TECHNICAL NOTE

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Flexible Pipes in Roadways

Introduction

Pipelines form an essential part of modern infrastructure and the development of pipeline systems in materials and design has been continuous throughout the evolution of modern man.

The development of flexible pipe systems are comparatively a recent event. The development of 20th century materials and the advancement of the understanding of the structural action of underground pipes has led to increasing use of flexible pipeline systems.

While flexible pipes have been used under road pavements extensively throughout the world and successfully throughout Australia, there has been some reluctance on behalf of designers to use flexible pipes in roadways in Australia.

The publication of AS/NZS 2566.1:1998 Buried Flexible Pipelines Part 1:Structural Design and AS/NZS 2566.1 Supp1:1998 Commentary, have provided a design methodology for underground applications of most typical flexible pipe materials.

This technical note covers the design philosophy of flexible pipes to AS/NZS 2566.1 and compares typical installation applications for flexible and rigid pipes.

History of Application

Worldwide
Flexible pipelines have an extensive history of successful use throughout the developed world, particularly in the United States and Europe where flexible pipes are generally used in preference to rigid pipes.

Australia
The attributes of flexible pipes have long been recognised in Australia with extensive use in both pressure and non-pressure applications over many decades. At the same time rigid pipes have revealed performance limitations particularly with respect to cracking and joint integrity.

For gravity sewerage applications in small and medium diameters, flexible pipes are now the material of choice. This trend is continuing into both larger diameters and gravity drainage with traditional rigid pipe materials being replaced by flexible pipe materials.

In Australia there has been some reluctance to embrace the use of flexible pipes under roadways. The reasons for this approach have been many and varied, but often revolved around the relatively poor performance of early flexible pipe products. This poor record was mostly related to the lack of understanding of the importance of installation parameters by the construction industry.

This situation has changed with designers and installers aware of the advantages and requirements of the flexible pipeline system. Advances in flexible pipe materials coupled with understanding of the performance limitations of rigid pipe system has seen increased use of flexible pipe systems in Australia.

Rigid v Flexible – How loads are carried

Rigid pipes carry load by transferring the load from the top of the pipe through the pipe wall to the pipe bedding. Rigid pipes thus concentrate load from a large area at the top of the pipe to a small area at the base of the pipe. Rigid pipes require high wall thickness to transfer the load to the bedding.

Flexible pipes carry load by transferring the load from the top of the pipe to both the bottom of the trench and into the side support of the trench. The mechanism of this transfer is the vertical deflection of the pipe under load, which results in horizontal deflection of the pipe into the side support of the trench. Flexible pipes dissipate the load from the top of the trench to a larger area through the side walls and base of the trench. Flexible pipes shed load because of the ability to deform without structural damage.

Flexible pipes do not use wall thickness to carry the loads, they use the pipe wall to transfer the load to the surrounding soil. As rigid pipes can not harness the side support in a trench, flexible pipes are a more efficient means of carrying load as they allow the less stiff flexible pipe to carry the same load as a stiffer rigid pipe.

In flexible pipes, the resisting force of the side support increases with deflection. The use of stiff surround material, eg crushed rock allows full support to be developed at less than 1% deflection.

Depending on material and application, vertical deflections up to 7.5% are allowable in flexible pipelines, so the minimal deflections required to harness the reaction of the side support are well within allowable material strain limits.

Pressure-V Non-Pressure

Pressure pipes and non-pressure pipes function in different manners and thus perform differently in buried applications.

The internal pressure or hoop stress carried by pressure pipes acts uniformly on the wall of the pipe and has the effect of wanting to keep the pipe in a circular shape. This action is called re-rounding and in most cases ensures that vertical deflection is minimised.

In some pressure pipe applications the combined loading of pressure, vacuum, deflection and buckling should be analysed.

Non-pressure pipes such as drainage and sewerage do not have any internal pressure, vertical deflection and buckling are the design criteria.

Design Basis

As flexible pipes have been used throughout the world for many decades, the understanding of the structural action of flexible pipes is well established.

Because of the broadness of origin of use and application, numerous methods of flexible pipe design have been developed throughout the world. These methods range from theoretical, empirical to observed results. These methods can use different design assumptions, equations and many other design factors and in some cases can lead to different theoretical results.

AS/NZS 2566.1 uses the prism load method to determine soil loadings which can be defined as the weight of the column of soil acting on the projected area of the pipe.

In trench applications, the prism method provides a relatively conservative means of analysing the performance of the pipe/embedment system as it assumes the total weight of soil and other loadings is transferred to the pipe. It thus ignores the contribution of friction between the trench walls and the trench.

