THE USE OF TRENCHLESS TECHNOLOGY FOR INSTALLING NEW AND REHABILITATING EXISTING STORM WATER CONDUITS

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ABSTRACT

Increasing urban densification in South Africa means that less space is available for digging trenches to install new buried services and replace aging services that have deteriorated. This is of particular concern for gravity water services, namely sewers and storm water drains because they are generally below the other services and are hence difficult and disruptive to access should they malfunction.

There are many advantages to using trenchless technology (TT) both for the installation of new buried conduits and rehabilitation of existing buried services. However the technical advantages of using these techniques are seldom fully appreciated.

As sustainable hydraulic performance, the primary function of storm water drains and culverts, is dependent upon their long term load carrying capacity, this paper focuses on the structural requirements that have to be met for trenchless installations. It emphasizes the similarities and differences between these and those for open trench installations.

1. BACKGROUND

1.1 The need

South Africa's urban population is growing at a rate almost double that of the overall population, but there is not a corresponding increase in the land available. Demands in urbanized areas for housing and visible services, such as roads and power supply, have taken precedence over the hidden services, such as water supply, wastewater disposal and stormwater drainage. Of major concern is that many of the first generation water supply pipelines, sewers and stormwater drains have reached the end of their design lives, have deteriorated and now need rehabilitation.

In addition to this the increasing urbanization and the densification of cities and towns these services are frequently under sized and replacement with larger diameters is required. There is little and at times no space available for trenching to install new services or rehabilitate and upgrade the existing ones as trenching is becoming technically more difficult in the limited spaces available, socially more disruptive, and environmentally less acceptable and more costly

Although the majority of new pipelines in South Africa are installed using the traditional open cut approach the demand for trenchless techniques will increase as it has done elsewhere in the world where similar problems have been encountered. This is particularly the situation with the rehabilitation and upgrading of existing gravity pipelines, because these are usually at depth below the other services. Internationally trenchless technology (TT) has been a growing industry for past four decades. Many of the techniques have or could be adapted to South African conditions.

Urban densification has resulted in increased storm water runoff and the need to convey this through areas where inadequate or no provision has been made for retention and detention storage and under established high volume transportation routes where flooding is unacceptable.

2. TRENCHLESS SOLUTIONS

Although TT is usually promoted on the basis of its social economic and environmental advantages, it is the underlying technical advantages that enable these benefits to be realised and these are seldom included in the motivation of projects where a TT alternative is proposed. This may be one of the reasons why decision makers are at times reticent to use the technology.

The requirements to be met by any water services are simply that they must be big enough to convey the amount of water, strong enough to carry the imposed loads, watertight to contain the flow and durable so that it they last. The latter means that the materials chosen need to be able to cope with any aggressive or abrasive elements in the fluid being conveyed or in the external environment as well as handle the stresses due to the imposed loads.

Pipelines consist of pipes made in a factory and joints made on site. As they are buried the interaction between the pipeline and the surrounding soil has to be considered. With trenchless installations the earth loads on pipes are significantly less, there is little disturbance of the natural soil and in many techniques the pipe is continuous from manhole to manhole. It is with these latter features that TT offers very distinct technical advantages.

3. LOADS UNDER SERVICE CONDITIONS

3.1 Forces acting on buried pipeline

There are primary and secondary forces acting on buried pipelines. The primary forces are due to superimposed loads such as earth loads, traffic loads, internal water pressure and external water pressure. The secondary forces are due to movements within the soil after the pipeline has been installed due to moisture changes, temperature effects and additional superimposed loads such as buildings constructed over the pipeline at some time after installation.

Pipes are designed to take the primary loads and joints are selected to take any movements resulting from the secondary forces that could occur. As the pipes are made in a factory they can be factory tested to ensure that they are strong enough to take the calculated primary loads. As pipes are jointed on site so they should be tested on site to check that the jointing has been correctly done.

When pipelines are installed using trenchless techniques the product is pulled or pushed through the soil and whether the pipeline is jointed or continuous these effects should be taken into consideration.

3.2 Calculation of in service earth loads

Irrespective of whether a pipeline is installed using open cut or trenchless methods, the in service loads to be carried are essentially two-dimensional. The earth loads can be calculated by using the Marston and Spangler theory for rigid pipes or the Iowa Formulae for flexible pipes.

For rigid gravity pipes the critical structural parameter is the strength to carry the external earth load and the main determinant of this load will be the installation condition, namely whether the pipe is installed under an embankment or in a trench. These are illustrated in the Figure 1. A useful concept is the geostatic load, which is the load on the pipeline due to the prism of material directly over it. In a trench installation the prism load will be dependent upon the trench width and in an embankment it will be dependent upon the external diameter of the pipe.

