VALUE OF ASSESSING OUTFALL SEWER CONDITION

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ABSTRACT

South Africa has made great strides in providing clean water for everyone. However waste water disposal has lagged this. Exposure to this dirty water can cause disease and death. Many outfall sewers installed 40 years ago or earlier are now under congested urban areas, have deteriorated, are semi-functional, have collapsed or are about to collapse. The risk to public health and safety as well as environmental pollution is serious.

With South Africa's first outfall sewers there was little idea of their service life or how to predict this. The technology to provide data for assessing their condition and the knowhow to predict their remaining life is now available. CCTV inspections plus laser and sonar profiling means that defects can be described in terms of their location, extent and severity. With invert and ground levels plus this detail sewers can be effectively managed and maintained and their residual strength and remaining life predicted.

The value of condition assessments is that the municipal engineer or his representative can make technically sound decisions on the repairing, rehabilitating or replacing of sewers based on social, environmental, practical and economic constraints. A strategy of rehabilitating existing sewers and simultaneously installing new sewers where existing capacity is inadequate or for new developments will accelerate the provision of sanitation for all in South Africa.

INTRODUCTION

Background

Water is by far the most frequently used commodity by man. On the average every man, woman and child on Earth uses about 300 cubic metres of water every year. The fact that there are some who survive on 15 litres or less per day drives home the desperate need for the equitable distribution of this precious resource.

When water is used it becomes dirty. South Africa has made great strides in providing clean water for everyone, but the provision of effective wastewater systems to handle this dirty water and return it, in the same condition as it was taken from the natural water sources has seriously lagged that of the clean water supply. Exposure to this dirty water and its use cause disease and death. While the seriousness of death is appreciated the impact on population's health is not. Sick persons are unable to function adequately at work or school and in the long term this has really detrimental consequences for the country. In addition to this the dirty water pollutes the natural water resources with detrimental effects on the environment.

There are several systems available for the disposal of wastewater. The conventional gravity system consists of reticulation, collector and outfall sewers installed to convey wastewater from the communities where it is generated to the treatment works where it is cleaned and purified before being discharged back to the natural watercourses. This paper focuses on outfall sewers which are the final stage of the conventional gravity system and in particular on concrete outfall sewers as this is the most frequently used material.

While there is a desperate need to provide water services to those who do not have them, there is also the problem of aged services. Traditionally sewers were designed for a 40 year service life (a generation). Many of South Africa's outfall sewers installed 40 years ago or earlier are now under congested urban areas, have deteriorated, are semi-functional, have collapsed or are about to collapse. The risk to public health and safety as well as environmental pollution is serious. Due the depth at which sewers are normally placed their replacement is extremely disruptive and far more costly than installing them in undeveloped areas. Extending their service life by rehabilitating using trenchless techniques is generally far more cost effective and causes little if any surface disruption. However to do this means that the sewer's condition needs to be assessed so that the appropriate remedial measures are taken before there is an unexpected failure that requires costly replacement from the surface.

Operational problems

As the primary function of a sewer is to convey wastewater the primary requirement to satisfy is capacity. Many of the operational problems experienced with what appears to be inadequate capacity are actually due to infiltration, sedimentation and misalignment due to leaking joints, loss of bedding or foundation support and cavity formation in the soil around the pipes.

The underlying causes for many of these problems may have been designed or built, or designed and built into these malfunctioning sewers. Typically the problems of localized energy losses, deposition and surcharging are as a result of:

- Changes in vertical alignment from steep to flat reaches
- Sharp changes in horizontal alignment at manholes when flow velocities are high
- Inadequate benching in manholes
- Detailing of benching at manholes that considers low flow, but not high flow conditions.

Similar problems can arise due to variable vertical alignment between manholes due to inadequate foundation or bedding construction, infiltration and exfiltration through poorly made joints, or joints that have opened due to differential settlement of underlying material, which may have been built into a sewer.

For a sewer to meet its primary requirement is must meet the secondary requirements of water tightness and strength. To continue meeting these requirements it must be durable. For concrete outfalls that have been correctly designed and installed the most frequent problems that can arise are due to durability as a result of operating conditions that differ those anticipated during design.

Significance of condition assessment

Before any decisions are made about any operational changes, maintenance, rehabilitation or replacement of an existing sewer it is essential to assess its condition in terms of any problems associated with its hydraulics, water tightness, durability or structural integrity at a particular date and how these relate to the required performance. This involves much, much more than listing the visually identified defects inside a pipeline using a CCTV camera that have been categorised and graded to describe the physical condition of the pipes and joints and the need for their maintenance or rehabilitation.

The condition assessment of a sewer consists of gathering data and evaluating it from as many sources as possible covering the performance of the above parameters relative to the originally specified requirements. This should include the effluent composition and details of the pipe soil system. Sufficient information must be gathered from evaluating this data to identify the problems, categorise them and then describe them in terms of their location, extent, severity and the underlying causes to enable a risk analysis to be done.