There are numerous other design philosophies used throughout the world, which could be used subject to the requirements of infrastructure owners. AS/NZS 2566.1 has an extensive commentary which documents the design theory and many of the assumptions underlying the method.

Detailed Design

Diametrical deflection is the major design criteria adopted in AS/NZS 2566.1, with the design method based on the Spangler/Watkins formula also known as the Modified Iowa formula.

$$\frac{\Delta_Y}{D} = \frac{K\, x\, 10^{-3}\, (w_g + w_{gs} + w_q)}{8\, x 10^{-6} S_D + 0.061\, E'}$$

Where

$\frac{\Delta_Y}{D}$ = percentage deflection

K = bedding constant assumed to be 0.1

$w_g + w_{gs} + w_q$ are soil dead load, surface applied dead load and surface applied live load respectively, all in kPa.

S_D is pipe ring stiffness, either short or long term depending on design criteria in N/m/m

E' is effective combined soil modulus in MPa

This equation is basically diametrical deflection equals loading forces multiplied by a factor divided by the sum of pipe and embedment stiffness both multiplied by factors.

Ring Bending Stiffness S_D S_{DI} & S_{DL}

Ring bending stiffness S_D S_{DI} and S_{DL} (initial and long term) is a measure of a pipes ability to resist deflection. For homogeneous pipes S_D is easily calculated, for non-homogenous or profile wall pipes, S_D is determined under experimentation by deflecting the pipe using line loading with no side support.

Pipe ring bending stiffness is defined in Section 2 of AS/NZS 2566.1.

Embedment Characteristics

The contribution of the embedment to the resistance of diametrical deflection is defined in section 3 of AS/NZS 2566.1. The standard provides information on the values of the effective soil modulus E' for a wide variety of materials, compaction levels and installation cases. The effective soil modulus combines the modulus of the embedment (E'_e) and the native soil (E'_n) using the Leonhardt correction factor.

One of the misconceptions of flexible pipes is that they require the embedment to be compacted to a much higher standard than rigid pipe, this is particularly erroneous for applications under roadways.

A review of many authority specifications reveals that the embedment compaction and material standards required for rigid pipe would easily provide the support required for a flexible pipe. This is because the governing criteria in roadways for both flexible and rigid pipes is ensuring that the level of compaction of the trench material is satisfactory to prevent subsidence of the trench at pavement level.

Satisfying this subsidence criteria first, a flexible pipe is also provided with its necessary side support.

Spangler's Denominator

It is important to be aware that in all typical installations, the stiffness of a pipe contributes only a small proportion of the overall stiffness of the installation. Spangler's equation from above is reproduced as follows:

$$\frac{\Delta_Y}{D} = \frac{K\ x\ 10^{-3}\ (w_g + w_{gs} + w_q)}{8\ x\ 10^{-6} S_{DL} + 0.061\ E'}$$

The equation is simplified as deflection equals sum of forces (top line) divided by sum of resistance to deflection (bottom line).

The denominator or bottom line of Spangler's equation or installation stiffness is the sum of the pipe stiffness and the embedment' resistance to deflection (called the embedment stiffness for lack of any other definition). In common flexible pipe applications, the ratio of 8 x 10^{-6} multiplied by the ring stiffness is often less than 15% up of the installation stiffness. The major contributor to resisting deflection is therefore embedment stiffness, not pipe stiffness.

The following table shows the proportion of the total installation stiffness that is provided by the pipe for a range of embedment moduli and pipe stiffness.

Table of 8 x 10^{-6} S_{DI} as a percentage of the sum of 0.061E' + 8 x 10^{-6} S_{DI}

E' (MPa)		S_{DI} (N/m/m)						
		2000	4000	6000	8000	10000	15000	20000
	1	21%	34%	44%	51%	57%	66%	72%
	3	8%	15%	21%	26%	30%	40%	47%
	5	5%	9%	14%	17%	21%	28%	34%
	7	4%	7%	10%	13%	16%	22%	27%
	10	3%	5%	7%	9%	12%	16%	21%
	14	2%	4%	5%	7%	9%	12%	16%
	20	1%	3%	4%	5%	6%	9%	12%

The above table demonstrates that except in the most extreme cases which do occur in practice (i.e. a ring stiffness of 20,000 and a embedment modulus of 1) the pipe stiffness times its factors typically contributes only a small proportion to the resistance of the pipe to diametrical deflection.

In small diameters typical pipe stiffness is 4000-8000. In very poor ground with an effective combined soil modulus of 3, the pipe stiffness contributes only 15 and 26% respectively to the resistance of diametrical deflection.

