INSTALLATION OF REINFORCED CONCRETE PIPES: THEORY AND PRACTICE

Husham Issa Al-Saleem and Wayne Langdon – Humes Pipeline Systems

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ABSTRACT

The classic theory of earth loads on buried concrete pipes was developed in the 1930's and was based on the concept of a bedding factor to relate the supporting strength of buried pipe to the strength obtained in a three-edge bearing test. Four types of bedding were developed and successfully used for years using conservative bedding factors. The later developments in engineering concepts and construction methods highlighted the limitations of the classical approach which developed standard beddings to fit assumed theories for soil support, rather than ease of and method of construction.

In the 1970's the American Concrete Pipe Association (ACPA) used state of the art finite element computer program results to replace the historical bedding methods with four new standard installations that more correctly reflect actual conditions. In developing the AS/NZS 3725:2007 standard, the committee appears to have developed bedding methods that combine both classical and new design concepts. The combination of dual design concept in AS/NZS creates the potential for ambiguity or uncertainty in certain industry applications.

A review of many TA specifications in NZ and the local practices used in design and bedding pipes presented in this paper, indicates that current specifications and practices are in many cases not complying with either the classical or the modern design theories. One of the causes of this departure is that selected bedding materials from AS/NZS 3725:2007 are not readily available in most NZ areas, with properties that do not fit the local work conditions. This paper will present case studies which indicate that installation based on the new design theories, rather than AS/NZS 3725:2007 may provide more reliable and economical results.

The paper will conclude with a specification proposal based on both modern theory and NZ proven construction and design practices.

Keywords

Concrete pipes, bedding, bedding design, load on buried pipes, bedding materials.

PRESENTER PROFILE

Husham holds, BSc, MSc (Civil Eng.) qualifications from the University of Baghdad – Iraq. and is recognized in New Zealand with CPEng, IntPE, MIPENZ.

Since 2009 Husham has been working as a senior civil engineer with Humes Pipeline Systems, where he is involved in research and development, management of technical projects, sales training and technical support.

1 INTRODUCTION

Anson Marston, who was Dean of Engineering at Iowa State University, investigated the problem of determining loads on buried conduits. In 1913, Marston published his original paper, “The Theory of Loads on Pipes in Ditches and Tests of Cement and Clay Drain Tile and Sewer Pipe” (Marston & Anderson 1913). This work was the beginning of methods for calculating earth loads on buried pipes. The formula is now recognized the world over as the Marston load equation (Moser 2001).

In 1933, M. G. Spangler presented three bedding configurations A, B, C, and the concept of a bedding factor to relate the supporting strength of buried pipe to the strength obtained in a Two or Three-Edge bearing test. Spangler’s theory proposed that the bedding factor for a particular pipeline and consequently the supporting strength of the buried pipe, is dependent on two installation characteristics (ACPA 2007):

1. Width and quality of contact between the pipe and bedding.
2. Magnitude of lateral pressure and the portion of the vertical height of the pipe over which it acts.

For the embankment condition, Spangler developed a general equation for the bedding factor, which partially included the effects of lateral pressure. For the trench condition, Spangler established conservative fixed bedding factors, which neglected the effects of lateral pressure, for each of the three beddings. Although conservative designs based on the work of Marston and Spangler have been developed and installed successfully for years, the design concepts have their limitations when applied to actual installations. The limitations include (ACPA 2007):

- Loads considered acting only at the top of the pipe.
- Axial thrust not considered.
- Bedding width of test installations less than width designated in the original bedding configurations.
- Standard beddings developed to fit assumed theories for soil support rather than ease of and methods of construction.
- Bedding materials and compaction levels not adequately defined.

Spangler’s bedding configurations and bedding factors were widely used in Australia and New Zealand, being adopted in both AS A35-1937 and AS CA33-1962 (NZS 4451:1974) (Standard Association of Australia SAA 1962).

In 1970, the ACPA began a long-range research program on the interaction of buried concrete pipe and soil. The research resulted in the comprehensive finite element computer program SPIDA (Soil-Pipe Interaction Design and Analysis) for the direct design of buried concrete pipe. Since the early 1980’s, SPIDA has been used for a variety of studies, including the development of four new Standard Installations of the AASHTO and ASTM Standards. This allowed the AS/NZS Standards, from 1989, to consider the replacement of the old A, B, C, and D beddings with the four new Standard Installations based on latest research (ACPA 2007).

The AS/NZS Standards recognized the developments of pipe installation design practice and consequently adopted the four new standard installations in the updated versions of AS 3725:1989 and AS/NZS 3725:2007. However, instead a of complete change to the new design, the documents adopt design methods that combine both old and new bedding standards in one system (Standard New Zealand 2007).

Spangler and ACPA design and Standard Installations are presented and compared with AS/NZS 3725:2007 Standard Installations and various New Zealand TA Standards. The conclusion and recommendations of this paper presents an outline for a proposed New Zealand Standard Installation. This should be developed to include the latest developments in buried pipe installation design theories, local New Zealand installation practices and locally available bedding materials.

2 BURIED PIPE DESIGN AND INSTALLATION

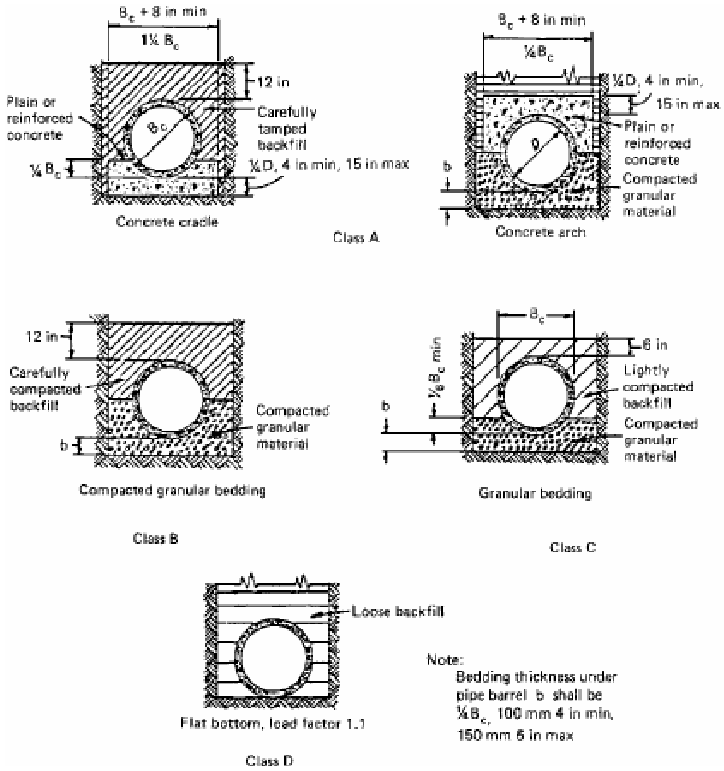
2.1 SPANGLER’S STANDARD INSTALLATIONS

Spangler’s standard installations (trench bedding) shown in Figure 1, are provided to distribute the vertical reaction around the lower exterior surface of the pipe and reduce stress concentrations within the pipe wall. The load that a concrete pipe will support depends on:

1. The width of the bedding contact area.
2. The quality of the contact between the pipe and bedding.

To achieve the best contact possible for any specific installation, bedding material should be selected to assure that positive contact can be obtained between the bed and the pipe with the compaction effort applicable to that installation. Since most granular materials will shift to attain positive contact as the pipe settles, an ideal load distribution can be attained through the use of clean coarse sand or well-graded, crushed rock. Both materials have high strength and stability to assure good durable support.

