A Comparison of

THE DESIGN & INSTALLATION REQUIREMENTS FOR RIGID PIPE AND FLEXIBLE PIPE

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ABSTRACT

In Australia and New Zealand the requirements for the design and installation of pipelines are specified in a number Australian/New Zealand Standards that relate to the pipe type and material to be used.

As important engineering projects the structural performance and in-service life of pipelines are dependent on the achievement of the specified design and installation requirements appropriate to the selected pipe material and the available site conditions.

This paper compares the differing design considerations and installation requirements contained in the relevant Standards for the following pipe type classifications and materials:

- Rigid – Steel reinforced Concrete Pipe, AS/NZS 4058 and AS/NZS 3725
- Flexible – Plastic and Metallic Pipe, AS/NZS 2566.1 and AS/NZS 2566.2

The design and installation requirements vary markedly with:

- the rigidity or stiffness of the pipe material selected, and
- its need or ability to react with the embedment materials, and
- the shape and dimensions of the embedment.

The requirements for each pipe alternative need to be assessed properly by the specifier, manufacturer and the installer as the diversity influences the immediate installed cost of the pipeline and any comparative analysis of the life cycle cost of the resulting asset.

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1 Introduction

Pipelines are important structures that must be designed and installed to specific engineering requirements. The structural performance and in-service life of a pipeline is dependent on achieving the specified design and installation requirements appropriate to the selected pipe material and the available site conditions.

The design and installation requirements vary markedly with:

- the rigidity or stiffness of the pipe material selected, and
- its need or ability to react with the embedment materials, and
- the shape and dimensions of the embedment.

The diversity of these requirements for each pipe alternative influences the immediate installed cost of the pipeline and, more importantly, any comparative analysis of the life cycle cost of the resulting asset. This paper examines the differing requirements for pipe types classified as rigid and flexible including the degree of soil-pipe structural interaction necessary for both pipe types. Section 2 provides further detail on the different pipe types.

There are Australian and New Zealand Standards that specify the requirements for the manufacture, design, testing and installation of the various pipe materials. This paper compares the design considerations and installation requirements contained in the relevant Standards for the following pipe type classifications and materials:

- RIGID - Steel Reinforced Concrete Pipe, 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)”

- FLEXIBLE - Plastic or Metallic Pipe, Australian/New Zealand Standards:
  - AS/NZS 2566.1: 1998 “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: “Buried flexible pipelines, Part 2: Installation”

The design criteria for these differing pipe types are compared in Section 3. The differences required in the design analysis and selection of a particular pipe type is

- Product component materials
- Product size class and load class
- Structural design for soil-pipe interaction under loading
- Product acceptance
- Pipeline life expectancy

In Section 4 the installation requirements appropriate to pipes of these classifications are discussed. These include:

- Amount of excavation
- Handling and storage
- Selected fill material
- Compaction of fill
- Dispersal of unused material

Section 5 contains a table summarising the comparisons presented in the preceding sections.

Section 6 details the Standards referenced and related CPAA publications.

2 Classification of pipe type

The design and installation requirements vary markedly with the strength or stiffness of the pipe material and its need or ability to react with the embedment materials and its geometry.

Figure 1 illustrates the interrelationship between a number of different Australian and New Zealand Standards that specify the requirements for the manufacture, design, testing and installation of the various pipe materials. These are:

(a) Rigid Pipe: The concept of a 'rigid' pipe is one that has sufficient inherent strength to carry the working loads on its own. Australian/New Zealand Standards based on this concept are:

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

  The purpose of this Standard is to provide guidelines and minimum testing criteria for the manufacture and quality assessment of concrete pipe.

- AS/NZS 3725:2007(and Supplement - Commentary) "Design for the installation of buried concrete pipes".

  The purpose of this Standard is to enable an appropriate load class selection and application of concrete pipe.

(b) Flexible Pipe: The concept of a 'flexible' pipe is one that deflects sufficiently to develop, by interaction with the soil embedment, sufficient combined strength to carry the working load. Examples of Australian/New Zealand Standards based on this concept are:

- AS/NZS 2566.1: 1998 (and Supplement – Commentary): "Buried flexible pipelines, Part 1: Structural Design"

- AS/NZS 2566.2: 2002: "Buried flexible pipelines, Part 2: Installation".

  The purpose of the three AS/NZS 2566 documents is to provide designers with procedures for the structural design and installation of buried flexible pipelines.

