SOUTH AFRICA'S FUTURE SERVICE NEEDS: DEVELOPMENTS IN TRENCHLESS TECHNOLOGY CAN MEET THE CHALLENGES

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ABSTRACT

South Africa's Civil engineering focus has shifted from economic infrastructure to social infrastructure and in particular providing basic services to those previously without. Urban populations, due to the migration of employment seekers, are growing at almost double the national rate, compounding the problem of meeting the service delivery backlog. Minimizing the social and environmental impact of construction in densely populated urban areas has to be met within economic and political constraints.

Buried service installation, in particular water services is especially disruptive to the movement of people and vehicles. Many existing services designed for smaller urban populations have reached the end of their planned service life. The local authority is now faced with quandary of whether to replace or rehabilitate these services whilst still providing technically sound and sustainable solutions within the constraints posed by future densified urban environments. Globally, big cities have faced similar situations but not at the rapid urbanization rates challenging South Africa's municipal authorities. Internationally, this led to the phenomenal development and growth in trenchless techniques for installing new and rehabilitating existing buried services. This was initially driven by the specialist contractor who could do the work at a lower cost than conventional open trench installation. However this is not the only benefit. The true costs of replacing buried services must include those associated with social, environmental and commercial disruption, worker and public safety and maintaining quality standards. When included the trenchless options are usually far more cost effective. By the very nature of the products and processes used the rehabilitated services will probably serve their function for considerably longer than the original period during which they operated.

Trenchless techniques are used for the installation of new services and the rehabilitation (maintenance, renovation and replacement) of existing water, sanitation, stormwater and cabled services. Some techniques, such as directional drilling and microtunnelling work where open trench methods are impossible and others, such as pipe bursting can replace and upsize pipelines using the same labour compliment as open cut methods, but at lower costs. Developments include multi sensor inspections which give a complete picture of an operating pipeline's internal conditions, providing essential data needed to assess its condition before deciding about whether remedial measures are needed and if so what techniques to use.

These cutting edge techniques can make a significant contribution towards reducing South Africa's service delivery backlog and several can simultaneously provide sustainable employment leading to the development of skilled and semiskilled workers.

INTRODUCTION

Water and education are probably the two most serious factors limiting the progress and upliftment of the under privileged in South Africa. The country has limited water resources and much has been done over the past decades to prepare the country for the growth in population, urbanization and industrialization anticipated. In this regard those previously involved with the planning, designing and construction of the macro water supply infrastructure have served the country admirably. With the changes in the country's political dispensation the problems of extending the provision of water to all has been challenging, but would not have been achievable had it not been for the foresight in developing this macro infrastructure. The provision of wastewater conveyance and treatment services has always lagged that of water supply.

Unfortunately the same cannot be said for the education system. Apart from overcoming the historical problems this needs to be extended beyond what is traditionally taught in the class room to cover the significance of basic hygiene and the use and conservation of water in the high density urban areas. This is beyond the scope of this paper. What is however essential is that those involved in all aspects of providing water services have a grasp of the basics involved with the movement of water, the interactions in the pipe soil system and the deterioration of pipe materials over time. These will be dealt with very briefly.

Shift in focus

Since the mid 1980's South Africa's Civil engineering focus has shifted from economic infrastructure to social infrastructure and in particular providing basic services to those previously without.

The urban population, due to the migration of employment seekers, has been growing at least 50% faster than the national population since 1995, compounding the problem of meeting the service delivery backlog. This can be seen from Figure 1 where the brown line and the right hand axis give the percentage of population that has urbanized. The densification of urban areas already serviced by the subdivision of stands and the building of townhouse complexes has added to the problem as these existing services were designed for larger stands and smaller urban populations spread over a wider area. The combined effect of these two factors means that there is a serious under capacity of the existing water services. In addition they have reached the end of their planned service lives and although they may well still be in good operating condition

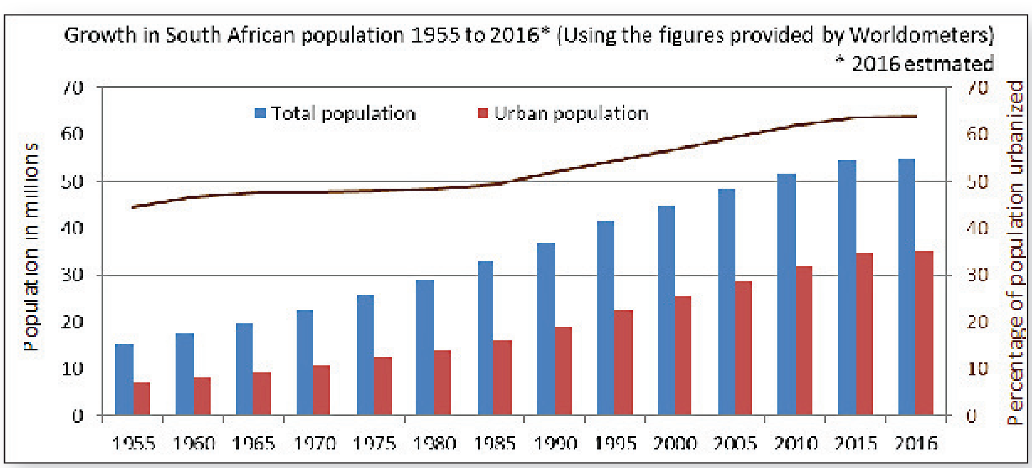


FIGURE 1 Growth and changes in South African population between 1955 and 2016 (Worldometers2015)

they have to be replaced to deal with the increased demands. The servicing of informal areas and multiple level residences where the population densities are at least an order of magnitude higher than that on the traditional urban erven mean additional demands on the capacity of water services.

