Asset Management Condition Assessment Techniques

The following are a snapshot of potential methodologies used to assess infrastructure assets (e.g. sewers, water mains, road networks).

1. Condition Assessment Methodologies - Wastewater Collection Systems/Storm and Sanitary Sewers

a. ***Visual/ person-entry inspection*** done by trained personnel can provide qualitative and quantitative information about pipe defects. For example, inspectors can note defects and deterioration, detect concrete de-lamination, measure pipe deflection, and take close-up photos. Deterioration of sewers is manifested as: (i) structural defects (e.g., cracks/broken pipe, pipe sags, deformation, open joints, displaced joints); (ii) service defects (e.g., protruding laterals, tree root intrusions, silt, grease build-up, encrustation, obstructions); system surcharges and sewer backups; and a high groundwater infiltration rate in sanitary sewer systems (Zhao et al., 2001).

Visual inspection can only observe defects above the flowline/waterline, and there is always the possibility of a subjective interpretation of defect type and severity and may not accurately establish the location of each defect (Zhao et al., 2001).

b. ***Smoke/Gas Testing*** is a quick and inexpensive method of inspecting a sewer system as it requires little equipment and manpower. Smoke testing has proven to be an effective tool for determining leaks/ the presence of broken pipes, improperly sealed laterals, illegal lateral drains, and cross connections between different systems. A non-toxic smoke bomb or liquid smoke is placed in a manhole along with a blower. The blower pushes the smoke through the system. Cracks or improper connections are exposed when the smoke is seen filtering out of the pipe (Allouche and Freure, 2002; NRC, 2004).

c. ***Dye testing*** is used to trace the flow of effluent through the sewer system and to check if stormwater drains are connected to sanitary sewers through illegal or unrecorded connections. A non-toxic powder dye is added to drains and mixes with fluid carried by the pipe, giving it a highly visible colour (e.g., fluorescent green) that can be easily traced. The flow of the fluid through the sewer system is then monitored by inspecting manholes located downstream from the point of the dye application (Allouche and Freure, 2002).

d. ***Closed Circuit Television (CCTV)*** is an effective tool and common industry method for inspecting pipes/sewers. It provides visual data on leaks, location of service laterals, and sediment and debris accumulation to assist municipalities with maintenance, design and to identify long and short term needs of its underground wastewater collection system. The inspection procedure involves moving a video camera through the sewer to record the condition of the interior surfaces of the sewer. Certified CCTV operators use the video footage to record the type and location of defects. Corresponding condition assessment is carried out subsequently by viewing the inspection tape and the inspection report (Zhao et al., 2001).

The primary disadvantages to CCTV technology are that it only provides a view of the pipe surface above the waterline; it does not provide any structural data on the pipe wall integrity; and it does not provide a view of the soil envelope supporting the pipe (USEPA, 2009; Zhao et al., 2001; Allouche and Freure, 2002;). As well, CCTV inspection cost increases with sewer depth because of increased set-up time and because of the additional cable length extending from the surface to the sewer (Zhao et al., 2001). For inspections of gravity lines, basic CCTV systems are not able to measure slope (USEPA, 2009).

The quality of defect identification and pipe condition assessment using CCTV is highly dependent on many factors including operator's interpretation, picture quality, and flow level (USEPA, 2009; USEPA, 2007).

e. ***Sonar/CCTV*** combines the use of sonar to inspect the portion of the sewer below the flowline and CCTV to inspect above the flowline to give a complete picture of the sewer. The sonar images can reveal the true shape of the pipe, sedimentation build-up at the invert and defects in the pipe wall greater than 4mm (Zhao et al., 2001).

Like CCTV, this inspection technique requires specially trained personnel both to perform the inspections and to interpret the results. The set-up arrangement and length limitations are similar to those for CCTV. However, the inspection speed can be significantly lower than for CCTV inspection alone. As with CCTV inspection, the set-up time for combined sonar/CCTV inspection is usually long in relation to the actual inspection time (Zhao et al., 2001).

f. ***Zoom Camera Technology*** - Truck-mounted camera equipment with long-range zoom lens and powerful halogen spotlights are used to conduct visual inspections of manholes and sewers. The camera is lowered into the manhole from the back of a truck to the elevation of the first pipe and remotely aligned with the pipe's longitudinal axis. Powerful halogen lights are used to illuminate the interior of the pipe, as the camera zooms into the pipe providing a continuous image of the pipe's interior surface. The image is displayed on a monitor located in the truck while at the same time being recorded for subsequent review and analysis. All of the sewer lines connected to the manhole are viewed in the same fashion. After reviewing all of the pipes the manhole itself can be inspected before removing the equipment and moving on to the next manhole (Allouche and Freure, 2002).