In large diameters pipes of lower stiffness are often used and the importance of the pipe stiffness to resistance to deflection decreases.

In many cases doubling the stiffness of a pipe may add only 10 to 15% of the resistance to deflection. It thus easier and cheaper to achieve the required installation stiffness and thus deflection parameters by ensuring the embedment is provided and compacted to an appropriate design/specification, rather than requiring a stiffer pipe.

While the above information indicates that pipe ring stiffness is not always the most important aspect of an installation, ring stiffness is important in considering transportation, handling, jointing and particularly the ability to compact material around flexible pipes.

Ring Buckling

While diametrical deflection is usually the governing design criteria for non-pressure pipes, designers should be aware that ring buckling can be an important design consideration.

Ring buckling occurs when a section of the pipe wall exhibits reverse curvature arising from differential pressure between the outside and the inside of a pipe. It is mostly a design consideration in pressure pipe applications where transient pressure conditions and high loads are present. It can also occur in non-pressure pipelines and is a design factor that needs to be considered.

AS/NZS 2566.1 provides a design methodology for both pressure and non-pressure applications.

AS/NZS 2566.1 details allowable buckling pressures based on the greater of two computations. q_{all1} is the allowable buckling pressure based on the pipe alone, q_{all2} is the allowable buckling pressure based on the pipe/embedment interaction.

$$q_{all1} = \frac{1}{Fs}\frac{24}{1-\nu^2}S_{DL}10^{-3}$$

$$q_{all2} = \frac{\sqrt[3]{S_{DL}\, x 10^{-6}}\; x\,(E')^{2/3}\; x 10^{3}}{F_s}$$

F_s is the design factor for buckling usually taken as 2.5,

ν is Poisson's ratio at 0.38 for UPVC, S_{DL} and E' are as defined previously

In cases where pipe cover is less than 0.5m, the second equation does not apply.

The actual buckling pressure ignoring the presence of the water table is computed as follows:

$$\gamma(H - H_W) + (\gamma_L + \gamma_{sub})\{\frac{D_e}{2} + H_W\} + w_{gs} + w_q + q_v \le q_{all}$$

Comparison with rigid pipe installation requirements.

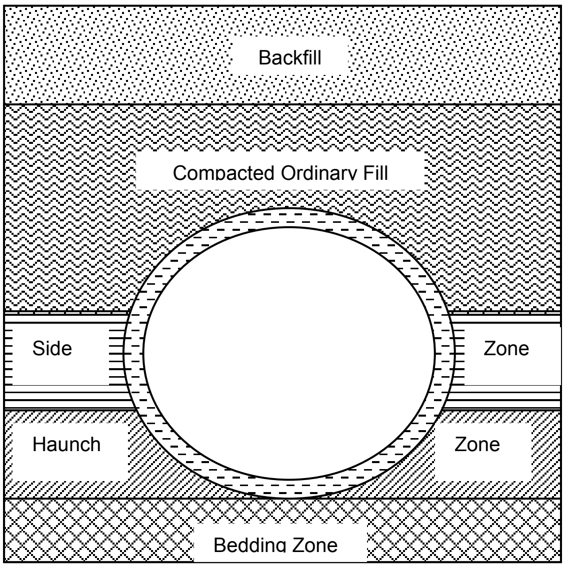
Effective Soil Modulus

AS/NZS 2566.1 uses a derived value called the effective soil modulus which is computed using the native soil modulus and the embedment modulus combined with the Leonhardt correction factor.

This very conservative approach is based on the principle that the zone of influence for side support extends to a distance 2.5 times the pipe diameter past the trench wall into the native soil on each side of the pipe.

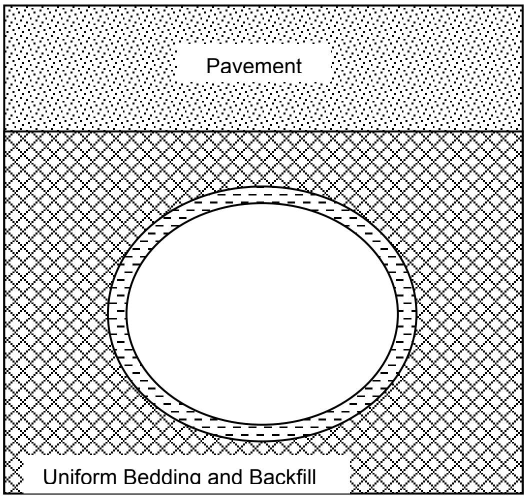
Rather than performing soil tests designers have often assumed the worst possible native soil having a modulus of 1. This practice is clearly inappropriate underneath road pavements as such material could not support a road pavement much less construction equipment to build a road. Examples in this technote have therefore assumed reasonable native soils with E'_n of 5 and 3.