This risk analysis should cover the performance of the pipes, the joints and the soil around them both qualitatively and quantitatively. It gives the condition of the sewer by stating its fitness for purpose at given date as well as predicting any future problems that are likely to occur and when they are likely to occur as well as stating failure probabilities and the consequences thereof. The critical issue is determining the sewer's remaining service life so that remedial measures can be taken to avoid structural failure.

SERVICE LIFE

The service life of a sewer is the period over which it is expected to meet the specified requirements. It does not necessarily mean that the sewer will cease to function at the end of this period. The concept of designing these systems for a generation is no longer considered appropriate. A more realistic approach is to design them for a 100 year service life and then to rehabilitate them to extend this.

Although they are frequently related, a distinction should be drawn between operating and structural problems. Operating problems affect the everyday functioning of the sewer and can be mitigated by regular maintenance; once structural problems start they become progressively worse and unless remedial action is taken the sewer will eventually collapse rendering the sewer non-functional. Depending on the severity of the structural problem the whole sewer or part of it will require rehabilitation or replacement. The danger with structural problems is that they involve the whole pipe soil system. The condition of the pipe can be determined but it is difficult to determine the external conditions around the sewer. Cavity formation around the pipes may go unchecked until pipes collapse and the sewer blocks or the cavity daylights as a sinkhole. Such events can occur with little or no warning.

Assessing a sewer's condition to ascertain when such events could occur will provide the detail needed to motivate the necessary measures to prevent them occurring and extend the sewer's service life.

Operational problems

There are many operational problems that can occur with sewers irrespective of the pipe material used, such as, manholes surcharging, infiltration and exfiltration, siltation, blockages, root penetration and odours. These and other similar ones can usually be classified as capacity or water tightness issues. If not addressed they will cause a gradual deterioration in the system operation and are likely to lead to structural problems with all pipe materials due to the loss of bedding support. Corrosion leading to a loss of structural integrity can be a serious problem with pipes produced from cementitious materials

Structural problems

Irrespective of the pipe material used the sewer itself is only part of the pipe/soil system. Care is needed to ensure that the bedding gives the pipe the support required to carry the external loads. The load carrying capacity of rigid pipes, such as concrete, fibre reinforced cement (FC) or clay, is only enhanced by a factor of between one and a half and two and a half by the bedding, whereas as this enhancement for a flexible pipe, such as PVC or PE, could be 12 or more. Hence flexible pipes are far more dependent upon assistance from bedding support to carry imposed loads than rigid pipes.

This does not mean that rigid pipes can be placed in a trench and backfill placed without compaction. Any trench is a potential water path as the compacted bedding and backfill will generally be far more permeable than the consolidated soil though which the trench has been excavated. As a result any groundwater flow will be intercepted by the trench and flow through the trench material. If this does not have a stable grading and has not been adequately compacted there could be a gradual loss of the material supporting the pipes resulting in the enhancement factor being lost and the pipes becoming overloaded. This initiates a sequence of events, namely broken or malfunctioning joints, infiltration, further loss of bedding support, further cracking or deformation of pipes, formation of cavities around the pipes and the risk of these cavities becoming progressively larger until they day light as sink holes. Inadequate bedding foundation and the corrosion of cementitious pipes are two occurrences that can exacerbate this situation

The structural analysis of sewers is based on the two dimensional plain perpendicular to the longitudinal axis. The hydraulic performance of sewers is however determined by the longitudinal gradient and its consistency. If the trench bottom which acts as the bedding foundation or the constructed bedding foundation is not constructed to grade and does not maintain this over time the vertical alignment of the sewer will vary along its length and this will give rise to problems with back falls, localized deposition and relative settlement between pipes.

Corrosion is peculiar to cementitious pipes and due to the biogenic formation of sulphuric acid under certain conditions leading to the structural deterioration, rapid loss of pipe wall material and sewer collapses. As concrete is the most frequently used pipe material for outfall sewers the problem is serious.

Extending service life

A utility's real assets are the holes through the soil. The sewers are merely the linings that ensure that the holes operate effectively and efficiently. As sewers age they develop defects, as described above, and unless remedial measures are taken they will eventually become non-functional. Before considering any remedial work or replacement it is essential to establish the severity, location and extent of the problems and their causes. This needs to be done for the whole pipe/soil system, not just the sewer. A distinction should be made between the identification of random defects that are due to isolated events and systematic defects that are generally designed or built into the sewer.

The problems and the underlying causes to be addressed will in general be due to a combination of factors related to the pipe materials, their condition and that of the surrounding materials. Any required remedial measures must be selected based on these factors as well as any social or environmental issues of relevance.