Figure 1: Standard Types of Installation (Moser 2001)



Embankment beddings follow the same general concept except the concrete arch (refer Fig 1 Class A, second design) which is not included in embankment bedding.

Under service conditions the vertical load on a pipe is distributed over its width and the reaction is distributed in accordance with the type of bedding. The in-place supporting strength of the pipe in any installation could be determined using the Marston equation, and the plant test strength of the pipe (Pipe Class) specified in the pipe manufacturing standards. Bedding factors must be developed to relate the in-place supporting strength to the more severe plant test strength. The bedding factor is the ratio of the strength of the pipe under the installed condition of loading and bedding to the strength of the pipe in the plant test. The two-edge bearing is the standard plant test in New Zealand and Australia, so all bedding factors relate the in-place supporting strength to the two-edge bearing strength.

Spangler, from analysis of test installations, established conservative fixed bedding factors for each of the standard classes of bedding used for trench installations. The same bedding factors were recommended for negative projection embankment installations, while higher bedding factor values were recommended for positive projection embankments. For wide trenches, Spangler developed the concept of using a variable bedding factor. The trench bedding factor transition to the higher value of the embankment factor as the trench widens (ACPA 2007).

The main theoretical principles and assumptions used in developing Spangler bedding factors are as follows:

1- The bedding factor for a particular pipeline, and consequently the supporting strength of the buried pipe, depends upon two characteristics of the installation:
   - Width and quality of contact between the bedding and the pipe
   - Magnitude of the lateral pressure and the portion of the vertical area of the pipe over which it is effective

2- In narrow trenches it is difficult to compact the bedding material and soil to the side of the pipe, therefore, the effect of lateral pressure was neglected in the development of the bedding factors, Table 1.

3- In positive projection embankment installations, the side fill material can be easily compacted. The effect of lateral pressure of the portion of installation above the pipe foundation is considered in evaluating the bedding factor. A variable bedding factor is recommended for each pipe depth/diameter, projection ratio, and settlement ratio, Table 1.

Table 1: Spangler's Bedding Factors

Bedding Type	Trench	Embankment (Max)*	Embankment (min)**
A	2.80	5.90	3.10
B	1.90	2.92	2.09
C	1.50	2.29	1.73
D	1.10	1.31	1.10
* Projection Ratio = 0.9, Settlement Ratio = 0, and H/D = 0.5			
** Projection Ratio = 0.3, Settlement Ratio = 1.0, and H/D = 15.0			

4- For wide trenches, Spangler and Schlick (early Iowa Engineering Experiment Stations publications) postulate that some active lateral pressure is developed in trench installations before the transition width is reached. Experience indicates that the active lateral pressure increases as the trench increases from a very narrow width to the transition width, provided the side-fill is compacted. A narrow trench is defined as a trench having a width at the top of the pipe equal to or less than the outside horizontal span plus one foot. Assuming a conservative linear variation, the variable trench bedding factor was determined by the following equation (ACPA 2007 – Appendix B):

$$B_{fv} = (B_{fe} - B_{ft})\left[\frac{B_d - (B_c + 1.0)}{B_{dt} - (B_c + 1.0)}\right] + B_{ft}$$

Where:

B_c = outside horizontal span of pipe, feet
B_d = trench width at top of pipe, feet
B_{dt} = transition width at top of pipe, feet
B_{fe} = bedding factor, embankment
B_{ft} = fixed bedding factor, trench
B_{fv} = variable bedding factor, trench

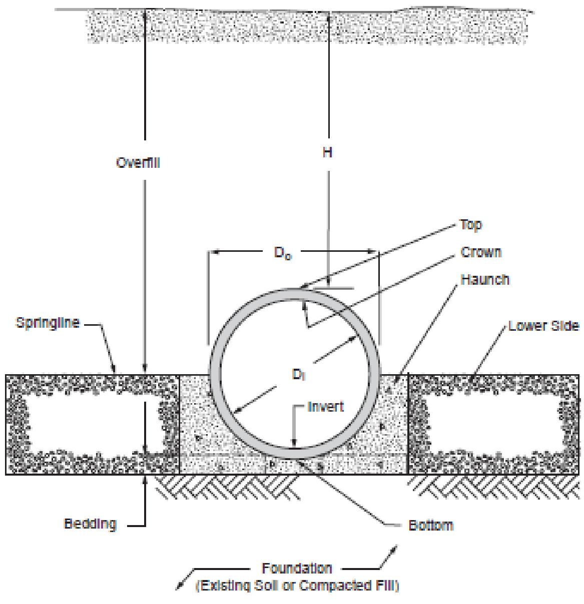
2.2 AMERICAN CONCRETE PIPE ASSOCIATION (ACPA) STANDARD INSTALLATIONS

2.2.1 ACPA STANDARD INSTALLATION

In 1970, ACPA began a long-range research program on the interaction of buried concrete pipe and soil. The research resulted in the comprehensive finite element computer program SPIDA, Soil-Pipe Interaction Design and Analysis, for the direct design of buried concrete pipe.

The ACPA research program resulted in the development of four new Standard Installations that replace the historical A, B, C, and D beddings used in the indirect design method, supported by a state-of-the-art method for the determination of bedding factors for the Standard Installations. Pipe and installation terminology used in the Standard Installations is shown in Figure 2 (ACPA 2007).

Figure 2: ACPA Installation Terminology



In 1996 the B, C, and D beddings, researched by Anson Marston and Merlin Spangler, were replaced in the AASHTO Bridge Specifications by the Standard Installations (ACPA 2007).

Various practical installations were selected after consultation with engineers and contractors and after the review of the results of numerous SPIDA parameter studies, four new Standard Installations were developed and are shown in Figure 3. The SPIDA studies were conducted for positive projection embankment, which is the maximum vertical load case for pipe, therefore it provides conservative results for other embankment and trench installation conditions.
The following parameters were studied to reflect ideas postulated from past experience which confirmed the following concepts:

- Loosely placed un-compacted bedding directly under the invert of the pipe significantly reduces stresses in the pipe.
- Soil in those portions of the bedding and haunch areas 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.
- Compaction level of the soil directly above the haunch, from the pipe springline to the top of the pipe grade level, has negligible effect on pipe stresses. Compaction of the soil in this area is not necessary unless required for pavement structures.
- Installation materials and compaction levels below the springline have a significant effect on pipe structural requirements.

The four Standard Installations provide an optimum range of soil-pipe interaction characteristics. For the relatively high quality materials and high compaction effort of Type 1 Installation, a lower strength pipe is required. Conversely, a Type 4 Installation requires a higher strength pipe, because it is developed for conditions with little or no control over materials or compaction. Generic soil types are designated in Table 2. The Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) soil classifications, equivalent to the generic soil types in the Standard Installations are presented in Table 3.

