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Condition assessment and rehabilitation of large sewers

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ABSTRACT: The Urban Infrastructure Rehabilitation Program of the National Research Council Canada (NRC) in conjunction with 10 municipalities and two consulting companies has just completed a set of guidelines focusing on the impact and condition assessments, and rehabilitation of large diameter sewers (> 900 mm) as well as access holes. The guidelines provide a consistent approach for assessing the impact of pipe failure, coding defects and assigning priorities for rehabilitation. The user-friendly approach is demonstrated with an example. By using unified definitions of terminology and a consistent defect coding system, information can be shared between utilities across the country. Pooling scarce sewer condition data from various municipalities across Canada will enable the development and verification of statistical models for assessing sewer deterioration and predicting its remaining service life.

1 INRODUCTION

It is encouraging to note that more and more municipal engineers take a pro-active approach in managing their buried municipal assets in order to maintain the expected level of service to their clients. The sewer system is one such service that is expected to function without interruptions.

The current state of practice in managing sewer systems varies from city to city, resulting in inconsistencies in use of terminology, inspection, condition assessment, selection of rehabilitation methods, and record keeping (Zhao 1998). Some municipalities have carried out extensive work to assess the condition of their sewers, whereas others may have not even started partially due to lack of user-friendly and consistent guidelines. While some Canadian municipalities have adopted the approach by WRc (1994), others have developed their own sewer inspection and condition assessment manuals (Edmonton 1996a, 1996b). The sewer manuals by NASSCO (1995) and ASCE (1994) are also available. Although these sewer manuals are useful, engineers often find themselves searching through various manuals to compile useful information and to formulate a practical approach to the problems on hand. Furthermore, there is no consistent approach for the assessment of impact factors associated with the sewer systems and of access holes.

The Urban Infrastructure Rehabilitation Program of the National Research Council Canada (NRC) in collaboration with 10 municipalities and two consulting companies has just completed a set of guidelines for the condition assessment and rehabilitation of large diameter sewers (> 900 mm) and access holes. The objective was to provide users with a practical and easy to follow approach on how to manage large sewers effectively. More specifically, users can find information on the following subjects:

- health and safety;
- availability, applicability and limitations of existing technologies for inspection, condition assessment and rehabilitation of large sewers;
- assessment of major impact factors in decision making;
- data management;
- selection of rehabilitation methods;
- prediction of existing sewer conditions; and
- cost estimates.

This paper summarizes the guidelines developed by NRC as a result of the joint research project. The use of the approach is also illustrated through a practical example. However, some details and rationale are omitted for this paper. A full document is expected to be published by NRC in the near future.

2 APPROACH

The necessary steps to maintaining the performance of sewer systems is illustrated in Figure 1. This approach is recommended for both the pipe and the access holes that are attached to the pipe. The contents and the relationships between each step will be discussed in detail in the following sections.

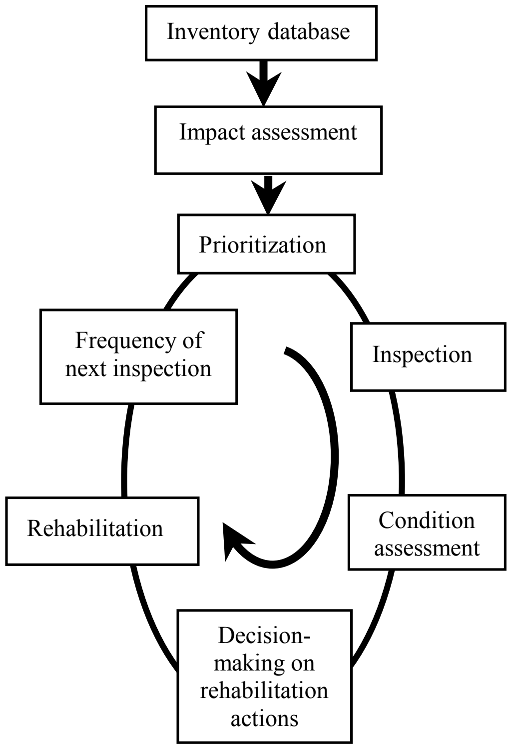

Figure 1. Approach for managing sewer assets

2.1 *Inventory*

As the first step, the available inventory data must be compiled in a manageable format for their effective use. The established database can then be linked to other databases such as inspection and rehabilitation databases. Pipe identification (pipe ID) or access hole identification (MH ID) can be used as unique identifiers to link different relational databases. Examples of the types of information that should be included in the inventory database are shown in Table 1. Database tables are to be filled in with the inventory information for each pipe segment, where each segment is expressed in a per-metre unit length.

