100 YEARS OF SUCCESSFUL CONCRETE PIPE INSTALLATION– WHERE TO NEXT?

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ABSTRACT

Steel reinforced concrete pipe is recognised as the most durable and economical solution for drainage pipelines and has been manufactured and installed in Australia and New Zealand for more than 100 years.

The design of the installation of buried pipes is a complicated soil structure interaction problem requiring a thorough understanding of both geotechnical and structural concrete design principles to achieve a solution that simulates the actual field conditions.

Appropriate determination of loads and laying specifications have been critical to this success. Various Standards have been adopted over the years which include NZS 4451:1974 (based on AS CA33-1962), NZS/AS 3725-1989 (based on AS3725-1989) and the current AS/NZS 3725:2007 - *Design for installation of buried concrete pipes.*

NZS 4452:1974 *Code of Practice – Construction of underground pipe sewers and drains* was developed to detail the requirements for installation of small diameter pipes (up to 350 mm diameter) in narrow trenches, to suit common "every day" pipe installations for existing and new urban developments. Along with the grading curve for the granular bedding material, and "compaction fraction" and "ease of compaction" requirements these specifications were successfully used for many years by the drainage contractors. Bedding material suppliers countrywide were easily able to produce granular materials to this specification.

The publication of NZS/AS 3725:1989 and AS/NZS 3725:2007 (and withdrawal of NZS 4452:1986 in 1998) imposed more onerous requirements for bedding materials and compaction, and quality assurance, than necessary for small diameter trenched pipeline installations.

This paper will review the historical development of concrete pipe installation Standards in New Zealand, basic principles and theories of installation design, and requirements for "every day" installation of small diameter pipes in urban developments, including how the concepts of the current Standard have been interpreted in Local Authority's Specifications. This interpretation has led to issues including cost and availability issues of select fill for bedding material, and compaction requirements which may result substantial cost increases, construction delays and pipe cracking.

Standards Australia/Standards New Zealand WS-006 Joint Committee – Concrete Pipes will be starting a review of AS/NZS 3725:2007 later this year. This paper will propose possible recommendations for changes/improvements required by the New Zealand Construction Industry for inclusion in this review.

KEYWORDS

Concrete Pipe Installation, Standards, Sustainability, Practical Construction

1 INTRODUCTION – HISTORICAL BACKGROUND

The design of buried pipes installations is a complicated soil structure interaction problem requiring a thorough understanding of both geotechnical and structural concrete design principles to reach a solution that simulates actual field conditions. Early in the development of this geotechnical science, research teams at the University of Iowa led by Marston and Spangler developed and tested simplified solutions based on theory of elasticity (Moser 2001). These provide acceptable conservative solutions which have proven to be safe to implement since first developed during the first half of the twentieth century. These solutions are still used in UK and Europe and included in BSI, EN and other National Standards. (ACPA 2007) (EN 2015) (UK WIR 1994)

Development of computer analysis techniques in the late 20th century, enabled the American Concrete Pipe Association (ACPA) to develop more accurate solutions. These are based on four pre-defined standard installations, finite element analysis of thousands of installation options, and selection of median representative solutions to provide safe installations. This approach was adopted in both National and Local North American Standards. (ACPA 2007)

Both Australia and New Zealand had adopted Marston/Spangler's solution until the late 1980s when the new Standard, AS 3725-1989 – *Loads on buried concrete pipe* was developed, and subsequently adopted in New Zealand as NZS/AS 3725:1989. This Standard is thought to be based on a combined approach of both Marston/Spangler and the new findings of the ACPA analysis and the field experiments conducted by the California Department of Transport (CALTRANS) in the 1980s. (Bacher & Davis 1980)

NZS 4452:1974 *Code of Practice – Construction of underground pipe sewers and drains* was developed to detail the requirements for installation of small diameter pipes (up to 350 mm diameter) in narrow trenches, to suit common "every day" pipe installations for existing and new urban developments. Along with the grading curve for the granular bedding material, and "compaction fraction" and "ease of compaction" requirements, these specifications were successfully used for many years by the drainage contractors. Bedding material suppliers countrywide were easily able to produce granular materials to this specification.

The withdrawal of NZS 4452:1986 in 1998 and the publication of AS/NZS 3725:2007 *Design for installation of buried concrete pipes* imposed more onerous requirements for bedding materials and compaction, and quality assurance, than necessary for small diameter trenched pipeline installations.

This paper will present a review of the historical development of concrete pipe installation Standards in New Zealand. Basic principles and theories of installation design, requirements for "every day" installation of small diameter pipes in urban development, and how the concepts of the current Standard have been interpreted in Local Authority's Specifications will be discussed. This interpretation has led to issues such as increased cost and availability issues of select fill for bedding material, compaction requirements which may result substantial cost increases, construction delays and pipe cracking.

Standards Australia/Standards New Zealand WS-006 Joint Committee – Concrete Pipes will be starting a review of AS/NZS 3725:2007 later this year. This paper will propose recommendations for changes/improvements required by the New Zealand Construction Industry for inclusion in this review, and/or the possibility of involvement of local Industry bodies such as Water New Zealand in developing and publishing a Code of Practice for Small Diameter Concrete Pipe Installation based on the same principles of the Standard but targeted to be more practical for "every day" installations.

2 BURIED CONCRETE PIPE DESIGN SOLUTIONS

2.1 MARSTON - SPANGLER

2.1.1 INSTALLATION CONDITIONS

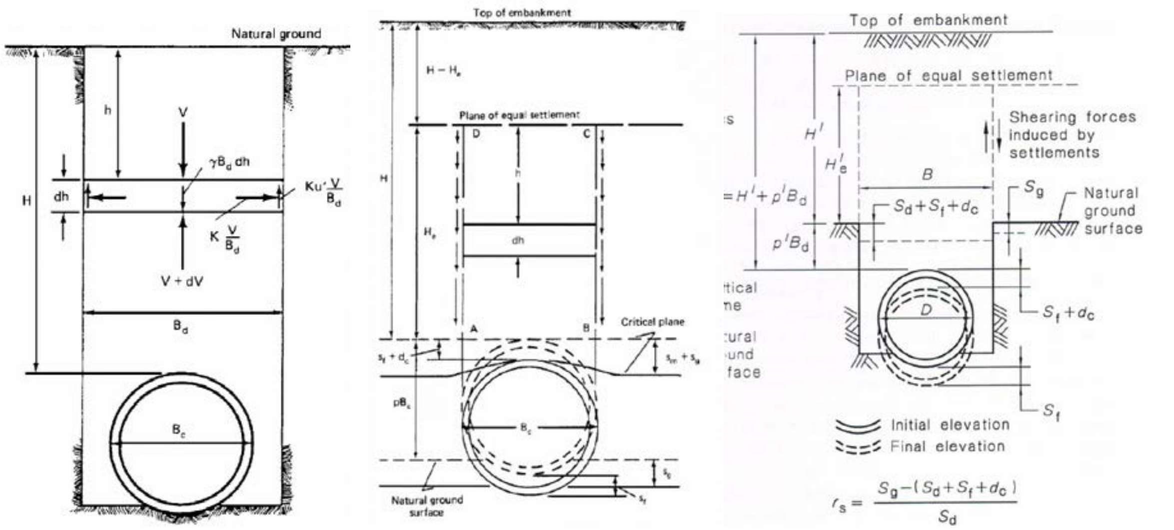
Marston defined two installation types based on the type of soil arching that occurred during installation and affected the magnitude of dead loads acting on the pipes due to backfill (Young & Trott 1984):

a) Trench Installation where the upward shear forces developed by differential settlement between the trench wall and the backfill reduce the load on the pipe from that of the column of soil over the pipe. (Figure 1a)
b) Embankment Installation (Positive Projection) where the downward shear forces developed due to the differential settlement between the backfill material on top of the pipe and that on the side of the pipe increase the load on the pipe from that generated by the column of soil on top of the pipe. (Figure 1b)