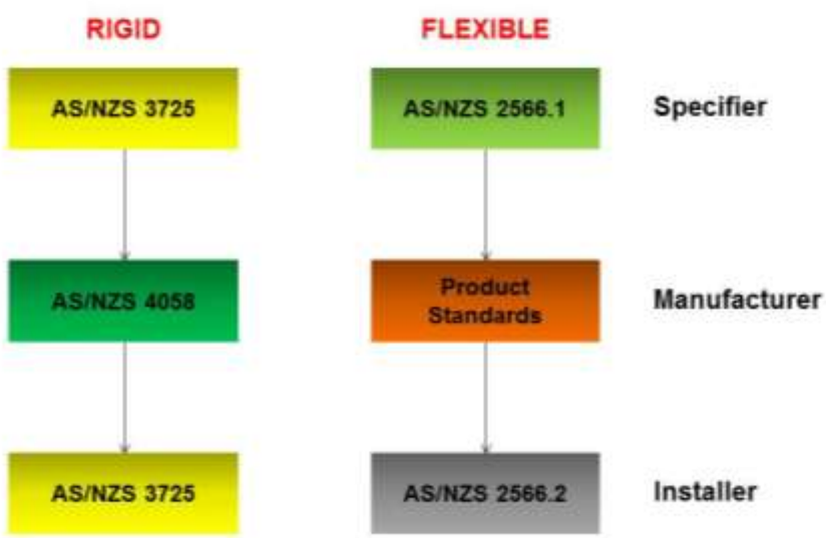


Figure 1 - Australian/New Zealand Standards for Pipe Design & Installation

3 Comparison of pipe design criteria

3.1 COMPONENT MATERIALS SELECTION

Product Standards detail the requirements for the constituent or raw materials to be used in the manufacturing process. Ideally these materials should be referenced to known Standards, preferably local. When these inputs are controlled a major source of variation in manufacturing the product is eliminated. For well established products made from conventional materials this occurs. For example, in AS/NZS 4058 all materials to be used in the manufacture of concrete pipe are referenced to an appropriate Australian or New Zealand Standard.

Difficulties can arise where the raw materials in use are

- newly developed and not covered by existing Standards, or
- where a Standard is left open to accommodate possible variations between manufacturers, or
- where a Standard is left open to accommodate the development of new materials.

As an example, in some Product Standards, 'filler' materials as used in many varieties of flexible pipe are not linked to a controlling specification.

3.2 PRODUCT SIZE CLASS AND LOAD CLASS

The respective pipe Product Standards differ significantly in the diameter range (size class) and load carrying capability (load class) of the product offered.

(a) Rigid pipe – Concrete

- Size Class 100mm to 4200mm
- Load Class 2 to 10 up to 3000mm
- Load Class 2 to 4 up to 4200mm

(b) Flexible pipe – various Plastic materials

- Size class > 75mm. Maximum varies with material type and manufacturing capability.
- Load class is not a directly applicable term. For example installation load carrying capability is dependent on combination of suitable pipe stiffness (initial stiffness S_{DI} > 1250 N/m/m, and long term stiffness S_{DL} > 625N/m/m) and embedment properties.

3.3 STRUCTURAL DESIGN FOR SOIL-PIPE INTERACTION UNDER LOADING

The structural performance and in-service life of a pipeline is dependent on achieving the specified design and installation requirements. These requirements must be appropriate to the selected pipe material and the available site conditions. Design and installation requirements vary markedly with the rigidity or stiffness of the pipe material and its need or ability to react with the embedment materials and the embedment geometry.

Section 2 nominates those Australian and New Zealand Standards that cater for these differences. These Standards can be used to specify a design appropriate for the pipe material selected and the achievable installation conditions. Significant differences addressed in these Standards include:

(a) Rigid pipe – Concrete:

- The shape of the embedment determines the effects of the magnitude of dead and live loads on the installed pipe. AS/NZS 3725 identifies the 'trench' or 'embankment' as the two main types of installation. Refer Figures 2 and 3.

- In a trench, of width B, the walls provide frictional support to the fill material over the pipe. The frictional forces reduce the effect of the fill load on the pipe.
- In an embankment formation the fill material either side of the pipe settles further than the soil prism of width D directly over the pipe. The frictional forces increase the effect of the fill load on the pipe.

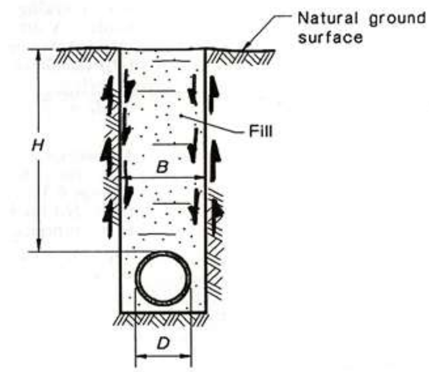


Fig.2 - Trench fill load $W_g = C_t w B^2$

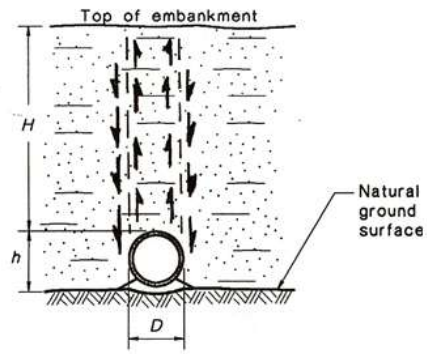


Fig.3 - Embankment fill load $W_g = C_e wDH$

- Rigid pipe as defined has a low dependency on soil-pipe interaction. The structural strength (load class) of the pipe chosen provides the capacity to carry all loads.
- The selection of the installation support type for the installation determines the load class of pipe to be specified Refer Figure 4 ,5 and Table 1
- The strength of the installed pipe increases with time(i.e. The concrete pipe continues to gain strength).

