



PIPA

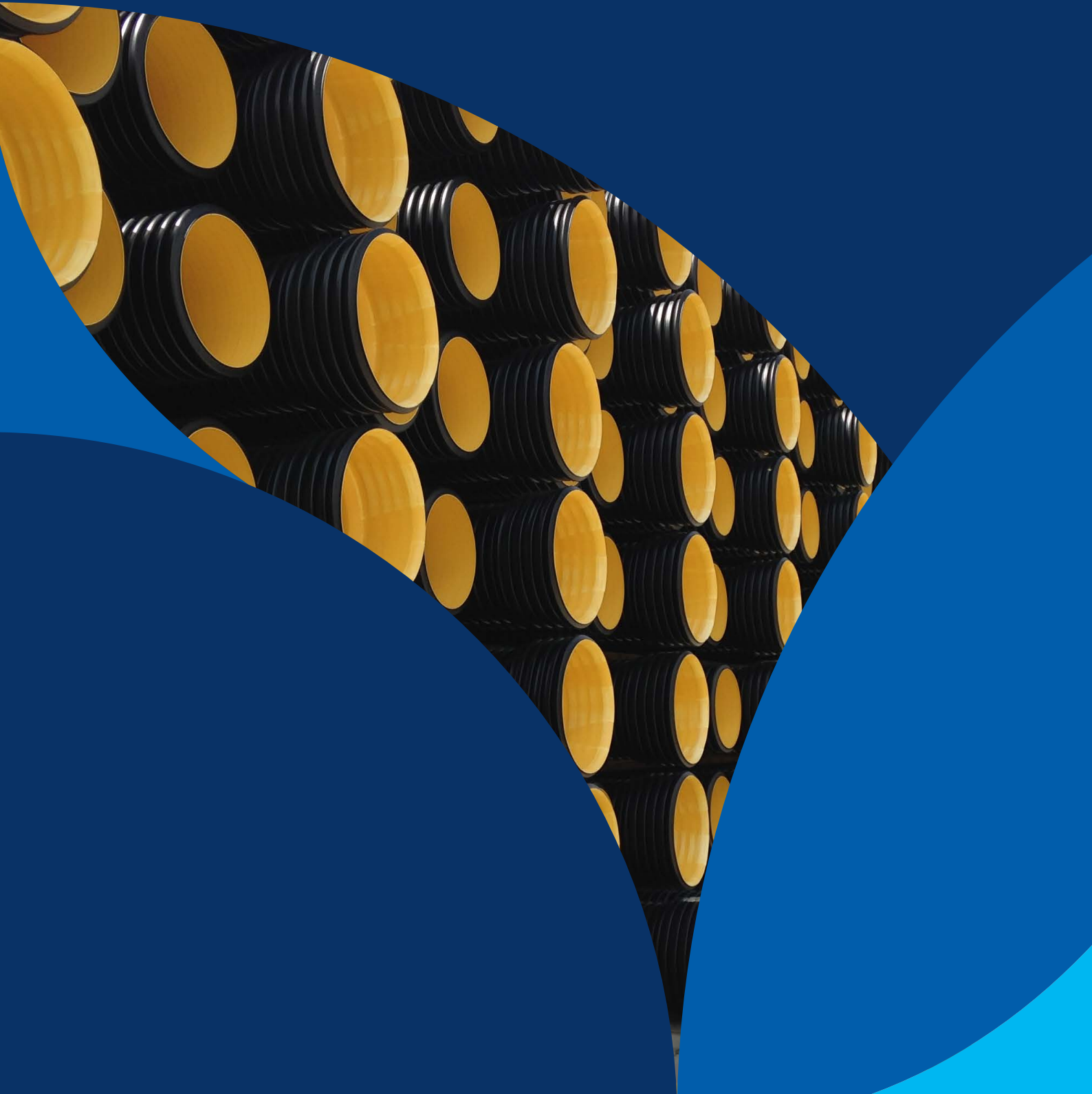
PLASTICS INDUSTRY
PIPE ASSOCIATION
OF AUSTRALIA LIMITED

INDUSTRY GUIDELINES

POP209

Structural Design of Buried Flexible
Thermoplastic Pipes for Non-
Pressure Applications

ISSUE 1 / MARCH 2026



STRUCTURAL DESIGN OF BURIED FLEXIBLE THERMOPLASTIC PIPES FOR NON-PRESSURE APPLICATIONS

1.0 INTRODUCTION

Flexible thermoplastic pipes have been successfully installed and used for critical road and rail applications for many decades around the world. Their performance is due to the integrity and durability which is achieved through a combination of material selection, product design, manufacturing, and installation. Plastic pipeline infrastructure has benefited enormously from the regulation of plastic pipe production and materials via Australian (AS/NZS) and/or international (ISO) product standards. This makes them suitable for complex engineering applications.

Note: This document covers non-pressure pipes only.

Structural design calculations for buried pipes are used to ensure that installed pipes are capable of supporting the applied loads for the intended design lifetime while performing their primary function, the transport of fluids. Structural design methods consider the combined system of the pipe and the surrounding soil, in combination with the static and dynamic loads they are expected to experience.

Rigid pipes, which do not deflect, must be designed so that the transmitted loads do not exceed the strength of the pipe itself and result in cracking. The support from the pipe foundation plays a fundamental role in pipe class selection and the design of allowable depths. Consequently, during installation of rigid pipes, it is important that the bed and haunch zones are properly compacted to ensure the bedding factors nominated for the installation type are achieved.

Flexible pipes, which tend to deflect into an oval shape in response to loads, derive significant support from the surrounding embedment material. In this case, the design calculations primarily ensure that the combined interaction of the pipe and its embedment prevent pipe deflection levels that exceed the design limits and ensure buckling of the pipe wall does not occur.

There are a number of national and / or international calculated design methods for structural design of buried flexible pipes. In Australia, the primary reference is *AS/NZS 2566.1 – Buried flexible pipelines, Part 1: Structural design*.

Calculated design methods, like other engineering models, are generally validated by measurements of in-situ installations. In 1996 The European Plastic Pipe and Fittings Association (TEPPFA) and the Association of Plastics Manufacturers in Europe (APME) undertook a comprehensive study ^[1] on the actual measured deflection of buried flexible thermoplastic pipes installed under various conditions. The findings from the TEPPFA / APME study resulted in the development of the 'Graphical design method' that predicts the expected long-term deflection based on the pipes ring stiffness rating (SN) and the degree of embedment soil compaction around the pipe.

Both the structural design method in *AS/NZS 2566.1* and the graphical design method are now referenced in *AS/NZS 2033 Design and installation of polyolefin pipe systems*. This guideline provides an overview of these structural design methods in relation to buried flexible thermoplastic pipes for non-pressure applications.

2.0 THERMOPLASTIC PIPES & DESIGN CRITERIA

THERMOPLASTIC MATERIALS

The most common thermoplastic materials used for non-pressure pipe applications are polypropylene (PP), polyethylene (PE, HDPE) and polyvinyl chloride (PVC).

TYPES OF WALL CONSTRUCTION

Thermoplastics pipes can have either plain walls or structured walls. Structured wall pipes have the advantage of using less raw material for the same application, which confers both environmental and handling benefits. Structured wall pipes include multilayer sandwich construction and profile wall or twin wall pipes. They are generally manufactured using coextrusion technology

STANDARDS

Conformance to product Standards for thermoplastic pipes is critical to ensure long-term performance of pipes in structural applications where design life may exceed 100 years.

Product Standards specify material and performance criteria that address the durability and stability of pipes in service.

