IS THAT LINER THICK ENOUGH?

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ABSTRACT

The amount of pipeline rehabilitation being undertaken in New Zealand is increasing each year. Larger diameter and deeper pipes are being rehabilitated, which require more specific design attention.

This paper compares different approaches to the design of liners for the rehabilitation of gravity pipes. The paper explores the impact that the various design input parameters have on the required strength of the liner and consequently the required thickness of the liner.

This paper:

- Explains the partially deteriorated and fully deteriorated design cases,
- Compares the different design methods specified in codes such as AS/NZS 2566.1 1998, ASTM F-1216-09, ASTM F1741-08 & ASTM F1947-10,
- Shows the impact that design input parameters have on the required thickness of the liner, and
- Provides recommendations as to how these factors should be estimated.

KEYWORDS

Pipe Rehabilitation, CIPP, Spiral Wound Liners, Fold PVC Liners

1 INTRODUCTION

Most specifications for pipe rehabilitation are performance based, with the contractor being responsible for the design of the liner. However, to design the liner there are a number of issues that need to be addressed, such as the loading cases that the liner must withstand, what standard should the liner be designed to and what input factors should be used in the design. Some of these input factors, like pipe diameter and depth, can be measured on site. Others are related to the properties of the liner, but a lot need to be estimated. The selection of these estimated factors can significantly affect the design thickness of the liner.

The price of the liner and the risk of problems occurring during installation can be increased considerably if conservative input factors are used. If the input factors selected are not conservative enough, then there is the possibility that the liner may collapse.

2 GENERAL OVERVIEW OF DESIGN STANDARDS & APPROACHES

2.1 DESIGN STANDARDS

Current practice in New Zealand is to design liners that are installed in circular gravity non-man-entry pipes in accordance with ASTM codes such as ASTM F-1216-09, in the case of Cured-In-Place (CIPP) liners and ASTM F1741-08 & ASTM F1947-10 for spiral wound liners and folded PVC liners. Alternatively AS/NZS 2566.1- 1998 is used. However this standard relates to the design of buried flexible pipelines and is required to be modified to address issues specific to lining of pipes.

The Water Research Centre (WRc) Sewerage Rehabilitation Manual is sometimes used for the design of liners installed in brick sewers or non-circular pipes. This standard is not addressed in this paper.

It is generally acknowledged that the current design approaches have a number of shortcomings. Whilst better models and design equations are available, the American Society of Civil Engineers note that work is required to validate these to insure that these potentially new industry standards don't suffer from their own limitations and shortcomings (American Society of Civil Engineers, June 2007). This paper does not seek to comment on shortcomings in the design standards currently used, other than to note where the approaches are conservative. However, the paper shows how different factors influence the selection of the liner thickness and compares the different design methods specified in the ASTM and AS/NZ codes.

2.2 DESIGN APPROACHES

The ASTM codes define two design cases, based on the condition of the existing host pipe:

- Partially deteriorated pipe condition, which is sometimes referred to in Australasia as the intact design case. It is assumed that the original pipe can support the soil and surcharge loads applied throughout the design life of the rehabilitated pipe. The existing host pipe may have leaking joints or other joint faults or contain cracking. Rigid pipes with deformation (CCTV codes, DF(M or L) or extensive pipe breaks that the liner will need to span (CCTV codes, PB(M or L) would not normally be considered to be partially deteriorated.

- Fully Deteriorated. It is assumed that the original pipe is not structurally sound and cannot support soil and live loads. This condition is evident when there are extensive longitudinal cracks, sections of the original pipe are missing or the pipe has lost its original shape.

In the partially deteriorated case the liner is designed to support hydraulic loads from groundwater. It is assumed that the existing host pipe will continue to support soil and surcharge loads.

In the fully deteriorated case the liner is designed to support all the loads that are expected to be applied throughout the life of the liner. It is assumed that the host pipe will not provide any support. This approach is conservative, as by definition, a host pipe that is truly fully deteriorated would have collapsed and not be suitable for lining. In reality all existing pipes being lined are capable of supporting the loads being applied and provide a factor of safety against collapse of at least 1.

