Concrete Pipe Association of Australasia Technical Paper

The design and installation requirements for various pipe types

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ABSTRACT

In Australia the requirements for the design and installation of pipelines are specified in a number Australian 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 – Concrete Pipe, AS 4058 and AS3725
- Semi-rigid – FRC Pipe, AS4139
- Flexible – Plastic and Metallic Pipe, AS266.1 and AS2566.2

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.

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 three pipe types classified as rigid, semi rigid and flexible including the degree of soil-pipe structural interaction necessary for each pipe type. Section 2 provides further detail on the different pipe types.

There are Australian 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:
    - AS3725 –1989 Australian Standard: Load on buried concrete pipes
    - AS4058 –1992 Australian Standard: Precast concrete pipes (pressure and non-pressure)
- Semi Rigid - Fibre reinforced concrete:
    - AS4139 –2003 Australian Standard: Fibre-reinforced concrete pipes and fittings
- Flexible - Plastic or metallic:
    - AS2566.1: 1998 Australian/New Zealand Standard: Buried flexible pipelines Part 1: Structural Design
    - AS2566.1: Supplement 1: 1998 Buried flexible pipelines Part 1: Structural Design-Commentary
    - AS2566.2: 2002 Australian/New Zealand Standard: Buried flexible pipelines Part 2: Installation

The design criteria for the three pipe types are compared in Section 3. The differences required in the design analysis and selection of a particular pipe type discussed are:

- 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 summarizing the comparisons presented in the preceding sections. Section 6 details the Standards referenced and related CPAA publications.

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 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. Examples of Standards based on this concept are:

- AS4058 –1992 Australian Standard: "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.
- AS3725 –1989 Australian Standard: "Loads on buried concrete pipes". The purpose of this Standard is to enable an appropriate load class selection and application of concrete pipe.

(b) Semi Rigid Pipe: The concept of a 'semi rigid' pipe is one that has sufficient strength to initially carry the working load, and with the capability to deflect under long term load, so as to gain support from the soil in which it is embedded. An example of a Standard utilizing this concept is:

- AS4139 –2003 Australian Standard: "Fibre-reinforced concrete pipes and fittings". The purpose of this Standard is to provide guidelines and minimum test criteria for the manufacture and performance assessment of fibre reinforced concrete pipes.

(c) 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 Standards based on this concept are:

- AS2566.1: 1998 Australian/New Zealand Standard (and Supplement –Commentary): "Buried flexible pipelines Part 1: Structural Design"".
- AS2566.2: 2002 Australian/New Zealand Standard: "Buried flexible pipelines Part 2: Installation. The purpose of the three AS2566 documents is to provide designers with procedures for the structural design and installation of buried flexible pipelines.

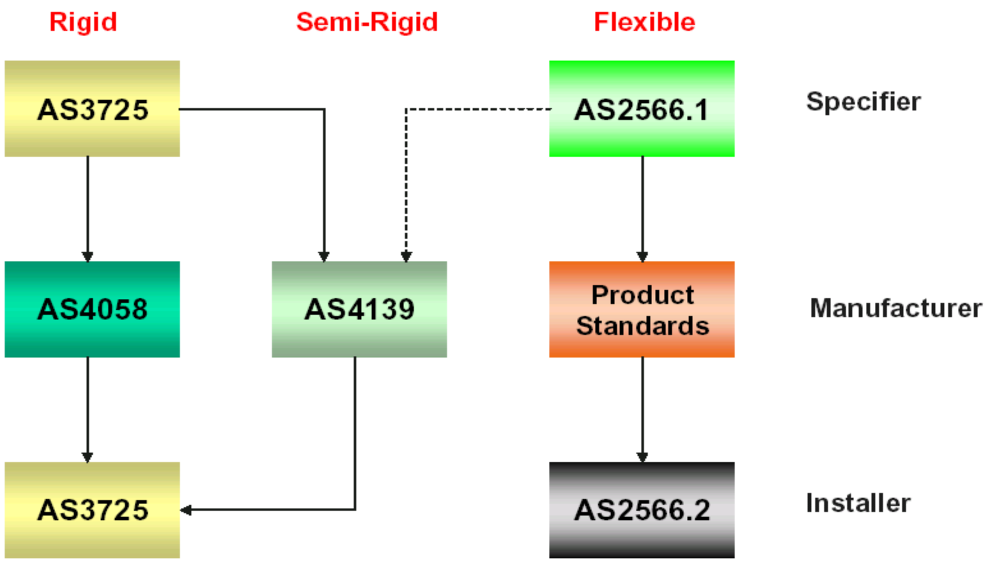


Figure 1. Australian Standards for Pipe Design & Installation

COMPARISON OF PIPE DESIGN CRITERIA

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 Australian. 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. e.g. In AS4058 all materials to be used in the manufacture of concrete pipe are referenced to an appropriate Australian 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 Standards is left open to accommodate the development of new materials.

