PHASED APPROACH TO WATER PIPELINE CONDITION ASSESSMENT

A.L. Ratliff, GHD, Sydney, Australia

ABSTRACT

Buried pipelines often operate in a state of anonymity with respect to internal or external corrosion. A condition assessment project allows a condition profile of the pipe to be developed through an examination and/or evaluation of the external and internal environment using various technology applications. External environments provide the typical culprits that promote water pipe corrosion and condition assessments provide useful information to determine pipe condition for renewal or monitoring decisions and future asset planning.

To avoid applying costly inspection technologies to long lengths of pipe, condition assessment could use a phased approach to focus on the segments of pipe with the highest potential for corrosion, so that the less disruptive methods are applied along the entire pipe alignment and more disruptive and expensive technologies are applied to only short segments of pipe. To identify locations where corrosion may be occurring, strategic phases are suggested as listed below.

- Phase 1 – Desktop Study
- Phase 2 – Soil Corrosivity Assessment
- Phase 3 – External Assessment
- Phase 4 – Direct Assessment
- Phase 5 – Structural Assessment

KEYWORDS

Pipeline corrosion, condition assessment, non-destructive evaluation, soil corrosivity, potential survey, close interval survey, acoustic survey, ground penetrating radar, broadband electromagnetics, ultrasonic thickness testing.

1 INTRODUCTION

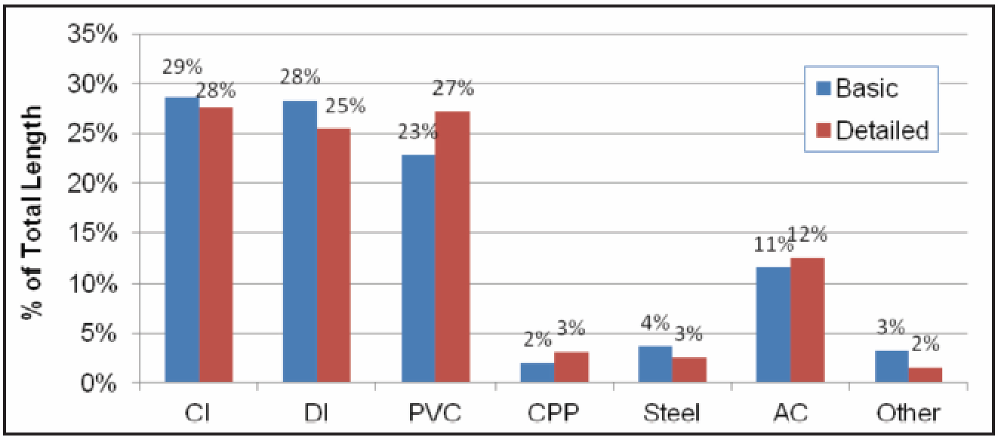
The condition assessment of drinking water transmission and distribution mains is a vital component in water infrastructure asset management, which supports sustainable water infrastructure. A good understanding of pipeline condition can help a utility optimize operations, maintenance, and capital improvement decisions. This helps reduce structural, water quality, and hydraulic failures and their adverse effects as well as minimizing

life-cycle costs.

Based on the age of pipes, replacement of those installed from the late 1800s to the 1950s is now eminent, and replacement of pipes installed in the latter half of the 20th century will dominate the remainder of the 21st century (Utah State University, 2012). In an update to the "Dawn of Replacement", the American Water Works Association (AWWA) has published "Buried No Longer" which states that for water systems in the USA, "more than a million miles of pipes are nearing the end of its useful life and approaching the age at which it needs to be replaced" (AWWA 2012). These replacement costs combined with projected expansion costs will cost more than $1 trillion over the next couple of decades.