Minimizing the social and environmental impact of upsizing these services in densely populated urban areas has to be met within economic and political constraints. This requires a shift in approach to find better and more efficient and less disruptive ways of meeting these needs.

Problems with buried service installations

Buried service installation, in particular gravity water services, such as sewers and storm water drains, which are frequently placed at depths exceeding two metres is especially disruptive to the movement of people and vehicles due to space requirements for trenches and spoil. When this is done in new developments the space is available to dig trenches and stockpile the spoil along the trench sides. However in established areas it is not just the space that the trench takes that has to be accommodated; it is the space for the excavated material, the storage of the products to be installed, for the equipment doing the installation and access for residents and businesses. For both the practical and safety aspects there are limits to the trench depths that can be dug by hand. Hence for sewers mechanized equipment is generally needed.

When these services have deteriorated and no longer providing the required service the local authority is faced with quandary of whether to replace or rehabilitate these services whilst still providing technically sound and sustainable solutions within the constraints posed by the future densified urban environments.

Globally, big cities have faced similar situations with rapid urbanization but probably not at the rates challenging South Africa's municipal authorities. Internationally, this led to the phenomenal development and growth in trenchless techniques for installing new and rehabilitating existing buried services. South Africa can learn from what has been developed elsewhere by adopting what is relevant and adapting to meet the local conditions.

ADVENT OF TRENCHLESS TECHNOLOGY

Trenchless Technology (TT) is the science of installing, repairing or renewing underground pipes, ducts and cables using techniques that minimize or eliminate the need for excavations. TT falls into four broad categories, namely:

- renovating existing services using techniques such as sliplining and cured in place pipe
- on-line replacing of existing services using techniques such as pipebursting and pipe splitting
- installing new services using techniques such as pipe jacking, micro tunnelling and directional drilling
- inspection and location of services (ISTT, pre 2000)

Prior to making any decisions about what work should be done it is essential that the condition of the service is assessed by undertaking a:

- site investigation to determine soil and groundwater conditions as well as surface constraints
- pipeline or service inspections to assess their condition
- survey to locate pipelines, other services and potential sub-surface obstacles
- a risk analysis of the situation, so that activities can be prioritised

TT is probably the most significant single development in service installation since the change from open channels conveying sewage running along city streets to the installation of service conduits below the surface. It has extended the use of the three dimensional space below the urban surface in a similar way that multi-storey buildings have extended living and working space above the surface ground level.

Historical development

TT development was initially driven by the specialist contractors who could install and replace services in the high density urban areas in the established European cities at a lower cost than the traditional open trench approach. With the increasing awareness of the negative impact of environmental damage, social disruption and hydrocarbon emissions the adoption of these techniques has been extended significantly. In addition to this there are certain technical advantages offered by these techniques which minimize and may even eliminate some of the difficulties in meeting the requirements of buried services.

Probably the biggest challenges at present facing the TT industry in Southern Africa are:

- little appreciation of the benefits resulting from managing buried services throughout their full life cycle
- little understanding or awareness of the capabilities and benefits of using TT
- the lack of national standards covering the designing, selecting, specifying of TT work
- the misconception that TT does not offer employment opportunities (Goyns & Crofts,2001)

Technical requirements

Irrespective of the way that a pipeline is installed the owner, on behalf of the end user, has certain requirements that need to be met, namely, size, water tightness, strength and durability. The decisions regarding these should be made before those of the short term cost considerations. When they are made based on a sound technical basis they will, generally, provide the best long term solutions with the minimum operating and life cycle costs. The argument that capital costs can be reduced by cutting on the planning, design and supervision of projects is not valid. They only represent about 8 % of the capital costs and reducing them compromises the quality of design and workmanship on site. This is having a detrimental impact on the long term performance of projects. Defects are designed and built into the systems and the operational and maintenance costs increase and the necessity to replace or rehabilitation can occur before the end of the expected design life of the service. The impact of this can be well in excess of the original preconstruction costs. A typical example of this is the number of outfall sewers installed since the mid 1980's, that should have used concrete pipes lined with polyethylene (PE) due to the aggressive nature of the effluent, but used concrete pipes with a sacrificial layer, or coated fibre cement pipes, that have needed rehabilitation or replacement before 40 years which at the time was considered to be an acceptable design life. The writer has been involved on projects were sewers and stormwater drains have had to be rehabilitated or replaced less than ten years after installation due to inadequate technical input prior to and during construction.