e.g. In AS4139 no material(s) Standard or other specification for reinforcing fibre(s) is nominated. Furthermore the selection of fibre reinforcement type(s) to be used is left to the manufacturer to control. Similarly, in the applicable product Standards, 'filler' materials as used in FRC pipe and many varieties of flexible pipe are not linked to a controlling specification.

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 4200m

(b) Semi-rigid pipe – FRC

- Size Class 100mm to 1200mm
- Load Class 1 to 4

(c) Flexible pipe – various materials

- Size class > 75mm. Maximum varies with material type and manufacturing capability.
- Load class is not a directly applicable term. i.e. 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.

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 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. AS3725 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.

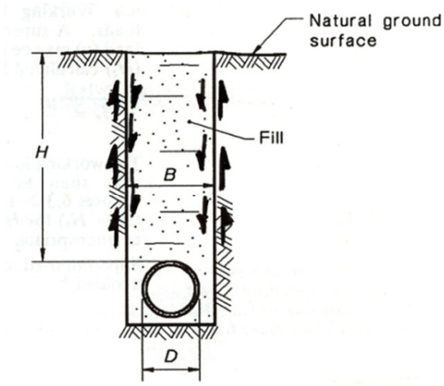


Figure 2. Trench fill load $W_g = C_t w B^2$

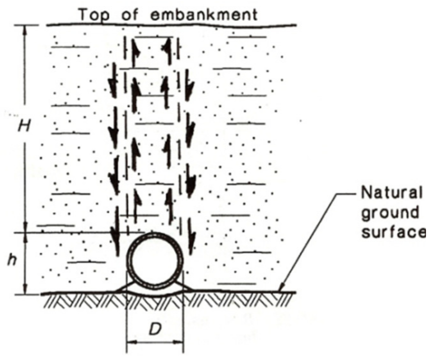


Figure 3. Embankment fill load $W_g = C_e w D H$

- 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.

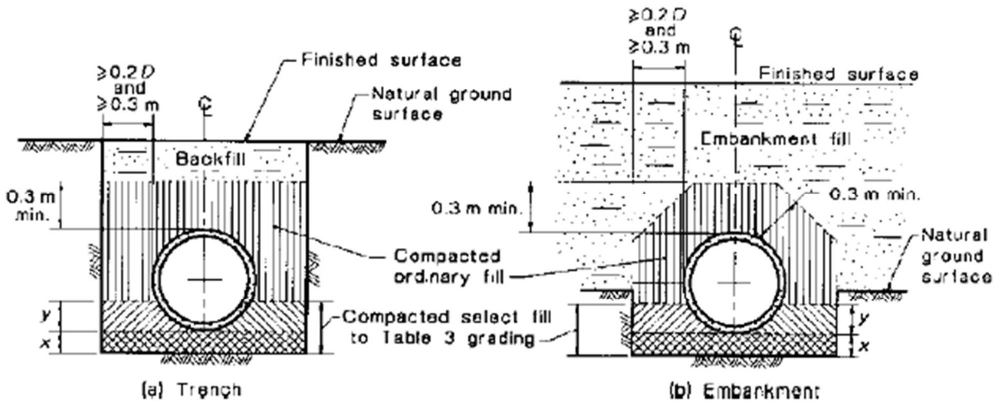


Figure 4. Type H1 and H2 support (REF.AS3725 Figure 15)

TABLE 1. (REF EXCERPT AS3725 TABLE 5)
Bedding Factors for Working Dead Loads

Support type		Minimum depth, mm		Minimum zone compaction,%*			Maximum factor 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 $D \leq 1\,500$; or 150 if $D > 1\,500$	0.1D	50	—	—	1.5
	H2		0.3D	60	—	—	2.0
	H3	0.25D but not less than 100	0.3D	—	—	—	2.5
HS	HS1	100 if $D \leq 1\,500$; or 150 if $D > 1\,500$	0.1D	50	50	85	2.0
	HS2		0.3D	60	60	90	2.5
	HS3		0.3D	70	70	95	4.0