3 PARTIALLY DETERIORATED DESIGN CASE

Equation X1.1 from ASTM F-1216-09 is used to determine the required thickness of the liner in the partially deteriorated design case. The equation is reproduced below. A similar equation is specified in ASTM F1741-08 & ASTM F1947-10 for spiral wound liners and folded PVC liners. AS/NZS 2566.1 1998 does not cover this design case. However, design specifications based on AS/NZS 2566.1 1998 would normally specify that the ASTM equation be used

$$P = \frac{2KE_L}{(1-\nu^2)} \cdot \frac{1}{(DR-1)^3} \cdot \frac{C}{N} \qquad \text{(X1.1)}$$

The formula is based on the theoretical buckling pressure of a long, perfectly circular, unrestrained pipe. An enhancement factor (K) is introduced to account for the restraint against buckling provided by the existing host pipe. 7 is used when the liner is in intimate contact with the host pipe, e.g. for CIPP liners or spiral wound liners where the annulus between the liner and the host pipe is filled with grout. Where there may be a gap between the liner and the host pipe, 4 is used, e.g. for ungrouted spiral wound liners. These factors have been derived from experiments where CIPP liners were inserted in steel casings and subjected to external pressure (Aggarwal, 1984). The enhancement factors that are adopted represent the lower bound of the experimental data and as such are conservative.

The following variables, in addition to the diameter of the host pipe, should be defined in the contract specification:

P = groundwater load, MPa, measured from the invert of the pipe. Typically it is assumed that the water table will be at the ground surface. This may be too conservative in some cases, e.g. where there is a steep slope.

K = enhancement factor of the soil and existing pipe adjacent to the new pipe. Typically 4 or 7 depending on the lining method being used.

C = the ovality reduction factor, which is a measure of the out of roundness of the existing host pipe. It should be estimated from CCTV inspection or measured from laser profiling and then calculated using the equation defined in Cl X1.2.1 of ASTM F-1216-09. Due to the difficulty in measuring ovality from a CCTV inspection, a minimum ovality of either 2% or 5% is typically assumed.

N = Factor of Safety, typically specified as a minimum of 2.

The following variables should be determined by the lining contractor as they relate to the properties of the liner.

EL = long-term (time corrected) modulus of elasticity for the liner (see Section 6.1 for more discussion).

μ = Poisson's ratio, typically 0.3.

DR = dimension ratio of liner.

Figure 1 shows the influence of ovality on the required thickness of the liner. In this particular example[1], if the existing host pipe was completely circular, with no ovality, the liner could be installed to a depth below the watertable of more than 10m. However, if the existing host pipe has an ovality of 10% then the liner would only be suitable for installation to a depth of 5m.

[1] All graphs in this paper, unless indicated otherwise, are based on a DN300, 7.5mm thick liner with 0% ovality and a long term modulus of elasticity of 1017MPa. A soil modulus of 2MPa is assumed.