The relevant Australian Standards are:

- AS/NZS 5065 – Polyethylene and polypropylene pipes and fittings for drainage and sewerage applications
- AS/NZS 1260 – PVC-U pipes and fittings for drain, waste and vent applications
- AS/NZS 1254 – PVC-U pipes and fittings for stormwater and surface water applications

PIPE STRUCTURAL CLASSIFICATION

Non-pressure thermoplastics pipe product Standards generally classify pipes by their nominal ring stiffness (SN). Where design methods refer to short-term ring-stiffness, ring-bending stiffness or stiffness class it is the ring stiffness (SN) that is being referred to. Ring stiffness or SN is the ability of a pipe to resist forces acting on it in the radial direction. It is determined using a performance test which measures the force required to achieve a 3% diametral deflection at 23°C. Ring stiffness is typically expressed in units of N/m/m or kN/m².



2.1 DESIGN CRITERIA

The key design criteria that need to be checked in the case of non-pressure buried flexible pipelines are as follows: -

- I. Maximum allowable long-term vertical deflection limit for the pipe – typically set at 7.5% for thermoplastic pipes manufactured in accordance with a recognised AS/NZS Standard.
- II. Minimum factor of safety against buckling
- III. Maximum allowable strain limit for the pipe material

Each of these design criteria is explained further below, with additional details and discussion given in the sections covering the Graphical Design and Calculated Design Methods.

DEFLECTION

One of the design considerations for buried flexible pipes is ring deflection. For flexible thermoplastic pipes, the long-term design limit is usually 7.5%. This limit reflects serviceability requirements in terms of the following:

- Upper limit of diametral distortion for pipe and fittings with elastomeric seal joints. Australian Standards require rubber ring joint performance tests (i.e. hydrostatic and resistance to liquid infiltration) to be carried out with the pipe deflected to 7.5%. This ensures a watertight seal in all installations.
- At 7.5% deflection, the hydraulic discharge capacity of the pipe is reduced by less than 1% discharge flow capacity is maintained to no less than 95% of maximum.

The 7.5% limit is **NOT** a reflection of strainability limitations. It has been shown in studies by Moser ^[9] and Janson ^[8] that non-pressure PVC, PP and PE pipes for practical purposes are not strain limited. This is demonstrated by non-pressure pipes manufactured to the recognised AS/NZS standard, having to meet the ring flexibility test up to 30% deflection without cracking, rupture or buckling (ref AS/NZS 1462.23).

The 30% deflection requirement in the ring flexibility test effectively means that a factor of safety of at least 4.0 ^[7] is applied for a vertical deflection limit of 7.5%.

BUCKLING

Another potential failure mechanism that should be checked in pipe design is buckling. If the incorrect class of pipe is selected, compressive stresses due to high external pressure and / or internal vacuum can lead to buckling of the pipe wall. As the pipe wall thickness, or ring-stiffness increases, the resistance to buckling increases. Soil support also greatly improves the resistance of buried pipe to buckling compared to unsupported pipe.

STRAIN

Thermoplastics pipes can withstand high levels of strain. This is particularly the case where pipes are held at constant strain and undergo stress relaxation. Studies ^[8,9] have shown that thermoplastics pipes held at constant deflection with high levels of bending strain have not shown any sign of cracking, even after long periods of time. This means that for practical purposes, thermoplastic materials are not strain limited.

Nevertheless, some design Standards, including *AS/NZS 2566.1* adopt strain limits and check bending strain is within these acceptable limits. At the specified 7.5% deflection limit for thermoplastic pipes, it is highly unlikely that strain will be a limiting factor in the structural design of buried thermoplastics pipes.

3.0 METHOD 1 – GRAPHICAL DESIGN METHOD

The graphical design method in section 6.0 – Installation of buried pipes and fittings of AS/NZS 2033 is a design methodology based on practical experience and extensive studies of the deflection history of pipes installed under different conditions. These studies were undertaken as part of a co-operative research study sponsored by The European Plastic Pipe and Fittings Association (TEPPFA) and the Association of Plastics Manufacturers in Europe (APME) that ran from 1996 to 1999, with findings being published in March 1999 by TEPPFA *“The Design of Buried Thermoplastic Pipes”*, Alferink, F. Subsequently, similar studies have also been performed in various countries outside of Europe.

3.1 TEPPFA STUDY SUMMARY

The objective of the study was to gain a better understanding of pipe soil interactions in buried thermoplastic pipe installations. The study focused on DN315 pipes of solid wall construction, made from either PVC or PE and having ring stiffness values ranging from SN2 to SN6. Pipes were embedded in either sand or clay soils, similarly for the surrounding native soil, thus allowing for differences between granular and cohesive soil types to be assessed in terms of pipe deflection control.

Burial depths varied between 1.15 – 3m and installation quality was determined by the level of embedment material compaction defined in terms of well, moderate and none. A total of 16 different installations were studied to assess the relative impact of the installation variables described.

KEY FINDINGS

The findings of the TEPPFA research were presented and discussed at international plastics pipe and civil engineering conferences during the late 1990’s and early 2000’s by the lead researchers, Prof. L.E. Janson, Mr. F. Alferink, Dr. J.L. Olliff, Mr. I. Björklund and Mr. J. Kallioinen. ^{[2] [3] [4] [5]}

There were several key findings from these studies; importantly: –

- Buried flexible pipes made from thermoplastic materials such as PVC, PE and PP behave differently than rigid pipes such as concrete.
- Current theoretical mathematical design models describing the performance of flexible pipes do not truly represent the physics of buried pipe deflection.
- Controlling the level of compaction during installation has the greatest influence over deflection and long-term performance.

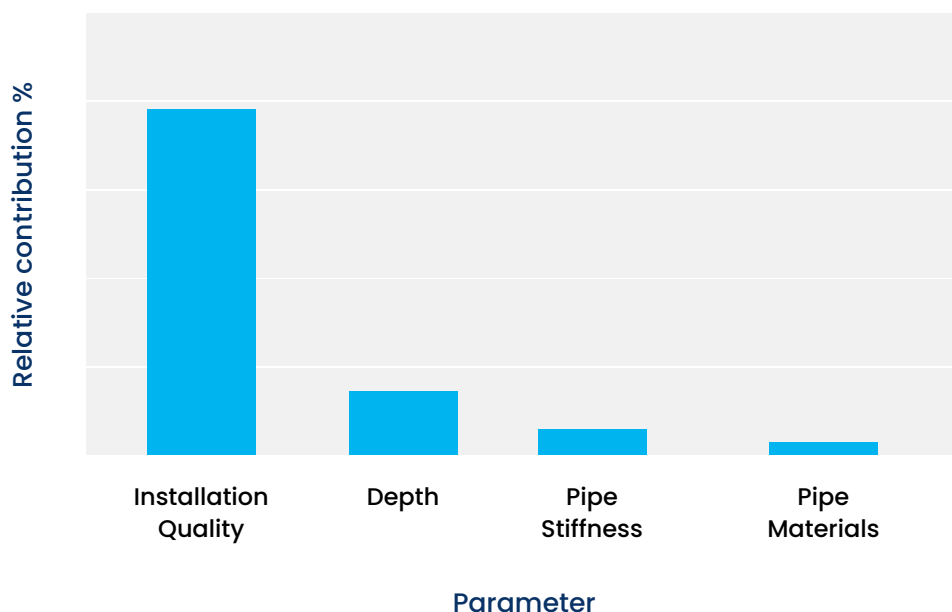


Figure 1 – Parameters’ influence on measured deflection

- Final deflection of pipes was controlled by the settlement of the soil after installation. Where installation was controlled, or self-compacting granular material was used, pipe deflections were consistently low regardless of installation depth, and traffic or other loads.
- There are various calculated design approaches used around the world. The study found that these methods tended to overestimate predicted deflection compared to what was observed in the actual pipe installations.

