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# TRUNK SEWERS IN CANADA

by

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**Abstract** Résumé


As with other buried infrastructures, more portions of the trunk sewers in Canadian municipalities' approach or exceed their design service life each year. Large size trunk sewers are usually installed below all other buried utilities under city streets. Collapse of a trunk sewer will not only cause severe interruptions to service and traffic, but also pose repair challenges to the engineers. Based the discussions and presentations at a forum sponsored by the National Research Council of Canada and attended by representatives from 12 municipalities across Canada, this paper summarizes the conditions of the aging trunk sewers, and the current state-of-practice in trunk sewer maintenance, inspection and rehabilitation techniques. Other relevant information, such as pipe sizes, types and materials, maintenance costs and distress statistics, is also presented.

Keywords: trunk sewer, state-of-practice, maintenance, condition assessment, inspection, rehabilitation

## 1. Introduction

Trunk sewers are typically used to intercept regular sewers, and receive and transport sewage to a few central places, such as a treatment plant or a discharge point on a riverbank. These sewers vary in size, and are installed along or deep than other buried utilities under city streets.

Trunk sewers have been installed in Canadian cities as early as 1800s, and have been expanding with the growth of urban communities ever since. A recent forum on trunk sewers, organized by the National Research Council of Canada (NRCC) and attended by representatives from 12 municipalities across the country, has revealed that trunk sewers have received minimum attention in many cities. Furthermore, the lack of standards and guidelines in trunk sewer inspection, condition assessment and rehabilitation has resulted in inconsistent terminology, rating systems, level of record keeping and assessments from city to city, and from year to year.

To maintain serviceability and prevent collapse, trunk sewers require regular inspection, condition assessment and rehabilitation. Collapse of a trunk sewer may, in addition to service interruptions, cause damage to buried structures above and around it and to the adjacent surface

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structures. Although buried trunk sewer pipes are generally well designed for their expected site conditions, their life can be significantly shortened due to accelerated deterioration processes. Deterioration in sewer pipe begins immediately after commissioning due to the harsh internal environment of carried sewage and, sometimes, the aggressive external soil environment. Continued condition assessment and rehabilitation are the key to maintain an acceptable level of service, and to avoid costly emergency repair; all this resulting in savings for municipalities and ultimately the taxpayers.

It should be noted that the term "trunk sewer" is not well defined in the literature. Some references classify sewers as either person-entry or non-person entry sewers (WRc, 1994). NASSCO (1995) defines sewers with diameters of 686 mm (27 in.) or more as large diameter sewers. "Trunk sewers", as used in this paper, follow more or less the administrative definition used by municipalities, and include pipes with varying minimum diameters. Municipalities usually divide budgets between regular sewers and trunk sewers based on their own definition of each. In order to use the data provided by the municipalities in this paper, the term "trunk sewer" is loosely used and diameter ranges are given when available to help interpret the data presented.

This paper summarizes the presentations made at the NRCC trunk sewer forum, the discussions at the forum and the follow-up data pertaining to general status of trunk sewers. In addition, this paper identifies trunk sewer problems experienced by the forum participants, inspection techniques and tools used, and a number of R&D issues. It is hoped that this document will provide useful information on trunk sewers for municipal engineers and managers. This paper, however, does not deal with storm sewers installed and maintained by provincial departments of transportation.

## 2. Existing Trunk Sewer Systems

### 2.1 Characteristics, length and asset values

Trunk sewers may vary in type, length and age but can generally be classified into four functional groups:

- sanitary sewer;
- storm sewer;
- combined sanitary and storm sewer; and
- partially combined sanitary and storm sewer.

The majority of trunk sewers are gravity type. In some cases forced mains are used in portions of the interception systems. Typical characteristics of trunk sewers are:

- deep burial;
- large diameter/size; and
- no redundancy (cannot be shut down).

These characteristics typically pose difficulties in maintenance, condition assessment and rehabilitation practices of trunk sewers.