At a later stage, Spangler defined another type of installation:

c) Embankment Installation (Negative Projection) where the pipe is installed in a trench, backfilled to natural ground level, and then an embankment constructed on top of the trench. As in the trench case, the downward shear forces developed due to differential settlement between trench wall and trench backfill reduce the load on the pipe from that of the column of soil on top of the pipe. (Figure 1c)

Figure 1: Loads on Pipes for Standard Installation Conditions



a) Trench *b) Positive Projection* *c) Negative Projection*

2.1.2 DEAD LOAD FOR VARIOUS TYPES OF INSTALLATIONS

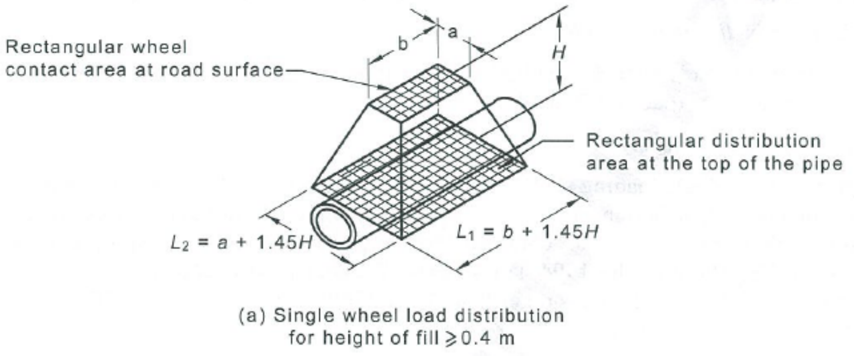
Marston and Spangler derived equations to calculate the load on the buried rigid pipes for each of the installation conditions shown in Figure 1.

The derivation of these equations can be found in many references such as Young and Trott (1984). These were based on the theory of elasticity, geotechnical principles, and many assumptions regarding the behavior of natural soil, bedding and backfill under load. Free body diagrams used for derivation of these equations are shown in Figure 1.

2.1.3 LIVE LOADS

The working loads due to superimposed live loads are a function of the intensity of the live load at the top of the pipe and the area of the pipe affected by this load. Figure 2 illustrates the load distribution used by AS/NZS 3725:2007 and other international standards.

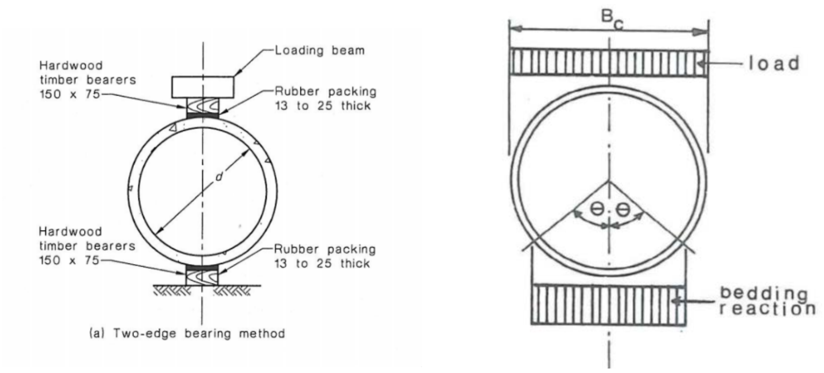
Figure 2: Live Load Distribution on Pipes



2.1.4 SUPPORTING STRENGTH AND BEDDING FACTORS

The Two-edge (or Three-edge Bearing) Test is used to determine the strength of the pipe in kN/m. This test results in the most severe loading any pipe will be subjected to, as there is no lateral support for the pipe during the test. Under actual field conditions the pipe has distributed bearing as well as lateral support which significantly reduces the bending moment applied to the pipe. Figure 3 illustrates the Two-edge bearing test and actual field conditions.

Figure 3: Illustration of Load on Pipes at Two Edge Bearing Test (Left) and Buried Pipes (Right)



The idealized model of the actual field loading of the pipes is illustrated in Figure 4, where the normalized bending moment at the invert of the pipe can be determined for varying values of the support angle 2θ (Young & Trott 1984).

The theoretical Bedding Factor **F** = **BM** (Figure 6a)/ **BM** (Two Edge Bearing Test)

The Test load applied to the pipe T_c is calculated using the following formula:

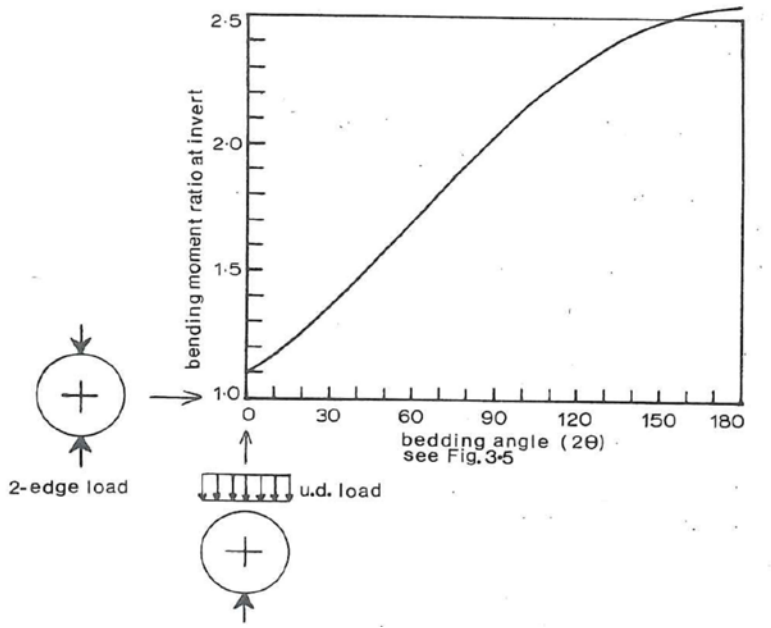
$Tc = W_g/F + W_q/F_q$, where

W_g = calculated working load on a pipe due to external dead loads
W_q = calculated working load on a pipe due to external Live loads
F = bedding factor for fill and superimposed loads

F_q = live load bedding factor (lesser of 1.5 or F)

The “Theoretical Bedding Factor” for various values of the support angle 2θ could be determined from the graph in Figure 4.