3.2 STANDARDS

The graphical design method has been adopted by various ISO and EN Standards covering design of buried thermoplastic piping systems since 2008:

- *CEN/TS 15223 Plastic piping systems – Validated design parameters of buried thermoplastics piping systems*
- *ISO 21138-1 Plastic piping systems for non-pressure underground drainage and sewerage – Structured-wall piping systems of PVC-U, PP and PE Part 1: Material specification and performance criteria for pipes, fittings, and systems*

3.3 GRAPHICAL DESIGN METHOD

The 'Graphical design method' shown in Figure 2 enables the designer to predict the maximum expected long term pipe deflection based on:

- Knowing the pipe ring stiffness (SN) (shown on the x-axis)
- The level of compaction of the surrounding granular embedment material
- Ensuring that the installation parameters given in Table 1 are met.

Three compaction levels are covered by the design:

- No compaction described as "non" shown by dotted line 'A' on the graph,
- "Moderate" compaction, line 'B'
- "Well", line 'C'

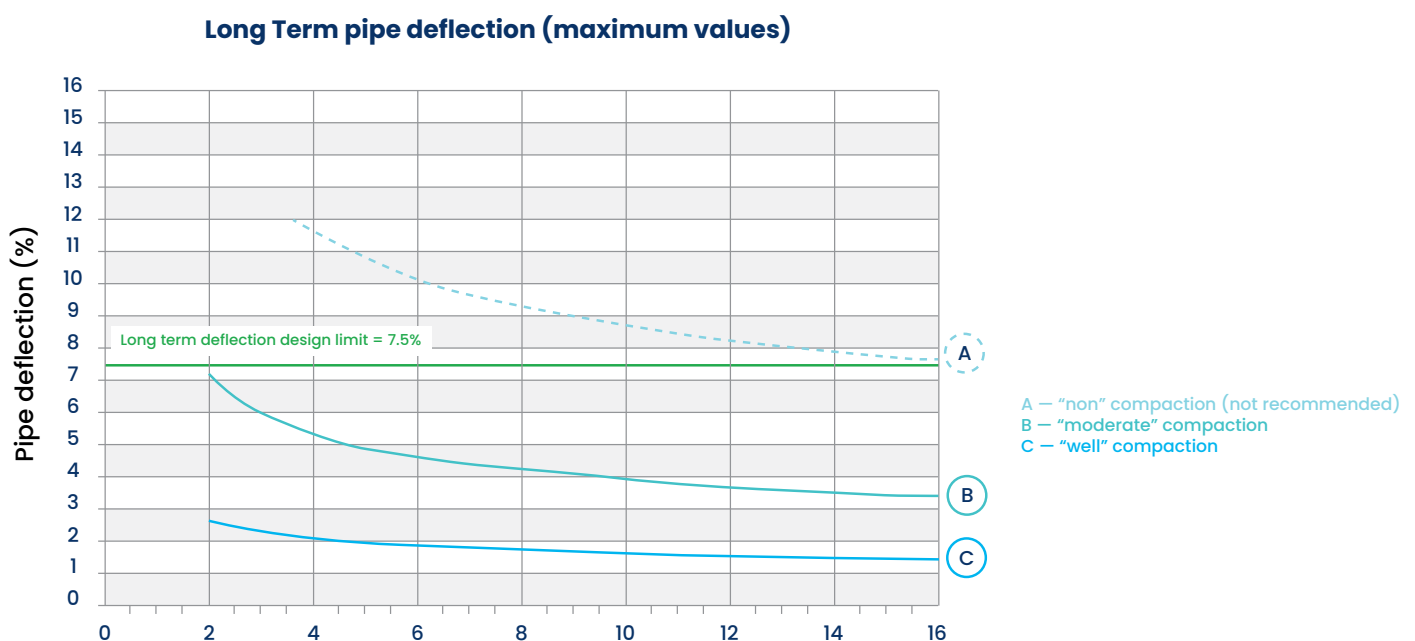


Figure 2 – Graphical design method

It can be clearly seen from the graph above that the “non” compaction line (A) is above the maximum allowable long term deflection design limit of 7.5% for pipe nominal stiffnesses ranging from SN2 to SN16.

Consequently, “non” compaction is likely to result in pipe vertical deflections (shown on the y-axis) exceeding 7.5% in the long-term. For this reason, PIPA does not recommend “non” compaction installations. However, for both the “moderate” and “well” compacted installations predicted long-term deflections are less than the 7.5% deflection design limit and reduce with increasing pipe ring stiffness.

Note:

- To minimise long-term pipe deflection, it is important that the well compacted installation condition be used in the case of major infrastructure, such as under roads.
- **PIPA does not recommend the use of the “non” compaction installation in Australia.**

3.3.1 INSTALLATION PARAMETERS

The graphical method is applicable for most general buried flexible non-pressure and pressure pipe installation conditions. Specifically, those installations that meet the parameters given in AS/NZS 2033 clause 6.2.2.1 and outlined in the table below.

Table 1 - Installation parameters valid for application of ‘Graphical’ method

PARAMETER	VALUE (REQUIREMENT)
Manufacturing Standards	<ul style="list-style-type: none"> → AS/NZS 5065 → AS/NZS 4130 → AS/NZS 4765 → AS/NZS 4441 → AS/NZS 1477 → AS/NZS 1260
Diameter	≤ DN1100
Ring stiffness	> SN2 (2000 N/m/m or 2 kN/m ²)
Minimum depth of cover above the pipe	0.8 m
Maximum depth of cover above the pipe	6 m
Depth of soil cover / pipe diameter ratio	≥ 2



3.3.2 EMBEDMENT COMPACTION (INSTALLATION QUALITY)

The quality of the pipeline installation is a very important factor in determining the actual long-term deflection of the pipe. Selection, and compaction of embedment soil, and the control of this process is critical. AS/NZS 2033 defines three embedment types of only which 'Well' and 'Moderate' are recommended.

EMBEDMENT TYPES

(A) Well compacted installation type

The embedment material should be granular (gravel or sand) and placed in lifts no greater than 300mm thick in the haunch zone and compacted to a relative density of greater than 94% or Density Index of at least 70%. There should be at least 150mm of compacted embedment above the pipe prior to trench fill being placed. Trench fill material should be specified and compacted in accordance with project specifications or documentation.

(B) Moderate compaction installation type

The embedment material should be granular (gravel or sand) and placed in lifts no greater than 500mm thick in the haunch zone and compacted to a relative density in the range 87% to 94% or Density Index in the range 50% to 70%. There should be at least 150mm of compacted embedment above the pipe prior to trench fill being placed. Trench fill material should be specified and compacted in accordance with project specifications or documentation.

(C) None compaction installation type – (not recommended)

The embedment soil of any type is added without compaction. However, big dry clumps of clay or rocks shall not be placed directly on the pipe.

Note: For any conditions which include very poor native soils, pipe sizes greater than DN1100, high ground water conditions or where pipe cover is greater than 6 metres the design calculation method in accordance with AS/NZS 2566.1 should be used.



3.4 EXAMPLE OF THE GRAPHICAL DESIGN METHOD

In the following example the pipeline designer is wanting to predict the expected long-term deflections for a drainage pipeline to be constructed using DN450, SN8 corrugated polypropylene pipe manufactured and certified in accordance with AS/NZS 5065. The minimum depth of cover at any point along the pipeline is 1m and the maximum depth of cover is 3.5m. A granular embedment material has been selected and is to be compacted to at least a “moderate” level i.e., Proctor density within the range of 87 – 94% for the embedment zone.

