BETTER UNDERSTANDING OF THE INTENT OF AS/NZS 3725:2007 – CASE STUDY

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ABSTRACT

The joint Australian – New Zealand Standard for design and installation of buried concrete pipes AS/NZS 3725:2007 states in one of its application Clauses that "*this standard shall not be interpreted so as to prevent the use of materials or methods of design or construction not specifically referred to herein, provided that such materials or methods can be shown to meet the intent of this Standard*". This clause allows users to divert from the use of the specified materials and methods to meet site specific conditions.

The Concrete Pipe Association of Australasia (CPAA) published a "Guidelines for Selecting Materials for Bedding SRC Pipes". This guideline addresses the intention of the Standard to achieve certain levels of pipe support for each installation condition, while allowing the use of materials outside the Standard grading limits. However, the CPAA guidelines exclude conditions where long term stability of installation might be affected.

In a recent pipe culvert installation, the contractors used gap graded materials outside the limits of the AS/NZS 3725:2007 to achieve both good compaction and free drainage conditions. These conditions allowed for the installation of the large diameter pipe culverts during the wet winter season of 2016. The Engineer requested a proof that this diversion met the intent of the Standard before signing off the work for further embankment construction.

A comprehensive study was made to evaluate the background behind the specified grading requirements, and their possible effect on performance of the existing installation. Results indicate that most of the culverts are satisfactory, while a few needed minor remedial works. All recommendations were accepted by the asset owner engineer and successfully implemented.

This paper clarifies the intent of the material grading requirements of AS/NZS 3725:2007 using the first principles of soil mechanics and the historical background of pipe installation theories and practices. The case study provides an example of how engineers could evaluate compliance of any diversion of the Standard.

KEYWORDS

Concrete Pipes, Installation, bedding materials, specifications.

PRESENTERS PROFILE

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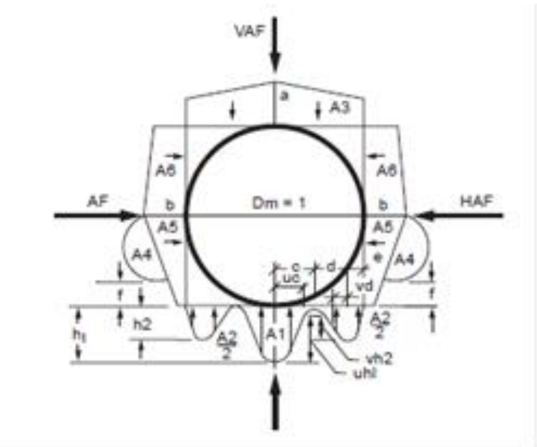
1 INTRODUCTION

The Classic Theory of earth load on concrete pipes and its developments overseas and in Australia-New Zealand has been discussed in detail in a paper to Water New Zealand Stormwater Conference 2015 (Al-Saleem & Langdon 2015). The paper concluded that AS/NZS 3725:2007 has selected bedding materials to meet the requirements for two different design concepts i.e. Spangler Classical Bedding Design and Side Support Design adopted by ACPA and based on Finite Element analysis and work of Heger who based his earth pressure distribution (ACPA 2007), for its Hunch and Side Support respectively. Heger's earth pressure distribution and assumptions are shown in Figure 1 below:

Figure 1: Heger Earth Pressure Distribution



- 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.

National Standards for pipe installation worldwide usually adopted one or both theories. Experience indicates that both are correct and achieve the same result of safe workable installation. Common to both theories is the importance of achieving uniform support of the pipes, in the bed, hunch, and side support zone. Typically this is achieved through the use of granular materials compacted to a specified level to achieve the required support and load transition.

Many National Standards achieve the required pipe support by specifying bedding materials in generic terms of soil types and soil classification. They leave the final assessment of suitability of any specific local or imported material and the proposed installation methodology to the Designers and Installers. Full investigation is required to justify the use of any selected material.

On the contrary, AS/NZS 3725:2007 (AS/NZS 2007) which adopts same pipe support theories, specifies material with certain grading limits to achieve pipe support objectives for all site and operation conditions. AS/NZS 3725:2007 bedding material grading was carefully selected to achieve the following:

- Good haunch and side support for all pipe size range
- Ease of compaction
- Long term stability by not allowing migration of fines

Therefore, it relieves Designers and Installers of the need to investigate the suitability of the bedding material to their specific application.

In field applications in New Zealand specifiers and contractors find difficulties in supplying materials to the Standard grading limits at feasible cost. Furthermore, many prefer to use open graded (free draining materials) as being more suitable to the wet conditions of New Zealand.

AS/NZS 3725:2007 already considered such implications by allowing Designers and Installers to divert from the Standard restrictions by stating that *"this standard shall not be interpreted so as to prevent the use of materials or methods of design or construction not specifically referred to herein, provided that such materials or methods can be shown to meet the intent of this Standard"*.

However AS/NZS does not provide a clear explanation for the recommended material grading, making it difficult for Engineers to consider other grading.

This work explains the intent of the Standard in selecting grading limits for bedding materials by referring to pipe bedding theories, overseas national standards, AS/NZS flexible pipe standard, and various comments in AS/NZS 3725:2007 and its commentary. The concept of accepting materials based on complying with the intent of the Standard is presented in this work as applied on actual culvert pipe installation in Waikato Express Way– Hamilton Bypass.

2 AS/NZS 3725:2007 MATERIALS AND METHODS

2.1 AS/NZS 3725:2007 Standard Bedding Materials

AS/NZS 3725:2007 specifies bedding materials in the bed and haunch zone that meet the grading limits of Table 5 of the Standard as reproduced in Table 1 below. The standard assumes as clearly shown in Clause C9.2.2 of its commentary that the materials complying with this grade are encountered in pipe trench excavation rather than imported. However, experience in New Zealand indicates that it is very rare to find such material in pipe trench excavations.

