STRUCTURAL DESIGN OF BURIED FLEXIBLE PIPES FOR TRENCHLESS INSTALLATIONS

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ABSTRACT

In Australia and New Zealand, the structural design of buried flexible pipes is carried out in accordance with AS/NZS 2566.1 Buried flexible pipelines, Part 1: Structural Design. Unfortunately, this standard only provides guidance for conventional trench and embankment installations. More and more pipelines are however now being constructed using trenchless installation methods. These methods are becoming more advanced often allowing the installation of lower stiffness pipes into an excavated bore, but without clear guidelines designers can err on the conservative side. For cost effective solutions that provide the service life that asset owners require, it is crucial that these installations are appropriately designed for both temporary and permanent loads. This paper provides a suggested design methodology based on the principles of AS/NZS 2566.1 but amended to suit trenchless installations of new pipe. It includes references to various overseas standards and other publications which provide guidance in this area. It also includes a number of case studies and design examples for a range of different plastic pipe materials.

1 INTRODUCTION

Trenchless methods of pipe installation continue to advance in terms of both capability and reliability. Recently developed techniques allow installation of a much wider range of pipe materials including flexible pipes with relatively low stiffness not necessarily manufactured specifically for trenchless installations. Unfortunately design methods have generally not kept pace with installation methods. AS/NZS 2566.1 (1) is used for the structural design of buried flexible pipes in Australia and New Zealand but this standard specifically excludes trenchless installations and states that it "*does not give design guidelines for … bored, jacked or mole-ploughed installations".* In an earlier publication presented at the Australasian Society for Trenchless Technology (ASTT) No-Dig Downunder 2017 Conference (2) an overview of structural design for both rigid and flexible pipes was provided for a range of different trenchless installation techniques as detailed in both local and overseas publications. In this paper a summary of these design methodologies will be provided with further information on how design can be carried out for trenchless installation methods for plastic and other flexible pipes based on the existing methodologies contained in AS/NZS 2566.1 with an emphasis on new pipe installations. Figure 1 shows an extract from a typical pipeline design drawing. In this example the designer has selected PE100 SDR17 pipe to be "installed using trenchless technology". The question that was and should be asked is: "Is the SDR17 pipe suitable for this installation for the permanent design loads?" This paper will provide the answer to this question.

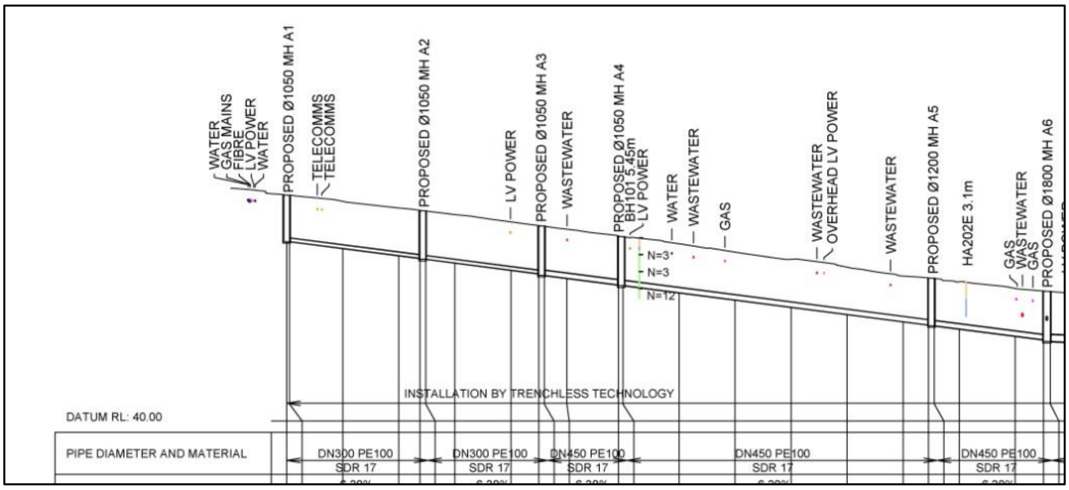


Figure 1 - Example Pipeline Design Longitudinal Section

2 TRENCHLESS INSTALLATION METHODS

Trenchless pipe installation methods are many and varied in terms of how pipe is installed. From the perspective of the structural design of the pipe for permanent design loads, how the pipe is installed is less important than what the installed pipe looks like in relation to the existing material in which it was installed. We use the term material here quite deliberately because the material could be either a soil or rock. Figure 2 shows some idealised examples of what such installations might look like for different trenchless installation methods.