The designer firstly checks that the installation parameters given above meet the seven graphical design validity requirements given in table 1. In this case the parameters given above meet those requirements, with the lowest depth of soil cover to pipe diameter ratio equalling 2.2.

As the commonly used SN8 drainage pipe has selected the designer now simply draws a vertical line on the graph starting at the SN8 position on the x-axis and extending it until it intersects with either lines B or C on the graph for the specified level of compaction for the installation. In this case, line B for moderate compaction. At this intersection point a horizontal line is drawn out to the y-axis to determine the maximum long-term pipe deflection. So, for an SN8 corrugated PP drainage pipe installed with moderate compaction the expected maximum long term vertical deflection = 4.3%, well below the 7.5% design limit.

If the designer chose to nominate a “well” compacted installation, the maximum long-term vertical deflection would reduce significantly to 1.75%. Figure 3 below shows the example design marked out on the graph and figure 4 shows an illustrated version of the design.

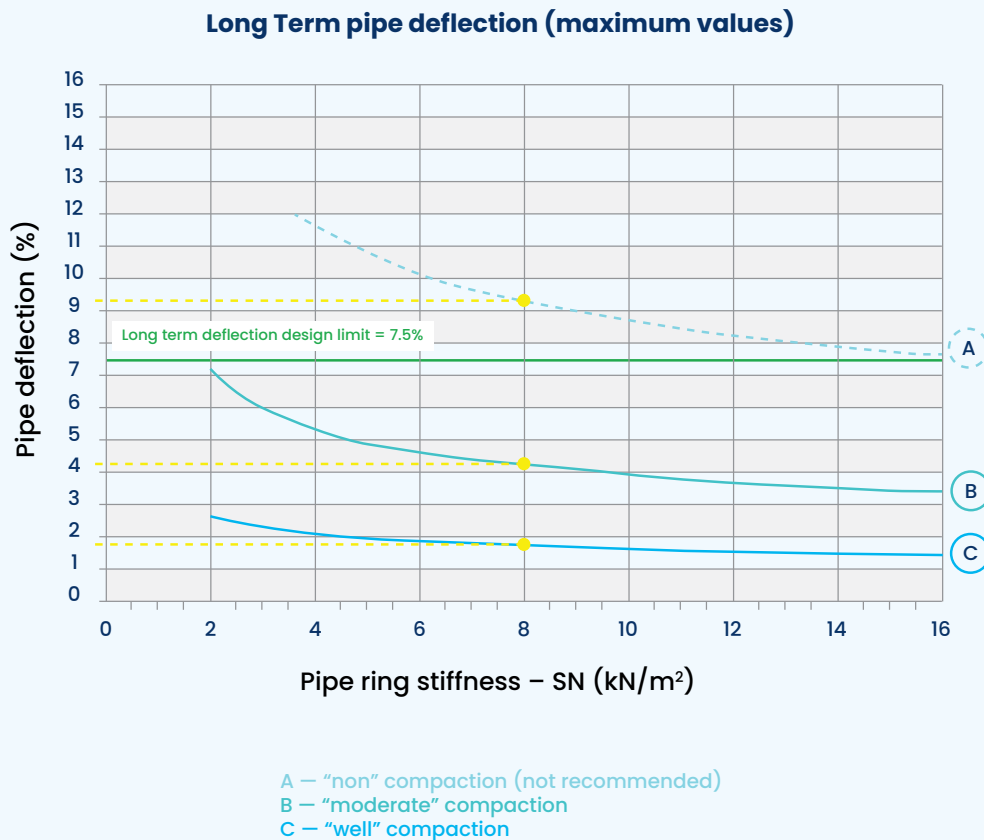


Figure 3 – A worked example of the graphical design method

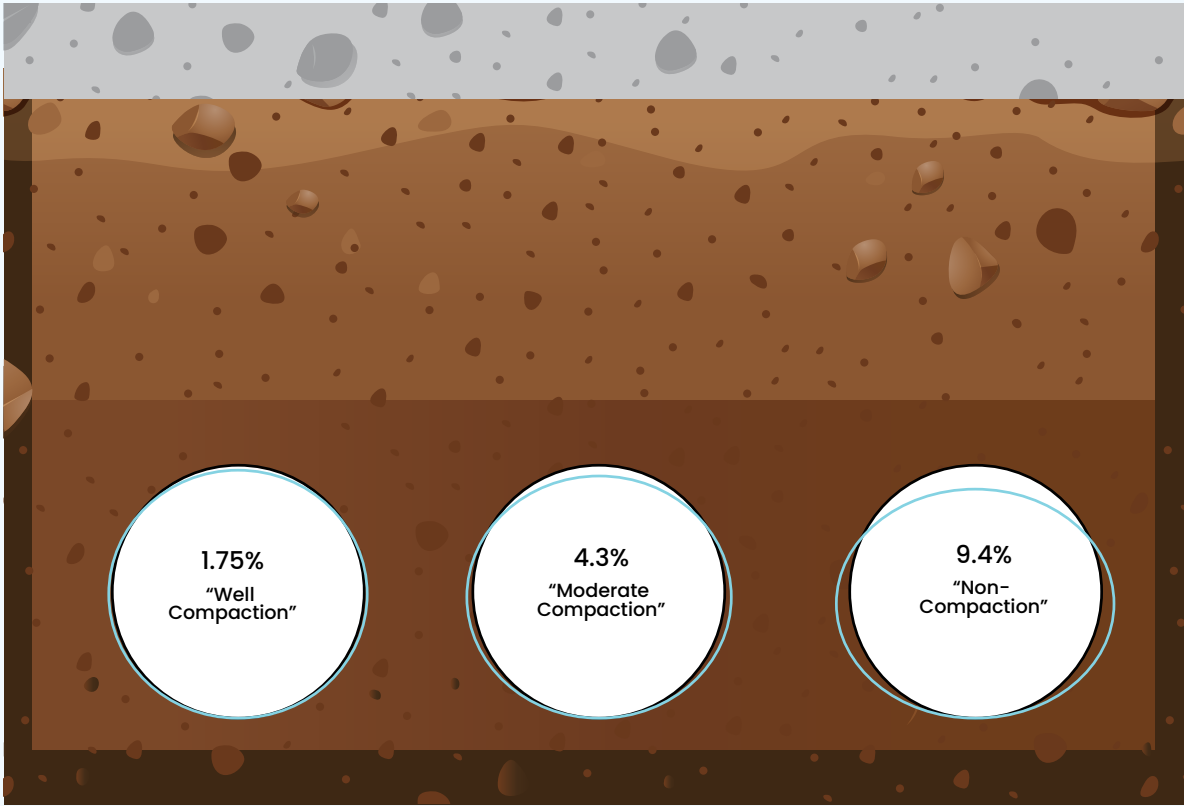


Figure 4 – The worked example showing predicted deflection vs. degree of compaction. Note: This figure is for illustration purposes only

In the case of an installation meeting either the moderate or well compaction requirements the 'graphically' predicted long-term vertical deflection % is well below the 7.5% limit for pipe stiffness ratings \geq SN8.



METHOD 2 – CALCULATED DESIGN METHOD

AS/NZS 2566.1 *Buried flexible pipelines, Part 1: Structural design* sets out a design method which provides equations for predicting pipe performance against the design criteria of deflection, strength and buckling. This design method provides conservative results.

To perform the calculations various input information is required, regarding the pipe material characteristics, the native and embedment soil, and the expected service loads. There are various AS/NZS 2566.1 online calculators and design tools available.