PREDICTING THE REMAINING LIFE OF SEWERS

Pipe materials

There is no perfect pipe material. The choice of pipe material is the most significant contributor to the life of any pipeline. Yet it probably receives less attention than any factor during the design process. For a pipeline to remain durable the material chosen must be able to handle any aggressive chemical elements in the effluent being conveyed or in the ground water and soil surrounding the pipeline as well as the physical properties of the effluent such as the abrasive effects of materials being carried and temperature. Under certain conditions the combined impact of chemical and physical factors can accelerate the deterioration of the pipe material. The material choice must be based on an analysis of the various components in and around the pipeline. The term pipe soil system is usually associated with structural aspects of the pipeline it is also applicable to durability considerations

Most reticulation and collector systems up to 300 mm in diameter are now constructed using PVC pipes. Many of the old sewers of this size were made from FC or vitrified clay. These are no longer produced, but as these pipes are still in the ground the problems that arise with them still have to be addressed. Although these problems are beyond the scope of this paper, many of the comments made about outfall sewers are equally applicable to reticulation and collector sewers. The main difference is one of scale.

Most large diameter collectors and outfall sewers consist of concrete pipes as this material has many advantages. However the corrosion of concrete under certain conditions is a serious problem. These conditions are frequently related to the operational problems already mentioned. Several competitive pipe materials, such as GRP and profiled wall PE which are both corrosion resistant are now available in South Africa. As these pipes are flexible they are more dependent on the surrounding soil conditions than the rigid concrete pipes. There are several orders of magnitude difference in the relative stiffnesses of the rigid and flexible pipes used for sewers. There is therefore a clear distinction between the structural parameters used when selecting these products. With rigid pipes it is the pipe strength that is the critical parameter; with flexible pipes it is the strength of the surrounding soil.

With flexible pipes, especially the thermoplastics such as PE and PVC, it is difficult to predict the remaining life. They are very strain tolerant and will deform way past the accepted deformation limits if the soil support is insufficient causing the joints to leak seriously. There will be infiltration as well as exfiltration depending on external groundwater levels and the flow depth within the sewer which will result in the further loss of soil support leading to the pipes actually buckling and collapsing. Under certain conditions the serious malfunction that occurs due to the deformation and siltation may render a sewer nonfunctional before the pipes actually collapse.

With rigid pipes which are stress tolerant, but not strain tolerant, they will crack if overloaded or there will be relative settlement between pipes. This cracking will probably be accompanied by the joints breaking and infiltration and exfiltration occurring through both. The loss of bedding support will result in further cracking and the pipes collapsing.

Corrosion prediction

When the first outfall sewers were installed in South Africa there was little idea of their service life or how to predict this. A 1949 report by the town engineer of Springs covering the severe corrosion of an outfall sewer serving that town initiated a research project funded by several local authorities and concrete pipe suppliers. Later at a conference of The Municipal Engineers a resolution was passed recommending that the corrosion of concrete sewers be researched. This was undertaken by the Council for Scientific and Industrial Research (CSIR). A key finding was that concrete using calcareous aggregate was especially resistant to sewer corrosion and an important recommendation was based on this. In addition, there were several recommendations about design detailing and sewer hydraulics (CSIR Series DR12. 1985).

The recommendations of this study were followed and since the early 1960's most concrete sewer pipes made in South Africa used dolomitic aggregates. In addition the concept of a sacrificial layer was introduced. It was anticipated that the combined effect would increase the life of concrete sewers by at least six fold. This approach has been effective and it was only after 2000 had any of these sewers had corroded to the extent that they needed to be rehabilitated. The major contributor to the corrosion problem was invariably inadequate attention to the sewer hydraulics, especially just downstream of rising mains and siphons.

This was followed by international research and by the mid 1970's a predictive model had been developed (Bowker *et al.* 1985). However it was only in 1984 that a publication with a hands-on design procedure for design engineers was written (McLaren, FR 1984.) This approach is called the Life Factor Method (LFM). This was based on the overlap of three different fields of expertise that corresponded to those identified by the CSIR publication, namely, biological dealing with the sulphur cycle, engineering dealing with the sewer hydraulics and materials dealing with cement chemistry.

The factors contributing to corrosion of concrete in sewers are the generation of hydrogen sulphide gas (H_2S) in the effluent due to anaerobic conditions in the effluent, the release of H_2S from the effluent and the biogenic formation of sulphuric acid (H_2SO_4) on the sewer walls. These are illustrated in Figure 1. (Goyns AM. 2008.) It is the reaction of this H_2SO_4 with the alkalinity in the cement that results in corrosion.