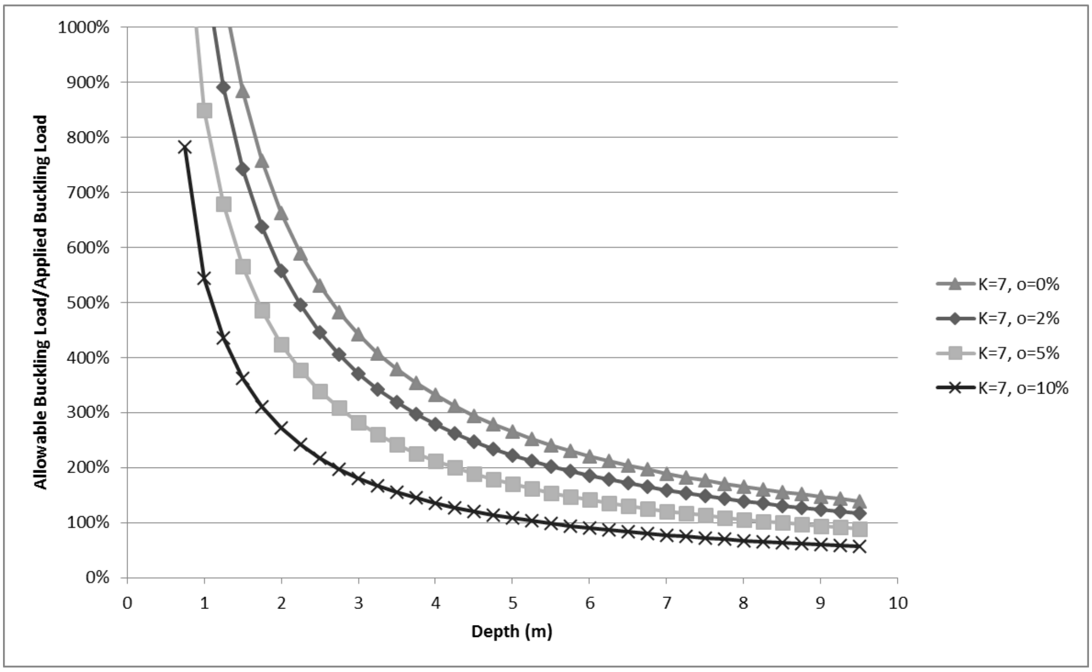

Figure 1 - Comparison of Intact Design - Ovality Factors

Figure 2 shows the effect of the enhancement factor. If the liner in this particular example had an enhancement factor of 7, i.e. CIPP liner or a grouted spiral wound liner, it would be suitable for installation to more than 10m below the watertable. However, if the enhancement factor was only 4, i.e. an ungrouted spiral wound liner or a folded PVC liner, the liner would only be suitable for installation to a depth of 7.5m. This highlights the importance of ensuring that grouting is correctly undertaken when using grouted spiral wound liners.

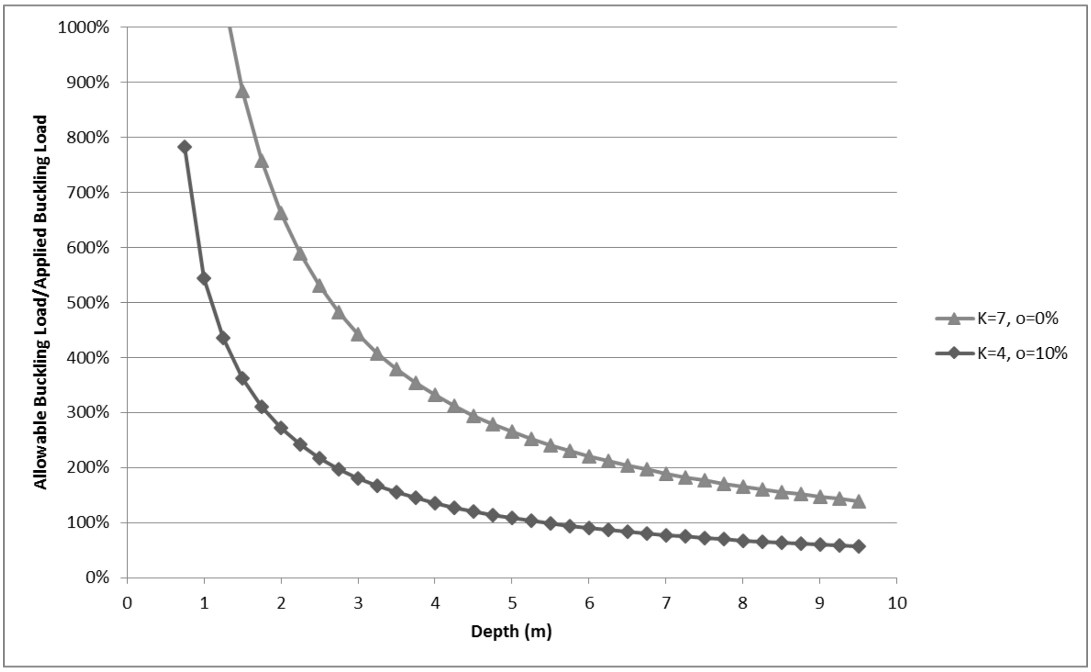

Figure 2 - Comparison of Intact Design Enhancement Factors

4 FULLY DETERIORATED DESIGN

The ASTM codes and AS/NZS 2566.1 differ in how they calculate the loads applied to the liner and how the required strength of the liner is calculated. The ASTM codes use similar approaches but differ in how they treat the ovality of the liner. These differences are discussed in the following sections.

The following variables should be defined in the contract specification:

- Diameter of host pipe
- Soil depth
- Groundwater depth
- Live/traffic loads
- Ovality reduction factor
- Soil modulus
- Factor of Safety

The following variables should be determined by the lining contractor as they relate to the properties of the liner.

