LEAK DETECTION IN TRUNK MAINS
A comparison of three systems
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Abstract
This paper explains the different techniques of leak detection on trunk mains and compares the results of a new non-invasive system with two established invasive technologies. Part 1 briefly reports simulation testing by Sydney Water on four commercial products. In Part 2, Gutermann equipment was subsequently tested by real-life comparisons in Manila, a busy Asian city with large levels of background noise, even in the middle of the night.

Introduction
Leak detection in large diameter water distribution mains or trunk mains is particularly challenging because the acoustic noise created by a leak must dissipate around the large circumference of the pipe before travelling along the pipe wall. Leak noise on large diameter pipes is much quieter and at a much lower frequency than the acoustic vibration used to find leaks in water reticulation networks. The leak noise is generated by the friction of water rubbing against the pipe wall as the water is escaping. A larger pressure differential between the inside and outside of the pipe forces the water to exit the pipe at a greater speed, creating a greater noise.

Trunk mains are often designed with long distances between access points to the pipe, with an average distance of 500m between two points. The low frequency and quiet leak noise on trunk mains has made it almost impossible to detect leaks using leak noise correlators, as the leak noise was only detectable over a typical distance of 50m or less. In the last 15 years, innovators developed techniques for finding such leaks.

Part 1: Technologies
Invasive Technologies
a) The Sahara System
The UK Water Research Centre developed the Sahara system, which is now marketed by Pure Technologies. This is an invasive technology with an acoustic sensor inserted into the pipe, which travels along the inside of the pipe to detect the leak noise from close proximity. It has been very successful at finding leaks and has highlighted the fact that trunk mains need to be surveyed every one to two years to minimise leakage and prevent major incidents caused by main breaks on large pipes.

The sensor is inserted into the pipeline through a device that allows the cable to pass through a seal.

The hydrophone-transponder head is carried downstream by water flow acting on a drogue or small parachute attached to the head and aided by a hydraulic winch that regulates the rate at which the cable is fed from a cable drum (Figure 1). The size of the drogue used for each survey varies according to the diameter of the pipe and the velocity of the flow. The speed of the survey is also largely determined by the flow rate and is typically equal to about half of the flow velocity. As the survey progresses, signals from the hydrophone are transmitted to an operator on the surface via the umbilical cable. Any sounds, including leak noises picked up by the highly sensitive hydrophone, are monitored by the operator using headphones, and are also displayed in spectrogram form on a computer monitor according to amplitude and frequency.

A second operator continually tracks the progression of the hydrophone-transponder head down the main on the surface. This is carried out using a specially designed receiver that amplifies a high-frequency signal emitted by the transponder. The two operators are in constant two-way radio communication, and when a leak is detected the transponder serves to accurately pinpoint its location.

At the end of the survey run the cable, along with the attached head and drogue, is drawn back by the winch and fed onto its drum by a separate drum motor. Provided the drogue remains intact, previously detected leak sounds can also be verified as the head is retrieved and, if necessary, adjustments can be made to the magnitude and location of leaks.

Survey distances of up to 2000m are possible from each insertion point. However, the length of a particular survey is primarily determined by the flow velocity and the number of bends and deflections in that section of pipeline. A minimum velocity of around 0.4m/sec is required, and as a rough guide, about 100m of survey distance can be achieved for every 0.1 m/sec increase in flow. The total change of direction that can be negotiated in the course of any one survey is about 180 degrees.

The pressure in the pipeline also needs to be high enough to cause any leaks to generate a detectable noise, and ideally at least 20m head to make the sound of the leak clearly distinguishable above background noise levels. Very high pressures can make the initial insertion process more difficult, and can also make the cable feed somewhat harder due to the need to use tighter seals at the cable entry point. Nonetheless, the system...
has been used with pressures as high as 245m. The system can identify leaks in pipelines constructed of all common pipe materials, including plastic. Even leaks as low as 0.1L/minute have been detected.

(b) SmartBall

SmartBall (from Pure Technologies) is an acoustic sensor that rolls through the pipe. In this case, the umbilical cable is dispensed with, and the free swimming sensor saves leak noise and position data continuously onto an inbuilt digital memory card.

The main application of SmartBall technology is leak detection in pressurised water mains; however, it can also be used in sewers. The ball (Figure 2), inside its protective outer foam ball (Figure 3), is inserted into the main via a tapping on the main, or through the removal of suitable fittings, such as air valves. A suitable tapping size is 100mm-150mm. The ball is inserted into a short riser and pushed down into the main using a rod with a plunger attachment. The ball is then free to travel with the flow.

The ball rolls freely along the invert of the pipe propelled by the water flow, travelling at slightly less than the flow velocity. The methodology used to track the ball during its progress involves the installation of sensors on surface fittings along the main. The ball emits a distinct high-pitched sound every three seconds, which is picked up by the sensors and time stamped. The sensors are then able to track the ball as it approaches and departs their location in real time. The position of the ball within the pipeline is critical for locating the exact position of suspected leaks. Upon retrieval, data stored during the survey can be downloaded from a circuit in the ball, which includes frequency spectrums of leaks and a rotational profile. The rotational profile and the sensor tracking (ie, distance vs time of travel) enable the leak location to be determined.

