LARGE DIAMETER SEWER CONDITION ASSESSMENT USING COMBINED SONAR AND CCTV EQUIPMENT

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ABSTRACT

Underwater Sonar equipment combined with enhanced CCTV provides an ideal engineering tool to inspect and assess large diameter sewers with high flow conditions. Using high frequency, rotating Sonar technology the full wetted perimeter of the sewer can be scanned and assessed. Combined with simultaneously retrieved CCTV images a comprehensive structural and hydraulic condition assessment can be prepared. This presentation will focus on the results of the inspection and assessment of over 50 km of large diameter interceptor and trunk sewers in Canada. Examples used to illustrate the technology include a 2900 mm brick-lined interceptor constructed in Toronto in 1910, a 2400 mm, 35 m deep fully surcharged concrete lined tunnel in Ottawa, and a 2100 mm concrete lined tunnel located in a very heavy industrial area in Hamilton, Ontario. An overview of trends and issues flowing from the results of these inspections is provided.

Keywords: trunk sewer, sewer maintenance, Sonar, surcharged sewers

1.0 INTRODUCTION

1.1 Overview and purpose

Large diameter, trunk sanitary sewers are, without question, among the most critical components of municipal infrastructure systems. Increased environmental awareness and a heightened sense of legal responsibility that has been imposed on municipalities reinforce the importance of maintaining the integrity of these critical sewers. The lack of significant preventive maintenance and the advanced age of the sewers are two signals that the time has come to pay more attention to them. Indeed, a 1984 survey of Canadian municipalities regarding the condition of infrastructure indicated, even then, that among other components, sewers "are entering a state where significant rehabilitation needs can be expected". An analysis of the survey concluded that extensive work needs to be undertaken to assess the condition of infrastructure in a precise manner and to identify options available for rehabilitation, and hence for extending the life of components (Adams, 1987).

But trunk sanitary sewers are difficult to inspect and hence assessment of their condition is a difficult proposition. Remote valley locations, deep manholes, and long reaches between manholes, all combine to frustrate access to the sewer. Ever increasing depths of flow make internal access and inspection difficult, if not impossible. The purpose of this paper, therefore, is to describe one method of inspection that is available to carry out a detailed inspection in spite of these constraints. Sonar equipment, specially adapted for use in sewers, can be used to provide an image of the interior, wetted perimeter. The equipment can be used under fully submerged conditions and is therefore ideally suited to the inspection of surcharged and full to partially full sewers. Alternatively, it can be combined with CCTV equipment, in partially full sewers, to provide details both above and below the water level.

1.2 Purpose

The purpose of this paper is to provide a brief summary of Sonar technology, as applied to sewers, along with an outline of the methodology used to undertake inspections. A series of three case studies which outline how the technology was used in different situations is also presented. The paper concludes with a summary to date of general trends observed in the trunk sewers inspected. These findings are related to three selected criteria and are intended to provide only a sense of trends that have so far been identified.

1.3 Scope

Numerous inspection techniques are available for smaller sewers and the assessment of them is well documented in the literature. In this paper, therefore, attention is focused on the inspection and condition assessment of large diameter sanitary sewers. Large diameter sewers are not nearly so well understood and inspection and assessment techniques are far less available. Large diameter sewers are considered here to be those that typically range from 1.5 or 1.8 meters in diameter up to, at least, 3 meters in diameter; depths of from 6 to 60 meters are common. These sewers are constructed using pre-cast concrete pipe in a cut-and-cover type of installation, or more commonly, through a cast-in-place concrete lining in a tunnel type of installation. As will be seen, some older brick lined sewers are also in use.

Service populations for these sewers can range from a few hundred thousand people up to a million people in some larger metropolitan areas. Typically they are located in close proximity to natural watercourses and valley systems. In fact, conventional interceptor systems typically incorporate overflow and diversion facilities to these watercourses. It follows therefore that uninterrupted service is critical. Complete failure, or even partial blockage, could lead to sewer system

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surcharging, widespread basement flooding, extensive public inconvenience, and significant discharges to the environment. The effects of failure could be experienced for several days up to several weeks or months as repairs could likely be difficult and complex. The ultimate consequences of failure could be catastrophic.