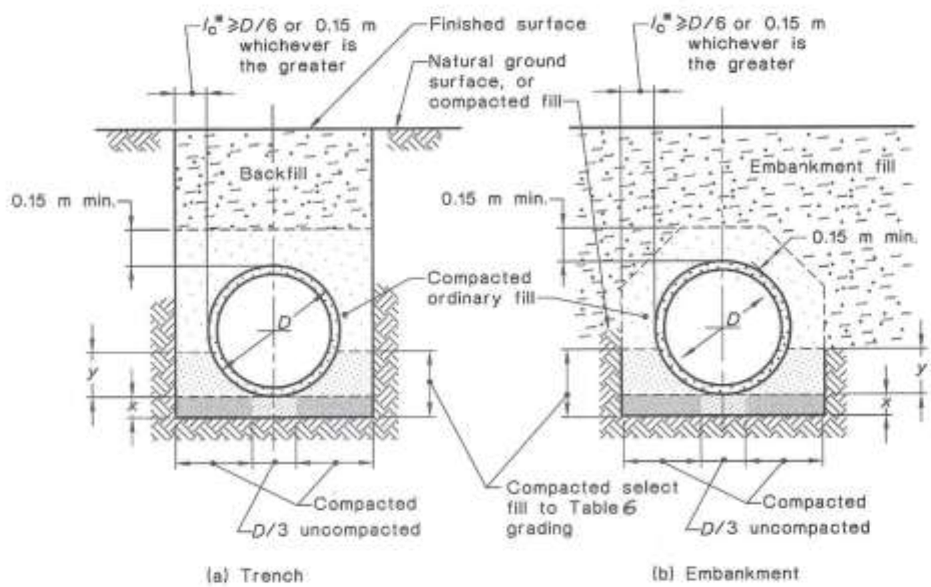


Fig.4 - Type H1 and H2 support (REF.AS/NZS3725 Figure 12)