Note: AS/NZS 2566.1 is a design method, not a product standard. Claims that a pipe product 'complies' with AS/NZS 2566.1 is a misleading statement. This is a fundamental misunderstanding of the scope and application of this Standard. Design calculations may conform to the Standard, but all inputs are required, not just the pipe material characteristics.

4.1 INPUT INFORMATION FOR DESIGN CALCULATIONS

4.1.1 PIPE CHARACTERISTICS

Both plain wall and structured wall pipes can be designed using AS/NZS 2566.1. Pipes are described in terms of their ring-bending stiffness (also commonly referred to as ring stiffness or stiffness).

Stiffness may be calculated or determined by testing. Non-pressure thermoplastics pipe product Standards generally classify pipes by their nominal minimum stiffness, or SN using a performance test, and this is the characteristic that is referred to here.

For thermoplastics pipes, which exhibit a time-dependent creep or viscoelastic response, so-called long-term properties are used in the design method. Again, long-term stiffness may be calculated using an apparent long-term creep modulus or determined by testing. For thermoplastics pipes, the long-term properties are an estimate of behaviour at a chosen point in time assuming constant stress or constant strain. This design point should not be confused with service life, which depends on many factors and will generally be much longer.

In practice, all flexible pipe installations, whether elastic or viscoelastic, may experience some further deflection after installation due to settlement and consolidation of the soil. The amount is dependent on the initial level of compaction of the backfill material and is usually stabilised within 2 years, at which point the shape of the pipe ring is fixed. Some design methods use a deflection lag factor to account for the consolidation of embedment. However, in AS/NZS 2566.1 the use of apparent long-term properties for all parameters is used to replace the deflection lag factors. (Ref AS/NZS supp C5.2(c))

For plastic pipes in some applications, long-term properties are defined at the 50-year design point. However, due to the stabilisation of the pipe-soil system within 2 years, the 2-year long-term modulus is a more suitable value for buried flexible pipe design. Beyond this time, thermoplastics pipes will not continue to creep and will be under constant strain. Thermoplastic pipes will subsequently undergo stress relaxation where the stress in the pipe wall reduces with time.

Table 2.1 in AS/NZS 2566.1 provides typical pipe material characteristics which may be useful to the designer. However, the values should be confirmed by the pipe manufacturer and values determined through testing are preferred.

4.1.2. EMBEDMENT AND SOIL CHARACTERISTICS

Pipe embedment has a significant contribution to the performance of the pipe-soil system. As was shown in the graphical design method, the effect of installation quality, including placement and compaction of embedment far outweighed the effect of pipe characteristics on the measured deflections of flexible thermoplastics pipes.

The installation and site parameters which must be established are the trench geometry, including width and depth, as well as the selected embedment material and how it will be compacted. The characteristics of the native soil are also considered because this affects the ability for the compacted embedment to be contained.

AS/NZS 2566.1 specifies typical minimum cover heights and trench spacings around the pipe. Soil properties, expressed in terms of soil modulus values for embedment and native soil materials, are provided and an equation is used to determine the effective combined soil modulus. This represents the composite effect of the native soil and embedment material. The relative importance of each is dependent on the trench width.

Figure 3.1 (Embedment Geometry) of AS/NZS 2566.1 shows values for determination of trench width. The values shown can be reduced or increased by the designer to take into account any advantages from the native soil and embedment soil strength. Figure 5 shows typical trench cross section.

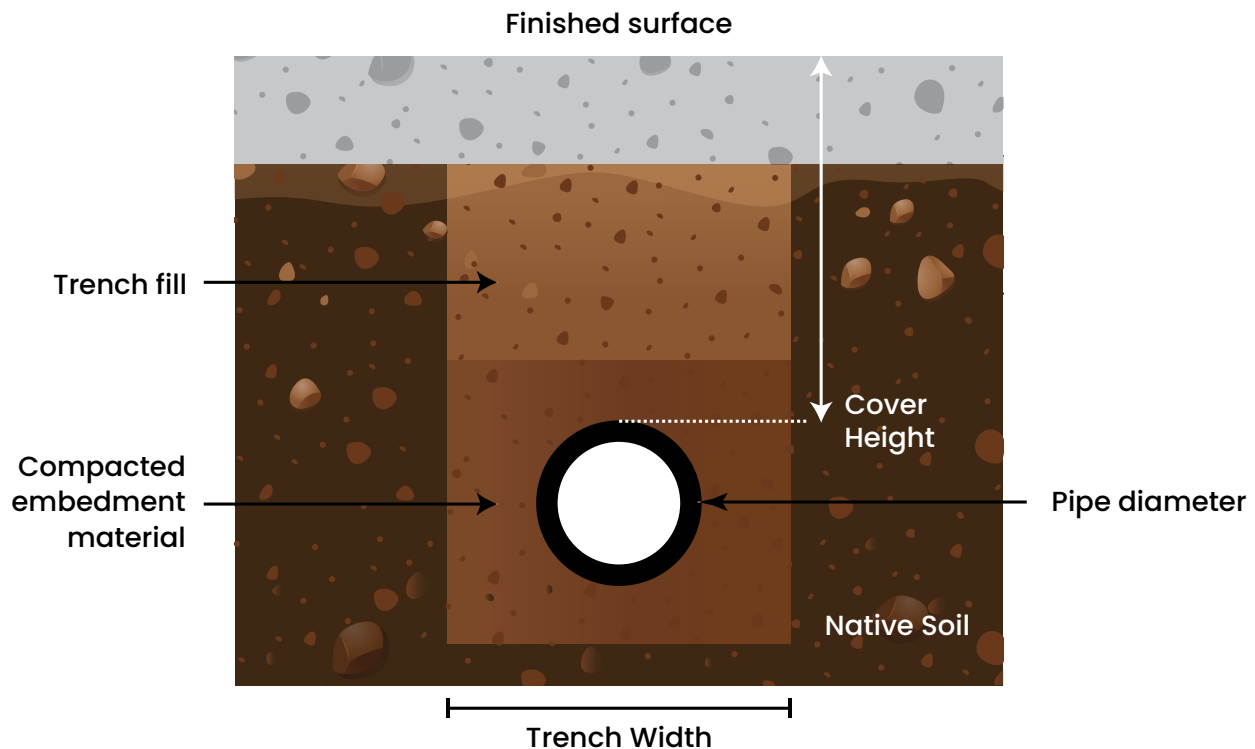


Figure 5 – Typical trench cross section

In AS/NZS 2566.1 both the native soil modulus and the embedment soil modulus are drawn from the same table (Table 3.2 Embedment and native soil moduli). This is different from other design methods such as the British and European Standards, BS 9295 and EN/TR 1295-3. The end result is that AS/NZS 2566.1 is conservative as discussed by Look and Cameron [6]. Users wishing to have more realistic design predictions should seek geotechnical advice.

4.1.3 DESIGN LOADS

The final input required to perform structural design calculations to AS/NZS 2566.1 is a knowledge of the loads that will be applied to the system over the design lifetime. These include static or dead loads, which are generally sustained permanently, and dynamic or live loads, which are transient.

DEAD LOADS

Dead loads are primarily due to the weight of the soil above the pipe, but other superimposed surface dead loads can also be considered. In AS/NZS 2566.1 the 'prism load' method is used which is simply the weight of the column of soil above the pipe. This method varies from some other design calculation methods which consider arching and slip plane friction which act to reduce the loads on flexible pipes.

The prism load method was adopted in AS/NZS 2566.1 because it is simple and provides conservative results (AS/NZS 2566.1 Suppl C4.3). The prism load becomes limiting at greater pipe depths, as noted in AS/NZS 2566.1 – Supplement 1 which presents an alternative option for depths > 10 times outside diameter. Figure 6 shows the soil prism loading.