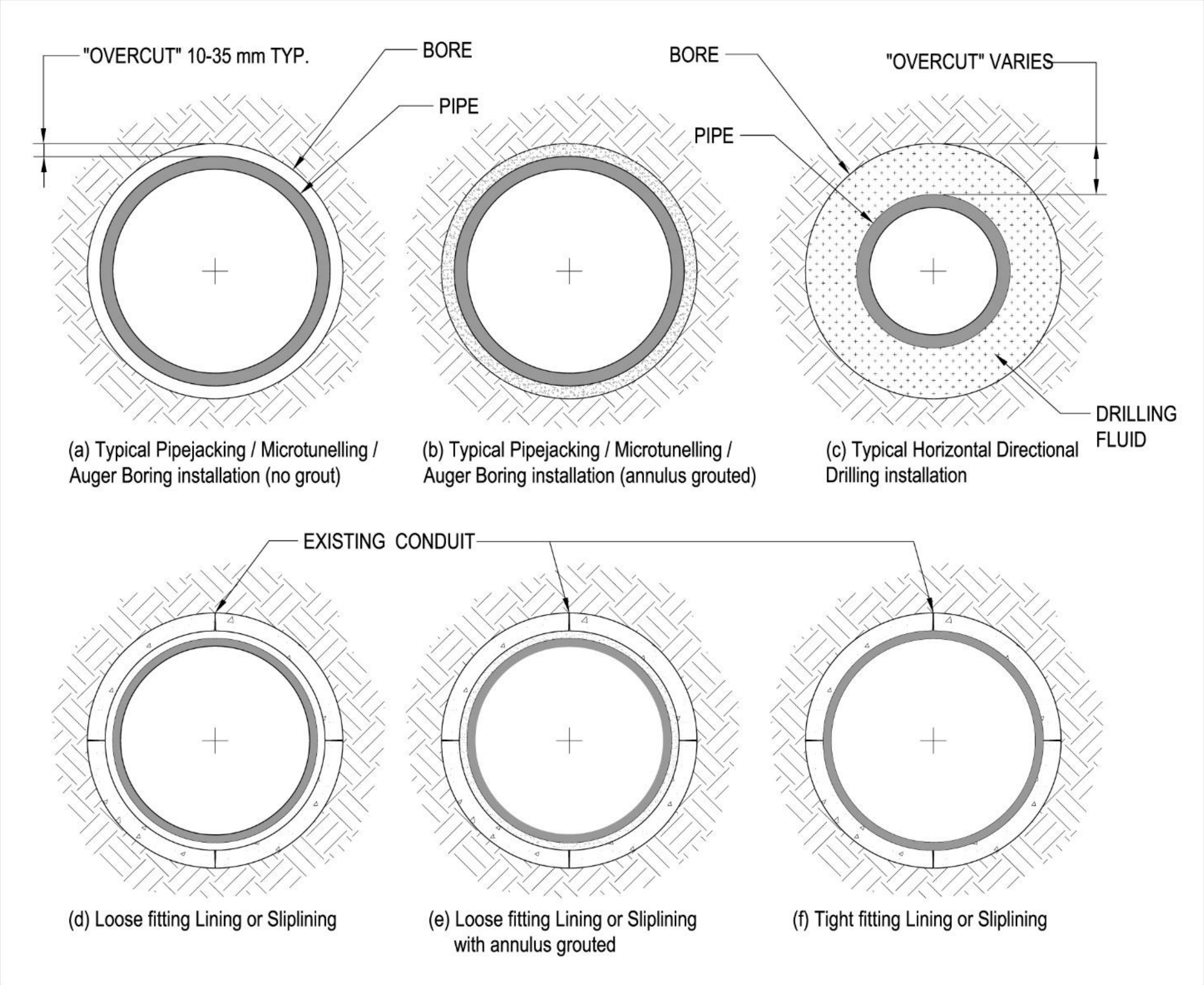


Figure 2 - Typical "pipe" installations using different trenchless installation methods

The examples shown in Figure 2 include both new pipe installations, (a) to (c) above, and typical pipeline renovation installations, (d) to (f) above. The focus of this paper is new pipe installations only. What is common to each of the new pipe installations is that the pipe is installed in a bore with a diameter larger than the outside diameter of the pipe. These diagrams also show a pipe concentric with the excavated bore and, in (b), the gap between the outside of the pipe and the bore is filled with grout. These are all schematic representations and actual installations will not necessarily look so symmetrical. For example, unless other measures are taken, it is unlikely pipes will be central within the bore. Some of these issues are discussed later in the paper.

3 LOADS ACTING ON PIPES FOR TRENCHLESS INSTALLATIONS

Marston and Anderson (3) as early as 1913 identified that the loads acting on a buried pipe depends on the method of installation. In many respects the same engineering principles detailed in this early work can be applied to trenchless installation methods.

For trenchless installations it is important to differentiate between loads applied during the installation and those that will act on the pipe for the balance of its asset life. In this paper these loads are differentiated as either:

i. **Permanent design loads** – these are loads that may be applied to a pipe after installation and for the balance of its service life after it has been installed. Such loads are usually only known by the pipeline designer and the initial pipe selection should be made by them after a consideration of these loads; or
ii. **Installation design loads** – these are loads that are applied to the pipe during installation. Such loads are usually only known by the pipe installation contractor and the pipe to be installed should be either checked or selected based on a consideration of these loads.