The extraction process consists of inserting a net into the main via a riser on a 100mm tapping. The net covers the bottom half of the pipe diameter and is controlled and secured with two fibreglass rods. A camera is also inserted into the main to observe the ball rolling into the net (in real time). The process is then reversed, with the ball being secured inside the net as it is collapsed and pulled to the surface. The operators claim 100% success in catching the ball in the net when it is deployed.

Non-invasive Technologies

More recently there have been developments with low-frequency sensor technology to enable manufacturers to develop point-to-point survey methods that do not require insertion of sensors into the pipe. With the latest low-frequency acoustic technology, leaks in trunk mains can be located using leak noise correlation techniques with both accelerometer and hydrophone sensors. An accelerometer sensor is connected to the pipe, valve or hydrant by a magnetic connection, while a hydrophone requires a tapping into the main to connect to the water column.

Accelerometer sensors (Figure 4) detect the vibration from the leak conducted by the pipe wall, and hydrophones (Figure 5) contain a submersible noise sensor that detects the leak noise travelling through the water column.

Air valves, gauging points, insertion probe flow meter installation points and water quality sample test points provide ideal locations for connecting a hydrophone (Figure 6).
With recent developments in low-frequency accelerometer sensors, there have been vast improvements in leak noise correlation technology for trunk mains from two manufacturers. Sydney Water has tested correlators from four manufacturers. A correlator measures the time delay between the leak noise arriving from one sensor to the next and calculates the leak position based on the pipe material, diameter and length between sensors entered by the operator (Figure 7).

Correlation results from leak noise correlations show the pipe length as a two-dimensional scale diagram, with sensor ‘A’ positioned on the left and sensor ‘B’ on the right. The positions generating noise appear with peaks above them. To interpret the results, the operator looks for one or two dominant peaks that are at least three times higher than the background level of noise found across the entire length of pipe.

**Field Testing of Non-invasive Technologies**

Over the last four years, Sydney Water has performed a range of trials for both the invasive and non-invasive technologies, and this has been documented in a report titled *An overview of innovative leak detection technologies for large mains in Sydney*, by Aravinda Stanley and Roger Wood.

Sydney Water conducted trials with leak noise correlators using both accelerometers and hydrophones on the Bankstown-Ashfield trunk main in 2008, and on the Lansdowne trunk main in 2009. The aim of the project was to test the operational capabilities and sensitivity of the equipment, the threshold levels in terms of leak flow rate, survey distance and leak location accuracy.

Equipment from four suppliers was trialled: Echologics, Primayer, Sewerin and Gutermann. After all suppliers reported a high level of background noise at the Bankstown-Ashfield main, a new site was identified. Consequently, the Lansdowne main (600mm CICL), located in bushland at Lansdowne, was selected for the second trial.

All the testing was performed on one pipe, which was a 600mm cast iron pipe approximately 40 years old with an average pressure of 50m. A map of its placement is shown in Figure 8. A leak was simulated by tapping in a ball-valve (Figure 9), which was partially opened to simulate small leaks of 3–10L per minute.
Five pits were purpose-built for this trial with valves and the ability to connect hydrophones at each point. The map shows the pit positions and the picture shows the simulated leak.

Leak Simulation

A hose was attached to the ball valve to measure the leak, and then removed to simulate the leak (Figure 10). As the pit filled with water, the differential in pressure between the water escaping from the pipe would have been reduced, causing a slight reduction in leak noise and frequency. All of these trials were performed during the day; background noise was evident during the trials and filtering was often required to get a clear leak position. It is expected that better results with less need to filter would be achieved if the correlation trials had been performed at night.

Stanley and Woods of Sydney Water reported: “The overall results for accelerometers showed that the lowest leak flow that could be correlated was 2L/minute over a distance of 232m with accelerometers. Over a longer distance of 400m, the lowest value correlated was 6L/minute with accelerometers and 3L/minute with hydrophones.”

Examples of the correlation results for the Gutermann Aquascan Trunk Main are shown in Figures 11, 12 and 13.

Background noise may cause interference, so it is advisable to correlate when pressure is greatest and background noise is lowest. A knowledgeable operator with an understanding of leak frequencies and how to filter background noises may work effectively during the day, as was done during this trial.

Part 2: Comparison of Sahara with the Aquascan in Manila

Following the Sydney simulation trials, Gutermann used their Aquascan equipment to test for a number of known leak sites in Manila. The leaks had previously been identified during a survey using Sahara, providing a perfect opportunity to compare the results. The objective was to enhance the performance of the correlator in busy Asian cities with large levels of background noise, even in the middle of the night. All of the field testing was performed at night and all of the sites were residential or light industrial areas.
The first round of testing was with accelerometer sensors, making a magnetic connection to the valve or gauging point, and the second round was with hydrophones.

