RIGID AND FLEXIBLE PIPE DESIGN, INSTALLATION AND LIFETIME COST

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ABSTRACT

Understanding the key differences between pipe materials and their design philosophies is important and often overlooked. Failings here can lead to long-term impacts on infrastructure and its whole-of-life cost. This paper explains some of these issues and the cost implications of them.

Some think that Flexible (plastic) pipes and Rigid (concrete) pipes are installed the same way. Actually the design concepts are entirely different. Rigid pipelines rely mainly on inherent pipe strength. Flexible pipelines rely principally on the soil pipe interface and a slight deflection to activate the support of the bed and surround (embedment) of the pipe to give the installation its strength. Only a slight deflection is appropriate as defections over 5-7% are indicative of failure (the exact percentages are a function of pipe, material and diameter).

Some think that the design lives of the different pipe types are the same but they are not. Although the materials may last a long time, the ring strength of plastic varies with age and designers have to calculate short term and long-term strains as the plastic creeps. Regression data is used to estimate the strength and deflection at 50 years. Concrete gains strength with age. In addition to the material strength, the flexible pipeline relies on the soil interface to give it strength. Deflection changes this interface and can weaken the installation if excessive. Additionally, any disturbance of the material surrounding the pipe from excavation nearby or from seismic activity can render the design assumptions invalid.

There is a common misconception that plastic pipe has a cheaper installed cost than concrete pipe. Plastic Pipe is often thought to be easier and therefore cheaper to lay because it is lighter. Yet, limits on safe manual handling, mean that both types of pipe will likely require lifting equipment to handle them on site. Weights do differ significantly e.g. a 6 m long DN 300 SN 4 PVC pipe weighs around 70 kg whereas an approximately 2.5 m long DN 300 Class 2 concrete pipe weighs around 240 kg but both of these exceed safe manual handling limits. If installed safely and correctly to the Australian and New Zealand Standards, then concrete pipe may have a cheaper installed cost than plastic.

Whilst there is no fundamental reason to exclude either pipe type from consideration in a project the differences in design and construction requirements, which have an impact on installation and lifetime costs, need to be understood and considered during design and construction to provide the best-value installation.

KEYWORDS

Flexible, rigid, plastic pipe, concrete pipe, Standards

PRESENTER PROFILE

Tony is a Principal Environmental Engineer based in the Christchurch WSP Opus office where he is involved in a wide range of 3-waters projects. He has a broad range of experience in water-related civil and agricultural engineering projects, in more recent years being predominantly involved with wastewater, stormwater and water supply reticulation projects.

1 INTRODUCTION

Pipes are typically identified as either flexible or rigid. Concrete pipes are considered rigid; plastic pipes are typically considered flexible. Whilst there is no fundamental reason to exclude either pipe type from consideration in a project the design and construction requirements for both differ and these differences, which have an impact on installation and lifetime costs, need to be understood and considered during design and construction to provide the best-value installation.

The key structural difference between flexible and rigid pipes is the interaction of the pipe and the soil in which it is installed. Rigid pipes have an inherent strength that means that they do not deform as much as the surrounding soil under normal load conditions. The strength of the pipe results in the load on the pipe being resisted by the pipe bedding. Flexible pipes on the other hand are not inherently strong and they deform under load. This deformation is resisted by the soil support at the sides of the pipe, and the ability of the installation to carry the load is primarily derived from the strength of this surrounding soil. This difference impacts the embedment and backfill requirements of both materials and is an important design consideration.

If the on-site material doesn't meet the requirements of the pipe bed and support zones required by the design and the material for these zones needs to be imported, flexible pipes typically require greater quantities of this imported material than rigid pipes.

Deflection testing is required for flexible pipes to comply with AS/NZS 2566, the flexible pipe Standard, however this important step for ensuring correct installation is often overlooked. Deflection testing is not required for rigid pipes.

These requirements for more imported material and ovality testing mean that rigid pipes should be cheaper to install than flexible pipes and have a corresponding lower whole of life cost.