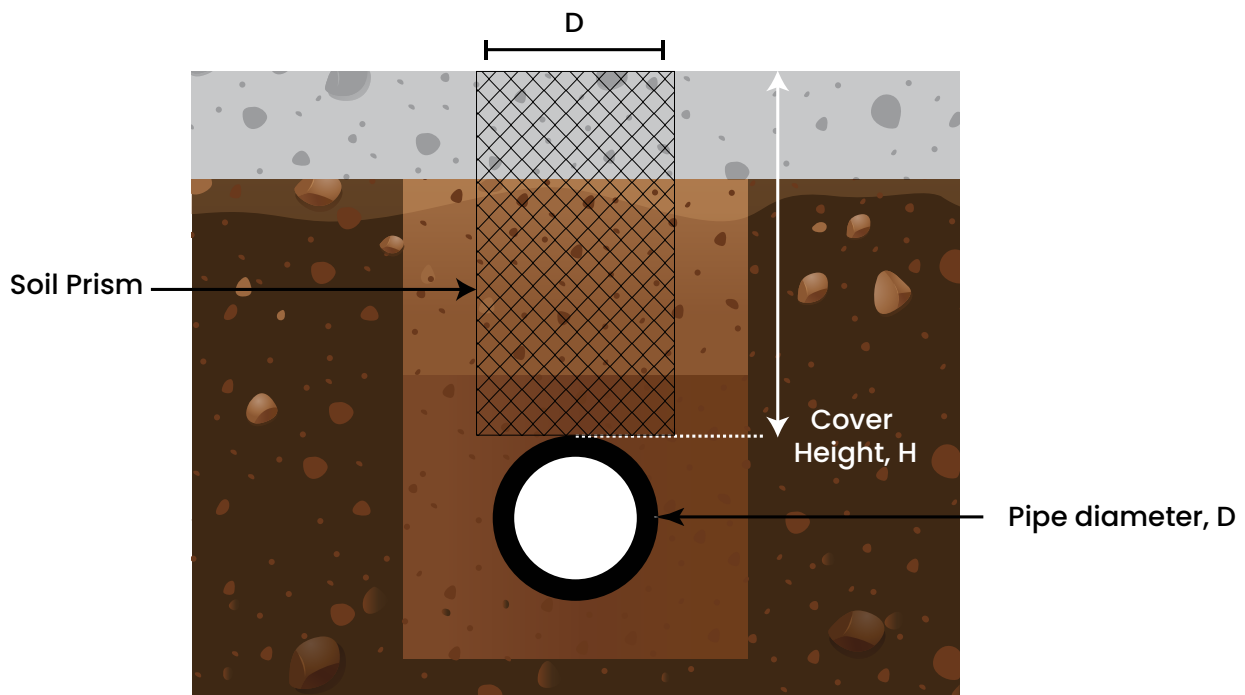


Figure 6 – Soil prism loading on pipe installed in a trench

LIVE LOADS

Live loads result from traffic loading of vehicles passing above the pipe. Surface loads are distributed through the soil, so depth of soil cover is an important factor in determining the load acting at the top of the pipe. While dead loads from the weight of soil fill increase with installation depth, live loads due to surface traffic are reduced at greater depth.

AS/NZS 2566.1 was published in 1998 and has not had a comprehensive revision since then. The content in the Standard for road vehicle loading in AS/NZS 2566.1 still refers to the historical Austroads Bridge Code which was current at the time the Standard was published but has since been revised into AS 5100.2 Bridge Design Part 2 Design Loads. The live loads used in structural design of buried flexible pipes under major roads should substitute the current AS 5100 design loads in AS/NZS 2566.1 calculations to align with current road design practices. This is easily done by replacing Clause 4.7.2 in AS/NZS 2566.1 with Clause 7 from AS/NZS 5100. Refer to [Appendix B](#).

Treatment of live loads is another area where different national design methods for flexible pipes vary. In many methods, for example the AASHTO method in the USA, the European and British methods, the transitory nature of live loads is recognised by using short-term properties for plastic pipes. AS/ NZS 2566.1 assumes that traffic loads, including impact effects are effectively permanent by using the long-term properties. This results in a conservative design.

A special case that must be considered for all pipe materials is loads on pipes during the construction stage. This may involve heavy equipment and occur before the final soil cover height is achieved. Minimum cover heights for construction live loads can be calculated using short-term properties and guidance tables are available. Alternative mitigation techniques can be used, such as temporary increases of cover heights at temporary vehicle crossing points.

HYDROSTATIC LOADS

When the water table height is above the pipe installation depth hydrostatic loads must be considered in the buckling evaluation.

A summary of the input parameters required for design calculations to AS/NZS 2566.1 and the typical source for this information is provided in [Appendix C](#).

4.1.4 DESIGN CALCULATIONS AND DESIGN CRITERIA

There are three main design criteria evaluated in AS/NZS 2566.1 for buried flexible non-pressure pipes. These are predicted deflection, strength (which is evaluated in terms of strain) and buckling.

The following discussion is related to buried flexible thermoplastic pipes. While glass-reinforced thermoset plastics, steel, ductile iron, or steel reinforced plastics pipes can be categorised as flexible and are covered in AS/NZS 2566.1, they have their own, material-specific design requirements and limitations which are not covered here.

DEFLECTION

The primary design consideration for buried flexible pipes is ring deflection. In the design calculations, predicted deflection is calculated from an equation that considers the inputs described above, the applied loads, the long-term pipe stiffness and the combined soil modulus. The predicted deflection is compared against design limits for the given pipe material and/or the application.

As noted previously the long-term design limit for deflection is usually 7.5% for thermoplastic pipes.

DEFLECTION MEASUREMENT AFTER INSTALLATION

For some applications, a deflection test is specified after installation. As noted above, field measurements have shown that pipe embedment and compaction is the primary contributor to pipe deflection. Measurement of installed deflection is, to some extent, a measurement of installation quality and workmanship.

STRAIN

In AS/NZS 2566.1 the ring bending strain is calculated using an equation that considers the predicted deflection, the pipe geometry and a shape factor which is related to the shape of the deflected pipe. The calculated strain is checked against specified acceptable limits for a given material.

BUCKLING

Resistance to buckling is also checked in AS/NZS 2566.1.

Both the unsupported and soil supported cases are considered as there are some situations, for example, shallow depths of cover, in which the soil support may not be adequate. A factor of safety is applied to the calculated buckling pressure.

5.0 CONCLUSION

Both the graphical design and calculated design methods can be applied to buried flexible thermoplastic pipes for non-pressure applications. Method 2, the calculated design method (AS/NZS 2566.1) is based on a theoretical model which attempts to predict what will happen in practice based on a range of assumptions. The graphical design method 1, is based on observations of actual pipes in practice. If the model and the observed results do not align, then some verification of the assumptions is required.

Where design calculations are required by contract or legislation and derived from AS/NZS 2566.1, the results of those calculations should be checked. If a discrepancy occurs between the model's predictions and a calculated result, the designer should check the assumptions used in their calculation as validated research indicates they are likely too conservative.

The actual behaviour of buried thermoplastic flexible pipes can be summarised as:

- After installation, deflection (ovalisation) of the pipe is controlled by the settlement of the surrounding soil.
- The amount of soil consolidation is dependent on the initial level of compaction (i.e. well compacted soil will have minimal further consolidation).
- Soil settlement (consolidation) is typically achieved within two years after installation or earlier where repeated traffic loading occurs.
- When soil consolidation around the pipe has been achieved the pipe will not deflect any further and stress relaxation begins.