The focus of this paper is on the permanent design loads although it should be understood that the installation design loads may control the final pipe selection.

AS/NZS 2566.1 considers the following types of permanent loads:

(a) Trench or embankment fill;
(b) External hydrostatic loads;
(c) Internal pressure;
(d) Superimposed dead loads;
(e) Superimposed live loads; and
(f) Mass of the contents of the pipe, if appropriate.

Of these loads only the first one is related to the method of installation. All others will act on the pipe in the same way whether the pipe was installed in a trench or was installed using a trenchless installation method and as such should be calculated as per current published methods such as those in AS/NZS 2566.1.

3.1 Soil Loads Acting on the Pipe

In trenchless installations no fill is placed above the pipe as part of the installation as the bore is constructed within native materials. A number of publications detail how the loads from the weight of material above the bore might be calculated. What is common to all of these methodologies is that the vertical soil pressure at the top of the pipe will be equal to or less than the height of fill multiplied by the density of fill above the pipe. This is sometimes referred to as the prism load although strictly the prism load is the weight of a column of earth with a width equal to either the width of the bore or the pipe. Reduction in load from the prism load is due to frictional forces within the soil and possibly also soil cohesion. For a more detailed explanation, our earlier paper (2) provides a detailed review of a number of different standards and other publications on this subject.

AS/NZS 2566.1 states that the design load due to dead load of trench or embankment fill is calculated from Equation 4.3 which is replicated as Equation 1 below:

$$w_g = \gamma H \qquad [1]$$

Where γ is the assessed unit weight of trench or embankment fill and H is the cover or vertical distance from the top of the pipe and the finished surface.

AS/NZS 2566.1 also states that this formula applies *"where H ≤ 10D. For H > 10D results may be conservative (refer Commentary)."*

The Commentary, AS/NZS 2566.1 Supp. 1 (4), provides an alternative formula for estimating the earth load (Equation 2 below), based on Terzaghi's silo theory, including the silo reduction factor (κ).

$$w_g = \kappa \gamma H \qquad [2]$$

where:

$$\kappa = \frac{1-e^{-2\frac{H}{B'}K_O tan\delta}}{2\frac{H}{B'}K_O tan\delta}$$

B' = width of slip plane at the top of the pipe.

K_o = ratio of lateral to vertical soil pressure (has a value between active and passive),

δ = friction angle on the slip plane, *$0<\delta<\phi$;*

ϕ = the soil friction angle for fill material.

Whilst AS/NZS 2566.1 specifically excludes providing advice on "bored" installations, Figure C 4.1 of the Commentary provides a suggested approach for "bores" which is replicated as Figure 3 below.

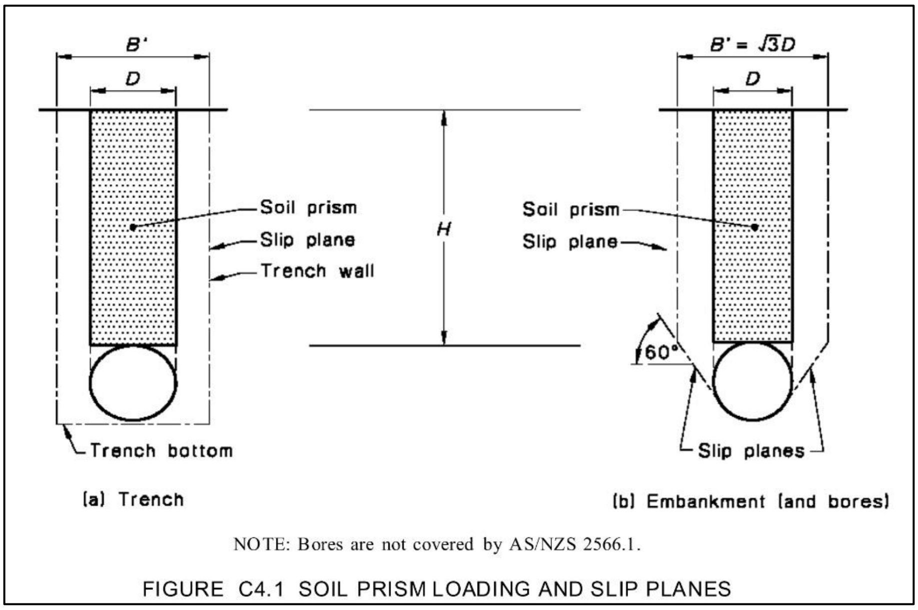


Figure 3 - Figure C4.1 from AS/NZS 2566.1 Supp. 1

Whilst the use of the silo reduction factor is commonly adopted in different design standards, there is variation in the actual design parameters used. Some of these variations are:

(a) The width of the slip plane. Some publications suggest that this should be the width of the bore rather than the pipe diameter. Adopting the terminology of AS/NZS 2566.1, D is the pipe diameter at the neutral axis which is probably not intended.