Table 1 identifies the estimated total trunk sewer lengths, estimated asset values and population served in a number of major municipalities in Canada (*N.B.,* the asset values are expressed in Canadian dollars).

**Table 1: Estimated trunk sewer lengths, asset values and population served**

| Municipality | Population served | Length (km) | Diameter/size range (mm) | Asset value ($) |
|---|---|---|---|---|
| Calgary | 767,100 | 5,847 | 200 - 3,000 | 2,000,000,000 |
| Victoria Capital Regional District (CRD) | 300,000 | 47 | 200 - 1,500 | N/A |
| Edmonton | 630,000 | 1,148 | 600 - 5,250 | 4,165,000,000 |
| Greater Vancouver Regional District (GVRD) | 1,656,000 | 440 | 150 - 3,100 | 422,000,000 |
| Regional Municipality of Hamilton-Wentworth (RMHW) | 353,300 | 1,988 | 150 - 2,600 | N/A |
| Metro Toronto† | 2,200,000 | 358 | 150 - 4,100<br>forced 75 - 150 | 2,800,000,000 |
| Quebéc City | 170,000 | 680 | N/A | N/A |
| Regional Municipality of Ottawa-Carleton (RMOC) | 745,000 | 213 | 610 - >1,680 | 1,000,000,000 |
| Regina | 180,000 | 88 | 900 - 2,600 | 95,000,000 |
| Saskatoon | 203,000 | 152 | 375 - 3,050 | N/A |
| Victoria | 77,000 | 114 | 250 - >1,500 | N/A |

† The data were obtained prior to the amalgamation of Metro Toronto and the City of Toronto.

**Table 2: Trunk sewer lengths and asset values per person**

| Municipality | Population served | Length per person (m/person) | Asset value ($/m) | Asset value ($/person) |
|---|---|---|---|---|
| Calgary | 767,100 | 7.62 | 342 | 2,607 |
| CRD | 300,000 | 0.16 | - | - |
| Edmonton | 630,000 | 1.82 | 3,628 | 6,611 |
| GVRD | 1,656,000 | 0.27 | 959 | 255 |
| RMHW | 353,300 | 5.63 | - | - |
| Metro Toronto | 2,200,000 | 0.16 | 7,821 | 1,273 |
| Quebéc City | 170,000 | 4.00 | - | - |
| RMOC | 745,000 | 0.28 | 4,695 | 1,340 |
| Regina | 180,000 | 0.49 | 1,080 | 528 |
| Saskatoon | 203,000 | 0.75 | - | - |
| Victoria | 77,000 | 1.47 | - | - |
| | Average = | 2.06 | 3,088† | 2,102† |

† Based only on available data.

The trunk sewers identified in Table 2 varied from 0.16 to 4.40 metre per person from one municipality to another. The average length was approximately 2.06 m/person, compared to 5.7 m/person for the entire sewer collection system in Canada (McDonald et al. 1994). The asset values varied from $255 to $6,611 per person with an average of $2,102/person (or $3,088/m). It should be noted that the methods used to calculate trunk sewer assets might vary from one municipality to the next.

## 2.2 Material types

Table 3 lists the material types of the trunk sewers that were in the ground as of 1994. The majority (57.7%) of the existing trunk sewers were concrete pipe. Vitrified clay tile (VCT) pipe made up 35.7%, followed by PVC pipe (3.4%) and corrugated steel (CS) or iron pipe (1.3%). The percentage of tunnel in the sample group was 0.3% and that of brick sewers was less than 0.7%. Included in the "Others" category were asbestos cement, fiberglass and plastic materials. The material type distribution in Table 3 provides an indication of existing pipe materials and the potential defects to be expected in the years to come.