(b) Semi rigid pipe – FRC:

- As with rigid pipe the shape of the embedment determines the effects of the magnitude of dead and live loads on the installed pipe. AS3725 is used to assess the magnitude of the load to be carried, initially, by the installed pipe.
- There is a requirement to assess the short term and long term strength losses in the pipe as it is influenced by
- a dry/wet factor(C), and
- a creep-regression factor (R)
- It is a requirement to assess a proposed installation to determine whether the pipe acts in a 'rigid' or 'semi rigid' manner. Where a pipeline is deemed 'semi-rigid' it must have sufficient deflection capability, initially and long term, to obtain passive soil support to provide an adequate combined structural strength throughout the service life of the structure. The pipe will act in the 'semi-rigid' mode if the flexural stiffness ratio Y > 10

  $Y = E'_y / S_{S2}$ where
  E'_y = the effective combined soil modulus
  S_{S2} = the saturated pipe stiffness at year 2

- The selection of the installation support type, assessment of strength losses and pipe classification has a marked influence on the pipe load class required. Refer Figures 4, 5 and Table 1.

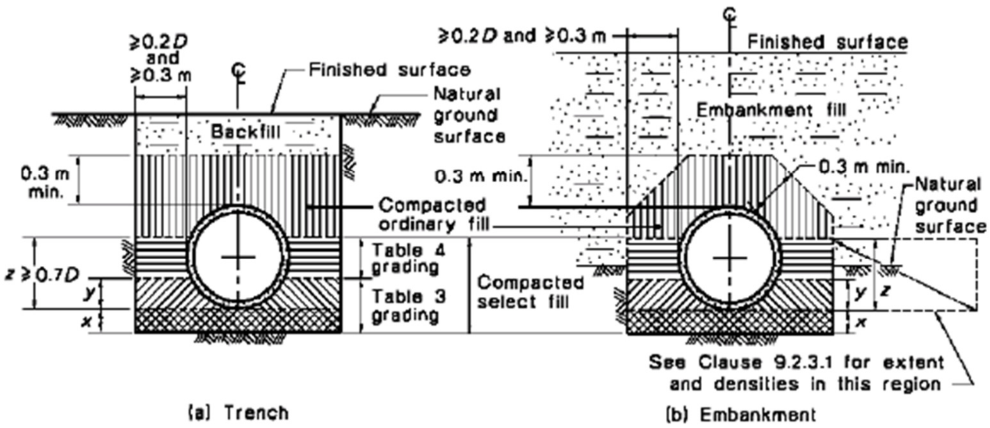


Figure 5. Type HS support (REF.AS3725 Figure 17)

(c) 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 AS2566.1 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 AS2566.1 $w_g = \gamma H$

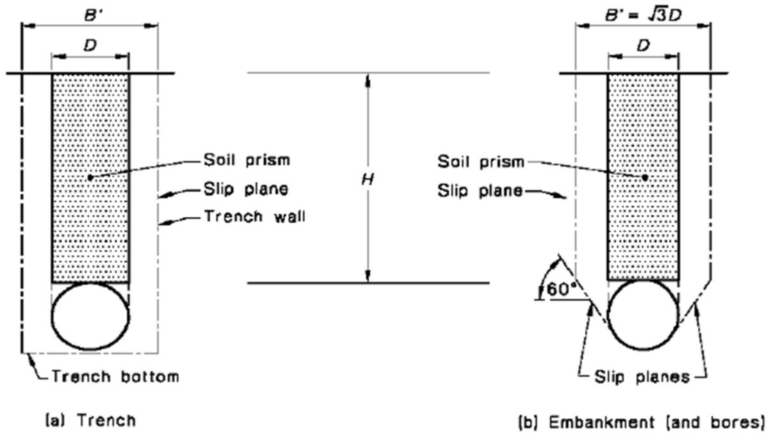


Figure 6. Soil Prism Load - Flexible Pipe (Ref.AS2566.1 Fig.C4.1)

- 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 AS2566.1-Commentary.