- Long-term (time corrected) modulus of elasticity for the liner
- Poisson’s ratio of the liner
- Thickness of the liner

4.1 COMPARISON BETWEEN ASTM F1216-09 AND AS/NZS 2566.1- 1998

4.1.1 DESIGN LOADS

Both standards assume that the full prism of the earth column above the liner will act on the liner as a vertical load. The loadings derived from the two standards are generally the same, as can be seen by comparing Figures 3 & 4.

The other point to note from Figures 3 & 4, is how the effect of the traffic load decreases with depth. However, at shallow depths the traffic load may govern and a thicker liner may be required to be installed. Even at 1.5m the traffic load may be significant, highlighting the importance of specifying a traffic load that is appropriate to the specific circumstances where the liner is being installed.

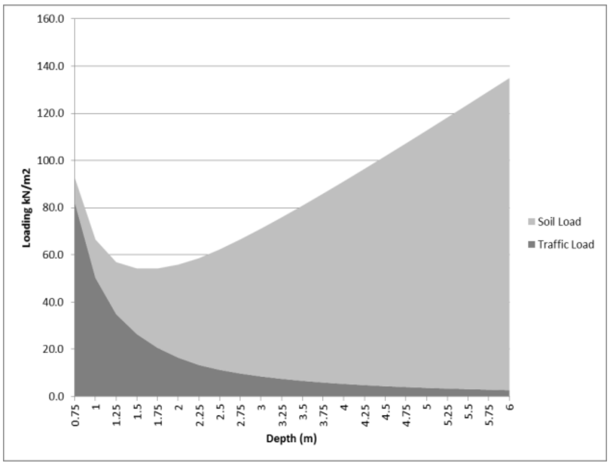

Figure 3 – Loadings applied to Liner – ASTM 1216

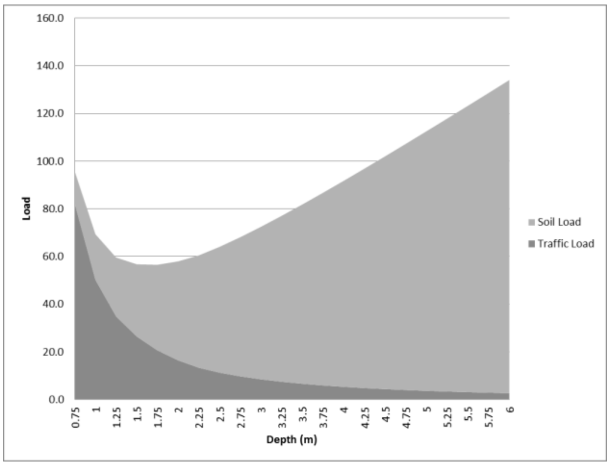

Figure 4 - Loadings applied to Liner – AS/NZS 2566.1

4.1.2 SILO EFFECT

The commentary for AS/NZS 2566.1 – 1998 notes that a silo effect correction can be applied for pipes that are deeper than 10 times the pipe diameter. When this factor is applied the loading is lowered significantly, as shown in Figure 5. The ASTM codes do not contain a silo effect correction factor, however some commentators have noted that it may be applicable to do so, but they note that it may not be valid in certain soils, such as cohesionless soils (American Society of Civil Engineers, June 2007).