With a trench condition the loading will always be less than the geostatic loading because the frictional forces reduce the load resulting in positive arching. With an embankment condition the load will always be greater than the geostatic load because the arching action is downwards or negative. With a tunnel type excavation the vertical load will always be less than the geostatic load because both friction and cohesion transfer the load to the columns of earth either side of the pipe and there is positive arching. With a trench condition the load is dependent on the trench width, with an embankment condition the load is dependent on the outside diameter of the pipe and with a trenchless condition the load is dependent on the tunnel diameter made to accept the pipe.

The calculation of earth loads for the various installation conditions is complex. However with these installations there are maximum values to the earth loads that can be easily calculated and in the case of a trench or trenchless installation they will have an upper limit. The formula and the limiting values for the loads on rigid pipes, such as concrete, for the various installation conditions are given by equations (1) through to (7).

Basic formula: $W_E = C_E \gamma B^2$ (1)

Where W_E is total earth load in kN/m on pipeline
C_E is earth load coefficient
γ is density of fill material
B is outside pipe diameter (B_C), trench width (B_T) or tunnel diameter (B_T)

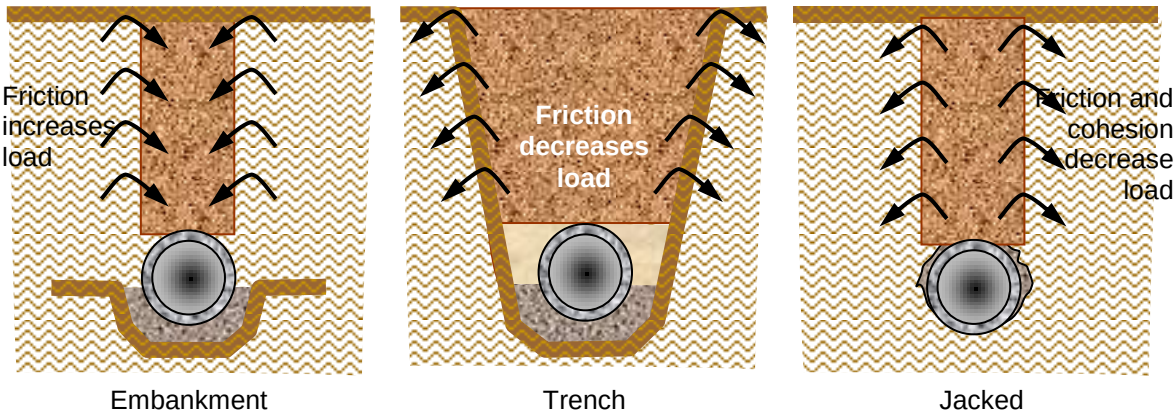


Figure 1: Comparison of pipe installation conditions

For the embankment loading condition the most severe loading is when the founding conditions are unyielding and the whole pipe projects above the founding level. Once the fill height, H exceeds 1.7 x B_C there is a straight line relationship between load and fill height and there will be no limiting value to the load. These loads will be:

$W_E = 1.69 \gamma$ Bc H in sand (2)

$W_E = 1.54 \gamma$ Bc H in clay (3)

For the trench loading condition the upper limits occur when there is complete arching action.

$W_E = 2.63 \gamma B_T^2$ in sand (4)

$W_E = 3.84 \gamma B_T^2$ in clay (5)

In practice the walls of a trench dug through a sandy material will not stand and the equation (4) is hypothetical. However both these equations are applicable to trenchless installations. For pipes less than 1000 mm in diameter the trench is usually at least twice the outside pipe diameter, hence the load on the pipe will be less than one quarter of that on a pipe placed in a trench where the height of fill over the pipe is the same.

With open trench installations the depth is seldom so deep that full arching action and limiting loads are achieved and it would be uneconomic to use these values to determine the required pipe strength. On the other hand with trenchless installations where the conduit is frequently placed at 10 diameters or more below the surface, full arching action is frequently developed. Under these conditions the limiting values to earth loading where the tunnel width is taken as B_T will be:

$$W_E = 2.63\,\gamma\, B_T^2 \text{ in sand} \quad (6)$$

$$W_E = 3.84\,\gamma\, B_T^2 \text{ in clay} \quad (7)$$

If the actual conditions are not known and it is not possible to calculate the actual superimposed load on the pipe the use of these limiting values will give product strengths that are safe, but still economic. This is because the load is based on the tunnel diameter and the load is reduced by both friction and cohesion. The full effects of the latter on a jacking installation are not considered in equations (6) and (7) as they are based on materials that have been excavated, replaced and compacted, not on undisturbed materials.