(b) The lateral earth pressure coefficient. DWA-A 161 (5) provides values for the silo reduction factor based on a value of lateral earth pressure coefficient of 0.5.

(c) The friction angle on the slip plane. A number of publications including ASTM F 1962 (6) and DWA-A 161 suggest that this angle should be equal to half the soil friction angle due to there being insufficient actual movement in the soil above the pipe to engage the full soil friction.

(d) The AS/NZS 2566.1 Supp. 1 equation ignores soil cohesion although some publications suggest it should be. For design of concrete pipes, AS/NZS 3725 (7) includes this soil parameter.

Akbarzadeh and Bayat (8) provide a good summary of some of the these issues as applied to Horizontal Directional Drilling (HDD) although the principles disucssed are common to all trenchless techniques. AS/NZS 2566.1 Supp. 1 provides a reference to the concrete pipe design standard AS/NZS 3725 and states that this standard provides values of the product of K_o and $tan\delta$ between 0.11 for soft clay and 0.16 for crushed aggregates.

DWA-A 161 provides values of soil friction angles for gravels and sands (Group 1 soils) of 32.5 degrees and for clays (Group 4) 15 degrees. Adopting $\delta = 0.5\phi$ and $K = 0.5$, this results in the product of K and $tan\delta$ of 0.07 for clays and 0.15 for sands and gravels. If one accepts the principle adopted in DWA-A 161 of $\delta = 0.5\phi$, it could be concluded that adoption values of the product of K_o and $tan\delta$ in AS/NZS 2566.1 Supp. 1 could result in too high a value of the silo reduction factor for clays but it could also be argued that ignoring soil cohesion in clay is also conservative.

3.2 Rock Loads Acting on the Pipe

Installing pipe in rock using trenchless techniques is very common. It is also common to assume that in rock there are no loads acting on the pipe. DWA-A 161 provides some general guidelines for installation in ‘loose’ or ‘solid’ rock without directly providing a definition of these terms. These general guidelines are:

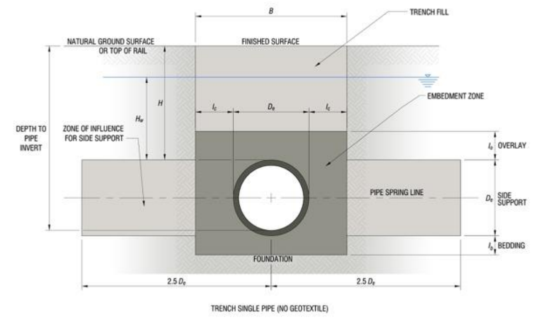
- In loose rock or in solid rock with an overlay of soil (i.e. all soil above pipe) adopt the same assumptions as for soil.
- In solid rock with a height of solid rock of two pipe diameters or less above the pipe (with possible soil above this) adopt the same assumptions as for loose rock.
- For installations exclusively in solid rock, it may be possible to reduce the calculated cover height to 2 x the pipe external diameter. (If relevant, the water table height may be greater).
- In local weathering zones, special considerations may be required.
- Non-quantifiable influences (e.g. point loads) may occur when jacking in solid rock (a typical example is a piece of rock that falls out of the roof of the bore on top of the pipe).

The criteria of adopting a cover height of 2 pipe diameters is common in a number of tunnelling applications. It should be noted however that the height of the water table in rock could be in excess of this value.

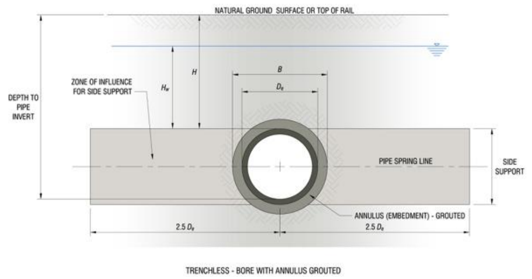
4 DESIGN FOR TRENCHLESS INSTALLATIONS – GROUTED INSTALLATIONS

As explained in Section 3, determining the loads acting on the pipe is not difficult albeit with some judgement required with regards the use of the silo reduction factor for soil loads. Determining the load effects (deflection, strain and buckling) does require further consideration.

Figure 4 (a) is a conventional (trenched) installation. Figure 4(b) is a trenchless installation with the pipe concentric in the bore with the gap (annulus) between the pipe and the bore filled with grout. In this latter installation the grout is the key element.



