PRACTICAL INSTALLATION DESIGN OPTIONS AND SAFETY IN DESIGN FOR DEEP EMBANKMENT'S STORMWATER CULVERTS

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ABSTRACT

Design for installation of reinforced concrete pipes in New Zealand usually follows the process in AS/NZS 3725: 2007: Design for installation of buried concrete pipes. This Standard provides a practical design approach to calculate loads on pipes based on the original works of Marston and Spangler, providing bedding factors for various types of installation, installation methods and materials.

Designers usually use the CPAA PipeClass Software, which is based on AS/NZS 3725 to calculate loads on culvert pipes and determine the appropriate pipe Class. The default options in PipeClass are suitable for simple, everyday installation design. More complex installations, such as culverts under deep embankments, typically requiring pipes > 1350 mm Ø and depths of fill in the range of 5-25 m require a better understanding of the Standard, it's Supplement and reference documents before using the PipeClass software, to facilitate the calculations.

A worked design example using CPAA PipeClass Software for a 2400 mm diameter concrete pipe installation under deep embankment fills is considered to represent an installation under deep embankment fills. The results indicate that pipes of up to strength Class 8 (the maximum strength class available in New Zealand) are suitable for embankment fills of up to 15 m for positive projection and up to 35 m for negative projection under PipeClass Software default conditions.

The effect of installation conditions on the load on the pipes and the selected safe pipe strength class is illustrated through various design results tables, and show that factors such as type of fill materials, projection type and ratio, trench width, and type of pipe support have a significant effect. Changing conditions might allow Designers to select lower strength Class pipes or utilize the maximum Class available for deeper installations of up to 48 m or possibly more, while maintaining safety in design.

However, the results of the worked example and their discussions indicate that, to maintain the original safety in design, Designers should allow, through continuous design reviews, for the possibility of an increase of load on pipes beyond the design expectation. In some cases, site-specific conditions and/or construction limitations result in a pipe installation that does not meet design assumptions.

KEYWORDS

Deep Embankment Culverts, Pipe Installation Design, Safety in Pipe Culvert Design.

PRESENTER PROFILE

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Dos has over 20 years' experience in the design, manufacture and installation of reinforced concrete pipe for both open trenched and trenchless applications.

He has been a member of Standards New Zealand/Standards Australia Committee WS-006 – Concrete Pipes since 2001, and was actively engaged in the development of AS/NZS 4058:2007 Precast Concrete Pipes - pressure and non-pressure and AS/NZS 3725:2007 - Design for installation of buried concrete pipes, and currently in AS 4198 – Precast Concrete access chambers for sewerage applications.

He is also a member of the Management Committee of the Concrete Pipe Association of Australasia (CPAA) since the early 2000's. He has been a speaker and presenter at many of the CPAA Roadshows and training sessions.

Dos was recognized as a Fellow of Engineering New Zealand in 2020 for his significant contribution to Engineering in New Zealand.

1 INTRODUCTION

Design for installation of reinforced concrete pipes in New Zealand usually follows the process in AS/NZS 3725: 2007: Design for installation of buried concrete pipes. This Standard provides a practical design approach to calculate loads on pipes based on the original works of Marston and Spangler, providing bedding factors for various types of installation, installation methods and materials.

This design approach results in conservative assessments of both load and bedding factor calculations. This conservatism in the Standard design can accommodate minor variations in the installation method or local soil conditions that would be expected during of the construction of complex culverts. The above, together with the manufacturing Standard used in New Zealand, AS/NZS 4048: 2007- Precast concrete pipes (pressure and non-pressure), results in reliable installations.

Experience in recent years shows that road construction in New Zealand is traversing more complicated terrains to meet the demand for more high-quality roads and to avoid densely populated areas. Construction in such terrain with varying stream cross sections, designing for future climate change over 100 years and maintaining Safety in Design often requires larger culverts under deep fills to meet the road profile requirements.

Designers usually use the CPAA PipeClass Software, which is based on AS/NZS 3725 to calculate loads on culvert pipes and determine the appropriate pipe Class. The default options in PipeClass are suitable for simple, every day installation designs. More complex installations, such as culverts under deep embankments, typically requiring pipes > 1350 mm Ø and depths of fill in the range of 5-25 m require a better understanding of the Standard, the Supplement and reference documents before using the PipeClass software, to facilitate the calculations.