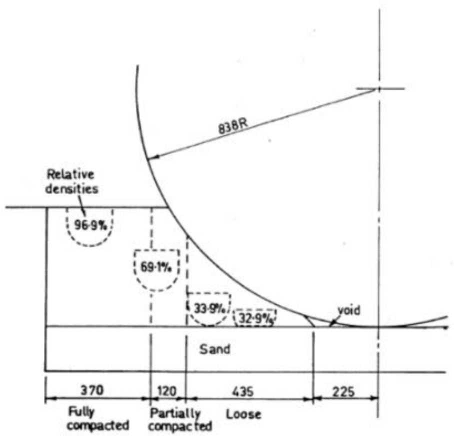
Figure 4: Theoretical Bedding Factor for Varying Support Angles



2.1.4 TRENCH INSTALLATION

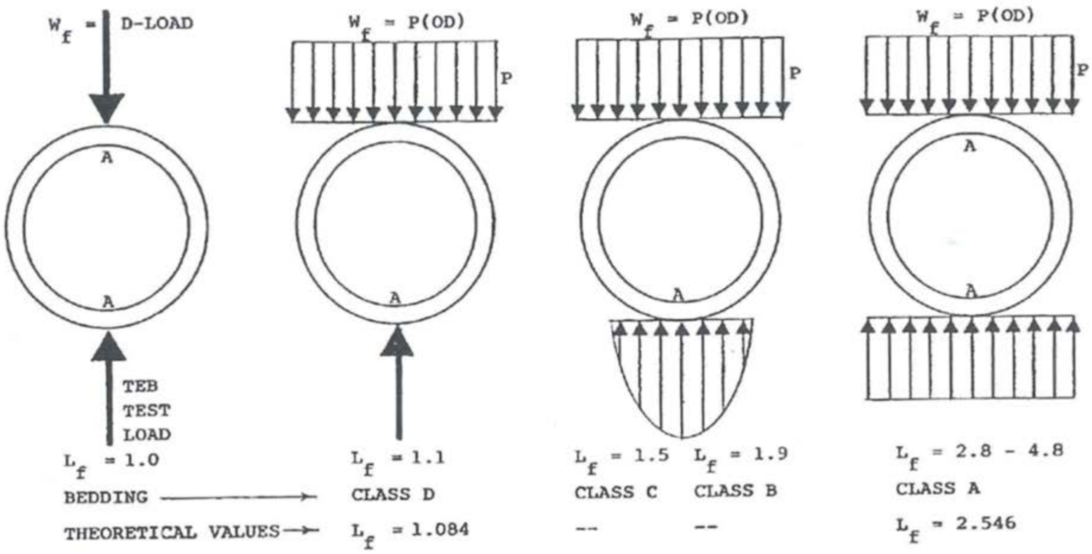
Observations of actual field installations show that it is very difficult to place well, and/or compact bedding material in the haunch zone under the pipe. Experimental work conducted in the University of Adelaide sponsored by the CPAA indicates that compaction of bedding materials on the side of the pipe will result in material density distribution shown in Figure 5. (Costin 1986)

Figure 5: Measured Density at Pipe Haunch and Side



This fact was acknowledged by the early theories by Spangler and his colleges in Iowa University in when Bedding Factor values were based on load distributions similar to that shown in Figure 6 for various bedding Classes. (Watkins & Anderson 2000)

Figure 6: Loading on Pipes and Bedding Factor for Various Spangler Bedding Classes



UK experience, which based on same theoretical approach and field test evidence to demonstrate its applicability (Young & Trott 1984), recommends different nomenclature for bedding Classes of small diameter pipes. For example:

a) Class F using single size uncompacted gravel bed, BF = 1.5. Small diameter pipe is expected to settle in the gravel to provide an appreciable bedding angle. This Class is identical to the American approach where compacted granular material extends up to 1/6 OD of the pipe.
b) Class N using graded compacted sand bed, BF = 1.1. Small diameter pipe will not settle as much into the compacted bed resulting in a point load on the pipe.
c) Class B using single size or gap graded uncompacted gravel up to the spring line of the pipe, BF = 1.9. This Class of bedding is also recommended for large diameter pipes with larger maximum sized of aggregates.

Spangler's Trench installation solution ignores the effect of any lateral pressure on the pipe. The narrow trench width and difficulties in adequately compacting support material at the side of the pipe prevents the development of a significant amount of active pressure.

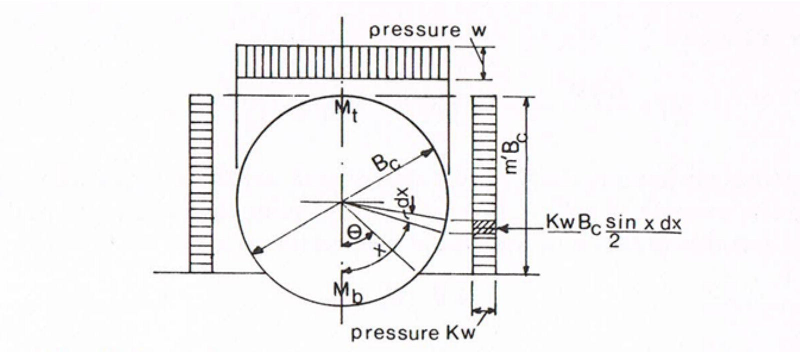
2.1.5 EMBANKMENT INSTALLATION

In a positive projection embankment, the nature of the construction process allows development of an active pressure that produces bending moments in the pipe ring that are opposite to those produced by vertical loads. This assumption leads to an active horizontal pressure on the pipe that can be represented as shown in Figure 7 (Young & Trott 1984).

Spangler's equation for embankment condition calculated BF values as function of the following:

- N, stiffness of the pipe side fill and the projection of the pipe. Tables of values of N were also developed for various Standard beddings, with lower value of 0.421 for Type A to higher value of 1.31 for Type D
- A parameter which is a function of area of the vertical projection of the pipe over which lateral pressure is effective.
- The ratio of total lateral pressure to the total vertical load.
- shape of the pipe.

Figure 7: Active Horizontal Pressure on Pipe in Embankment in Spangler's Theory



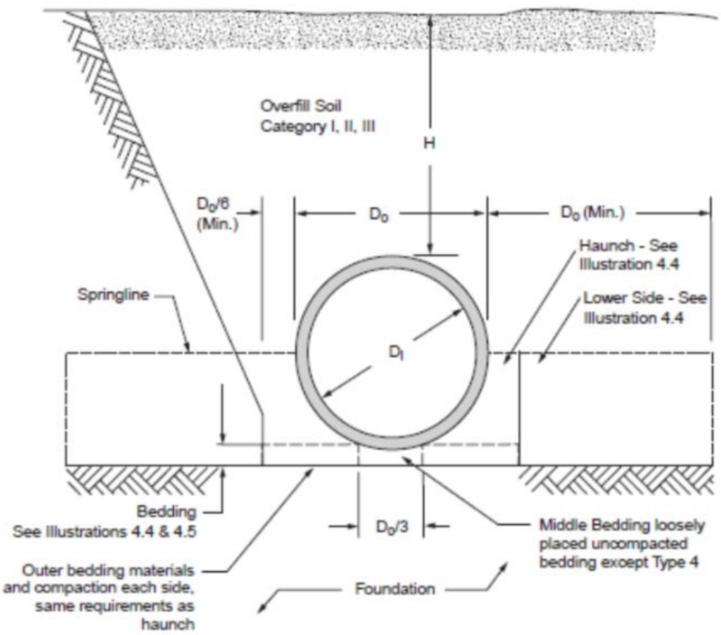
2.2 AMERICAN CONCRETE PIPE ASSOCIATION (ACPA)

The ACPA approach was mainly developed for culverts in highway applications where larger diameter pipes are installed mostly under high embankment fill. This requires high Bedding Factors to reduce the Class of the pipes required for the installation.