2.2 *Impact assessment*

The criteria used to prioritize inspection and rehabilitation should include not only the physical condition of the pipe, but also the degree of impact of a sewer failure. The proposed impact assessment ranks the pipe segments in unit length in terms of six major factors – location, type of embedment soil, burial depth, pipe size, functionality and seismic zone. The assessment will generate a ranking of impact for the sewer system. The premise for an impact factor follows from the fact that not all pipe segments have the same likelihood of failure or the same consequence of failure.

Table 1. Sewer pipe inventory

Field name	Entry example(s)
Pipe ID	XYZ-ABC
Upstream access hole ID	ABC-1234
Downstream access hole ID	ABC-1235
Installation year	1950
Material	Concrete
Construction method	Cast in place
Length	Value in metres
Slope	Value in percent
Shape	Circular/ellipse/arch
Dimensions	Values in millimetres
Joint type	Bell and spigot/welded
Soil type	Clay/native
Burial depth (to crown)	Value in metres
Sewer function	Interceptor/collector
Service lateral Connections	Yes/no
Service lateral type	Concrete/PVC
Land use	Residential/commercial/ industrial
Seismic zone	Rating based on city
Internal lining type	Mortar/asphalt

Each of the six factors is assigned a degree of impact defined by low, medium or high. How each factor is assessed is explained below:

- The impact based on pipe location is assessed on how the public and environment will be affected if failure occurs. The contributing aspects include land use, traffic intensity, access for repair, location under or adjacent to critical establishments and environmental classifications. These factors were considered similarly by the City of Phoenix (Brown and Caldwell 1998). For instance, a segment of pipe within an airport perimeter or under 6 lanes of traffic or in a commercial area will have a high degree of impact (rating of 3). On the other hand, a pipe in an industrial park or under 1 or 2 lanes of traffic will have a low degree of impact (rating of 1). The pipe location affects both the likelihood of failure and the severity of failure consequence.
- Soil support is an integral component of the pipe-soil system. Void formation and loss of soil support resulting from fractures and open joints in the presence of sufficient hydrostatic head can contribute to premature pipe failures. The types of supporting material that pose the greatest threat are silts and sands (rating of 3), while medium to high plasticity clays have the lowest degree of impact (rating of 1). Soil support affects the likelihood of failure.
- The magnitude of repair work and the selection of rehabilitation methods are dependent on pipe size. If a failure occurs the size of the pipe will have an impact on the amount of contamination to the surrounding environment. As a result, a pipe with a diameter (or

vertical size) of less than 900 mm is given a low rating (1) while those with diameters greater than 1800 mm are given a high rating (3). The pipe size affects the severity of failure consequence.
- The deeper a pipe is buried the greater the degree of difficulty in accessing it for repair and inspection. The burial depth rating will be low (1) for pipe buried less than 3 m and high (3) for a burial depth greater than 10 m. The burial depth affects both the likelihood of failure and the severity of failure consequence.
- The function of the sewer includes both the types of waste carried and the location of the segment of the system. For example, the environmental consequences will be more severe for a sanitary sewer failure than a storm sewer failure. Also, the failure of a pipe segment entering the treatment plant will be more severe than that of a collector pipe. The rating for a high degree of impact is 3 (pipe entering/exiting a treatment plant) and 1 for a low degree of impact (collector pipe). The sewer function affects both the likelihood of failure and the severity of failure consequence.
- Areas prone to seismic activity based on information from the National Building Code (1995) are assigned a rating of 1 for a low seismic (zonal velocity or acceleration between 0 and 2), and 3 for a high seismic zone (zonal velocity or acceleration between 5 and 6). The seismic factor is generally the same for one region and its inclusion facilitates the comparison of condition assessments from different regions of the country. The seismic zone affects the likelihood of failure.

For all of the factors listed above, the medium degree of impact falls between the high and low extremes and is assigned a value of 1.5. A weighted impact rating formula is used to combine the influence of each of the six factors described above for each pipe segment within the system (Eq. 1)

$$I_w = (0.2) f_l + (0.16) f_s + (0.16) f_z + (0.16) f_d + (0.16) f_f + (0.16) f_q \quad (1)$$

where f_l = location factor, f_s = embedment soil factor, f_z = size factor, f_d = burial depth factor, f_f = sewer function factor and f_q = seismic factor.

