Transmission Main Leakage: How to Reduce the Risk of a Catastrophic Failure

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Abstract

The condition of transmission mains is often taken for granted until there is a major pipe burst and city streets or private properties are flooded. When this happens, what results is a huge public relations issue which goes far beyond the cost of lost water. The stress and man-hours associated with such a break can cost a utility hundreds of thousands of dollars and bad press for months to come. The occurrence of such catastrophic breaks can be significantly reduced by proactive condition assessment and targeted leak detection.

With distribution lines, most condition assessment is conducted through leak detection, which shows where leaks are occurring and how many leaks there are in different areas. This creates a quantitative picture of the condition of these pipes. Transmission mains are more difficult to quantify because standard leak detection practices are limited by the loss of acoustic signal inherent with the pipes’ increasing sizes or diameters.

This paper examines the problems associated with standard leak detection conducted on large-diameter pipes and suggests specific asset-management methods and new technology to improve the level of knowledge of transmission pipe condition.

Introduction

There is never a good time for catastrophic water pipe failures. Though they are not generally the source of the greatest amount of loss in a water system (service pipes and connections generally hold this record), they are what the public perceives as the biggest problem. This is because they are the most newsworthy. It only takes one major leak to make the utility look as if it is either poorly run, has not taken care of the existing infrastructure, or both.

Figure 1. Catastrophic water transmission line failure.
There are many methods available for locating and reducing distribution-system water loss. The most common of these -- acoustic leak detection -- does not work effectively on large-diameter pipes. This paper addresses the problems associated with large-diameter mains, as well as some other leak-detection methodologies and technologies which are effective in reducing the risk of a catastrophic failure. Figure 2 below outlines the methodologies and technologies briefly discussed in this paper.

**Stage 1: Basic Transmission Main Leak Detection and Reduction**

Following are preliminary steps to beginning leak detection and asset condition assessment of large-diameter pipes:

- Inspect all valve chambers (including air valves, washouts, control valves, hydrants, etc.) for signs of leakage from valve glands, pipe joints, etc.
- Examine discharge pipe work from washouts along each pipeline.
- Inspect adjacent ditches, dykes, and field drain discharges for signs of leakage from the pipeline.
- Inspect all meter installations at the start, along, and at the end of each pipeline. Take flow readings for use in carrying out a water balance for each transmission main system.
- Identify and confirm all branches and connections (including service connections) from the pipeline and assess flows through these connections.
- Sound the pipeline as a whole, using specialist acoustic equipment for detecting leakage, if suspected.
- These initial methodologies do not always find the leaks in a transmission system because the main equipment uses acoustic techniques connected to the outside of the pipes through fittings such as hydrants or valves. As discussed in the following section, acoustic signals are generally poor on large-diameter mains. There are systems and methodologies which can improve the accuracy of leak detection. These are discussed later in this paper.
Reduced Effectiveness of Acoustic Leak Detection in Large-Diameter Pipes

Acoustic leak detection involves listening to audible signals either at ground level or on a fitting connected to the pipe (e.g., a valve or hydrant). If the leak detection crew listens at the surface with a listening stick or ground microphone, the acoustic signal will often be difficult to hear. This is because these pipes are often deeper than distribution pipes (up to 50 feet deep in some cases). In these cases, the success of subsurface acoustic leak detection will depend on several factors. The distance from the leak to the monitoring point will alter the accuracy of the signal detected with a noise attenuation rate of 40 dB per meter of soil (Hunaidi et al.; 1999). Deeper leaks are therefore much harder to trace and detect. Furthermore, higher frequency signals attenuate more rapidly in soil than lower frequencies. The type of soil in the monitoring area also influences the quality of the leak signal received at the surface. For example, sandy soil provides better sound conduction than clay-based soil, which gives poor sound conduction.

If the listening device is set onto the pipe via a fitting, this will have more chance to pick up a noise signal. However, depending on the pipe material, pipe diameter, and system pressure, the signal may not travel far enough for a leak to be heard. In transmission systems, fittings are often large distances apart. This makes correlation of any leak noises difficult.

Pipe materials influence the frequency and amplitude given off by a leak, and so different types of leaks emit varying signals. Most acoustic monitoring hardware is designed for traditional asbestos cement (AC) or cast or ductile iron pipes. Over the last 20 years, however, these pipes have been replaced by PVC, polyethylene (PE), and other plastic water lines. Acoustic leak detection of PVC and PE pipes is far more difficult than water supply pipes constructed of more traditional materials. Plastic pipes have a higher acoustic attenuation than metallic lines. Their acoustic attenuation is five times greater than that of cast-iron pipes, with the amplitude of a leak signal diminishing quickly by 0.25dB/m (Hunaidi et al., 2000). The cause of this is the radiation of the leak sound energy into the adjacent soil as the pipe vibrates from the water escaping through the leak. Tests show that the optimum frequency range for a standard 150mm (6") PVC pipe is between 15 and 100Hz, although this will be affected by the pipe diameter and conditions at the site, including traffic and soil type. Both can interfere with the leak signal frequency. Generally, for PVC pipes, the acoustic signal given off by a leak will be < 50Hz (Hunaidi et al., 2000, 2004).

An increase in pipe pressure at the time of the leak will generally result in an increased frequency in response to the higher flow rate within the pipe. This will produce the same frequency signal as long as the opening or leak in the pipe remains a fixed size. For PVC pipes, higher frequencies of >35Hz will accompany an increase in pressure.