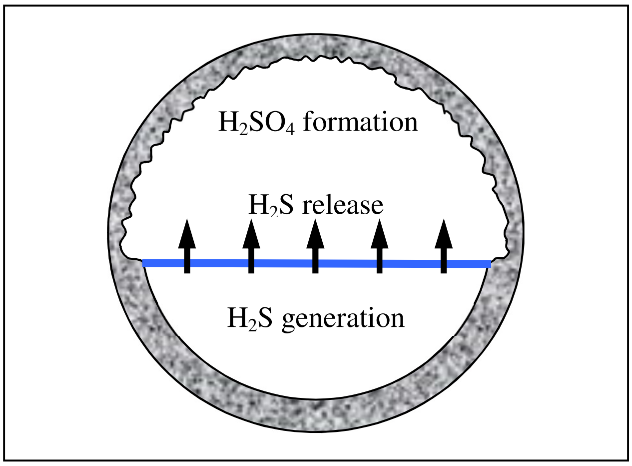

Figure 1: Factors contributing to sewer corrosion

Further research in South Africa where pipes made of various cementitious materials have been exposed for 25 years in an experimental section of a sewer in Virginia in the Free State were the conditions are very aggressive has shown that concrete made using calcium aluminate cement (CAC) and calcareous aggregate is at least three to four times as effective as the use of Portland cement (PC) and calcareous aggregate. (Goyns & Alexander.2014.) The Life Factor Model (LFM) as given in the ACPA manual has been modified to include a material factor. (Goyns AM. 2008.) The designer can then predict the life of a sewer under a given set of conditions using a range of cementitious materials provided that the material factor is available. Ongoing trials are taking place in this experimental section of sewer and the civil engineering laboratory at the University of Cape Town (UCT) to determine the material factors for a concretes made with various combinations of binders, extenders and aggregates.

For new sewers the designer can apply the equations given in these publications to determine the most cost-effective pipe material for a particular sewer. The equations can also be applied to determine the remaining life of an existing sewer based on the remaining wall thickness. It needs to be appreciated that this corrosion does not occur in all sewers; it only occurs in those where H_2S is generated and released.

A more detailed study of the subject shows that corrosion is to a large extent determined by the system hydraulics. Low velocities result in the effluent being oxygen deficient and the generation of hydrogen sulphide (H_2S) in the effluent. High velocities and turbulence result in the release of H_2S from the effluent into the sewer atmosphere. A combination of H_2S generated in the upstream reaches of a sewer where the velocities are low and the release of H_2S in the downstream reaches is frequently the underlying cause of sewers corroding.

Pipe strength

Factory test loads and reactions are concentrated, but field loads and reactions have a parabolic or radial distribution. The structural requirements for rigid pipes are specified in terms of the pipe strength, whereas the structural requirements of flexible pipes are defined in terms of their deflection. It is assumed that in-situ loads are uniformly distributed over a pipe and that reactions are either parabolic or uniform, depending upon the bedding material.

This is realistic for sewers as they are usually placed with at least 600 mm of cover over them, except in the case of larger diameter pipes where this cover should be at least half the pipe diameter. Under these circumstances any traffic loads are distributed over the whole outside pipe diameter. The required strengths for a rigid pipe or the stiffness for a flexible pipe under given installation conditions can be calculated using the procedures given in pipe manufacturer's literature.

Remaining life

Pipelines deteriorate with age. The critical issue for the sewer owner is its remaining life before it needs rehabilitation or replacement. The secondary issue is how effectively and efficiently the sewer will perform for this remaining life. Answers to these questions will depend to a large extent on the pipe material used.

For concrete sewers the required pipe strengths along the sewer needed to carry the actual loads determined using the installation conditions can be calculated. Assuming that the material around the pipes is still intact it will have consolidated over time and the loads on the pipes will probably be less than those used to determine the pipe strength. On the other hand if cavities have formed around the pipes and bedding support has been lost the load carrying capacity will be less than it was when the pipes were installed.

The corrosion just above the average effluent flow level (about half way up the pipe) is usually greater than that at the crown of the pipe, so the residual strength should be calculated based on this wall thickness. As these pipes are generally reinforced and this reinforcement generally accounts for at least half the pipe's strength, a good indicator of the residual strength is whether or not the reinforcement is exposed, where it is exposed and the extent to which it has corroded. If the steel at the crown of a pipe is corroded through at places then the pipe could be very close to collapsing and will probably have to be replaced. On the other hand if the steel is exposed and corroded at the sides of a pipe and not exposed at the crown the pipe will still have some strength and the pipe can probably be rehabilitated.

The required pipe strength based on the actual conditions needs to be compared to the predicted pipe strength based on the remaining wall thickness and whether or not the steel reinforcement is intact. This will indicate just how much residual strength the pipes have. The remaining life of the pipes can then be estimated by applying the Life Factor approach to their residual strength. This is a fairly complex exercise for a reinforced concrete pipe as there will be a dramatic loss of strength once the reinforcement is no longer intact.