Although these factors do not change dramatically from year to year, periodic updating may be necessary.

2.3 *Prioritization*

Once the weighted impact rating is completed for individual pipe segments, a citywide color-coded impact map can be produced highlighting areas where the impact rating is high. This impact assessment can then be used in a number of ways in the decision-making process. First, it can be used to prioritize inspection tasks. The areas to investigate first, if no other information is available, will be those showing a high impact rating. Secondly, the impact ratings can be used in combination with the physical condition rating of a pipe to prioritize rehabilitation work and the future inspection frequencies. For instance, of the pipe segments with the same physical condition rating, those with higher impact ratings would be considered first for rehabilitation.

In addition, those pipe segments in the vicinity of a watermain burst, locations with chemicals of above-normal concentrations, locations with ground settlements, and those pipe segments with known problems (e.g., inflow and infiltration I/I) should be given special attention. Other considerations include coordinating pipe inspection with road refurbishment or watermain replacement efforts. Finally, in high seismic areas, those pipe segments surrounded by soils with high liquefaction potentials should be identified.

It should be pointed out that the approach for impact assessment could be adopted for smaller sewers (< 900 mm), or for watermains.

2.4 *Inspection*

Once the pipe segments have been prioritized, the inspection of those segments can take place. The methods used for inspection include, but are not limited to, closed circuit television (CCTV), combined Sonar/CCTV, person-entry, and stationary camera.

Some of the inspection methods are more suited for partial pipe lengths (special purpose) or in conjunction with other methods (in-line) while others can be used to inspect from access hole to access hole (full-line). Depending on the budget and if additional information is known about the pipe segments, the choice of inspection technique may be obvious. For instance, person-entry may be the most effective and economical method for inspecting large storm sewers and culverts.

The most widely used method for sewer inspection is CCTV which is an example of a full-line inspection method. Defects present above the flow surface can be located, identified and ranked by a trained operator. The operators, as well as the crew who will carry out a person-entry inspection, should be trained in order to ensure consistency and uniformity of the inspection results. Other examples of full-line inspection methods are combined sonar/CCTV, person entry and stationary cameras. The combined sonar/CCTV is beneficial to inspect the pipe surface below the flow surface. Person-entry inspections allow the gathering of first-hand and detailed information about the defects in the pipe.

If a CCTV inspection has flagged a particular pipe segment with numerous defects, further investigation may be required to assess the extent of the damage. If that is the case, one of the special purpose inspection techniques might be used. For example, where an open joint exists, it might be a good idea to investigate whether or not voids are present behind the pipe walls. Ground penetrating radar and infrared thermography are available methods for detecting voids around the pipe (EPA 1999). If the full-line inspection is completed by person entry, there are in-line testing techniques that could be used to further assess the integrity of the pipe wall and surrounding soil support. Examples of in-line testing techniques include impact echo, coring and in-situ strength testing.

Sewer defects are commonly grouped into two categories – service and structural, and each defect has a unique defect name and definition. The types of service defects are infiltration (I), root intrusion (R), encrustation (E), debris (DE) and protruding service connection (P). Examples of structural defects include fractures (F), cracks (C), deformed pipes (D), collapsed pipes (X), broken pipes (B), joint displacements (JD), joint openings (JO), surface damage (H) and sags (S). The letters in brackets indicates the abbreviation used to identify the defect. The defects identified are coded based on clear definitions of each type of defect and its severity.

When appropriate the degrees of severity are clearly defined giving dimensions to help quantify the differences between a defect that would be considered light (L), moderate (M) or severe (S). An example is presented (infiltration) to illustrate the information that is provided for each defect. The final letter in the defect code symbol indicates the level of severity of that defect.

Infiltration – the ingress of groundwater through a defect or defective joints or connections
Defect codes – *Light* (IL) – seeping or dripping,
Moderate (IM) – running or trickling,
Severe (IS) – gushing or spurting.
Rationale – severe infiltration poses a high possibility of loss of soil fines which leads to loss of soil support, as well as increased sewer volume to be treated (e.g., more load on the treatment facility).

This system defect coding is similar to those of WRc (1993) and Edmonton (1996a and 1996b). But unlike those methods the proposed system is not limited to camera inspections. With proper training, defect coding can be carried out by person-entry inspection crews, or by certified divers for inundated siphon sections.