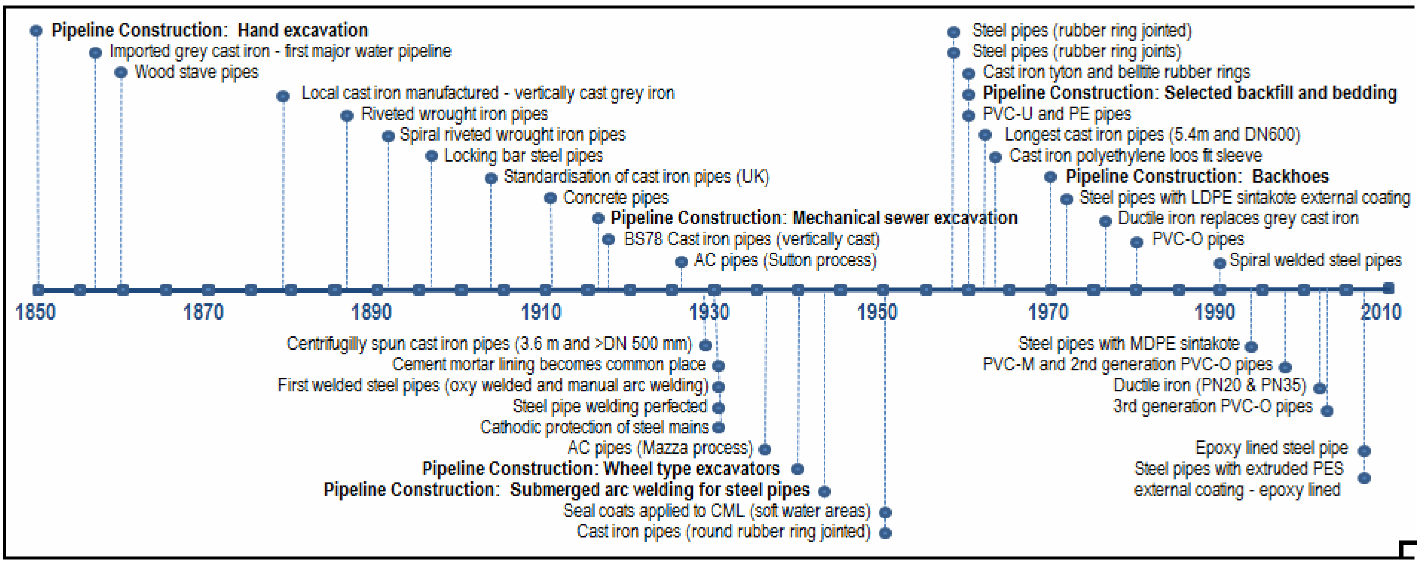
As shown in Figure 1, based on the extensive survey performed recently in the USA and Canada (Utah State University, 2012), almost 50% of the total water pipe installed is comprised of cast iron (CI) or ductile iron (DI) material and almost 70% of that is 200 mm in diameter or less. Failure rates determined for CI and DI were 24.4 breaks within 161 km per year and 4.9 breaks within 161 km per year, respectfully. The primary causes of failure among the respondents were 50 percent circular crack (possible loading or trench failures) and 28 percent corrosion (primarily external). The material with the highest failure rate was CI (55%) followed by asbestos cement (AC) (17%).

Figure 1: Percentage of total length of pipe by material type (Utah State University, 2012)



In Australia (NPR 2010-11), the average frequency of unplanned water service interruptions have declined since 2006-07, but the duration of these has increased since 2009-10 to their highest levels since 2006-07. Of the utilities reporting, a total of approximately 145,481 km of water main are installed in Australia. Water main breaks per 161 km of main ranged from 10 to 27 across all utilities reporting resulting in real losses of 15 to 415 L/connection/day. Overall a decrease of 5% in breaks was reporting since 2009-10, with smaller utilities having, on average, fewer breaks per 161 km of main. The reduction may be the result of reduced operating pressures that were implemented to reduce breakages and lower leakage rates. Figure 2 (WSAA 2010) provides a summary of the Australian pipe history.

Figure 2: Australian Pipe History (WSAA 2010)



To avoid costly replacement of all pipes coming due for replacement now and into the future, an approach is needed to identify the condition of specific lengths of pipe that require replacement, rehabilitation, re-inspection at some later date, additional maintenance, or those that do not require any action. Condition assessment, combined with risk assessment, provides a process to separate the corrective action costs needed for Capex or Opex budget planning and scheduling.

Corrosion, as a major cause of water pipeline failure, is the deterioration of a substance or its properties because of a reaction with its environment. To identify potentially high risk pipes subject to corrosion, a pipeline evaluation needs to identify parameters likely to affect the structural degradation of the pipe (e.g. soil corrosivity, and DC current flows) and the mechanical strength of the pipeline (e.g. pipe wall thickness). These parameters provide information and data necessary to evaluate the ability of the pipeline to perform satisfactorily in terms of conveying water at the required pressure and flow rate.

