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Acoustic Leak Detection Survey Strategies for Water Distribution Pipes

By Osama Hunaidi

The ability to detect leaks in municipal water distribution pipes is a critical aspect of leakage management programs. This Update reviews several strategies used to survey for leaks using acoustic equipment and presents recent experience with regard to their performance.

Municipalities need to manage leakage in their water pipe networks. This requirement has become more urgent owing to water shortages caused by recent droughts, increasing demand, environmental, social and political pressures, escalating energy costs, and pending regulatory requirements.

Leakage management generally comprises four main elements: water audits; leak detection or monitoring; pressure control; and leak location and repair. This Update presents survey strategies that can be employed for leak detection using acoustic equipment. A previous Update reviewed equipment used for detecting leaks.¹

Hidden or unreported leaks in water distribution networks can be detected by surveying pipes for the acoustic noise generated by water as it leaks from them under pressure. All areas of the pipe network are normally surveyed whether or not leakage is suspected. Strategies that can be used include manual acoustic surveys employing listening equipment or noise correlators, and automatic surveys using acoustic noise loggers. Adoption of a particular strategy depends on available resources (both financial and human), characteristics of the pipe network, and operating conditions.

This Update reviews these strategies, discusses the pros and cons of their operation, and presents recent experiences with their performance.



Figure 1. Worker conducts a listening survey

Listening Surveys

In listening surveys, experienced inspectors work their way around the pipe network listening at pipe fittings using acoustic equipment (Figure 1). The survey can be general or detailed. In general surveys, inspectors listen at convenient locations such as fire hydrants, whereas in detailed surveys they listen at all fittings including curb stops. Listening surveys are carried out during the night in areas where high ambient noise from busy road traffic or high water demand preclude daytime studies.

Listening for leaks can be done using simple equipment of the mechanical type such as aquaphones or geophones. Though simple, these devices are most effective in the hands of experienced leak inspectors.

Alternatively, listening can be done using modern electronic devices often equipped with signal amplifiers and noise filters that may make leak sound stand out in noisy environments.

The loudness of leak sounds and the distance they travel depend greatly on the pipe material and diameter. Leak sound travels best in small-diameter metallic pipes (≤ 300 mm) but is greatly attenuated (or damped) in plastic and other non-metallic pipes and in large-diameter pipes. The attenuation effect increases with the frequency of the sound. Consequently leak sound in non-metallic and large-diameter pipes is dominated by low-frequency components, which humans are not good at hearing, as can be seen from the equal loudness contours of human hearing.

The lower the frequency of sound (below roughly 500 Hz), the lower the sensitivity of human hearing. The lower the sound level, the more pronounced this effect is. In other words, sensitivity to sound decreases most sharply with a decrease in the frequency of sound at the threshold of hearing. For instance, sensitivity of hearing to sound at 500 Hz is about 10 and 100 times higher than at 100 and 50 Hz, respectively.

Consequently, leak sounds in plastic pipes, in concrete and asbestos cement pipes, and in large-diameter pipes, which are dominated by low frequencies (≤ 50 Hz), are hard to detect in listening surveys unless listening points are very close to the leak locations. For example, an NRC Construction study found that listening devices were not effective for detecting a simulated leak in a 152-mm diameter PVC pipe unless they were attached to access points that were roughly within 5 metres of the leak.² Listening surveys may also have difficulties in detecting large leaks. This is counter-intuitive as one would tend to think that leaks become louder as they become larger. This may be true up to a point beyond which leak flow becomes less turbulent and its sound subsides, becoming harder to hear.

Difficulties with listening surveys for non-metallic pipes and large leaks were confirmed in recent work by NRC Construction with listening crews in two Canadian cities.³ For example, a general listening survey in an asbestos cement (AC) pipe area using an electronic listening device at fire hydrants detected hydrant leaks only. The survey did not succeed in detecting other leaks that contributed to a sizable 393 L/minute water loss in the area. This included a 190 L/minute leak from a circumferential crack in a 152-mm diameter AC pipe that was approximately 95 metres from the nearest fire hydrant. This large leak could not even be heard on adjacent curbstops a few metres away.

Another general listening survey did not succeed in detecting a huge 600 L/minute leak from a full circumferential crack in a 254-mm diameter cast iron pipe that was only 70 metres from the nearest fire hydrant, which is relatively close for metallic pipes.

The lower the frequency of sound (below roughly 500 Hz), the lower the sensitivity of human hearing. The lower the sound level, the more pronounced this effect is.