The advantages of this method include significantly reduced inspection time and cost in comparison with conventional CCTV, since prior cleaning of the pipes and manhole entries are no longer needed. In addition, the manhole condition can also be evaluated, which is not the case with many CCTV inspections. The main limitation of this method is the range of operation, which is limited by the depth of penetration of the illumination equipment (Allouche and Freure, 2002).

g. ***Sewer Scanners and Evaluation Technology (SSET)*** is a multi-sensor, non-destructive, pipeline inspection system developed to overcome some of the limitations of standard CCTV systems by providing multi-source data obtained through a scan of the pipe's circumference. A SSET system scans the entire diameter of the pipe as it moves through the system, recording a 360-degree view of the pipe's interior. The information collected is processed and presented to the operator as uniform, high-resolution 2D images. SSET systems are more effective than traditional CCTVs because there is no need for the operator to slow down in damaged sections to ensure that all of the damage is recorded. Another advantage of the SSET system is the fact that it can measure horizontal and vertical pipe deflections using the gyroscope system (Allouche et al., 2002).

h. ***Ground Penetrating Radar (GPR)*** works by emitting a pulse of radio waves into the ground or any other non-metallic medium. An image can then be generated by measuring the strength and delay time of the refraction waves (echoes). The primary application of GPR for buried infrastructure is to identify the location and depth of buried pipes and conduits. A more recent application is the utilization of specialized GPR units that are inserted into the pipe to evaluate the quality of rehabilitation projects using various lining methods such as slip lining and cure-in-place liners (Allouche et al., 2002). GPR can also potentially be used to locate leaks, since saturated soil slows radio waves, resulting in a GPR profile showing a pipe deeper than would be expected (USEPA, 2009).

i. ***Ultrasonic Inspection (Sonar)*** devices utilize bursts of well-defined, high frequency sound waves that are sent towards the surface of the object of interest. The sound waves are reflected back towards the source at the interface of adjacent surfaces or when it encounters materials with different densities and elastic behaviours. Variations in the amount of energy that is returned to the mechanism for analysis and the period of time it takes for the sound waves to travel to the target and return to the source are used to estimate the location (i.e. orientation and distance with respect to the source) of the various targets (Allouche et al., 2002).

The system is able to detect pipe-wall deflection, corrosion losses, and cracks/pits in the cross-section of the pipe wall. In addition, ultrasound inspection can provide information regarding the volume of debris in the invert. Ultrasound inspection is not well suited to analyzing the interior of brick sewers due to the random edges that characterize the brick-mortar interface. Ultrasound detection methods can be used in plastic, concrete and clay pipes that are either filled or empty. If used in partially filled pipes, information can be collected regarding either the empty or submerged portion of the pipe only (Allouche et al., 2002).

j. ***Acoustic sensors*** - In pipeline assessment, acoustic sensors are used to detect signals emitted by defects. There are three types of acoustic technologies that can be used for inspection of water mains and also can be used for force main inspection: *leak detectors*, which are used to detect the acoustic signals emitted by pipeline leaks; *acoustic monitoring systems*, which are used to evaluate the condition of pre-stressed concrete cylinder pipe (PCCP) by detecting the signals emitted by breaking pre-stressed wires; and *sonar, or ultrasonic systems*, which emit high frequency sound waves and measure their reflection in order to detect a variety of pipe defects (USEPA, 2009).

k. ***Electrical/Electromagnetic*** currents are the basis of several sewer evaluation techniques. The electrical leak location method is used to detect leaks in surcharged non-ferrous pipes. Eddy current testing (ECT) and remote field eddy current (RFEC) technology identify defects in ferrous pipes (USEPA, 2009).

l. ***Laser profiling*** uses a laser to create a line of light around the pipe wall, highlighting the shape of the sewer. This technique allows for the detection of changes to the pipe's shape, which may be caused by deformation, corrosion, or siltation. Laser inspection can only be used to inspect dry portions of a pipe or the portions of a pipe wall that are above the water line. To assess the entire internal surface of a pipeline requires the pipe to be taken out of service. Lasers are often used in combination with other inspection methods, most commonly CCTV and/or sonar (USEPA, 2009).