Water lines vary in diameter, and that must be taken into consideration when monitoring for leaks. The sound waves produced by the leak don’t travel separately through the pipe wall and water core. Instead, they travel together. Therefore, pipe diameter affects leak signal. It is already known that leak signals travel greater distances along metal pipes than along plastic pipes. This is because of reduced attenuation within the pipe. However, larger-diameter pipes of any material have the same effect on the leak signal, weakening it and making it harder to detect. The increase in diameter effectively reduces the frequency of the leak noise, which results in greater attenuation of the leak signal through the pipe.
Stage 2: Sophisticated Transmission Main Leak Detection

Direct Leak Detection

Because acoustic leak detection as used for distribution systems does not transfer easily to the transmission main environment, other tools are necessary to reduce the risk of failure to a reasonable level.

District metered areas are commonly used to aid with leak detection of the distribution system. Because they can encompass portions of the transmission system, DMAs can also be used as aids to locate transmission system leaks. Step tests can be used to determine a stretch of pipe where a leak is occurring, but this does not precisely locate the leak and takes the pipe out of service for the length of the test.

Currently, Sahara™ (see Figure 3) is the only technology commercially available which accurately assesses the location of a leak in transmission mains with repeatability. This tool has been in operation within North America since 2004. It was developed by the Water Research Centre in the U.K.

The Sahara™ technology deploys acoustic tools directly into the transmission main. By doing this, leak detection is taken directly to the leak, removing the factors of pipe material, pipe diameter, and soil type. This does give an indication of the condition of the pipe, depending upon the amount of leaks in a section of pipe. However, it does not give detail regarding the overall condition of the pipe. The Sahara technology is also relatively expensive, so other techniques and equipment can target and prioritize where it would be most useful.

Figure 3. Schematic of Sahara™ transmission main leak detection system (courtesy of Pressure Pipe Inspection Company).

In addition to leak detection methods, pressure management can be used to reduce the amount of leakage out of a transmission system. As with the distribution system, reducing pressure on a pipe can also reduce the amount of leaking water.
**Asset Condition Assessment**

There are a number of asset-condition assessment tools which can be used to assess the risk of failure. In pre-stressed concrete cylinder pipe (PCCP), electromagnetic methods such as remote-field eddy current can be used to assess the amount of stress on a PCCP pipe by determining the number of broken wires in the body of the pipe. When combined with information about the operation of the supply, estimates of risk can be evaluated. Figure 4 shows a working example of this equipment inside a dewatered pipe. Currently this technology needs to be used within a dewatered pipe and is only useful for PCCP. This means that the condition assessment needs to be planned well in advance and will not aid knowledge of ductile iron or plastic transmission mains. To evaluate the condition of these other types of pipes, analysis of external corrosion or removal of sections of pipe and testing of the material properties are the most valuable methods of assessment.

![Figure 4. Remote-Field Eddy Current (electro-magnetic) tool inside PCCP pipe.](image)

The External Corrosion Assessment Tool (ECAT) is another tool which can be used on metallic pipe to assess exterior corrosion and pipe-wall thickness, thereby giving information on the in-situ state of the pipe work.
Based on both the minimum wall thickness measurement and deepest pit depth reading, a worst-case corrosion rate can be estimated, assuming original maximum wall thickness as specified. This can then be applied to the thinnest section in order to estimate when the pipe will burst. This methodology is relevant for metallic pipes which do not need to be taken out of service. In the case of plastic pipes, the most effective method of condition assessment is still physical testing of the material. This can be conducted proactively by cutting out pieces of pipe in areas of higher risk (such as areas of higher pressures). Also, if a burst occurs on a main, there is the chance to take a physical sample from a problem area which can be analyzed in the laboratory. These analyses can be used to test the flexibility and strength of the pipe material, and this can be compared with the original pipe specifications. With this information, an assessment of the asset life can be determined.

**Targeting to Improve Cost-Effectiveness of Transmission Main Leak Detection**

Targeting tools include district metered area (DMA) measurements using temporary or permanent meters to evaluate whether there are leaks on a stretch of pipe. This methodology is detailed in many other papers and so is not revisited here. The DMA does not show where a leak is, but it does show whether there is a problem in the area. DMAs have been used effectively across the world to target leaks in relatively small zones within utility systems. They are used primarily for distribution systems, but also incorporate transmission main elements. There are a number of computer software packages which can improve the response time for these types of systems by analysing trends and updating utility personnel on a daily basis.

These methods look for actual leaks within systems but do not evaluate the condition of the pipe with view to assessing the risk of failure compared to already-failed pipe. The following sections review some of the asset condition assessment tools which can aid this process.

In addition to new technologies and tried-and-tested methodologies, there are also database management efforts including system water audits which can reduce the risk of
pipe failure. For example, plotting and analysing leak location data, targeting corrosion potential, and evaluating pressure transients in the system will often aid with short- and long-term system management decisions and thereby reduce failures.

Figure 6 below shows an example of where corrosive soils have been assessed and plotted onto a GIS map overlaid with a system water line. The areas most at risk of corrosion are then highlighted and can be targeted and prioritised for further analysis.

![Figure 6. GIS map targeting corrosion risk to system pipelines.](image)

Due to the complexities of leak detection in large-diameter mains, there will always be problems locating leaks. However, as the knowledge of system asset condition improves, the likelihood of any catastrophic failure will decrease significantly.

Review

In overview, the risk of a catastrophic transmission main failure can be significantly reduced by using a combination of the methods and technologies outlined above. In order to reduce leaks, methods such as Sahara can locate existing leaks. District metered areas and analysis of GIS system data can be used to target definite areas of leakage so that the leak-detection technologies are used in the most cost-effective way. In order to improve the asset condition and design life of the pipes, technologies such as electromagnetics, ECAT, and pressure management can be implemented. Each of these has a place in improving the asset condition, extending asset life, and reducing the risk of a catastrophic failure.

References