Indirect and direct pipeline inspection techniques are used to evaluate two key areas, i.e., soil geophysics and physical and operational pipeline parameters. Specialized inspection technologies for corrosion testing include linear polarization resistance testing (LPR), electromagnetic (Emag) survey, Wenner 4-pin, geotechnical investigation, potential and stray current testing, acoustic testing, ground penetrating radar (GPR), acoustic testing, broadband electromagnetic (BEM) testing and ultrasonic thickness (UT) testing. In order to determine when and where to implement these specialty technologies, a phased approach is used to define these according to when they need to be implemented (Table 1). Progression from one phase to the next is based on the results of the previous phase to determine if subsequent phases of inspection are necessary. Each step is designed to focus on smaller segments of the pipeline for which the next level of assessment is indicated.

Table 1: Proposed Phased Approach to Condition Assessment

Work Phase	Description	Methods
1	Desktop Assessment	Available records, reports, data review & evaluation Internal corrosion potential assessment Risk assessment for prioritisation
2	Soil Corrosivity Assessment	Electromagnetic (Emag) survey Wenner 4-pin survey Soil Salinity Linear Polarisation Resistance (LPR) Testing Groundwater sampling and testing Soil sampling and testing
3	External Assessment	Metallic Pipe: Baseline potential surveys Stray current surveys Pipe-to-soil potential survey Close-interval survey Other materials: Acoustic surveys for leaks and pipe thickness
4	Direct Assessment	Metallic Pipe: Broadband electromagnetic (BEM) testing Ultrasonic testing (UT) Cement mortar sampling/testing Reinforced Concrete Pipe: Ground penetrating radar (GPR) survey Asbestos-cement Pipe: Broadband electromagnetic (BEM) testing (experimental)
5	Structural Assessment	Critical Thickness Remaining Life

The collection of data and information through indirect monitoring and reporting, direct inspection, observation and investigation, and the analysis of the data and information to make a determination of the structural, operational, and performance status of capital infrastructure assets are incorporated into a condition assessment program.

1.1 LIMITS OF CONDITION ASSESSMENT DATA

Often, the level of accuracy possible from specific technologies is not always clear. In most cases, the results may be accurate to within the allowance design tolerance of the pipe. In some cases, the exact thickness of the existing pipe is not known or documented. Often, only nominal diameters are available, and sometimes the pressure rating of the pipe is not known. The results of inspections are limited by the least accurate data being provided for analysis. However, inspection results are good indicators of deteriorated conditions, but limitations of the data accuracy must be understood.

Research projects are currently underway by various regulatory and research organisations to determine the accuracy of these inspection technologies. However, they are being compared to known design parameters. When used for assets where little design data is available, the accuracy of the results diminishes. This does not mean that the results are not useful. As indicators of potential problems, they still have value and are useful for planning purposes.

2 PHASE 1 – DESKTOP ASSESSMENT

As the existing water system consists of pipes made of several different materials, coatings / linings, diameters and ages, different technologies or approaches need to be implemented. The resulting data provides condition information data on which to base decisions of asset reliability. A desktop assessment starts by assessing all available data and reports available for the pipes to be assessed as well as evaluating the internal corrosion potential and implementing a risk assessment.

2.1 INTERNAL SCALING POTENTIAL

An evaluation of the internal scaling potential is related to the scale-forming tendency inside the pipe based on the ability to precipitate or dissolve calcium carbonate. Using existing water quality data, water scaling indices are determined from industry standards such as the Langlier Saturation Index (LSI) (derived from the theoretical concept of saturation providing an indicator of the saturation of water with respect to calcium carbonate), and the Ryznar Stability Index (RSI) (quantifies relationship between calcium carbonate saturation state and scale formation). There are a number of on-line tools that can be used to calculate the scaling index.

Other parameters that are used to determine the internal corrosion potential of water is the calcium carbonate precipitation potential and knowing the pH of the system at the start of the system and the extreme ends of the system. Internal corrosion is not expected to be a problem in current times (due to routine sampling and reporting of water quality) unless the area is considered a "soft water" area.