2.0 SONAR TECHNOLOGY

2.1 Basic Principles and methodology

Sonar technology involves the emission of an acoustic pulse from a transducer and the subsequent reception of the pulse echo reflected from some surface. The time delay from the instant of transmission to the instant of reception can be used to determine the distance from the transducer to the surface which reflected the pulse. Determination of the acoustic frequency to be used is influenced in part by two competing factors; background 'noise' decreases as frequency increases, however, as frequency increases so too does signal loss. The chosen frequency also effects image sensitivity and power requirements. The inspection work addressed in this paper involved the use of equipment using a frequency of 2 MHZ.

At low frequencies (200 KHz or less) penetration of pulses into the sewers walls could occur, thereby providing a sense of structural condition and wall thickness. However, at these low frequencies, the accuracy over short distances (for example within a 2000 mm diameter sewer) quickly drops off. At the selected frequency of 2 MHZ a suitable accuracy for work in sewers is obtained, however, there is no surface penetration. As a result, the observations made during inspections show the interior shape of the sewer including all surface irregularities and discontinuities but does not provide any information on wall thickness or soundness.

In the case of sewer inspection, the Sonar transducer is mounted in an appropriate housing and towed through the sewer. The acoustic signal, or pulse, is transmitted radially toward the sewer wall using a rotating transducer and by analysing the received echo the distance from the transducer to the wall can be calculated and the shape of the interior wetted perimeter thereby determined. The on-board computer generates images of the interior perimeter in real time and produces a display.

The Sonar equipment is deployed similar to camera inspection equipment. That is, the equipment is placed in a rig configured to the size of the sewer, a tow cable is used to advance the rig and Sonar through the sewer, and a umbilical cable provides communication with the control and monitoring computer at the surface. When used in conjunction with CCTV equipment the Sonar is suspended in the sewage below the rig.

The inspection record sheets contain coded information which identifies all observations made during inspection of a particular reach of sewer. Information recorded includes, among other things, noted defects (such as cracks, encrustation, missing bricks, open joints, etc.), alignment changes, changes in cross-section or pipe material, sediment deposits, and connection sizes and locations. All coding was completed in accordance with the standards developed by the Water Research Center in the United Kingdom. This standard was used since it is well suited to large diameter sewers, is recognized and accepted in the sewer industry throughout North America and Europe and since it has recently been adopted by the Association of Pipeline Inspectors of Ontario (APIO).

As the Sonar equipment passes through a sewer a continuous series of digital images is returned to a computer on board the support vehicle. These images, as well as video images from the CCTV equipment are monitored on site in real time. A continuous video tape record of the Sonar images and the CCTV images is recorded during inspection.

2.2 Benefits and Limitations

The precision of the Sonar results are a function of several factors including the speed of longitudinal movement through the sewer, the quantity of suspended solids in the sewage, and the degree of turbulence. Under ideal operating conditions, in a 2400 mm diameter sewer using extremely slow forward advancement, the Sonar could indicate openings or cracks as small as, say, 5 mm. Under normal operating conditions however, using a more practical speed of advancement (say, 100 mm/second), coverage of the wall is reduced such that very small defects may not be seen. The Sonar image will, however, in normal use identify those defects clearly requiring action.

The primary use for Sonar equipment is to inspect and assess the structural condition of otherwise inaccessible or flooded sections of sewers. In particular, Sonar allows inspection of the portion of the sewer cross-section below the water line. A particularly useful benefit of Sonar is the production of quantifiable cross-sections of the inspected sewer. Precise, quantitative measurements of the surveyed sewer can be made from the images generated by the Sonar.

Several factors influence the quality and clarity of the Sonar images.