Table 1: Grading Limits of Materials for Bed and Hunched Zone

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

The Standard also specifies material with wider grading range for side zone as shown in Table 2, but practice shows that use of two bedding materials is not practical and most installers adhere to the more restricted Table 1 specification for their all bedding materials.

Table 2: Grading Limits of Materials for Side Zone

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

The Standard also acknowledges that complying materials may not be available on site and, hence it advises that it is possible to still use noncomplying materials provided that it is either cement stabilized or could be compacted to the required limits and bedding factors are reduced as per the following text of Clause 9.3.2:

1. *Bedding factors should be reduced to 1.5 for both H and HS supports if the bed and haunch zones materials have a fraction passing the 0.6 mm sieve outside the specified limit, and not otherwise cement stabilized.*

2. *Any maximum bedding factors should be reduced by 15% if the grading of the bed and haunch zones materials fell outside the limits of other sieve sizes.*

2.2 AS/NZS 3725:2007 STANDARD BEDDING

AS/NZS 3725:2007 specifies 6 types of installation with correspondent Bedding Factor for each installation as shown in Table 3 below:

Table 3 – AS/NZS 3725:2007 Bedding Factors

Support Type		Minimum depth, mm		Minimum zone compaction, %			Bedding factor (*BF*)
		Bed zone x	Haunch zone y	Bed and haunch zones *ID*	Side zones		
					ID	*RD*	
U		75					1.0
H	H1	100 if D < 1500; or 150 if D > 1500	0.1D	50			1.5
	H2		0.3D	60			2.0
HS	HS1	100 if D < 1500; or 150 if D > 1500	0.1D	50	50	85	2.0
	HS2		0.3D	60	60	90	2.5
	HS3		0.3D	70	70	95	4.0

The bedding factors represent the ratio between the maximum bending moment in pipe in the 2 edge bearing test, to the maximum actual bending moment in the installed pipe. Bending moment for H1 and H2 installation were calculated by Spangler using theory of elasticity, while bending moment for side support types HS1 to HS3 were calculated using Finite Element analysis and Heger's Earth Pressure distribution.

The HS types are recommended for major installations where bedding materials are extended to the springline of the installed pipes. Engineering design and input are usually required when this level of support is specified. Less Engineering input is usually practiced with H1 and H2 installations.

2.3 FACTORS AFFECTING SUPPORT AND STABILITY

Review of Table 3 illustrates that the bedding factor for various types of side support increase as the compaction increases. Therefore, the main control on the construction process are compaction tests. Other factors that might affect pipe support and stability are achievable within AS/NZS 3725:2007 by the use of the specified materials as detailed below:

2.3.1 Compaction

National Standards other than AS/NZS 3725:2007 which do not place restrictions on the bedding materials grading, allow for the difficulty to compact materials under the hunch of the pipe. The Standards either assume that it is not well compacted and hence, redistribute the earth pressure on the pipe like the American Concrete Pipe Association's Heger's assumption, or reduce the bedding factor from the theoretical value following Spangler's approach, as per the old New Zealand Standard, UK, European and many other standards.(NZS 1986)(EN 2015)(EN 1997)

Figure 2 – Theoretical Bedding Factors from Theory of Elasticity (Young & Trott 1984)

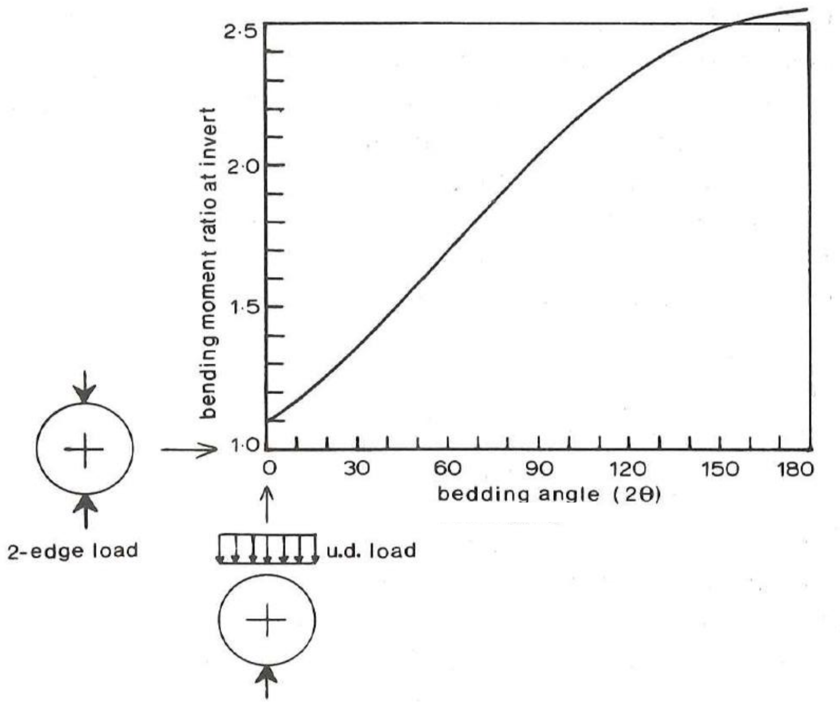


Figure 2 indicates that theoretical bedding factors for H1 where the angle equal to about 50 Degrees is about 1.5, and the bedding factor of angle 90 Degrees correspondent to bedding H2 is about 2. This means that AS/NZS 3725:2007 is relying on the material grading and compaction control at the surface of the bedding to achieve the theoretical bedding factor values. While most National Standards use a bedding factor of 1.9 for a bedding angle of 180 Degrees where the theoretical bedding factor is 2.5.