A few simple basic facts need to be understood by all concerned with making decisions about water services:

- The client's real asset is the hole through the soil. The pipeline is just the lining to the hole which should ensure that it operates effectively and efficiently and that it will remain structurally sound.
- The hydraulic performance of pipes flowing under pressure and those flowing partly full is different.
- Buried pipelines consist of pipes, joints and the surrounded by soil. So there is a pipe/soil interaction.
- With gravity systems in general it is the soil that plays the dominant role. If the soil surrounding the pipes has inadequate strength and compaction the system will be overloaded and fail structurally.
- When a pipeline leaks its bedding support is removed over time and eventually the pipeline is no longer able to carry the external loads and this too will result in structural failure.

- The corrosion of pipes made from cementitious materials is due to a combination of hydraulic and biological factors. Pipes made with a standard Portland cement concrete could last as little as five years or more than fifty years dependent upon the combination of these factors.
- When a pipeline is lined, the lining will seldom bond to the host pipe. This means that there will be a gap between the host pipe and liner which will fill with groundwater and the groundwater pressure will generally be the critical factor in the liner design.
- Rehabilitation can minimize the impact of defects designed and built into a system, but can't eliminate them. In some cases the only way to rectify the situation is to replace the service.

The benefits

The direct costs of digging trenches are described above. However the true costs of installing new or replacing buried services must include those associated with social, environmental and commercial disruption, worker and public safety and maintaining quality standards to ensure that requirements of the service are met. When these factors are taken into account the trenchless options in urban areas where trenches deeper than 1.5 m are required are usually more cost effective.

In addition to this with the rehabilitation and upgrading of existing services the problem of damage to existing services is minimized because most of the work is done within the existing conduit which is being rehabilitated or upgraded. Any excavation that has to be done is usually done by hand as it is in confined spaces and in close proximity to other services where the use of excavating equipment is inappropriate.

Trenches dug across existing roads to install new services disrupts traffic. But as this work is done in a hurry the backfilling of these trenches is invariably inadequate resulting in surface settlement and the need for frequent maintenance. There are trenchless techniques for doing this that do not disrupt the traffic and provided that they are correctly done do not affect the road surface.

The type of material and the processes used for the rehabilitation of existing services means that they will probably serve their function for considerably longer than the original pipes did. This is because the materials most frequently used for liners, such as, PE, PVC-M and those for cured-in-place-pipe (CIPP) are corrosion resistant to most effluents and the soil around the host pipe has already consolidated, so there is seldom soil movement after service has been rehabilitated. When an existing service is replaced on line with pipe-bursting the pieces of the original pipe are pushed and compacted into the surrounding soil. Installation of new services using techniques such as directional drilling or moling usually use thermoplastics such as PE or PVC that are corrosion resistant, robust and flexible. As the installation loads imposed on these conduits usually govern the structural requirements any problems that occur do so during construction and it is extremely unlikely that any problems will occur once these conduits are in service. If problems do occur they are almost always due to the lack of attention during the preconstruction stages and in particular to inadequate geotechnical investigation, resulting in an inappropriate technique or equipment being used.

RANGE OF TRENCHLESS TECHNIQUES

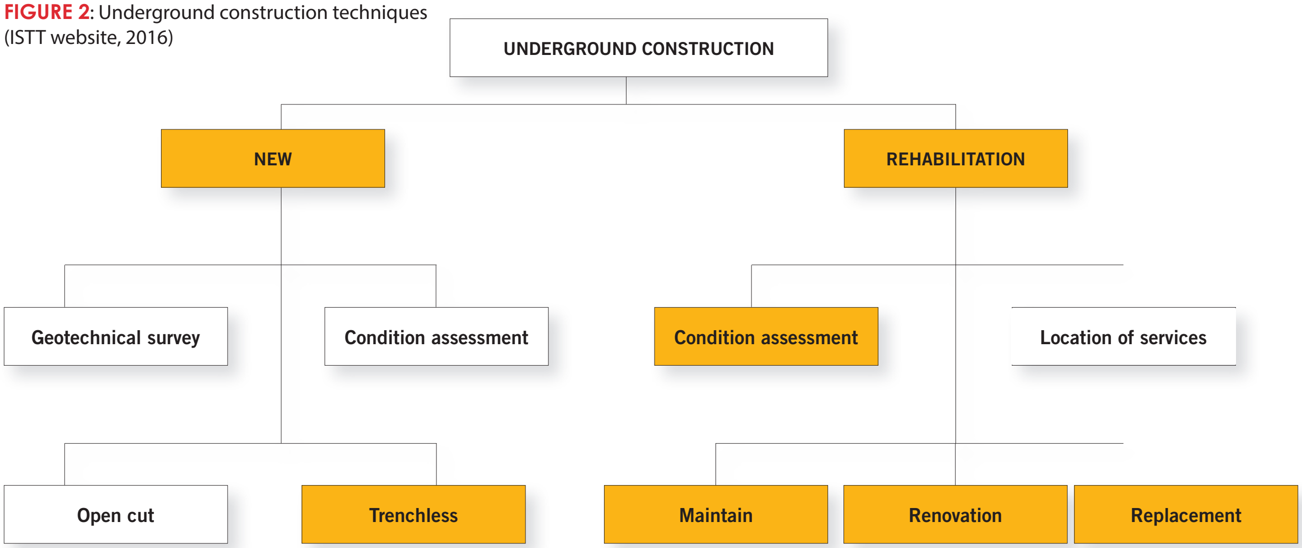
The International Society for Trenchless Technology (ISTT), of which the Southern African Society for Trenchless Technology (SASTT) was one of the earliest members, has produced a diagram showing the relationship between the various TT techniques and underground construction as a whole. This is condensed in Figure 2. This paper will cover the shaded components of the diagram as they relate to water services.