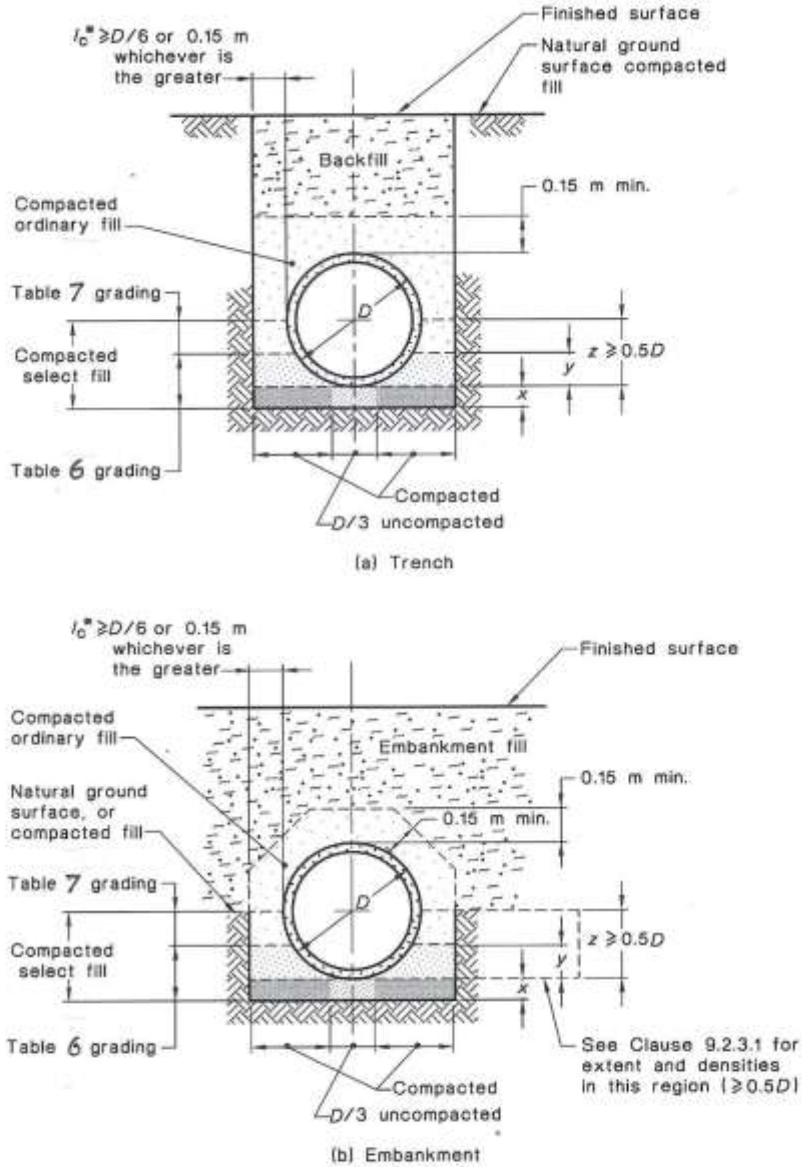


Fig. 5 - Type HS Support (Ref.AS/NZS 3725 Figure 13)

BEDDING FACTORS FOR WORKING DEAD LOADS (U, H AND HS SUPPORTS)

Support type		Minimum depth, mm		Minimum zone compaction, %*			Bedding factor§
		Bed zone	Haunch zone	Bed and haunch zones	Side zones		
		x†	y†	I_D‡	I_D‡	R_D‡	(F)
U		75	—	—	—	—	1.0
H	H1	100 if $D \leq 1500$; or 150 if $D > 1500$	0.1D	50	—	—	1.5
	H2		0.3D	60	—	—	2.0
HS	HS1	100 if $D \leq 1500$; or 150 if $D > 1500$	0.1D	50	50	85	2.0
	HS2		0.3D	60	60	90	2.5
	HS3		0.3D	70	70	95	4.0

Table 1 - (Ref. Excerpt AS/NZS 3725 Table 5)

(b) Flexible pipe – including various Plastics and Metals:

- Unlike the other pipe types the basic shape of the embedment is not considered when calculating the loads carried by a flexible pipe (i.e. the AS/NZS 2566.1 Commentary nominates that buried flexible pipes "deform in the vertical direction at least as much as the embedment so that frictional effects cannot develop to increase the load on the pipe beyond that of the prism load").

  i.e. Equation 4.3 from AS/NZS 2566.1 $w_g = \gamma H$

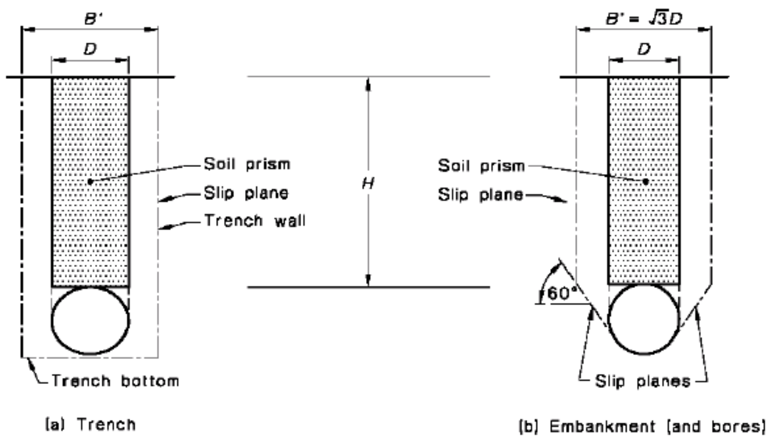


Fig.6 - Soil Prism Load - Flexible Pipe (Ref. AS2566.1 Fig.C4.1)

- The term 'ring bending stiffness' is used to define the structural capacity of a flexible pipe at a particular time.

  $S = E.\ I\ .10^6 / D^3$
  E = ring bending modulus at a particular time.
  I = second moment of area of pipe wall for ring bending
  $= t^3/12$ for plain wall pipe of thickness t.

  As a result of creep (or relaxation) the ring bending stiffness of a flexible pipe decreases with time. Short term and long term values for ring bending stiffness (S_{DI} & S_{DL}) are estimated for an initial E_b (3-minute value) and a long -term modulus E_{bL}. Limiting values of pipe stiffness are S_{DI} > 1250 N/m/m, and S_{DL} > 625N/m/m.

- It is a design requirement to determine that the installed pipe will act in a flexible manner. The designer must check that the pipe deflects enough, relative to the surrounding soil, to ensure the soil envelope will take the loads. This is quantified in clause C1.4.6.2 by comparing the long-term relative stiffness of the pipe (S_{DL}) and the embedment soil (i.e. combined soil modulus *E')*.

  - Where $S_{DL} / E' < 7500$ the installed pipe will act in the flexible mode.
  - Where $S_{DL} / E' > 7500$ the installed pipe will act in the rigid mode.