2.2.1 TYPES OF INSTALLATIONS (STANDARD INSTALLATION)

Unlike the traditional Spangler approach, the ACPA solution is based on four specified Standard Installations (Support Types) where each installation has a specified type of soil and level of compaction extending to the spring line of the pipe.

Figure 8: ACPA Standard Installation Conditions (Trench & Embankment) (ACPA 1980)



ACPA uses the 4 installation types for both pipes in trenches and embankment conditions as shown in Figure 8.

The Soil Pipe Interaction problem was analyzed and solved for positive projection embankment conditions, which result in the highest vertical load condition on pipes. It was also acknowledged that his analysis results conservative outcomes for pipes in trench conditions. The main assumptions considered are:

- Loosely placed un-compacted bedding directly under the invert of the pipe significantly reduces stresses in the pipe as soil in the bedding and haunch directly under the pipe is difficult to compact.
- The soil in the haunch area from the foundation to the pipe springline provides significant support to the pipe and reduces pipe stresses.
- Installation materials and compaction levels below the springline have a significant effect on pipe structural requirements.
- Compaction levels of the soil from the pipe springline to the top of the pipe grade level, have negligible effect on pipe stresses. This means high compaction of the backfill in this area is not necessary unless this is required to reduce differential settlement under a pavement structure.

ACPA Standard installations are based on using “Generic” soil types (or manufactured aggregates) based on standard soil classes ranging from high quality “Gravelly Sand Category I” to “Silty Clay Category III”

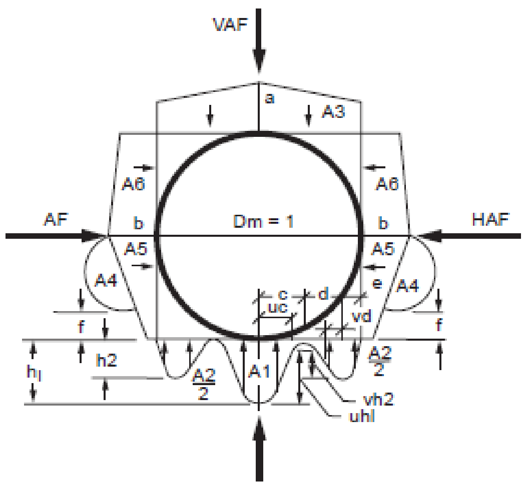
Type 1 to Type 4 Standard ACPA installations are based on pipe embedment with compacted fill to the springline, using one of the specified Generic soil categories, and minimum relative density values specified for each soil type.

Type 1, the highest quality installation, requires the use of highest quality bedding material compacted to 95% dry density ratio. The lower quality installations use either high quality materials with lower compaction requirements or lower quality materials with higher compaction requirements. Type 4 does not specify compaction requirements except for the lowest quality material, where 85% dry density ratio is specified.

2.2.2 DEAD LOADS FOR VARIOUS TYPES OF INSTALLATIONS

Dead Load distribution on the pipes was developed for the four Standard Installations by Dr Frank Heger and represented in Figure 9. Values of Arching Coefficient (VAF) associated with this theory could be found in various references. (ACPA 1980)

Figure 9: Heger’s Load Distribution on Pipes in Standard Installations



The vertical load on the pipe is calculated for each type of installation as follows:

- Positive Projection Embankment and wide trenches, W_g = VAF X Prism Load on Pipe
  (VAF values are 1.35 for Type 1, 1.4 for Types 2 & 3 and 1.45 for Type 4.
- Narrow Trench vertical load is calculated using Marston/ Spangler theory
- Live Load effect is calculated as previously discussed in section 2.1.3.

2.2.3 SUPPORTING STRENGTH AND BEDDING FACTORS

As previously discussed, Dead Load Bedding Factor is the ratio between the calculated Bending Moment in pipe wall when the pipe is subjected to field loads and the maximum Bending Moment in pipe wall in the Two Edge Bearing Test.

Bedding factors values for various pipe diameter and installation types are shown in Table 1.

Table 1: Bedding Factors for ACPA Standard Installations

Pipe Diameter	Standard Installation			
	Type 1	Type 2	Type 3	Type 4
300	4.4	3.2	2.5	1.7
600	4.2	3	2.4	1.7
900	4	2.9	2.3	1.7
1500	3.8	2.8	2.2	1.7
3600	3.6	2.8	2.2	1.7

Variable bedding factor values were also specified for live loads in embankment conditions which range from 1.1 for shallow installed large diameter pipes to 2.2 for deep installations.

For trench installation, minimum values of bedding factor were specified for each Type of installation. A variable BF to be used in design is then calculated by assuming linear variation between the minimum bedding factor and the bedding factor for the embankment condition, which begins to govern at a transitional trench width (ACPA 2007)

2.3 SUMMARY OF INTERNATIONAL PRACTICE

Most international standards are based on the two theories detailed above.

Tables 2 & 3 overleaf summarise various installation Classes and Types adopted by main North American and European Standards for Trench and Embankment conditions respectively.

2.4 AUSTRALIA & NEW ZEALAND PRACTICE

Various approaches were followed over the years by the Australian and New Zealand Standards Committees to detail for Concrete Pipe Installation Design.

These approaches are summarized as follows:

- A35:1937 - includes pipe installation design as an Appendix.
- AS CA33 – 1962 Concrete Pipe Laying Design. This adopted Marston/Spangler theories as mentioned in its introduction, and also includes some of (then) new approaches developed by Schlick and adopted in ACPA Handbooks. (AS 1962)
- NZS 4451:1974 (superseded) which replaced AS CA33 – 1962 as the New Zealand Standard.