TECHNICAL REFERENCES

- [1] Alferink, F. (1999) 'Design of Buried Thermoplastic Pipes – Results of a European Research Project' TEPPFA
- [2] Janson L.E., "Long term studies of PVC and PE subjected to forced constant deflection", Report nr.3 from the KP council, Sweden 1991.
- [2] Alferink, F., Janson, L.E., Olliff, J.L., (1998) 'Design of Thermoplastics Pipes: – Prediction of Pipe Deflection Versus Measured Values – Proceedings of 10th Plastic Pipe Conference' *PPX Plastic Pipes Conference, Gothenburg*.
- [3] Alferink, F., Björklund, I., Kallioinen, J., (1998) 'The Design of Thermoplastics Pipes: – A Recent Update – Proceedings of 10th Plastic Pipe Conference' *PPX Plastic Pipes Conference, Gothenburg*.
- [4] Alferink, F., (2001) 'Design of Large Diameter Buried Pipes – Proceedings of 11th Plastic Pipe Conference' *PPXI Plastic Pipes Conference, Munich*.
- [5] Alferink, F., (2001) 'Soil-Pipe Interaction: A Next Step in Understanding and Suggestions for Improvements for Design Methods – Proceedings of 11th Plastic Pipe Conference' *PPXI Plastic Pipes Conference, Munich*.
- [6] Look, B., Cameron, D., (2018) 'Buried Flexible Pipes: Design Considerations in Applying AS2566 Standard', Australian Geomechanics, Volume 53 No2 June
- [7] Moser, A.P., Folkman, S., (2008) 'Buried Pipe Design', 3rd Edition, McGraw-Hill, New York.

STANDARD REFERENCES

AS/NZS 2566.1 – *Buried flexible pipelines, Part 1: Structural design*

AS/NZS 2033 *Design and installation of polyolefin pipe systems*.

AS/NZS 5065 – *Polyethylene and polypropylene pipes and fittings for drainage and sewerage applications*

AS/NZS 1260 – *PVC-U pipes and fittings for drain, waste and vent applications*

AS/NZS 1254 – *PVC-U pipes and fittings for stormwater and surface water applications*

CENT/TS 15223 *Plastic piping systems – Validated design parameters of buried thermoplastics piping systems*

ISO 21138-1 *Plastic piping systems for non-pressure underground drainage and sewerage – Structured-wall piping systems of PVC-U, PP and PE Part 1: Material specification and performance criteria for pipes, fittings, and systems*

APPENDIX A

WORKED EXAMPLE – COMPARISON OF LONG-TERM DEFLECTIONS PREDICTED USING THE GRAPHICAL AND CALCULATED DESIGN METHODOLOGIES

EXAMPLE

A polypropylene DN300 SN8 corrugated outer wall, smooth bore drainage pipe conforming to AS/NZS 5065.

- Pipe is to be installed in a trench 2.5 metres deep below a single lane road pavement.
- No ground water is present.
- Native soil is stiff clay with $E'n=5.0\text{MPa}$
- Embedment material is gravel graded (GW) and compacted to a dry density ratio of 90%, $E'e = 7.00\text{MPa}$.
- Bedding constant 'K' = 0.1
- Unit weight of trench fill soil = 20 kN/m^3
- Specific gravity of soil particles = 2.65
- Trench width = 944mm ($344 + 2*300$)

LIVE LOAD DETAILS

- Load distribution to AS 5200.2
- Lane type = single
- Load type: Austroads AS 5100.2 SM1600, in this case the M1600 moving traffic load represents the worst case.
- Live load intensity (wq) = 15 kPa

THE PIPE MANUFACTURER HAS PROVIDED THE FOLLOWING DETAILS REGARDING THE PIPE

- Mean outside diameter = 344mm
- Long term ring bending stiffness (2 years) = 1794 N/m/m
(calculated as per AS/NZS 2566.1 eqn 2.2.3)
- Long term ring bending stiffness (50 years) = 1231 N/m/m
(calculated using the nominal 50-year modulus for PP = 200 MPa and 3-minute ring bending modulus = 1300 MPa)
- Initial ring bending stiffness is 8000 N/m/m
(minimum required as marked on the pipe and confirmed by laboratory testing)

CALCULATED DESIGN METHODOLOGY – AS/NZS 2566.1

AS/NZS 2566.1 *Buried flexible pipelines, Part 1: Structural design* sets out a design method which provides equations for predicting pipe performance against the design criteria of deflection, strength and buckling.

Using the input variables provided above the long-term 50 year predicted vertical deflection in the pipe can be calculated as per equation 5.2(2) given in section 5.0 of AS/NZS 2566.1

5.2 Deflection

The predicted long-term vertical deflection shall satisfy the following equation:

$$\frac{\Delta y}{D} \leq \frac{\Delta y_{\text{all}}}{D}$$

WHERE

$$\frac{\Delta y}{D} = \frac{K \times 10^{-3} (W_g + W_{gs} + W_q)}{8 \times 10^{-6} S_{DL} + 0.061E^1}$$

And where:

K	= 0.1
Δy	= predicted long-term vertical deflection (m)
Δy_{all}	= allowable long-term vertical deflection (m)
E^1	= effective combined soil modulus
S_{DL}	= long-term ring bending stiffness of the pipe (N/m/m)
W_g	= vertical design load (pressure at top of pipe) due to soil dead load (kPa)
W_{gs}	= vertical design load (pressure at top of pipe) due to surface applied dead load (kPa)
W_q	= vertical design load (pressure at top of pipe) due to surface applied live load (kPa)

In this example the 2-year value for ring bending stiffness can be used in the deflection equation to represent the design basis for 50-year deflection, ring-bending strain and buckling response, as we are not dealing with weak native soils or poor embedment conditions with a high water table (ref AS/NZS 2566.1 clause 5.1.2 and AS/NZS 2566.1 Supplement 1 clause C2.2.2).

Note: worked example does not go through each of the required calculations in detail.

RESULTS

Calculated 50-year vertical deflection using 2-year ring bending stiffness as per eqn 5.2(2) = **1.68%**

Calculated 50-year vertical deflection using 50-year ring bending stiffness as per eqn 5.2(2) = **1.70%**

GRAPHICAL DESIGN METHODOLOGY – AS/NZS 2033

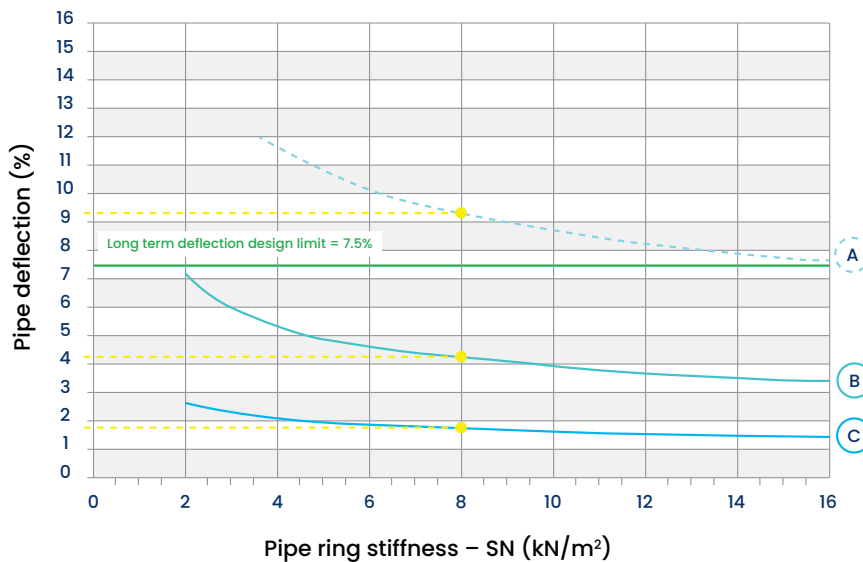
Confirm that installation parameters are met as AS/NZS 2033 clause 6.2.2.1 and outlined in the table below.