Both rigid and flexible pipes require care in installation; neither pipe type should be just 'buried'. Proper installation requires attention to ensure that the pipes are not damaged by poor handling, that they have a good bed, and that pipe support materials and backfill are well placed and compacted.

In the event that the design or installation is faulty, or loading on the pipe increases beyond what was assumed in design, concrete pipes will typically crack, and flexible pipes will typically deflect. Cracked rigid pipes can be strengthened and cracks can be repaired but the only practical remedial action to counter significant deflection in a flexible pipe is removal and reinstallation.

2 PIPE SUPPORT REQUIREMENTS

For both rigid and flexible pipe types, the foundation material (the material beneath the pipe bed) must be able to support the loads placed on it, provide an even bed and maintain alignment of the pipes.

The bedding requirements of both concrete pipes (as the most common example of rigid pipes) and flexible pipes are similar. With reference to the Australian and New Zealand

Standards (AS/NZS 3725 for concrete pipes and AS/NZS 2566 for flexible pipes), pipe bedding is to be 100 mm in depth for pipes up to 450 mm outside diameter (effectively DN375). For flexible pipes, the bedding depth changes at this point to 150 mm. For concrete pipes, the bedding depth does not increase to 150 mm until the pipe outside diameter is over 1500 mm (effectively DN1350). For pipes of the same nominal size, these differences in bed material volumes between rigid and flexible pipes are small.

It is in the 'support' zones, the haunch zone and side zone for concrete pipes, and embedment zone for flexible pipes that significant differences occur between concrete and flexible pipe installations (see Figure 1 below for support terminology).

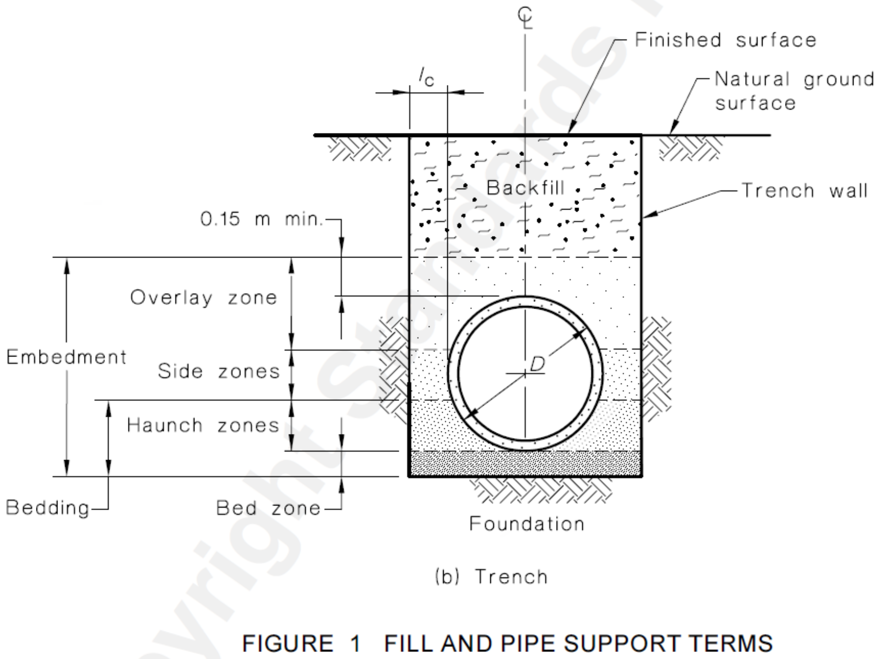

Figure 1 Fill and Support Terms (from AS/NZS 3725)

As noted above, a flexible pipe installation relies on the strength of the surrounding soil, so the quality of the material that surrounds the pipe, from the bed to 150 mm above the pipe, is integral to the pipe installation. For concrete pipes, the critical zone is what is known as the haunch zone. This extends from the bed to between 10% and 30% of the pipe outside diameter depending on the support type (U, H and HS – see Table 5 AS/NZS 3725). For the HS support type the requirements in the side zone (from the top of the haunch zone to not less than the pipe spring line) are also important. These differences lead to the volumes of these materials differing significantly between the different pipe types.