2.2 RISK ASSESSMENT

Risk assessment related to pipe condition is the process whereby potential pipe failure hazards are identified, the risk associated with the hazards are analysed and evaluated, appropriate ways to eliminate or minimise the hazard are determined, and the residual risk is evaluated. In practical terms, a risk assessment is a thorough evaluation to identify those things, situations, processes, etc that may cause harm, to people or the environment as a result of a pipe failure.

Pipeline risk assessment should include the following parameters, at a minimum, for assessment:

- Pipeline Attributes: Material, diameter, installation date, coating, lining, cathodic protection, depth;
- Soil Environment: Soil corrosivity, pH, soil classification, salinity, groundwater elevation/ fluctuations, proximity to rivers, lakes, etc;
- Pipe Location (Vertical and Horizontal): Vertical (above or below ground, submerged), horizontal (crown of street, gutter, sidewalk, easement, etc.);

- Water Chemistry: Water pH, conductivity TDS, Ca^{2+} , $HCO3^{-}$, temperature at plant and extreme end of the system;
- Potential Stray Current Sources: Nearby gas mains with cathodic protection, DC powered rail networks, electric power poles, power stations, or any other source of electric current in proximity to the pipe;
- Failure Histories: Failure type, cause of failure, material, diameter, and corrective action; and
- Existing Test Data: any existing test data on or near the pipe in question.

If information is not available, then the condition assessment program should include activities to obtain enough field data for assessment.

3 PHASE 2 – SOIL CORROSIVITY ASSESSMENT

Results of the Phase 1 Desktop Assessment identify high-risk pipes with a potential for failure. The next step is to perform a soil corrosivity assessment on these priority pipes. The evaluation of soil corrosivity is one of the key components of pipeline condition assessment. The soil corrosivity survey is made up of soil resistivity and geotechnical investigation. Soil resistivity can be determined by various methods: electromagnetic conductivity survey, Wenner 4-pin survey, and LPR survey. When these methods are not practical, a salinity study may suffice. Sampling and analysis of soils and groundwater (if groundwater is present in the soil borings) is performed based on the results of the soil resistivity investigation.

3.1 SURFACE ELECTROMAGNETIC SURVEY

Electromagnetic (Emag) conductivity testing is conducted at accessible locations along the entire length of the pipe. The Emag measures soil conductivity, which is converted to resistivity and then plotted on a graph for review. This portion of the field work involves walking the entire alignment of each pipe selected for Phase 3 work. Emag equipment tracks the position using global positioning system (GPS) technology.

3.2 WENNER 4-PIN

Wenner 4-pin testing is conducted based on interpretation of the Emag data. Where the Emag survey data does not alert to specific Wenner survey locations, the interval spacing for the 4-pin measurements should be about 150 m apart in areas of interest. Utilizing a specially manufactured multi-conductor wiring harness, the 4-pin tests are completed for nominal vertical pin-spacing of 1.0, 1.5, 2.5, 3.0, and 4.5 m of depth (or less if the pipe is shallower). The Wenner 4-pin testing at pipe depth in combined with Emag to provide soil resistivity data to evaluate against industry-accepted categories of corrosion and assist with where soil borings should be performed.

3.3 LINEAR POLARISATION RESISTANCE

LPR is an electrochemical technique for corrosion monitoring. This method allows corrosion rates to be measured directly. It is limited to electrolytically conducting liquids or soils. Linear polarization resistance is particularly useful as a method to identify the corrosion potential and rate of corrosion. This method requires soil samples be taken from the pipe zone for analysis.

3.4 SOIL SALINITY

Emag, Wenner 4-pin, and LPR may not be practical methods to determine soil resistivity if the groundwater is expected to be above the pipe invert. An alternative approach is a salinity and topography study to identify areas of high potential for external corrosion. Dryland salinity landscapes contain significant stores of salt in soils, rocks, groundwater, and surface waters formed through deposition with the host material (connate salt) and atmospheric salt transfer (rainfall). When pipes are located within dryland salinity landscapes, an understanding of how salts migrate and concentrate is needed.

Three types of degradation can occur include the following.