Figure 3: ACPA Standard Trench/Embankment Installation

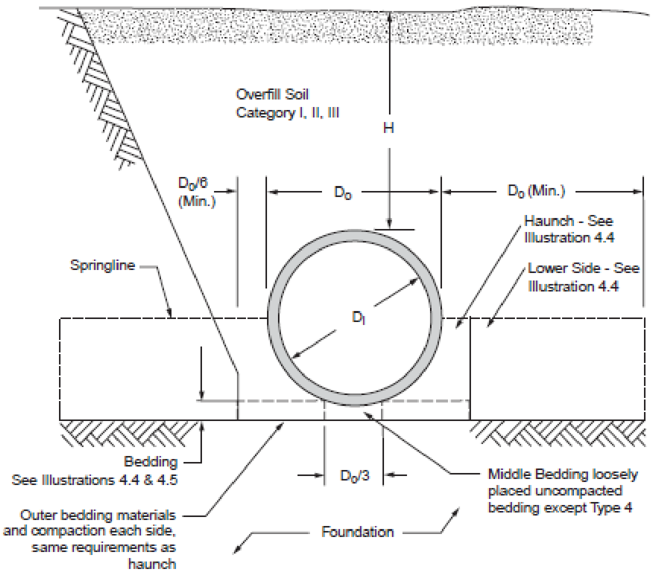


Table 2: ACPA Standard Installations Soil and Minimum Compaction Requirements

Installation Type	Bedding Thickness	Haunched and Outer Bedding	Lower Side
Type 1	Do/24 minimum, not less than 75 mm (3"). If rock foundation, use Do/12 minimum, not less than 150 mm (6").	95% Category I	90% Category I, 95% Category II, or 100% Category III
Type 2	Do/24 minimum, not less than 75 mm (3"). If rock foundation, use Do/12 minimum, not less than 150 mm (6").	90% Category I or 95% Category II	85% Category I, 90% Category II, or 95% Category III
Type 3	Do/24 minimum, not less than 75 mm (3"). If rock foundation, use Do/12 minimum, not less than 150 mm (6").	85% Category I, 90% Category II, or 95% Category III	85% Category I, 90% Category II, or 95% Category III
Type 4	No bedding required, except if rock foundation, use Do/12 minimum, not less than 150 mm (6").	No Compaction required, except if Category III, use 85% Category III	No Compaction required, except if Category III, use 85% Category III

Notes:

1. *Compaction and soil symbols - i.e. "95% Category I"- refers to Category I soil material with minimum standard Proctor compaction of 95%. See Illustration 4.5 for equivalent modified Proctor values.*
2. *Soil in the outer bedding, haunch, and lower side zones, except under the middle1/3 of the pipe, shall be compacted to at least the same compaction as the majority of soil in the overfill zone.*
3. *For trenches, top elevation shall be no lower than 0.1 H below finished grade or, for roadways, its top shall be no lower than an elevation of 1 foot below the bottom of the pavement base material.*
4. *For trenches, width shall be wider than shown if required for adequate space to attain the specified compaction in the haunch and bedding zones.*
5. *For trench walls that are within 10 degrees of vertical, the compaction or firmness of the soil in the trench walls and lower side zone need not be considered.*
6. *For trench walls with greater than 10 degree slopes that consist of embankment, the lower side shall be compacted to at least the same compaction as specified for the soil in the backfill zone.*
7. *Sub-trenches*
    a) *A sub-trench is defined as a trench with its top below finished grade by more than 0.1 H or, for roadways, its top is at an elevation lower than 1ft. below the bottom of the pavement base material.*
    b) *The minimum width of a sub-trench shall be 1.33 Do or wider if required for adequate space to attain the specified compaction in the haunch and bedding zones.*
    c) *For sub-trenches with walls of natural soil, any portion of the lower side zone in the sub-trench wall shall be at least as firm as the majority of soil in the overfill zone, or shall be removed and replaced with soil compacted to the specified level.*

Table 3: USCS and AASHTO Soil Classifications for SIDD Soil Designations

	Representative Soil Type		**Percent Compaction**	
SIDD Soil	**USCS**	**Standard AASHTO**	**Standard Proctor**	**Modified Proctor**
Gravelly Sand (Category I)	SW, SP, GW, GP	A1, A3	100 95 90 85 80 61	95 90 85 80 75 59
Sandy Silt (Category II)	GM, SM, ML, Also GC, SC with less than 20% passing #200 sieve	A2, A4	100 95 90 85 80 49	95 90 85 80 75 46
Silty Clay (Category III)	CL, MH, GC, SC	A5, A6	100 95 90 85 80 45	95 90 85 80 75 40

The SPIDA design runs with the Standard Installations were made with medium compaction effort of the bedding under the middle-third of the pipe and with some compaction of the overfill above the springline of the pipe. This middle-third area under the pipe in the Standard Installations has been designated as loosely placed, uncompacted material. The intent is to maintain a slightly yielding bedding under the middle-third of the pipe so that the pipe may settle slightly into the bedding and achieve improved load distribution. Compaction in the middle-third of the bedding with mechanical compactors is undesirable and could produce a hard flat surface, which would result in highly concentrated stresses in the pipe invert similar to those experienced in the three-edge bearing test. The most desirable construction sequence is to place the bedding to grade; install the pipe to grade; compact the bedding outside of the middle-third of the pipe; and then place and compact the haunch area up to the springline of the pipe. The bedding outside the middle-third of the pipe may be compacted prior to placing the pipe.

The selection of a Standard Installation for a project should be based on an evaluation of the quality of construction and inspection anticipated. A Type 1 Standard Installation requires the highest construction quality and degree of inspection. Required construction quality is reduced for a Type 2 Standard Installation and reduced further for a Type 3 Standard Installation. A Type 4 Standard Installation requires virtually no construction or quality inspection. Consequently, a Type 4 Standard Installation will require a higher strength pipe and a Type 1 Standard Installation will require a lower strength pipe for the same depth of installation.

2.2.2 BEDDING FACTORS FOR ACPA STANDARD INSTALLATIONS

Bedding factors for embankment conditions were determined for a range of pipe sizes and for the four standard installation investigated in the SPIDA program, Table 4 presents these bedding factors (ACPA 2007).

Table 4: ACPA Bedding Factors, Embankment Conditions

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

Notes:

1. *For pipe diameters other than listed in Table 4, embankment condition factors, can be obtained by interpolation.*
2. *Bedding factors are based on the soils being placed with the minimum compaction specified in Table 2 for each standard installation.*

For trench installations as discussed previously, experience indicates that active lateral pressure increases as trench width increases to the transition width, provided the side-fill is compacted. A SIDD parameter study of the Standard Installations indicates the bedding factors are constant for all pipe diameters under conditions of zero lateral pressure on the pipe. These bedding factors exist at the interface of the pipe wall and the soil and are called minimum bedding factors, to differentiate them from the fixed bedding factors developed by Spangler. Table 5 presents the minimum bedding factors.