The paper will review the effects of various design assumptions on the value of calculated load on pipes based on the Standard and the Supplement. These will include the following:

a) Depth and materials of embankment fill;
b) Natural soil type, conditions and other geotechnical factors such as water table and stability;
c) Pipe Projection as controlled by natural topography and construction operations;
d) Bedding materials quality, compaction and quality assurance;
e) Trench width as controlled by construction operations, type of bedding, health and safety and area topography;
f) Various live and construction loads;
g) Limitation of the availability of high Class concrete pipes;
h) Availability of resources to control construction processes and modify design in case of non-compliance;
i) Quality of workmanship available or expected;

Worked examples will be presented to show how various factors affect the load on pipes.

The paper will conclude with recommendations to Designers on various options they may consider in the design to achieve a practical, economical installation, whilst maintaining and ensuring Safety in Design.

2 NEW ZEALAND TYPICAL CULVERT DESIGN

2.1 GENERAL

Steel reinforced concrete pipes (SRCP) are extensively used in road construction for culverts to divert stormwater from one side of a road embankment to the other, and as a drainage pipelines to collect and divert rainwater from the surface of the road to a designated stormwater outfall.

Design for installation of reinforced concrete pipes in New Zealand usually follows the process in AS/NZS 3725: 2007: Design for installation of buried concrete pipes. This Standard provides a practical design approach to calculate loads on pipes based on the original works of Marston and Spangler, providing bedding factors for various types of installation, installation methods and materials.

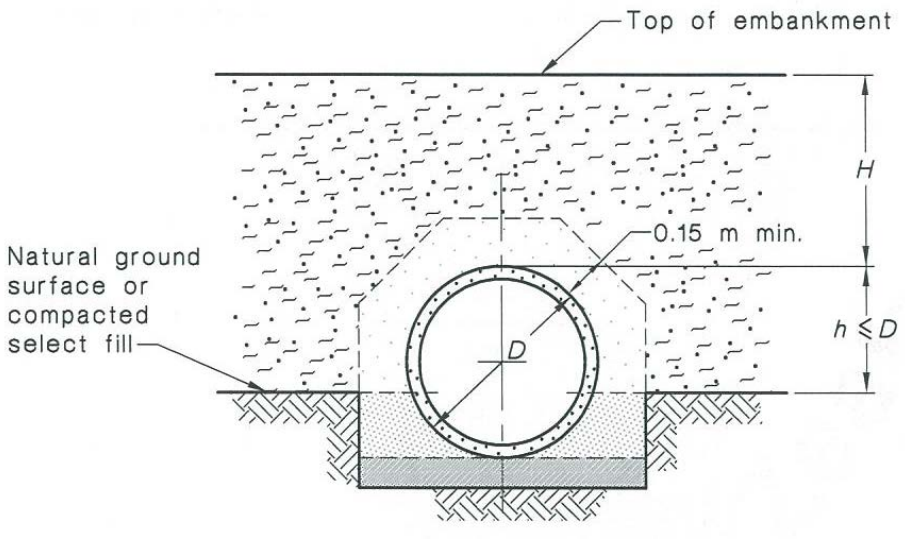
This paper will only consider culvert pipes used where “Embankment Conditions” generally prevail. AS/NZS 3725 considers embankment conditions exist when the pipe is installed into the natural ground or partly constructed embankment, and the balance of the embankment is constructed above the pipe. There are two types of embankment conditions:

1. Positive projection embankment in which; the concrete pipe is placed such that the top of the pipe is at or above the natural ground surface.
2. Negative projection embankment in which; the top of the pipe is below the natural ground surface.

2.1.1 Positive Projection Embankment

Figure 1 below from AS/NZS 3725 illustrates the general terms used when considering a positive projection embankment.

Figure 1: Typical Positive Projection Installation



In a positive projection embankment condition the top of the pipe extends above the natural ground surface and then the embankment fill is constructed above the top of the pipe.

The natural ground surface can be either the existing undisturbed natural ground or an equivalent built up compacted fill.

The Standard uses the term ”Projection Ratio” p to indicate the projection of pipes above the natural ground level and

Positive Projection Ratio $p = h/D$

The weight of the soil acting over the top of the pipe is a function of the weight of fill above the outside diameter of the pipe and is often referred to as the prism load = wHD.

2.1.2 Negative Projection Embankment

Figure 2 below from AS/NZS 3725 illustrates the general terms used when considering a negative projection embankment.