2.5 *Condition Assessment*

After the inspectors carry out the preliminary assessment of the pipe by coding the defects using a set of defined defect codes, a more rigorous condition assessment can be carried out. The assessment can be based on the per-metre length, or the access-hole to access-hole length (MH-MH length, for abbreviation), depending on the level of decision-making. If the decision-making is on the global level of a system to determine which areas are worse, the MH-MH length is appropriate to use. On the other hand, if the decision-making is on the macro level to determine what defects exist and what rehabilitation methods are most appropriate, the per-metre unit length is then the more appropriate length to use. With the help of an electronic database, data that are input on the per-metre assessment length can also be queried to give information globally.

The structural and service condition ratings are established directly from the inspection data. Weights are assigned based on the defect type and the severity.

Tables 2 and 3 show the service and structural defect codes and their weights, respectively. If the user currently uses another method to code defects, a conversion table like Table 4 can be set up to convert those codes to the ones presented here.

Table 2. Service defect codes and weights

Defect type	Code	Weight
Roots		
fine roots, restricting flow <10%	RL	2
10% to 25% diameter loss	RM	8
> 25% diameter loss	RS	10
Debris		
< 10% flow restriction	DEL	5
10% - 25% diameter loss	DEM	8
> 25% diameter loss	DES	10
Encrustation		
< 10% flow restriction	EL	2
10% - 25% diameter loss	EM	8
> 25% diameter loss	ES	10
Protruding service connection		
< 10% flow restriction	PL	2
10% - 25% diameter loss	PM	8
> 25% diameter loss	PS	10
Infiltration		
Seeping, dripping	IL	2
Running, trickling	IM	5
Gushing, spurting	IS	10

Table 3. Structural defect types, codes and weights

Defect type	Code	Weight
Longitudinal fracture		
< 10 mm wide	FLL	5
10 mm – 25 mm wide, or 2 – 3 fractures	FLM	10
> 25 mm wide, > 3 fractures	FLS	15
Circumferential fracture		
< 10 mm wide	FCL	5
10 mm – 25 mm wide	FCM	10
> 25 mm wide	FCS	15
Diagonal fracture		
< 10 mm wide	FDL	5
10 mm – 25 mm wide	FDL	10
> 25 mm wide, multi-occurrence	FDS	15
Multiple fractures	FM	20
Broken pipe		
> 100 diameter or 100 square	B	15
Longitudinal crack		
No leakage	CLL	3
With leakage	CLM	5
With leakage, multiple	CLS	10
Circumferential crack		
No leakage	CCL	3
With leakage	CCM	5
Diagonal crack		
No leakage	CDL	3
With leakage	CDM	5
Deformed pipe		
< 5% diameter change	DL	5
5% - 10% diameter change	DM	10
> 10% diameter change	DS	15
Collapsed	X	20
Joint opening		
< 10 mm	JOL	3
10 mm – 50 x wall thickness	JOM	10
> 50 x wall thickness	JOS	15
Joint displacement		
< ¼ pipe wall thickness	JDL	3
¼ - ½ pipe wall thickness	JDM	10
> ½ pipe wall thickness	JDS	15
Surface damage		
< 5 mm pipe wall thickness spalled or worn out, pitting on metal pipe	HL	3
5 mm – 10 mm pipe wall thickness lost, exposed reinforcement or aggregates, extended corrosion in metal pipe	HM	10
More than 10 mm pipe wall thickness lost, corroded reinforcement, corroded through metal pipe	HS	15
Sags		
< 50 mm	SL	4
50 mm – 100 mm	SM	10
> 100 mm	SS	15

A spreadsheet template or database can be easily created to organize the inspection data and determine the service and structural defect ratings. Table 5 shows an example of the database fields for evaluating the service and structural ratings of a sewer pipe. The analysis recognizes the importance to distinguish between a pipe with lots of light defects and one with a severe defect. The analysis looks at both the peak score (the worst defect within the assessment length) and the total score. The total score is the sum of all defect weights within an assessment length. The structural and service condition ratings are determined based on the peak score of the defect. The ratings from 0 to 5 are assigned according to Tables 6 and 7. The structural and service ratings will be combined with the impact factor as part of the decision making process for rehabilitation.