The Supplement of AS/NZS 3725 (AS/NZS 2007) also discusses in detail compaction requirements. It proposes cement stabilization to achieve the required compaction when the grading of the bedding materials is outside the fine content limits, specifically that less than sieve size 0.15mm. However, it stops short of discussing cases where coarse materials content exceeds the upper limits, possibly because it emphasizes on use of "as dug materials" as clearly shown in Clause C9.2.2.

UK Standards and the old NZS 4452:1986 use an ease of compaction test in addition to the use of bedding factor values already reduced from the theoretical, with no reference to gradation other than ease of compaction values.

The UK Water Industry Information and Guidance Note on "Bedding and Side fill Materials for Buried Pipelines" IGN 4-08-01 (UK WIR 1994) specifies in Section 3 that ideal bedding material should comply with a list of general properties including the following;

- It should be easy to scrape or shovel to form a bed on which to lay the pipe, and also be easy to distribute uniformly beneath the haunches of a pipe by tamping;

- It should require little or no compactive effort.

2.3.2 Stability in Saturated Conditions

Cohesive materials have very high shear strength when dry, which could make them an attractive option for pipe support especially when considering their availability as local excavated material from trenches or cut to fill embankments. However, they lose most of their strength when saturated, making them unsuitable for pipe bedding. It is also difficult to compact in confined areas like pipe trenches under the inverts of the pipes.

To assure stability at all conditions and compactability, AS/NZS 3725:2007 specifies that bedding materials shall contain limited quantities of fine plastic materials or otherwise, be cement stabilized to maintain stability in saturated conditions and improve compactability.

Other National Standards either specify granular materials like gravel or sand free from cohesive fines passing sieve 0.075mm (less than 10 %) like UK Standards, or accept higher contents of fines but with lower bedding factor like the ACPA as shown in Tables 4 5 and 6.

Table 4: ACPA Standard Installations Soil and Minimum Standard Compaction Requirements

Installation Type	***Bedding Thickness***	***Haunch and Outer Bedding***
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*
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*
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*
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*

Table 5: USCS and AASHTO Soil Classifications for Pipe Bedding Materials

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

Table 6: 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

Flexible pipe standard AS/NZS 2566:1998 (AS/NZS 1998)uses the same approach by reducing bedding material supporting stiffness with the increase of fine cohesive materials content of the bedding materials as shown in Table 7.

Table 7: AS/NZS 2566:1998 Table 3:2

EMBEDMENT AND NATIVE SOIL—MATERIALS AND MODULI*

Materials			Moduli E'_e and E'_n MPa				
Description	Classification		Uncompacted	R_D (%)			
				85	90	95	100
				I_D (%)			
				50	60	70	80
	AS 1726 †	AS 2758.1	Standard penetration test ‡ Number of blows				
			≤ 4	> 4 ≤ 14	> 14 ≤ 24	> 24 ≤ 50	> 50
Gravel— single size	—	Coarse aggregate	5§	7§	7§	10§	14
Gravel— graded	GW		3§	5§	7§	10§	20
Sand and coarse-grained soil with less than 12% fines	GP, SW, SP and GM-GL, GC-SC etc.	—	1	3§	5§	7§	14
Coarse-grained soil with more than 12% fines	GM, GC, SC SM and GM-SC, GC-SC	—	NR	1§	3§	5§	10
Fine-grained soil (LL<50%) with medium to no plasticity and containing more than 25% coarse-grained particles	CL, ML, mixtures ML-CL and ML-MH	—	NR	1§	3§	5§	10
Fine-grained soil (LL<50%) with medium to no plasticity and containing less than 25% coarse-grained particles	CI, CL, ML, mixtures ML-CL, CL-CH and ML-MH	—	NR	NR	1	3	7
Fine-grained soil (LL>50%) with medium to high plasticity	CH, MH and CH-MH	—	NR	NR	NR	NR	NR

2.3.3 Maximum Size of Aggregates

The size of aggregates in bedding material affect mainly how the material will be packed in the bed layer and how it will fill the void under the haunch of the pipe. As a general practice, the larger the size of the pipe the easier larger size material can fill all gaps and achieve the required support.

AS/NZS 3725:2007 specifies materials all passing 20mm sieve as its selected material for bed and haunch zone. It specifies a more relaxed grading with all passing 75mm for its side zone materials, however, for practicality reasons most projects in New Zealand use the same materials for both zones and hence, use the all passing 20mm by default.

While the 20mm aggregates size is necessary to achieve the thin bedding thickness of 100mm and avoid leaving gaps under the haunches of small diameter pipes, it might be unnecessarily fine for installation of large diameter pipes but will give satisfactory results.

AS/NZS 3725:2007 tries to avoid confusion on sites where different sizes of pipes are installed by specifying one size that will be suitable for all sizes of pipes.

The old NZS 4425:1986 Standard, which was designed for installation of small diameter pipes follows the same trend by specifying material with 95-100% passing sieve 26.5mm.

AS/NZS 2566:1998 Standard for flexible pipes specifies a wide range of materials including single size and graded aggregates and sands but limits its maximum size of aggregates to 20mm as for AS/NZS 3725:2007 possibly because most flexible pipes were then small in diameter. AS/NZS 2566:1998 specifies that the higher the granular content, the more supportive the embedment material becomes to the pipe where equivalent compactive effort is given to the embedment.