CONDITION ASSESSMENT

General

Condition assessment is comparing the performance of an asset at a given date with its performance when the asset was first put into service in terms of the requirements specified. For a sewer this involves determining these original requirements, studying the drawings to location sections where problems are likely to occur and walking the route where possible to search for telltale indications of problems and accessibility for inspection equipment as well as surface constraints both natural and manmade. This will provide a realistic overview of the surface conditions.

Desktop study

Once the preliminary overview has been done and before undertaking any internal inspections the hydraulics of the system should be evaluated to locate where there are:

- flat gradients or changes from steep to flat gradients and deposition is likely to occur
- rising mains, rising mains feeding into the sewer or siphons where H_2S is likely to be generated
- steep gradients where H_2S is likely to be released because they are downstream of sections where H_2S is likely to be generated
- sudden changes in vertical and horizontal alignment, as this is typically where H_2S release is a problem
- residential, commercial or business developments in close proximity to the sewer
- other services I close proximity to the sewer
- sections of sewer running in close proximity to transportation routes
- high fills over the sewer in particular where these are below transport routes
- sections of sewer traversing wet lands, adjacent to watercourses or below the 50/100 year flood lines

This preliminary study should identify any critical sections on the sewer where it may be necessary to do some preliminary checks by doing short inspection either side of manholes to determine whether there are sections of sewer that need to be cleaned before inspection and whether the camera should be transported through the sewer on a tractor or a pontoon. Together with the surface inspection of the site it will greatly assist in planning the subsurface inspections.

Internal inspection

The use of reliable and affordable CCTV inspection systems to inspect gravity pipelines and capture a visual representation of their internal condition has probably been the major driving force behind the development of trenchless rehabilitation techniques. The age old adage about ‘out of sight - out of mind’ can no longer be used. Pipelines can now be inspected and an accurate visual representation of their hydraulic performance, water-tightness and durability and structural integrity obtained.

CCTV cameras are designed to give high resolution colour images and can be fitted with a variety of lenses. The simplest have a fixed, forward viewing head, whereas the more sophisticated ones have a pan and rotate head so that the detail of a specific defect or feature in a pipeline can be viewed. They can also be fitted with zoom lenses to obtain close up views of specific areas. The cameras are waterproof so are able to operate in a gravity system that is flowing partly full. Adjustments can be made to the lens height so that it remains above the flow level anticipated in the pipeline to be inspected. Most cameras are mounted on self-powered tractors which are operated from a console panel in a vehicle parked on the surface. However at times it may be necessary to place a camera on skids or floats so that it can move through a pipeline operating under specific conditions.

The CCTV cameras can go into pipelines much, much smaller than man entry, they are not susceptible to the hazards of noxious gases and they provide a permanent visual record of the conditions inside the section of sewer inspected. Defects are identified as well as their location and extent. However these inspections may only give an indication of the defect severity, do not show conditions below effluent surface do not give physical measurements and don't provide information about the conditions in the soil outside the sewer.

This traditional inspection approach provides visual imagery, however vital decision making questions remain, namely, is corrosion present, and if so to what extent, what is the current capacity loss due to debris and is the pipe deformed and to what extent.

The introduction of lasers for above water scanning and sonars for below water scanning can now be added to a pontoon carrying the CCTV camera and provide a digitized profile of the whole pipe surface and its internal dimensions at very close centers. As the information is digitized the full 360° of the pipe surface along a prescribed length of sewer can be represented in two dimensions as a 'flat sheet' which is colour coded to illustrate the extent of defects.

While CCTV cameras will provide above water indications that there is sediment or corrosion, they do not quantify either. Using a multi-sensor technology (synchronized CCTV, sonar and laser) system is a great forward in the understanding of conditions inside a large diameter sewer. Sonar data (sub-surface) enables the owner to establish the depth and quantity of siltation along the sewer invert. Knowing this means that cleaning contractors are able to provide realistic quotes as they will not have to carry the risk of handling unknown quantities of debris. In addition this information on the debris gives a modeller an understanding of their model output. The laser (above surface) is critical because it will give a measure of pipe wall that has corroded away.

The only detail missing from this combination of inspections is that describing the external soil conditions.

Physical Inspection

The CCTV inspections and laser/sonar profiling provide valuable information using inexpensive means, but still do not provide a complete picture. It is therefore recommended that a few spot physical measurements be made. This involves the identification of sections of a sewer where severe corrosion is anticipated which can be easily exposed from the surface and an inspection window cut so that an investigator can do a live inspection and if necessary take measurements, photographs and material samples. Such a window is illustrated in Figure 2.