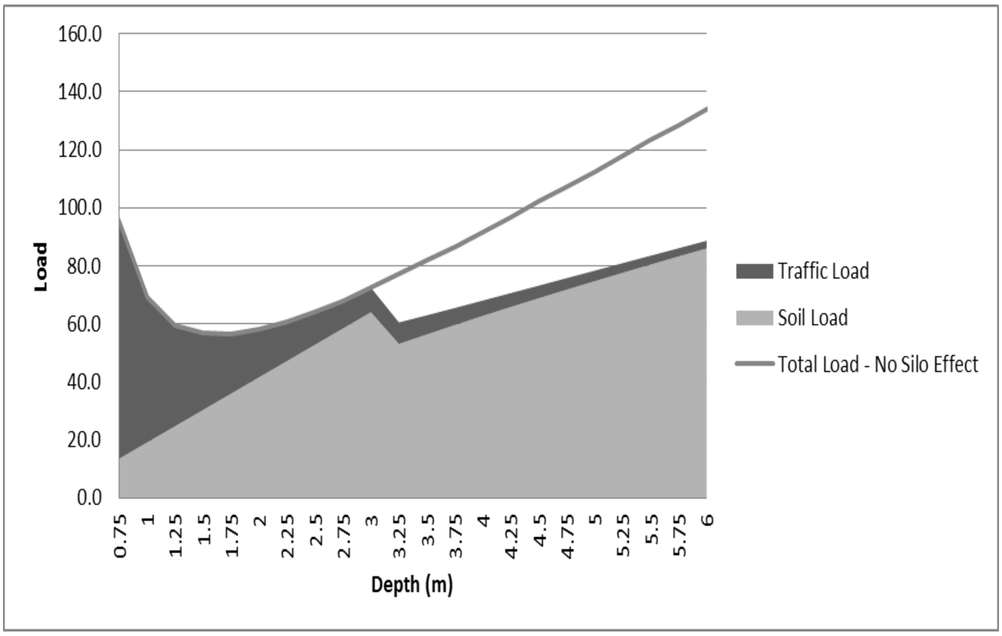

Figure 5 - Loadings applied to Liner with Silo Effect – AS/NZS 2566.1 1998

4.1.3 COMPARISON OF BUCKLING CAPABILITY

Figure 6 compares the allowable buckling capacity of a liner calculated using the ASTM & AS/NZS standards (values greater than 100% indicate that the liner satisfies the minimum design requirements). These calculations have been prepared based on the assumption that the pipe is perfectly circular and has no ovality.

The graphs indicate that, if the silo effect is ignored, then designs prepared using either of the two standards will result in liners of similar thickness. However, there is considerable difference in the design thickness of deeper liners if the silo effect is considered. In the case of the liner for this comparison, the liner could be installed to depths of more than 6m if the silo effect is considered, but only to about 4.5m if it is ignored.