For flexible pipes the critical structural parameter is the stiffness to resist the deflection due to the external load and the main determinant of this load will be the composite stiffness of the surrounding embedment material and natural soil. Irrespective of the installation type used the load will always be less than the geostatic load calculated by using the outside pipe diameter. This is because the flexible pipe deforms under load, settles more than the earth on either side of it and sheds the load onto this material. The earth loads on flexible pipes are conservatively taken as:

$$W_E = \gamma\, B_C H \quad (8)$$

In practice if the earth loads on a flexible pipe increase it will deform more than the adjacent columns of earth and the frictional forces between the columns of earth will increase and the maximum load will actually have an upper limit as given by formulae (6) and (7) above.

3.3 In service traffic loads

As most trenchless installations are at several metres below ground surface the effects of traffic loading is far less than that of earth loading. An additional factor is that at these depths live loads can be considered as being uniformly distributed through the soil and acting as a surcharge on any buried conduits provided they have at least one pipe diameter of cover over them. For most applications the vertical pressures due to traffic loading at these depths can be taken as the total vehicular load distributed at 1 times the fill height from the perimeter of the loaded area.

4. REQUIRED PIPE STRENGTH FOR TRENCH INSTALLATIONS

4.1 Basic principles

There are two fundamental differences in the way that the required strengths of rigid and flexible pipes are determined. Firstly a rigid pipe is placed on a bedding cradle that distributes the foundation reaction around a part or the entire bottom portion of the pipe and enables the pipe to carry a greater load than it does in the factory test. A flexible pipe is completely surrounded by an embedment that supports the pipe so that the load can be transferred to this embedment. These differences can be seen in the installation details shown in Figure 2.

Secondly the resistance offered by the rigid pipe is its strength and ability to carry the load directly. On the other hand the resistance offered by the flexible pipe is its stiffness and ability to transfer the load to the surrounding embedment when it deforms.

The bedding factor is the ratio of the installed load to the test that will generate the same maximum bending moment. For a rigid pipe in a trench it is assumed that there is no lateral soil support, however, with an embankment installation this is considered and slightly higher bedding factors are used. A flexible pipe deforms, pushes into the embedment, causing lateral pressures to develop and this results in much higher bedding factors.

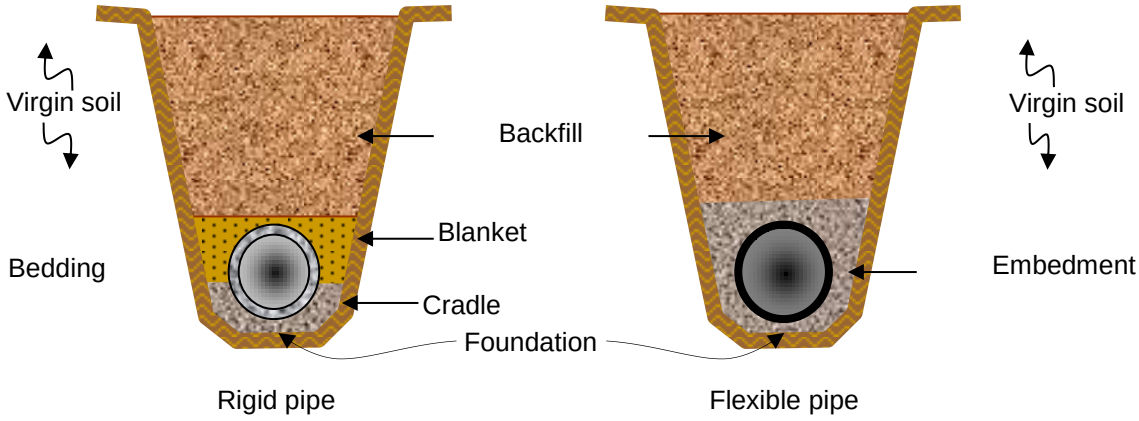


Figure 2: Comparison of rigid and flexible pipe installation details

4.2 Rigid pipe strength

Pipe strength is determined from formula (9), developed by Marston and Spangler:

$$W_T = (W_E + W_L)/B_F \qquad (9)$$

Where W_T is test load in kN/m of pipe length
W_E is earth load in kN/m of pipe length
W_L is traffic load in kN/m of pipe length
B_F is bedding factor

The bedding factors for granular beddings used in South Africa are given in table 1. The bedding angle defines the angle of support given by the bedding cradle to the pipe. With rigid pipe selection the focus is on ensuring that the pipe is sufficiently strong to carry the loads imposed on it.