Table 5: ACPA Trench Minimum Bedding Factors

Standard Installation	**Minimum Bedding Factor**
Type 1	2.3
Type 2	1.9
Type 3	1.7
Type 4	1.5

Notes:

1. *Bedding factors are based on the soils being placed with the minimum compaction specified in Table 2 for each Standard Installation.*

2. *For pipe installed in trenches dug in previously constructed embankment, the load and the bedding factor should be determined as an embankment condition unless the backfill placed over the pipe is of lesser compaction than the embankment.*

A conservative linear variation is assumed between the minimum bedding factor and the bedding factor for the embankment condition, which begins at transition width. The ACPA provides illustration 4.23 and equation 14 to calculate the transition width and the trench variable bedding factors (ACPA 2007).

The ACPA design method also provides variable bedding factor values for live loads. The live load bedding factors decrease with increase of pipe size, but they consequently increase with the increase of height of fill over the pipe. The values range from 2.2 for 300 mm pipe with 150 mm – 1500 mm of fill, to 1.1 for 3600 mm pipe with less than 150 mm of fill (ACPA 2007).

2.3 AUSTRALIAN AND NEW ZEALAND STANDARDS

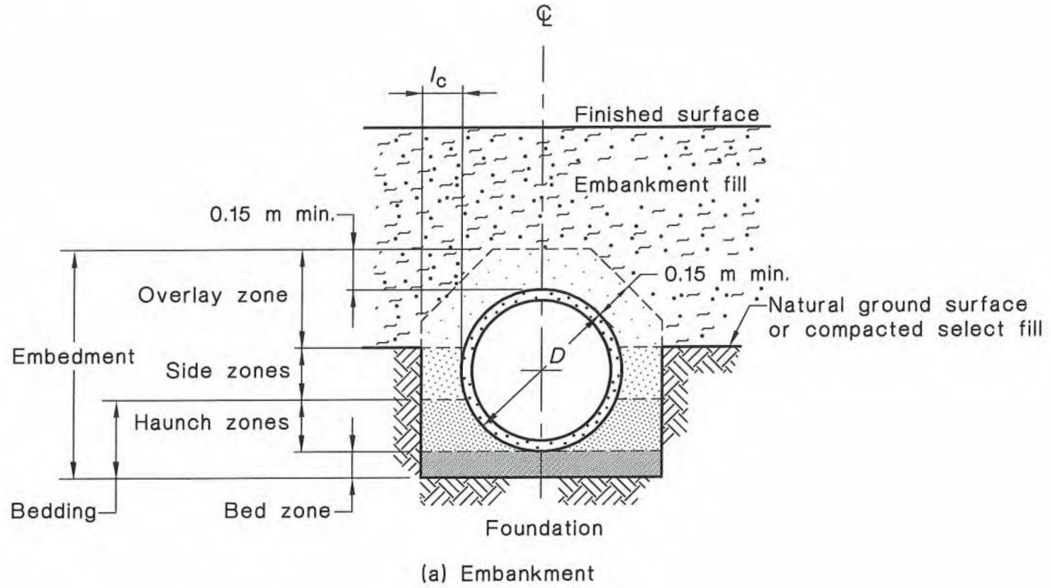
2.3.1 HISTORY AND BACKGROUND

Installation design of reinforced concrete pipes was first included as an appendix included in the 1937 edition of Australian Standard A35, Precast Concrete Drainage Pipes. It was omitted from the 1957 edition of that standard, reviewed and issued separately in 1962 as Australian Standard CA33-1962, Concrete Pipe Laying Design. In 1974 the New Zealand Standards Association declared this standard as NZS 4451:1974, and issued NZS 4452:1974, Code of Practice for the Construction of Underground Pipe Sewers and Drains, later reviewed and issued as NZS 4452:1986.

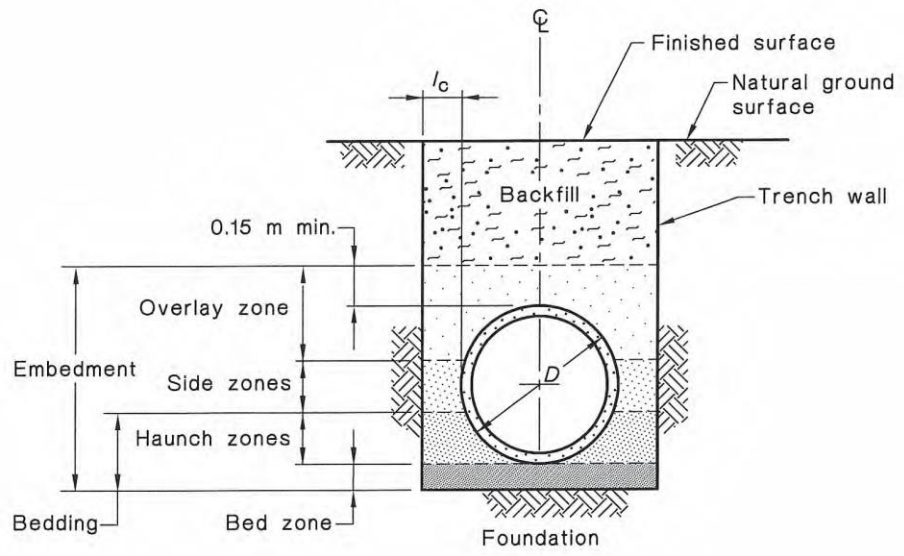
CA33-1962 and all related New Zealand Standards adopted Spangler's A, B, C, and D standard installations and bedding factors with minor changes to the depth and shape of granular bedding which did not affect the basic design criteria as proposed by Spangler.

In 1989, developments in the design of concrete pipe installation by the research work of the ACPA and the investigation work of the California Department of Transport, resulted in the issue of a new Australian Standard AS 3725:1989 Design for Installation of Buried Concrete Pipes. This Standard adopted a combination of concepts, Spangler's and the latest ACPA methodology and will be presented in the following paragraphs. The same design principles were extended and issued in the latest edition of, what is now a joint AS/NZS Standard, AS/NZS 3725:2007.

Figure 4: AS/NZS Standard Installation



(a) Embankment



(b) Trench

2.3.2 AS/NZS 3725:2007 STANDARD INSTALLATIONS

The AS/NZS 3725:2007 standard installations shown in Figure 4 have adopted Spangler's standard installations B & C for the H type support, where granular materials are compacted in the haunch zone, extending to 0.3D and 0.1D for H2 and H1 support. However, AS/NZS 3725:2007 allows the extension of the support to the springline of the pipe for HS3, HS2, and HS1 beddings at various compaction specifications ranging from 95% for HS3 to 85% for HS1, thus partially adopting the same ACPA designs for Type 1, 2, & 3 installations. Although AS/NZS 3725:2007 uses the same installation design as Spangler's and the ACPA, the bedding factor values for the same type of bedding are sometimes substantially different from the original source. Table 6 presents AS/NZS 3725:2007 bedding factors and compares with the equivalent as per Spangler and the ACPA.