1. Incoming flow from connections can cause considerable air entrainment in the main sewer immediately downstream of the connection. The entrained air bubbles tend to partially block the Sonar signal, and as a result interference may be seen in the image. As a result the extent and relative location of the sewage mixing phenomena can clearly be seen at the Sonar progresses along the sewer.
2. Heavy suspended solids and debris in the sewage can also partially block the Sonar signal. "Clouds" of silt can clearly be identified in the lee of discontinuities and can therefore be used to identify sudden changes in the sewer invert.

3.0 CASE STUDIES

3.1 General

Combined Sonar and CCTV equipment has been used in the past two years to inspect over 50,000 m of trunk sanitary sewers and combined sewer interceptors in Canada. Three of these sewers have been selected for presentation here as brief case studies. In each case pertinent details regarding the sewers are provided as well as a description of why the inspections were initiated. A brief overview of key findings is also provided.

3.2 High Level Interceptor, Toronto, Canada

The High Level Interceptor was constructed primarily by tunnel starting in 1908 as part of a comprehensive treatment and collection scheme to help improve surface water quality in the nearby Lake Ontario. Sections inspected included: triple brick ring lining, circular unreinforced concrete tunnel with brick invert lining, and cast-in-place concrete pipe (with brick invert lining) with reinforced concrete foundation (through difficult soil conditions). The reaches inspected ranged in size from 1825 to 2600 mm diameter with an average depth of cover of less than 10 m. Approximately 10,000 m of the High Level Interceptor was inspected. The municipality initiated a systematic inspection and assessment program for all trunk sewers in 1996. The size and high depth of flow in the Interceptor indicated that it should be included within the Sonar inspection part of the program. The nearby Low Level Interceptor Sewer, which was part of the original drainage scheme, was also inspected.

The High Level Interceptor passes directly through the central business district of Toronto. As a result numerous short sections of it have been reconstructed over the past 40 years to accommodate the installation of underground pedestrian passages between buildings and the subway system. These new sections result in rapid cross-sectional transitions. Several large overflow chambers have also been constructed on the Interceptor.

In most cases regular, high flows obscure all of the brick invert lining. Use of Sonar allowed a detailed assessment of the lining. In most cases this lining was found to be in good to very good condition except several isolated areas of damage likely caused by bucket cleaning. Inspection also confirmed that the brick-to-concrete interface at the springline was also in good condition. The condition of the invert at the various transitions were also carefully reviewed with the Sonar and found to be in good condition.

3.3 Western Sanitary Interceptor Sewer, Hamilton, Canada

The interceptor, together with a large, regional sewage treatment plant, was constructed in the late 1950's. The total length is approximately 18 km of which 9 km of selected sections were inspected. The tunnelled sewer ranges in size from 1525 mm (60") to 2590 mm (102") and the depth from 10 m to 30 m with an average in the order of 12 to 15 m deep. The structure is unreinforced cast-in-place concrete poured directly against undisturbed soil. Primary steel-plate liners were only used at railway crossings and possibly in short areas where extremely poor soil conditions may have been encountered.

Hamilton is the center of Canada’s industrial heartland and includes a district which is home to several of the largest steel producing factories in the country. The interceptor passes directly through this district of the City with numerous heavy industries discharging directly into it. Invert corrosion due to high chemical content in the sewage has been an ongoing concern for the municipality. It was this concern that lead to a detailed inspection and assessment of the interceptor (particularly the invert) using Sonar.

Detailed review of the Sonar images showed that significant chemical corrosion had not occurred in the sewer. However, this review did indicate that some structural distortion had occurred subsequent to construction which is likely due to inherent weaknesses in the unreinforced concrete tunnel lining. Observation of isolated longitudinal cracks in the pipe with the CCTV equipment confirmed the Sonar findings. Although the distortion was generally small, it was found that it was likely significant. Future, repeat inspections will be able to confirm whether the distortion is stable or progressive.