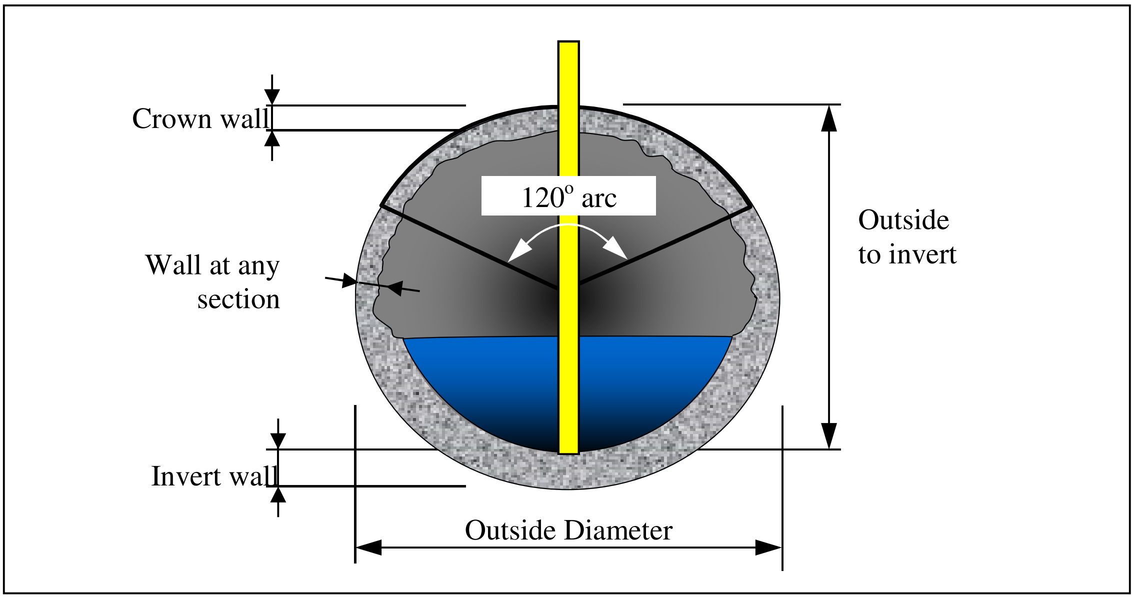

Figure 2: Illustration of an inspection window

This type of inspection can be carried out concurrently with a CCTV inspection and the respective results calibrated to provide a comprehensive impression of the sewer condition. Although the LFM and the additional factors described above endeavour to model actual conditions, it would be extremely useful if the data obtained from these models could be compared and empirically confirmed. By comparing the corrosion rates from the theoretical analysis with the physical measurements of corrosion in an existing sewer and the output from an internal survey the modelled condition can be verified or disproved.

A diagram illustrating the interaction between the various sources of data obtained from a sewer is presented in Figure 3. If the corrosion rates determined from the theoretical analysis and the physical inspection correlate and the CCTV survey indicates that the conditions are consistent along the sewer the response to the sewer condition will be straightforward. The rehabilitation procedure depends on technical issues related to the severity and cause of the problems, the size of the project and availability of technology.

If the corrosion rates in this comparison do not agree, the reasons should be investigated. In most such cases effluent being conveyed is domestic and the measured corrosion is greater than that predicted. This indicates a higher dissolved sulphide content than that calculated by an analysis of the sewer-section hydraulics and that it is necessary to extend the analysis to include the upper reaches of the sewer. An upstream rising main or siphon with a long retention time is usually the source of the problem.