(a) Conventional Installation



(b) Trenchless Installation (Grouted)

Figure 4 - Typical Conventional (Trenched) and Trenchless Installations

There are a number of issues with the grout in the trenchless installation which need to be considered. These are:

i. If the strength and thickness of the grout are too high, then the system will tend to behave like a plastic lined rigid pipe. This may be ok, but it is then important to understand the design methodology.
ii. Does the grout add to the overall load carrying capacity of the installation or in other words can it be considered equivalent to the embedment for a conventional installation?
iii. Is the grout sufficient to assume that the native soil will provide side support to the pipe?

DWA-A 161 contains very different design equations and methodology to AS/NZS 2566.1. It does however address the issue of grouting and side support and states:

> *"With flexible pipes – in an operating state and on the condition of having complete bedding – the supporting effect of the lateral bedding reaction pressure can be accounted for when horizontal deformations are caused as a result of vertical loading. Complete bedding exists when the annular space is grouted permanently, and fully once jacking is complete. The method of installation and the soil must guarantee these conditions."*

Unfortunately, DWA-A 161 does not provide any guidance on what constitutes grout or how it should be specified. In the following section we provide some references to material requirements for grout from different sources.

4.1 Grout Material Requirements

If design equations for flexible pipes are to be used, then ideally the grout would behave like a soil. The US Bureau of Reclamation (9) refers to the use of controlled low strength material (CLSM) as embedment material in conventional installations and refers to a material as having a compressive strength of between 50 to 150 lb/in^2 (0.3 to 1 MPa) at 7 days with an assumed modulus E' of 4000 lb/in^2 (28 MPa) for the lower compressive strength value. In this publication they refer to the use of this modulus in combination with the native soil modulus to obtain a combined soil modulus (AS/NZS 256.1 terminology) to design an installation using flexible pipe design theory.

AS/NZS 2566.2 (10) Appendix K provides information on CLSM's and states that they will provide a material of suitable stiffness and stability as an alternative to mechanically compacted granular fill used in the embedment or trench fill zones. Table K1 provides typical mix proportions for a material that should achieve a compressive strength in the range 0.6 to 3.0 MPa at 28 days which is replicated as Table 1 below.

Table 1 - Typical CLSM Mix Proportions (AS/NZS 2566.2 Appendix K)

Material	% by mass
GP cement	2 – 6
Fly ash	0 – 20
Granular material	60 – 80

The origin of this suggested mix proportion is not known, but it is understood that a material with such a high proportion of granular material (sand) is not likely to have the required workability for grouting of trenchless installations and that a mix with just cement, fly ash, water and various additives is more appropriate.

Vicroads Technical Note 07 (11) refers to the use of flowable fill available in three strength grades with the lowest having a compressive strength in the range 0.5 to 2.0 MPa at 28 days. They refer to materials with compressive strengths of between 0.3 and 0.7 MPa providing an equivalent bearing capacity to well compacted fill materials.

In research on the use of grouts for use with slip lined pipe renovations, Smith, Hoult and Moore (12) reported on results of testing for both a low and high strength grouts. The low strength grout had an average compressive strength of 1.3 MPa and consisted of a cement/water/foam mixture with about 60% foam in the mix by volume. They also reported that this grout had an elastic modulus of 2,350 MPa and a Poisson's ratio of 0.469. They concluded that this value of Poisson's ratio is very similar to many soils which combined with the low compressive strength "*lends credence to the assumption that it can be considered to be equivalent to having soil between the two pipes*". (In this research grout was placed between a corrugated metal host pipe and a polyethylene slip-lined pipe). The research also indicated that the low strength grout did not display any significant shrinkage but the high strength (about 30 MPa compressive strength) grout did.

In summary, for flexible pipe design the grout needs to be considered as a soil and for this to occur the compressive strength should not exceed about 1.0 MPa. For grouts in a thin annulus, say less than 15 mm, this requirement is considered unnecessary. In this case the thin grout layer will crack allowing the pipe to deflect but the grout is still likely to provide the necessary support such that the side support from the native soil will be provided. It is also important that the grout has low shrinkage.

4.2 Effectiveness of Grouting

As stated in DWA-A 161, if the supporting effect of the lateral supporting pressure is to be accounted the annular space must be grouted permanently and fully. This raises the issue of how effective grouting might be in a number of different installation methods. In Figure 2 (a) and (b) above, the installations depicted are of a typical pipe being jacked in behind a boring machine. In these installations the annulus is quite small. In non-person entry pipes (say < DN1200) grouting after installation needs to be done between the launch and reception pits and in many soils grouting is unlikely to be effective along the full length of the pipeline. In person-entry sized pipes it is possible to include grout injection fittings within the pipes (typically every third pipe) and such grouting via these fittings could be considered to be effective in most soil conditions.

There are a range of different trenchless installation methods which could be classified as microtunnelling which allow the excavation of an unsupported bore which is then slip-lined with a pipe which is either pushed or even pulled into position. Such methods allow installation of a range of different plastic pipe materials including PVC, PE, PP and GRP. Of these only the GRP might be a classified as an actual jacking pipe. Figure 5 shows some examples of such installations. Both these examples are installed in rock but such installations may also be possible in stiff clays and some other soils.