Table 4. Conversion table for the defect codes

Defect type (L/M/S)	Codes in this paper	Edmonton's equivalent	WRc's equivalent
Longitudinal fracture	FLL/FLM/FLS	FL/FM/FS	-/FL/-
Circumferential fracture	FCL/FCM/FCS	-	-/FC-/
Diagonal fracture	FDL/FDM/FDS	-	-/-/FM
Broken	B	FX	B, H
Longitudinal crack	CLL/CLM/CS	CL/CM/CS	-/CL/CM
Circumferential crack	CCL/CCM	-	-/CC
Diagonal crack	CDL/CDM	-	-
Deformed	DL/DM/DS	DL/DM/DS	D(<5%)/ D(5-10%)/ D(>10%)
Collapsed	X	DX	X
Joint opening	JOL/JOM/JOS	OL/OM/OS	-/OJM/OJL
Joint displacement	JDL/JDM/JDS	JL/JM/JS	-/JDM/JDL
Surface damage	HL/HM/HS	HL/HM/HS	SSS,SWS/ SSM,SWM/ SSL,SWL
Sags	SL/SM/SS	SL/SM/SS	-
Roots	RL/RM/RS	RL/RM/RS	RF(J)/RT(J)/ RF(J)
Debris	DEL/DEM/DES	BL/BM/BS	DE(<10%)/ DE(10-25%)/ DE(>25%)
Encrustation	EL/EM/ES	EL/EM/ES	EL(J)/EM(J)/ EH(J)
Protruding services	PL/PM/PS	PL/PM/PS	CNI(<10%)/ CNI(10-25%)/ CNI(>25%)
Infiltration	IL/IM/IS	IL/IM/IS	IS(J), IS(J)/ IR(J)/IG(J)

Table 5. Template for structural and service condition ratings based on inspection results

Field name	Entry example
Pipe ID	S-1450
Upstream access hole	N12AH6
Downstream access hole	N12AH7
Inspection date	06/1980
Chainage (m)	5.0
Impact factor	2
Structural defect codes	FM, JOL
Peak score	20
Unit total score	23
Cumulative score	□
Structural rating	5
Service defect codes	DEL, EL
Peak score	5
Unit total score	7
Cumulative score	□
Service rating	3
Comments	

Table 6. Structural condition rating threshold

Peak score threshold	Structural condition state
0	0
1 – 4	1
5 – 9	2
10 – 14	3
15 – 19	4
20	5

Table 7. Service condition rating threshold

Peak score threshold	Service condition state
0	0
1 – 2	1
3 – 4	2
5 – 6	3
7 – 8	4
9 – 10	5

2.6 *Rehabilitation and future inspection frequency*

A rehabilitation action plan can be established based on the priority that is determined from the condition state and impact rating (Table 8). Recommended frequencies for future inspections are shown in Table 9. However, it is emphasized that such decision-making tools are by no means a substitute for engineering judgement.

The database should be re-examined to determine the prominent type and extent of the defects if rehabilitation is warranted. This process will help reduce the rehabilitation choices (e.g., spot repair or continuous repair) and determine the funding requirement for rehabilitation.

A database that includes available rehabilitation methods, their characteristics and applications, their unit costs and expected service lives, as well as defects that each rehabilitation method is expected to remedy can be created to further assist in selecting the appropriate rehabilitation method. User-friendly defect-orientated rehabilitation data sheets can be generated from the database based on the type of the prominent defect. For instance, if the predominate defect is circumferential cracking, a query on the defect-orientated database will list all applicable rehabilitation methods designed to remedy circumferential cracking.

Table 8. Condition state and rehabilitation priorities

Condition state	Implication	Impact rating	Rehabilitation priority
5	Failed or imminent failure	1 to 5	Immediate
4	In bad condition, high structural risk	5	Immediate
		1 to 4	High
3	In poor condition, moderate structural risk	4 to 5	Medium
		1 to 3	Low
2	In fair condition, minimal structural risk	5	Medium
		1 to 4	Low
1 or 0	In good or excellent condition	1 to 5	Not required

The historical unit cost and expected service life will help select the preferred rehabilitation method for a particular pipe length. Municipalities may develop their own unit cost data based on their previous projects. In some cases, the rehabilitation method providing the longest service life may not be the best choice. Depending on the future capital projects, a short-term fix may be all that is required if a major reinvestment is planned in the near future. Other factors to consider when deciding the most appropriate rehabilitation technique include groundwater level, aggressiveness of soil and groundwater, life cycle costs, corrosion of pipe materials and seismic zoning.