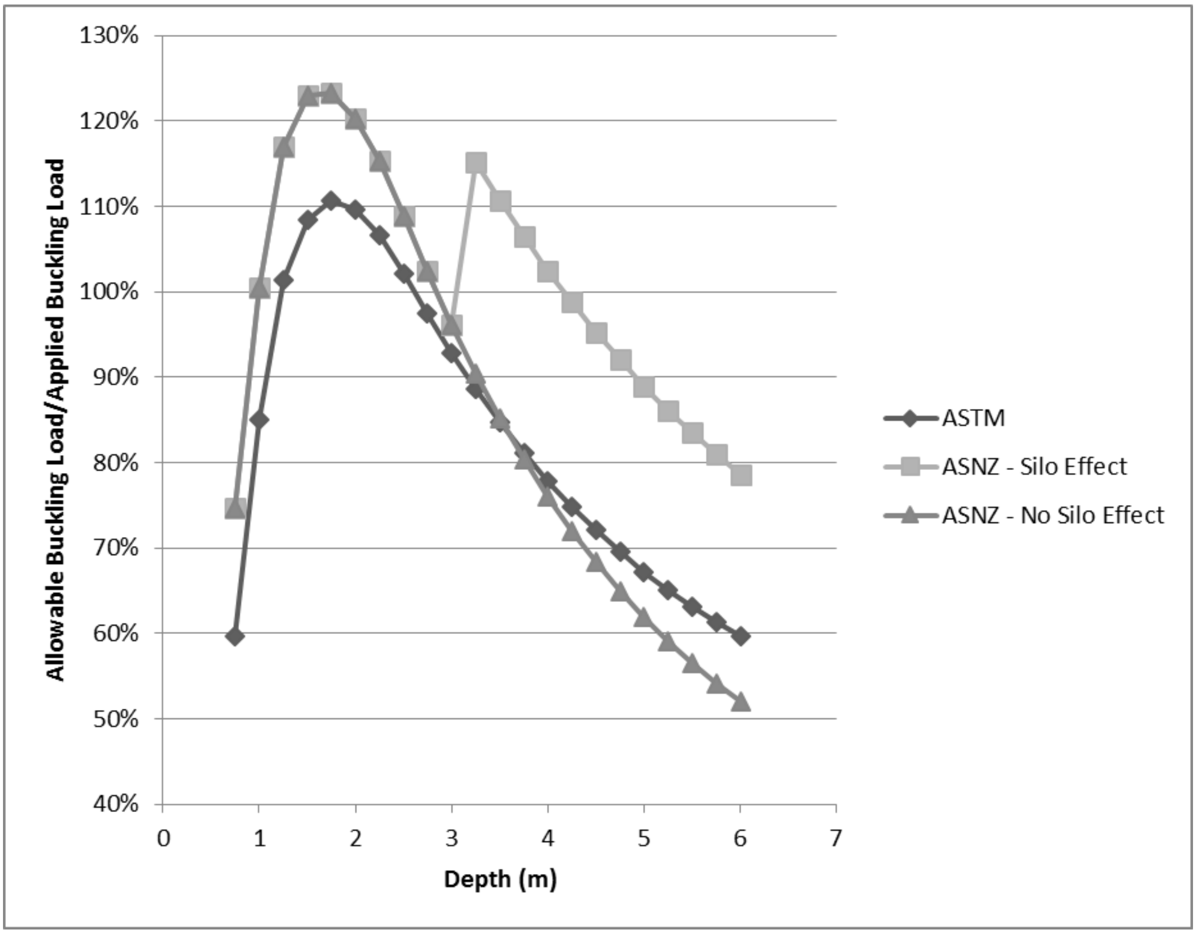

Figure 6 – Comparison of Buckling Capability

4.2 OVALITY

Installed liners will tend to follow the shape of the host pipe. If the host pipe is out of round the liner will also tend to be out of round.

The design methods in the ASTM standards include corrections for ovality when designing for the fully deteriorated condition. However, AS/NZS 2566.1- 1998 does not, as this standard is generally applicable to the installation of new pipes. It is therefore recommended that if AS/NZ 2566.1 is used, a correction for ovality should also be applied, in a similar manner to ASTM F1216-09.

Whilst the ASTM standards include corrections for ovality in the host pipe the way that ovality is treated is different. The formula for calculating allowable buckling loads was amended in the latest version of ASTM F1216-09, but not in the other two standards F1741-08 & F1947-10. This change has resulted in F1216-09 being less conservative than the other two standards, as is demonstrated in Table 1.

It is understood that proposals to change the formula in the next revisions of F1741 & F1947 are being considered. This would seem sensible and some specifiers are already adopting the amended formula in F1216-09 for the design of spiral wound liners and folded PVC liners.

Table 1 – Influence of Ovality on Capacity of Liner Against Buckling

Ovality	ASTM F1216-09	ASTM F1741-08 & F1947-10
0	100%	100%
2%	92%	84%
5%	80%	64%
10%	64%	41%

Another way to consider the impact of ovality is to assume a degree of ovality and then ask what would be the increase in factor safety if the host pipe was perfectly circular, as is the case with most pipes. The affect is shown in Table 2. If an ovality of 5% is assumed, but in fact the pipe is perfectly circular then the factor of safety would be increased from 2 to 2.5. This highlights how taking a conservative approach to the selection of design input parameters can add to the conservativeness of the liner design. Care needs to be taken to ensure that this conservativeness is not compounded resulting in excessively thick liners.

Table 2 - Influence of Ovality on Factor of Safety of Liner Against Buckling

Ovality	ASTM F1216-09	ASTM F1741-08 & F1947-10
0	2	2
2%	2.2	2.4
5%	2.5	3.1
10%	3.1	4.9

5 SOIL MODULUS

Soil modulus is a measure of how much support the surrounding soil will provide to the liner. The lower the soil modulus the stronger, and thicker, the liner needs to be.

The ASTM standards do not provide guidance on what soil moduli should be used. However, AS/NZ 2566.1 provides a table of commonly used soil moduli for various embedment and native soils. Soil moduli vary between 1 to 10MPa based on soil type and standard penetration test results.

The standard approach in New Zealand and Australia is to use a soil modulus of 2MPa for liner design, on the basis that if the pipe is in fact fully deteriorated and cannot sustain the soil and other loads applied, this deterioration has probably occurred because of poor backfilling. Therefore a low soil modulus is assumed.

In reality very few pipes have deteriorated to the fully deteriorated state, even though liners are often designed for this condition. So using a soil modulus of 2MPa is generally conservative.

In North America and Europe higher soil moduli, in excess of 5 MPa, tend to be used.

Table 3 shows the effect of soil modulus on liner stiffness, e.g. if the soil modulus is 1MPa then the liner needs to be 40% stiffer than if the soil modulus was 2MPa.