- The success of a flexible pipe installation is dependent on a thorough assessment of the inherent pipe stiffness and its direct interaction with the surrounding soil to resist excessive
  - Vertical deflections (short and long term).
  - Ring bending strain
  - Buckling

- "The structural performance of flexible pipe depends primarily on the extent and degree of compaction actually achieved in the field. It is important that all embedment is compacted to the minimum density specified in Table 2, as the compaction influences the long term performance of the pipeline." Clause C3.3.2 of AS/NZS 2566.1 - Commentary.

EMBEDMENT AND NATIVE SOIL—MATERIALS AND MODULI*

Materials			Moduli E'_e and E'_n MPa				
Description	Classification		Uncompacted	R_D (%)			
				85	90	95	100
	AS 1726 †	AS 2758.1		I_D (%)			
				50	60	70	80
			Standard penetration test ‡ Number of blows				
			≤ 4	> 4 ≤ 14	> 14 ≤ 24	> 24 ≤ 50	> 50
Gravel— single size	—	Coarse aggregate	5§	7§	7§	10§	14
Gravel— graded	GW		3§	5§	7§	10§	20
Sand and coarse-grained soil with less than 12% fines	GP, SW, SP and GM-GL, GC-SC etc.	—	1	3§	5§	7§	14
Coarse-grained soil with more than 12% fines	GM, GC, SC SM and GM-SC, GC-SC	—	NR	1§	3§	5§	10
Fine-grained soil (LL<50%) with medium to no plasticity and containing more than 25% coarse-grained particles	CL, ML, mixtures ML-CL and ML-MH	—	NR	1§	3§	5§	10
Fine-grained soil (LL<50%) with medium to no plasticity and containing less than 25% coarse-grained particles	CI, CL, ML, mixtures ML-CL, CL-CH and ML-MH	—	NR	NR	1	3	7
Fine-grained soil (LL>50%) with medium to high plasticity	CH, MH and CH-MH	—	NR	NR	NR	NR	NR

Table 2 - (Ref. Excerpt from AS/NZS 2566.1 Table 3.2)

3.4 PRODUCT ACCEPTANCE :

The Standards vary considerably in defining the requirements for the acceptance of product as suitable for installation. Where the performance of the installed pipe can be related with confidence to the product strength then routine load testing of the pipe is a preferable option.

(a) Rigid pipe

- Acceptance is based on a demonstrated ability of the pipe and to meet the requirements of a range of performance type tests and routine tests as specified in AS/NZS 4058.
- A key test is the application of a proof load test (T_c) calculated from the installation parameters selected from AS/NZS 3725. They are:
    - The installation loads (W), and
    - The bedding factor (F), appropriate to the selected bedding type.

T_c is calculated as follows:

$$T_c = W_g / F + W_q/1.5 \text{ where}$$

W_g = the working dead load, and
W_q = the working live load

(b) Flexible

- Acceptance is by design calculation, based on attaining the required embedment properties, and that predict the installed pipes ability to meet the

    - specified long term vertical deflection
    - specified long term ring bending strain
    - buckling effects of external hydrostatic pressure and internal vacuum.
    - defined ‘flexible pipe’ pipe/soil relative stiffness ratio, and

- There is a requirement to test short-term vertical deflections in the installed flexible pipeline. This is a ‘performance test’ in addition to the theoretical design calculations. Clause 6.5.1 AS/NZS 2566.1 describes it as necessary because “Deflection measurement is a valuable method of assessing the adequacy of embedment material placement and compaction.” Since the Standard was written the use of CCTV as a method for monitoring pipe deflection has been more widely accepted. Its cost is offset by the convenience of conducting the inspection and the quality of the reporting obtained.

3.5 PIPELINE LIFE EXPECTANCY:

The pipeline life expectancy is a major consideration in any comparative analysis of the life cycle cost of the resulting asset. The in-service life of a pipeline installation is dependent on a combination of:

- the application (i.e. intended use).
- the installation environment the pipeline is subjected.
- the pipe material & manufactured quality.

Currently concrete pipe (rigid) has a documented service history of over 100 years. Where a 100 year in-service life is specified, pipes manufactured in accordance with AS/NZS 4058 and installed in accordance with AS/NZS 3725 have been assessed as suitable for use in stormwater and drainage pipeline installations in a ‘normal environment’ and certain defined ‘marine environments’. Pipes subject to ‘other environments’ (i.e. more aggressive) should be assessed individually for specific service life suitability using appropriate engineering judgement and additional guidelines available from the CPAA.

The flexible pipe AS/NZS 2566.1 and AS/NZS 2556.2 Standards is based on the requirement for manufactured product and installations predicted by calculation as suitable for a 50-year life. The documented service history, for installations using flexible pipe materials is also limited because of their comparative recent introduction. Many have a service life history less than the 50-year predicted life.

4. Comparison of installation requirements

The installation requirements contained in the Australian and New Zealand Standards AS/NZS 3725 and AS/NZS 2566 vary considerably. The variation is mainly attributable to the differences necessary to design for each pipe types:

- intrinsic strength or stiffness and
- need or ability to react with the embedment materials and its geometry.