Table 9. Future inspection frequency

Condition State	Impact Rating	Inspection Frequency (years)
5	1 to 5	0†
4	5	0†
	1 to 4	2 to 6
3	5	3
	1 to 4	5 to 10
2	5	5
	1 to 4	10 to 15
1 or 0	5	10
	1 to 4	15 to 25

† Immediate rehabilitation required

3 PRACTICAL EXAMPLE

The approach presented above is illustrated by applying it to a section of a collector sewer that was inspected in the City of Ottawa (formerly the Region of Ottawa-Carleton). The trunk sewer pipes, totaling over 200 km within the city, range from 600 mm to 3 m in diameter. The inventory of these has been compiled using a commercial database program. The city conducts regular inspections of their sewer pipes and uses the WRc method to code the defects.

The pipe section selected for demonstration here was a section called “the Pinecrest Collector”. The collector sewer, constructed in 1975, consists of concrete pipes ranging from 750 to 900 mm in diameter.

Based on the sewer’s inventory information and alignment, an impact assessment was carried out considering all six major impact factors. The entire collector sewer was assigned a location factor of high impact because it passed under commercial/business areas and a primary highway. The degrees of impact of other impact factors are shown in Table 10. When these factors were combined into the weighted formula, the impact threshold was 1.72. The corresponding impact rating is therefore 3, which means the impact of this collector sewer is moderate in terms of likelihood of failure and/or the severity of failure consequence.

The available CCTV inspection video from the city was used to identify defects. The quality of the video was good except for one length from MH PC03900 to PC03800 where the steam from the sewer flow worsened the picture quality, thus preventing an analysis of this MH-MH length.

Table 10. Impact factor determination for Pinecrest Collector

Factor	Degree of impact	Rationale
Location	High (3)	Commercial area, large buildings, highway, restricted access for repair
Embedment soil	Low (1)	Medium to high plasticity clays
Size	Medium (1.5)	Diameter 750 – 900 mm
Burial depth	Medium (1.5)	Ranges from 5.3 – 6.9 m
Sewer function	Medium (1.5)	Trunk sewer
Seismic zone	Medium (1.5)	$Z_a = 4.0$, $Z_v = 2.0$

Table 11. Pinecrest Collector from PC03600 to PC03500, structural defect inspection results

Chainage (m)	Defect	Peak score	Total score	Cumulative score	Condition rating
15	CLS	10	10	10	3
16	CLS	10	10	20	3
17	CLS	10	10	30	3
18	CLS	10	10	40	3
19	CLS	10	10	50	3
26.5	CLL	3	3	53	1
27	CLL	3	3	56	1
28	CLL	3	3	59	1
59	CLS	10	10	69	3
60	CLS	10	10	79	3
61	CLS	10	10	89	3
62	CLS	10	10	99	3

The remaining 11 MH-MH lengths were evaluated using the defect coding systems presented in Tables 2 and 3. The condition assessment on the per-metre unit is demonstrated in Tables 11 and 12 where the non-defective chainages are omitted for brevity.

The structural condition of the collector sewer was therefore rated 3, meaning that it was in poor condition with a moderate structural risk. The longitudinal cracks formed a map or spider web pattern on the interior surface of the pipe. There was no evidence of leaks at the cracks but the quantity of cracks was a concern.

If the results of the previous inspection were available, they would be compared with the results of the current inspection to track the changes in the defects and their severity.

Table 12. Pinecrest Collector from PC03600 to PC03500, service defect inspection results

Chainage (m)	Defect	Peak score	Total score	Cumulative score	Condition rating
2.9	IL, EL	2	4	4	1
5.9	IL	2	2	6	1
9.1	IL, EL	2	4	10	1
11.2	IL, EL	2	4	14	1
15	EM	8	8	22	4
22.8	EL	2	2	24	1
32.4	IL	2	2	26	1
37.5	EL	2	2	28	1
49.1	IL	2	2	30	1
51.9	IL	2	2	32	1
57.7	IL	2	2	34	1
63.6	EL	2	2	36	1
71	EL	2	2	38	1
74.4	IL	2	2	40	1
77.8	EL	2	2	42	1
80.1	EL	2	2	44	1
86.3	EL	2	2	46	1
90.3	EL	2	2	48	1

Encrustation and infiltration at the joints were the major types of service defects in this section of the collector sewer. The overall service condition rating would be 1. All incidences of encrustation and infiltration were light except at the 15 m location where the encrustation reduced the pipe diameter by 10% to 25%.

