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Sewer systems: Failures and rehabilitation

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Abstract: Sewer systems are constantly subject to several (i.e., physical, chemical, etc.) stresses due to deficiencies in the design, construction problems or functional causes. These stresses eventually lead to defects of the systems and furthermore their malfunction. The proper maintenance and operation of the sewer systems are essential if the works are to achieve their designed objectives, since malfunction may cause potential problems to the wastewater treatment plant, be harmful to the environment, cause public health risks and, in general, degrade the quality of life. In this report, we deal with the most common failures of sewer systems and provide an overview of the current state-of-the-art in practice and rehabilitation of pipes and structures within the wastewater collection system. Over the last thirty years, engineers have developed a whole range of technologies to rehabilitate sewer pipes, manholes, pumping stations and other elements of sewer systems without the need for excavation, the "no dig technology". In recent years, trenchless replacement and construction techniques have been used more frequently, including pipe bursting, microtunneling, directional drilling, etc. The goal of maintenance is to guarantee a well-functioning sewer system against the lowest possible costs.

Key words: sewer system malfunctions, trenchless replacement, microtunneling, directional drilling.

1. WHY DO SEWER SYSTEMS KEEP FAILING?

Sewer systems are subject to several (i.e., physical, chemical, etc.) stresses which may be caused by (www.unitracc.de, 2014):

i. Design and/or construction deficiencies.
ii. Lack of maintenance or inadequate maintenance.
iii. Natural aging of the sewer system.
iv. External influences, such as uncontrolled stormwater connections, traffic loads, etc.

These stresses lead sooner or later to system failures. Common failures are:

i. Infiltration – inflow and exfiltration.
ii. Flow obstacles.
iii. Abrasion – corrosion.
iv. Positional deviations.
v. Deformations.
vi. Cracks, breaks, pipe collapse.

1.1 Infiltration – inflow and exfiltration

Inflow occurs when and where surface water either enters directly into the sewer pipe (via surface manholes, service connections etc.) or by lateral sub-surface flow. Infiltration on the other hand represents a slow response process resulting in increasing flows mainly due to elevated groundwater entering the drainage system, and primarily occurring through defects in the pipelines. Exfiltration represents losses from the sewer pipe.

Infiltration – inflow and exfiltration may be caused by:

i. Design and/or construction deficiencies.

ii. High water table and high permeability ground.
iii. Uncontrolled stormwater connections.
iv. Materials ageing.
v. Other failures

The integrity of sewer systems in terms of infiltration-inflow gains and exfiltration losses represents a very important element in sustainable urban water resource management and has significant economic consequences for sewer system operators and wastewater utilities (Figure 1).

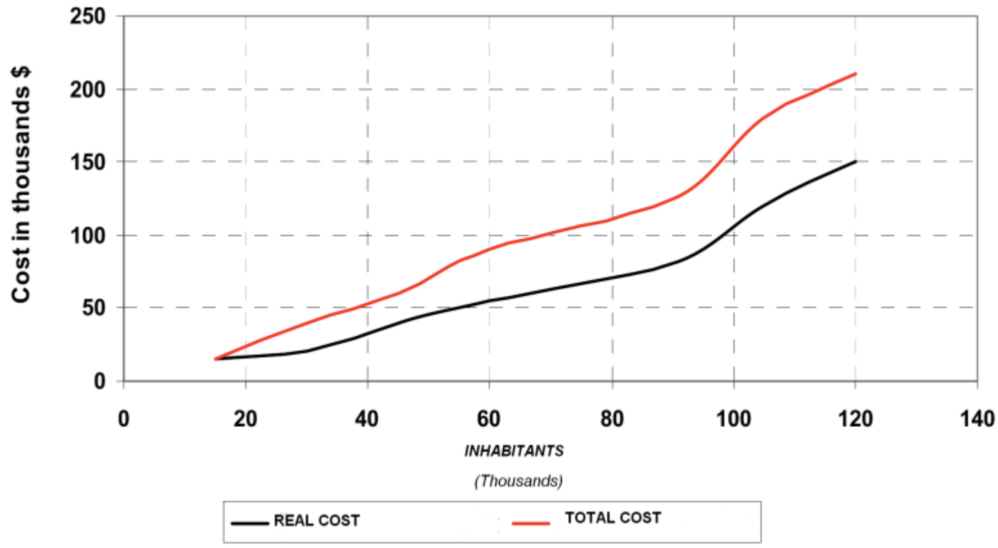

Figure 1. Additional cost due to Infiltration (Zalachori et al., 2008)

Exfiltration has potential health impacts on ground water, drinking water distribution systems, and surface water. Apart from the above, the exfiltration of sewage can be associated with the damaging effect of soil piping.