ASTM adopted the ACPA approach in its pipe installation practice standard C1479M-07 (ASTM 2009). The Standard also specifies the following limitation for selection of bedding materials and methods:

- Clauses 9.3 and 11.2 specifies that maximum size of aggregates for bedding large diameter pipes shall be 38.5mm.
- Clause 9.4 specifies that when insitu soil is used for bedding, maximum size of aggregates shall not be greater than 75mm.
- Clause 9.5 specifies that the use of aggregates larger than 25mm shall be limited to 20% of bedding materials by weight.

The European specifications for "Construction and testing of drains and sewers" DIN EN 1610 (EN 2015) specifies also in its Clause 5.2.3 that imported materials suitable for bedding may include:

- Single size granular material
- Graded granular material
- Sand
- All-in aggregates
- Crushed aggregates.

DIN EN 1610 Clause 5.2.1 specifies also maximum particle sizes as follows:

- 22 mm for DN 200 mm and less
- 40 mm for DN 200 – 600 mm
- 60 mm for DN > 600 mm

The UK Water Industry Information and Guidance Note on "Bedding and Side fill Materials for Buried Pipelines" IGN 4-08-01 (UK WIR 1994) specifies the following:

- The largest particle size should not be excessive in relation to the pipeline diameter otherwise impact damage and concentrated point loading can occur;
- The grading should be such that water passing through will not encourage fine materials to be carried away and thus reduce the support for the pipeline.

In its tables for suitable bedding and side fill materials it specifies the following grading of aggregates:

- 10, 14, or 20mm (Single size or graded down to 5mm) for DN 150 to 300mm
- 14 or 20mm (Single size or graded down to 5mm) for DN 300 – 550mm

- 14, 20, or 40mm (Single size or graded down to 5mm) for DN > 550mm

It also specified values for ease of compaction test for each bedding type, and referred to the British Standard that accept a percentage of aggregates larger than the maximum specified provided that 100% pass the next larger sieve size.

2.3.4 Migration of Fines

Experience with various soil structure interaction construction indicates that fine particle migration can result in significant loss of soil support leading to serious instability the structure. Pipeline bedding can be affected by migration of fines by one or more of the following:

- Contamination of bedding materials with plastic cohesive fine materials affect long term stability of the installation when wet.
- Migration of fines from pipe bedding cause loss of support to pipe and overloading.
- Migration of fines from side soil can cause loss of support to top or adjacent structures.

The gradation and relative size of the embedment material and adjacent native soils and fill materials should be compatible in order to minimize migration. Where significant ground water flow is anticipated, placing coarse, open-graded materials, above, below, or adjacent to finer materials should be avoided, unless methods to prevent migration are employed.

Where there is a possibility of migration of fines between the native soil and the embedment zone, a geotextile filter fabric shall be provided to ensure that the integrity of the side support to the pipe is not compromised. Alternatively, graded bedding material complying with the following basic principles of soil mechanics filter criteria could be used without geotextile (AS/NZS 1998).

(a) D15/d85 < 5, where D15 is the sieve opening size passing 15% by weight of the coarser material and d85 is the sieve opening passing 85% by weight of the finer material; and

(b) D50/d50 < 25, where D50 is the sieve opening size passing 50% by weight of the coarser material and d50 is the sieve opening passing 50% by weight of the finer material. This criterion need not apply where the coarser material is well graded (see AS 1289.3.6.1).

Where the finer material is a medium to highly plastic clay (CL or CH), then the following criterion may be used in lieu of the D15/d85 criteria: D15 < 0.5 mm where D15 is the sieve opening size passing 15% by weight of the coarser material.

All National pipe installation Standards required Engineers to provide methods to prevent migration of fines which might affect the stability of the installation or support when ground water or soil conditions are conductive. Some Standards like AS/NZS 2566 required Engineers to test grading of both bedding materials and existing soil for filter criteria, while others only required care or specify geotextile surround of bedding material.

The New Zealand – Australian Standard, AS/NZS 3725:2007 uses an approach of specifying a material grading that suitable to restrict migration of fines when used with all types of soils. Furthermore, for medium and highly plastic clay where filter criteria of D15<0.5 is prevailing, AS/NZS 3725 uses the next available sieve size in Australian Standard of 0.6mm as its governing guide to achieve this criteria. It specifies that D20<0.6 to make sure that all bedding materials will achieve the filter criteria. When any material outside this limit is used, AS/NZS 3725 assumes that the bedding will not be stable for any site condition and reduces the BF to a minimum of 1.5.

NZTA M/3 which is not for pipe installation however it includes solutions for a similar problem of soil structure interaction in pavement subgrade construction. NZTA uses a similar particle migration test criteria used in AS/NZS 2566 to check stability of poorly graded subbase materials constructed on various subgrades in its M/3 Specification Clause 5.4.

Materials grading selected for use in subbases construction are based on filter gradation criteria, however, it is further stated the following as an alternative solution:

"Instead of ensuring compatibility an alternative acceptable strategy is to assume that some subgrade intrusion is going to take place and to check that the assessed reduction in CBR for the intrusion zone at the bottom of that subbase layer does not invalidate the pavement design."

In other words NZTA allows the designer to use lower CBR values for the subbase layer when intrusion is expected.

3 ALTERNATIVE DESIGN TO MEET THE INTENT OF AS/NZS 3725:2007

3.1 CPAA ENGINEERING GUIDELINES

CPAA Engineering Guideline "Selecting Materials for Bedding Steel Reinforced Concrete Pipes" published in 2015 (CPAA 2015) presents a good review of both AS/NZS 3725:2007 and its Supplement, international standards, and actual experience.