Performance and condition assessment

The pipeline owner wants to know how well the service is performing and its condition at a particular date, how this relates to its designed performance and how well it is going to meet the original requirements in the future so that decisions can be made about the need for maintenance and repair, renovation or replacement and when this will be required, so that the necessary planning can be done. This means that the performance and condition assessment needs to be done before any preliminary planning and design work is done so that the economic implications of any work required can be realistically established. A distinction needs to be drawn between the hydraulic performance of the conduit in terms of meeting the capacity requirements and the physical condition of the conduit which will determine its remaining life. There may be no problems whatsoever with the condition of the conduit, but it may have insufficient capacity for the present flows and consequently be seriously undersize for the predicted future flows. On the other hand the capacity may be adequate, by the condition may be such that collapse is imminent.

There is the misconception that the classification and grading of defects based on the output of inspections is condition assessment; it is

FIGURE 2: Underground construction techniques (ISTT website, 2016)



not. The output from CCTV, laser and sonar inspections (multi sensor inspections) and the classification and grading of defects based on these are the critical and most bulky input required by the condition assessment process. But the performance and condition assessment involves a holistic evaluation of data from as many sources as possible. In addition to the internal inspection data it should cover detail gained from:

- flow measurements to determine the actual performance
- a surface inspection along the route to identify the surface constraints
- the as built drawings (if these are available)
- an analysis of the effluent composition
- an evaluation of the soil conditions around the conduit (it may be necessary to dig a few trial pits

The condition assessment of a buried conduit should conclude with:

- a statement of the problems, their location, extent, severity and causes
- a comparison of hydraulic performance with that required during normal and peak flow conditions
- an estimate of the remaining life of the pipeline/service along its length
- a risk analysis based on the risk of the service failing and the consequences of failure. This too should look at the whole length of the service so that action on any critical sections can be prioritized.

Rehabilitation

Based on the output from the condition and performance assessment decisions can be made about the necessary measures needed to ensure that the pipeline provides the required level of service for a specified time period. These measures could involve:

- doing nothing if the performance and condition are satisfactory
- maintenance and repairs, such as cleaning, sealing joints and point repairs/replacements
- renovation which could be non-structural, such as spray lining to inhibit or prevent corrosion or structural, such as cured-in-place-pipe (CIPP) where the pipeline's structural integrity has deteriorated and the liner is required to strengthen the pipeline to prevent its collapse
- replacement using techniques such as pipe cracking or reaming where the pipeline has either insufficient capacity or has deteriorated structurally to the extent that it cannot be renovated

Repair and maintenance

Many of the sewers in South Africa's coastal cities are installed at very flat gradients and it is almost impossible to maintain self-cleansing velocities. There are several factors that exacerbate this problem that are either designed or built into these sewers and in many cases cannot be remedied by renovation. Hence routine maintenance is necessary to keep them functioning.

Practice of using a single value for self-cleansing velocity. The size of particle that can be transported by the effluent in a conduit is dependent upon the flow velocity. Flow velocity in turn is influenced by sewer roughness, diameter and gradient. By way of example, if the velocity needed to transport a 3 mm stone through a 150 mm sewer is 0.7 m/s the velocity must be increased to 1.06 m/s to transport the same stone through an 1800 mm sewer. Failure to make the necessary gradient adjustments will result in deposition.

Wherever possible the gradients should be adjusted during design to ensure that the minimum downstream velocity is linked to the upstream velocity so that once an object enters a system it can be carried through it.

Insufficient attention paid to founding conditions. When there are very flat gradients (< 1/600) as frequently occurs with large diameter sewers any differential settlement between manholes could result in local changes to the gradient from one pipe to the next which in combination with the tolerances on the internal diameters of individual pipes can result in the specified laying tolerances not being met and the localized accumulation of silt. As the flow under these conditions will be sub-critical any disturbances to flow could have a cumulative effect moving upstream resulting in further deposition and reduced capacity. This consolidates over time and may become difficult to remove as it gathers objects such as cans, bottles and other waste materials that would normally be conveyed by the effluent flowing at a consistent velocity.

This is likely to occur when the founding conditions are variable or have insufficient bearing capacity and provide inadequate foundation support for the pipe bedding. The situation cannot be rectified with the bedding placement or the pipe installation, no matter how much care is taken, as it is due the conditions in the underlying insitu material. Under these conditions it is essential to ensure that the founding conditions below the bedding are stabilized by importing and compacting inert materials, such as crushed rock or stone into the underlying material, or removing and replacing this founding material with material that remains stable and provides a uniform bearing surface for the bedding.

Checking levels at manholes after installation and not along each individual pipe as it is installed is not adequate under these conditions. It is essential that potential problems with founding conditions are identified during the planning stages of a project and when required that the necessary measures as described above are included in the project specification and checked during installation to ensure that the prescribed gradients are achieved and can be maintained. It may also be necessary to specify tighter tolerances that those given in the SANS standards for the internal diameters of the pipes to be installed. Should these not be done a problem could be built into the system requiring routine cleaning to remove deposits and ensure that the sewer maintains the necessary capacity.

