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Inspecting Systems for leaks, pits and corrosion

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Abstract:

The National Research Council Canada (NRC) has recently completed a project to assist the City of Montreal in determining the condition of its water and sewer system. NRC staff members reviewed available and future diagnostic techniques for both systems, conducted experiments on corrosion monitoring, CCTV inspection and mechanical inspection methods and provided general scientific advice during the course of the project. This paper describes the results of the review of diagnostic techniques for metallic and pre-stressed concrete pipes. Both older techniques such as water audits and leak detection and new approaches such as acoustic emission monitoring and remote field effect inspection are discussed. Advantages and disadvantages of each technique are tabulated and approaches are suggested for combining the different techniques to provide a complete diagnosis of a water system.

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Introduction:

The pipes in water distribution and transmission systems are difficult to inspect for damage due to their location below the surface of the ground. Even where the pipe is large enough to be entered by a human inspector, most of the damage to the pipe occurs on its outside surface (for metallic pipes) or in the centre of the pipe wall (for prestressed concrete pipes). This difficulty has led water utilities to rely on techniques such as breakage records, leak detection and water audits to determine the health of their systems. While these techniques have been shown to be very useful in prioritising repairs and replacements, they have the disadvantage of being reactive in nature. In each case, problems with the water system only become apparent after the pipes have failed in some manner. As a result, water utilities repair damage rather than preventing it from happening.

In 1992 an American Water Works Association Research Foundation (AWWARF) report on techniques for inspecting metallic water lines evaluated the then available inspection technologies and called for new research¹. Since then new methods of inspecting metallic, concrete and plastic water pipes have been developed. In some cases these methods were improvements on past approaches, while in others the technology was completely new. More importantly, some of these methods allowed water utilities to prevent pipe breaks from occurring, rather than reacting to them. In 1997 the Institute for Research in Construction (IRC) of the National Research Council Canada (NRC) began a collaborative project with the City of Montreal, Quebec's National Institute for Scientific Research – Water (INRS-EAU) and the Centre for Engineering and Research in Urban Infrastructure (CERIU) in Montreal to determine the condition of the City of Montreal's water and sewer systems. IRC's role in the project was to provide advice on appropriate diagnostic techniques and to act as an overall scientific advisor. This paper reviews the diagnostic techniques that were investigated in the course of the project for the inspection of the City's cast iron water

distribution system and prestressed concrete transmission system. Their characteristics are tabulated to indicate their advantages and disadvantages and recommendations are given as to when the different techniques should be used. It also examines possible new developments in this field.

General Approaches

Water Audits

Water audits are the simplest way of evaluating the condition of large parts of a water system. In this type of test a comparison over an entire city or within a district is made between the minimum nightly flow rate per person or per household and a target value that represents the background leakage (produced by seeping at joints and similar sources). The difference between the two is an indication of how much water is being consumed at night in the area being monitored.

If all night time industrial usage and a standard value for normal night time use per consumer household are then subtracted from the total water consumption, the remaining water consumption is considered to be “unaccounted for water” and is assumed to be due lost through breaks and leaks.

The water audit therefore provides an estimate of a system’s water loss. A coarse, system wide audit can be done by monitoring the flow rates through a city’s transmission lines and comparing the resulting overall water consumption to regional or national averages. However, it is more effective to follow a system wide audit with district measurements. In this procedure the city is divided up into individual districts or segments of pipeline that are isolated from the rest of the system except for one valve that allows water into the district and a second that allows water to leave it. Such a division lets the city compare individual districts with each other and determine which areas are most likely to be experiencing serious leakage problems. This type of measurement can have a number of benefits²:

it quickly quantifies leakage potential, identifying good candidates for immediate acoustic surveys;

it provides opportunities to update the city's data base on such matters as water consumption patterns, hydrant locations and valve locations; and

it provides an opportunity to exercise valves that are not normally used and reveal those which are not working properly and may cause potential flow problems during fire fighting.

While periodic city wide leak detection campaigns are typical in North America, more systematic approaches to leak detection using water audits may be taken by logging meters that are permanently installed at the entrances and exits to each district. NorthWest Water in the United Kingdom uses a weekly cycle of monitoring flow meters to target specific districts for leak detection campaigns³. Readings are taken each Wednesday and analysed as described. The value for water loss per district or zone is then converted into an equivalent number of service line breaks or "ESLB". This number is then used to work out the number of households per ESLB in each district of their system. The districts with the lowest numbers of households per break are given priority as targets for leak detection and repair efforts. The ESLB value is also compared on a week to week basis since large increases in the rating may be signs that a distribution main has broken. This type of audit can also be used to estimate the effectiveness of repairs, since an audit before and after a repair should show an improvement in the minimum night flow ratio.