- Spalling, due to mechanical stresses within the concrete resulting from the formation of expansive salts within the matrix itself. Disruption caused by any salt is more severe with wetting and drying cycles and no leaching. Any porous masonry is prone.
- Leaching: leaching of the calcium in the concrete, especially with soft water.
- Destabilization of the calcium silicate structure.

3.5 GEOTECHNICAL INVESTIGATION

Based on the results of the soil corrosivity evaluation, specific sites are identified for geotechnical investigation to determine whether the soils surrounding the pipe could be contributing to external corrosion. Soils are sampled near the pipe depth and below to provide some insight into potentially corrosive environments. Samples are analysed to determine the concentration of soluble chemical species that are known to contribute to corrosion, along with "as received" and saturated soil resistivity, and pH. AS 1726 provides a standard for geotechnical site investigations and AS 1289 provides a standard for Methods of testing soils.

3.6 GROUNDWATER SAMPLING AND TESTING

If encountered during soil sampling, groundwater is sampled and characterized by obtaining one-time grab samples along the pipe route where groundwater is found in the pipe and trench zone (the area between the pipe invert and the ground surface) to identify the nature, extent, and concentration of any contaminant present according to AS/NZS 5667.

4 PHASE 3 –EXTERNAL ASSESSMENT

External assessment is undertaken based on the results of the Phase 2 work. If areas are identified with a high potential for corrosion, then the external assessment is focused on specialty technologies directed to the pipe material.

4.1 NON-METALLIC PIPES

External assessments for non-metallic pipes involve different specialty technologies that can be applied to any pipe material.

4.1.1 PRESSURE TESTING

Pressure testing of pipe is performed to evaluate the limits of pipelines in terms of reliability, maximum capacity, leaks, joint fittings, and pressure. Allowance is made for local topography to ensure that low lying pipe work is not over-stressed during the test. For particularly long lengths of pipe work it is customary to sub-divide the length of pipe under test to identify problems and manage factors such as air entrainment more easily. Pressure testing deficiencies may be validated by follow-on acoustic testing to locate specific sites of leaks.

4.1.2 ACOUSTIC TESTING

Acoustic testing is available in internal and external applications. The advantage of the external system is that the pipe does not need to be depressurized/dewatered nor damaged in order to perform the testing. One provider of external acoustic testing also provides the average pipe wall thickness for follow-on structural analysis. When using an acoustic testing system, acoustic signals are induced in pipes by releasing water from the pipe in a controlled manner using acoustic sensors positioned at two longitudinally separated points on a pipe.

The sensors are attached at easy-to-access points, such as control valves, or directly on pipes in existing access structures. The length of the pipe section over which the acoustic velocity is measured can be arbitrarily chosen. Initially a 90- to 200-m-long section may be chosen. Subsequently, if a higher resolution is needed, when a section of pipe is thought to be in poor condition or when there are concerns about a particular section, the resolution can be increased by moving the acoustic sensors closer together. When the distance is too long between access structures, potholes provide access to connect wires to the pipe for additional listening stations.

If no problems are indicated during Stage 2, no additional work is required, and the data provides the baseline for a future inspection, usually recommended at 10-year intervals.

4.2 METALLIC PIPE

Metallic pipes can be inspected using a variety of techniques to determine pipe thickness or pitting (the precursor to pipe failure).

4.2.1 STRAY CURRENT SURVEY

A stray current survey of metallic and reinforced concrete pressure pipe is performed to determine if any current is being carried by the pipe that could result in anodic areas of corrosion. Pump stations, treatment plants, direct current (DC) electrified rail systems, high-tension electric lines, and third-party cathodic protection systems, are all sources of stray current. If stray current exists, this must be addressed prior to any further assessment.

4.2.2 CONTINUITY TESTING OF METALLIC PIPE

A test of the state of the electrical continuity along metallic pipelines is completed to validate the installed condition. The continuity testing task is important in the overall evaluation of the pipeline because it is during this testing that open joints (i.e., non-welded push-on joints without bond cables) are located for possible excavation and inspection. The electrical continuity testing is conducted along pipeline alignments where feasible. The testing hinges on pipeline appurtenance connection details and accessibility such as blow-offs, air vacuum/pressure relief valves, test stations, and connection points to foreign structures.