The guidelines concludes that the principles of pipe support and bedding factors of the Standard are in agreement with a selection of bedding materials based on the following:

"In addition to the detailed requirements of AS/NZS 3725, the CPAA provides the following guidelines for the selection of fill material to be utilized when selected fill in accordance to the Standard is difficult to source or work with:

General requirements for use of materials – Select fill complying with the generic soil classes as defined in AS 1726 and shown in Table 1 of AS/NZS 3725 (refer to Table A of this document), but not complying with the particle size distribution of Tables 6 and 7 of AS/NZS 3725 may be used in the bed, haunch, and side zone, provided that:

Table A

TABLE 1 FROM AS/NZS 3725: SOIL CLASSES AS DEFINED IN AS 1726

Abbreviation	Description
SC	Clayey sands with fines of low plasticity
SP	Poorly graded sands
SW	Well-graded sands
GC	Clayey gravels with fines of low plasticity
GW	Well-graded sand and gravel mixtures with little or no plastic fines
GP	Poorly graded sand and gravel mixtures with little or no plastic fines

a) It shall be demonstrated through construction plans, quality control plans, and field trials that the degree of compaction shown in Table B of this guideline, corresponding to the selected bedding type and material, can be achieved, and,

Table B

MINIMUM COMPACTION REQUIREMENTS FOR VARIOUS BEDDING TYPES AND SELECT FILL SOIL CLASSES

Bedding Type	HS3		HS2		HS1		H2		H1	
Bedding Material	I_D	R_D	I_D	R_D	I_D	R_D	I_D	R_D	I_D	R_D
SW, SP, GW, GP	70	95	60	90	50	85	60	90	50	85
SC, GC	n/a	n/a	70	95	60	90	70	95	60	90

NOTES: 1. I_D refers to Density Index (%) and is for cohesionless materials (refer to Clause 8, AS/NZS 3725 for more information).
2. R_D refers to Dry Density Ratio (%) and is for cohesive materials (refer to Clause 8, AS/NZS 3725 for more information).

b) Methods to prevent migration of soil fines from, and into the bedding material, shall be provided when ground water movement or existing soil and bedding conditions are conducive to particle migration, and,

c) Long thin particles are not used (despite complying with the grading standards), due to their angular shape which increases the risk of stress on the pipe due to inadequate or non-uniform bedding, and,

d) Maximum particle size of select fill materials in bed, hunch, and side zones shall not be greater than the recommended limits given in Table C, or so selected to ensure uniform support around the pipes, and prevent concentrated point loading.

Alternatively, if a) to d) inclusive cannot be achieved, the bedding material must be cement stabilized.

Table C

RECOMMENDED MAXIMUM PARTICLE SIZE (mm)

Pipe diameter	Bedding Zone	
DN	Bed and Haunch	Side
225- 1350	20	40
1500 - 2250	40	75
> 2250	65	75

NOTES: If the requirements for the above recommendations are met, the bedding factor reduction outlined in AS/NZS 3725 Clause 9.3.2will not apply. However, as in accordance with AS/NZS 3725 Clause 9.3.3, bedding factors will be reduced in line with the Standards recommendations if the conditions prescribed for the use of these materials cannot be demonstrated or achieved."

3.2 REDUCED BEDDING FACTOR

AS/NZS 3725:2007 accept the use materials outside the grading limit of the Standard with a reduction of 15% of the maximum bedding factor, provided that the material is compacted to the specified limit. However, the standard considers the risk of contamination of the bedding material with fine cohesive materials from the surrounding soil by specifying that "*where the fraction passing the 0.6mm sieve is outside the limits, and is not cement stabilized, the bedding factor shall be 1.5".*

The above requirements of the Standard give a low reduction in BF of 15% only for low effect diversion of the standard and very high reduction when the fraction passing the 0.6mm sieve is outside the limits, especially when the Designer is planning to use HS3 bedding with BF = 4.

Other specifications like the ACPA proposed a gradual reduction in bedding factor with the use of lower and lower quality bedding materials, with the provision that migration of fines is considered unlikely.

In the absence of a standard criteria for the Designers to allow for possible effect of diversion from the grading limits of the Standard on their design, and keeping in mind that the bedding factors of the Standard are an absolute upper limit, It is recommended that designers follow the NZTA M/3 proposed strategy mentioned earlier by assuming that some contamination of the bedding is going to take place, and/or some parts of the bedding will not be compacted to the required limit, and check if the resulting reduction in the bedding factor may invalidate the installation design.

An example of how this strategy may work for a proposed HS3 installation is shown below:

- BF = 4 for Standard materials compacted to 95% relative compaction

- BF = 2.5 – 3.4 for granular materials outside the grading limit where there is risk of cavities under the hunch of the pipe, low risk of contamination with plastic fine cohesive materials, and bedding materials compacted to 95% relative compaction.

- BF = 2.0- 2.5 for granular materials outside the grading limit where there is risk of cavities under the hunch of the pipe, higher risk of contamination with plastic fine cohesive materials, and bedding materials compacted to 95% relative compaction.

- BF = 1.5 when bedding materials in not compatible with surrounding soil, flowing ground water conditions and no measures to control movement of fines are taken.

Design engineers can also refer to Table 3:2 of AS/NZS 2566:1998 as presented in this paper in Table 7 to judge the effect of diversion from the standard both in quality of material and compaction on the stiffness of the bedding material, same proportional reduction could be used for the bedding factor of the ideal conditions of the AS/NZS 3725:2007.

4 CONCLUSIONS

From the above discussion and review it is possible to draw the following conclusions:

- AS/NZS 3725:2007 specifies bedding material with grading limits that satisfy all requirements of installation by achieving good compaction and support to the installed pipes.

- The Standard bedding material grading have been selected to mitigate the risk of migration of fines form to surrounding soils and maintain stability in both wet and dry conditions.

- The Standard bedding maximum size of aggregates is designed to suit all sizes of concrete pipes.