Inadequate details specified for manhole construction. Changes in both vertical and horizontal alignment are (or should be) made at manholes. If a manhole is not benched to match the profile of the conduit flowing into and out of it there will be significant energy losses and in extreme cases these losses can exceed the velocity head in the sewer even though there are no changes in alignment. When there are sudden changes in either or both vertical and horizontal alignment the problem is compounded causing significant energy losses accompanied by reduced velocity and the deposition of any solids too heavy for the reduced flow velocity to transport. As velocity increases the problem due to the potential energy losses becomes greater.

When the flow is subcritical the situation with changes in horizontal alignment can be rectified or partly rectified by redoing the benching so that it follows a smooth radiused curve from the inlet to the outlet with a profile dimensioned to match the bottom half of the pipes and then then continues to above the pipe over at a width equal to the pipe diameter. Figures 3 and 4 show poorly and correctly formed benching.

When the flow is supercritical the problems are more difficult to address as any obstructions to flow as can be initiated by poorly detailed transitions can result in the formation of a hydraulic jump within the sewer and the surcharging of manholes. This is illustrated by the photo inside a manhole under normal flow conditions in Figure 5. The flow is supercritical and a portion of broken benching is obstructing the flow. During peak flows the energy losses are far greater causing the manhole to surcharge and dislodge the lid. Evidence of this is shown in Figure 6. In this case the problem could be rectified. However there are many situations where the only way of rectifying such a problem that has been designed or built into a sewer is to rebuild the manhole correctly and this is seldom, if ever done.

FIGURE 3 Inadequately formed benching

FIGURE 4 Correctly formed benching

FIGURE 5 Broken benching & supercritical flow

FIGURE 6 At peak flows losses cause surcharging losses

A change in vertical alignment from a steep slope where the flow is super-critical to a flatter slope where the flow is sub-critical will result in a hydraulic jump and deposition. There is no simple solution to this problem. However if the siltation is serious and the frequent cleaning costly it may be viable to build a silt trap/grit chamber so that the periodic cleaning operation takes place at a fixed dedicated location rather than along a long stretch of sewer.

During the design of a sewer the problem can be eliminated or minimized by flattening the gradients to ensure sub-critical flow and introducing drop manholes or drop structures when the sewer becomes is too close to the ground surface. With a drop manhole the downstream invert level out of the manhole is possibly a pipe diameter lower than upstream invert level and a plunge pool that dissipates energy and provides sufficient head for the flow to enter the downstream pipe is formed.

A drop structure on the other hand consists of a chamber containing a spillway that drops several metres into a stilling basin where a hydraulic jump is forced to occur. With these two vertical discontinuities to a sewer the losses are sudden and contained at a predetermined position, which as with a silt trap, means that arrangements can be made for access should the need arise.

However as the flow into and out of these drops is subcritical the size of particles that can be carried into them can generally be transported through them.

Point repairs are at times required when services are damaged over a short distance by random events such as 'excavator attack'. In South Africa this damage is usually repaired by excavating from the surface and replacing the broken section. From a technical and practical perspective when this is done to water services the result is not always very effective. This is because when a water pipe or sewer breaks the surrounding soil becomes saturated and softens. When the soft material is removed and the pipe replaced the backfilled material frequently does not get sufficient compaction and because the soil some distance either side of the break has consolidated over time relative settlement can take place causing the joints between the new and old pipes to malfunction and possibly resulting in further breaks. This frequently happens with fibre cement and clay pipes. Although these products are no longer produced in South Africa there are still in the ground providing a service.

There are other ways of repairing short sections of pipes using trenchless methods that involve re-rounding followed by an adaption of one of the renovation techniques described below.

Renovation

The distinction between non-structural and structural renovation is that the non-structural renovation is done merely to prevent a pipeline from deteriorating to the extent that the system becomes structurally unsound, whereas structural renovation is done to restore the load carrying capacity of a host pipeline that has already has deteriorated structurally.

The non- structural techniques described below are not frequently used in South Africa, but are applicable. There are several techniques used for the structural renovation of both gravity and pressure pipelines. Descriptions of the most commonly used in South Africa follow.

Joint and crack sealing are techniques that eliminate the infiltration/exfiltration of groundwater flowing into a pipeline and overloading the system, and prevent effluent from flowing out of the pipeline into soil causing pollution. Infiltration also results in the loss of bedding support leading to the formation of cavities around the pipeline and the eventual possibility of the whole pipe/soil system collapsing and the cavities daylighting as sinkholes.

Spraying of inert linings/coatings, such as an epoxy onto a cleaned host pipe, generally steel that bond to steel and prevent further corrosion that would compromise the structural integrity and encrustation that would reduce the hydraulic capacity.

Mortar lining is an alternative to spray lining. This is generally applicable to water supply pipelines operating under pressure and seldom done on sewers. Although the recent findings on the effectiveness of concrete made with calcium aluminate cements (CAC) and aluminate or dolomitic aggregate in coping with the biogenic corrosion in concrete sewers (Goyns 2016) may prove to be a viable alternative to the inert, impermeable liners currently used on sewers which necessitate that the liners are designed to handle the external groundwater pressures.