For metallic pipes with no coating or no CP system, but are electrically continuous, a baseline potential test is performed to confirm that the pipe is electrically continuous. Intermediate 2-wire test stations may need to be installed to facilitate potential testing if appurtenances are too far apart. If not electrically continuous, then the pipe requires a cell-to-cell potential survey.

4.2.3 POTENTIAL SURVEY OF METALLIC PIPE

Electrochemical (galvanic) corrosion takes place when two metals come into contact with a conductive liquid (for buried pipes it is the soil moisture) resulting in a flow of direct current electricity. The current always flows away from the anodic metal (anode), and the anode is corroded. The potential that causes the current to flow is always due to some kind of difference between the anode and the cathode, such as a difference in the two metals, concentration of the conductive liquid, a difference in temperatures, a difference in the amount of oxygen present, or some other difference in conditions.

When a long pipe is buried, the moisture in the soil is always the electrolyte. The anode and the cathode areas are both on the same pipe structure, and the pipe itself provides the return circuit. The lower the resistance or the more conductive the electrolyte, the greater the flow of electricity and the more active the rate of corrosion. Potential surveys are used to measure pipeline potentials by an electrical connection to the pipeline with a set of reference electrodes at ground level, positioned directly over the pipeline, and at intervals of about one meter (NACE 2007).

For metallic pipes with no CP and are electrically discontinuous, a cell-to-cell potential survey is used similar to the pipe-to-soil potential survey, only over individual sections of pipe in areas where there is a high potential for corrosion.

As a follow-on survey to the baseline potential survey, a close-interval survey (CIS) then evaluates whether the pipe has any indications of corrosion. Based on this testing, if specific locations of corrosion are identified, they are then recommended for the next phase of work. CIS is also used to test the effectiveness of installed cathodic protection (CP) systems. If the static potentials along a pipeline were of equal values, galvanic currents could not flow, and there would be no corrosion. If potential results are outside of the expected values for the pipe material, then a direct assessment would be needed.

5 PHASE 4 – DIRECT ASSESSMENT

Prior to performing direct assessments, excavations are required to expose the pipe for the direct assessment. Excavations are performed in accordance with standard specifications requiring due diligence to protection of existing utilities, minimizing damage to surface features, and supervised by quality control staff. Following the direct assessment, backfilling and surface restoration is performed according to accepted standards and meeting the requirements of the utility owning the pipeline.

5.1 STEEL, DUCTILE IRON, CAST IRON PIPE

Broadband electromagnetic (BEM) hand scanning kit (HSK) is an external method applied to the outside surface of the pipe and used to provide an average thickness of the metal pipe, without removal of a coating. Based on the results of the BEM-HSK, ultrasonic thickness (UT) testing may be recommended. BEM-HSK offers a useful screening tool to identify specific locations around the exposed pipe surface where pitting, thinning, or occlusions within the pipe wall are located.

The BEM-HSK is able to determine the steel pipe thickness through coatings up to 75 mm thick. If the scan (Figure 3) indicates potential corrosion sites (area circled in red on Figure 3), follow-up UT testing could be performed. If the steel thickness indicates no concern for steel thickness reduction, no additional work is necessary.