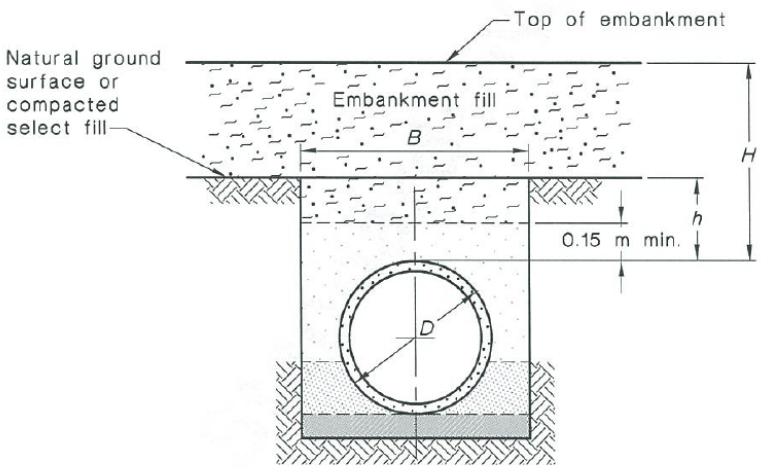
In a negative projection installation, the pipe is installed in a trench and the top of the pipe is below natural or equivalent ground level.

The Standard similarly uses the term ”Projection Ratio” p to indicate the projection of pipes below the natural ground level, but in this case:

Negative Projection Ratio $p = h/B$

The weight of the soil acting over the top of the pipe is a function of the weight of fill above the pipe and the width of the trench, and the prism load =wBH.

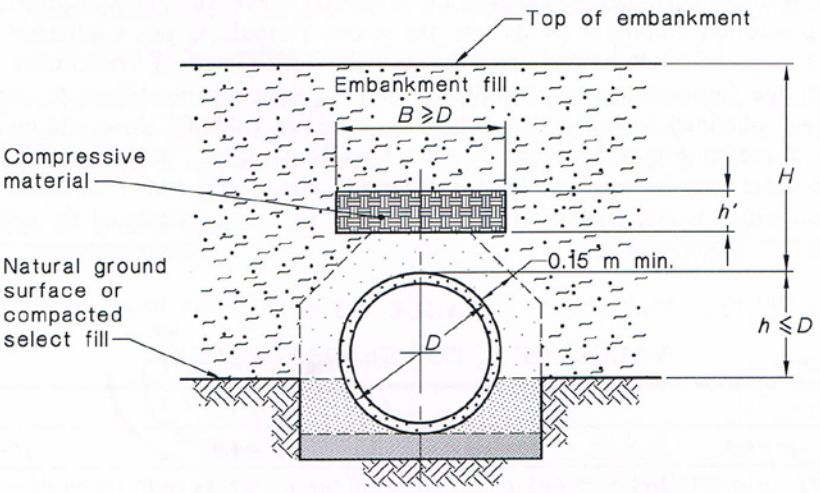
Figure 2: Typical Negative Projection Installation



2.1.3 Induced Trench Installation

Figure 3 below from AS/NZS 3725 Supplement 1 illustrates the general terms used when considering an induced trench installation.

Figure 3: Typical Induced Trench Installation



In an induced trench installation, the pipe is installed with the top of the pipe extending above the natural ground or equivalent surface, and then the embankment fill is constructed to a level some distance above the top of the pipe. A trench is then excavated partway through the fill above the pipe, filled with compressible material and the construction of the embankment continued normally to its full height.

The Standard's Supplement treats this installation as a Negative Projection Embankment, where same design equations and graphs are used, but in this case:

Negative Projection Ratio/Induced Trench $p = h'/B$

In the Induced Trench installation, as for Negative Projection Embankment, the weight of the soil acting over the top of the pipe is a function of the weight of fill above the pipe and the width of the trench and the prism load =wBH, where *w* is the density of the backfill. However, reduction of trench width B to Pipe Diameter D just above the, substantially reduces the weight of soil acting over the top of the pipe.

2.2 CULVERT DESIGN PROCEDURES

The CPAA PipeClass Software, which is based on AS/NZS 3725:2007, provides designers with a very practical tool for the design of SRCP installations allowing designers to consider design options to cover different site-specific conditions, construction methods and materials. Designers can also investigate the feasibility of alternative options such as installation conditions, type of pipe support, and compare requirements for pipe strength Class required against available strength Classes.