Table 3 - Influence of Soil Modulus on Capacity of Liner Against Buckling

Soil Modulus (MPa)	Effect on Liner Stiffness
1	71%
2	100%
4	141%
5	158%
6	173%

6 PARAMETERS DETERMINED BY LINING CONTRACTOR

6.1 LONG TERM MODULUS OF ELASTICITY

The modulus of elasticity of the liner, which is one of the factors that contributes to its stiffness, will decrease over time as load is applied and the liner creeps. The more flexible the resin the greater the tendency to creep.

The lining contractor should provide long-term test results to justify the modulus of elasticity used in the design. Typically the long-term modulus of elasticity for standard polyester resin CIPP liners would be expected to be approximately 50% of the short-term value. Spiral wound liners and folded PVC liners also have similar ratios between the short-term & long-term properties. However, the creep factor for epoxy CIPP liners is quite variable. The long-term value can range from between 0.25 & 0.6 of the short-term value depending on the curing agent used (Lanzo Lining Services Inc).

AS/NZS 2566 Cl 5.1.2 states that the two-year values for the modulus of elasticity may be used as being representative of the fifty-year value.

The use of the 2-year value rather than the 50 year value does not significantly affect the design, as most of the reduction in the modulus occurs early in the liner's design. For example if the 50-year modulus is 50% of the initial modulus, then the 2-year modulus will be 57.75% of the initial (based on AS/NZS 2566 equation 2.2.3).

The ASTM standards do not specifically state which modulus should be used. However, they state that "the choice of value will depend on the estimated duration of the application of the load in relation to the design life of the structure. For example, if the total duration of the load is estimated to be 50 years, either continuously applied, or the sum of intermittent periods of loading, the appropriately conservative choice of value for modulus of elasticity will be that given for 50 years of continuous loading at the maximum ground or fluid temperature expected to be reached over the life of the structure."

This statement on the need to sum the intermittent periods of loading, supports the AS/NZS 2566 approach. In reality the full loadings allowed in the design, i.e. full watertable depth and traffic loading, will only be applied to the liner for intermittent periods and sum of these periods is very unlikely to be anywhere near two years over the 50 year life of the liner.

7 HOW SHOULD THE SPECIFIER DETERMINE THE DESIGN PARAMETERS TO BE USED?

In preparing a performance based specification for a pipe rehabilitation project, where the rehabilitation contractor is responsible for designing the liner, the specifier should first define:

- values for parameters that can be measured or observed on site. These would typically include values for:
    - Diameter of host pipe
    - Soil depth
    - Live/traffic loads
- the design standards to be used, e.g:
    - whether either, or both, the ASTM codes or AS/NZS 2566.1 can be used for design,
    - how ovality is to be considered in determining allowable buckling loads
    - the required Factor of Safety
- what test results or other information is required to be submitted by the rehabilitation contractor to justify the long-term properties of the installed liner.

The specifier should then determine the condition of the existing host pipe and establish whether it is capable of continuing to support the loads applied. That is, determine whether the liner should be designed for the partially deteriorated or fully deteriorated design cases. In practice most pipes being lined are capable of supporting the loads likely to be applied through the design life of the liner. Whilst the partially deteriorated case may be appropriate in these cases, most specifiers in New Zealand tend to specify the fully deteriorated case to provide a conservative design that allows for deterioration of the existing host pipe. Whilst this may be appropriate, care needs to be taken to ensure that conservative design input factors are not also specified, which compound the conservativeness, increasing the cost of the liner and increasing the risk of problems occurring during installation.

To determine the design input parameters that cannot easily be measured on site, such groundwater depth, ovality (which is difficult to measure from CCTV) and soil modulus, the specifier should first estimate the likely values of these parameters. They should then test the validity of these assumed values by asking themselves what would be the factor of safety if the actual situations were worse than assumed.

For example the specifier may estimate, based on the observed condition of the host pipe and existing knowledge of geotechnical conditions, that the groundwater level might typically be 2m below the ground surface, that the pipe is perfectly circular and a soil modulus of 5MPa is appropriate. They might then test the validity of these parameters by reviewing a worst case of the groundwater being at the surface, the pipe having an ovality of 5% and a soil modulus of 2MPa. They would then check that the liner designed based on the likely parameters would still have a factor of safety well above 1 if the worst case scenario occurred. If necessary they would refine the likely design parameters to ensure that this was the case.

Through this approach the rehabilitation contractor is still responsible for the design of the liner and is free to select a rehabilitation method and thickness of liner that suits their preferred installation methodology, but the design approach and input parameters are specified to an extent that provides confidence that the liner design will be fit for purpose.