Table 2: International Installation Classes and Types for Trench Installation Conditions

Standard Practice	Installaion Type	Installation Class	Depth of Bedding	ϕ	Theoratical Bedding Factor	Specified Bedding Factor	Bedding Material	Load Calculation
Old ACPA Spangler	Trench	D	0	0	1.10	1.10	Compacted Granular Material	Marston's Trench
		C	0.17OD	58	1.75	1.50		
		B	0.50OD	180	2.50	1.90		
UK Practice	Trench	D	0	0	1.10	1.10	Compacted Granular Material*	Marston's Trench
		B	0.50OD	180	2.50	1.90		
		S	0.3m top of pipe	360	2.50	2.20		
ATV-DVWK-A 127E	Trench			60	1.75	1.59	Compacted Granular Material	Marston's Trench
				90	2.10	1.91		
				120	2.35	2.18		
AASHTO	Trench	Type 4	0.5OD	180	2.50	1.5 + TE**	No Compaction or 85% Category III***	Marston's Trench
		Type 3	0.5OD	180	2.50	1.7 + TE**	85% Category I, 90 Category II or 95% Category III***	
		Type 2	0.5OD	180	2.50	1.9 + TE**	90 Category I or 95% Category II***	
		Type 1	0.5OD	180	2.50	2.3 + TE**	95% Category I	
Caltrans	Trench	Type 3	0.5OD	180	2.50	2.2 - 2.5	85% w/min SE 25 or 90%	Heger's Positive projection Embankment
		Type 2	0.5OD	180	2.50	2.8 - 3.2	90 w/min SE 25	
		Type 1	0.5OD	180	2.50	3.6 - 4.4	95% w/min SE 30 and max passing 200 = 12%	
	* 14 or 20 or 40mm nominal single size or 14-5 mm graded or 20-5 graded or 40-5 graded CF 0.3 max							
	** Transitioned to Embankment BF values depending on trench width							

Table 3: International Installation Classes and Types for Embankment Installation Conditions

Standard Practice	Installaion Type	Installation Class	Depth of Bedding	ϕ	Specified Bedding Factor	Bedding Material	Load Calculation
Old ACPA Spangler	Embankment	D	0	0	1.13 - 1.18	Compacted Granular Material	Marston's Projection @ projection = 0.5 and Settlment Ratio = +1.0
		C	0.17OD	58	1.8 - 1.92		
		B	0.50OD	180	2.17 - 2.33		
UK Practice	Embankment	D	0	0	1.13 - 1.18	Compacted Granular Material*	Marston's Projection @ projection = 0.5 and Settlment Ratio = +1.0
		B	0.50OD	180	2.17 - 2.33		
		S	N/A				
AASHTO	Embankment	Type 4	0.5OD	180	1.70	No Compaction or 85% Category III***	Heger's Positive projection Embankment
		Type 3	0.5OD	180	2.2 - 2.5	85% Category I, 90 Category II or 95% Category III***	
		Type 2	0.5OD	180	2.8 - 3.2	90 Category I or 95% Category II***	
		Type 1	0.5OD	180	3.6 - 4.4	95% Category I	
Caltrans	Embankment	Type 3	0.5OD	180	2.2 - 2.5	85% w/min SE 25 or 90%	Heger's Positive projection Embankment
		Type 2	0.5OD	180	2.8 - 3.2	90 w/min SE 25	
		Type 1	0.5OD	180	3.6 - 4.4	95% w/min SE 30 and max passing 200 = 12%	
	* 14 or 20 or 40mm nominal single size or 14-5 mm graded or 20-5 graded or 40-5 graded CF 0.3 max						

- NZS 4452:1974 (superseded) “Code of Practice for the Construction of Underground Pipe Sewers and Drains”; for small diameter, trench installation conditions. This code adopted an approach similar to the UK practice or low bedding factor installation types.
- AS/NZS 3725: 1989 (superseded. This is generally similar to the current AS/NZS 3725:2007.
- NZS 4404:2010 (Current) “Land development and subdivision infrastructure”. This Standard uses traditional Spangler approach for bedding and installation without specifying design method or bedding factors.
- AS/NZS 3725:2007 (Current) “Design for installation of buried concrete pipes”. This current Standard will be discussed in more detail.

The intention and theoretical background of AS/NZS 3725:2007 was discussed in detail in a paper presented at Water New Zealand – Stormwater Conference 2018 by one of the authors of this paper titled "Better Understanding of the Intent of AS/NZS 3725:2007 – Case Study". (Al-Saleem & Langdon 2015)

In general, AS/NZS 3725:2007 adopted simplified Marston/Spangler theories for load calculation on pipes for various types of installations and specifies a restricted grade of bedding materials and degree of compaction for various bedding types. It uses the same bedding types for both Embankment and Trench conditions and specifies Bedding Factors slightly higher than Spangler's for Haunch only support types (H1 & H2) and similar values of Bedding Factor to ACPA for Haunch and Side Support (HS1, HS2 & HS3).

The dead loads are calculated as follows:

$\boldsymbol{W}_g$ (Trench) = Spangler Coefficient $\mathbf{C_t}\,\omega B^2$
$\boldsymbol{W}_g$ (Positive Projection Embankment) = Spangler Coefficient $\mathbf{C'_e}\,\omega \mathbf{D}$
$\boldsymbol{W}_g$ (Negative Projection Embankment) = Spangler Coefficient $\mathbf{C'_n}\,\omega \mathbf{B}$

Where ω = assessed unit weight of fill material and
Spangler Coefficients (C_t, C'_e and C'_n) are derived from Figures 6 to 8 of the AS/NZS 3725.

Table 4 below details AS/NZS 3725:2007 standard support types and Table 5 shows the grading of bedding materials specified in Tables 6 & 7 of the Standard.

Table 4: AS/NZS 3725 Support Types for Trench and Embankment Installation Conditions

Standard Practice	Installaion Condition	Installation Class	Depth of Bedding	ϕ	Theoratical Bedding Factor	Specified Bedding Factor	Bedding Material	Load Calculation
AS/NZS 3725	Trench	U	0	0	1.10	1.00		Marston's Trench + Marston's Positive projection for wide trench
		H1	0.1OD	50	1.50	1.50	3725 Table 6 at 85% Compaction	
		H2	0.3OD	90	2.00	2.00	3726 Table 6 at 90% Compaction	
		HS1	0.5OD	180	2.50	2.00	H1 3725 Table 6 at 85% Compaction + 3725 Table 7@85% Compaction	
		HS2	0.5OD	180	2.50		H2 3725 Table 6 at 90% Compaction + 3725 Table 7@90% Compaction	
		HS3	0.5OD	180	2.50	4.00	H2 3725 Table 6 at 95% Compaction + 3725 Table7@95% Compaction	
AS/NZS 3725	Embankment	U	0	0	N/A	1.00		Marston's Projection @ projection = 0.5 and Settlment Ratio = +1.0
		H1	0.1OD	50	N/A	1.50	3725 Table 6 at 85% Compaction	
		H2	0.3OD	90	N/A	2.00	3726 Table 6 at 90% Compaction	
		HS1	0.5OD	180	N/A	2.00	H1 3725 Table 6 at 85% Compaction + 3725 Table 7@85% Compaction	
		HS2	0.5OD	180	N/A	2.50	H2 3725 Table 6 at 90% Compaction + 3725 Table 7@90% Compaction	
		HS3	0.5OD	180	N/A	4.00	H2 3725 Table 6 at 95% Compaction + 3725 Table7@95% Compaction	

Table 5: AS/NZS Standard Bedding Materials Grading

PIPE SUPPORT MATERIALS REQUIRMENTS AS/NZ 3725/2007

GRADING LIMITS FOR SELECT FILL IN BED AND HAUNCHED ZONES

Sieve size (mm)	19.0	2.36	0.60	0.30	0.15	0.075
Weight passing %	100	100-50	90-20	60-10	25-0	10-0

GRADING LIMITS FOR SELECT FILL IN SIDE ZONES

Sieve size (mm)	75.0	9.5	2.36	0.60	0.075
Weight passing %	100	100-50	90-20	60-10	25-0

Experience indicates that for normal applications, the design methods are simple, and results obtained are conservative enough to allow for some variations in installation conditions between the actual field conditions and those assumed during design.