m. ***Impulse Hammer*** is a technique developed to evaluate the structural integrity of brick sewers. The evaluation is conducted from a manhole, where a dynamic hammer is used to generate a broadband frequency excitation of the structure being tested. The dynamic response of the sewer structure is monitored by an accelerometer attached to the structure. The hammer's force input and the accelerometer's output are used to evaluate the structural soundness of the sewer (Allouche et al., 2002).

n. ***Infrared Thermography*** involves the use of an infrared camera to measure the temperature variations over a specific area and is a potential method of detecting sewer defects such as leaks and voids, both of which can result in surface temperature variations when a sufficient internal/external temperature exists (USEPA, 2009). This method is susceptible to the surrounding local meteorological conditions (e.g. rain and snow) that tend to mask the heat signature of a leak (Allouche et al., 2002).

2. Condition Assessment Methodologies – Water mains/ Water Distribution Systems

There are a wide range of both direct and indirect techniques for determining both the existing condition of a pipeline and the rate of its deterioration. Indirect methods are relatively simple and less costly than direct intrusive methods. Indirect techniques do not require access to either the internal or the external surface of the main and therefore do not disrupt operations or require local excavations. However, indirect methods may not provide the level of detail, timeliness, or confidence required for maintenance and renewal decisions about pipes with a high consequence of failure (USEPA, 2007).

a. Indirect condition assessment techniques for water mains include:

(1) historical data such as the age of pipe, manufacturer, when and who laid it, and experience of various pipe materials;

(2) environmental techniques include a consideration of the chemistry of the water and surrounding soil (e.g. soil conditions, ground water tables, surface conditions) and;

(3) operational data such as flow, maintenance and repair records. This information, from which pipe and/or network condition can be inferred, coupled with information about potential consequences of failure, is of great value in focusing an investigation strategy to those sections in most need of assessment.

b. Direct methods of condition assessment of water mains (water distribution systems) include:

(1) ***Visual inspection*** is the most obvious method of evaluating the condition of a pipe, its coating (external) or its lining (internal) which may be done for larger diameter pipes or the exterior of excavated pipes, or it may be done by CCTV for the interior of a wide range of pipes sizes. CCTV is used for both water main and force main inspections. CCTV can be beneficial, but it inspects only the inner wall of the pipe, not wall thickness, the outer wall, and pipe bedding voids (USEPA, 2007).

Ian Vickridge and Tony Lau noted that because CCTV inspection has been used for many years to obtain information on the condition of sewers and drains, many people mistakenly believe that it can also provide similar information about water mains. Whereas the condition of a sewer or drain can be assessed from visible defects such as cracks, displaced joints, and pipe deformation, the condition of a pressure pipe relates much more to the remaining wall thickness which cannot be seen. A CCTV survey will only provide a preliminary and qualitative assessment of the presence or condition of the internal lining and as the water supply needs to be shut down during the survey it is an expensive and disruptive method to obtain only a very limited amount of information.

(2) ***Destructive testing*** involves *pipe coupon sampling* (i.e. removal of a sample of the pipe wall) and analysis for thickness, defects, damage, and residual strength. *Hydrostatic testing* (i.e. isolating pipe, filling, pressurizing, then observing pressure or fluid loss) is a nondestructive evaluation except in cases where pressurizing the pipe causes failure at weak spots. Hydrostatic testing is the most common (i.e., 20% of surveyed utilities) investigation method for sewer force mains among surveyed utilities (USEPA, 2007).

(3) ***Nondestructive testing (NDT)*** methods measure various structural parameters without damaging the inspected material. NDT methods available for pipes include *penetrant testing* for cracks (not common for water pipes), x-ray inspection (not common for water pipes), *acoustic emissions* (e.g., for wire break events in prestressed concrete cylinder pipe (PCCP)), *acoustic leak detection*, *remote field eddy current* (for ferrous pipe), *remote field eddy current/transformer coupled* (for broken wires in PCCP), *magnetic flux leakage* (mostly for steel pipe), *ultrasonic pulse velocity* (for wall thickness measurement), *ultrasonic guided waves* (primarily for pipe with welded steel joints) , and *seismic methods* (for PCCP defects) (USEPA, 2007).