1.2 Flow obstacles

Flow obstacles may be caused by:
i. Design and/or construction deficiencies.
ii. Lack of maintenance or inadequate maintenance.
iii. Root intrusion.
iv. As effect of inflow–infiltration.

Possible consequences of damage caused by flow obstacles in sewer systems are the reduction of hydraulic performances and the blockages which lead to overflows.

1.3 Abrasion and Corrosion

Abrasion and corrosion may be caused by:
i. Design deficiencies.
ii. Wastewater with special components like uncontrolled industrial discharges.
iii. Improper materials selection.

Abrasion and corrosion cause tuberculation, which can lead to water quality issues and reduced flow and pressure. They can also result in wall thinning that weakens the pipe, and holes which cause leakage or eventually rupture.

1.4 Positional deviations

Positional deviations may be caused by:

i. Design and/or construction deficiencies.
ii. Settling and earthquakes.
iii. Hydro-geological changes.
iv. Load changes.
v. As a result of leaks.

The most common damages associated with the positional deviations are grade and alignment problems, leaks, breaking off the lateral pipes, pipe collapse and high maintenance costs.

1.5 Deformation

Deformations in the sense of damage may be caused by:

i. Design and/or construction deficiencies.
ii. Material deficiencies in laying and/or bedding.
iii. Effects of temperature.

The possible consequences of deformation are leaks, pipe brake or eventually rupture.

1.6 Cracks

Cracks in the sense of damage may be caused by:

i. Design and/or construction deficiencies.
ii. Damages during transport, storage and installation.
iii. As effect of wear.

The possible consequences of cracks lead to pipe collapse.

2. SYSTEM MAINTENANCE AND MANAGEMENT

The current performance of many collection systems is poor and many systems have received minimal maintenance for many years. Money is usually spent where the ratepayer can see the results. Most of the facilities are “out-of-sight, out-of-mind”, so there is little public pressure to carry on maintenance programs (WEF, 1992; EPA, 1999, 2009; NEIWPCC, 2003).

Failures tend to develop gradually, as opposed to being catastrophic, so that a failure may be “buried” for several years after it has occurred.

The lack of proper maintenance has resulted in deteriorated sewers with overflows and other safety, health and environmental problems. Overloaded treatment plants are some symptoms of collection systems with inadequate capacity and improper management, operation and maintenance.

The poor performance of many sanitary sewer systems and the resulting potential health and environmental risks, highlight the need to optimize the operation and maintenance of these systems.

Commonly accepted types of maintenance include two classifications: corrective maintenance and aggressive preventive maintenance.

Maintenance classified as corrective, is reactive. Only when the system fails, is maintenance performed. Reliance on reactive maintenance will always result in poor system performance, especially as the system ages. However, an effective maintenance program can reduce normal emergencies like a pipe break or a blockage in a sewer.

Maintenance classified as preventive, is proactive and is defined by a programmed, aggressive systematic approach to maintenance activities. This type of maintenance will always result in improved system performance apart from the case where major chronic problems are the result of design and/or construction flaws that cannot be restored by maintenance activities.

Aggressive preventive maintenance can be scheduled on the basis of specific criteria such as critical pipelines, known problem areas, equipment operating time since the last maintenance was performed, or passage of a certain amount of time.

Aggressive preventive maintenance program ensures that sewer lines remain in proper working order and prevents many problems before they occur. A real-time early warning system for overflows may allow administrators to alleviate the failure before causing more serious and expensive problems.

Cost of failures in terms of property damage and reconstruction can be enormous compared to the cost of preventive maintenance. Therefore, it is usually in the best interest of the owner to develop and implement an aggressive preventive maintenance program.

A good aggressive preventive maintenance program is the key to keeping a sewer system in good repair and helps preserve capital investment while preventing service interruptions and system failures. The proper functioning of these sewer systems is among the most important factors responsible for the general level of good health (EPA, 2009).

3. REHABILITATION METHODS

Sewer rehabilitation methods include (WEF, 2009):

- Repair
- Renovation
- Replacement

The progression from repair to replacement, generally describes an increasing level of investment, responding to a decreasing level of pipe integrity.