Type HS2 installation is required under AS 3725 – 1989 for installation of concrete pipe under roads. HS2 type installation is as follows:



Type HS2 installation requires Table 3 material (gravel less than 19mm) for the bedding and haunch zone and Table 4 material (gravel less than 75mm) for the side zone.

The trench backfill has to be sufficiently strong to resist the traffic loads and ensure the trench does not subside leaving a rut in the road. In practice construction crews do not segregate the backfill into bed, haunch, side and other zones so the whole trench is backfilled with the same crushed rock material as per the following diagram.



This type of installation is typical of what is required for flexible pipes as per Figure 3.1 of AS/NZS 2566.1

Design Example

Consider a DN 375 Ultrarib SN 8000 pipe with 1m cover from the top of the road pavement.
Pipe External Diameter = 400mm
Trench width = 800mm
Assuming Table 3 from AS 3725 bedding as required and that this material is continued for the full depth of the trench as per usual construction practice. Under the classification of soils this gravel would be described as GW, graded gravel.

For concrete pipe Table 5 of AS 3725 requires compaction to a density index (I_D) of 60%. Compaction to this standard for a flexible pipe yields an E'_e of 7 MPa.

To adequately support construction equipment, a pavement and eventually live traffic loads, the pavement subgrade must have a minimum strength otherwise it would be removed and replaced with suitable material. Two cases are therefore analysed, Case 1 assumes a native soil modulus (E'_n) of 5 MPa, Case 2 assumes a native soil modulus of 3 MPa.

E' - Effective soil Modulus

The design factor Δ_f and Leonardt correction factor ζ are defined and the means for their calculation are detailed in Section 3 Embedment Characteristics in AS/NZS 2566.1

Case 1 (E'_n = 5 MPa)
$\Delta_f = 0.6247$
$\zeta = 0.8153$
E' = 0.8.53 * 7 = 5.707, say 5.7 MPa

Case 2 (E'_n = 3 MPa)
$\Delta_f = 0.6247$
$\zeta = 0.5698$
E' = 0.5698 * 7 = 3.989, say 4.0 MPa

Spanglers Denominator

Case 1 E'_n = 5 MPa, E' = 5.7 MPa

$8 \times 10^{-6}\, S_D + 0.061\, E' =$
$8 \times 10^{-6} \times 8000 + 0.061 \times 5.7$
$64.0 \times 10^{-3} + 347.7 \times 10^{-3} = 411.7 \times 10^{-3}$
of which the pipe stiffness contributes 15.6%.

Case 2 E'_n = 3 MPa, E' = 4.0 MPa

$8 \times 10^{-6}\, S_{DI} + 0.061\, E' =$
$8 \times 10^{-6} \times 8000 + 0.061 \times 4.0$
$64.0 \times 10^{-3} + 244.0 \times 10^{-3} = 308.0 \times 10^{-3}$
of which the pipe stiffness contributes 20.8%.

Pipe Loads

Trench Load

$W_g = 20 KN/m^3 \times 1.0 m$ depth = 20 kPa
Top line of Spangler's equation = $0.1 \times 10^{-3} \times 20$kPa = 2.0×10^{-3}

Combined Trench & Live Load

The worst case load from Austroads Bridge design Code for 1m depth is 34 kPa as per Fig 4.1 AS/NZS 2566.1

Top line of Spangler's equation
= $0.1 \times 10^{-3} \times (20 + 34$ kPa$) = 5.4 \times 10^{-3}$

Diametrical Deflection

Combining top and bottom line of spanglers equation deflection =

Case 1: (E'_n = 5 MPa, E’ = 5.7 MPa)
Trench Load Only
2.0 x 10^{-3} / 411.7 x 10^{-3} = 0.005 or 0.5%
Predicted deflection = 2.0 mm
Trench & Live Load
5.4 x 10^{-3} / 411.7 x 10^{-3} = 0.013 or 1.3%
Predicted deflection = 5.2 mm

Case 2: (E'_n = 3 MPa, E’ = 4.0 MPa)
Trench Load Only
2.0 x 10^{-3} / 308.0 x 10^{-3} = 0.006 or 0.6%
Predicted deflection = 2.4 mm
Trench & Live Load
5.4 x 10^{-3} / 308.0 x 10^{-3} = 0.018 or 1.8%
Predicted deflection = 7.2mm