Water audits by themselves can not precisely locate leaks. However, they can be used to prioritise areas for leak location procedures. They are commonly used by municipalities during the beginning of a leak detection program and may be reduced in extent or dropped as the program matures. The American Water Works Association publishes a manual that describes how to set up and perform both a water audit and a leakage detection campaign⁴.

Sonic and Acoustic Leak Detection

Leaks produce a distinctive sound which can be used to identify and locate them. This may

be done by methods that enhance the natural hearing of a listener (these are referred to as sonic leak detection), or that are electronic in nature (acoustic leak detection)⁵. These two methods are the most common in use today amongst municipalities of all sizes across North America, and there is ample evidence that a vigorous program of leak detection and repair can drastically reduce the amount of unaccounted for water in a water distribution system^{1,4,6-8}. Typical sonic leak detection methods involve the use of stethoscopes or listening horns placed against hydrants or the ground above a pipe. Acoustic methods may use similar locations, but with geophones or hydrophones to pick up the sound, allowing it to be recorded for future reference. Typical systems use an autocorrelator to compare the signals from two different hydrants or sites. A comparison between the time of arrival of the sounds from each device is used to deduce the approximate location of the leak.

Experience with leak detection suggests that under good operating conditions, leaks in all sizes of service lines and valves may be detected, with flow rates ranging from as little as one litre per minute to as much as 4000 litres per minute⁵ (0.25-1000 gpm). In order to maximize the effectiveness of this technique, care must be taken to minimise sources of background noise (open valves, traffic, digging, etc.) which may interfere with the detection process. Consequently, it is often preferable to conduct these tests at night.

Leak detection systems have been used primarily in metallic distribution systems. However, two new developments promise to extend their use to other water lines. A system for performing leak detection on large diameter water lines has recently been developed in the United Kingdom⁹. This system places a neutrally bouyant hydrophone into an operating pipe (Figure 1). A parachute like droud is then deployed so that the force of the water flow carries the hydrophone downstream for a distance of up to two miles. The droud is then collapsed and the hydrophone is

slowly wound in to the entry point while it listens for leaks inside the pipe. The loudest leak noises would be expected to be heard at the point where the detector is closest to the leaks, allowing them to be located precisely. The major advantage of this system is that very few access points to the pipe are required from the surface. It can therefore be easily deployed within a deeply buried, long transmission line where surface leak detection techniques would not work.

A recent AWWARF/NRC co-sponsored project investigated the use of acoustic leak detection in plastic pipes¹⁰. This project determined that while current leak detection equipment is capable of detecting leaks in PVC piping, it rarely succeeded in detecting the leaks in automatic mode due to inappropriate filter settings. In addition, operators tended to shift filter settings into a higher range when they were unable to detect the artificial leaks created for the project. For plastic pipes, lower filter settings are needed. Leak signals in plastic pipes are dominated by low frequency components (below 50 Hz) which often means that the leaks can not be detected by human hearing. It is expected that the results of the project should lead to improvements in leak detection equipment and procedures so that leaks in these pipes can be readily detected.

While the effectiveness of leak detection is well recognised by municipalities, there do not appear to have been any tests done to determine what percentage of leaks were actually found during a survey. In addition, some municipalities may prefer to minimise the number of falsely detected leaks (false positives) in order to minimise unnecessary excavations¹¹. Consequently, operators may tend to set the threshold levels in their devices to reduce the number of false positive leaks that are detected, which would also increase the likelihood of missing real leaks with weak noise signals.

The issue of the percentage of missed leaks needs to be explored. Some North American cities have unaccounted for water losses of around 25% despite conducting leak detection

programs^{2,11}. It is likely that at least some of this unaccounted for water is due to undetected leaks. Furthermore, not knowing the true number of leaks in a water line means that incorrect decisions may be made regarding choices between repairing, rehabilitating or replacing water lines. The detection of 10 leaks in 5000 metres (3 miles) of pipe may mean that the repairs are the lowest cost option for a water utility. However, if those 10 leaks are an indication that 20 more lie undetected below the ground a more extensive program of rehabilitation or replacement may produce lower long term costs.

A final point to bear in mind is that leak detection methods will only find current problems and will not predict where problems will occur in the future. Leak detection allows municipalities to be reactive, rather than proactively protecting their systems. In order to be effective, these programs must be conducted on a regular basis, with the times between tests on an individual line chosen to maximise the possible economic impact to the city⁶.

Inspection Techniques for Metallic Pipes

Metallic pipes (grey cast iron, ductile cast iron and steel) generally fail due to corrosion related factors, although other causes are also found¹². In grey cast iron these failures may be mechanical in nature where the pipe has been weakened by corrosion pits or may simply be due to corrosion produced through pits that allow the water inside the pipe to leak out. In ductile iron and steel the corrosion through pit is the typical failure mode. The inspection methods for these pipes therefore rely on either directly detecting corrosion activity or, more commonly, on detecting the presence of possible corrosion pits in the pipe wall.