For a given depth of installation and size of pipe, the elements within control of the designer are the class of pipe and the quality of the pipe support provided. The designer has the ability to modify one or other or both of these parameters in the design process. If a pipe of a certain class is unable to withstand the loads applied to it, either the pipe class is increased or the quality of pipe support is increased. One way to do the latter is the use of a different material. There are limitations on what materials can be used in the pipe support zones and in some locations the specified material may not be readily available. Other ways are to use a higher level of compaction on the material available, or increase the width of the support material. As noted above, flexible pipes are more reliant on the quality of side support as they do not have the inherent strength that rigid pipes have, so if flexible pipes are used it is more likely that trench width will need to be increased than is the case for rigid pipes. These increases, in either higher quality materials or wider embedment widths, will increase the costs of the installations and these increases can make the difference in economic terms between the choices of pipe type used.

3 CONSTRUCTION

The compaction requirements of pipe support material and backfill are not likely to vary significantly between the pipe types as typically, beyond support of the pipe, the remaining material in the trench needs compacting to adequately support the surface.

For concrete pipes the overlay zone (see the diagram in Installation Terminology at end of the report) is the area extending around the outside of the pipe from the top of the last placed side zone or haunch zone to at least 150 mm above the pipe. The material requirement for this zone is what is referred to as 'ordinary fill' for which the requirements are listed in the Standard (AS/NZS 3725), but they are not particularly stringent and more often than not met by the material excavated from the trench. Achievement of adequate compaction in this zone is still important.

The material above either the overlay zone (concrete pipes) or embedment (flexible pipes) is the backfill. The volumes of these areas are the same for both pipe types if the trench widths are the same. The compaction requirements for this material are determined by the environment within which the pipe is to be installed. If the pipe is under a carriageway, the compaction requirement may be as high as that required for support of the pipe.

Although the weights of concrete and flexible pipes are significantly different (a 6 metre long DN300 SN4 PVC pipe weighs about 70 kg whereas a DN300 Class 2 concrete pipe (approximately 2.5 m long) weighs about 240 kg) increasing concern about worker health and safety, and limits on safe manual lifting, mean that both of these pipes will likely require lifting equipment to move them on site.

4 CONSTRUCTION MONITORING

Both concrete and flexible pipe design and installation assume and require compaction of the installation media to a particular value that varies depending on the loading on the pipe and the pipe class or stiffness. During construction, the actual compaction achieved needs to be monitored regardless of the degree of compaction required; failure to do so puts the installation at risk of failure.

It is common practice for the asset owner to require some form of post-construction testing on a pipeline but some of these tests are not standardised. A common test is a hydrostatic or low pressure air test to confirm the integrity of the pipeline and its joints. The Concrete Pipe Association of Australasia provides a guideline for testing concrete pipes; for flexible pipes, AS/NZS2566.2 has a section on field testing that includes methods of testing for leaks.

For flexible pipes there is an additional test that is important for assessing the adequacy of the embedment material placement and compaction, and that is a deflection test which is carried out as soon as practicable after installation. This test is not needed for rigid pipes but is an important post-construction test for flexible pipes where deflection is a major design criteria. A deflection slightly higher than the Standard (AS/NZS 2566) allows is unlikely to impact the capacity of the pipeline (a deflection of 10% reduces hydraulic capacity by about 2.5 %) but if high enough it will impact the ability of the pipe joints to remain watertight. The Standard states that for pipes less than 750 mm in diameter the test is to be carried out with a prover of a diameter a little less than the allowable expected internal diameter. For larger pipes the minimum vertical internal diameters of every pipe are to be measured both immediately after laying and before the side support is placed and compacted and again at the specified agreed time after completion.

The costs of leak testing are likely to be similar for rigid and flexible pipelines; the cost of defection testing only applies to flexible pipelines and especially for larger pipes could add significant cost.