(a) DN225 uPVC Pipe (SN8) inside 375 mm Dia, Bore (Courtesy Pezzimenti Tunnelbore)

(b) DN400 GRP Pipe – small annulus (Courtesy Pezzimenti Tunnelbore)

Figure 5 - Examples of Slip Lined Pipes Inserted into Excavated Bores

Figure 5(a) shows the installation of a DN225 uPVC pipe in a larger bore. Timber spacers have been used to centralise the pipe in the bore. For this example, with installation in rock, the structural design of the pipe may not be critical but in soil it may be. In this case grouting would be effective along the full length of the bore and with spacers included the pipe would be centralised in the bore and as such it would be reasonable to consider the grout as an embedment as for a conventional installation. Grout however needs to act like a soil and based on the information contained in Section 4.1, the grout should have a compressive strength between 0.5 and 1.0 MPa at 28 days and have low shrinkage.

Figure 5(b) shows a GRP jacking pipe being slip lined into an excavated bore but with a much smaller annulus. Grouting along the full length of this pipeline is likely to be still effective but with no spacers and the small annulus the grout would be ignored in the design and the combined soil modulus would be equal to that of the native soil.

4.3 Design Approach for Grouted Installations

It is suggested that the design equations contained in AS/NZS 2566.1 for a grouted installation are valid for a pipe installed using trenchless technology provided the annulus is fully grouted and the grout meets certain criteria as detailed below:

i. The designer needs to be confident that the grout completely fills the annulus along the full length of the bore. For non-person entry sized pipes, for this to occur the bore needs to remain stable along the full length of the installation until grouting is completed.
ii. The grout should have a minimum compressive strength of 0.3 and a maximum of 1.0 MPa at 7 days. The maximum could be relaxed to 1.5 MPa if necessary. For grout thicknesses of less than 15 mm the maximum grout strength requirement can be relaxed.
iii. When pipes are installed in a bore with spacers, the spacers ensure the pipe is concentric with the bore and therefore the grout could be considered as an embedment material.

Otherwise the contribution to the installed strength of the installation from the grout is ignored and the combined soil modulus value should equal that of the native soil.

iv. It should also be understood that the grouting is another installation load which needs to be considered by the installer particularly with thermoplastic pipes which may lose stiffness due to the heat of hydration.

If grouting is not done or is not effective, then the design provisions in Section 5 below may be appropriate.

5 DESIGN FOR TRENCHLESS INSTALLATIONS – UNGROUTED INSTALLATIONS

Grouting the annulus for most trenchless installations is generally a good idea particularly for on-grade installations such as sewers or stormwater pipelines. Grouting may assist with preventing settlement and also prevent flow of water along the length of the installed pipeline which otherwise could lead to creation of voids along the length of the pipeline and premature failure. Pipelines installed using HDD represents a special case which is discussed further below.

Whilst grouting may be a requirement, it may not be effective in filling the complete annulus along the full length of the pipeline. The most common example of this would be installation of non-person entry sized pipes in cohesionless soils or other soils for which the bore is unlikely to remain stable for the complete duration of both the pipe installation and subsequent grouting. In this situation there is likely to be voids in between the pipe and the native soil or if native soil collapses onto the pipe there may be soil in the annulus of unknown consistency. As such, the contribution to the strength of the installed pipe provided by the soil around the pipe should be ignored.

The main design equations in AS/NZS 2566.1 which contain the combined soil modulus are the equations for both deflection and buckling. Buckling is perhaps the simplest to consider. The capacity of the pipe installation is provided by the two equations for allowable buckling pressure which are equations 5.4(4) and 5.4(5) in AS/NZS 2566.1 which are replicated as Equations 3 and 4 below.

$$q_{all\,1} = \frac{1}{F_s} \frac{24}{(1-\vartheta^2)} S_{DL} 10^{-3} \qquad [3]$$

$$q_{all\,2} = \frac{(S_{DL} x\ 10^{-6})^{1/3} (E')^{2/3} x\ 10^3}{F_s} \qquad [4]$$

The allowable buckling pressure for fill heights (H) of 0.5 m or greater is the greater of the value determined by these two equations. For H < 0.5 m only Equation 3 applies. The first equation (Timoshenko's buckling equation), depends only on the long-term stiffness (S_{DL}) and Poisson's ratio (ϑ) of the pipe material. The second equation, known as Moore's equation, is dependent on both the long-term pipe stiffness and the combined soil modulus (E'). If the native soil is not effective in providing side support, then the combined soil modulus is zero and the allowable buckling pressure is determined by Equation 3 only; resistance to buckling is provided by the properties of the pipe only.