**Table 3 - Material types in existing trunk sewers (km)**

| Municipality | Conc. | Brick | VCT | Tunnel | PVC | CS/Iron | Others |
|---|---|---|---|---|---|---|---|
| Calgary | 617.0 | - | 31.0 | - | 62.0 | - | - |
| CRD | 13.4 | 0.7 | - | 1.4 | 21.8 | 0.5 | 9.8 |
| GVRD | 355.7 | - | - | 8.1 | 19.6 | 45.0 | 12.0 |
| RMHW | 675.0 | 26.0 | 1,239.0 | - | 32.0 | - | 16.0 |
| Quebéc City | 518.2 | - | 161.4 | - | - | - | - |
| Regina | 79.7 | 0.1 | 6.9 | - | - | 1.2 | - |
| Saskatoon | 65.2 | - | - | 3.7 | | 3.1 | - |
| Total | 2,324.2 | 26.8 | 1,438.3 | 13.2 | 135.4 | 50.8 | 36.5 |
| % | 57.7 | 0.7 | 35.7 | 0.3 | 3.4 | 1.3 | 0.9 |

## 2.3 Pipe age

Pipe age is given in Table 4, based on data provided by each municipality. The majority of the existing trunk sewers are between 20 and 50 years old. Some brick sewers in the City of Toronto were as old as 197 years. It also appears that very few trunk sewers were built between 1930 and 1949.

In general, about 6% of the existing trunk sewers were 70 years or older, and 10% were approaching or surpassed 50 years of service life. Trunk sewers are commonly designed for a service life of 50 years minimum; however, some municipalities use an average life span of 90 years with a variance of ±15 years (Calgary 1994) as their service life. A recent survey study (Malik et al. 1997) indicates that once a sewer pipe has passed 65 years of service, it requires increased maintenance and repair. This study found that for sewers with an average age of 65 years or more that almost two-thirds of repairs could be directly attributed to structural problems, and that another one-quarter was due to inflow and infiltration (I/I).

Each year more portions of the aging trunk sewers reach or past their design service life. By the year 2010 approximately 80% of the existing trunk sewers in Canada will reach or past the 50 year mark. To better manage and maintain the buried trunk sewers, municipal engineers should start planning for condition assessment and staged rehabilitation to avoid costly emergencies of trunk sewer failure.

**Table 4: Pipe age group in percentage (%)**

| Municipality | <1930 | 1930's | 1940's | 1950's | 1960's | 1970's | 1980's | 1990's |
|---|---|---|---|---|---|---|---|---|
| Calgary | 6.0 | 0.4 | 2.5 | 13.2 | 17.5 | 31.4 | 15.3 | 13.8 |
| CRD | 0.7 | | | | | 20.9 | | 26.0 |
| Edmonton | 5.5 | 0.2 | 0.1 | 17.2 | 19.0 | 41.6 | 15.4 | 0.9 |
| GVRD | 3.1 | 1.0 | 4.9 | 9.0 | 23.0 | 46.4 | 6.3 | 6.3 |
| RMHW | 17.0 | 2.0 | 4.0 | 26.0 | 10.0 | 14.0 | 20.0 | 7.0 |
| Metro Toronto | | -------------10.0------------- | | -------80.5--------- | | -----9.0------ | | -----0.5---- |
| Quebéc City | | | --------------------33.0------------------ | | | -----------------67.0--------------- | | |
| RMOC | | --------------5.0-------------- | | 6.0 | 31.0 | 35.0 | 11.0 | 12.0 |
| Regina | 7.0 | 0 | 0 | 35.9 | 19.3 | 17.7 | 19.3 | 0 |
| Saskatoon | 21.4 | 0.7 | 1.64 | 21.0 | 43.5 | 40.2 | 20.0 | 3.60 |
| Toronto | | | | (average 78 yrs, 8% over 100 years) | | | | |
| Victoria | | | ---------------------------------71.8--------------------------- | | | | 19.6 | 8.5 |