Sliplining is probably the simplest method for rehabilitating of both pressure and gravity pipelines. It consists of pulling a new pipeline into an existing one. The new pipe usually PE provides a watertight, corrosion and abrasion resistant continuous joint free conduit from manhole to manhole. However, as the liner pulled into place has an external diameter smaller than the inside diameter of the host pipe and there will be a significant reduction in the flow area and consequently a smaller hydraulic capacity. Once the liner is in place the annulus between liner and host pipe is usually grouted which prevents the flow of groundwater through the annulus between the liner and host pipe, and improves the load carrying ability of the liner.

In addition to this the entry manhole has to be enlarged to make an entry pit and space is needed to accommodate the pipe string before it is pulled into place. The space requirement for the pipe string can be eliminated by using short pipe lengths that have snap on joints so that pipes are joined in a manhole and then pushed or pulled through the pipeline.

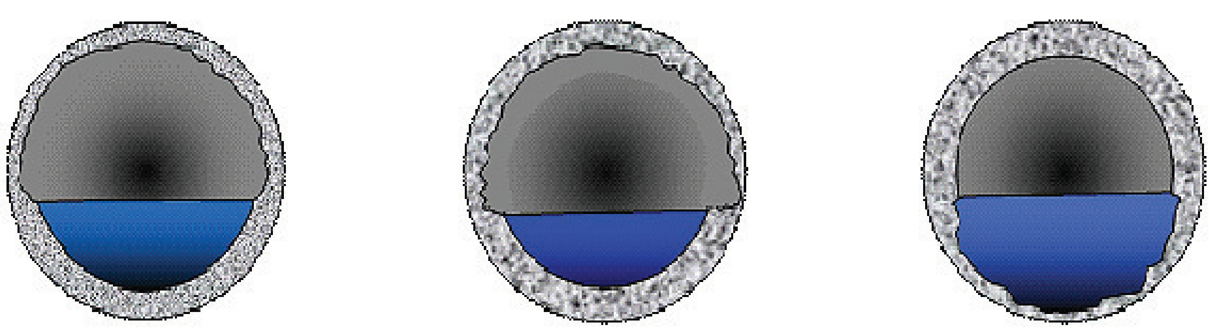
Cured-in-place-pipe (CIPP) involves the insertion of a resin impregnated fabric tube as a soft-liner into a section of pipeline which is then expanded and cured by heat or ultra-violet light. CIPP is suitable for renovation of pipes from as small as 50 mm to larger than 1200 mm. The liner can be formulated to deal with a wide range of aggressive conditions and is designed to structurally reinforce host pipes that have seriously deteriorated. As it is continuous from manhole to manhole and has a smooth surface it usually improves the hydraulic performance of the pipeline. As a CIPP liner will fit the host pipe shape it can be used for the renovation of non-circular conduits. The limiting factor is the liner thickness that can be made and inserted into a pipe.

A disadvantage of conforming to the shape of the existing pipe, which may have sharp edges if the host pipe severely corroded as can occur downstream of a rising main. This influences the structural design as any serious longitudinal defects on the host pipe will induce a buckling node and require a thicker liner to handle this. See comments under the section dealing with spirally wound liners and referring to Figure 7.

There are a range of CIPP systems using various materials, but they are all based on the same principle. The most commonly used resins are polyester and epoxy and these can be reinforced so as to provide stronger and thinner liners. The systems are quick to install and cause minimal surface disruption. CIPP was originally designed for sewers, but the technique is now being applied to the renovation of water pipelines operating under pressure.

Spirally wound liners are formed by feeding a PVC or PE profiled strip into a mandrel that helically winds it into a tube that spirals into the pipe to be rehabilitated, usually a sewer or stormwater pipeline. This eliminates the need for an entry pit as the profiled strip is formed into a circular shape within the confines of the manhole. The edges of the strip lock together forming a water-tight seal. Once the liner has reached the next or destination manhole there is a mechanism that releases a locking wire, which allows the tube formed to expand so that it fits tightly inside the host pipe. An alternative way of placing a spirally wound liner is using a machine that travels through the host pipe as it forms the liner. This is used on larger conduits where the cross sectional shape is not necessarily circular and the liner is installed to conform to the host conduit profile by using a winding cage matching the conduit profile.

FIGURE 5 Different corrosion profiles on concrete sewers



Typical corrosion pattern | **Corrosion downstream of rising main** | **Corrosion due to effluent with low pH**

Although the wound profile forms a close fitting liner groundwater can enter the annular space between the liner and host pipe and flow along this. It is therefore essential that the there is an effective seal between the between the liner and the host pipe either side of the manholes or any other connections on the line.

Reinforced spirally wound liners are used where a stiffer (stronger) lining is required. The profiled strips are made from PE and the ribs are reinforced with encapsulated steel strips. Under such conditions the annulus is grouted with the ribs providing a physical lock between the liner and the grout. When this is done the liner must be stiff enough to handle the grouting pressures without deforming. Once the grout has set the liners stiffness will be enhanced and it will be able resist much higher external pressures before buckling than it would do as a free standing pipe within a pipe.