Leak Noise Mapping

Leak noise mapping is an enhanced form of general listening survey that was developed at the Halifax Regional Water Commission.⁴ This approach follows the usual practice of listening to leak sounds at easily accessible contact points with water pipes. In Canada, fire hydrants are generally 150 metres apart and hence provide convenient contact points. Sounding is performed using electronic listening devices that are equipped with a sound level display, either analog or digital.

To minimize interference from other noise sources, especially in areas having busy road traffic and/or high daytime water demand, surveys for leak noise mapping are performed at night. It is very important to ensure that all acoustic listening devices are properly calibrated and procedures for attaching acoustic sensors are strictly followed by all inspectors to ensure consistency of measured leak sound levels.

Leak inspectors listen to leak sounds and document sound levels together with other standard descriptors such as pump or other mechanical noise or high-pitch noise (normally corresponding to fire hydrant leaks). Sound levels are input into a geographic information system (GIS) for the pipe network to produce coloured contour maps of leak sound levels. These maps enable leak managers to easily compare the latest sound levels with those previously collected to identify zones where more detailed surveys are needed. The maps also provide a visualization of leak noise patterns, which can help identify the presence of multiple leaks in a particular zone. Subsequently, managers can effectively plan the work of leak inspectors for pinpointing and validating suspected leaks. Zones with validated or confirmed leaks are re-inspected after leak repair and leak noise is re-mapped to detect remaining leaks. The process is repeated until no detectable leaks remain in the water distribution network.

The noise mapping technique can be applied to metallic pipes but like other listening techniques it cannot be used effectively for plastic and other non-metallic pipes and large-diameter ones, owing to their significant noise attenuation. Moreover, the technique may not be effective when applied to zones of metallic pipes with a large number of repairs using plastic pipe splices and/or plastic fire hydrant leads.

A general listening survey and a leak noise mapping survey of the 1100-km water distribution network in Halifax, carried out in series between early April and early June 2000, revealed 32 and 216 leaks, respectively.⁴

In-Pipe Leak Detection Systems

For large-diameter pipes, problems encountered by listening surveys can be solved by inserting hydrophones into the pipes.⁵ For example, in one commercial application, a tethered hydrophone is inserted into a large pipe at a special tap and pulled through the pipe by water flow against a parachute-like contraption (Figure 2). The intent is to get as close as possible to the location of leaks. The sound level is measured continuously by the hydrophone while the latter's position is tracked on the ground surface. The location at which the sound level peaks would correspond to a potential leak in the pipe.

In another application of the in-pipe concept, the hydrophone and associated electronics are encased in a buoyant foam-wrapped aluminum ball that is also inserted in large pipes at a special tap. The untethered ball is pushed inside the pipe by water flow and later fished out at a downstream valve.

In-pipe acoustic listening systems are highly specialized and sophisticated. They are suited mainly for large-diameter pipes.



Figure 2. Schematic of an in-pipe leak detection method (Used with permission, Pure Technologies Ltd.)

Leak Noise Correlation Surveys

An alternative to listening surveys that can be used for both non-metallic and large-diameter pipes involves the use of leak noise correlators (Figure 3). Correlators are less susceptible to interfering noise and are not dependent on the listening skills of leak inspectors.

Leak noise correlation works by measuring pipe noise at two locations that bracket the position of a suspected leak. The leak position is then calculated using a simple relationship involving the time delay between the measured signals, the distance between the measurement points and the propagation velocity of sound in the pipe, which can be calculated or measured easily.

Two inspectors are needed to conduct a leak correlation survey. The survey route is planned carefully in advance. Selected contact points—typically fire hydrants—are marked and numbered in sequence on two pipe network maps (one for each inspector), together with approximate distance and pipe type and size between them. One inspector attaches a first sensor and the other attaches a second sensor and runs the correlator. If a leak is detected, its approximate location is marked on pipe maps for later pinpointing. Inspectors communicate via radios to move their sensors between fire hydrants alternately or simultaneously in a leap-frog fashion. A two-person team experienced in the use of correlators can survey about 3 km/day (about 15 minutes per correlation) for pipes that require the use of hydrophones, (e.g., PVC pipes). They can survey about 9 km/day (5 minutes per correlation) for pipes on which accelerometers can be used, (e.g., those made of ductile and cast iron). These per-day rates assume an average hydrant spacing of 150 metres and an 8-hour workday, of which 5 hours are spent on actual correlations, 2 hours on planning and 1 hour on travel to and from sites.