## 2.4 Defects, Distresses and Failure

The portions of the existing trunk sewers that have been inspected to date, appear to be in good condition for the most part, keeping in mind that only a small portion of the entire trunk sewers has been inspected. Older sewers have more reported problems, such as incidents of failure or blockage. Some cities had more reported problems than others. For example, the City of Calgary had up to 500 incidents of choked mains per year for all types of pipe and varying ages. Quebec City had poor ratings for 1.5%, 8% and 1% of its pipes with ages over 30 year, under 30 years and under 20 years, respectively. The City of Regina had two collapses in its 75-year-old clay and concrete trunk sewers, while Metro Toronto had one incident of pipe settlement for its 60-year-old concrete pipes. During a 1983 inspection, the City of Toronto discovered that its brick sewers had 200 m of collapse, 1,000 m of fracture, 1,000 m of dropped invert, 1,800 m of deformed section, 6,600 m of missing mortar and 19,000 m of brick missing. All this on a total length of 135,000 m.

Reported types of defects, distresses and failures in trunk sewers are summarized in Table 5:

**Table 5: Defects and distresses related to service and structural conditions**

| Service conditions | Structural conditions |
|---|---|
| • blockage | • collapses |
| • Infiltration/Inflow | • fractures/cracks |
| • Odor | • deformed sections |
| • Debris | • pipe settlement |
| • root intrusion | • $H_2S$ corrosion |
| • grease build-up | • sulfate attack externally |
| • sedimentation | • surcharge |
| • transient flow conditions | • joints (worn out, separation, etc.) |
| | • mortar missing |
| | • bricks missing |
| | • rock bolt rust in tunnel sewers |

## 2.5 Inspection

The most frequently used method identified in the survey was closed-circuit television (CCTV) inspection, followed by person-entry inspection. The cost for CCTV inspection varied from \$1.75/m to \$14.00/m, whereas that for person-entry inspection ranged from \$1.33/m to \$20.00/m (Table 6). Other inspection methods included Sonar, combined CCTV/Sonar and zoom camera. Inspection by divers was also carried out in high flow conditions or forced trunk sewers. It should be mentioned that Sonar works only below water, while CCTV is effective on the above-water portion of the sewer.

Annual budgets for trunk sewer inspection varied from \$0.50/m to \$3.20/m. A number of cities did not have any funds allocated for the inspection of their trunk sewers.

Time to complete an inspection cycle was reported to vary from 5 to 7 years, and inspection frequency (time between inspections) to range from 2 to 15 years. Currently, there are no guidelines available to determine the best time for inspection and the appropriate inspection frequency.

**Table 6: Inspection methods used**

| Methods used | Approximate unit cost |
|---|---|
| CCTV | \$1.75 – 14.00 per metre |
| Sonar | \$6.00 – 10.00 per metre |
| person-entry | \$1.33 – 20.00 per metre |
| combined CCTV/Sonar | \$6.6 per metre |
| zoom camera | \$44.25 per MH |
| divers | - |

To facilitate effective inspection, the following tasks need to be completed:

- conduct manhole (or maintenance hole, referred herein as MH) survey to inventory their locations and distances between two consecutive MH's;
- determine sewer hydraulic characteristics; and
- establish condition assessment methods including rating systems for both structural and service conditions.

High flow conditions and limited access (e.g. long distances between two consecutive MH's, some are 1 to 2 km apart) both create difficulties in carrying out trunk sewer inspection. Person entry into deep and flowing trunk sewers is always a safety concern. "In-sewer" communication is difficult since currently available electronic communication tools do not function in buried pipes and tunnels.

The condition rating system based on CCTV inspection developed by WRc (1993) has been adopted by a number of organizations such as the Association of Pipe Inspectors of Ontario and the Centre d'expertise et de recherche en infrastructures urbaines (CERIU) in Montreal. Some Canadian cities have developed their own rating, reporting and condition assessment methods (Edmonton 1996a; 1996b).

Of all the participating municipalities, six used a database or a geographic information system (GIS) while the rest had plans to use a database in the near future. The software used included ORACLE and MCSII. The City of Calgary also looked into the joint development of a common GIS system for common and administration activities.