In addition to these tests, a CCTV inspection is often required by the asset owner. This inspection has the potential to identify installation defects such as open joints and pipes damaged in the installation process. In the case of flexible pipes it will also show severe deformity but it should not be considered an alternative to the Standard's deflection testing.

5 ASSET LIFE

Assuming that a pipeline is installed well and in accordance with its design, its life expectancy will be determined by the conditions of its use. Concrete pipe, when manufactured in accordance with AS/NZS 4058 and installed in accordance with AS/NZS 3725 in a normal environment, is expected to have a service life of 100 years. The properties of concrete are such that the pipe will maintain or increase its load carrying capabilities over time. Flexible pipe design normally considers a design life of 50 years (refer AS/NZS 2566.1). This is not the same as the service life; design life is the period of time considered when determining the pipe properties and load conditions to be used in the design. The design assumption is that flexible pipe properties change over time and that pipe strength decreases, so in theory if the pipe is in a load condition that matches its design condition for the full 50 years, the pipe will be unable to support that load beyond the 50 years. Flexible pipe that is not continuously subject to its design load condition could be expected to last longer than 50 years.

For both concrete and flexible pipes the actual service life will vary dependent on such factors as the nature of the ground in which the pipe is installed and the composition of the fluid the pipes are conveying. There are instances of both concrete and flexible pipes failing prematurely when the fluid conveyed differs from that assumed in design. For example concrete pipes are subject to damage from acidic conditions (e.g. sulphuric acid from sewage gases), and some plastic pipes are subject to damage from hydrocarbons. What is important is that the design life conditions be taken account of in design.

If the loading on the pipe increases beyond what was assumed in design e.g. the amount of fill over the pipe is increased, or the design or installation are faulty, the limits of the pipe will be exceeded. Concrete pipes will crack and in extreme cases deform. Flexible pipes will typically deflect but may also buckle. Post-construction during the life of a pipe it can be 'reinforced' by the installation of a structural liner that seals the pipe and provides structural support, but the only practical remedial action to counter significant deflection in a flexible pipe is removal and reinstallation.

Whole of life costs, including ultimate replacement cost, should always be considered during the design phase of a project, noting that pipelines are often constructed in a green-field environment that in the future may well be built up. Replacement may be at a significantly higher cost than the original construction.

6 COST IMPLICATIONS

As noted above, the differences between the design and construction requirements of rigid and flexible pipes have cost implications.

Bed, haunch, overlay and embedment volumes are a function of pipe outside diameter (OD) and the Standard requirements for trench width. All flexible pipes of similar OD, of whatever materials (e.g. PVC, PE, GRP), have the same embedment volume if the minimum trench widths are suitable. In the table below, these volumes for some typical pipe sizes of approximately similar value have been given for comparison. The emboldened text in the volume columns is the volume of imported material required if the local materials are unsuitable for pipe support. For the concrete pipe, the values assume an H2 installation, H2 being a commonly specified installation standard. For an H1 installation, the volumes of potentially imported material would be less.

Table 1: Trench Widths and Volumes for Some Different Pipe Types and Sizes

Standard and Pipe Type	**DN**	**OD**	**Minimum Trench Width**	**Bed & Haunch Volume**	**Overlay Volume**	**Embedment Volume**
	mm	**m**	**m**	**m^3/m**	**m^3/m**	**m^3/m**
AS/NZS 2566						
PVC/PE/GRP	300	0.30	0.70			**0.31**
	600	0.60	1.20			**0.80**
	900	0.90	1.50			**1.09**
	1800	2.00	2.70			**3.53**
AS/NZS 3725						
RCRRJ	300	0.37	0.67	**0.11**	0.19	
	600	0.70	1.10	**0.24**	0.42	
	900	1.04	1.44	**0.38**	0.63	
	1800	2.01	2.67	**1.21**	1.79	

As noted above, there are circumstances when the minimum trench width is not suitable. An increase in trench width will result in an increase of the volume of bed, haunch and overlay, or embedment. There are too many variables to state a typical case of this.