3.4 Ottawa River Interceptor and Outfall Sewer, Ottawa, Canada

The Ottawa River Interceptor and Outfall Sewer is approximately 15 km in length and comprises sections of 2100 and 2400 mm diameter concrete lined tunnel. Most of the interceptor was constructed, starting in 1959, in rock and as a result no primary liner system was used and the concrete lining is unreinforced. The furthest downstream reach was constructed in very soft clay and as a result was tunnelled with a primary liner system comprising steel ribs with timber lagging and a reinforced concrete lining. Representative sections of the sewer were selected for inspection based on their relevance and their suitability for inspection. The sewer ranges in depth from 12 to 55 m. Shaft spacing varies from 450 to 2400 m with shaft depths up to 30 m.

The main pumping station, located at the sewage treatment plant, is operated with a relatively large wet well storage height to maintain high head on the pumps in order to reduce potential pump cavitation (and thereby increase the station capacity). This imposed head results in significant continuous surcharging in the interceptor both in terms of depth and length. Concerns that the abnormal surcharging under otherwise low dry weather flow conditions might lead to excessive sediment buildup in the relatively flat interceptor lead the Region to undertake the Sonar inspection.

For this work, since the sewer is under constant surcharge, only Sonar was used. That is, standard CCTV equipment was not used in tandem. By briefly reducing the storage depth at the wet well, short periods of non-surcharged flow could be created to allow insertion of the rig into the sewer at a shaft. Once inserted, flow was allowed to return to normal, and the inspection was carried out under full surcharge.

The Sonar images clearly showed, in the sections inspected, that not only was there not significant buildup but in fact the invert was particularly well scoured. A small groove, up to 25 mm deep, which was likely caused by scour in the invert, was observed in most areas. Assessment of the Sonar images showed that sewer cross section was slightly larger in diameter than designed. This apparent 'as-constructed' condition results in a 7 to 9% increase of pipe cross section as compared with the theoretical design cross section.

4.0 SYNOPSIS OF FINDINGS

4.1 Overview

The findings resulting from the inspection of numerous trunk sewers, including the three case studies reviewed here, indicates several general trends. These are briefly considered following. By necessity, these trends are very broad in nature since only limited data is available to date and since the characteristics of each sewer inspected are also very broad.

Three key characteristics were selected as being the best indicators of interceptor performance. The characteristics considered are (1) existing sewer size as compared to theoretical size, (2) sediment build-up, and (3) hydraulic roughness. These characteristics were chosen in part because they are readily assessed through the normal observations using Sonar and camera equipment and are somewhat representative of system operation.

4.2 Sewer Size

Sonar provides a convenient and precise way to measure the cross-sectional area of a sewer. It is valuable to review actual as-constructed size as compared to the theoretical design size in order to better determine estimated hydraulic capacity. It is thought the size differences identified in the sample of inspected sewers may help to highlight important trends for use of system modellers elsewhere.

In general it has been found that trunk sewers have been constructed with cross sectional areas greater than design. Typically, sewers were found to be from 1% to 10% larger than planned.

4.3 Sediment Build-up

In general, in all reaches of each sewer inspected, little to no sediment build-up was observed. This is particularly interesting for sewers with very flat slopes and for sewers operating under forced full flow conditions. In cases were sediment build-up was observed it was relatively short in extent and, for the most part, not significant in depth.

Scour or wear of gullies in the invert of each the concrete sewers inspected has been observed. These gullies are believed to be caused by the action of solid transport in the invert. They have been noted regularly in cast-in-place concrete sections but rarely in pre-cast concrete pipe sections. It had been expected that sewers operating under full flow conditions because of backwater effects (that is, not because of high flow rates) would have exhibited significant sediment deposits. This was particularly worrisome for the Ottawa River Interceptor and Outfall Sewer. In fact, important deposits were never found. This suggests that even the reduced velocities in the full flowing sections didn't induce sedimentation, that normal velocities are sufficient to continually scour, or periodic high flow conditions (that is during high wet weather flows) are sufficient to scour the sewer clean.