The peak shown in Figure 14 on the 750mm Algesirus line is close to a bridge. Sensor A is deployed on a gauging point with an insertion probe flow meter attached. Turbulence noise is generated by the insertion probe flow meter; however, the correlator is still able to produce a good result at 38.3m, which was 0.6m from the location indicated by Sahara.

Figure 15 shows a correlation of another section of the Algesirus line that had been surveyed by Sahara. The pipe starts as a 750mm OD cast iron pipe from sensor A and then reduces to a 650MM OD pipe at 56m from sensor B. Sahara was unable to go through the valve on this reducer, so the last 56m had not been surveyed. It took almost seven hours to survey this section with Sahara. It took the Aquascan approximately one hour to survey the same section.

Sahara reported a small leak 94m from sensor A and two large leaks at 306m and 318m from sensor A. Aquascan’s correlation result clearly indicates a leak at 318.8m from sensor A. A secondary peak lies approximately 310m from sensor A. At 220m from sensor A there was a busy road. A small peak generated by this traffic can be seen on the graph; however, this seems insignificant in comparison to the peaks created by the leaks.

Figure 16 shows the longest distance correlated at 599.5m, with the most number of leaks. There are two large peaks very close together and close to sensor B. The largest peak is the closest to sensor B; this is a throttled valve. The second peak has a 3m deviation from the leak location indicated by Sahara. This larger deviation will be caused by the long time delay with this long distance and the indicated leak position being on the far edge of the correlation. In addition to these large peaks there are small peaks that correspond with the small leaks found by Sahara at 106m, 201m and 303m. These peaks are small and may not have been picked up prior to the repair of the big peaks. Now knowing these points are leaks, it is also possible the small peaks at 490m from A and 500m from A are leaks too.

The correlation shown in Figure 17 was performed with hydrophones when pressure was recorded on site at 20 PSI (14m). It was after 5am when work...
started to correlate this section, and lots of people were up, coming out of their homes and the traffic was picking up. The pressure is very low and there are a couple of bends and a couple of tees in this section. The correlator has identified four peaks, accounting for four out of the five known leaks in the area, as previously detected by the Sahara survey. These were a small leak at 19m, a large leak at 43m, a medium leak at 82m, a small leak at 84m and a small leak at 242m (all distances from sensor B.)

One of the challenges for operators of a correlation-based product is being able to confirm that the peak is a leak and to pinpoint it on-site. The leak noise on trunk mains is typically such a low frequency that it cannot be heard by the human ear, even with amplification equipment like ground microphones. The engineers at Gutermann have created a new Aquascope ground microphone and listening stick kit with significantly greater amplification and a frequency multiplication option, enabling the operator to enhance low inaudible frequencies to an audible frequency. The Aquascope 550 is shown in Figure 18.

Conclusions

Despite having lower pressure, multiple leaks and a larger pipe diameter in Manila, the results were better than obtained in Sydney. The most noticeable difference in comparing these two test sites is that the simulation was a part-open valve, while the others were real leaks. The Aquascan has been programmed to recognise the frequency signature of a leak and performs better with real leaks than simulated leaks.

The testing in Manila proved the Aquascan is effective at finding leaks in busy Asian cities over distances of 600m or more. The setup time for each correlation is about half-an-hour, with the processing time being 15–30 minutes. This makes the Aquascan a fast and effective solution for finding leaks on trunk mains. There are now advanced automatic filtering options to enable the operator to quickly identify potential leak locations and suppress some of the background noise.

In addition to the site preparation work required to create access points for Sahara, it will often take five hours or more to survey a stretch of about 600m. Nonetheless, Sahara seems to provide the most thorough and accurate survey on trunk mains, finding very small leaks. Engineers may question whether it is economical to repair these small leaks.

SmartBall is a little more efficient with time and can find small leaks, but it is unlikely to be as accurate as Sahara. In complicated networks it might be difficult to catch the ball.

With the installation of an accelerometer sensor only requiring a magnetic connection to the pipe or pipe fitting, and a hydrophone needing a tapping point in the line for water access, the ease and cost of installation greatly favours the accelerometer. The performance of hydrophones is greater than accelerometers on most occasions; however, the results are always similar. After field testing the Aquascan we are confident that correlating over distances of 400–600m with accelerometers will locate leak positions for leaks of 10L per minute or greater.

The Author

Andrew Clark (email andrewc@gutermann.net.au) is currently the Asia Pacific Regional Manager for Gutermann and has been involved in the training and supply of a wide range of pipe location and water leak detection equipment to the water industry for over 10 years. He has travelled extensively throughout Asia and is familiar with the extreme conditions many leakage operators face in busy cities with very low pressures.

References

(Copies of these documents can be obtained from the author.)

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