The following is an example of the construction cost differences that can occur resulting from the use of different pipe materials with minimum trench widths, along with the need to test the ovality of the installed flexible pipe. The two materials compared are concrete and GRP, the latter having been chosen as it is often the cheapest of the flexible pipe materials available in the DN900 size, the size chosen for the example.

Pipe material costs have been obtained from pipe suppliers. QV Costbuilder has been used as a source of cost data for bed, haunch, overlay and embedment cost estimation. The rates for using excavated material as backfill is $52/$m^3$. The price for imported and compacted AP20 is $86/$m^3$ and for disposal is $17.40/$m^3$ resulting in the additional cost of importing fill being $103.40/$m^3$.

Cost items such as those to excavate, to backfill above the pipe installation, and of surface restoration are typically common to both pipe types and are not included.

Table 2: Cost Difference Example

Item	**Unit**	**Concrete**	**GRP**	**Difference**
Pipe material cost	$/m	390	470	80
Bed and haunch volume	m^3	0.38	-	
Bed and haunch cost (imported material)	$/m	0.38*$104=39	-	
Overlay volume	m^3	0.63	-	
Overlay cost (re-used excavated material)	$/m	0.63*$52=33	-	
Embedment volume	m^3	-	1.09	
Embedment cost (imported material)	$/m	-	1.09*$104=113	
Ovality testing	$/m	-	35	
Total cost	**$/m**	**462**	**618**	**156**

This shows a difference in cost of $156/m in favour of concrete pipe. If the trench width is made greater for any reason, for example for ease of construction or as a design requirement for either the concrete or GRP pipe, this cost/metre difference will increase as the volume of imported fill will increase more for the GRP pipe option than the concrete pipe option. For example if trench width needs to increase to 2.5 m, this cost difference increases to $229/m.

In practice and for practical material handling reasons it is often the case that in a concrete pipe installation, the overlay material is the same material as either the bed/haunch material or the backfill material. If the installations were shallow, road restoration requirements would dictate a higher quality backfill requirement that also may impact on the necessary quality of the overlay material. In the DN900 example above, changing the cost of the overlay component to $104/m^3 reduces the cost differential between GRP and concrete pipe from $156/m to $123/m.

The following chart shows the additional expense for GRP pipe over concrete pipe over a range of sizes using the same assumptions as in the DN900 example above. GRP has been chosen for this comparison as it is available across the full range of sizes and is comparable in cost to or cheaper than other flexible pipes in many sizes. The expenses are shown as two components, the pipe cost and the bed / haunch / overlay / embedment / testing cost. For the DN900 pipe it shows the $156/m is made up of $80/m for the pipe and $76/m for the bed / haunch / overlay / embedment / testing. The chart also shows graphically that even if pipe material costs were comparable (and in some market conditions they may be), the costs of the bed / haunch / overlay / embedment / testing (the blue parts of the columns) are always higher for flexible pipe and these costs increase with increasing pipe diameter.