Table 1: Bedding factors for rigid pipes

Bedding class	Trench	Embankment	Bedding angle
B	2.0	2.4	180^0
C	1.5	2.0	90^0
D	1.1	N/A	0^0

4.3 Flexible pipe deflection

Pipe deflection is determined from the Modified Iowa formula, given below:

$$\Delta y = (D_L K_B \gamma H)/(8EI/D^3 + 0.061E') \qquad (10)$$

Where Δy is change in pipe diameter, maximum value usually specified as 5%
D_L is deflection lag factor, having a value between 1.0 and 1.5
K_B is bedding constant, having a value between 0.11 and 0.083
γ is soil density in kN/m^2
H is fill height in m
EI/D^3 is pipe ring stiffness in kN/m^2
E is long-term elastic modulus of pipe material in kN/m^2.
I is moment of inertia of pipe wall, about its centerline, per unit length in m^3
D is pipe diameter in m
E' is embedment modulus in kN/m^2, values from < 700 to 20 000

By using typical values for pipe ring stiffness (PRS) and E' of 2 and 7 000 kN/m^2 respectively into formula (10) it can be seen that the main determinant of pipe deflection is the embedment stiffness. Hence with flexible pipe installations the design effort is focussed on determining the details of the embedment needed to transfer the load from the pipe to the natural material without the pipe deforming excessively.

4.4 Effect of groundwater pressure

For most projects where gravity pipelines are rehabilitated the critical long term loading on the liner is the external groundwater pressure. When the host pipe does not support the liner the critical buckling pressure, P_C is calculated using Love's equation. For a solid wall pipe using the standard diameter ratio (SDR) P_C is:

$$P_c = 2E\,\{1/(1-\mu^2)(1-SDR)^3\}\,C \qquad (11)$$

Where P_c is groundwater pressure in kN/m^2
E is long-term elastic modulus of pipe material in kN/m^2.
SDR is OD / t
OD is outside diameter, mm
t is minimum wall thickness, mm
C is ovality correction factor, (OD min / OD max)^2

The calculation of the buckling resistance for an unsupported pipe is iterative. The critical buckling resistance of the initial choice is compared to the anticipated groundwater pressure. If the calculated buckling resistance is significantly larger than the anticipated groundwater pressure, the procedure is repeated using a thinner wall. The design buckling resistance should provide an adequate safety factor (SF) over the maximum anticipated groundwater pressure. Where the actual conditions are unknown it should be assumed that the maximum ground water level will be at the ground surface and a SF of 2 should be used. In practice the host pipe cradles the liner and this increases its buckling resistance, as accounted for by the factor 'K' in equation (12).

$$P_P = 2KE\,\{1/(1-\mu^2)(1-SDR)^3\}\,C/SF \qquad (12)$$

Where P_P is the permissable external water pressure in kN/m^2
E is long-term elastic modulus of pipe material in kN/m^2.
K is an enhancement factor from support of surrounding soil and host pipe
SDR is OD/t
OD is outside diameter, mm
t is minimum wall thickness, mm
C is ovality correction factor, (OD min / OD max)^2
SF is safety factor usually taken as 2

The value of K depends on the lining technique as well as the support from the host pipe and surrounding soil. Filling the void between the liner installed using slipling and the host pipe with material such as low strength grout can increase the liner's buckling resistance by a factor of 3.5. With a thin close fit liner where the D/t ratio of the liner is 50 or more a K value of 7.0 can be used.

There are several different techniques for placing a liner into a host pipe, such as sliplining and its variations, spirally-wound lining, close-fit lining and cured-in-place pipe (CIPP) that all rely on the host pipe for support. Sometimes old pipelines are structurally unsound or hydraulically inadequate. When this occurs these techniques may not be appropriate and on-line replacement techniques such as pipe bursting, pipe splitting, pipe reaming and pipe eating, are used where the pipeline can be simultaneously upsized and relined. All of these involve breaking and displacing the original host pipe and replacing it with a new pipe that is pulled in behind the breaking mechanism.

For all these lining techniques the critical in-service-loading condition can generally be assumed to be the external water pressure where the maximum water level is at the ground surface, unless there is any information that can justify using another value. A typical situation arises where the lined pipeline is below a flood plain where the water could stand for prolonged periods.

It should be appreciated that these statements will not necessarily hold true for pressure pipelines where the effects of internal pressures and unsteady flow conditions must be considered.