Table 6: Bedding Factors for Various Standard Installations

Support Type		Minimum Depth mm		Minimum zone compaction %			Bedding Factor AS/NZS 3725			Spangler's BF			ACPA BF	
					Side Zones									
		Bed Zone	Haunch Zone y	Bed and Haunch zones I_D	I_D	R_D	3725 graded materials or cement stabilized	bedding materials outside 3725 zones	bedding materials with passing seive 0.6mm outside 3725 zones	Trench	Embankment (min @ Zero Projection)	Embankment (Max. @ 0.9 projection)	Minimum Trench	Average Embankment***
U		75.0					1.0	1.0	1.0	1.1	1.1	1.3	1.5	1.7
H	H1	100 unless D>1500, use 150	0.1D	50			1.5	1.275	1.5	1.5*	1.7*	2.29**	N/A	N/A
	H2		0.3D	60			2.0	1.7	1.5	1.9**	2.02**	2.92**	N/A	N/A
HS	HS1	100 unless D>1500, use 150	0.1D	50	50	85	2.0	1.7	1.5	N/A	N/A	N/A	1.7	2.4
	HS2		0.3D	60	60	90	2.5	2.125	1.5	N/A	N/A	N/A	1.9	3.0
	HS3		0.3D	70	70	95	4.0	3.4	1.5	N/A	N/A	N/A	2.3	4.0

** Spangler's Based on y = 0.166 D*

*** Spangler's Based on y =0.5 D*

**** Variable with pipe size*

The result of adopting a hybrid concept of two designs, which are based on different theoretical approaches of pipe soil interaction analysis, is a document with some basic technical irregularities. Application of the document is very difficult and costly in most parts of New Zealand, causing a lot of confusion to Asset Owners, Engineers, and Constructors.

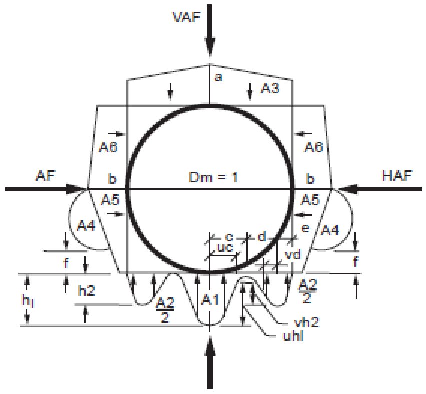
The following points present some of the issues that have been highlighted in New Zealand with the implementation of AS/NZS 3725:2007 for concrete pipe design and installation;

1. Mixing of Spangler's and the ACPA approaches becomes very clear when AS/NZS 3725:2007 specifications for compaction of materials in bed and haunch zones is considered. The ACPA concept of allowing a loosely compacted zone to 1/3 of the width of the pipe directly under the pipe is adopted, which is incorrect for Spangler's installation, where all materials in this zone should be compacted to the highest possible stiffness. On the other hand, for HS installations the specification requires full compaction and testing for the bedding materials in the haunch zone, directly under the pipe, with AS/NZS 3725 Supp. 1: 2007 stating the following;

   > In order to achieve adequate compaction in the field, fill material should be placed and compacted in relatively thin layers. For ordinary fill (no stones larger than 150 mm), the layer thicknesses should not exceed 200 mm. For select fill (no stones larger than 75 mm), the layer thicknesses should not exceed 150 mm. The moisture content of cohesive fill should also be kept within a specified range, usually taken to be 85% to 115% of the optimum moisture content of the material. Where physically possible, field tests, as outlined in AS 1289/NZS 4402, should be regularly used to measure the degree of compaction being achieved. In areas such as beneath the pipe in the haunch zone, it is not possible to conduct tests such as AS 1289.5.3.1/NZS 4402.5.1.1 due to limited headroom. Yet, in such areas compaction can be extremely critical and it is suggested that a dynamic cone penetrometer, such as that described in AS 1289.5.3.2, be specified to be used on an angle to probe adjacent to the haunch. It would be necessary to calibrate the cone, operating at the same angle in the same material, with a known degree of compaction.

   The above statement is correct for Type H bedding, provided that includes the materials in the bed zone directly under the pipe. However, it is not correct for Type HS beddings, where the analysis assumed that soils in the bed and haunch area directly under the pipe are difficult to compact and hence were left lightly compacted (D/3), or an uncompacted haunch. Analysis of the earth pressure distribution for the ACPA or Type HS installation shown in Figure 5 below illustrates this point.

Figure 5: ACPA Earth Pressure Distributions



2. The limitations on grading of fill materials for the bed zone was based on the concept that fine, well graded sand will compact well in the difficult areas directly under the pipe as required by Spangler's approach. This may be correct for Type H bedding, but is not required for Type HS bedding as supported by the finite element analysis of the ACPA installations.

3. The limitation on grading of fill materials only allows the use of "Category 1" materials for all type HS beddings, while ACPA analysis allows the use of lower quality materials at higher compaction levels to achieve the same installation type results. The AS/NZS 3725:2007 limitation on material grading excludes the use of locally available materials such as fine dune sands and river gravels, which are available in large quantities around New Zealand and could be easily compacted to the required level. Furthermore, AS/NZS 3725:2007 generally does not allow the use of excavated materials even if high compaction standards are achievable without high cost cement stabilization. Table 7 below presents a list of natural soils that could be used for pipe bedding as per the ACPA Standard Installation. Apart from the MH, CH, and "Class V" soils, all materials listed are acceptable for pipe bedding at various compaction levels that give the required final stiffness. Lime drying practice, which is very common in New Zealand, may also reduce the plasticity of the CH and MH soils to allow their use for pipe bedding.

4. The limitation on grading of fill materials may be due to the Australian Standard adopting the results of the California Department of Transport study in the early 1970's which concluded that the use of well graded aggregates will produce better pipe support than single size aggregates (Bacher & Davis 1980) . However, the recommendation of that study was not conclusive and may be attributed to construction techniques. This study was superseded by the more advanced work of the ACPA that has been adopted in the US.