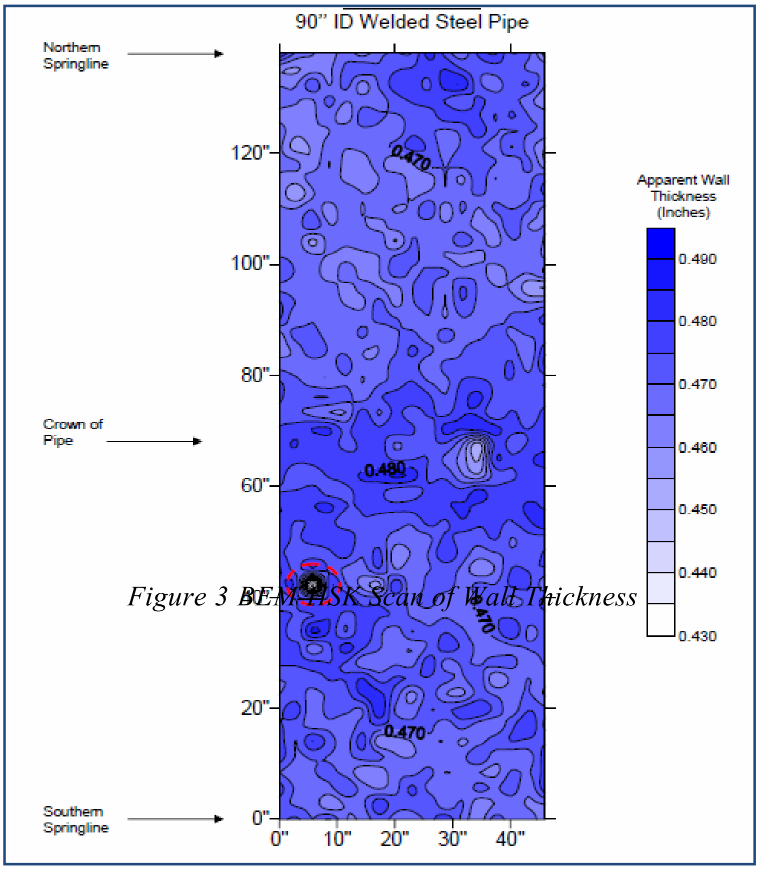


Figure 3 BEM-HSK Scan of Wall Thickness

If ultrasonic thickness testing is recommended, additional information is gathered about the pipe condition including: cement-mortar coating sampling and testing data from the joint and factory pipe mortar. Analysis of the mortar samples includes pH, chlorides, and sulfates.

5.2 ASBESTOS-CEMENT PIPE

Leaks identified by acoustic testing are verified during direct assessment of an AC pipe. In the event of a significant leak, a portion of the pipe may need to be replaced while the excavation is open. If, however, no visible leaks are verified, a BEM HSK resistance test could be performed to document a baseline condition for the pipe.

As the AC pipe deteriorates, more moisture is absorbed into the pipe. BEM-HSK resistance testing is a relatively new application, and more data sampling is needed to validate the results, but could provide a baseline data set that can be documented and compared to a similar test in the future to evaluate deterioration rates.

5.3 PLASTIC PIPE

Leaks identified during acoustic testing are verified during direct assessment of a plastic pipe. Generally, if leaks are validated, repairs or replacement are undertaken to restore the pipe to full operating condition.

6 PHASE 5 – STRUCTURAL ASSESSMENT

To provide the highest level of accuracy as to the remaining service life of a pipe, a section of pipe must be removed and sent to a structural laboratory for testing. If this is not possible or feasible, then a limited analysis of the thickness measurements from Phases 3 and 4 will have to suffice for the remaining service life estimate. There are a number of tools available to evaluate the remaining useful life tool. A structural engineer should perform the structural analysis to ensure accurate and consistent results.

7 CONCLUSIONS

The application of specialised inspection technologies for water pipeline condition assessment and the development of a strategic field work approach to deploy specialized technologies provide a cost-effective approach to inspecting pipeline systems. The results provide information related to the reliability of the pipelines to perform as designed or determine corrective measures needed to return the pipelines to full operating capability. Utilities will benefit by developing a condition database on which to base decisions for asset reliability, renewal, or optimal maintenance. An effective program will focus on pipe lengths where the potential risk of failure and consequence of failure is high and not on long lengths of pipe where risks may be much lower. Planning for needed Capex or Opex projects based on a more accurate remaining life estimate of pipeline assets will avoid costly failures that come with a high potential for social or legal costs.

ACKNOWLEDGEMENTS

The author would like to acknowledge the work previously performed the Southern Nevada Water Authority, Las Vegas, Nevada in 2009-2010.

REFERENCES

NACE *Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipeline",* SP020-2007, US National Association of Corrosion Engineers.

Utah State University, Steven Folkman, *Water main Break Rates in the USA and Canada, A Comprehensive Stud* (April 2012)

WSAA, *Common Failure Modes in Pressurised Pipeline System (*November 2003)

CSIRO, WSAA *Condition Assessment Guidelines for Pressurised Pipes, Water for a Healthy County Flagship Report* (October 2010)

Australia Government, National Water Commission, *National Performance Report (2010-11), Urban Water Utilities*

Ratliff, Alison L. and Russo, Mark, *Condition Assessment of 108-miles of Water Transmission Laterals, American Society of Testing Materials (ASTM) Pipeline Conference, Denver, Colorado (2010)*