5. LOADS DURING INSTALLATION

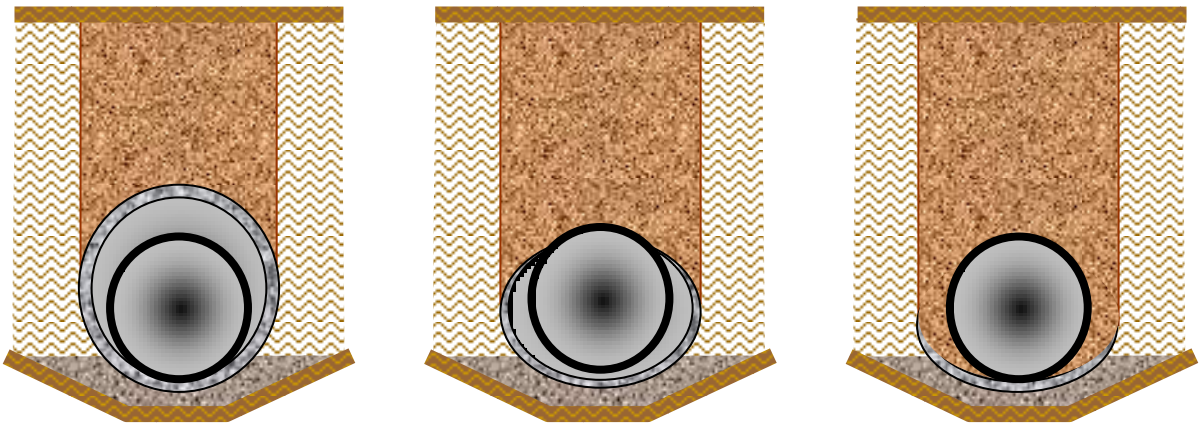
5.1 Installation forces on buried pipelines

When a new conduit is installed in an open trench the forces imposed on the pipes and joints are negligible if the correct jointing procedures are used. However when a conduit is installed using trenchless techniques it may be pulled or pushed through the spoil and significant resisting forces may have to be overcome friction between the conduit and the surrounding soil, resistance at the beginning of the conduit due to the displacement of soil and resistance of soil to any deflections along the existing conduit.

The tensile or compressive stresses generated in overcoming these imposed loads will probably far exceed those generated while in service. These must be checked to ensure that they do not exceed the allowable values for the pipe material being used. In general rigid pipes are pushed and flexible pipes are pulled through the soil. When the conduit is being pushed the higher stresses will be developed at the trailing end of the conduit and when pulled at the leading end. In addition, these forces are in a longitudinal direction and not in a cross-section at right angles to the pipeline as are the service loads. The impact of these on the pipes and the joints, in particular, are usually far more severe during installation than when the pipeline is in service.

5.2 Frictional forces

There will be lower and upper limiting values to the frictional forces when a new pipeline is pulled or pushed through the soil or a host pipeline. A lower value that is applicable when the new pipe or liner rests on the bottom of the tunnel or host pipe with no superimposed load on it and an upper value when the surrounding soil collapses onto it. The limiting values can be calculated, but judgement is needed for intermediate conditions. These are illustrated in figure 3.



Host pipe sound | Intermediate condition | Host pipe ineffective

Figure 3: Range of vertical loads during trenchless installations

If a pipe is being pushed or pulled through a preformed hole or an existing pipeline that is well aligned and straight the only contact made is between the invert of the tunnel or host pipe and a portion of the new pipe or liner's circumference. The resistance to be overcome would be the friction between the two contact surfaces based on the new pipeline mass. At the other extreme would be the situation where the frictional and cohesive forces between the columns of earth above the tunnel and those adjacent to it were insufficient to prevent the roof of the tunnel collapsing onto the new pipe. The

resistance to be overcome would be the friction between the whole outside circumference of the pipe and the surrounding material based on the mass of the new pipe and the superimposed loads on it. Typical values of these coefficients are given in table 2 (2, p 184).

Table 2: Friction coefficients for use with trenchless installations

Natural material	Smooth surface	Concrete surface
Gravel	0.55	0.88
Sand	0.45	0.65
Loam	0.35	0.40
Alluvial clay	0.30	0.35
Clay	0.20	0.25

Thomson (2, p184) describes a simplified approach applicable to pipe jacking. This involves calculating the horizontal and vertical earth pressures acting normal to the pipe assuming the earth pressure coefficients at rest. The required jacking force can then be calculated from equation (13) below that considers the pipe mass as well as the superimposed load.

$$W_J = L_J F_J \{W_P + \pi B_C (P_v+P_h)/2\} \qquad (13)$$

Where W_J is jacking force required in kN
L_J is length of the jack in m
F_J is friction coefficient for the contact surfaces (from Table 2)
W_P is pipe mass in kN/m
B_C is outside diameter of pipe in m
P_v is vertical earth pressures acting on pipes
P_h is horizontal earth pressures acting on pipes

When a pipe is being pulled or pushed through a self-supporting tunnel, as can occur when excavating through a cohesive material as clay, or a host pipe that is still structurally sound then the second term within the brackets falls away. In practice the force needed to move the pipes under these conditions will be about a third of the total pipe mass.