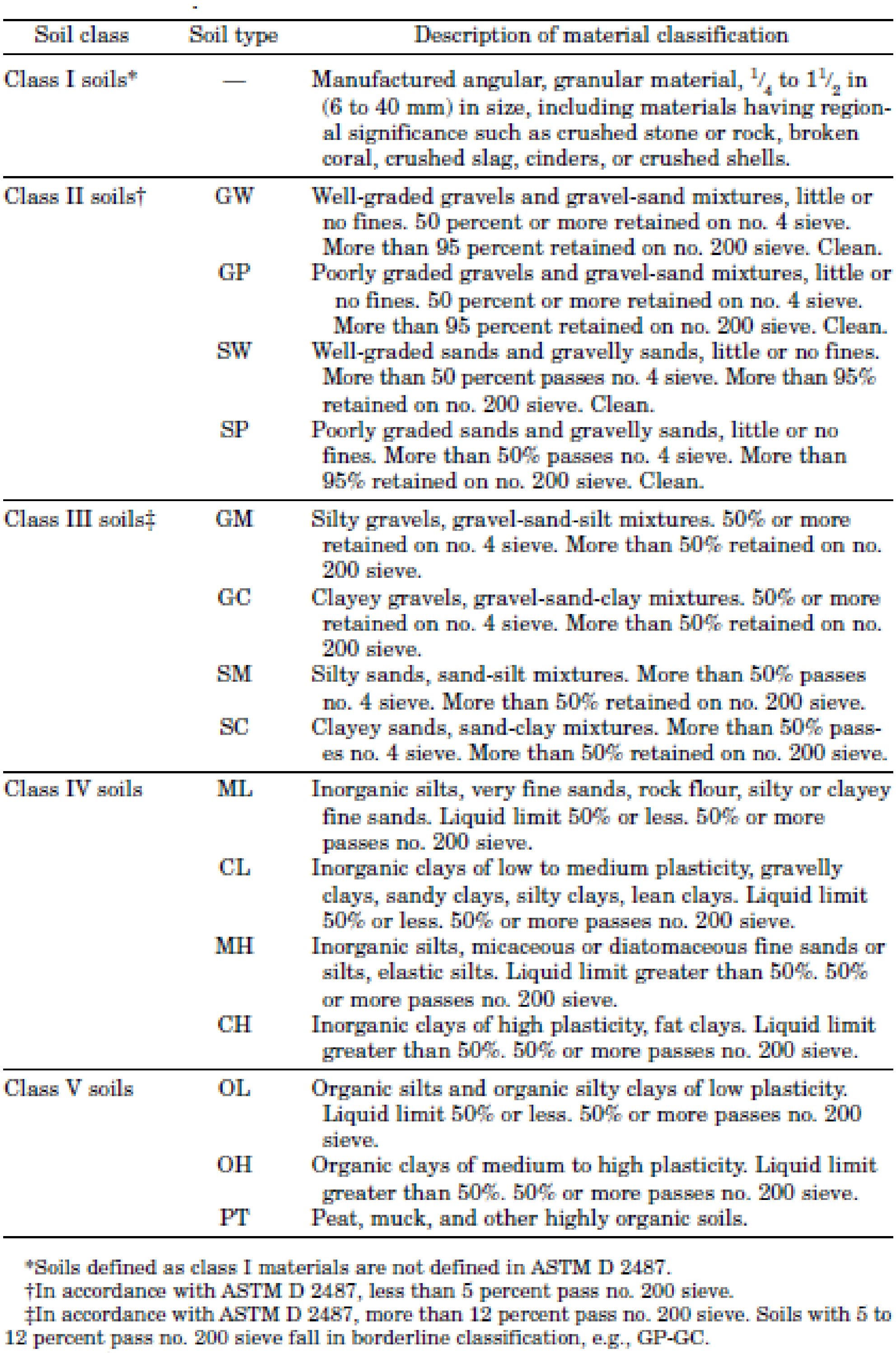
5. The values of bedding factors for Type U, HS1, and HS2 beddings are much lower than the equivalent ACPA Type 4, 3, and 2 beddings. If the limitation on grading is considered, which is not applied for ACPA bedding with similar materials, further reduction in the bedding factor is required. This results in the use of much higher Class pipes for similar installation conditions. This fact is highlighted in Table 6. The reduction of the bedding factor to 1.5 when materials with portion passing sieve size 0.6mm outside the specified limit, is not supported by any theoretical or practical approach, or used by any of the original installation standards. Self-compacting single size crushed rock, for example, could be used as an ideal material for HS3 bedding in narrow trenches. However, AS/NZS 3725:2007 downgrades the high supporting value of this material to what is equivalent to "No Bedding" as per the ACPA standard installation, without any apparent reason.

6. AS/NZS 3725:2007 uses the same bedding factors for both trench and embankment installations. This may be correct when considering the general practice in New Zealand where wider trenches are used to achieve good compaction of the bedding materials, and to comply with H & S requirements, but narrow trenches with trench shields are also used, especially in urban areas, or for deep trenches. Calculation of the transition width, actual bedding factor and clarification of applicability of each installation type to the proposed

installation, is required. Table 2 solutions do just this while AS/NZS 3725:2007 is unclear in places and restrictive in others.

7. AS/NZS 3725:2007 uses a constant live load bedding factor of 1.5 for all installations where the dead load bedding factor is 1.5 or more. The use of a constant live load bedding factor of 1.5 for all pipe sizes and installations shows a wide range in real world factors from conservative to potentially overly optimistic.

Table 7: Description of Bedding Material Classification (Moser 2001)



Soil class	Soil type	Description of material classification
Class I soils*	—	Manufactured angular, granular material, $^1/_4$ to $1^1/_2$ in (6 to 40 mm) in size, including materials having regional significance such as crushed stone or rock, broken coral, crushed slag, cinders, or crushed shells.
Class II soils†	GW	Well-graded gravels and gravel-sand mixtures, little or no fines. 50 percent or more retained on no. 4 sieve. More than 95 percent retained on no. 200 sieve. Clean.
	GP	Poorly graded gravels and gravel-sand mixtures, little or no fines. 50 percent or more retained on no. 4 sieve. More than 95 percent retained on no. 200 sieve. Clean.
	SW	Well-graded sands and gravelly sands, little or no fines. More than 50 percent passes no. 4 sieve. More than 95% retained on no. 200 sieve. Clean.
	SP	Poorly graded sands and gravelly sands, little or no fines. More than 50% passes no. 4 sieve. More than 95% retained on no. 200 sieve. Clean.
Class III soils‡	GM	Silty gravels, gravel-sand-silt mixtures. 50% or more retained on no. 4 sieve. More than 50% retained on no. 200 sieve.
	GC	Clayey gravels, gravel-sand-clay mixtures. 50% or more retained on no. 4 sieve. More than 50% retained on no. 200 sieve.
	SM	Silty sands, sand-silt mixtures. More than 50% passes no. 4 sieve. More than 50% retained on no. 200 sieve.
	SC	Clayey sands, sand-clay mixtures. More than 50% passes no. 4 sieve. More than 50% retained on no. 200 sieve.
Class IV soils	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands. Liquid limit 50% or less. 50% or more passes no. 200 sieve.
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. Liquid limit 50% or less. 50% or more passes no. 200 sieve.
	MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts. Liquid limit greater than 50%. 50% or more passes no. 200 sieve.
	CH	Inorganic clays of high plasticity, fat clays. Liquid limit greater than 50%. 50% or more passes no. 200 sieve.
Class V soils	OL	Organic silts and organic silty clays of low plasticity. Liquid limit 50% or less. 50% or more passes no. 200 sieve.
	OH	Organic clays of medium to high plasticity. Liquid limit greater than 50%. 50% or more passes no. 200 sieve.
	PT	Peat, muck, and other highly organic soils.

*Soils defined as class I materials are not defined in ASTM D 2487.
†In accordance with ASTM D 2487, less than 5 percent pass no. 200 sieve.
‡In accordance with ASTM D 2487, more than 12 percent pass no. 200 sieve. Soils with 5 to 12 percent pass no. 200 sieve fall in borderline classification, e.g., GP-GC.

8. AS/NZS 3725:2007 does not allow for some installation conditions commonly seen in New Zealand, such as;
    - Possibility of migration of fines where gap graded bedding material is used (mentioned only in the Supp.)
    - The use of free drainage bedding materials in wet installations.
    - The use of sub-trenches.
    - Installation in weak soils.
    - Installation under various levels of supervision.