**Table 7: Maintenance budgets**

| Municipality | Annual maintenance budget† | | |
|---|---|---|---|
| | total ($) | ($/m) | ($/person) |
| Calgary | 7,431,000 | 1.20 | 9.60 |
| CRD | 0 | 0 | 0 |
| GVRD | 601,000 | 1.40 | 0.36 |
| RMHW | 3,594,000 | 1.81 | 10.20 |
| Metro Toronto | 1,065,000 | 2.97 | 0.50 |
| Quebéc City | 0 | 0 | 0 |
| RMOC | 1,600,000 | 7.50 | 2.10 |
| Regina | 0 | 0 | 0 |
| Saskatoon | 1,123,630 | 7.40 | 5.50 |
| Toronto | 0 | 0 | 0 |
| | average‡ = | 3.70 | 4.70 |

† Some cities did not separate their budgets for regular and trunk sewers. In such cases, the budget for trunk sewers was estimated by the proportion of trunk sewers in length.

‡ Zero budgets were not included.

### 2.6 Maintenance and Rehabilitation

Maintenance budgets are given in Table 7 for general information. The maintenance budgets varied from $1.40/m to $7.5/m (or from $0.36/person to $10.20/person served) per year. A number of cities had no allocated budgets for the maintenance of their trunk sewers. This lack of attention may be due to a number of factors, such as:

- There have been fewer incidences of reported trunk sewer problems;
- Large portion of trunk sewers have not been inspected; and their condition remain unknown;
- In some Canadian cities, most trunk sewers are under the jurisdiction of a regional government; whereas cities look after regular sewers only.

Open excavation replacement of failed pipe sections was the most frequently used repair method. Other methods included trenchless repairs such as cured-in place pipe (CIPP) lining, stainless steel sheet lining, plastic pipe sliplining, chemical or cement grouting, shotcreting and spot repairs. Haas et al. (1995) report that, based on a comparative study of four spot repair methods – open cut, keyhole excavation, resin injection and robotic equipment suite in the City of Austin, the conventional open-cut repair was the least economical solution. Collins and Stude (1995) compared three rehabilitation alternatives: shotcrete, CIPP and sliplining for the rehabilitation of masonry sewers in the City of St. Louis. They concluded that reinforced shotcrete was the least expensive option. Typical costs were US$130/m$^2$, US$280/m$^2$ and US$380/m$^2$ for shotcrete, sliplining and CIPP, respectively.

**Table 8: Rehabilitation budgets**

| **Municipality** | **Annual rehabilitation budget** | | |
|---|---|---|---|
| | **total ($)** | **($/m)** | **($/person)** |
| Calgary | 4,300,000 | 0.74 | 5.60 |
| CRD | 0 | 0 | 0 |
| Edmonton | 1,300,000 | 1.13 | 2.06 |
| GVRD | 623,000 | 1.40 | 0.40 |
| RMHW | 3,6000,000 | 1.81 | 10.00 |
| Metro Toronto | 1,000,000 | 2.80 | 0.45 |
| Quebéc City | 0 | 0 | 0 |
| RMOC | 1,700,000 | 7.98 | 2.28 |
| Regina | 125,000 | 1.42 | 0.70 |
| Saskatoon | 710,530 | 4.67 | 3.50 |
| Toronto | 0 | 0 | 0 |
| | average† = | 2.70 | 3.10 |

† Zero budgets were not included.

Table 8 shows the budgets for rehabilitation by various municipalities. A number of municipalities did not have a specific budget figure for trunk sewer rehabilitation. Where budgeting numbers were provided, the municipalities spent an average of $2.70 per metre, or $3.10 per person on trunk sewer rehabilitation.

## 3. Approach in Condition Assessment and Rehabilitation

There is a general consensus among municipal engineers and managers that there is much to be learned about the maintenance, inspection, condition assessment and rehabilitation of deep, large size trunk sewers. Some questions, for example, include “when is the appropriate time to inspect?” “are we doing too little or too much?”, “should we worry more than we do now?”, “ what are the failure mechanisms in trunk sewers?”