- The Standard allow Designers and Installers to use materials other than that specified provided that they proof that the alternative material can easily be compacted in both hunch and side zones to the specified compaction level, and the risk of migration of fines to and from surrounding soils is low.

- Designers may use standard soil mechanics checks of compatibility of bedding material with insitu soil to check the risk of migration of fines in location where water movement is anticipated.

- Designers may use a reduced bedding factors values with level of reduction based on Engineering Judgment to mitigate the risk of overloading the pipes when non uniform compaction and/or contamination of bedding material is anticipated.

5 CASE STUDY

5.1 BEDDING MATERIALS

The City Edge Alliance requested Humes to comment on their use of materials not complying with the grading limits of AS/NZS 3725:2007 for bedding culverts pipes in Waikato Expressway Hamilton Section last winter. The wet conditions on site and presence of water in the pipe sub trenches has made the use and compaction of the fine graded materials specified in AS/NZS 3725:2005 to bed, hunched and side support of large diameter pipes physically impossible. A change was made to the traditional New Zealand practice of "self-draining" materials to achieve the required bedding support. The first group of culverts were successfully installed using locally supplied GAP 65 with grading properties shown in Figure 3, and subsequently bedding material changed to a local GAP30 which more close to AS/NZS 3725:2007 material. The grading properties of the GAP30 are shown in Figure 4.

Figure 4: Example of Particle Size Distribution of GAP 65 used in bedding

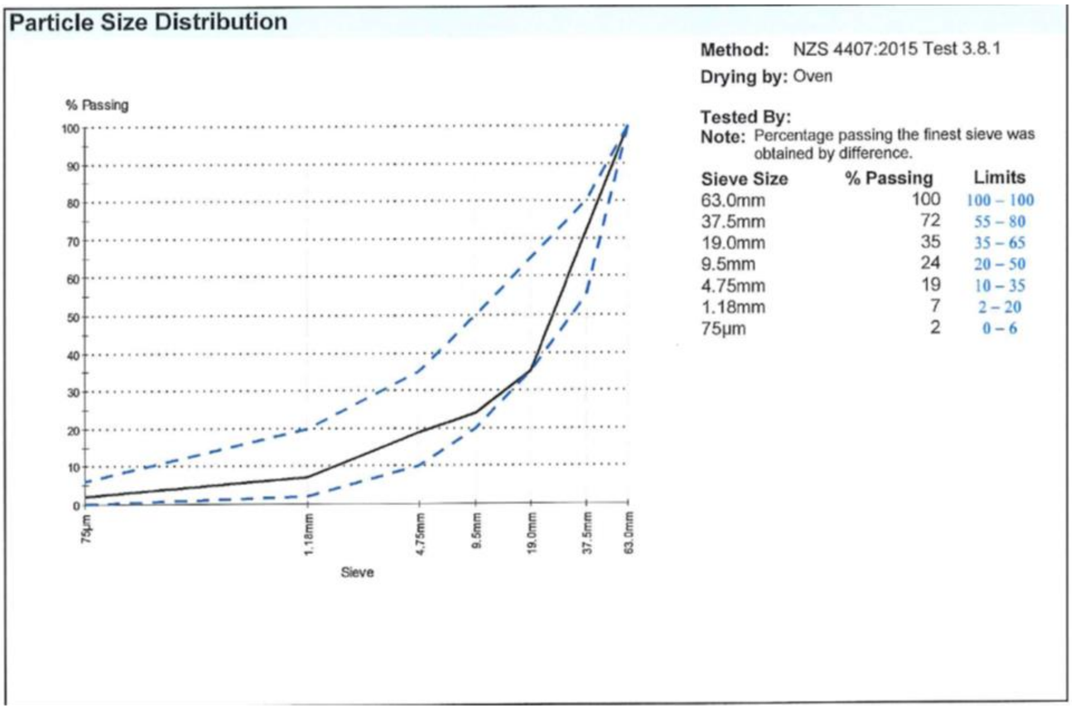
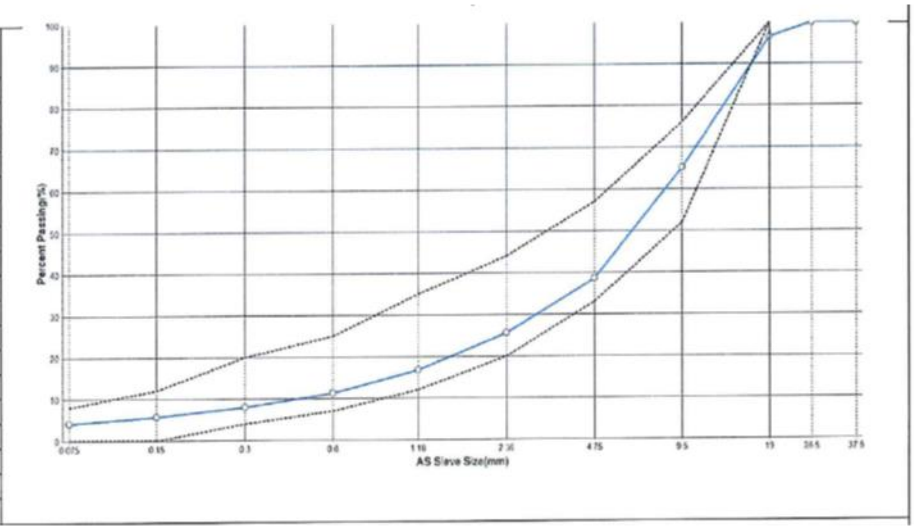