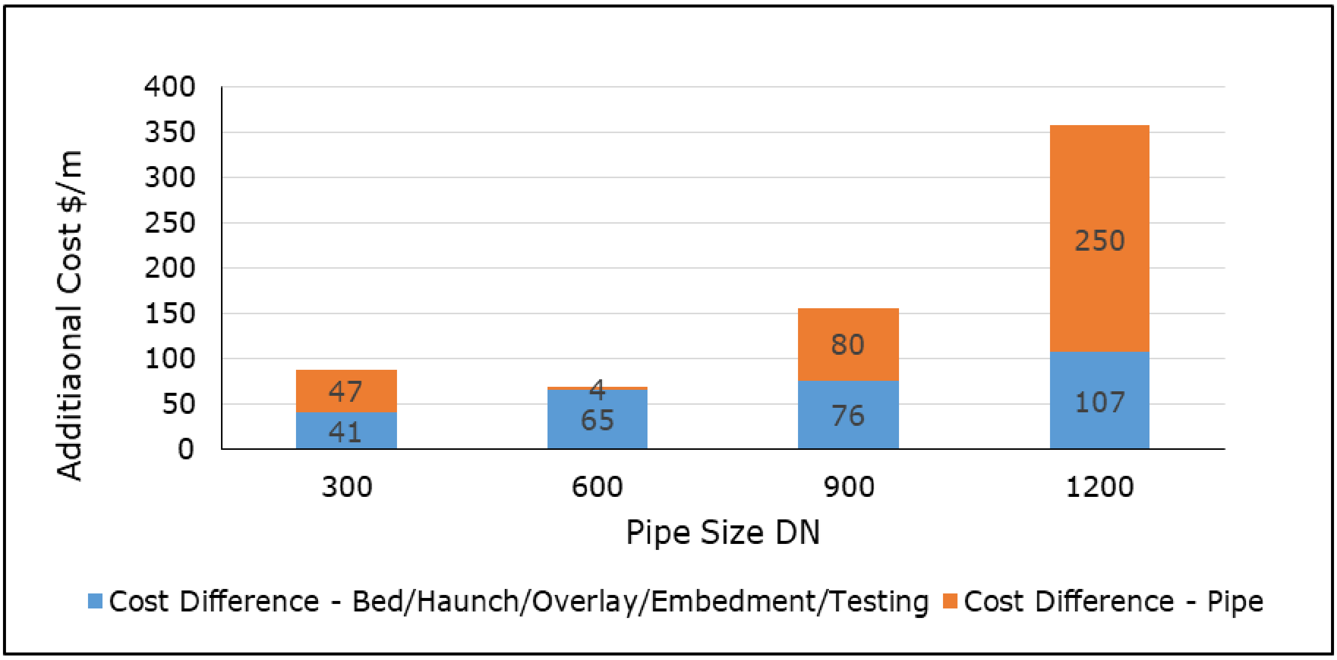

Figure 2: Additional Cost of GRP over Concrete Pipe Installations

7 CONCLUSIONS

Rigid and flexible pipes differ in their material properties and how they behave in the ground. These differences influence design and installation methodologies, particularly with regard to backfill and testing requirements. It is therefore important that these differences be recognised and adequately priced when selecting pipe materials. If they are not adequately addressed they can adversely impact asset life and subsequently the whole-of-life cost of the installations.

A full consideration of the many influencing factors is needed to provide the lowest whole-of-life cost and the best-value installations.

REFERENCES

CPAA Publications

Designing Rigid & Flexible Pipeline Systems, Technical Note, July 2013

Understanding Flexible Plastic Pipe, Technical Brief

A Comparison of The Design & Installation Requirements Rigid Pipe and Flexible Pipe, prepared for the CPAA by D.J. Matthews

Australian/New Zealand Standards

AS/NZS 3725:2007 Design for the installation of buried concrete pipes

AS/NZS 3725 Supplement 1:2007 Design for installation of concrete pipes - Commentary

AS/NZS 4058:2007 Precast concrete pipes (pressure and non-pressure)

AS/NZS 2566.1: 1998 Australian/New Zealand Standard: Buried flexible pipelines Part 1: Structural Design

AS/NZS 2566.1: Supplement 1: 1998 Buried flexible pipelines Part 1: Structural Design- Commentary

AS/NZS 2566.2: 2002 Australian/New Zealand Standard: Buried flexible pipelines Part 2: Installation

British/European Standards

BS 9295:2010 Guide to the structural design of buried pipelines

BS EN 1295-1 Structural design of buried pipelines under various conditions of loading — Part 1: General requirements

APPENDIX

Key Differences between Concrete and Flexible Pipes

The following table lists some of the key differences between concrete pipes and flexible pipes:

Table 3: Comparison between Concrete and Flexible Pipes

	Precast Concrete Pipes	**Flexible Pipes**
Applicable Australian/New Zealand Material Standards	AS/NZS 4058 Precast concrete pipes – pressure and non-pressure; AS/NZS 4139 Fibre reinforced concrete pipes	AS/NZS 1260 PVC-U pipes and fittings for drain, waste and vent applications; AS/NZS 4130 PE pipes for pressure applications; AS/NZS 1254 PVC-U pipes and fittings for stormwater and surface water applications; AS/NZS 5065 Polyethylene and polypropylene pipes and fittings for drainage and sewerage applications (There is no AS or NZS Standard for GRP pipe which is typically made to ISO and EN Standards)
Required Pipe Strength or Stiffness	Dead load, live load, and bedding factor need to be calculated to determine the required pipe strength from the Test Loads for Load Classes table 4.2 in AS/NZS 4058 (or use the CPAA design software PipeClass).	Vertical deflection, ring-bending strain and buckling need to be calculated (AS/NZS 2566:1) to determine what stiffness of flexible pipe is required. For PVC pipes, the minimum stiffness requirements are given in Table 3.2 of AS/NZS 1260, and follow the SN classes (e.g. SN 4 = 4,000 N/m/m stiffness).
Applicable Design Standards	AS/NZS 3725 Design for installation of buried concrete pipes	AS/NZS 2566.1 Buried flexible pipelines - Structural design

	Precast Concrete Pipes	Flexible Pipes
Applicable Installation Standards	AS/NZS 3725 Design for installation of buried concrete pipes give some guidance but does not specifically cover installation	AS/NZS 2566.2 Buried flexible pipelines – Installation; AS/NZS 2032 Installation of PVC pipe systems; AS/NZS 2033 Installation of PE pipe systems
Structural integrity	Derived from pipe-soil structure – integrity primarily from the pipe Moderate changes to the soil envelope over time will not compromise the structural integrity	Derived from soil-pipe structure – integrity from the soil envelope Changes to envelope over time can produce deflections that lead to premature system failure
Principal structural design consideration	Pipe strength	Pipe deflection, strain and buckling
Soil Stiffness	The native soil modulus is not normally a factor in design	The native soil and embedment material modulus is important to the structural performance of the pipe.
Impact of embedment compaction	Less significant	More significant
Compaction Requirements	Compaction requirement for overlay zone may not be as stringent as that for flexible pipe embedment	Compaction standards apply through whole of the embedment
Compaction Lift Requirement	The compaction lift requirements for rigid pipes stem from roading specifications rather than a requirement for pipe installation. The pipe can self-support in poor backfill conditions however under roads and other situations settlement of the trench materials due to poor compaction is not acceptable.	Table H2 in AS/NZS 2566 gives required compaction effort and lifts for varying soil/embedment material types. Generally each lift should be between 150 mm and 300 mm depending on compaction effort type. This is necessary to provide adequate soil strength to support the flexible pipe.
Attention required at construction	Comparatively low requirement	Comparatively high requirement due to influence of soil envelope
Installation Testing	No specific testing requirements in Standard but local authorities may require compaction testing, CCTV inspection and low pressure air or hydrostatic tests.	Leakage testing required for wastewater applications, deflection testing for all applications required at 30 days (or other timeframe as practicable) after installation is complete (AS/NZS 2566.2). Local authorities may also require CCTV inspection.

	Precast Concrete Pipes	Flexible Pipes
Service Life	Generally concrete pipes are considered to have a service life of 100 years when manufactured and installed in accordance with the Standards.	Generally the flexible pipe standards state a minimum design life of 50 years. This is based on 50 years extrapolated test data. The expected life of flexible pipes when correctly designed and installed is thought to be "in excess of 100 years before major rehabilitation is required" (from the Foreword in AS/NZS 4130 and the Preface of AS/NZS 1260).
Environmental Conditions	Acid soils and coastal locations can be detrimental to concrete material	Some solvents can be detrimental to PVC material. Hydrocarbons can be detrimental to PE material.
Flammability	Not applicable. Non-combustible. Structural integrity not destroyed.	PVC is flammable but needs external fuel source. PE is flammable and self-fuelling. Once burning, does not need external fuel source. Emit toxic fumes when burning.
Floatation	Resists buoyancy forces best of all products.	Pipe is lighter than the fluid/soil weight it displaces. Buoyancy forces can affect line and grade.