To help answer these and other questions, a generic procedure is provided below. Similar approaches have been utilized in Canada and the United States (Apostolidis 1993; Edmonton 1996a, 1996b; Shahbahrami et al. 1997; Waldron and Ratchinsky 1997; Smith 1996).

<u>Step 1 - Inventory</u>

The first step in managing a system is to establish and maintain an up-to-date inventory of the trunk sewer networks. It is imperative to know what is your inventory. Use of databases can facilitate easy management of data. The overwhelming amount of information needed includes the original design and construction information, as-built records, site conditions, adjacent utilities, land use and surface structures. Information on reported defects, failures, maintenance records, inspection records, condition ratings, if any, and rehabilitation records, if implemented, should also be included in the database. Creating a database is not a trivial task, and may take a couple of years and revisions. Commercial database and management packages are available. It is strongly advised that municipalities that have not started using a database system should get start as soon as possible, in order to better handle the condition assessment and rehabilitation of their sewer systems before they start to have problems. Updating the database is seen as important as creating one.

<u>Step 2 – Categorizing and prioritizing</u>

Once the database is established, categorization can be made with respect to age, material type, soil condition, and past failure records in order to identify the "hot spot" areas. Rating systems have been used to factor in various service, system and installation factors such as diameter, burial depth, pipe location, land use and service importance (Edmonton 1996b). The outcome of this sorting and categorizing is the prioritization of the existing trunk sewers for condition assessment.

<u>Step 3 – Inspection</u>

Ideally, the first condition assessment should be completed soon after the pipe is installed or when warranty expires, to establish benchmarking baseline data. Afterwards inspection should be carried out at a schedule most appropriate for particular pipeline segments, i.e., some segments may require more frequent inspections than others due to their advanced state of deterioration. A priority list may be established to help schedule inspection work. More frequent inspection is expected as the pipe gets older. While some cities currently use a 15-year inspection cycle or frequency (Edmonton 1996b), optimal inspection schedule that is aimed at determining the most appropriate and cost-effective inspection schedule for pipeline, remains a research subject (Hong 1998).

<u>Step 4 – Condition assessment</u>

While the ability to know exactly how long a trunk sewer will last remains a challenge, efforts should be made to forecast the residual service life of the existing trunk sewers. Such a forecast usually cannot be achieved without the assessment of the pipe conditions, its environment and its expected functionality. Condition assessment is a process to evaluate service and structural conditions of an existing structure based on the original design and material data, the inspection and environmental data, and the cause and rate of deterioration. This process establishes a list of pipe segments (or lengths) that have specific defects at a given point in time, and the need for repair and the types of repair in priority orders.

<u>Step 5 – Determining rehabilitation needs and methods</u>

Available rehabilitation techniques are usually defect-dependent, and the selection of the most suitable method requires the consideration of types and severity of the defects, location, depth of burial, degree of urgency, budgetary constraints, functional requirement and required service life of the refurbished pipe. Some repairs are structural and others non-structural. Structural repairs restore the structural integrity of a defected sewer segment to a degree that is comparable to or better than that of the adjacent non-defect segments. Depending on the methods used, the repaired segment can return to its original life curve or last much longer than the rest of the pipeline. Non-structural repairs enhance the sewer's efficiency (for example, reducing I/I, reducing root intrusion etc.), but do not improve the factor of safety of the sewer against structural failure. Guidelines and methods are available for selecting rehabilitation methods (Stein 1994; McKim 1997; Apostolidis 1993; WRc 1981, 1994; Iseley et al. 1994).

## 4. Knowledge Gaps and Needs

It has been realized that there is a lack of methodologies for forecasting the residual service life of a sewer, for determining the optimal inspection schedule, and for selecting the most appropriate rehabilitation techniques. Universal defect recording for sewers of all material types needs to be developed. The capability to assess the conditions of a sewer pipe and its surrounding soils is still a challenge. Some of these knowledge gaps and needs are detailed below:

<u>Collective approach</u>

So far, each municipality has been carrying out its own trunk sewer inspections, assessments and rehabilitation in its own ways. Some are more advanced than others, but each has unique and valuable experience that could be shared with others. To better deal with the necessity asset of trunk sewers in our municipalities, a collective approach is needed for sharing information, experience and knowledge. The forum participants expressed a strong interest in the proposed collective approach and networking to enhance communications among municipal sewer managers engineers and researchers.