Some minor differences result from the time elapsed between publication of the two installation Standards.

In the following cases, the variations noted effect the installed cost of the pipeline. Failure to meet these requirements can have a major impact on the service life of the installation.

4.1 AMOUNT OF EXCAVATION

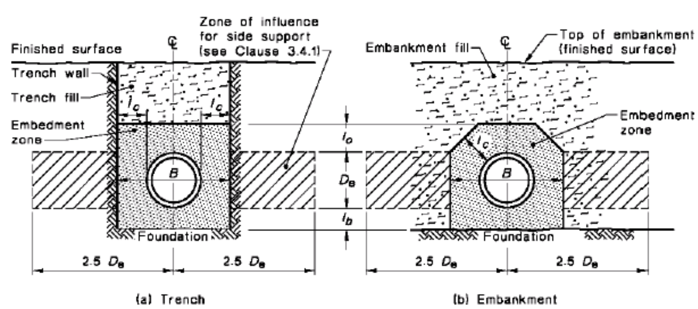
Both Standards contain recommended embedment dimensions that impact on the amount of excavation of the native soil material. Both Standards recommend that caution must be exercised in the selection embedment geometry that will accommodate all equipment necessary to complete the installation. Differences in approach defining the trench geometry are:

(a) Rigid

- In AS/NZS 3725 the embedment widths are specified with consideration given to accommodating the available equipment to compact the fill in the haunch and side area of the pipe installation. Refer to Figures 4 & 5. (AS/NZS 3725 Figures12, and 13)

(b) Flexible

AS/NZS 2566 trench geometry differs from AS/NZS 3725. Overall minimum trench widths are theoretically narrower than a minimum trench width calculated using AS/NZS 3725 geometry. However the minimum dimensions (e.g. I_c at sides of pipe) are accompanied by the requirement that the compaction percentages specified must be achievable. (AS/NZS 2566.1 Fig 3.1). . The decision on trench geometry is dependent on the available compacting equipment and the availability readily compacted embedment materials



D_e	Minimum values*		
	l_b	l_c†	l_o‡
≥75 ≤150	75	100	100
>150 ≤300	100	150	150
>300 ≤450	100	200	150
>450 ≤900	150	300	150
>900 ≤1 500	150	350	200
>1 500 ≤4 000	150	$0.25D_e$	300

Fig.7 - Flexible pipe embedment geometry (Ref. Excerpt AS/NZS 2566.1 Fig.3.1)

4.2 HANDLING AND STORAGE

Each pipe product Standard contains handling and storage requirements appropriate to that material. The following are differences that can effect on the overall construction cost of the installation.

(a) Rigid pipe
- Is usually heavier/metre and shorter in length than less rigid pipe of the same diameter.
- Is structurally self sufficient and remains dimensionally stable when stockpiled & stacked.
- Is capable of supporting the variety of loads experienced in the various stages of construction

(b) Flexible pipes
- Are usually lighter than other pipe types and often available in longer lengths.
- Can have both product dimensions & its structural integrity affected when transported, handled and stored inappropriately. These vary considerably across the wide range of pipe materials available. Many can be effected by extremes in the climatic conditions Reference to the requirements in the individual pipe product specifications is important.

4.3 SELECTED FILL MATERIAL

The requirements for the selected fill material in the embedment zones in immediate contact with the pipe vary significantly for each pipe type. AS/NZS 3725 and AS/NZS 2566 specify differing requirements for selecting and placing suitable fill materials in each embedment zone.

(a) Rigid
- For a typical installation (i.e. 'H' support) Table 6 in AS/NZS 3725 specifies the grading limits for select fill materials used in the 'bed' and 'haunch' zones. Ordinary fill is used for the remainder of the embedment around the pipe. Refer to 'select fill' and insitu backfill in figure 8.
- Where a 'HS' support is required (e.g. high load applications), select fill as specified in Table 7 AS/NZS 3725 is required in the 'side' zones. Ordinary fill is used for the remainder of the embedment around the pipe.
- Table 5 in AS/NZS 3725 details the dimensional requirements for each embedment zone.

(b) Flexible
- AS/NZS 2566 defines the embedment zone as a single zone that fully encases the pipe with select fill. This represents a significant increase on the select fill depth specified in AS/NZS 3725 where typically select fill is only required up to the top of the haunch zone. Refer to 'Embedment Material' in Figure 8.
- The designer specifies an appropriate embedment fill material. Refer to Table 2. (Table 3.2. AS/NZS 2566). The selection is based on the materials ability to be compacted to the required value. This is essential if the soil envelope is to take the loads transferred from the pipe as it deflects.