In complicated, high loading conditions such as deep embankments, and culverts that replace existing water courses, thus installed in trench under new deep embankments, it is necessary that designers thoroughly consider the factors below which might affect the assessment of Spangler factors, and hence impact the load on the buried pipes. It is necessary that Designers ensure these are controlled and not changed during construction:

a) Width of trench
b) Unit weight and friction angle of fill materials
c) Projection ratio
d) Settlement Ratio

Designers also should be aware that AS/NZS 3725:2007 adopts Spangler definitions for the first two factors, whilst adopting a different approach for the last two.

AS/NZS 3725 defines projection ratio in reference to Natural or Equivalent surface rather than Natural surface considered in the original theory. Furthermore, a single value of Settlement Ratio was adopted for each of the positive and negative installation conditions, rather than a range of values proposed by Spangler. AS/NZS 3725 ensures applicability of the original theory by explaining in the Supplement the detailed installation conditions and procedures where designers can use the specified fixed values, and proposed an alternative option when conditions are different (detailed in the Supplement)

2.4.1 ISSUES ARISING FROM THE USE OF AS/NZS 3725:2007

Various papers presented at Water New Zealand Stormwater conferences over the years (Gordon 2018, Al-Saleem & Langdon 2015) have discussed issues arising in the implementation of AS/NZS 3725 in New Zealand especially for the construction of stormwater collection networks in urban environment and highways where small diameter pipes in shallow trenches are commonly used.

A review of the current construction specifications of some of the main cities in New Zealand shows that the Local Authorities are either still using the old Spangler installation types, or, if referring to AS/NZS 3725, are specifying non-compliant bedding materials, support type or compaction levels as shown in Table 6 overleaf.

Typical issues arising include:

- Great difficulty in finding local sources of material complying with AS/NZS 3725 across New Zealand, unless blending high cost manufactured aggregates, or adding cement to an already expensive material.
- Difficulty in compacting and testing the complying graded materials in a trench installation without increasing the width of the trench. This results in losing the benefit of both load reduction on the pipes and reduction in bedding material quantities.
- Difficulty in compacting the complying bedding materials during the common wet weather periods in New Zealand.
- Attempting to compact the bedding materials to the specified limits, often results in circumferential cracking, and in some cases longitudinal cracking at the springline of the small diameter pipes.
- Specification of Density Index values of 50, 60 and 70 for cohesionless soil in lieu of Dry Density Ratio values of 85%, 90% and 95% has led to a confusion in

interpreting field test results. Research indicated that his relation is only correct for 95% Dry Density Ratio (Mujtaba et al 2019)

Table 6: Examples of Bedding Types (Support Types) Currently Specified in New Zealand

Standard	Bedding Type	Type of Bedding Material	Depth of Bedding	Bedding Factor	Notes
NZS 4404:2010	Type 1	Concrete	D/4	Not Specified	
	Type 2	Granular Materials	D/2	Not Specified	
	Type 3	N/A			For Fixable Pipes
	Type 4	Granular Materials	D + 150mm	Not Specified	Where migration of fines expected (wrap with Geotextile)
Hamilton City	H2/ HS2	Free draining granular materials	0.3D/0.5D	2.0/ 2.5	With reference to AS/NZS 3725:2007
Nelson City	H2	AP20 +	D/3 @ Clegg Impact Value 35 for roads and 25 for others	Not Specified	Geotextile wrap where migration is possible
Wellington Region	N/A	20/5 or 40/5 Drainage or Native Sand or Graded Material	AS/NZS 3725 Table 5 @ 95% compaction	Not Specified	
Palmerston North	N/A	20/5 or 40/5 Drainage or Graded Material of AS/NZS 3725	D/4 @ CIV =25	Not Specified	Compaction 95% to top of trench. Spec. Text required AS/NZS 3725
Dunedin City	4404:2010	Granular or Concrete	D/2 or D + 150	Not Specified	
Hastings City	4404:2010	Granular or Concrete	D/4 or D + 150	Not Specified	
Auckland City	H2	GAP20	D/2	2.0 or 1.7?	Calculated as per AS/NZS 3725:2007
Christchurch City	N/A	AP40/AP20	D + 150 compacted to 2050 Kg/M3	Not Specified	

In contrast, the use of AS/NZS 3725 for design and installation of Highway Culverts was generally successful, except with some issues regarding sourcing of bedding materials and selecting an appropriate BF for non-complying materials, and interpretation of the design limitations that are only detailed in the Supplement.

3 ALTERNATIVE PROPOSAL FOR UPDATED VERSION OF AS/NZS 3725

To address the issues identified it is proposed that the Standard be split into 3 Sections:

Part 1: Design for Installation of Concrete Pipes, includes:

- Calculations of test loads for Standard Wide Trench and Embankment installations
- Calculation of test load for Alternative (Non-Standard) installations:
    - Narrow trench using Marston Theory
    - Negative Projection embankment and induced trench installation
- Calculation of test load for Multiple Pipe Conditions,
- Calculation of test load for Jacked or bored pipes conditions,
- Calculation of test load for pressure pipes.

Part 2: Commentary (or Supplement) to part 1 including:

- Theories and principles used in design and load calculations,
- Theories and principles used in developing Bedding Factors values,
- Tables (or graphs) of minimum width of trench for each pipe size and depth where installation type HS3 might be used (transition width),
- Reference to use of FEA and/or existing Software for installation design,
- Design examples.

Part 3: Guidelines for Installation of Concrete Pipes includes the following:

- Excavation of trenches and installation under embankments,
- Materials for embedment including details of soil types, method to control migration of fines, compaction and field testing and testing for "Ease of Compaction",
- Backfilling and compaction above the pipes,
- Installation to avoid cracking during construction, including details of construction loads, safe distances, materials and type of equipment,
- Details of Induced trench installations,
- Jointing, joints and watertightness,
- Testing and acceptance of small diameter pipelines (optional)

3.1 PROPOSAL FOR STANDARD INSTALLATIONS

Standard Installations proposed in the updated AS/NZS 3725 Standard are based on the latest practice adopted by the ASCE, Caltrans (California Department of Transport), ASTM, AASHTO and ACPA. The design concept was developed from the ACPA Finite Element Analysis Program SPIDA and has been used successfully used for the last 40 years. Details proposed for both Embankment and Trench installations are similar to that previously shown in Figure 8 modified to use AS/NZS 3725 terminology.