Table 2 (Ref. Excerpt from AS3725 Table 3.2)

EMBEDMENT AND NATIVE SOIL—MATERIALS AND MODULI*

Materials			Moduli E'_e and E'_n MPa				
Description	Classification		Uncompacted	R_D (%)			
				85	90	95	100
				I_D (%)			
	AS 1726 †	AS 2758.1		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	Coarse aggregate	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

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 AS4058.
- A key test is the application of a proof load test (Tc) calculated from the installation parameters selected from AS3725. They are:

  - The installation loads (W), and
  - The bedding factor (F), appropriate to the selected bedding type.

T_c is calculated as follows:

$T_c = W_g / F + W_q / 1.5$ where

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

(b) Semi rigid

- Acceptance is based on a demonstrated ability of the pipe and to meet the requirements of a range of performance tests as specified in AS4139.
- A key test is the application of a failure load test P_M to a dry pipe, based on installation parameters from AS3725 and increased in line with the requirements of AS4139 for the time dependent strength losses that occur in FRC pipe. They are:

  - AS3725 - The installation loads (W), and
  - AS3725 - The bedding factor (F), appropriate to the selected bedding type.
  - AS4139 - The dry/wet factor(C) , and
  - AS4139 - The creep-regression factor (R) for the batch.
  - AS4139 – Determination of pipe's semi rigid status (Y). Refer section 3.3(b).

P_M is calculated from the following alternatives:

Where the pipe is in the 'rigid' mode

$$P_M = 1.5\ CRT_c$$

Where the pipe is in the 'semi-rigid' mode

$$P_M = 1.5\ CT_c \text{ or}$$
$$P_M = 2\ T_c \text{ whichever is the greater.}$$

(c) 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 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.

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 approaching 100 years. Where a 100-year in-service life is specified, pipes manufactured in accordance with AS4058 and installed in

accordance with AS3725 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 semi rigid pipe Standard AS4139 and flexible pipe AS2566.1 Standards are 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 these particular pipe materials is also limited because of their comparative recent introduction. Many have a service life history less than the 50-year predicted life.

AMOUNT OF EXCAVATION

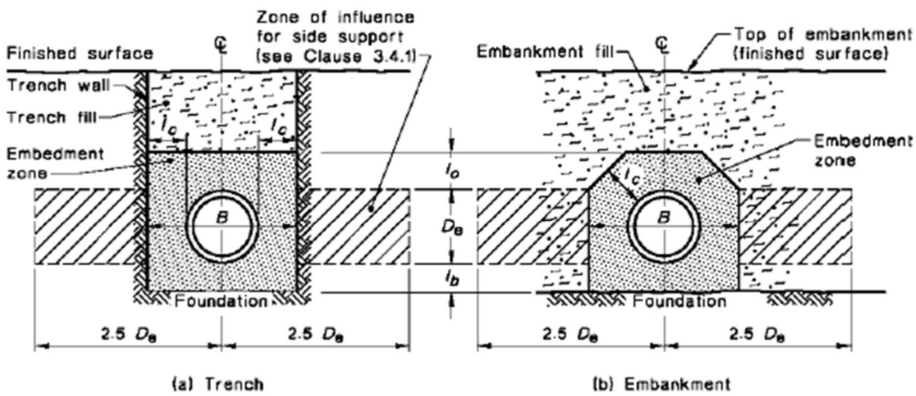
Both Standards contain recommended embedment dimensions that impact on the amount of excavation of the native soil material. Both Standards recommend that caution must be exercised in the selection embedment geometry that will accommodate all equipment necessary to complete the installation. Differences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

(a) Rigid & semi-rigid

- **When drafting AS 3725 the embedment widths were specified with consideration given to** accommodating the, then available, equipment to compact the fill in the haunch and side area of the pipe. Refer to Figures 4 & 5. (AS3725 Figures 15, 16 and 17)

(b) Flexible

- At the time of writing AS2566 trench widths narrower than AS3725 were included. These dimensions were accompanied by the requirement that the compaction percentages specified were met. (AS2566.1 Fig 3.1) This decision was reached on the basis of improvements in compacting equipment and the increased use of readily compacted embedment materials



D_o		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	$0.25D_o$	300

Figure 7. Flexible pipe embedment geometry (Ref. Excerpt AS2566.1 Fig.3.1)

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 (i.e. concrete)
- 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) Semi rigid
- Is usually lighter than rigid pipe and often available in longer lengths.
- Is structurally adequate for short term storage and site handling.