However, if the soil above the pipes collapses onto them as they move through the soil the normal load could be far greater than the total pipe mass. As a result the force required to overcome the friction could be considerable. SABS 0102 Part II (8,p30) adopts a simpler approach for jacking pipes, grouping pipes, normal forces and friction on them as a single item called the jacking resistance factor and gives an equation reproduced as (14) below.

$$W_J = R_J L_J \pi B_C \qquad (14)$$

Where W_J is jacking force required in kN
R_J is jacking resistance factor in kN/m^2
L_J is length of the jack in m
B_C is outside diameter of pipe in m

Values of R_J will depend on pipe mass, overburden height and soil conditions. In addition the duration and continuity of a jacking operation can have a significant effect on this resistance. When it has been stopped and then restarted an increase in of $\pm$ 50% can be expected. On the other hand the use of a lubricant, such as bentonite, between pipe and soil can reduce the resistance by between 30% and 50%. Typical values of the resistance factor as given in Table 3 (8,p30) actually combine the effects of friction and overburden load on the new pipeline.

Table 3: Typical values for jacking resistance factor

Subsurface conditions	R_J values in kN/m^2	
	Minimum	Maximum
Rock	2	3
Boulders in clay	5	18
Firm clay	5	20
Wet clay	10	15
Silt	5	20
Dry loose sand	25	100
Embankment fill		Up to 45

As the same principles are involved with any pipeline being pulled or pushed through the soil, the above approach could be used for determining the frictional forces generated using any other trenchless techniques. However, there are several factors that, in general, will reduce the resistance factor, namely:

- Coefficient of friction between the pipe material and the soil
- Influence of lubricants between the new pipeline and the hole or host pipe
- Pipeline mass

The above comments confirm the rule of thumb that the force needed to move a pipeline through the soil or an existing host pipeline, assuming that the alignment is straight and the space around the new pipeline is lubricated, is about one third of the new pipeline weight.

5.3 Soil displacement

Many of the trenchless advantages result from the new pipeline displacing soil rather than the soil having to be removed and later replaced when the pipeline has been installed. However many of the problems experienced with trenchless installations are due to the displacement of soil around and ahead of a conduit as it pushes the soil or the old pipeline outwards into material that is consolidated. The problems are even more serious when the soil around the conduit collapses onto it.

Soil resistance ahead of a new installation has to be addressed independently of the effects of radial soil displacement or collapse around the pipeline. The latter will impact on the overburden load and is taken into account when selecting the resistance factor covered in the section above.

If a liner is being pulled or pushed through a self-supporting tunnel or a well-aligned clean host pipe such as should happen with slipling there will be no end resistance. However, if the material through which the new pipeline is being placed does not allow for a self-supporting tunnel, or the host pipeline has to be broken before a new pipeline can be installed such as occurs with pipe bursting, the force needed to overcome this resistance must be established before the installation starts.

In South Africa most jacking operations are open-faced where a tunnel is manually dug just ahead of the new pipeline and there will be little if any face resistance. However in unstable soil conditions it may be necessary to push the shield leading the pipes hard against the face so that it cuts into this material before it is removed. The required force can be estimated from equation (15).

$$P_S = \pi D_S t_s p_s \qquad (15)$$

Where P_S is leading edge resistance in kN
D_S is external diameter of shield in m
t_s is thickness of leading edge in m
p_s is face resistance in kN/m^2

Typical values of face resistance are given in Table 4 (2, p180).

Table 4: Values of face resistance

Soil type	Face resistance kn/m^2
Soft rock	12 000
Gravel	7 000
Dense sand	6 000
Medium sand	4 000
Loose sand	2 000
Stiff to hard clay	3 000
Soft to firm clay	1 000
Silt or alluvium	400

5.4 Influence of bends or deflections

Any bends or deflections along a pipeline being installed using trenchless techniques will have an impact on all the pipes that follow it in the case of pipes being pushed and on all pipes ahead of it in the case of pipes being pulled. The problem with any deviation from alignment is that it takes at least three adjustments to bring the pipeline back onto its original course. The corrective adjustments involve turning the pipeline, parallel to the original route, back to its original alignment and then along its original alignment and route.

The whole pipeline will have to negotiate these four bends and this will significantly increase the force needed to move the pipeline through the soil. When the axial force is applied the individual pipe elements will attempt to re-align themselves as they negotiate each bend. This will result in high stresses between the pipe faces on the inside of the curves. In a stiff soil a small deviation of 0.1^o could mean an increase in pushing or pulling force equivalent to that needed if an extra three pipe lengths were added to the pipeline (2, p199). If the corrective action to bring the pipeline back onto alignment was made this could be equivalent to adding 12 pipe lengths.

6. PIPE STRENGTHS REQUIRED DURING INSTALLATION

6.1 Different conditions to consider

The longitudinal pipe strengths required during installation will depend upon whether the pipes are:

- Installed in their final position using conventional open trench techniques
- Pushed into place as in pipe jacking
- Pulled into place as in sliplining
- Cured in place as with mortar lining or cured-in-place lining

For conventional installations the only longitudinal stresses developed are during jointing. These are negligible and provided the manufacturer's jointing procedures are followed there should be no problems. At the most they would amount to about a third of the pipe mass.