3.1.1 BEDDING AND HAUNCH MATERIAL

The materials proposed for the Bed & Haunch/Side zones are based on "generic" soil types rather than pre-specified grading. Table 7 below provides a generic definition of the proposed bedding materials:

Table 7: Proposed Standard Bedding Materials

Bedding Material	Representative Soil Type	
	AS 1726 Class	Standard AASHTO
Gravelly Sand (Group I)	SW, SP, GW, GP	A1, A3
Sandy Silt (Group II)	GM, SM, ML, Also GC, SC with less than 20% passing #200 sieve	A2, A4
Silty Clay (Group III)	CL, MH, GC, SC	A5, A6

The adoption of the above bedding materials specification will have the following advantages:

- Allows Specifiers and Contractors to use locally available materials based on the concept of "Higher Compaction for Lower Quality Materials" as previously suggested in CPAA Guidelines (CPAA).
- Allows the use of self-compacting materials, avoiding heavy compaction in small diameter pipe installations that can lead to pipe cracking. The use of these types of

materials is in line with the current BS Standard – BS 9295:2020 – *Guide to the structural design of buried pipes*. This will be supported by a detailed "Ease of compaction" test to allow installation in narrow trenches without the requirement compaction testing of the haunch and side fill.

- Allows the use of materials traditionally used for pipe bedding such as sands, scoria, and drainage aggregates.
- The possible issue of "Migration of fines" will be left to Designers/Specifiers to consider on a case-by-case basis, rather than restricting all installations to avoid this "relatively rare" phenomenon (in line with AS/NZS 2566).
- The use of self-draining materials, testing for migration of fines, examples of materials grading, test for compactability and other possible design and installation issues to be covered the proposed "Guidelines for installation of concrete pipe" section of the Standard (in line with AS/NZS 2566 Part 2).
- Remove the reference to cement stabilization which is not required for Standard installations, and hence reduce the cost of bedding, or accept lower quality insitu soils for higher quality installation type when using "Cement or Lime Stabilization"
- Remove the requirements for reduction of BF giving the designers and installers a wider range of options to achieve the design BF by using combination of a generic bedding material and degree of compaction.

3.1.2 EMBANKMENTS AND TRENCHES

The proposed new Standard will use haunch and side support for Embankments based on the requirements of the original SPIDA program, but using same terminology as the current AS/NZS 3725. Haunch only support is proposed for Trenches in a similar manner to traditional Spangler approach and UK practice.

The proposed support types for both Embankments and Trenches are shown in Table 8.

Table 8: Proposed New Support Types for Embankment and Trench Installation Conditions

All Installation Conditions	Embankment Installation Condition			Trench Installation Condition		
Bed Zone	**Support Type**	**Haunch and Side Zone**	**Embankment Lower Side Compaction**	**Support Type**	**Hunch and Side Zone**	**Trench Wall**
100 if D <1500; or 150 if D > 1500. Compacted as for Haunch and Side Zone.	**HS**	D/2 minimum, No zone Compaction required, except if Group III, use 85% Group III	No minimum zone compaction required, except if Group III, use 85% Group III	**TH**	D/6 minimum, Group I or "Self Compacting"; No minimum zone compaction required, except if Group III, use 85% Group III	Natural soil or fill.
100 if D <1500; or 150 if D > 1500. Compacted as for Haunch and Side Zone.	**HS1**	D/2 minimum, zone compaction 85% Group I, 90% Group II, or 95% Group III	85% Group I, 90% Group II, or 95% Group III	**TH1**	D/2 minimum Hand Compaction Group I, 90% Group II, 95% Group III or "Self Compacting"	Natural soil or fill.
100 if D <1500; or 150 if D > 1500. Compacted as for Haunch and Side Zone.	**HS2**	D/2 minimum; zone compaction 90% Group I or 95% Group II	85% Group I, 90% Group II, or 95% Group III	**TH2**	D/2 minimum; zone compaction 90% Group I or 95% Group II	Natural soil or fill.
100 if D <1500; or 150 if D > 1500. Compacted as for Haunch and Side Zone.	**HS3**	D/2 minimum; zone compaction 95% Group I or CLSM bedding material	90% Group I, 95% Group II, or 100% Group III	**TH3**	D/2 minimum; CLSM bedding material	Natural firm soil or engineered fill.

Note on Table 8: *Quality of bedding compaction might be controlled in the lab by test on the selected materials and field trials, to confirm the specified degree of compaction is achievable. No in-situ test required for Group I and Self Compacting bedding materials except for HS2 and HS3 support types.*

The main advantages of the proposed new support types are summarized as follows:

- The use of the concept of "the better the bedding materials, the lower the compaction required to achieve the targeted stiffness". Similar to the concept adopted by CPAA Guidelines (CPAA),
- Compaction is defined by Relative Compaction (RC) rather than Density Index (I_D). Research in Australia and overseas indicates that I_D = 70 is almost equivalent to RC=95%, but for lower RC values where stiffness and pipe support is already known through SPIDA program. The value of I_D is dependent on material type, in most cases, I_D = 0 for RC = 80 to 85% for coarse aggregates and sand, and for "Self-Compacting" materials, I_D = 0 for RC>90% in some cases,
- Haunch only support will be used for trenches, therefore compaction requirements in trenches will be removed unless the trench is wide enough to be treated as an embankment.

3.1.3 DEAD LOADS FOR STANDARD INSTALLATIONS

W_g = (VAF) φDH

Where VAF is Heger's Vertical Arching Factor. Values for VAF are shown Table 9:

Table 9: Vertical Arching Factor Values for Proposed Installations

Installation Type	VAF
HS	1.45
HS1	1.40
HS2	1.40
HS3	1.35
TH, TH1, TH2	1.45
TH3	1.40

These load values will be simple to calculate and are used for both Embankment and Trench conditions.

Comparison of the dead loads on pipes (W_g) in common trench installations calculated for both the proposed "Standard Installation" approach and current AS/NZS 3725 approach indicates good agreement for small diameter pipes (where most trench installations are used)., Table 10 below illustrates the comparative values:

Table 10: Comparison of Load on Pipes using the Proposed Method and AS/NZS 3725 Method

Fill Height H	ND	Trench Width B	OD	W_g	
				Proposed Standard Installation VAF = 1.45	Current AS/NZS 3725
2000	300	1000	362	21.0	20.7
2000	450	1200	534	31.0	30.3
2000	600	1400	699	40.5	38.9
2000	750	1600	870	50.5	45.3
2000	900	1750	1043	60.5	51.9
2000	1200	2000	1372	79.6	64.7
5000	1200	2000	1372	198.9	153.8
5000	1200	2500	1372	198.9	194.6

The correct use of "AS/NZS 3725:2007 Trench Installation" requires Designers to predetermine the installation parameters listed below. This requires that all parameters should be confirmed before pipe installation, and installation should be redesigned if any one of the parameters are not met. The design parameters are:

- Width of the trench at top of the pipe
- Slop of trench walls and strength of wall soil at pipe level.
- Type of fill material
- Method of installation and removal of trench shield.
- Whether settlement of fill materials is allowed or not for installation under roads.

3.1.4 DEAD LOAD – ALTERNATIVE (NON-STANDARD) INSTALLATIONS

Alternative (Non-Standard) installations will include methods of calculation using original Marston Spangler's methods but with clear reference to the conditions where they are applicable, as follows:

Trench installation

Application conditions as per original Marston Spangler's methods in current AS/NZS 3725.