Figure 3. Sensors for noise correlation system

The rates of 15 and 5 minutes per correlation mentioned above were achieved by NRC Construction staff in surveys conducted in small residential areas and applied to all fire hydrants. Rates should double by correlating pipe only between alternate hydrant pairs (every second hydrant). However, correlation of alternate hydrant pairs may miss some small leaks because signal attenuation increases with distance between sensor and noise source. The greater the distance between monitored fire hydrants, the higher the chance of missing small leaks.

Recent experience by NRC Construction staff revealed that problems could be encountered in detecting some leaks by correlation surveys.³ For example, an experienced city crew surveying a cast iron pipe area did not succeed in detecting a huge ~600 L/minute leak that a general listening survey also missed. This was unusual and could be due to equipment



Figure 4. Hydrophone connected to a fire hydrant

problems, (e.g., damaged sensors). NRC Construction and city staff later successfully correlated the missed leak with NRC Construction's correlator, using acceleration sensors at fire hydrants 193 metres apart.

In areas where use of water softeners is common, large leaks can also be missed by a correlator-based leak survey (even with hydrophone sensors) owing to interference by noise from the softeners. These are typically programmed to regenerate, or backwash, between midnight and 4 a.m. For instance, an initial correlation at night by NRC Construction staff using hydrophones at fire hydrants (Figure 4) ~216 metres apart did not detect a large ~190 L/minute leak in a 152-mm diameter asbestos cement pipe. This leak was also missed by an earlier general listening survey by a city crew. However, the leak was successfully correlated at a later time. It was demonstrated that in the initial correlation, the leak was masked by a high-amplitude, low-frequency noise outside of the bracketed location, most likely due to a draw from water softeners widely used in the area.

Leak Noise Logging

Manual acoustic leak surveys, using either listening devices or noise correlators, suffer from a number of other drawbacks. They are labour intensive and hence may be inefficient for regular surveys, especially for large distribution systems. Also, they require extensive training and special skills. They are carried out only periodically and hence the time from leak occurrence to detection may be significant, which may lead to excessive water losses. An alternative developed recently to overcome these limitations is automatic acoustic surveys using leak noise loggers (Figure 5).

Acoustic loggers are compact devices composed of a vibration sensor (or hydrophone), a programmable data logging module, and a communication module. They are deployed in large numbers temporarily or permanently at underground valves, 200 to 500 metres apart. The loggers are programmed to listen for pipe noise during the quietest time of the night, normally between 2 a.m. and 4 a.m. They operate every night and when a leak is suspected, they wirelessly transmit an alert to a receiver, roaming or fixed.

A recent development for water systems with automatic meter reading (AMR) is to attach noise loggers to service pipes adjacent to customer water meters in order to exploit the existing wireless communication infrastructure of AMR for transmitting leak alerts. Another recent development is “correlating noise



Figure 5. Noise logging system

loggers” that record a short sample of pipe noise when a leak is detected. The noise sample is stored and later downloaded wirelessly to a PC via a roaming or fixed receiver where it is correlated to pinpoint suspected leaks.

Frequent claims are made about the superior performance and cost effectiveness of acoustic noise loggers in comparison to traditional acoustic leak detection surveys. Documented field trials by three water utilities (one each in the United States, the United Kingdom and Canada) do not support such claims. In fact they uncovered some problems, including false alerts and missed leaks, in addition to hardware reliability issues.^{6,7,8} These trials involved head-to-head evaluation of noise loggers with acoustic listening surveys.

Nonetheless, automatic leak surveys using closely-spaced loggers may be a worthwhile, convenient and effective alternative to nighttime manual acoustic surveys for detecting leaks in city centres and other busy areas having a high level of interfering noise during the day.

Summary

The adoption of a particular acoustic leak detection strategy depends on available resources, characteristics of the pipe network, and operating conditions.

Listening surveys, including leak noise mapping, are mainly suitable for small-diameter metallic distribution pipes. They are generally ineffective for detecting leaks in non-metallic and large-diameter pipes. They may also have difficulties in detecting large leaks in all types of pipes, metal or otherwise. Problems can be overcome by using in-pipe acoustic devices propelled inside pipes by water flow. These devices are highly specialized and sophisticated and are suited mainly for large-diameter pipes.

Leak noise correlation surveys can work for both non-metallic and large-diameter pipes. They could fail, however, in detecting leaks due to equipment problems. Large leaks can be missed owing to interference by noise from water softeners where such appliances are extensively used.

Manual acoustic leak detection surveys using either listening devices or noise correlators are carried out periodically and may be inefficient, especially for large distribution systems. They also require extensive training and special skills. An alternative is automatic acoustic surveys using leak noise loggers.

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