PARAMETER	VALUE (REQUIREMENT)	ACTUAL DESIGN VALUES
Manufacturing Standards	AS/NZS 5065, AS/NZS 4130, AS/NZS 4765, AS/NZS 4441, AS/NZS 1477 and AS/NZS 1260	AS/NZS 5065 - ok
Diameter	≤ DN1100	DN300 - ok
Ring stiffness	> SN2 (2000 N/m/m or 2 kN/m ²)	SN8 - ok
Minimum depth of cover above the pipe	0.8 m	2.5m - ok
Maximum depth of cover above the pipe	6 m	2.5m - ok
Depth of soil cover / pipe diameter ratio	≥ 2	2.5/0.344 = 7.26 - ok
Embedment compaction (Installation quality)	Well or moderate compaction of granular type embedment soil.	Well granular embedment - ok

Using the graph of long-term pipe deflection vs. Pipe ring stiffness for “well” compaction determine the maximum long term pipe deflection.

Long term pipe deflection for SN8 pipe “well” compaction = 1.75%

Long Term pipe deflection (maximum values)



A – “non” compaction (not recommended)
 B – “moderate” compaction
 C – “well” compaction

RESULTS

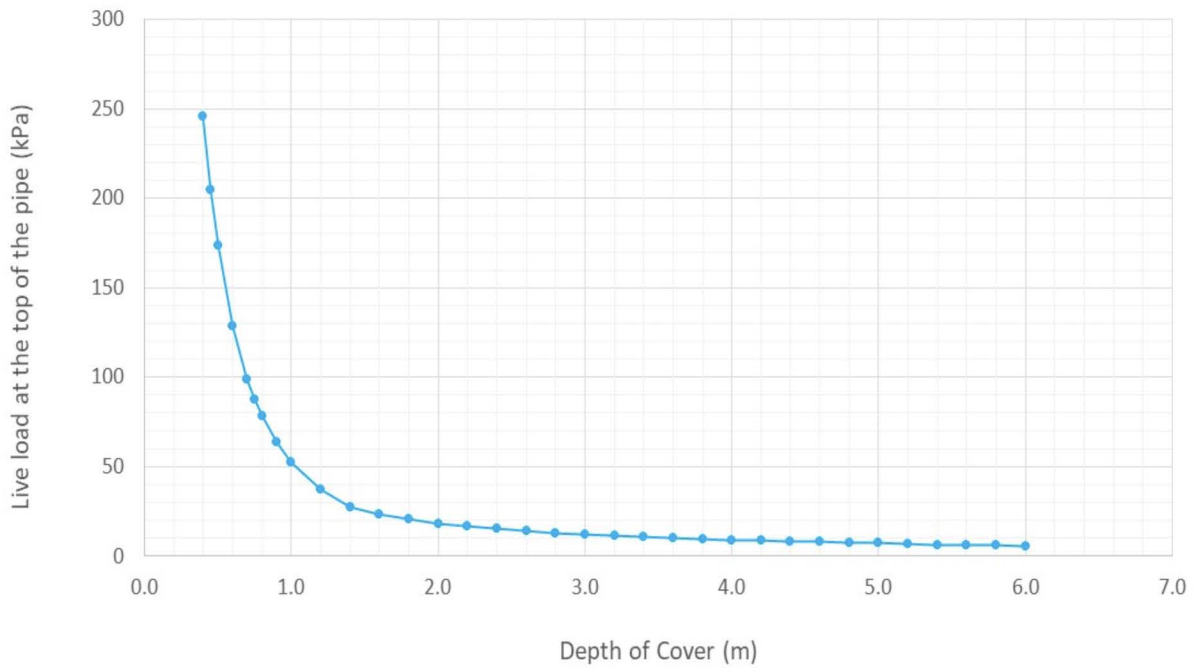
In the case of “well” compaction for the installation and operational parameters described above the graphical and calculation design methods predict deflections that are in close agreement.

APPENDIX B

Table of average load intensity for SM1600 vs cover height

DEPTH OF COVER (M)	SM1600 ROAD VEHICLE LOADS (SINGLE LANE) (kPA)
0.4	246
0.5	174
0.6	129
0.7	99
0.75	88
0.8	78
0.9	63
1.0	52
1.2	37
1.4	27
1.6	23
1.8	21
2.0	18
2.2	17
2.4	15
2.6	14
2.8	13
3.0	12
3.2	11
3.4	11
3.6	10
3.8	9.6
4	9.1
4.2	8.6
4.4	8.2
4.6	7.9
4.8	7.5
5	7.2
6	5.8

SM1600 Live load pressure distributed in accordance with AS 5100.2



APPENDIX C

Structural Design Input Information and Data Sources

	INPUT PARAMETER	SYMBOLS	SOURCE	DESCRIPTION	
Pipe Characteristics	Diameter	De	Product Standard or pipe manufacturer	Outside Diameter	
		D		Diameter at Neutral axis	
	Wall thickness	t		Wall thickness for plain wall pipe.	
		tes		Effective wall thickness for structured wall pipes which is twice the distance from the neutral axis to either the inside or outside wall, whichever is greater.	
	Stiffness – short term	SDI		By calculation from pipe dimensions and short-term modulus	Calculation requires information for I, the second moment of area of the pipe wall in ring bending. This is related to the wall thickness for plain wall pipes but is more complex for structured wall pipes.
				By testing to ISO 9969	
Stiffness – long-term (2 year)	SDL	By calculation from pipe dimensions and long-term modulus	Can also be calculated from the short-term stiffness and long-term modulus.		
		By testing to ISO 9967			
Embedment Characteristics	Native soil modulus	E'n	AS/NZS 2566.1 Table 3.2 or geotechnical information		
	Embedment modulus	Eé	AS/NZS 2566.1 Table 3.2	Native soil modulus and embedment soil modulus are used together with the trench width, to calculate the combined soil modulus.	
	Trench Width	B	Project information		
	Cover Height	H	Project information	H is the height of soil above the pipe.	
Hw		Hw is the height of the water surface above the pipe level. This is used to determine the hydrostatic load which is used in buckling resistance calculations			
Design Loads	Load due to trench fill	wg	Calculated from cover height and the unit weight of soil		
	Superimposed Dead loads	wgs			
	Superimposed Live loads	wq	Project information – for pipes in roadways AS/NZS 5100	Loads from road, rail or aircraft which will travel over the surface of the installed pipe	



PIPA

PLASTICS INDUSTRY
PIPE ASSOCIATION
OF AUSTRALIA LIMITED

PO Box 957 North Lakes Q 4509

E plasticpipe@pipa.com.au

P +61 (0) 459 919 437

pipa.com.au

Disclaimer

In formulating this guideline PIPA has relied upon the advice of its members and, where appropriate, independent testing.

Notwithstanding, users of the guidelines are advised to seek their own independent advice and, where appropriate, to conduct their own testing and assessment of matters contained in the guidelines, and to not rely solely on the guidelines in relation to any matter that may risk loss or damage.

PIPA gives no warranty concerning the correctness or accuracy of the information, opinions and recommendations contained in the guidelines. Users of the guidelines are advised that their reliance on any matter contained in the guidelines is at their own risk.