8 FUTURE CONSIDERATIONS FOR DESIGN OF LINERS

As new rehabilitation techniques are developed and our understanding of design considerations develop, there may be a number of changes required to how the design of liners is approached. Some of these may include:

- Design of UV cured CIPP liners. These liners are typically much thinner than traditional CIPP liners and can be heavily reinforced with glass fibre. Imperfections in the host pipe and wrinkling in the liner can have far more impact on the strength of the liner than for traditional CIPP liners. Maximum strain criteria also need to be considered to ensure that the reinforcement is not compromised. These issues are not covered under ASTM F1216-09.

- The standards typically used in New Zealand for design of liners assume that the host pipe either fully supports the soil and traffic loads applied or provides no support at all. In reality there is an interaction between the host pipe and the liner, which influences the loads applied to the liner. It is possible that new design approaches will be adopted as this interaction between the liner and host pipe is understood better.

- Research currently underway into the behaviour of liners during earthquake conditions may result in changes to design approaches for liners installed in areas that are susceptible to earthquakes.

9 CONCLUSIONS

Whilst most specifications for pipe rehabilitation are performance based, with the contractor being responsible for the design of the liner, it is essential that appropriate design input parameters are specified to ensure that the designed liner is fit for purpose.

This paper has compared various design standards and has shown the impact of various design input parameters from which the following conclusions can be drawn:

- Design codes ASTM F1216-09, ASTM F1741-08 & F1947-10 include similar formulas for designing liners to the partially deteriorated design case. This design case is not covered under AS/NZS 2566.1-1998.

- Design codes ASTM F1216-09, ASTM F1741-08 & F1947-10 and AS/NZS 2566.1-1998 produce similar designs for the fully deteriorated design case if the host pipe is perfectly circular and the silo effect that can reduce the loading applied to deep liners is not considered.

- If AS/NZ 2566.1-1998 is used for the fully deteriorated design case then design calculations should be amended to include allowances for ovality and consideration should be given to whether the silo effect is applicable, given the soil conditions around and above the pipe being lined

- ASTM F1741-08 & F1947-10 which cover spiral wound liners and folded PVC liners handle ovality in a different manner to F1216-09, which covers CIPP liners. This results in more conservative design for the fully deteriorated design case. It is understood that this may be changed in the next revisions of ASTM F1741 & F1947. Specifiers may consider it appropriate to extend the approach to ovality specified in F1216-09 to cover the other two lining methods.

- Traffic loading may have a significant impact on the required thickness of shallow liners. Specifiers need to ensure that the loading that they specify is appropriate for the site conditions.

- Design input factors such as groundwater depth, ovality and soil modulus cannot be easily measured and need to be estimated, but they can have a significant influence on the required thickness of the liner. Specifiers need to ensure that the parameters they specify are appropriate for the expected conditions so that the liner is appropriate for the likely and worst case conditions, but is not too conservative resulting in excessive cost and risk during installation.

- The properties of the liner can be expected to decrease during the life of the liner as load is applied. As such the long term properties should be used for design. It is considered appropriate to use the two-year values for modulus of elasticity, as determined by testing, for liner design. However, the rehabilitation contractor should provide test certificates to justify the long-term properties used.

REFERENCES

Aggarwal, S.C. &. Cooper, M.J. (1984). *External Pressure Testing of 'Insituform' Linings.* Coventry (Lanchester) Polytechnic.

American Society of Civil Engineers. (June 2007). *Emerging Concepts for the Design of Pipeline Renewal Systems.*

AS/NZS . *AS/NZS 2566.1:1998 Buried flexible pipelines - Structural design*

ASTM International. (2009). *F1216-09 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube.*

ASTM International. (2008). *F1741-08 Standard Practice for Installation of Machine Spiral Wound Poly (Vinyl Chloride) (PVC) Liner Pipe for Rehabilitation of Existing Sewers and Conduits.*

ASTM International. (2010). *ASTM F1947-10 Standard Practice for Installation of Folded Poly (Vinyl Chloride) (PVC) Pipe into Existing Sewers and Conduits.*

Lanzo Lining Services Inc. *Engineering Design Guide for Rehabilitation with Cured-In-Place Pipe, 2nd Edition.*

Water Research Council. (1986). *Sewerage Rehabilitation Manual, 2nd Edition.*