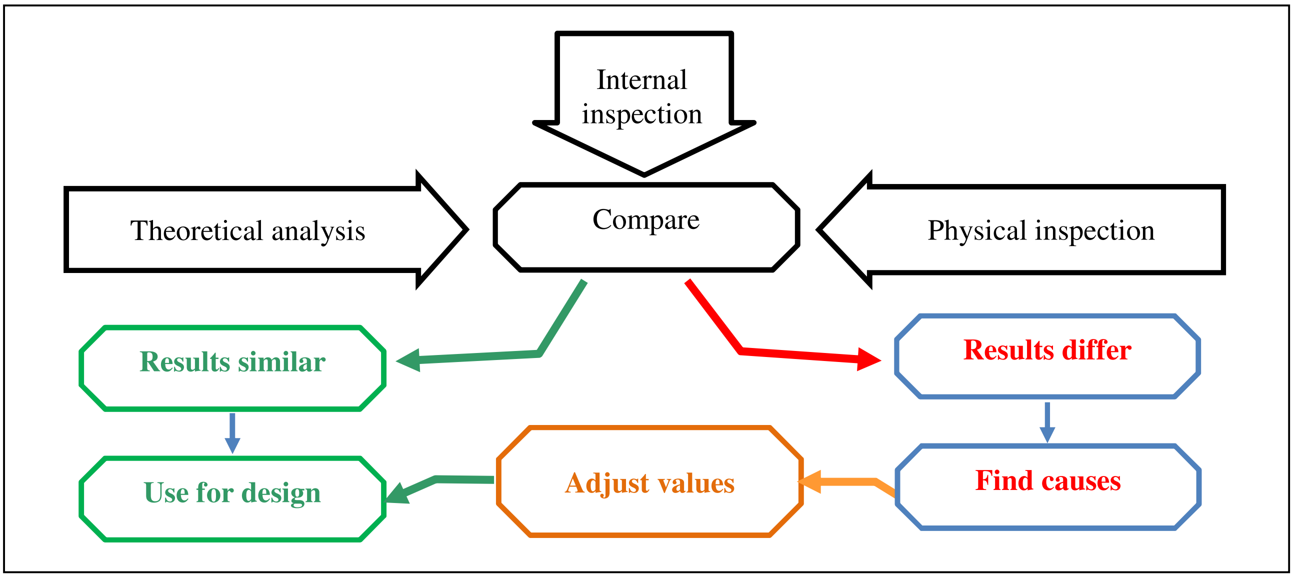

Figure 3: Comparing physical, theoretical and inspection results

Joints, transitions and manholes

The function of the joints is to provide both a seal and flexibility between the individual pipes in a pipeline. The movements that can occur within the soil mass around a pipeline require the joints to handle movement in three dimensions, namely, draw or longitudinal movement along the pipeline, deflection or radial movement relative to the pipeline centreline and relative settlement or displacement of an individual pipe relative to the adjacent pipes.

Apart from the upper reaches of reticulation systems the access to sewers is via manholes. They are placed whenever there are junctions, transitions and changes in alignment and where access is needed on long straight sections. As the loading on manholes is different from that on the adjacent sections of pipeline there can be relative movement between manholes and pipes.

Many of the defects leading to failures in sewers occur at joints and in particular those at manholes where changes are made. If measures are not taken to minimize the disruption to flow through manholes and the associated energy losses not considered the hydraulic performance of a sewer can be seriously compromised and if measures are not taken to accommodate any potential relative movement between pipes and manholes, pipes can crack or deform resulting in leakages. It is therefore essential that special attention be given during inspections to identify any defects which occur at joints and this is why a CCTV camera with the ability to pan and rotate should be used for sewers.

The above and following comments on pipes are equally applicable to manholes and other on line structures.
Risk analysis

The final stage of the condition assessment of a sewer is the risk analysis. The risk of not rehabilitating or replacing a sewer once its condition has been assessed has to be evaluated in terms of the probability of failure and the consequences of failure. There are two categories of failure to be considered, namely structural and hydraulic. While corrosion is the primary cause of structural problems, this can also have a significant influence on the hydraulic performance due to the aggregate fallout accumulating on the invert.

CLASSIFICATION AND GRADING OF DEFECTS

All the defects (there are a multitude of them) that occur inside a sewer can be broadly classified in four categories that correspond to the performance criteria given above, namely hydraulics, water tightness, durability and structural integrity that are or will be compromised when it ages and/or malfunctions.

In addition to classification the defects need grading so that decisions about condition are quantifiable. While there are a multitude of defects that have to be recorded the grading of these should be kept simple, with few options and clear guidelines to provide a straightforward procedure for the inspection equipment operator. In Europe operators are trained and certified. In South Africa the required facilities to do this are not available and operator training is done in house by the companies offering this service. An grading system requiring a minimum of specialised skills, but is accurate and consistent should be employed. Serious defects indicating a failure or an imminent failure of a sewer require priority treatment, whereas minor inaccuracies in the classification of less significant imperfections should not be seen as critical.

A grading system using five defect severity levels is usually adopted for sewers or stormwater drains. These are normal, minor, moderate, severe and critical. They are defined as follows.

Normal - a section or reach of sewer that does not have any defects or where there are defects or marginal incidents that do not affect the functionality of the sewer or its life expectancy. This includes any defect that may have occurred during the manufacture or installation of the pipe, such as small variations in dimensions and alignment, or minor surface imperfections that fall within the requirements of SABS 1200 or any other relevant standard and are thus acceptable.

Minor - any defect that is not currently a problem but might become one in time. Typically this would be a defect such as a root or any other object that should not be in the sewer. Any defect that by itself is not a problem, but when considered in conjunction with other defects could contribute towards a future problem in the sewer means that this reach should be given this overall classification.

Moderate - any defect that affects the effluent flow, might result in the pollution of ground-water, or threatens the structural integrity of the sewer. This includes any defect that has the potential to result in a blockage in the medium to long term, infiltration or exfiltration at joints or affect the structural integrity of a pipe in the reach.

Severe - any defect that has immediate negative consequences for a pipe reach. Where multiple severe defects occur in a pipe reach between manholes, the pipe requires urgent attention and should be scheduled for rehabilitation in the short to medium term. This includes defects such as obstructions and broken (not collapsed) pipes. Such defects can result in severe obstructions to flow during peak periods which could be indicated by the surcharging of the upstream manholes.

Critical - any defect that poses a threat that will render the sewer non-functional and needs immediate attention. This includes defects such as collapsed pipes and blockages. If such defects are not dealt with immediately they can result in really serious outcomes such as major sewer spills or whole sections of a sewer collapsing.