Remote Field Inspection

Remote field inspection is a through wall, electromagnetic non-destructive evaluation technology. It has a history of use in the inspection of heat exchangers¹³ and oil well casings¹⁴ and

has recently been introduced commercially for the inspection of grey and ductile cast iron pipes. In this technique a circular emitter coil is placed inside the pipe so that the axes of the pipe and coil are parallel¹⁵. A pickup sensor, also inside the pipe, is located more than 2.5 pipe diameters away from the emitter (see Figure 2). Passing an alternating current through the coil produces an alternating magnetic field that can reach the sensor coil by two paths. The first is down the inside of the pipe through the water column, while the second is through the pipe wall near the emitter, down the outside of the pipe, and then back through the pipe wall. In the former case the strength of the magnetic field attenuates very rapidly. In the latter case the field is reduced during each passage through the pipe wall, but little attenuation occurs while it travels outside the pipe. By the time the field reaches the receive coils, the signal from the outside route is much greater than that from the inside one. In addition, since the attenuation of the “outside” field depends on the thickness of the pipe wall, the technique is sensitive to changes in that thickness. This property allows corrosion pits, general wall thinning and some forms of cracking to be detected.

In the commercially available form, remote field inspection provides an estimate of the amount of wall loss in cast iron pipes due to corrosion pitting, provided that the total loss exceeds a certain threshold value. It can also detect areas of substantial cracking. In a recent IRC evaluation¹⁶, a commercial tool was found to be able to locate and size corrosion pits of more than 3600 mm³ (0.21 in³) in volume, with an accuracy of ± 0.55 m. (22 in.). It was not, however able to detect smaller pits, even when they represented through-hole leaks, nor was it able to accurately detect service connections. The tool has been redesigned since the evaluation took place with additional coils and software tools that can locate corrosion pits more accurately and with improved size sensitivity¹⁷.

All remote field effect measurements require that the inspection tool be located inside the

pipe being inspected. One commercial tool for 150 mm (6") pipe is designed to enter the pipe system through hydrants and does not require that the pipe be emptied of water before being inspected. Larger diameter pipes require special fittings so that the tool can be placed inside¹⁷. All commercial tools are designed to pass through pipes with some amount of tuberculation. The remote field effect itself is not affected by the presence of tuberculation and non-metallic linings, allowing the tools to inspect any pipe they can pass through.

This technique is more expensive than water audits and leak detection on a per metre of pipe inspected basis. However, it is the only commercially available inspection method that can detect damage and pitting in pipes before they leak, rather than afterwards. At the moment, the state of knowledge about cast iron pipes does not allow a direct translation between the depth of a defect and the residual life of the pipe. Instead, the pipe owner must decide, based on past problems, the aggressiveness of the soil, and the wall loss detected by the tool, which sections of pipe require further monitoring, active repair measures or complete replacement. Risk assessment software is available to assist in this process¹⁷.

Magnetic Flux Leakage

This inspection method will only work on cast iron and steel objects. An arrangement of magnets is designed to put a steady, D.C. magnetic field into the pipe wall so that the field travels in the same direction as the pipe axis. If the field in the wall is strong enough, a small amount of it will come out of the pipe wall wherever a corrosion pit or similar defect is present (Figure 3)¹⁸. This leakage field can then be detected by sensors inside the pipe. This technique is commonly used in the gas and oil pipeline industry for inspecting steel piping. It is currently not used for inspecting cast iron pipes, although the Gas Research Institute is sponsoring a project to develop a tool for 150 mm (6") grey cast iron gas mains¹⁹. However, using magnetic flux leakage in metallic water pipes is made more difficult by the requirement for the tool to maintain close contact with the pipe wall to be effective. This contact is strengthened by the magnetic forces between the tool and the wall, which pull the two together. As a result, the tool will tend to scrape off any interior coatings or build up within the pipe. This limitation is not a problem in unlined gas and oil pipelines, where the cleaning effects of the tool are sometimes considered beneficial, but in a water line the likely result is damage to any linings in the pipe and the unwanted removal of tuberculation. Any magnetic flux leakage tool that is developed for the water industry is therefore likely to be limited to cleaned, unlined pipes.

Ultrasound

Ultrasonic inspection is performed using a beam of coherent sound energy, with a frequency that is many orders of magnitude higher than a human being can hear²⁰. The sound wave travels into the object being inspected and is reflected whenever there is a change in the density of the material. Some of the energy in the wave will then be detected by a receiver while the rest will pass into the new material (Figure 4). Ultrasonic beams can be used to make images the human body, inspect aircraft or examine oil pipelines. The technique is capable of detecting pits, voids and cracks, although certain crack orientations are much more difficult to detect than others.