This is an effective way for rehabilitating concrete sewers where the corrosion above the average flow level is severe, resulting in longitudinal sills along the sides and giving the sewer a 'mushroom' shape. It also an option for concrete sewers where industrial waste with a low pH (<5.5) has been discharged into them and the invert has been eaten away, sometimes completely. Using a close fit liner, such as CIPP, fold and form or swaged linings, as described below, for the conditions shown in Figure 7 would force the liner to bend over the longitudinal sills and initiate the formation of buckling nodes due to external groundwater pressure (Gumbel 2001), which is usually above the invert level of large diameter (> 600 mm) gravity pipelines. On the other hand when a reinforced liner is wound into place and expanded, it will keep its circular shape and the annulus left between it and the host pipe can be grouted. With the typical corrosion pattern, where there is a gradual transition from the section of sewer below the effluent level to that above the effluent level and the corrosion has not yet exposed the reinforcement the use of the close fit liners is quite adequate.

Other close fit techniques such as fold and form and swaged linings are used internationally, but to date have seldom been used in this country. They perform in the same way as the CIPP and may under certain conditions be preferable as their dimensions are predetermined and there is no on site curing is required. In general they do not provide a renovated pipe with the same hydraulic performance as the materials used, such as PVC and PE use thicker sections than the CIPP solution.

Lateral connections are required on all reticulation systems, whether they are water supply or wastewater disposal systems. Although there are robotic cutters controlled by radar that can do this remotely, in South Africa most of these connections are done using a labour intensive approach.

Replacement. There is a clear distinction between structural renovation of and replacement of a conduit. With the former a liner is designed to take the load imposed on it and, provided the host pipe has not fully deteriorated, the strength of the liner is enhanced by the support from the host pipe and the surrounding soil. With the latter a standalone pipe is designed to take the loads imposed on it with support from the surrounding soil only.

When old pipelines are structurally unsound or hydraulically inadequate the renovation techniques described above are not appropriate and on-line replacement where the pipeline is simultaneously upsized and relined is used. There are several techniques such as pipe bursting, pipe splitting and pipe eating.

Pipe bursting involves the online replacement of a sewer by a bursting head that breaks the old pipe into fragments and forces these into the surrounding soil. As the bursting head progresses through the old sewer the new pipe is simultaneously pulled or pushed into place behind it. The bursting head is larger than the internal diameter of the old pipe and slightly larger than the outside diameter of the new pipe, so the friction on the new pipe is reduced as it is travels through the soil. This bursting action that expands the original pipe into the surrounding soil also consolidates this soil, which in turn provides support to the new pipe. The amount that the surrounding soil can be consolidated usually the factor that limits the upsizing achievable.

The advantage of this technique over others is that a sewer's diameter can be significantly increased (doubled) thus providing slightly more than a six-fold increase in capacity (capacity increases by ID8/3). In many other respects this technique is similar to sliplining because it involves pulling a new pipe, usually PE into place. The alignment of the upsized conduit will be determined by that of the original host pipe, so this technique cannot be expected to eliminate any localized problems there may have been with the gradient.

An important aspect of on-line replacement with pipe bursting pipe in the South African context is that pipelines replaced and upsized use the same labour compliment as open cut methods, but at lower costs.

Reaming and pipe eating of existing pipes both involve breaking and displacing the existing pipe and replacing it with a new pipe that is pulled in behind the breaking mechanism. For on line replacement techniques the critical in-service-loading condition can generally assumed to be the ground water pressure where the maximum water level is taken at ground surface, unless there is any information that can justify using a smaller value. It should be appreciated that this will not necessarily hold true for pressure pipelines where the effects of internal pressures and unsteady flow conditions must be considered. In the case of pipelines carrying higher pressures these will be the critical loading conditions.

New services are installed using TT where open excavations are impossible or extremely difficult. The most commonly used techniques in SA are pipe jacking and directional drilling. Techniques such as pipe ramming, moling auger boring are also used. Microtunnelling has been introduced.

Pipe jacking and microtunnelling are internally used for the installation of services from 150 mm to several m in diameter. Pipe jacking involves installing pipes behind a shield and progressively pushing these from a thrust wall (generally located in a subsurface launch pit) into the hand excavation that is made within the protection of a shield that is steerable so that corrections to alignment can be made. The excavated material is transported back along the pipeline and removed at the launch pit. In order to reduce the frictional forces between the pipes and the surrounding soil a lubricant, usually consisting of a mixture of bentonite and other materials is injected into this annular space. For long jacks inter-jack stations are placed at intervals along the line. The jacked pipeline then moves through the soil in stages rather like a caterpillar. Where the length that can be jack without an inter-jack is ≤ ± 65m depending upon soil conditions, lengths of several hundred metres can be done by incorporating a series of inter-jack stations at regular intervals. The limitation to the length is probably dictated by the removal of the excavated material. In SA pipe jacking is done from 900mm to 3.0m ID, the limitations being man entry and size of product that can be transported.

Recent improvements made to the jacking of concrete pipes and box culverts in SA have been introduction of cast in steel sockets to replace concrete sockets, which allow for a wider contact area during jacking as well a sealed joint and the connecting adjacent products to more effectively control their alignment when passing through low strength and variable soil conditions. This will extend the use of these products to the provision of access and service tunnels below congested city streets. Internal dimensions of up to 4.0 m wide and 3.0 m high are planned that will be able to take heaviest loading that can occur on any public transport system.