For pipes or linings that are cast or cured in place longitudinal stresses can develop due to shrinkage. Provided the correct curing and joint-making procedures are followed no problems should occur.

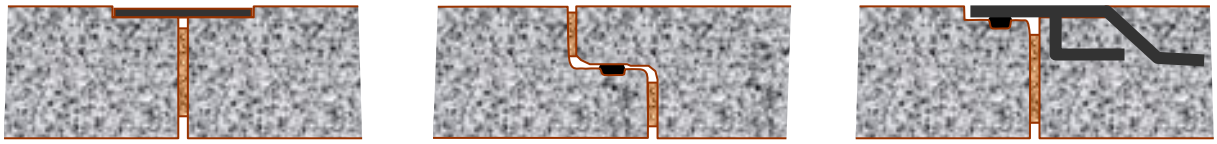
However when a hole is made ahead of a pipeline and it is then pushed or pulled into place axial (longitudinal) compressive or tensile stresses are generated in the pipe walls. These stresses need to be checked to ensure that the pipe walls will not be overstressed during installation. As the maximum

stresses will occur in the pipe immediately next to the pushing or pulling device these stresses must be calculated using the actual area over which the force is to be applied. This means that joint details are needed to do these calculations.

6.2 Pushing rigid pipes

Rigid pipes such as reinforced concrete or vitrified clay are used when pipes are to be pushed through the soil as in the jacking technique. These need a high compressive strength to transfer the required axial forces along the pipeline as well as meeting their long-term requirements such as ensuring that the joints that seal.

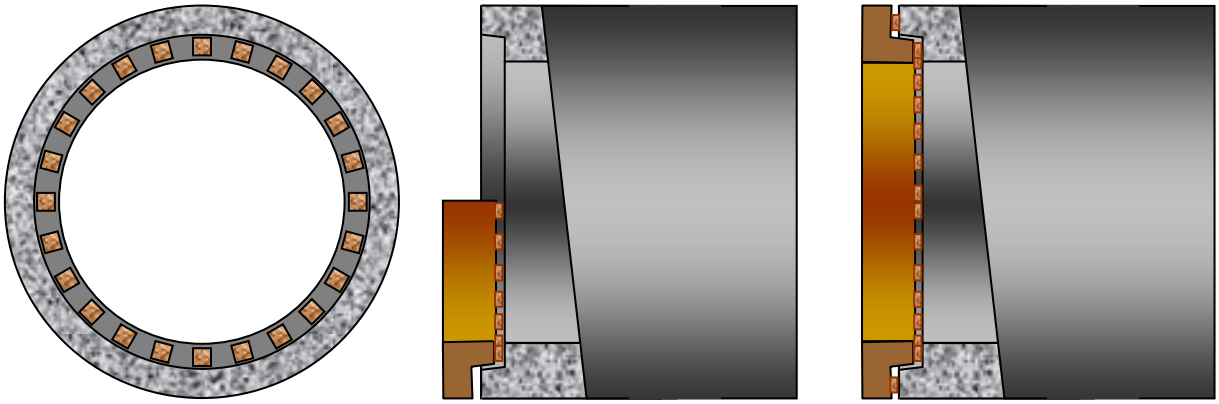
Any pipes that are moved through the soil must have a constant outside diameter to avoid additional resisting forces as they are moved. This means that joints, including any sealant, must be contained within the pipe wall thickness. In addition to this the edge effects when pushing against a hard rigid material must be considered. Hence the area available for transmitting jacking forces will be significantly less than the whole wall thickness. Figure 4 shows the typical joint details on concrete jacking pipes.



Butt & recess | In-the-wall | Cast in steel band

Figure 4: Sections through typical concrete jacking pipe joints

If dimensions were added to these sketches it can be seen that the area available for transferring the longitudinal jacking forces is about 30mm less than the pipe wall when steel band type joints are used and about 50mm less when using the in-the-wall joints. With jacking the maximum forces are generated at the tail end of the pipeline. The contact between the last pipe and the pushing ring is usually the location where the highest stresses are developed. The critical factor is the effective contact area between pushing ring and end pipe which will depend upon the proportion of pipe circumference covered by pushing ring and the dimensions of the packing between the pushing ring and pipe face as shown in Figure 5.



End pipe elevation with | Section of 180º pushing | Section of 360º pushing

Figure 5: End pipe and alternative pushing ring configurations

For short jacks, such as a storm water crossing under a roadway or railway the pushing ring is usually 180º segment of a circle and the jacking force is applied to the inner face of the joint only. This means that less than 25% of the pipes axial strength is used and if the pipes are correctly aligned and jointed the stresses on the last pipe will be at least 4 times those on any other pipe in the

line. On longer jacks, such as those using tunnelling equipment, or were high jacking forces are anticipated it is advisable to use a pushing ring that transfers the jacking force to both joint faces and over the full pipe circumference as shown in the third sketch of Figure 5.