There are commercially available ultrasonic tools for inspecting oil pipe lines²¹. Although this type of tool has not yet been adapted for use in water lines, IRC's current research²² suggests that ultrasound should have no difficulty in detecting corrosion pitting in tuberculation free small diameter grey cast iron water pipe. However, tuberculation will greatly reduce the effectiveness of ultrasound as a means of inspecting water piping. Tuberculation causes the ultrasonic beam to be scattered and attenuated to such an extent that it may never enter the pipe wall at all, let alone returning to the inspection tool after reflecting off of a pipe defect on the outside of the pipe.

Corrosion measurements

Corrosion activity measurements are a common method of evaluating prestressed concrete water pipes²³⁻²⁶. They have also been used to determine if protective coatings or cathodic protection are required for new ductile iron pipes²⁷. However, techniques such as the Soil Aggressiveness Value method²⁸, half cell potential measurements²⁹ and soil resistivity measurements³⁰ have not been applied as commonly as diagnostic methods for cast iron water lines. These methods were investigated experimentally for use by the City of Montreal as a means to quickly determine which pipes should be inspected by other, more expensive non-destructive

evaluation techniques. The results of this investigation were, however, inclusive as to the techniques utility for diagnosing the condition of urban water mains³¹, so only a basic description of the different methods being given below.

There are two principal techniques to quickly locate areas where pipes are most susceptible to corrosion: soil corrosivity analysis and half cell potential measurements. The two techniques are complementary. The soils analysis identifies areas where corrosion cells can easily develop and may enable an estimate of the corrosion rate while half cell potential measurements can give information on the condition of the pipe and its tendency to liberate electrons in a given environment.

The most common test for soil corrosivity is the 10-points system developed by the Cast Iron Pipe Research Association and standardised in an Appendix of ANSI/AWWA C105/A21.5²⁷. It is based on five different measurements of the soil, including resistivity, pH, redox potential, sulfide content and moisture levels. As each of these soil parameters have different contributions to the soil corrosivity, a point rating is used to evaluate the overall corrosion hazard a particular soil presents to a pipe. Each parameter is evaluated for a given soil sample and the total number of points is calculated to obtain the soil aggressiveness value (SAV). If SAV is ten points or more, the soil is considered to be a corrosive environment to gray or ductile cast-iron pipe. Corrosion is then considered likely to occur unless protective measures are taken. A SAV of less than ten indicates corrosion is not considered to be a severe problem and that protection of the pipe should not be necessary.

The soil resistivity is the most important parameter in the SAV because it gives an indication of the corrosion rate. A lower resistivity allows a higher current to flow between the anode to the cathode and consequently produces a greater loss of metal at the anode. The

understanding of the importance of the role of soil resistivity in the corrosion process led to the development of a method to estimate soil corrosivity based only on resistivity measurements²⁸. It gives ratings such as highly corrosive, corrosive and moderately corrosive depending on the resistivity value.

Corrosion activity can also be evaluated with half-cell potential measurements²⁹. Each metal has its own unique potential for a given environment. This potential is also time dependent, changing in value as corrosion occurs. In general, the more negative the potential of a metal, the more anodic it is and the higher it's tendency to corrode. Corroding areas along a pipe or other metallic object can therefore be determined by pipe to soil half cell potential surveys. The exact application of information from the survey depends on the distance between the measurements in the field. Frequent measurements at close intervals are necessary to locate specific areas of corrosion while fewer measurements at wider spacings will give a more general overview of the extent of corrosion on the surface of a pipe. This constraint often means that localised pitting can be very difficult to detect with this inspection method. In addition, other factors such as stray currents may affect the half cell potential readings, which may cause difficulties in determining whether corrosion activity is truly taking place.

Prestressed Concrete Cylinder Pipes

PCCP fails when a sufficient number of loops of pre-stressing wire have broken in the same area of the pipe. The wires normally break when corrosion activity has reduced their diameter to the point where the stress applied to them exceeds their yield point. This process may also cause damage to the mortar around the wires (allowing an acceleration of the corrosion process) or to the concrete inside the pipe. Diagnostic methods for PCCP systems therefore rely on detecting corrosion activity, detecting damaged concrete on the inside of the pipe or detecting the broken

wires. Until very recently the only techniques available for inspecting prestressed concrete cylinder pipes (PCCP) were based on measuring the corrosion activity in the pipe, internal visual inspections and tapping on the inside and outside of the pipe. Recently, three new techniques have been developed which have the potential to greatly improve the management of these large diameter pipes.

Corrosion monitoring

This group of techniques has been discussed previously, although there is a separate body of literature on its application to PCCP²³⁻²⁶. Half cell potential methods in particular have been used successfully to find pipe segments with corrosion problems. However, while they are commonly used to measure corrosion activity in these pipes in rural settings, NRC research³² suggests that they may not be as effective for monitoring corrosion activity of PCCP in an urban setting. Multiple sources of corrosion activity and stray currents may hinder the accurate assessment of the urban PCCP condition.