As a follow-up, IRC/NRCC has set up a trunk sewer discussion page on the web (www.nrc.ca/irc/trunk) to enhance communication among municipal sewer managers, engineers and researchers. An email group for trunk sewers has also been established. If you are interested in joining the group, send a message to the following address (jack.zhao@nrc.ca).

<u>Development of guidelines</u>

The lack of standards and guidelines in trunk sewer inspection, condition assessment and rehabilitation was well recognized at the forum. This has resulted in different terminology, different rating systems, different level of record keeping and inconsistent assessments from one city to another, even from year to year within the same city. The guideline should include methodologies for data analysis, report of actual conditions, remaining service life forecasting and determination of maintenance and rehabilitation needs. Sewer manuals developed in the UK (WRc 1981, 1994) and other countries (ASCE 1994) may be adopted where appropriate.

NRCC is currently seeking interest from municipalities in Canada for participation in the development of trunk sewer guidelines.

<u>New techniques for condition assessment</u>

There is a need for the development of robotic techniques/tools for inspection and condition assessment (or diagnostics) for deep burial, large diameter, flow-year-round trunk sewers. New techniques should be economical and non-destructive, and produce results quickly. Inspection equipment that can examine the pipe wall, and the surrounding ground, is yet to be developed. Marine technology may be considered for sewer applications. Remote controlled robotic systems would minimize the need of sending people down.

Method for service life forecasting

There is a lack of methods for forecasting the service life of trunk sewers, partially due to the lack of condition assessment data. Enhanced awareness of trunk sewer conditions, and the collective approach will help obtain pipe deterioration data with the help of database. Such data could be used to determine the rates of deterioration of trunk sewer systems and to develop a method that will enable the engineer to forecast the remaining service life and determine rehabilitation priorities. A predictive model, using a database of CCTV inspection data and pipe data, has been developed and used by Fick et al. (1993) for the City of San Jose. Basic data, such as an inventory detailing location, dimensions, year installed, material, and current information describing system conditions must be available.

Independent review of new technologies and products

Municipal engineers involved in underground pipeline design are faced with having to choose the most suitable technology or product among various options, for a particular project. This has become increasingly challenging, not only because of the many options available on the market and new products/techniques being introduced, but also because of the claims and counter-claims of product suppliers. Municipal engineers and managers would like to see independent evaluations of new technologies and products by credible organizations.

As a follow-up, IRC/NRCC has set up an evaluation centre called the Canadian Infrastructure Technology Evaluation Centre (CITEC). For more details, contact Harry Baker at the following location (harry.baker@nrc.ca).

I/I detection and remediation

Sewer inflow/infiltration (I/I) can cost tens of thousands of dollars as a result of the increased volumes of wastewater to be treated. New techniques are required to detect I/I sources and to remediate the problem in both regular sewers and trunk sewers. A US$120 million I/I reduction program by Metropolitan Dade County is reported by Sheller et al. (1994).

Prevention of tree root intrusion

Root intrusion into sewers is one of the perpetual problems for sewer lines in general. Better techniques for tight joint seal are required to alleviate the problem. Stal (1997) reported his study of the root intrusion problem in Sweden, based on a survey of 232 Swedish municipalities carried out between 1993 and 1995. The results show that 99% of the Swedish public sewer systems are affected by root damage, with an estimated annual cost of $18 million (£4.5 million).

Sediment detection

Some Canadian municipalities have experienced sedimentation problems in part of their systems. Sedimentation is believed to cause odor and $H_2S$ problems in trunk sewer systems as well as reducing their hydraulic capacity. Existing sediment detection is carried out manually or by Sonar technology. Innovate and automatic techniques to detect and clean the build-up of sediment are required.

