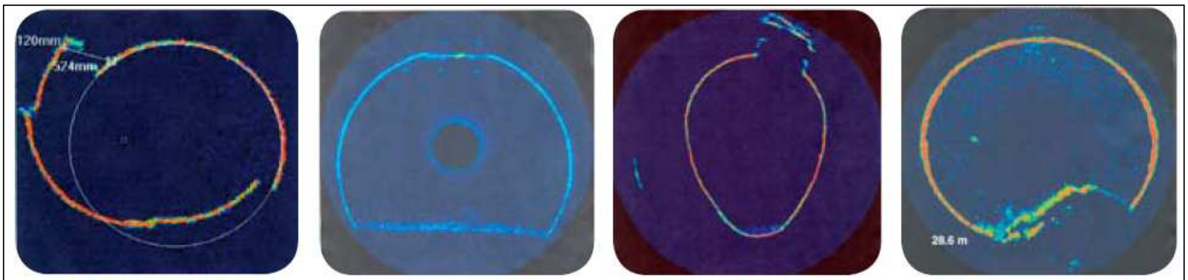
Significant advances have been made recently in an acoustic pipe wall assessment technology. Acoustic pipe wall assessment takes advantage of a known relationship between the speed of sound and wall thickness within a given pipe. An acoustic wave is induced in the pipe, and propagates as a compression wave in the fluid, and a dilatational wave in the pipe (the water hammer mode). As the wave travels, the pipe will breathe on a microscopic level, and therefore the pipe will go into stress. The thicker (and therefore stiffer) the pipe wall is, the less the pipe wall will breathe, resulting in a faster speed of sound in the pipe. From an intuitive perspective, this is akin to trying to run on a trampoline versus solid ground; as the bounding layer becomes more flexible, the propagation velocity decreases.

Two deployment methods are in development for the mobile-sensor version of acoustic pipe wall assessment: tethered, and free-swimming. The free swimming version of the technology, a negatively buoyant ball rolls along the pipeline, propelled by the flow of water. The tethered arrangement, offers the potential for even higher resolution and accuracy. In this arrangement, two hydrophones are attached to an umbilical cable, separated by a known distance. A pulsar is used to generate acoustic waveforms, which are detected by both sensors. An odometer is also used to measure the length of cable deployed, providing absolute position of each measurement.

In both cases, the results are presented as an average thickness per pipe segment, which enables focused repairs or replacement programs. However both platform are not yet commercially available.

6.2. PipeDiver®

Recent R&D for the PipeDiver® platform included the addition of a CCTV and sonar segments for survey of other pipelines such as cement lined steel, GRP, and concrete pipes. Such type of main water transmission lines often cannot be inspected due to their length, presence of butterfly valve or other ID restrictions or constrains. This technology can provide visual evidence of internal damages to lining anomalies and allowing certain quantification utilizing the sonar platform.



Broken Pipe w/ Circle & Measurement | 40 Inch Siphon | Pipe Image with Lateral Opening | GRP Pipe w/ Debris

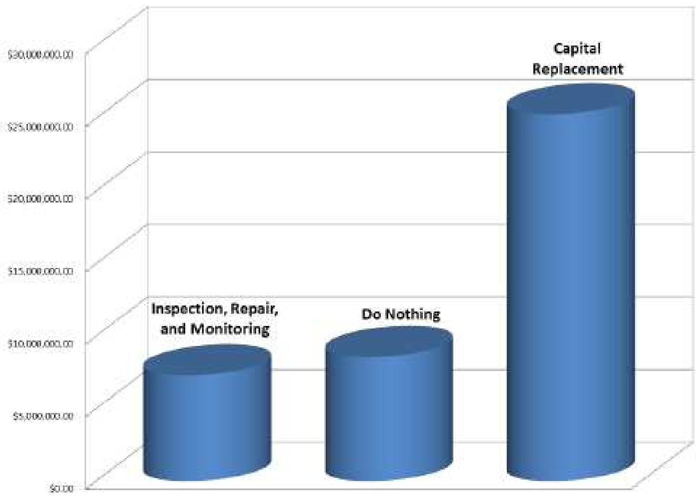
Other inspection techniques are being considered for integration with the PipeDiver® platform, which allows for inspection of pipelines while in service.

7. Financials

The large amount of capital needed in the coming decades to upgrade aging infrastructure in the industrialized world and build new more efficient "smart" networks will stretch public finances (Leigh 2012).

Financial analysis of the various pipeline management strategies should be conducted to determine the most cost effective approach and provide a business case for the recommended action. There are three common alternatives for asset management:

A. Implement a capital replacement program
B. Do nothing and wait for the pipe to fail
C. Implement a comprehensive management program that identifies sections in need of immediate replacement or repair.



Each approach should be considered based on specific needs and feasibility of a particular pipeline and assessed for technical applicability. Depending on the overall condition of the pipeline, repair/rehabilitation costs, capital replacement costs, etc., a Net Present Value (NPV) for each option can be established. The figure on the left provides such a NPV calculation for a 8 kilometer, 1200mm PCCP that traverses through rural and urban areas. The capital replacement costs are based on an actual North American utility's engineering estimate for a ductile iron replacement in the same alignment. The 'Do Nothing' costs assume a failure every 5 years at a total cost of $2,000,000 per failure. This cost includes the utilities internal staff costs, contractor fees, and any legal/customer claims associated with the failure and is based on AWWA studies. As the data indicates, proactive management of existing pipeline assets is much more cost effective than capital replacement.

Understanding the condition of a pipeline and remaining useful life of a pipeline allows the operator to plan for appropriate repairs in a proactive and cost-effective manner. Estimates on rates of deterioration and condition allow for the remaining useful life to be maximized and therefore utilizing the maximum value of the asset while ensuring the safety of the pipeline. Repairs can then be scheduled for individual sections of the pipeline that are deteriorating at a higher rate than the pipeline as a whole while allowing for replacement or repair well in advance of costly failures. Maintenance efforts can be focused on these high risk pipes and immediate action can take place where necessary and postponed where feasible. Traditionally, decisions to replace or repair pipelines have been based on maintenance reports, failure history, flow testing, type, size and age of the pipeline, and visual inspections. Utilizing a variety of innovative non-destructive methods of inspection, structural, and financial analysis provides reliable information related on the overall condition of the pipeline without always relying on capital replacement.

8. Conclusion and Recommendation

In many countries buried infrastructure has reached or even exceeded its designed life and new networks are continuously being built. Utilities have accepted that appropriate condition assessment is required to understand the actual requirements. This however burdens the utilities with increasing capital, operating, maintenance and associated costs.

A toolbox of technologies is available for multiple pipe materials and different operating conditions. By combining inspection tools with a sound and balanced engineering approach, an effective pipeline risk management strategy can be developed. While each pipeline requires a unique set of tools and techniques for condition assessment, overall the approach to asset management is similar.

Owing the advancement of technologies in recent years, it has become a possible for utilities worldwide to correctly assess the condition of their buried infrastructure. This accurate condition assessment information enables utilities to extend the life of their critical infrastructure rather than embark on expensive capital replacement programs. Capturing this data is critical to allow for informed decisions regarding planning, prioritization and budgeting of pipeline rehabilitation. Having sound knowledge about the condition of the buried infrastructure forms the basis of a solid risk management strategy and allows focusing on the most critical items. Pipelines which were earlier contemplated for replacement can now be investigated and correctly assessed.

What You Cannot Measure, You Cannot Manage

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