2.3.3 NEW ZEALAND STANDARDS, COUNCILS AND OTHER TERRITORIAL AUTHORITY SPECIFICATIONS:

Most New Zealand Territorial Authority Standards, and the latest version of NZS 4404:2010, Land Development and Subdivision Infrastructure, use the old Spangler installations in one way or another, many with modifications that are based on practical experience rather than theoretical background. Only NZTA Specifications clearly reference AS/NZS 3725:2007 as the standard for the design and installation of concrete pipes. All other authorities generally fail to specify values for bedding factor or advise the use of the standard to calculate pipe class and to select type of bedding, although some discuss either the 1989 or 2007 versions of 3725 in their texts.

Table 8 presents installation specifications of the existing New Zealand Standards and local installation specifications of some of the larger New Zealand City Councils. Analysis of the data in Table 8 indicates the following:

1. Most TA specifications theoretically provide pipe support that resulting in bedding Factors of 4 or more, nevertheless the selection of pipe Class is normally based on a bedding factor value of 1.5 or 2.0.

2. Some specifications require granular bedding to extend over the pipe top, while theory indicates that bedding above the springline of the pipe provides no advantage to pipe support.

3. Many specifications require the use of high quality, crushed rock materials for bedding which can be difficult to compact. The theory indicates that such materials are not required to produce the lowest value of support of 1.5 that is used in design.

4. No specification clearly indicates that cost effective locally available materials and/or excavated materials are acceptable for bedding, provided that correct installation methods and bedding factors are used. Theory and overseas practice clearly supports this approach.

5. No specifications recognize the effect of compaction level on pipe support; typically a single value of compaction is specified or the specifications include a general term of “compacted granular materials”.

*Table 8: New Zealand Installation Specifications**

Standard	Bedding Type	Type of Bedding Material	Depth of Bedding	Bedding Factor	Notes
NZS 4452:1986	Type A	Concrete	D/4	Not Specified	
	Type B	Compacted Granular Bedding	D/4	Not Specified	
	Type C	Compacted soil free from large stones	D/6	Not Specified	Shape subgrade for earth foundation(no bedding)
	Type D	N/A			Flexible Pipes
	Type E	None		Not Specified	Not Recommended
NZS 4404:2010	Type 1	Concrete	D/4	Not Specified	
	Type 2	Granular Materials	D/2	Not Specified	
	Type 3	N/A			For Flixable Pipes
	Type 4	Granular Materials	D + 150mm	Not Specified	Where immegration of fines expected (wrap with Geotextile)
Tauranga City					Same as NZS 4452:1986
Hamilton City	H2	Free draining granular materials 95% Compaction	D + 300	2.0 or 1.7?	With referance to AS/NZS 3725:2007
Nelson City	H2	AP20 + Clegg Impact Value 35 for roads and 25 for others	D/3	2.0 or 1.7?	Geotextile wrap where immegration is possible
Wellington Region	N/A	5-20 Drainage to D/4 + 20 & 40 Drainage to D + 150mm	D +150	Not Specified	Geotextile wrap where immegration is possible
Palmerston North	Normal	Same as WR	D/4	Not Specified	Compaction 95% to top of trench.
	Others				Spec. Text required AS/NZS 3725
Dunedin City	N/A	Concrete	Various	Not Specified	
Hastings City	N/A	Granular Bedding	D/4	Not Specified	NZS 4451:1976
Auckland City	H2	GAP20	D/2	2.0 or 1.7?	Calculated as per AS/NZS 3725:2007
Christchurch City	N/A	AP40	Variable, D to D/4	Not Specified	Under Review

** For Reference see (SNZ (1986), SNZ (2010), TCC (2011), HCC (2010), NCC (2010), WCC (2012), PNCC (2014), DCC (2010), HDC (1997), AC (2013), and CCC (2013))*

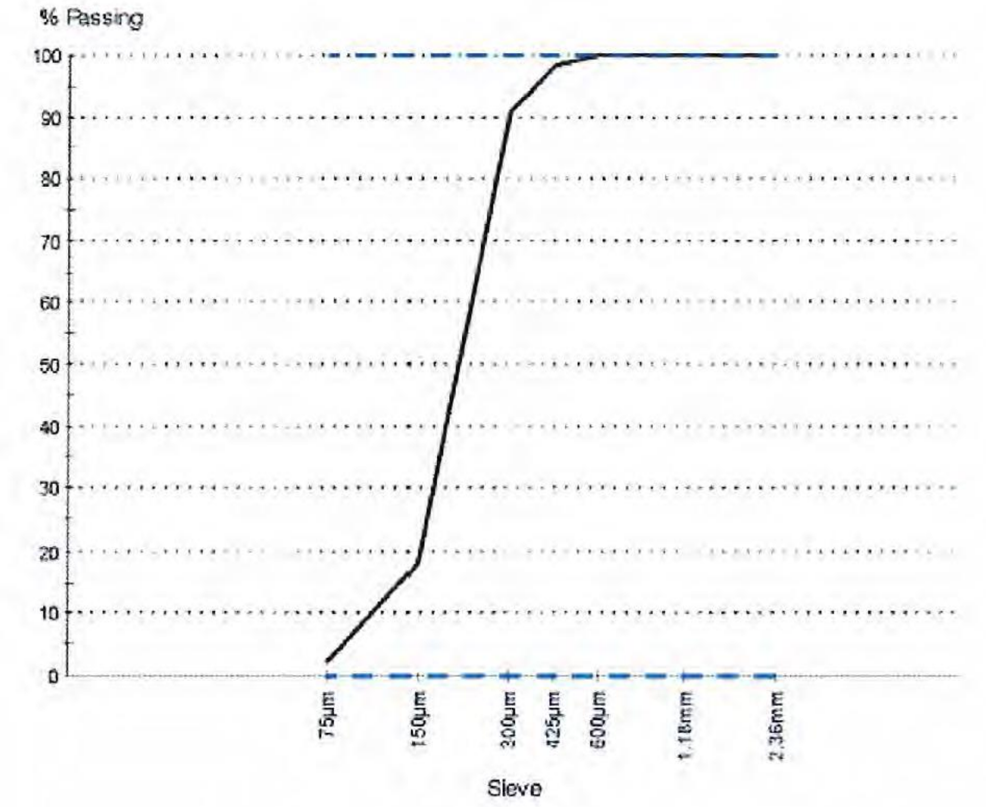
6. Some specifications still refer to the obsolete concrete bedding which was phased out in New Zealand practice in the 1980’s. Flowable fill bedding is widely used to replace concrete bedding when high design bedding factors are required. Generally the use of flowable fill agrees with correct theory and practice.

2.4 CASE STUDY

For a major roading project in the North Island, abundant quantities of fine dune sand were available on site along the construction area. Grading of this sand, shown in Figure 6, was presented to the project engineers for approval and comment. The project engineers rejected all the materials as the grading was outside the limits of Table 5 and 6 of AS/NZS 3725:2007. They also commented that, even if this material is compacted to the standard requirements, it will not achieve the design bedding factor of 2.5 (HS2 Bedding - Clause 9.3.2 –a of the Standard), unless it is cement stabilized.

However, Clause 2.2 of AS/NZS 3725:2007 allows the use of materials other than that specifically referred to in the Standard, providing such material can be shown to meet the intent of the Standard. At the request of the project team, research was undertaken to investigate any possible installation conditions that could utilize the available fine sand as a bedding material, while addressing the requirement of the Standard at the same time.