Figure 5: Example of Particle Size Distribution of GAP 30 used in bedding

Remarks

AS Sieve Size(mm)	Percent Passing	Specification Limits (% Passing)
75		
63		
53		
37.5	**100**	
26.5	**100**	
19.0	**97**	100-100
serhead_notes		
13.2		
9.5	**65**	52-76
6.7		
4.75	**39**	33-57
2.36	**26**	20-44
1.18	**17**	12-35
0.600	**11**	7-25
0.425		
0.300	**8**	4-20
0.150	**6**	0-12
0.075	**4**	0-8

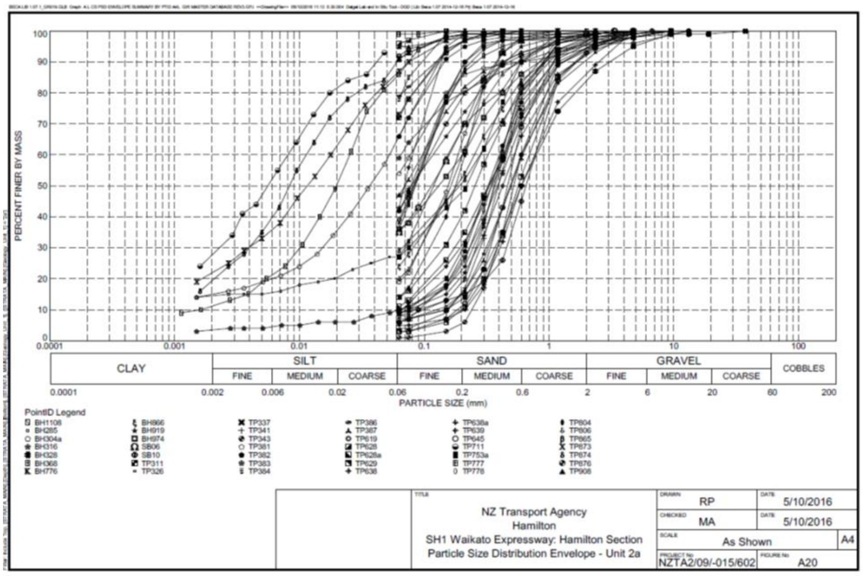


5.2 EMBANKMENT MATERIALS

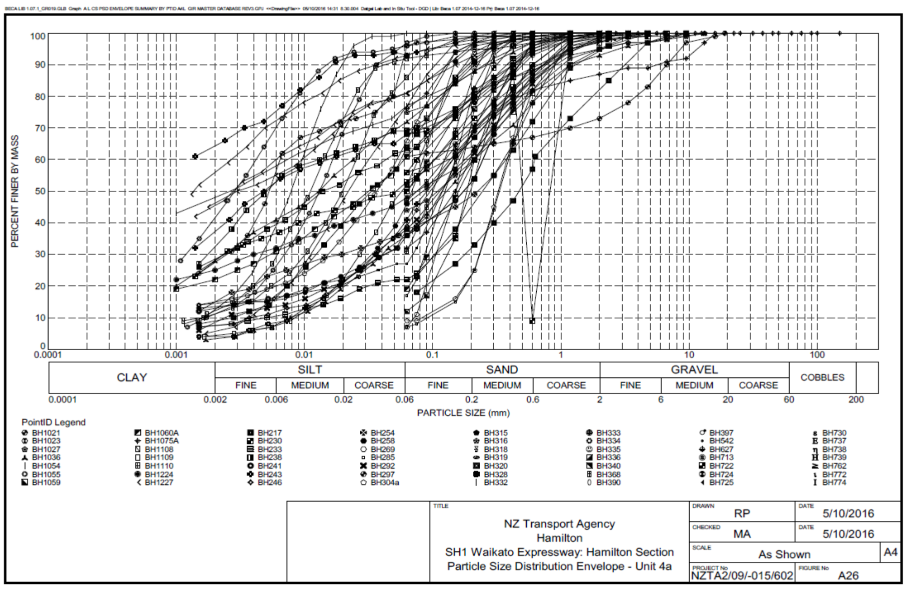
Review of the properties of cut to fill materials used for construction of embankment indicates that for earthworks soil can generally be grouped into the following main geological units:

- Plot A20 (Figure 6), Unit 2A, interbedded silts/sands of the Hinuera Formation, for insitu material in the lowlands areas, the grading varies between a sand to a silt. This variability will occur over very short distances and shallow depths. (All Culverts Except Culvert K)
- Plot A26 (Figure 7), Unit 4A, predominantly cohesive, Hamilton Ash, our insitu material in the Hamilton Hills areas. (Culvert K)

FIGURE 6: PLOT A20



- *FIGURE 7 : PLOT A26*



5.3 QA OF BEDDING COMPACTION

QA reports indicate that compacted granular materials extended to the springline of the pipe to form a hunch and side zone. The results of compaction tests indicate that compaction exceeds 95% relative compaction, hence the bedding meets the geometry and compaction requirements of HS3 bedding in all culverts except Rybun 1. Bedding of culvert Rybun 1 met the requirements of HS2 bedding by achieving more than 90% relative compaction.

5.4 ANALYSIS OF AS BUILD BEDDING

5.4.1 PIPE SUPPORT & BEDDING FACTORS

The geometry of bedding materials placement under and around the pipes, and its compaction to more than 95% relative density for most of the culverts or to 93% relative density for culvert Ryburn 1 made the bedding in agreement with bedding types HS3 and HS2 respectively. However, the use of maximum size of aggregates of 65mm which is outside the recommendations of the CPAA guidelines might cause some kind of non-uniformity of support in the hunch zone under the pipe, therefore, it is fair to assume that the bedding factors of 4 and 2.5 correspondent to bedding types HS3 and HS2 might not be achieved, and a reduced value of bedding factor should be considered for this installation. Furthermore, the use of gap-graded materials without providing Geotextile layer to protect from contamination, may justify the assumption that the bedding factor might need to be reduced to the value of the lower quality bedding material as per the ACPA practice & using same analogy proposed by NZTA for subbase courses.