4.4 COMPACTION OF FILL

In section 4.3 the overall depth of select fill required increases as the reliance of the installed pipe on the surrounding embedment increases. The compaction requirements for the completed installation therefore increase both in quantity and degree of compaction as the pipe rigidity decreases. This occurs because

- The numbers of layers to be compacted increase as the depth of select fill to be compacted. Refer to Figure 8 for a comparison of the depth of select fill / embedment material to be compacted.

- A flexible pipe design relies on obtaining the soil modulus nominated by the designer for that installation. This value is determined from Table 2 (Table 3.2 AS/NZS 2566.1). The designer selects the most appropriate combination of available fill and compaction percentage applicable for that specific material. Selection of a viable, achievable yet economic combination is important. Typically the compaction percentage required increases with the shift from rigid to flexible.

Where available and economical, the use of self-compacting materials (e.g. specified coarse aggregate, gravel or stabilized materials) can reduce the time to place and compact the embedment zone.

4.5 DISPERSAL OF UNUSED EXCAVATED MATERIAL

Excavated material not suitable for use in the embedment zones must be disposed of. The quantity for removal from the site is proportional to amount of imported select fill placed. In section 4.3 the depth of select fill increased as the pipe type became less rigid. Consequently the time and effort associated with dispersal of unused excavated material will also increase for less rigid pipe materials.

Figure 8 provides comparative illustrations of the typical proportions of:

- imported material required (designated as 'select fill' or 'embedment material').
- re-use of previously excavated material, where suitable (designated as 'insitu backfill').

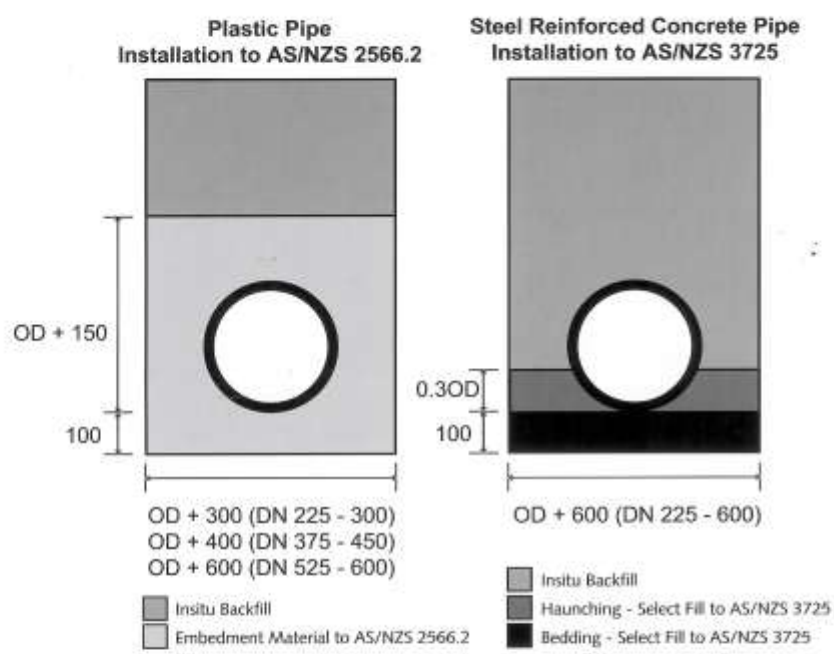


Fig.8 - Embedment geometry comparison.

5. Summary and Conclusions

The following tabulation summarizes the design and installation requirements for the various pipe types and pipe materials as detailed in this paper.

The table provides a comparison of the differing requirements that result from the variation in the strength or stiffness of the pipe material considered and its need or ability to react with the embedment materials and its geometry. In addition to the table, Section 6 'References' lists additional Concrete Pipe Association of Australasia (CPAA) publications with useful subject matter relating to comparisons of the various pipe materials, comparisons of installation costs and life cycle analysis and costing.

Item or Requirement for Comparison				**REF**
Pipe	**Type**	**Rigid**	**Flexible**	
	Material	Concrete	Plastics, Metals	Section 2
Aust/NZ Standard	Specifier	AS/NZS 3725	AS/NZS 2566.1	
	Manufacturer	AS/NZS 4058	Various	
	Installer	AS/NZS 3725	AS/NZS 2566.1	
Control raw materials specification in pipe – i.e. referenced to a Standard		All referenced to appropriate Aust/NZ Standards.	Fillers not referenced to a Standard.	3.1
Product Class specified in Standard	Size Class DN.	100 to 4200	>75mm. Maximums vary with pipe material.	3.2
	Load Class	Class 2 to 10 up to 3000mm Class 2 to 4 up to 4200mm	Not applicable	
Design of installed pipe	Treatment of external working loads	Embedment shape determines the magnitude of the soil load transferred to the pipe	Soil loads are transferred directly to the pipe. Embedment shape does not affect the magnitude.	3.3
	Capacity of pipe to carry load	Nil to low dependency on soil-pipe interaction	Designer to assess: - If pipe acts in a flexible mode; $S_{DL}/ E' < 7500$ or a rigid mode; $S_{DL}/ E' > 7500$ - The short and long term performance of pipe interaction with embedment to resist excessive: (i) Deflection (ii) Ring bending strain (iii) Buckling	
	Selection of installation support type	The support type selected directly determines the required pipe load class suitable to carry external loads.	Structural performance of the installation is totally dependent on the compaction achieved in the prescribed fully encasing embedment support.	
	Strength of installed pipe over time	Increases	Decreases	