Visual Inspection and Tapping

This technique has been described in detail by Price³³. Pipes are entered by a two or three man crew, which travels down the pipe looking for evidence of concrete damage. One crew member looks for visible cracking, a second sounds the pipe by tapping it using a metal rod in order to find concrete delaminations, while the third records the location and type of damage that is found. In lined pipes two people are sufficient as the sounding is not deemed to be required. This approach assumes that all broken wires will produce observable concrete damage. It also requires dewatering the pipes for the inspection.

Acoustic Emission Monitoring

This technique was originally developed by the U.S. Bureau of Reclamation for use in embedded type PCCP³⁴. Hydrophones are placed inside the pipe at two or more locations so that the region to be monitored is between at least two of the hydrophones. Automatic systems then monitor the pipe for the sounds of wires breaking and alert the operator of the system when a wire break sound has been recorded. An IRC evaluation has shown that these sounds have a characteristic form which is readily distinguishable from other noises that might be encountered in the pipe³⁵. By recording the time of arrival of the sounds the location of the wire breaks can be determined, while the number of breaks that are recorded over the monitoring period can indicate the severity of the problem. Once the locations of the wire failures are known, the owner of the pipe system can then decide whether the damaged pipe sections should be exposed to check their overall condition. This method can be employed in operating PCCP lines. It is described as a monitoring rather than inspection method because it can only determine what is happening in a PCCP line at any given time, rather than providing a complete picture of past damage.

Remote Field Inspection

The basic principle of the remote field effect has been described previously. In PCCP the basic remote field effect interacts with a second, transformer coupling between the coils that produce the A.C. magnetic field and the loops of pre-stressing wire around the pipe. The concrete and mortar of PCCP lines are transparent to the technique, while the steel cylinder in the pipes provides the metal tube that is necessary for the remote field effect to work. The technique is currently commercially available for inspecting embedded type PCCP. It can detect the presence of a single broken wire loop in this type of pipe and can differentiate between groups of approximately five breaks – i.e. a single wire break can be differentiated from a group of five wire

breaks but not from a pair of wire breaks³⁶. Research is currently being performed to develop the method for use in bar wrapped and lined cylinder PCCP. This inspection technique has the advantages of being able to produce a complete record of damage to a section of PCCP and of directly detecting broken pre-stressing wires. However, it can only be performed in dewatered pipes that have been temporarily taken out of service.

Impact Echo/Spectral Analysis of Surface Waves

Both of these closely related techniques have been used as tools for inspecting PCCP. The apparatus consists of a source of controlled impacts, such as a falling weight or a large pneumatic hammer and one or more geophones that are mounted against the wall of the pipeline (Figure 5). Low frequency surface waves are produced when the wall of the pipe is struck by the hammer or weight³⁷. These waves are then detected by the geophones. The major difference between the two techniques is that the impact echo method generally looks only at the actual waveform produced by the impact and uses a single receiver, while spectral analysis of surface waves (SASW) uses more geophones and separates the waves into different frequency components³⁸. These different components travel at different speeds and penetrate to different depths in the soil beyond the pipe, allowing more information to be gathered about the pipe condition. It is important to note that the results of these tests give information about the overall condition of the line, and may not necessarily locate specific small defects (An cracked area is likely to be located, but not a single crack). Both techniques have been successfully used in the analysis of damaged prestressed concrete cylinder pipe^{39,40}. Impact echo has also been successfully applied to a large diameter water supply tunnel with 12 courses of brick³⁹. One difficulty in interpreting the results of this type of prestressed concrete pipe inspection is that there does not appear to be published evidence relating specific types of concrete damage to wire breaks. Without that relationship, these technique can only indicate that the concrete of the pipe has become damaged and not the cause of that damage. Both techniques are currently only available for manual use in large diameter tunnels that are easily accessible by human operators. The developers of these systems are looking at automating them to speed their use and allow deployment in smaller pipelines.

Conclusions

Table 1 shows a comparative listing of the different techniques reviewed in this report for inspecting metallic water pipes. Each technique is named and the relative advantages and disadvantages of the technique are given. Table 2 shows a similar listing for prestressed concrete pipes. It is apparent from table 1 that most of the techniques available for inspecting metallic water pipes complement, rather than compete with each other. Water audits provide broad, reactive information about the condition of a wide area of a water distribution network. Acoustic leak detection methods find already broken or damaged pipes, corrosion monitoring, can, in theory, detect areas where corrosion activity on pipes is likely, while the remote field effect can inspect pipes to find damage before they fail. A complete diagnostic program is likely to use all of these inspection methods. Northwest Water³ and the City of Boston² provide examples where water audits and leak detection have been combined to provide a better diagnosis of a water distribution system. The remote field effect could be combined with such a program to examine selected lengths of water mains and determine whether they should be repaired when damaged or scheduled for replacement. Pipe sections found to have significant wall loss throughout or in many locations would tend be more economical to replace than continue to repair since they are likely to fail frequently. Those pipe sections with few pits and little wall loss could continue to be economically repaired as they failed. The selection of pipe sections to be inspected by the remote field effect would be determined by the results of water audits, leak detection, historical breakage records or corrosion measurements.