The deflection from both these examples is significantly lower than the 7.5% allowable for PVC materials in AS/NZS 2566.1

Ring Buckling

As detailed earlier the allowable buckling pressure is the greater of q_{all1} and q_{all2} as per the following equations:

$$q_{all1} = \frac{1}{Fs}\frac{24}{1-v^2}S_{DL}10^{-3}$$

$$q_{all2} = \frac{\sqrt[3]{S_{DL}\,x10^{-6}}\;x\,(E')^{2/3}\,x\,10^{3}}{F_s}$$

S_{DL} for Ultrarib is 3500 N/m/m

q_{all1} = (1/2.5)(24/(1-0.38^2)) x 3500 x 10^{-3}
= 39.3 kPa
Case 1 E'_n = 5 MPa, E’ = 5.7 MPa
q_{all2} = ((3500 x 10^{-6})$^{1/3}$ (5.7)$^{2/3}$ x 10^3)/ 2.5
((0.152) x (3.19) x 1000) / 2.5 = 194.0 kPa

Case 2 E'_n = 3 MPa, E’ = 4.0 MPa
q_{all2} = ((3500 x 10^{-6})$^{1/3}$ (4.0)$^{2/3}$ x 10^3)/ 2.5
((0.152) x (2.52) x 1000) / 2.5 = 153.2 kPa

As $q_{all2} > q_{all1}$ in both cases q_{all2} is the governing buckling pressure.

Computing the allowable buckling pressure as follows:

$$\gamma(H-H_W)+(\gamma_L+\gamma_{sub})\{\frac{D_e}{2}+H_W\}+w_{gs}+w_q+q_v \le q_{all}$$

q_{all} = 20 (1-0) + (10 +12.45)x(0.4/2 + 0) + 0 + 34 + 0
= 20 + 4.49 + 34 = 58.5 kPa

58.5 kPa is less than the allowable buckling pressures of both 194.0 and 153.2 kPa in Case 1 and Case 2 so it is satisfactory in both cases.

Vertical Deflection Under Pavements

A common misconception in the operation of flexible pipes is that the vertical deflection under fluctuating load conditions (such as vehicle traffic) is of a large magnitude. The argument purports that continual deflection can lead to significant moving of fines within the trench embedment which will lead to trench subsidence and eventual failure.

While AS/NZS 2566.1 allows diametrical deflections of flexible pipes up to 7.5%, in practice small deflections are the norm.

Considering the extremes of both the native soil modulus and loading cases in the previous example, a theoretical difference in deflection of only 3.2mm (5.2 - 2.0) in case 1 and to 4.8mm (7.2 – 2.4) in case 2 is computed.

When the conservative nature of the prism method in ignoring the soil friction on the trench wall is considered, the actual deflection will be significantly less.

The pipe is confined to its location by trench walls and the embedment. As the pipe and embedment operate together, a large amount of embedment has to move to enable the pipe to deflect. Inter-particle friction prevents continuous deflection and in practice deflection is minimal.

Joint & Structural Integrity

One of the major limitations of rigid pipes is that of joint performance through joint fracture or root intrusion. Minimisation of infiltration and exfiltration is a major factor in maintaining the integrity of the pipeline system.

Rigid pipes were initially made flush jointed, but consequent joint problems have forced the industry to develop a rubber ring joint. This rubber ring joint is considerably larger than the barrel of the pipe and the subsequent differential loading has contributed to the premature failure of many joints.

More recently other limitations on concrete pipe systems have come to light, particularly cracking of pipes in the field due to the use of vibratory compactors during construction. As rigid pipes transfer load from the top of the pipe through the pipe wall to the bedding, they crack once loaded past design limits.

Flexible pipes have a secure rubber ring joint, which in most instances is the same joint used for pressure pipelines. The close fitting nature of rubber ring joints used in most flexible pipes ensure that the differential settlement problems are removed.

Conclusion

Flexible pipe systems are used for pressure and non-pressure applications in the telecommunications, energy, water, gas, sewerage and drainage industries throughout the world.

Flexible pipes have the ability to deform without structural damage and provide designers and users a wide range of advantages which are now being recognised by the infrastructure community.

The structural action and design methodology of flexible pipes is well understood. Their use in all buried applications and particularly in roadways is well established throughout the world and now in Australia.

As flexible pipes transfer load through deflection, loading outside design parameters leads mostly to deformation without structural damage. Flexible pipes thus provide a substantial insurance for operational conditions outside design parameters.

For further information about our products and applications, see our web site at

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