Figure 6: Grading of Dune Sand in Construction Area



Compactibility of the local fine sand was tested using the intended construction methods in actual trenches in the field. The results shown in Table 9 indicate that flooding the sand overnight and plate compactor compaction will give relative densities in excess of 100%, which exceeds the 95% specified for HS3 Bedding and 90% specified for HS2 Bedding.

The final conclusions of the study, which were implemented in the project, are as follows;

1. The fine sand and installation conditions in the project are suitable to achieve the highest support type as calculated by ACPA design procedure since the bedding material is classified as Category I and the 95% compaction standard is achievable.

2. AS 3725:1989 also allows the material and method with a 15% reduction in bedding factor. Hence a bedding factor of 3.4 could be used, as the required degree of compaction for HS3 bedding is achievable. CPAA design software “PIPE CLASS V2” gives the same result, while the design bedding factors for that installation was 2.5 (HS2).

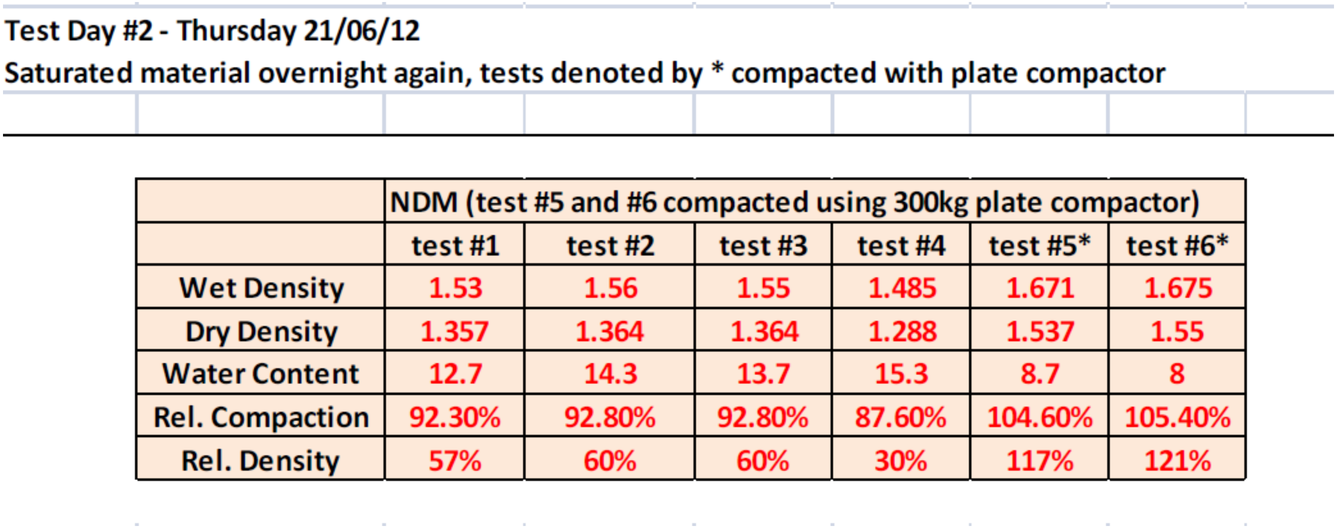
3. The limitation of the bedding factor value to 1.5 as per AS/NZS 3725:2007 may not be applicable to this case for the following reasons:

- Cement stabilization was not needed to enhance compaction as materials finer than 0.150 mm sieve were within the standard limits.

- Scouring of bedding materials and/or migration of soil fines is unlikely in this installation as it is an embankment installation with total sand environment and there will be no water channels through bedding materials, a condition mentioned in the standard.

- Geotextile wrapping of the pipe sub-trench could be used to provide more assurance to the long term stability of the bedding.

Table 9: Field Test Results



Test Day #2 - Thursday 21/06/12

Saturated material overnight again, tests denoted by * compacted with plate compactor

	NDM (test #5 and #6 compacted using 300kg plate compactor)					
	test #1	test #2	test #3	test #4	test #5*	test #6*
Wet Density	1.53	1.56	1.55	1.485	1.671	1.675
Dry Density	1.357	1.364	1.364	1.288	1.537	1.55
Water Content	12.7	14.3	13.7	15.3	8.7	8
Rel. Compaction	92.30%	92.80%	92.80%	87.60%	104.60%	105.40%
Rel. Density	57%	60%	60%	30%	117%	121%

CONCLUSION

The following conclusions may be drawn from the issues discussed in this paper:

1. The developments in computer aided analysis techniques in the 1970s have led to a better understanding of the complicated concrete pipe soil interaction problems, and hence to the development of more practical and economical installation design and construction practices.

2. It is now time to develop a New Zealand National Installation Design Standard that implements the scientifically proven understanding of the pipe–soil interaction problem, the use of locally available materials and nationally established construction practice.

3. The general features of the new installation standard should consider the following:

    I. All installations should be based on haunch and side support, HS. Fill materials should be extended to the springline of the pipe.

II. Bedding factors should be consistent with compaction standards achievable for a range of materials. Higher factors being nominated for "high" compaction standards of quality material, lower bedding factors for "low" compaction and/or the use of lower quality materials.

III. Fill material should be based on any available material that is free from lumps or very large rocks, organic materials and highly plastic clays. Selection of bedding factors for design should be based on the expected stiffness of the selected fill material. Selection of bedding material and installation design should also consider the future stability of the pipe support in the specific installation.

IV. The same bedding factors could be adopted for both embankment and wide trench installations, while different bedding factors should be specified for narrow trenches.

V. Selection of bedding materials and installation methods should be designed and specified by the Design Engineer.

VI. Design should be reviewed if site conditions require changes to the specification.

VII. The quality of the pipe subgrade, trench side support, possibility of impregnation of fines and fill compaction should be controlled by a suitably qualified site engineer or supervisor.

VII. The range of specified bedding factors could be reduced by a value appropriate to the expected level of "Quality Assurance" on site, example, 0% reduction when full testing and control is available on the project and 50% reduction when no control is available. Values could be interpolated for various other control levels.

RECOMMENDATIONS

It is recommended that a small working group be assembled of designers, manufacturers and installers to review the application of AS/NZS 3725:2007 in New Zealand conditions where local materials, water table and historical practice may require future special consideration under the standard by way of amendments or regional variations, the working group could consider (but not limited by) the following points to be addressed:

1. The joint Australian New Zealand Standard AS/NZS 3725:2007 has endeavored to implement latest installation design developments, but at the same time retain the well-established 1930's procedures. This mixing of standards, that are based on different concepts, has led to confusion and misunderstanding of what the standard set out to achieve.

2. The AS/NZS 3725:2007 document also adopts a highly conservative approach, possibly based on the assumption that the installation may be carried out without any expert quality control or supervision. However, the standard specifies highly restrictive testing regimes without considering the practicality of implementation.

3. Most New Zealand Territorial Authorities declined to implement the AS/NZS 3725:2007 Standard for their concrete pipe installation design and construction.

Instead, they specify a single type of installation without any reference to bedding factor or design input by the Design Engineers.

4. The confusion between standards has led to the use of installations that are highly overdesigned in most cases, the use of expensive imported fill materials, complicated and costly construction operations and higher pipe classes.

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