Negative Projection Installation

The use of this installation condition will be subject to confirmation that the design parameters are known with reasonable accuracy during design and confirmed on site before pipe installation. The settlement ratio will be changed from that of AS/NZS 3725 to better reflect conditions. The design parameters are:

- Width of trench (with a requirement that if pipe is to be installed in a water course, the width of the trench is that of firm soil after removal of all unsuitable trench side wall material)
- Projection Ratio (similar note as above, and requirement that projection is from natural ground not embankment fill)
- Properties and compaction specifications of natural soil and backfill to insure a negative "Settlement Ratio" and predict its value with a reasonable accuracy.

3.1.5 DEAD LOAD - MISCELLANEOUS INSTALLATIONS

This will be similar to current AS/NZS 3725 for the following installations:

1. Multiple Pipe Conditions
2. Jacked or bored pipes conditions

3. Induced trench conditions (Similar to negative projection)
4. Pressure Pipes

3.1.6 SETTLEMENT RATIO

The method to predict the values of Settlement Ratio for various conditions of Negative Projection and Induced Trench will be clarified in the "Guidelines". It will show how the nature of the subgrade, degree of compaction of bedding and compaction of backfill adjacent and on top of the pipe will affect those values.

Recommended design values based on those developed by Spangler and adopted by the ACPA will be included in the Standard. Values are detailed in the Table 11:

Table 11: Proposed Settlement Ratio for the Proposed Alternative Design Options

Installation Condition	Settlement Ratio	
	Usual Range	Design Value
Zero Projection		0.0
Negative Projection	-1.0 to 0.0	
p' = 0.5		-0.1
p' = 1.0		-0.3
p' = 1.5		-0.5
p' = 2.0		-1.0
Induced Trench	-2.0 to 0.0	
p' = 0.5		-0.5
p' = 1.0		-0.7
p' = 1.5		-1.0
p' = 2.0		-2.0

3.1.7 LIVE LOADS, SURCHARGE LOADS AND INTERNAL WATER

No change is proposed for the calculation of the effects of live, surcharge and internal water loads from the approach in the current AS/NZS 3725:2007.

3.2 PIPE SUPPORT AND BEDDING FACTOR

The proposed dead load bedding factors are based on the following concept:

1. With the adoption of the "Standard Installation" the Embankment BF remain similar to current AS/NZS 3725 and these will be in line with the ACPA Standard.
2. The possibility of using same BF as the ACPA (variable with pipe DN) will be considered during the development of the new Standard.
3. For trenches it is proposed to ignore most of the side support and base the bedding factors on the "Haunch Support" only with a slight increase to the values of "Minimum Trench BF" of the ACPA for the following reasons:
   - Simplified calculation process.
   - Allows for slight increase for the effect of side support.
   - Removes the need to specify and control trench width.
   - Removes the need for compaction test which is specified mainly to control the quality of side support. Further compaction at the side of the pipe will not improve the density of materials at haunch zone as previously identified by the CPAA supported research at University of Adelaide.
   - The bedding under the pipe barrel will eventually be compressed/compacted during construction process. This needs to be firm before pipe laying to ensure designed pipeline invert alignment, not to improve pipe support.

- Trench BF are the same as those proposed by Spangler and still used successfully in UK and used for 80 years in Australia and NZ without problems.
- Deep trenches where, H&S requirements and size of equipment usually require wider side clearance, the change to "Embankment Installation" and BF is appropriate to ensure the higher BF is achievable (generally for large diameter pipes),

4. Loads on pipes in shallow trenches are mostly controlled by Live loads, which has a constant bedding factor of 1.5 for all types of installations. Higher values of DL bedding factors will not alter the effect of the live load on the pipe. Tools to find the transition width of Trenches where Embankment type support could be used for Trenches, will be included in the Standard.

The proposed dead load bedding factors are detailed in the following Table:

Table 12: Proposed Dead Load Bedding Factors for Various Support Types

Installation Type	Bedding Factor
TH	1.5
TH1	1.9
TH2	2.1
TH3	2.5
HS	1.5
HS1	2.0
HS2	2.5
HS3	4.0

The LL bedding factor to remain 1.5 with the possibility of using variable values as per ACPA to be considered during development of the updated Standard.

4.0 CONCLUSION

Standards are developed by consensus to codify best practices, methods and technical requirements to create a safe and sustainable built environment for the community. They are living documents which are updated to suit the changing needs.

This paper has discussed the development of New Zealand and Australian Standards for the design and installation of reinforced pipe up to the present AS/NZS 3725: 2007. It has highlighted some of the issues arising from the use and interpretation of this Standard.

Proposals have been developed, based on original theory and more recent developments published by the ACPA, which address these issues. These proposals include the use of a wider range of bedding materials, variations to installation details and compaction requirements, modifications to dead load calculations and bedding factors.

It is also recommended that the Standard be developed with 3 Parts with the inclusion of Guidelines for Installation of Concrete Pipes to provide more guidance to ensure actual construction matches design intent and requirements.

The proposed changes are intended to provide more sustainable installation design and construction options appropriate for the next 20 years.

REFERENCES

Al-Saleem, H.I. and Langdon, W. (2015) "installation of reinforced concrete pipes; theory and practice" Water New Zealand, Stormwater Conference 2015.

American Concrete Pipe Association (1980) Concrete Pipe Handbook, ACPA, USA

American Concrete Pipe Association (2007) Concrete Pipe Design Manual, ACPA, Ch. 4

Australian Standard CA33-1962 "Concrete Pipes Laying Design" Standard Association of Australia, N.S.W 1962

Bacher, A.E. and Davis R. E. (1980) 'Rigid Culvert Tests – Mountainhouse Creek – Part II' Concrete Pipe Association of Australia – 1980 Seminars, Concrete Pipe News, 89-93.

Concrete Pipe Association of Australasia (2017) Engineering Guideline – Selecting Materials for Bedding Steel Reinforced Concrete Pipe, CPAA

Costin, SA (1986) "A Study of Improved Installation Method for Reinforced Concrete Pipes Under Embankment" MESc Thesis, University of Adelaide.

EN, The European Specifications (2015) EN 1610 "Construction and Testing of Drains and Sewers – English Translation" DIN, Berlin 2015. P10.

Gordon T. 2018 "Rigid and Flexible Pipe Design, Installation and Lifetime Cost" Water New Zealand Conference 2018

Moser, A.P. (2001) Buried Pipe Design, 2nd ed., McGraw-Hill, New York, Chapter 2 & 3.

Mujtaba, H. et al. 2019 "Laboratory and field investigations in granular soils to correlate relative density, relative compaction and grain size", Journal of the South African Institution of Civil Engineering ISSN 1021-2019 Vol 62 No 2, June 2020, Pages 12–21, Paper 0516

UK WIR (1994) "Water Industry Information and Guidance Note IGN 4-08-01, Reprinted by UK Water Industry and published by WRc plc, London 2006.

Watkins, R. K. & Anderson L.R. (2000) "Structural Mechanics of Buried Pipes" CRC Press LLC, USA 2000, Chapter 12

Young, O.C. and Trott J.J. (1984) "Buried Rigid Pipes" Elsevier Applied Science Publisher Ltd, Essex, England 1984.

Al-Saleem, H.I. and Langdon, W. (2015) "installation of reinforced concrete pipes; theory and practice" Water New Zealand, Stormwater Conference 2015.