Under the traditional method of sewer repair or relief, a replacement or additional parallel sewer line is constructed by open cut replacement. Over the last thirty years trenchless technology has grown from humble beginnings to being the leader in rehabilitation methods. Trenchless methods of rehabilitation generally use the existing pipe as a host for a new pipe or liner.

Awareness of the indirect and social costs associated with utility work in congested urban areas (i.e., traffic congestion, loss of pavement life, business impacts, noise, and dust) have encouraged the use of “full” costing approaches in determining the choice between open-cut replacement and trenchless rehabilitation or replacement methods.

3.1 Repair

Repairs typically address maintenance issues (i.e., cleaning) and leakage (i.e., water tightness). Repairs may be temporary or permanent depending on the methods and technologies.

The first step is to diagnose if the pipe has structural problems.

When the pipe is structurally sound, we are able to clean the pipe with several cleaning methods (i.e., jetting, mechanical, hydromechanical), or achieve water tightness with chemical grouting materials and nonstructural sleeves. Chemical grouting systems use materials that react with water in order to restore water tightness, which make them ideal solutions for water intrusion issues. If we do not have access to the inside of the pipe, external grouting may be used.

Structural repairs from inside of man-accessible sewers and structures are carried out by machine or by hand and/or with the use of suitable aids or apparatus. In non-man-accessible sewers used remote controlled robots and CCTV cameras. Generally epoxy materials and structural sleeves are used.

3.2 Renovation

Renovation is more comprehensive than repair and describes rehabilitation techniques that renew the structural integrity of the sewer. Pipeline renovation systems use the existing pipe structure to "build" a new pipe or support a new lining. The systems used for carrying this out are coating and lining. The cross sectional dimensions of the section of the sewer to be rehabilitated in the application of these systems are generally reduced. The process always extends for at least one section of the sewer, from manhole to manhole.

Coatings with cast in place concrete or gunite are effective methods to increase the strength of the sewer. In order to control corrosion, there is a variety of nonstructural coatings that can be applied by hand or spray methods.

Linings are installed continuously from one access point to the next. Lining technologies vary with the type of material used, installation methodology, and curing (if any) procedures used.

The lining with prefabricated pipes is a method in which, new pipes are pushed and/or pulled through the existing sewer. The renovated pipeline can be either continuous or segmental (segmental lining process).

Another renovation technique is based on creating a pipe in situ by using PVC-ribbed profiles with interlocking edges (Spiral-Wound pipe).

Fold and form lining is a technique, in which a folded liner is inserted in the sewer and the liner is expanded or re-rounded back to a circular shape through various means (i.e., heat, pressure, mechanical, etc.).

3.3 Pipe line replacement

The classic method to rehabilitate sewers is to replace them. Many problems such as structural, grade, etc. may be too severe for renewal techniques. Replacement is often cheaper than lining technologies, but requires more construction time and needs open trenches.

This section mainly deals with pipeline replacement, without the need for excavation. In early years, trenchless replacement and construction techniques have been used more frequently, including pipe bursting, directional drilling microtunneling, etc.

Additional advantages of trenchless replacement over the open cut replacement are indirect cost savings, due to (1) less traffic disturbance, (2) shorter time for replacement, (3) less business interruption, (4) less environmental disturbance, (5) reduced surface paving expenses, and other social benefits.

3.3.1 Pipe Bursting

Pipe bursting (IPBA, 2012) is defined as a trenchless replacement method in which an existing pipe is broken either by brittle fracture or by splitting, using an internal mechanically applied force applied by a bursting tool. At the same time, a new pipe of the same or larger diameter is pulled in, replacing the existing pipe. The back end of the bursting head is connected to the new pipe and the front end is connected to a cable or pulling rod. The new pipe and bursting head are launched from the insertion pit, and the cable or pulling rod is pulled from the receiving pit. Pipe bursting can only be considered a "less dig" rather than "no dig" technique, because it is still necessary to excavate launch and reception pits and the bursting head smashes any lateral connections which must then be excavated to be restored.

Pipe bursting can be applied on a wide range of pipe sizes and types, in a variety of soil and site conditions. The size of pipes replaced by pipe bursting typically ranging from 50mm ID to 900 mm ID; however, advancements are made for both smaller and larger pipes. The maximum bursting length is about 300 m and depends on factors such as ground conditions, existing pipe material, etc.