Table 13 shows a summary of the findings for all sections evaluated to illustrate the use of MH-MH assessment length. The condition rating presented in this table is the structural condition rating. The poorest condition occurred from MH PC03500 to MH PC03400, with a peak score of 10 and a total score of 323. Two other inspected sections with a peak score of 10 were PC04400 – PC04300 and PC03600 – PC03500.

Using the condition ratings arrived in this example the decision-making approach for determining rehabilitation priorities (Table 8) could be used. The worst section was from MH PC03500 to MH PC03400 but no immediate rehabilitation was required because the structural condition was 3 with an impact rating of 3. The condition assessment summary results are highlighted for this section. No rehabilitation was required because other sections of the collector sewer were in good or fair condition.

The condition ratings were used to determine when to carry out the next inspection/condition assessment of the collector sewer. For the sections with a condition rating of 3 and an impact rating of 3, the next inspection/condition assessment should be carried out between 5 to 10 years (using Table 9). For the sections with condition rating less than 3 and impact rating of 3, the time frame would be between 10 and 25 years.

Table 13. Pinecrest Collector condition assessment summary

Upstream MH	Down-stream MH	Length (m)	Impact rating	Peak score	Total score	Condition rating
PC04600	PC04500	53.2	3	8	30	2
PC04500	PC04400	57.7	3	2	38	1
PC04400	PC04300	74.3	3	10	73	3
PC04300	PC04200	76	3	8	43	2
PC04200	PC04100	70.5	3	8	29	2
PC04100	PC04000	77.5	3	3	47	1
PC04000	PC03900	99.1	3	3	117	1
PC03800	PC03700	112	3	3	65	1
PC03700	PC03600	46.8	3	8	60	1
PC03600	PC03500	95	3	10	147	3
PC03500	PC03400	99.4	3	10	323	3

Other factors that need to be considered in determining rehabilitation actions and techniques include service defects, sewer hydraulics, rehabilitation of other adjacent utilities (watermain and road), experience with previous rehabilitation methods, existing pipe materials, funding availability and life cycle costs.

4 SUMMARY

The current state of practice in managing sewer systems varies from city to city, resulting in inconsistencies in use of terminology, inspection, condition assessment, selection of rehabilitation methods, and record keeping. With the support from 10 municipalities and two consulting companies, the NRC's Urban Infrastructure Rehabilitation Program has completed a set of guidelines for the condition assessment and rehabilitation of large diameter sewers (> 900 mm) and access structures to assist municipal engineers manage buried sewers more effectively and consistently.

The approach provides a consistent and user-friendly method for data management, impact assessment, inspection, condition assessment, and rehabilitation of the large sewers and the associated access holes. The use of unified definitions of terminology and a consistent defect coding system permits sharing of information between utilities. Pooling scarce sewer condition data from various municipalities across Canada will enable the development and verification of statistical models for assessing sewer deterioration and predicting its remaining service life.

The step-by-step approach starts with the management of sewer inventory data. The ever-growing sewer systems warrant the use of electronic database. The impact assessment is an important step for prioritization. It considers the factors that either affect the likelihood of failure or the severity of the consequence of failure. The assessment rating is based on a scale from 1 – 5 with 5 being the highest impact. Impact assessment can be carried out prior to any physical inspections.

Inspections provide valuable information about the condition of the sewer pipes. A list of the types of defects and their definitions is provided to clarify the ambiguity or subjectivity that could interfere with the coding of the defects. The defects are separated into either service or structural defects. Defects are coded according to their severity and weights are assigned and combined to determine the condition of each pipe segment. Rating of both service and structural condition is carried out on a scale from 0 to 5 with 5 indicating the worst condition.

The decision on whether to rehabilitate or not is based on the impact, the structural and service condition rating values. Although the decision-making approach does not take the place of engineering judgment, it can be used as a guide to assist in the decision-making process. The condition ratings of each pipe segment are used again to determine when to carry out the next inspection/condition assessment.

The concept and the user-friendly approach was demonstrated through a practical example of a collector sewer in the City of Ottawa. Although the guidelines for access holes are not included in this paper, the approach is similar. The impact assessment approach presented could also be applied, with some modifications, to other buried utilities such as watermains.

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