REMEDIAL MEASURES

The condition assessment of a sewer provides the information needed to make decisions about what needs to be done to a sewer to reinstate its serviceability. This may just be to routinely maintain the efficient operation by routinely cleaning the sewer. There may be isolated sections of the sewer which cause problems, such as poorly constructed or inadequate benching at manholes or damaged pipes due to random occurrences which need localized or point repairs. Then there could be whole sections of sewer that have deteriorated, generally due to a systematic defect built into the sewer which need rehabilitation. For these decisions about the most suitable method for the sewer, taking into account the capacity, water tightness, durability and structural requirements needs to be determined.

Trenchless rehabilitation techniques currently available in South Africa are:

- Sliplining involves the insertion of a smaller diameter liner pipe into a larger diameter host pipe. A continuous string of the liner pipe is created by welding sections of new pipe together on site. The main advantages are ease, speed and economy of installation, while providing a sealed section of sewer. As this is not a tight fit solution this technique will reduce the inner diameter of a pipe and is therefore only suitable where capacity is not critical. A further disadvantage is the space required for the launching pits.
- Cured-In-Place-Pipe (CIPP) involves the insertion of a resin impregnated, soft-liner into a sewer. The liner is then inverted and cured by heat or ultra-violet light. It is quick to install and causes minimal disruption. It is suitable for large diameter sewers where hydraulic capacity is critical as the liner is thin and a tight fit having a minimal impact on the capacity. In fact there is usually a slight increase in capacity. The liner is both highly chemical resistant and can be structurally designed should the existing host pipe have deteriorated so badly that collapse is imminent. As it is a close fit it will conform to the shape of the host pipe and this may be a problem if there are sharp changes in pipe profile causing the liner to be over stressed.
- Spiral-Wound Lining involves feeding profiled uPVC or HDPE strips into a mandrel placed in a manhole to form a continuous spirally wound pipe whose external diameter is slightly smaller than the internal diameter of the host pipe. When this liner is extended along the host pipe to the required length it is expanded so that it fits tightly inside the existing host pipe, while still keeping its circular shape. It is suitable for large diameter pipes where hydraulic capacity is critical as the flow reduction is minimal.

The hydraulic and structural requirements of a sewer as well as the site constraints will need to be evaluated before making choices. As these lining systems are water tight, the rehabilitated sewer can also be made water tight, if required, by sealing the liners into the host pipe at the manholes. Hence all these techniques need to be designed to handle external water pressure. The preferred technology for a particular sewer will also be based on whether the flow in the pipe can be diverted and whether it is possible to install the technology in a live or partly live system.

On reticulation and collector sewers which have deteriorated and have insufficient capacity a frequently used on line replacement technique is pipe-cracking/upsizing which provides a new sewer of a larger diameter, hence greater capacity. Other trenchless technologies that are used for local repairs are the CIPP patch repair, and grouting for sealing joints. The latter techniques may well be justified when there are isolated defects over short sections of sewer where point repairs from the surface are inconvenient and rehabilitation from manhole to manhole is not economically justified.

CONCLUSIONS

The value of condition assessments is that the municipal engineer or his representative can make technically sound and cost effective decisions on the repairing, rehabilitating or replacing of sewers based on social, environmental, practical and economic constraints. A strategy of simultaneously rehabilitating existing sewers and installing new sewers where existing capacity is inadequate or for new developments will accelerate the provision of sanitation for all in South Africa.

If the sewers used to line the holes through the soil are not effective the holes will not function effectively or efficiently and there is the possibility that the holes will collapse and daylight as sinkholes. Sewers will gradually deteriorate with time and eventually fail to serve their function. They should be inspected periodically to assess their condition and when necessary rehabilitated to ensure a sustainable service.

With the technical information currently available there is no reason why new outfall sewers cannot be cost effectively designed and installed to last for 100 years or longer. The secret to this is making sure that both designer and contractor are competent, and that the appropriate pipe is selected. Using a competent designer and contractor may incur an initial capital cost that is slightly higher, but will reduce operational costs and significantly lengthen the period before rehabilitation is necessary.

CCTV inspections plus laser and sonar profiling can describe defects in terms of their location, extent and severity. This plus installation details means that their residual strength and remaining life can be predicted.

South Africa can no longer afford short term solutions; we need solutions that are technically sound and cost effective in the long term that will serve future generations. With the condition assessment tools available there is no reason why existing sewers cannot be rehabilitated to serve future generations.

RECOMMENDATIONS

Condition assessment should always precede rehabilitation. This will ensure that only those sections of sewer that need rehabilitation are rehabilitated.

Newly installed sewers should be assessed to ensure that they meet the specified requirements.

Existing sewers should be periodically inspected so that their condition can be assessed and remedial measures taken to rectify any defects identified before they become serious problems.

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