(c) Flexible pipes
- Are usually lighter than other pipe types and often available in longer lengths.

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. AS3725 and AS2566 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 3 in AS3725 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 4 AS3725 is required in the 'side' zones. Ordinary fill is used for the remainder of the embedment around the pipe.
- Table 5 in AS3725 details the dimensional requirements for each embedment zone.

(b) Semi rigid
- The requirements of AS3725 that apply to pipes supplied in accordance with AS4139 vary subject to its 'rigid' or 'semi rigid' status.
- Where a pipe is assessed as in semi-rigid mode (i.e. refer to Sect 3.4 (b)) provision for the effective support of the side zones is essential for the deflecting pipe
- The depth of select fill in the embedment zones including HS support will be dictated by an assessment of the pipes need for side support.

(c) Flexible
- AS2566 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 AS3725 where typically select fill is only required up to the top of the haunch zone. i.e. Refer to 'Embedment Material in Figure 8.
- The designer specifies an appropriate embedment fill material. Refer to Table 2. (Table 3.2. AS2566) 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.

Compaction Of Fill

In section 4.3 the overall depth of select fill required increased as the reliance of the installed pipe on the surrounding embedment increased. 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 number 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 AS2566.1). 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.

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').

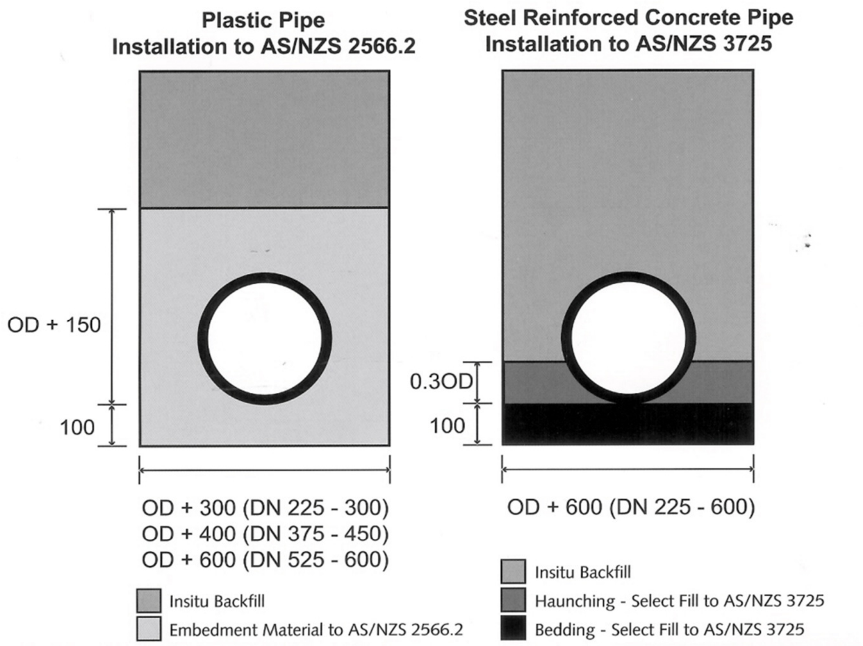


Figure 8. Embedment geometry comparison

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 7 '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	Semi rigid	Flexible	Section 2
	Material	Concrete	FRC	Plastics, Metals	
Australian Standard No.	Specifier	AS3725	AS3725	AS2566.1	
	Manufacturer	AS4058	AS4139	Various	
	Installer	AS3725	AS3725	AS2566.1	
Control raw materials specification in pipe – i.e. referenced to a Standard		All referenced to appropriate Australian Standards	Fibre Reinforcement & fillers not referenced to a Standard	Fillers not referenced to a Standard	3.1
Product Class specified in Standard	Size Class DN.	100 to 4200	100 to 1200	>75mm. Maximums vary with pipe material.	3.2
	Load Class	Class 2 to 10 up to 3000mm Class 2 to 4 up to 4200mm	Class 1 to 4	Not applicable	
Design of installed pipe	Treatment of external working loads	Embedment shape determines the magnitude of the soil load transferred to the pipe	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 the installed pipe acts in a semi rigid mode; ($Y = E'_y / S_{S2}$ >10) or rigid mode; (Y<10). - The pipe strength losses over time when (i) wet. (C) and when (ii) under load (R) - Long term - dependent on soil 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.	The support type selected in combination with - pipe strength losses and - pipe classification (rigid, semi-rigid) has a marked influence on pipe load class required	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	Decreases	