$H_2S$ and odor control

One of the most common problems in sewer pipes is hydrogen sulfide ($H_2S$), which causes odor problems, accelerates corrosion of concrete and metal pipe and is extremely toxic and combustible. $H_2S$ gas is released from the sewage to the air space, and is deposited on the moist pipe or structure wall above the flow line, causing sulfide corrosion. There has been a great deal of research on $H_2S$ generation, corrosion, and protection (Kienow and Allen 1993; Parker 1951).

Understanding failure mechanisms

The forum participants expressed the need to understand failure mechanisms in trunk sewers, pipe deterioration due to chemicals in sewage (decay parameters, process of decay, sludge effect, $H_2S$ attack, etc.), and water chemistry in sewers. This need has been recognized by other researchers and engineers. For example, Kienow and Allen (1993) note that failure to understand the mechanisms involved in the corrosion process has led to the unnecessary rehabilitation or replacement of large diameter concrete pipe. Najafi (1997) gives an overview of causes of pipeline deterioration.

Decision-making methodology

When to inspect, at what frequency, when to repair and what is the remaining service life? These are the common questions asked by municipal engineers and managers. Answers to these simple questions can be based on experience (or gut-feeling, rule-of-thumb), but reliability-based answers are yet to be developed. There is a need to develop a decision-making methodology based on life-cycle cost and performance factors. Such a reliability-based methodology would enable the manager/engineer to determine the best time for the next inspection, and the most appropriate schedule for repair implementation. Similar methodologies have been developed for water distribution systems by NRCC researcher Kleiner (1996).

Repair technologies

The need for better repair technologies is acknowledged. Since trunk sewers cannot be shut down even in the event of failure, robotic repair systems are the preferred choice. The traditional replacement method in open excavations should be compared with various available trenchless technologies in terms of cost and performance. The methods for diverting flows in trunk sewers also require attention.

Management guidelines

Management issues included, but not limited to:

- funding/financing
- due diligence (personnel safety, system security)
- system monitoring and recording
- crew training
- level of service
- maintenance (flushing)

There is a need to prepare management guidelines for trunk sewer managers and engineers. A committee composed of representatives from various municipalities can develop such guidelines. A similar document, called Design and Service Level Standards for Sewer Collection Infrastructure, was prepared by The Technical Committee on Urban Infrastructure (1991).

## 5. Summary

Trunk sewers are the vital links for conveying sewage from the sanitary and storm sewer collection systems to the centralized treatment/discharge locations. These large size, deep burial trunk sewers cannot be shut down even in the event of failure. Municipal sewer engineers and managers need to act in a timely manner to inventory their systems, and to carry out condition assessment and rehabilitation, if required, in order to maintain an acceptable level of service and prevent costly collapse.

Trunk sewers in Canada averaged to approximately 2.06 m per capita. The majority (57.7%) of the existing trunk sewers were constructed of concrete pipe. About 6% of the pipe was 70 years or older, and 10% approaching or having pasted the 50 year mark.

The most frequently used inspection method was CCTV. Other inspection methods included person-entry, Sonar, combined CCTV/Sonar, zoom camera and by divers. The cost for CCTV inspection varied from \$1.75/m to \$14.00/m, which was comparable to that for person-entry inspection. Inspection cycles varied from 2 to 15 years.

Some Canadian municipalities paid more attention to their trunk sewers than others, this being reflected by the allocated budgets for trunk sewer maintenance, inspection and rehabilitation. Based on the nonzero budget figures provided, the average budget was \$2.00/m, \$3.70/m and \$2.70/m for inspection, maintenance and rehabilitation, respectively.

A common 5-step approach in the condition assessment and rehabilitation of trunk sewers was outlined in this paper. The recognized knowledge gaps and needs were also presented. A collective effort is required of the municipal sewer engineers, managers and researchers to enhance the exchange of information and experience. More research is required with respect to unified guidelines, sewer service life forecasting, optimal inspection scheduling, and decision-making methodology. Better inspection tools and rehabilitation methods are still desired.

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