Ultrasonic inspection and magnetic flux leakage inspection methods could be substituted for remote field effect inspection if they are successfully commercialised. However, both methods will have considerable difficulty inspecting tuberculated pipe, with the flux leakage technique damaging pipe linings and removing tuberculation and the sound waves used in ultrasonic

inspection being scattered and absorbed by tuberculation. It is therefore likely that the remote field effect will remain the method of inspection of choice when the goal is to proactively determine the condition of metallic water mains.

In contrast to the above situation, most of the methods of inspection for prestressed concrete pipes are designed to directly or indirectly detect broken pre-stressing wires. While corrosion monitoring only detects the presence of corrosion activity near the pipes, acoustic emission monitoring detects wire breaks as they occur. The remote field effect finds previously broken wires and the visual inspection, impact echo and spectral analysis of surface waves techniques find the damage to the concrete of the pipe produced by broken wires. The PCCP owner is likely to choose only one of the last four techniques, possibly in conjunction with some form of corrosion monitoring or a continuing program of acoustic emission monitoring. Each of those four methods provides approximately equivalent information, indicating where wire damage has taken place throughout the pipe's history. However, the remote field effect has the advantage of directly measuring broken wires. The other methods measure concrete damage, which is presumed to be due to broken wires. Unless it can be shown that this is the case, and that all wire breaks will produce detectable concrete damage, the remote field effect is likely to become the method of choice when full pipe inspection is desired.

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References:

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1. Jackson, R.Z., Pitt, C., and Skabo, R., Nondestructive Testing of Water Mains for Physical Integrity, American Water Works Association Research Foundation, Denver, Colorado, 1992.
2. Sullivan, J.P., 1990, Leak Detection and Repair: Boston's Conservation Success Story, Proceedings of the 1990 American Water Works Association Conference, Cincinnati, Ohio, pp. 13-23, 1990.
3. Pearson, D., Personal Communication, NorthWest Water, Warrington, United Kingdom, 1997.
4. AWWA Manual M-36, Water Audits and Leak Detection, Denver, Colorado, 1990
5. Schultz, S., Soderberg, L., Iadarola, C., Leak detection and water conservation, Metro Water Conservation, Inc., Monograph Series - No. 1., 1986.
6. Pilzer, J and Sowby, S, 1980. Leak detection - case histories, Proceedings of the 1980 American Water Works Association Conference, pp.1037-1043, 1980.
7. Griffin, A., and Carr, C. L., Examination of the benefits of leak detection, Proceedings of the 1984 American Water Works Association Conference, Dallas, Texas. pp.69-98, 1984.
8. Harrison, D., The City of Calgary leak reduction program, 44th Annual Convention of the Western Canada Water and Wastewater Association, Calgary Alberta, pp. 101-108, 1992.
9. Marshallsay, D., Personal Communication, Water Research Centre, 1997.
10. Hunaidi, O., et. al., Effectiveness of Leak Detection Methods for Plastic Water Distribution Pipes, AWWA Distribution System Symposium, Austin, Texas, 20-23 September, 1998.
11. Choquette, G., Personal Communication (Superintendent, Water Meter Testing and Inspection), Regional Municipality of Ottawa-Carleton, 1997.
12. Jakobs, J.A., Underground Corrosion of Water Pipes in Canadian Cities – Case: The City of Calgary, Final Report, Caproco Corrosion Prevention Ltd., (CANMET Contract Report No.

- OSQ81-00096, Canadian Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada. Canadian Government Publishing Centre, Ottawa, Canada) 1985.
13. Mackintosh, D. D., et. al., Remote field eddy current for examination of ferromagnetic tubes, *Materials Evaluation*, vol. 54, no. 6, pp. 652-657, June 1996.
 14. Schmidt, T.R., Atherton, D.L., Sullivan, S., Experience with the Remote Field Eddy Current Technique, *Proceedings of 3rd National Seminar on Nondestructive Evaluation of Ferromagnetic Materials*, Houston, 23-25th March, 1989.
 15. Atherton, D.L., Remote Field Eddy Current Inspection, *IEEE Transactions on Magnetics*, vol. 31, no. 6, November. pp. 4142-4147, 1995.
 16. McDonald, S. and Makar, J., Assessment of the Hydroscope 201TM Condition Index Evaluation of Gray Cast Iron Pipe from Gatineau, Quebec, NRC Report A-7015.3, National Research Council, Ottawa, Ontario, 1996.
 17. Russell, D., Personal Communication, Russell Technologies, Inc., 1996.
 18. Corrosion Service Compagnie Limitee and Russell Technologies Inc., Reports for Ville de Gatineau, Ville de Dollard des Ormeaux and Ville de Brossard, 1995.
 19. Atherton, D.L., Magnetic Inspection is key to ensuring safe pipelines, *Oil and Gas Journal*, vol. 87, no. 32, pp. 52-61, 1989.
 20. Gas Research Institute, Pipe Inspection: Adapting Technology to Inspect 'Live' Mains for Metal Loss, *GRID*, p. 17, Winter 1996/1997.
 21. Birks, A. and Green, R., Editors, *Nondestructive Testing Handbook Second Edition*, Volume 7: Ultrasonic testing, American Society for Nondestructive Testing, Columbus, Ohio., 1991.
 22. Kiefner, J.F., Hyatt, R.W., and Eiber, R.J., Metal-loss, crack-detection tools targeted, *Oil and*