Various reduced values of Bedding Factor where used to calculate the possible field load on pipes, the results are presented in Table 8.

Table 8: Results of Installation Redesign Using Various Reduced BF

No.	Culverts	Bedding Material	Culvert Chainage (approx)	Pipe Diameter ND *mm*	Pipe Class	Standard Test Proof Load *kN/m*	Average Field Compaction *%*	Posative Projection Embankment Load on Pipe *kN/m*					Negative Projection Embankment Load on Pipe *kN/m*	
								HS3 - BF = 4.0	HS3 (Reduced) - BF = 3.4	HS2 - BF = 2.5	HS1 - BF = 2.0	H1 - BF = 1.5	HS3 (Reduced) - BF = 3.4	HS2 - BF = 2.5
1	B	GAP30	550	1650	4	116	98.88	N/A	43.9	53.2	62	76.7	N/A	N/A
2	C	GAP30, GAP65	750	1050	2	42	102.1	N/A	28.5	34.9	41	N/A	N/A	N/A
3	C1	GAP65	1050	1500	3	81	99.7	N/A	47.8	62	75.4	N/A	N/A	N/A
4	D	GAP30	1700	1050	2	42	96.8	N/A	30.2	37.7	N/A	N/A	N/A	N/A
5	E	GAP65	1900	1200	2	46	100	N/A	35.8	46	N/A	N/A	N/A	N/A
6	F	GAP65	2450	1050	2	42	96.4	N/A	37	N/A	N/A	N/A	N/A	39.9
7	G	GAP65	2800	1500	4	108	96.8	N/A	61.7	81.4	100	N/A	N/A	N/A
8	H	GAP65	3600	1200	4	92	96.8	N/A	45.5	59.5	72.4	N/A	N/A	N/A
9	K	GAP65	4500	900	4	74	96.5	N/A	54.3	72.7	N/A	N/A	N/A	66.9
10	AF	GAP65	14350	1050	4	84	97.9	84	126	N/A	N/A	N/A	68.7	92.7
11	Ryburn 1	GAP65	240	525	2	23	93.3	N/A	N/A	N/A	N/A	17.5	N/A	N/A
12	Ryburn 2	GAP65	445	525	2	23	99.3	N/A	N/A	N/A	N/A	17.5	N/A	N/A

The results indicates that that load on pipes of all culverts except culverts F & AF are within safe pipe capacity limit when a reduced bedding factor of 2.5 or less is conservatively assumed for their installation, while for culverts A & AF same conservative solution could be achieved by converting the installation from positive projection to "Induced Trench" negative projection installation.

Redesign of culvert Ryburn 1 where 95% relative compaction density was not achieved indicates that a conservative bedding factor of 1.5 is still sufficient to produce safe loading design.

5.4.1 MIGRATION OF FINES

The migration of soil particles is associated with both movement of ground water and compatibility of soil grading. In road embankment construction such as the investigated one, control of ground water movement is one of the basic specification requirements in this type of construction. Cohesive soils loss its shear strength when saturated, therefore, embankments usually designed with a proper water drainage system to collect surface water and intercept ground water movement. Subsoil drains, swales and under channel drains are installed to achieve this goal.

In the light of the above design specification, it is not expected that water movement that might cause fine soil particles migration will happen during the life time of the newly constructed embankment, furthermore, checking the compatibility of grain size distribution of the bedding materials and average soil type in the construction area indicates that for most culverts the value of D15/d85 as shown in Table 9 below, and derived from geotechnical details shown before, is less than 5 which indicates limited possibility of soil fines migration into the graded course bedding materials.

Table 9: Results of Filter Criteria Test

	Culverts	Bedding	Culvert Chainage (approx)	Insitu Gound Conditions	D_{15} mm	d_{85} mm	D_{15}/d_{85}
1	**B**	GAP30	550	Unit 2A (Hineura Silts/Sands)	1.5	0.6	2.5
2	**C**	GAP30	750	Unit 2A (Hinuera Silts/Sands)	1.5	0.6	2.5
3	**C1**	GAP65	1050	Unit 2A (Hinuera Silts/Sands) - Some peat/recent alluvials	3	0.6	5
4	**D**	GAP30	1700	Unit 2A (Hinuera Silts/Sands) - Some peat/recent alluvials	1.5	0.6	2.5
5	**E**	GAP65	1900	Unit 2A (Hinuera Silts/Sands)	3	0.6	5
6	**F**	GAP65	2450	Unit 2A (Hinuera Silts/Sands)	3	0.6	5
7	**G**	GAP65	2800	Unit 2A (Hineura Silts/Sands)	3	0.6	5
8	**H**	GAP65	3600	Unit 2A (Hinuera Silts/Sands)	3	0.6	5
9	**K**	GAP65	4500	Unit 4A (Hamilton Ash)	3	0.2	15
10	**AF**	GAP65	14350	Unit 2A (Hineura Silts/Sands)	3	0.6	5
11	**Ryburn 1**	GAP65	240	Unit 2A (Hinuera Silts/Sands)	3	0.6	5
12	**Ryburn 2**	GAP65	445	Unit 2A (Hinuera Silts/Sands)	3	0.6	5

The only exception is culvert K which was constructed in area of very fine soil with high risk of migration of fines. The study recommended further investigation of the hydrology of the culvert and the pipe bedding surrounding soil. The study recommends a possible solution including measures to eliminate the movement of water and hence, the possibility of migration of fines, concrete seep collars around the pipe and intersecting the trench were considered. However, in subsequent communication the project team advised that this culvert was pulled and reinstalled due to changes in design levels.

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