Except for acoustic leak detection and location, and acoustic wire break detection for PCCP, NDT for pressure pipes is not in widespread use. One estimate is that current NDT technology is only applicable to about 10% of U.S. drinking water mains (Dingus, et al., 2002). Limited use of NDT methods can be attributed to several causes including their high cost, disruptiveness and for most methods the lack of a track record. Slow development of NDT methods for water pipes may be attributed to small market size, challenging testing conditions in water mains, and/or lack of understanding and consensus regarding the requirements for pipe inspection (USEPA, 2007).

(4) ***Broadband Electro-Magnetic (BEM)*** is a patented technology developed in Australia that is commercially available. It uses the equivalent of a continuous range of electromagnetic frequencies to measure the wall thickness of a pipe by sensing the attenuation and phase delay of the signal passed through the pipe wall (Ian Vickridge and Tony Lau). It can see through even significant linings and coatings without their removal, which is a major advantage. Another advantage over ultrasonics is that it generates a contour plot of the whole section of pipe. It can detect metal loss to 1/25" of an inch. To scan internally the pipe has to be out of commission and a short section of pipe removed to allow insertion of the BEM pig (USEPA, 2007).

Ian Vickridge and Tony Lau noted in their research (lessons learnt from pipeline condition assessment in Hong Kong) that because water mains carry a much lower value product; they normally have an internal lining of cement mortar, epoxy, or bitumen (making direct contact with the wall of the pipe impossible) and they include numerous vertical and horizontal bends. Therefore, the use of intelligent pigs and other such expensive and sophisticated techniques for the condition assessment of water mains is therefore neither technically feasible nor financially viable. It therefore becomes necessary to identify a basket of appropriate techniques that together will provide sufficient information on the condition of pipes to make rational and informed decisions.

(5) Acoustic technology (developed by National Research council of Canada) is used for measuring the remaining general wall thickness for water pipes. This method is non-destructive and does not require taking pipes out of service. The method uses acoustic signals induced in pipes by releasing water from fire hydrants. These signals are measured by acoustic sensors at two points 300 to 600 ft apart along a pipeline. In principle, this new method can be used on all types of pipes including cast and ductile iron, steel, PVC, asbestos cement and PCCP (USEPA, 2007).

C. Condition Assessment Methodologies – Roads

Infraguide has published a best practice, titled: *An Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks* which outlines several methods for investigating and assessing the structural capacity, condition, roughness, and safety of roads based on the Pavement Design and Management Guide (TAC, 1997).

Structural Capacity

The structural capacity of a pavement is typically determined using field tests, such as the Benkelman Beam, the Dynaflect®, and the Falling Weight Deflectometer. These tests measure pavement deflections under a load.

Condition
Visual surveys are commonly used to measure pavement distress. Pavement condition surveys should include the type of distress as well as its extent, severity, and location. Surface defects, permanent deformation and distortion, cracking, and patching are the most common types of distress.

Roughness
Pavement roughness is a primary indicator of serviceability. The Riding Comfort Index (RCI) is commonly used in Canada as a measure of serviceability. The International Roughness Index (IRI) has recently been gaining industry acceptance as well. A panel would drive along a road, and their opinions on the roadway would form the RCI. In recent years, several mechanical tools have been developed to measure pavement roughness.

Safety
Pavement safety can be quantified in terms of skid resistance, ruts, light reflectivity of the pavement surface, and lane demarcation. There are several methods used to measure skid resistance. Visual inspections are commonly used to assess ruts, light reflectivity, and lane demarcation.

While the foregoing has provided a snapshot of potential methodologies to assess various infrastructure assets, a rational decision about whether it is worthwhile to implement, or improve these condition assessment techniques requires that estimates be made regarding the applicability, technical and economic feasibility and value of condition assessment tailored to meet municipalities needs within Saskatchewan.

Glossary

Force main – is a pipeline that conveys wastewater under pressure from the discharge side of a pump or pneumatic ejector to a discharge point. Pumps or compressors located in a lift station provide the energy for wastewater conveyance in force mains.

Manhole – is a covered opening in a road which a worker can enter in order to reach underground pipes, wires or drains which need to be examined or repaired.

Sewer – is a large pipe, usually underground, which is used for carrying waste water and human waste, such as urine and solid waste, away from buildings to a place where they can be safely got rid of.

Water main - Is defined as the main underground pipe in a system of pipes supplying water to an area.

Wastewater Collection System/Sanitary Sewer System – Is a network of pipes and pumping systems used to convey sanitary flow to a wastewater treatment facility for treatment prior to discharge to the environment. A wastewater collection system is designed to convey only sanitary flow, whereas a combined system is designed to convey sanitary and stormwater flows.

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