The essential difference between jacking and microtunnelling is that with the latter excavation is done by a steerable remote controlled tunnelling machine and the material is removed by a conveyor system. Microtunnelling can be used from pipes that are much smaller than man entry to several metres in diameter. Larger than this the tunnel excavated would be lined in place or with precast elements. Microtunnelling has started in the country, but only being done on a limited scale.

Directional drilling is by far the most commonly used TT for the installation of small diameter new services in South Africa. It is a two stage operation where a drilling machine makes a pilot hole along a pre-determined route which can be curved to avoid obstacles. The hole is then enlarged in stages by drilling machine pulling reamers of larger and larger sizes through it until the required size has been obtained. On the last pull through the product pipe, usually PE is attached to the reamer via a swivel connector and pulled into its final position. Drilling fluid, the term 'mud' is used, is pumped through the hollow drill string to the bore- head and returns through the cavity between the drill string and the hole made. The 'mud' serves a dual function by keeping the bore of the hole open and transporting the excavated material back to the surface where it is cleaned and reused. It also serves to reduce the friction between the material through which the hole is being bored and the equipment being used. The 'mud' is a bentonite/water mix.

The rigs used need both torque to rotate and axial thrust to push the drill string through the sub-surface material to make the original pilot hole and pull back force to enlarge the hole by reaming. A sonde is built into the drilling head so that its location can be tracked throughout the operation and the direction of the drill path changed where necessary. In South Africa the biggest drilling rigs can make a hole large enough to accommodate a kilometre length of 600mm pipe under favourable conditions. For larger diameters the length that can be installed is limited by the pullback force available and is therefore shorter.

Design of trenchless installations

Conduits used for trenchless installations are designed to handle the loads imposed during installation and when in service. Depending on the particular technique and the site conditions either could be critical and therefore both need to be determined. Loads and the stresses during installation will be longitudinal due to pulling or pushing whereas as those when the conduit is in service will be predominately circumferential due to external loads and internal pressures.

CONCLUSIONS

1. South Africa's urbanization challenge requiring provision of quality wet services to an urban population that is growing at a rate at least 50% higher than the overall rate is a serious one. This coupled to densification within the urban areas means that there is little or no space for open excavations to install services that need to be placed at depth below the surface. In many situations the solution is replacement online and upsize existing services by using techniques such as pipe bursting.
2. As TT is a young industry there are international developments taking place all the time and as South Africans we need to be aware of these and adopt and adapt the appropriate ones to meet SA conditions.
3. There have been recent developments, such as the use of directional drilling equipment to do the online replacement of old water mains and changes to the details of large concrete pipes and box culverts used for jacking installations so that their alignment can be maintained even when the soils through which they are being jacked are unstable or variable and that longer lengths can be jacked.
4. With some of the techniques, such as pipe bursting there are opportunities for small business that offer sustainable employment as well as the development of skilled and semiskilled workers.
5. It is essential to appreciate the differences between trenchless and open cut installations and to use the most appropriate for the project in question.
6. For many applications TT offers the combination of a continuous pipeline, whether new or rehabilitated, from manhole to manhole resulting in a quality durable service being installed with a minimum of social and environmental disruption. The use of these cutting edge techniques can significantly contribute towards reducing South Africa's service delivery backlog at reduced life cycle expenditure.

RECOMMENDATIONS

Within the public authorities:

- Recognition by the decision makers involved that the imbalance of water supply and wastewater disposal may actually be exacerbating the health and environmental problems in high density urbanised areas.
- Appreciation that long term durability of services requiring minimum maintenance depends on planning, design and specification quality before and workmanship and supervision quality during construction.
- Formalize a feedback loop from operational and maintenance personnel to those involved with planning and the supervision of designers and contractors, so that problems can be investigated, their causes identified and the necessary changes to procedures and standards made to eliminate them in the future.
- Ensure that the records of where various services are located is continuously up dated and that a call in service is provided by all local authorities to assist contractors with the location of existing services.

By the trenchless industry:

- A more concerted effort is needed to inform the non-technical decision makers within the utility organizations and those providing them with services about the benefits of TT.
- Produce standards for the design and installation of trenchless services. In most cases these will be based on international standards adapted to meet the installation conditions and skills levels in the country.
- Develop and offer training courses for users, designers and installers of trenchless work based on the standards written.

REFERENCES

1. Worldometers (www.Worldometers.info) Elaboration of data by United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2015 Revision

2. Goyns A Mc N and Crofts FS, "A framework for the development of trenchless technology Guidelines and Standards in Southern Africa". WRC Report No KV 133/01, 2001

3. International Society for Trenchless Technology (ISTT), Trenchless Technology Guidelines, International Society for Trenchless Technology, London (not dated, but pre 2000)

4. ISTT website, Underground construction techniques , ISTT, 2016

5. Goyns A in conjunction with UCT. Virginia Experimental Sewer Progress Report No 7. Unpublished. 2016

6. Gumbel J, New approach to design of circular liner pipe to resist external hydrostatic pressure. 2001