In general, where unexpected significant sediment deposits were found, they indicated the presence of structural defects or irregularities, or poor hydraulic conditions. To date two sewers have been inspected where very large sediment deposits occur on a regular basis. Indeed, both of these sewers were inspected specifically because of the extensive regular cleaning programs that were in place. In both cases, the extent and location of the deposits mapped by the Sonar coincided exactly with readily identified hydraulic deficiencies.

4.4 Hydraulic Roughness

Roughness is a fundamental performance characteristic of a sewer. Therefore it is one of the key characteristics to be investigated in assessing operation. The following factors affecting roughness were considered: surface structure, sliming and grease deposits, and encrustation. Based only on the visual and Sonar investigations done here it is difficult to determine an absolute measure of roughness. Rather a relative measure of roughness at time of inspection as compared to the original design value, or theoretical value, at time of construction is considered.

Surface Features: With the exception of mineral deposits and encrustation, sewer walls were found to be generally clean and free of any surface deposits. For concrete sewers it was found that the surface appeared to retain its original texture with only slight slime or mould buildup. As such it appears that the texture of the concrete itself does not materially effect the roughness of these sewers over time.

Slime and Grease: In most cases where slime and mould deposits were observed they were found to be relatively minor in thickness but widespread in extent. It is difficult to determine the precise nature of deposits on the walls of the sewers based on the CCTV observations. However, it is believed that deposits, where they exist, would tend to slightly reduce roughness. The overall effect though is likely minimal. In most cases grease build-up on the walls of the sewer were not present. Regular evidence of grease balls and deposits were observed in many shafts.

In a trunk sanitary sewer there are constant fluctuations in water level and velocity. Normally, on a somewhat regular basis, the sewer can become completely full and surcharged. This constant change coupled with regular periods of increased velocity presumably helps to minimize deposits on the walls and grease buildup.

Encrustation: Construction joints and other circumferential cracks are relatively common and exist with various frequencies throughout the sewers inspected. Where the groundwater surface is above the sewer, which is usually the case, these joints and cracks become a significant source for groundwater infiltration. Mineral buildup and encrustation at these points is, as a result, also common.

Encrustation can take various forms ranging from relatively thin coatings over an extensive area of the sewer wall to narrow but protruding ridges. In areas of heavy encrustation a particular ridge could protrude on average as much as 15 to 30 mm into the sewer. Such a ridge would typically cover 50% to 100% of the perimeter of the sewer above the normal water line meaning as much as 50% of the wetted perimeter under full flow could be effected. Particular ridges could protrude as much as 100 mm into the sewer at specific points on the perimeter. This extreme protrusion would normally correspond to a discrete point of relatively heavy infiltration.

5.0 DISCUSSION

A wide range of operational needs can be identified in the field of sewer system operation and maintenance. One such need is research into the operation of large diameter interceptor and trunk sanitary sewer facilities. Although theses systems are often the most critical, they have received, until now, very little attention in terms of operational review and assessment. Another need is for a comprehensive understanding of sewer life expectancy and rehabilitation opportunities. The availability of tools and techniques to assist in the assessment of systems is yet another area requiring investigation.

Interceptors and other large trunk sanitary sewers often lack the benefits of regular maintenance and inspection. The successful completion of programs in Ottawa, Toronto, and Hamilton using Sonar technology augers well for the future of large diameter sewer management. These programs have confirmed that the use of Sonar technology is feasible and produces good results. It also confirms that the inspection of large sewers, even when surcharged, is possible and can yield practical results.

Having developed a better understanding of how large diameter sewers operate, engineers will be better able to assess capabilities and model behaviour. Today, trunk and interceptor sewers are often modelled with little knowledge of actual physical characteristics of each section of pipe. As a result, offsetting, or compensating, influences on hydraulic capacity may actually be blended into a single estimated parameter which appears to best represent the system response but may actually over look real conditions.

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