<table>
<tr><th colspan="4">Item or Requirement for Comparison</th><th>REF</th></tr>
<tr><td rowspan="2">Pipe</td><td>Type</td><td>Rigid</td><td>Flexible</td><td></td></tr>
<tr><td>Material</td><td>Concrete</td><td>Plastics, Metals</td><td></td></tr>
<tr><td colspan="2">Product Acceptance</td><td>Performance basis:
- Demonstrated ability to meet test requirements specified in AS/NZS 4058.
- Pipe is tested to a proof load calculated from AS/NZS 3725
$T_c = W_g / F + W_q /1.5$
to demonstrate specified load class has been achieved</td><td>Design basis:
- Calculation is required to predict the short and long term performance of pipe interaction with embedment to resist excessive:
(i) Deflection
(ii) Ring bending strain
(iii) Buckling
Performance basis:
- Line deflection testing to assess the adequacy of the embedment material placement and compaction</td><td>3.4</td></tr>
<tr><td colspan="2">Pipeline Life Expectancy</td><td>Pipe assessed as suitable for 100-year in-service life required in normal environments and certain defined marine environments.
Service history approaching 100 years</td><td>50-year life predicted by AS/NZS 2566 calculation based on shorter term testing.
Many current flexible materials have service histories less than 50 years.</td><td>3.5</td></tr>
<tr><td rowspan="6">Installation requirements</td><td>Amount of excavation -
Embedment width</td><td>AS/NZS 3725 widths based on providing access for compaction equipment</td><td>AS/NZS 2566 narrow widths accompanied by a requirement that specified compaction must be achievable. (i.e. or width increased)</td><td>4.1</td></tr>
<tr><td>Handling and Storage</td><td>- Heavier per metre.
- Structurally self-sufficient.
- Can support loads experienced in construction.</td><td>- Usually lighter than other two pipe type
- Dimensional and structural integrity can be affected if handled & stored inappropriately or in adverse climatic conditions.</td><td>4.2</td></tr>
<tr><td>Selected Fill Material - Depth required</td><td>Support type:
H - to haunch zone.
HS – to side zone.</td><td>Pipe to be fully encased to a specified safe minimum depth above the pipe.</td><td>4.3</td></tr>
<tr><td>Compaction of fill</td><td>- Less depth of select fill to be compacted than flexible.
- Lower levels of compaction % specified</td><td>- Increase depths of select fill require more passes.
- Compaction % usually higher than other two pipe types. (Need for support is essential)</td><td>4.4</td></tr>
<tr><td>Dispersal of unused excavated material</td><td>Potentially least quantity of unused material requiring dispersal.</td><td>Increased depths (use) of select fill generates high quantity of unused material for dispersal</td><td>4.5</td></tr>
<tr><td>Pipeline deflection testing</td><td>Not required</td><td>Required to confirm correct placement and compaction of fill.</td><td>3.4</td></tr>
</table>

6. References

This document was prepared using information, references including clauses, illustrations and tabulations from the following:

AUSTRALIAN STANDARDS

1. AS/NZS 3725:2007 Design for the installation of buried concrete pipes
2. AS/NZS 3725 Supplement 1:2007 Design for installation of concrete pipes - Commentary
3. AS/NZS 4058:2007 Precast concrete pipes (pressure and non-pressure)
4. AS/NZS 2566.1: 1998 Australian/New Zealand Standard: Buried flexible pipelines Part 1: Structural Design
5. AS/NZS 2566.1: Supplement 1: 1998 Buried flexible pipelines Part 1: Structural Design-Commentary
6. AS/NZS 2566.2: 2002 Australian/New Zealand Standard: Buried flexible pipelines Part 2: Installation

Additional information on the comparisons in this paper and related subjects can be found in the following:

CPAA PUBLICATIONS

7. Engineering Guideline: Designing Durable Concrete Pipelines.
8. Technical Brief: Life Cycle Cost Analysis in Drainage Projects.
9. Engineering Guideline: Discharge Capacity of Pipelines of Different Materials
10. Technical Brief: Flow Characteristics of RC & HDPE Pipe for Stormwater Drainage Applications.
11. Technical Report: GH&D Report- Impacts on the Life Cycle Costs of Stormwater Drainage Assets.
12. Technical Brief: Understanding Flexible Plastic Pipe.
13. Technical Brief: Deflection of flexible plastic pipe.