Gas Journal, vol. 87, no. 17, p 69-71, April 1989.

23. Rajani, B., Makar, J., McDonald, S., Jen, C.K., Viens, M., Levesque, H., Poon, C., Benak, T., Chapman, T., Fahr, A., 4th Periodic Report, Determination of residual life of cast and ductile iron water mains, Report NO. A-7020.4, National Research Council, Ottawa, Ontario, 1997.
24. Benedict, R.L., Corrosion Mitigation on Concrete Cylinder Pipe, Proceedings: Distribution System Symposium, Dallas, Texas, September, 10-13, 1989, American Water Works Association, 1990.
25. Bianchetti, R. L., Corrosion and Corrosion Control of Prestressed Concrete Cylinder Pipelines – A review, Materials-Performance, vol. 32, no. 8, August, pp. 62-66, 1993.
26. Diab, Y.G., Reinforced and Prestressed Concrete Pipe Diagnosis, Proceedings of the International Conference on Pipeline Infrastructure, American Society for Civil Engineering, pp. 355-368, 1993.
27. Price, R.E., The investigation, cause and prevention of PCCP failures, Proceedings of the 1990 American Water Works Association Conference, American Water Works Association, pp. 663-683, 1990.
28. American National Standard for Polyethylene Encasement of Ductile Iron Pipe Systems, Appendix A, Notes on Procedures for Soil Survey Tests and Observations and Their Interpretation to Determine Whether Polyethylene Encasement should be used, ANSI/AWWA C105/A21.5-93, American Water Works Association, 1994.
29. Peabody, A. W., Control of pipeline corrosion, National Association of Corrosion Engineers, Houston, 1967.
30. O'Day, D., External Corrosion in Distribution Systems, American Water Works Association Journal, October, p. 45-52, 1969

31. Makar, J.M. and Chagnon, N., Techniques d'auscultation des réseaux enfouis de la ville de Montréal – Rapport final, NRC Report A7030-1, National Research Council, Ottawa, Ontario, 1998. (in French)
32. Brousseau, R.J., Chagnon, N., Baldock, B., Potential survey of prestressed concrete pipes, Materials Performance, August, 36 (8), pp. 64-67, 1997.
33. Price, R.E. and Brooks, M.B., Evaluation of Concrete Pressure Pipelines and Prevention of Failures, Proceeding of the American Society of Civil Engineers Annual Convention, San Diego, California, American Society of Civil Engineers, 1995.
34. Travers, F.A., Acoustic Monitoring of Prestressed Concrete Pipe, Construction and Building Materials, Vol. 11, No. 3, pp. 175-187, 1997.
35. Makar, J., Evaluation of Acoustic Monitoring for Prestressed Concrete Cylinder Pipe, NRC Report B-5103.1, National Research Council, Ottawa, Ontario, 1998.
36. Mergelas, B., Personal Communication, Pressure Pipe Inspection, Mississauga, Ontario, 1998.
37. Sack, D. and Olson, L., In-situ Nondestructive Testing of Buried Precast Concrete Pipe, Proceedings of the American Society of Civil Engineers 1994 Materials Engineering Conference, San Diego, November 13-16, 1994.
38. Krstulovic Opara, N., Woods, R.D., Al Shayea, N., Nondestructive testing of concrete structures using the Rayleigh wave dispersion method, American Concrete Institute Materials Journal, Vol. 93, no. 1, pp. 75-86, 1996.
39. Holt, R. Personal Communication, NDT Engineering, Inc., Westborough, Massachusetts, 1997.
40. Olson, L., Personal Communication, Olson Engineering, Boulder, Colorado, 1997.