The deflection equation contained in AS/NZS 2566.1 is a modified version of the modified Iowa equation and is Equation 5.2(2) in AS/NZS 2566.1 and is replaced as Equation 5 below.

$$\frac{\Delta y}{D} = \frac{K\ x\ 10^{-3}(w_g + w_{gs} + w_q)}{8\ x\ 10^{-6}\ S_{DL} + 0.061\ E'} \qquad [5]$$

In a similar manner as described above, it is possible to calculate a deflection from Equation 5 by adopting a value of E'= 0. This has been done for the example introduced in Figure 1 earlier but with different values of E'between 10 and 0 MPa. The results are shown in Figure 6 for a DN450 PE100 SDR17 pipe with a depth to invert of just over 4 m and full highway loading.

As an alternative to AS/NZS 2566.1, ASTM F1962 (6) contains a formula for calculating deflection for pipes installed using HDD which is this standard is Equation X2.5 which is replicated as Equation 6 below.

$$\frac{\Delta}{D} = \frac{0.0125 P_E}{(E/12(DR-1)^3} \qquad [6]$$

Where:
P_E= Earth pressure (kPa)
E = modulus of elasticity (kPa). A value of 260,000 kPa for PE100 was included.
DR = pipe dimension ratio.

ASTM F1962 states that "*as slurry surrounding the pipe* [installed using HDD] *provides essentially no side support, there is little pressure at the springline to restrain vertical deflection. The primary resistance to deflection is provided by the pipe's stiffness."* The result for Equation 6 for the same pipe is also plotted in Figure 6.

As can be seen in Figure 6, the result from the AS/NZS 2566.1 and ASTM F1962 equation is the same for the same loading conditions. Whilst equations 5 and 6 look quite different they are essentially the same formula if $E'$is excluded.

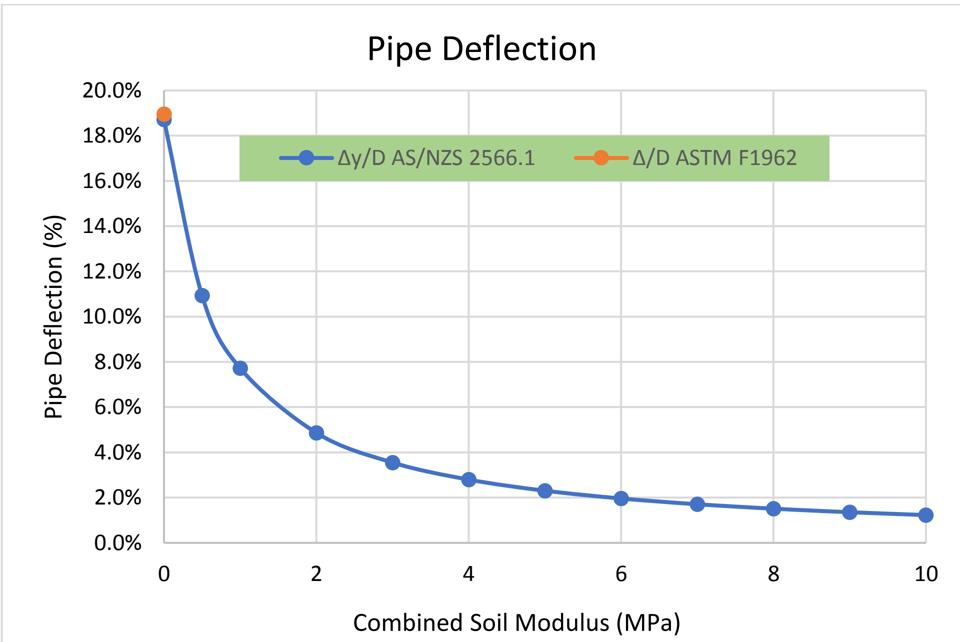


Figure 6 - Deflection of DN450 PE100 SDR17 Pipe for Different E' Values

The only other calculation for the ungrouted trenchless installation that needs some explanation is the calculation of ring bending strain. The formula for ring-bending strain in AS/NZS 2566.1 is

Equation 5.3.1(2). This includes the value of the shape factor (D_f). As explained in AS/NZS 2566.1 Supp. 1, the shape factor adjusts strain values to account for the deflected pipe ring shape. Where the pipe is a pure ellipse the shape factor is three. As the ratio of S_{DL}/E' decreases, the shape factor increases accordingly. For the ungrouted trenchless installation the pipe shape will be an ellipse and a shape factor of 3 is appropriate.

6 CASE STUDY RESULTS

In the example introduced in Section 1, the designers of this pipeline have nominated that DN300 and DN450 PE100 SDR17 pipe should be installed using "Trenchless Technology" without nominating the actual method of installation. Some installation contractors may be capable of installing this pipe using HDD although installation of such a pipe using this method "on-grade" can be a challenge. There is however other microtunnelling type equipment available which could be suitable to install such a pipe by pulling the polyethylene pipe into the completed bore.