International standards usually permit a maximum concrete stress of between 11 and 13 MPa at the interface between the pushing ring and the pipe face. However, with concrete made on the spinning processes, where 7-day strengths usually exceed 55 MPa, it would be realistic to increase this value to at least 15 MPa.

6.3 Pulling flexible pipes

Flexible pipes, usually HDPE, are used when pipes are to be pulled through an old pipeline or through the soil as with the slipling or directional drilling techniques. Such pipes need sufficient tensile strength to transfer the required axial pulling forces along the pipeline as well as meeting their long-term requirements such as ensuring that the joints that seal.

The maximum pulling force can be calculated using equation (16).

$$MPF = \{(TS / FS)\ \pi\ (OD^2 - ID^2) / 4\}\ 10^{-3} \qquad (16)$$

Where MPF is Maximum pulling force in kN
TS is tensile strength of pipe material in MPa
FS is safety factor for pipe material, usually taken between 1.5 and 2.0
OD outside diameter of pipe in mm
ID inside diameter of pipe in mm

As this calculation is done to check that the pipe chosen for a particular application will have sufficient strength to be pulled through the soil the maximum pulling length as calculated by equation (17) is compared with the actual distance that the pipe must be pulled.

$$MPL = MPF / (W_P\ C_F) \qquad (17)$$

Where MPL is maximum pulling length in m
MPF is maximum pulling force in kN
W_P is pipe mass in kN/m
C_F is friction coefficient between pipe material and soil (see Table 2)

When the safe tensile strength for this type of installation is calculated a check on the strength of the joints and the effects of scratching on the outside of the liner pipe must also be done.

6.4 Monitoring progress

An essential component of any technology is the proof that the theory works in practice and that the practical problems that occur during construction can be investigated and explained in theory. By checking on how well systems perform means that ways of preventing the problems repeating in the future can be fed into standards and the design process. Problems that have occurred, for whatever reason can be identified and their causes investigated. Paying attention to this means that an in depth understanding of how these systems operate is obtained and this can be applied to the design construction and operation of similar systems in the future so that they are more effective.

As TT involves pipes being pushed or pulled through the soil using power packs or winches it is possible to measure the pressures being applied and convert these to forces. From these the axial stresses being developed in a pipe wall can be calculated. By monitoring the forces being used on a particular project and converting these to stresses in the pipe wall any necessary adjustments can be made to the operation before the allowable stresses are exceeded. Controls of this nature should be an essential component of the quality management on projects of this nature, but are seldom applied.

7. CONCLUDING REMARKS

The social, environmental and economic benefits of using TT for the installation of new services and the rehabilitation of existing services result from the underlying technical and practical factors that are frequently not appreciated. To realise the full benefit of these techniques and ensure that the installations are technically sound and cost effective it is essential that the factors influencing the required product strengths are understood and used during the design, specification and installation stages of this work. This is easier said than done, as there are hardly any South African national standards covering the design of such installations. This is probably the biggest hurdle to realizing the full potential of TT in South Africa. With the development of standards that were appropriate for South African conditions there would be:

- A better understanding of management of buried services during their lifecycle
- An awareness of the capabilities and benefits of using TT
- The means of designing, selecting, specifying and constructing TT installations.

The compilation of standards, in particular design guidelines and their incorporation at later stage into a code of practice, and an associated awareness campaign to promote their use would encourage the use of these techniques in South Africa. This will mean significant and widespread benefits for the utility companies. Service installations will be designed to meet actual requirements and site conditions, thus eliminating both over-design resulting in excessive capital costs and under-design where the risk of failure is unacceptably high and the cost of remedial work exorbitant. This would enable the client and designer to do a realistic comparison of open trench and trenchless installations to determine which would be the most suitable for a particular project.

To date the use of TT for storm water applications in South Africa has essentially been limited to pipe jacking under heavily trafficked transportation routes. With the densification of urban areas where the flooding of residential areas and transportation routes will be unacceptable and where space is limited there will be the need for effectively removing the excess runoff that will occur. Trenchless ways will play a greater role handling in effective this problem without the disruption associated with digging open trenches.

The Southern African Society for Trenchless Technology (SASTT) is currently compiling TT standards that are appropriate for local conditions and skills levels based on international standards. In addition the association is arranging short seminars on various aspects of TT that will be hosted at the main centres around South Africa. These will be a lead up to the International Society for Trenchless Technology's 36th Annual No-Dig conference and exhibition being held in Cape Town during October 2018, which SASTT won the bid to host.

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