3.3.2 Horizontal Directional Drilling

Horizontal directional drilling (HDD) is a mature and widely used trenchless method for installing utilities and pipelines under roads or railroad tracks. It is a suitable technology, because it does not require large excavation pits nor does it greatly interfere with traffic (FHWA, 2011). When drilling the initial borehole, the drill can be easily tracked and its path altered unlike other trenchless technologies such as “jack and bore”. HDD is also versatile as it can be used for large diameter pipelines and pipelines spanning a large distance.

A pilot hole is drilled along the desired path, followed by a reamer enlarging the pilot hole. Sometimes multiple reamers are used to gradually increase the size of the bore. After reaming the hole to the diameter required for pipe installation, pipe pullback can begin.

HDD can be applied on a wide range of pipe sizes, in a variety of soil and site conditions (Najafi, 2005). The size of pipes installed by HDD typically ranging from 50mm to 1200mm. The maximum drilling length is about 1800 m and depends on factors such as ground conditions, etc. High Density PE, ductile iron, steel and PVC are a few of the pipe materials with restrained joints that can be installed through this technique.

3.3.3 Microtunneling and Pipe Jacking

Microtunneling and Pipe jacking are trenchless construction methods used to install pipelines beneath highways, railroads, harbors, rivers, and environmentally sensitive areas. Microtunneling is defined as a remotely-controlled, guided, pipe-jacking operation that provides continuous support to the excavation face by applying mechanical or fluid pressure to balance groundwater and earth pressures.

Microtunneling requires jacking and reception shafts at the opposite ends of each drive. The microtunneling process is a cyclic pipe jacking operation. A microtunnel boring machine (MTBM) is pushed into the earth by hydraulic jacks mounted and aligned in the jacking shaft. Pipes are jacked behind the MTBM as it progresses through ground.

The method does not have a size limitation, although the range of pipe that can be installed through this technology is typically 600 mm to 2300 mm.

Microtunneling allows for close control of the line and grade, and it is also able to function in difficult ground conditions.

The pipe jacking process involves the excavation of soils ahead of the jacking pipe manually or by using small excavating machines. Because the method requires personnel at the operating face, its application for sizes smaller than 900 mm is not recommended. Pipes up to 2800 mm in diameter have successfully been installed.

The process starts with excavating a jacking and an exit pit. Then the first pipe section is lowered into the pit and jacked into place. The excavation process then resumes, followed by further jacking of the pipe sections.

3.3.4 Open cut replacement

Open-cut replacement has been the traditional method in the past, but its preferential use over trenchless techniques has been significantly diminished in the past two decades – particularly in the wastewater sector. A cost-effectiveness analysis typically is performed to determine whether open cut replacement is more cost-effective than trenchless techniques. However, in many cases the choice of trenchless technologies is driven by acknowledged environmental constraints and expected public pressure rather than by a quantitative calculation of full direct, indirect, and social costs.

Open-cut construction may offer several distinct advantages. The open cut construction becomes more cost-effective when many laterals exist. Some existing site conditions such as soil type, depth of installation limit the options to open-cut construction only. In open-cut construction there is the opportunity to fully inspect the pipe and ensure that is constructed according to the standards.

Today the majority of pipeline construction is still done by open-cut trenching; it is expected that trenchless market will increase over the years, as more utilities become more aware of their capabilities.

3.4 Manholes failures and rehabilitation

A manhole is the most accessible component of the gravity sewer system and is typically the only element to be routinely exposed at the surface. Due to the fact that it is exposed, a manhole offers significant potential for infiltration and inflow to the sewer system. Common failures of manholes are (ASCE, 1997):

i. Infiltration – inflow and exfiltration.
ii. Surround ground settlements.
iii. Hydrogen sulfide release may attack concrete manholes.
iv. Corrosion of cast-in-place rungs can be an important safety issue.
v. Structural problems.

Rehabilitation approaches use techniques similar to those of piping systems but can take advantage of the person accessibility available. Specific techniques, fall into the following categories:

Replacing the upper components (frame and cover) of the manholes, casting a new internal lining, sprayed or centrifugically cast concrete linings, sprayed polymer linings, cured-in-place lining systems, grouting and sealing approaches, and finally open cut replacement.

4. CONCLUSIONS

The utilities need a preventive maintenance program to keep their sewer system functioning properly and to accomplish the city's goal to protect the environment. A comprehensive program of aggressive preventative maintenance, leads to:

- Provide adequate capacity to convey peak flows.
- Increase of life span of existing investments.
- Achieve economy of resources, which, specifically nowadays, has particular value.
- Protect the public health and the environment.
- Use effectively human and material resources.
- Improve the living conditions of the citizens.

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