Calculations were performed for the DN450 PE100 pipe for a number of different design scenarios using the Trenchless version of the software FlxPipe® (www.trenchless.flxpipe.com) and a summary is presented in Table 2 below.

Table 2 - Design to AS/NZS 2566.1 Results Summary

Parameter	Symbol	Allowable	Result 1	Result 2	Result 3	Units
Pipe Nominal Diameter	DN		450	450	450	
Material			PE100	PE100	PE100	
Standard Dimension Ratio	SDR		17	11	17	
Pipe short-term stiffness	S_{DI}		19575	77900	19575	N/m/m
Pipe long-term stiffness	S_{DL}		5357	21320	5357	N/m/m
Depth to invert			4.34	4.34	4.34	m
Height water table	H_w		3.34	3.34	3.34	m
Installation Condition			Ungrouted	Ungrouted	Grouted	
Embedment modulus			N/A	N/A	3	MPa
Native soil modulus			N/A	N/A	3	MPa
Combined soil modulus			0	0	3	MPa
Silo reduction factor	κ		1.0	1.0	1.0	
Traffic loading			Yes	Yes	Yes	
Deflection	$\Delta y/D$	7.5%	18.7%	4.7%	3.5%	%
Ring-bending strain	ε	4.0%	3.5%	1.4%	0.8%	%
Buckling FOS		2.5	1.6	6.4	3.8	

A silo reduction factor of 1.0 was adopted for all design scenarios – i.e. no soil load reduction due to frictional effects. In this example the ratio H/D < 10 and as such a literal interpretation of Clause 4.3 of AS/NZS 2566.1 as explained in Section 3.1 above has been applied.

As explained in Section 4.2 above, grouting of small diameter non-person entry pipes can be difficult. The first design scenario considered as detailed in Results 1 is the ungrouted installation with the specified pipe (SDR17). As can be seen in the results the pipe deflection and buckling do not meet the specified requirements of AS/NZS 2566.1 with the deflection exceeding the maximum allowable value and the buckling factor of safety is less than the minimum recommended value of 2.5.

The second design scenario considered as detailed in Results 2 is the ungrouted installation with a higher stiffness (lower SDR) pipe (SDR11). As can be seen in the results this provides a significant increase in pipe stiffness and acceptable deflection, strain and buckling results are all complying with the minimum specified or recommended values in AS/NZS 2566.1.

The third design scenario considered as detailed in Results 3 is the grouted installation with the specified pipe (SDR17) and a native soil modulus of 3 MPa. Again, acceptable results were obtained. Whether or not grouting is actually possible with pipe of this diameter would depend very much on the actual soil conditions and the actual techniques offered. If in doubt, a better design option may be to use the higher stiffness pipe. The SDR17 also may not have sufficient axial capacity to be pulled into place. The design of this aspect of the installation is beyond the scope of this paper but ASTM F1962 would be a useful reference along with a paper by Bower and Steedman (13) for information regarding applying ASTM F1962 design methods with PE100 pipe.

The suitability of using HDD for such an installation is worth further comment. HDD techniques are particularly well suited to placing pipeline and conduits under obstacles such as roads, rivers, major services etc. The technique is also well suited to pressure pipelines where control of the vertical alignment is generally not critical. For gravity sewers and stormwater pipelines, as in this example, it is important that pipes are installed on a consistent vertical alignment matching the grade shown on the design drawings and this may be difficult to achieve using HDD in some ground conditions. The other potential issue with HDD is the size of the annulus. For a pipe of this diameter the recommended bore diameter is 1.5 x Pipe OD (14) or in this example 675 mm. This results in a theoretical annulus of 112 mm. Although not shown in Figure 1, this example involved installation of a pipeline longitudinally under suburban roads in a major city. This size of annulus could lead to unacceptable settlements at the road surface if this annulus is not grouted. Grouting of HDD installations, whilst possible, is not often done as there is a risk of heave and other unintended consequences if it is not done well. As demonstrated in this paper, grouting does offer a number of advantages for design and pipe selection but is also important to reduce settlement risks.

7 CONCLUSIONS

There is a continuing trend to install plastic pipes using trenchless methods which have a pipe stiffness originally intended for conventional (trenched) installations. It is important that design methods keep pace with this installation capacity so that authorities can have confidence that the installed pipe is suitable for all design loads which it may be subjected to during its service life. This paper has demonstrated how the principles of AS/NZS 2566.1 can be applied with only limited modification for design of flexible pipes installed using trenchless technology. A number of the suggestions included in this paper could quite easily be incorporated into a future revision of AS/NZS 2566.1. Grout and grouting are seen as a key design issue. Both need to be better addressed and understood for all trenchless methods and in particular HDD. Relevant specifications for both grout and grouting do need to be developed so that designers can be confident that design intents are reflected in actual construction methods.

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