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Product Acceptance	- Performance basis: Demonstrated ability to meet test requirements specified in AS4058. - Pipe is tested to a proof load calculated from AS3725 Tc = Wg / F + Wq /1.5 to demonstrate specified load class has been achieved	- Performance basis: Pipe must meet test requirements in AS4139. - Dry pipe is tested to a failure load PM to demonstrate specified load class has been achieved. for the rigid mode PM = 1.5 CRTc or the semi rigid mode PM = 1.5 CTc or PM = 2 Tc whichever is the greater. i.e. Tc calculated from AS3725 is modified to account for the time dependent strength losses (C & R) and pipe classification (Y).	- Design basis: i.e. 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	3.4
Pipeline Life Expectancy	Pipe assessed as suitable for 100-year in-service life required in normal environments and certain defined marine environments. Service history approaching 100 years	50-year life predicted by AS4139 calculation based on shorter term testing. Service history much less than 50 years.	50-year life predicted by AS2566 calculation based on shorter term testing. Many current flexible materials have service histories less than 50 years.	3.5

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Installation requirements	Amount of excavation - Embedment width	AS3725 widths based on providing access for compaction equipment	AS3725 widths based on providing access for compaction equipment	AS2566 narrow widths accompanied by a requirement that specified compaction must be achievable. (i.e. or width increased)	4.1
	Handling and Storage	- Heavier / metre. -Structurally self-sufficient. - Can support loads experienced in construction.	- Lighter than rigid pipe - Structurally adequate for short term storage and handling.	- Usually lighter than other two pipe types. - Dimensional and structural integrity can be effected if handled & stored inappropriately or in adverse climatic conditions.	4.2
	Selected Fill Material - Depth required	Support type: H - to haunch zone. HS – to side zone.	Support type: H - to haunch zone. HS – to side zone.	Pipe to be fully encased to a specified safe minimum depth above the pipe.	4.3
	Compaction of fill	- Less depth of select fill to be compacted than flexible. - Lower levels of compaction % specified	- Less depth of select fill to be compacted than flexible. - Extent of select fill & level of compaction % specified (e.g. in side zones) dependent on need to provide for semi-rigid mode (Y) of pipe.	- Increased depths of select fill require more passes. - Compaction % usually higher than other two pipe types. (Need for support is essential)	4.4

	Dispersal of unused excavated material	Potentially least quantity of unused material requiring dispersal.	Less than flexible: Depth of select fill needed for support will determine extent of unused material to be dispersed.	Increased depths (use) of select fill generates high quantity of unused material for dispersal	4.5
	Pipeline deflection testing	Not required	Not required	Required to confirm correct placement and compaction of fill.	3.4

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REFERENCES

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

Australian Standards

1. AS3725 –1989 Australian Standard: Load on buried concrete pipes
2. AS4058 –1992 Australian Standard: Precast concrete pipes (pressure and non-pressure)
3. AS4139 –2003 Australian Standard: Fibre-reinforced concrete pipes and fittings
4. AS2566.1: 1998 Australian/New Zealand Standard: Buried flexible pipelines Part 1: Structural Design
5. AS2566.1: Supplement 1: 1998 Buried flexible pipelines Part 1: Structural Design-Commentary
6. AS2566.2: 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. TB5/95. Technical Bulletin: Designing Permanent Pipelines.
8. TB9/96. Technical Bulletin: Life Cycle Cost Analysis in Drainage Projects.
9. TB10/02. Technical Bulletin: Recommended Practice – Installation of Steel-Reinforced Concrete Drainage Pipelines.
10. BO5/95. Discharge Capacity of Pipelines of Different Materials
11. R2/95. Carr McNamara & Muir Report: Flow Characteristics of RC & HDPE Pipe for Stormwater Drainage Applications.
12. R3/97. GH&D Report: Impacts on the Life Cycle Costs of Stormwater Drainage Assets.
13. FS1/05. The Facts about Cellulose Fibre Reinforced Concrete Pipe.
14. FS2/05. Flexible Plastic Pipe Fact Sheet.
15. FS3/05. Plastic v Concrete Pipes – Installation Fact Sheet.