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Table 1. Comparison of Diagnostic Techniques for Metallic Water Mains

Technique	Advantages	Disadvantages
Zone Water Audits	<ul style="list-style-type: none"> • cheap • covers large areas of a city quickly • allows for a comparison of water losses between individual districts • useful as a screening process for other techniques • can be used to evaluate the effectiveness of repair programs 	<ul style="list-style-type: none"> • does not give the precise location of leaks • requires isolation of zones • work must be performed at night • only gives an overview of current problems
Sonic/Acoustic Leak Detection	<ul style="list-style-type: none"> • widely practised • known to find leaks accurately • known to find leaks of different sizes • operates from outside the water line 	<ul style="list-style-type: none"> • percentage of leaks missed by the technique is unknown • currently works best in metal water lines • only gives information on the current condition of the line (the tool has little predictive value) • background noise problems
Remote Field Inspection (Hydroscope)	<ul style="list-style-type: none"> • most advanced technique currently available • detects areas of corrosion pitting, as well as through holes • can be used to give an estimate of the future life of a line 	<ul style="list-style-type: none"> • more expensive than leak detection • requires access to the inside of the water line, which may require cleaning • knowledge of the relationship between pit size and residual life of the pipe is not yet complete • model evaluated by NRC would not detect pits of less than 3000 mm³ in size.
Magnetic Flux Leakage	<ul style="list-style-type: none"> • established technology in oil and gas industry • known to be capable of detecting small defects and through holes in steel pipe 	<ul style="list-style-type: none"> • not yet commercially available for water lines • requires access to and complete cleaning of the inside of the pipe
Ultrasound	<ul style="list-style-type: none"> • most versatile NDE technique • established technology in oil industry • NRC tests show that it can detect and size corrosion pitting 	<ul style="list-style-type: none"> • Technique will not work through tuberculation • not yet commercially available for water lines • requires access to and complete cleaning of the inside of the pipe
Soil Corrosivity Measurements	<ul style="list-style-type: none"> • simple to conduct • may act as a screening mechanism for more expensive methods 	<ul style="list-style-type: none"> • cities may have similar levels of corrosivity across their region, making use difficult • NRC tests in Montreal do not show a clear correlation between corrosion measurements and number of pipe breaks
Half-cell potential measurements	<ul style="list-style-type: none"> • simple to conduct • may act as a screening mechanism for more expensive methods • well established as method to detect corrosion activity in buried objects 	<ul style="list-style-type: none"> • factors such as stray currents and soil conditions may affect readings • accuracy of results depends on distance between readings • small areas of localised corrosion can not be detected

Table 2. Comparison of Inspection Methods for Prestressed Concrete Pipes

Technique	Advantages	Disadvantages
Half-Cell Potential measurements	<ul style="list-style-type: none"> • standard technique • results easy to interpret • simple to perform • does not require pipe entry 	<ul style="list-style-type: none"> • past NRC experience suggests the method is ineffective for use with these lines in an urban setting • indicates the presence of corrosion activity on or nearby the pipe, but not the extent of the damage.
Visual Inspection and Sounding	<ul style="list-style-type: none"> • longest record of successfully detecting damaged pipes • examines condition of concrete 	<ul style="list-style-type: none"> • requires man entry into pipes • does not give direct information on wire breaks • unclear whether all wire breaks will produce noticeable concrete damage • subjective in nature and dependent on skill of inspection team
Acoustic Monitoring	<ul style="list-style-type: none"> • works in an operating pipeline • can detect wire breaks during monitoring period and locate them • works in all types of prestressed concrete pipes 	<ul style="list-style-type: none"> • only detects damage that occurs during monitoring period
Remote Field Inspection	<ul style="list-style-type: none"> • can detect single or multiple broken wires • inspection gives complete picture of damage to the pipeline 	<ul style="list-style-type: none"> • currently only available for use in embedded type pipelines • requires man entry into pipes
Impact Echo/Spectral Analysis of Surface Waves	<ul style="list-style-type: none"> • examines condition of concrete • objective measurement system 	<ul style="list-style-type: none"> • does not give direct information on wire breaks • slower inspections than remote field effect • requires an empty pipeline

Figures

1. A schematic of the Water Research Centre's large diameter pipe leak detection system.

2. The remote field effect. The thick arrows show the two paths of the electromagnetic field from the exciter coil to the pickup coils. The field inside the pipe is attenuated very rapidly, while the field outside the pipe is only attenuated as it goes through the pipe walls.

3. A typical magnetic flux leakage tool, showing the permanent magnets and the flux leaking out of the pipe wall at a corrosion pit.

4. An ultrasonic inspection arrangement for finding corrosion pits in metallic pipes. The solid arrows show the beam as it enters the pipe wall and reflects back a receiver. The dashed arrows show the components of the beam reflected away from the desired path when material interfaces are crossed. Significant beam losses occur in the tuberculation – in many cases the beam would not reach the first tuberculation/pipe wall interface.

5. A typical set up for an SASW experiment. A hammer or similar device hits the wall, creating a surface wave that propagates along the wall to the sensors that can detect. By measuring the dispersion of the different frequencies in the surface wave, the overall condition of the wall can be determined.