Meeting the design requirements using PipeClass or AS/NZS 3725:2007 is generally a simple process with conservative output. However, using PipeClass or the Standard for the design of culverts under deep embankments requires Designers to have good understanding of the theoretical background of the Standard to achieve the expected safety in design. Generally deep embankments (>10 m) will require larger diameter and higher strength Classes of pipes which may not be available off the shelf, and minor changes in expected site conditions and materials may result in significant design load variations.

Designers are typically recommended to follow the steps below to achieve that goal:

a) Collect all available information on site boundary conditions including, but not limited to, geotechnical data, existing and design ground levels along the proposed pipe alignment, and invert levels and diameter of the proposed pipe required by the hydraulic designers;
b) Investigate the available strength classes of pipe available and their actual dimensions, particularly the outside diameter *D*;
c) Design the installation using PipeClass, applying the known boundary conditions and material properties. Where conditions are not considered in PipeClass Designers should refer to the graphs, tables, and equations provided in the Standard and its Supplement, or other references;
d) Issue clear Construction Drawings and Specifications including notes detailing all original expected boundary conditions, design assumptions and requirements during construction stages;
e) Revisit the Design, Drawings and Specification at preconstruction stages to ensure that properties of pipes, materials and construction procedures, quality assurance methods, H & S processes intended for use by the Contractor are all in agreement with the original design assumptions and requirements. If necessary, revise the design, to accommodate the changes proposed or identified by the Contractor;
f) Revisit the Design, Drawings and Specifications during first stages of construction to ensure no further changes have been identified since the preconstruction review, particularly in the original design boundary conditions;
g) Review all QA Data during construction, correct any non-compliance or adjust design to reflect actual condition if accepting non-compliance.

The following section will present a worked example that uses the typical design procedure, whilst the subsequent sections will discuss in detail the effect of various design assumptions on the design outcome, as represented by load on pipes and/or the proposed Class of pipe for each design condition.

3 WORKED DESIGN EXAMPLE

The effect of various design assumptions and boundary conditions on the design of a culvert under a deep embankment is illustrated in the following detailed worked example of a large diameter pipe under a road embankment.

The assumed boundary and installation conditions considered are as follows:

Outside Pipe Diameter D: 2742 mm (Note: D generally varies for different manufacturers and processes);

Application: Drainage, single barrel & both or skew orientation;

Embankment Material: Wet Clay;

Installation Condition-1: Embankment Positive / Various Projection Ratios;

Installation Condition-2: Embankment Negative / Various Projection Ratios;

Height of Fill: 5 – 45 m;

Width of Trench: Default PipeClass/AS/NZS 3725:2007 minimum = 3656 mm;

Support Type: HS2 & HS3;

Live Load: HN-HO-72;

The calculations were carried out using the CPAA PipeClass software.

The tables below illustrate the pipe strength classes required for embankment depths ranging from 5-45 m.

Table 1, based on "Positive Projection Embankment Installation" conditions, illustrates the pipe strength requirements for different projection ratios, and support conditions.

The maximum embankment depth possible for wet clay embankment fill with a positive projection installation is around 25 m for the pipe strength classes available.

Table 1: Pipe Loads for Worked Design Example – Positive Projection

Depth of pipe m	**5**	**10**	**10**	**15**	**20**	**20**	**25**
Projection	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Projection Ratio	0.5	0.5	0.5	0.5	0.5	0.0	0.0
Bedding Type	HS2	HS2	HS3	HS3	HS3	HS3	HS3
Soil Type	Wet Clay	Wet Clay	Wet Clay	Wet Clay	Wet Clay	Wet Clay	Wet Clay
Load on Pipe kN/m	156.9	315.8	198.8	291.8	386.9	284.5	342.8
Pipe Class	**6**	**10**	**6**	**8**	**10**	**8**	**10**
AS/NZS 4058:2007 Minimum Test Proof Load of 2400 mm Pipes (Serviceability Limit) kN/m	**Class 6**	234	**Class 8**	312	**class 10**	390	

Table 2, based on "Negative Projection Embankment Installation" conditions, illustrates the pipe strength requirements for different projection ratios and support conditions.

Table 2: Pipe Loads for Worked Design Example – Negative Projection

Depth of pipe m	**25**	**25**	**30**	**30**	**35**	**35**	**45**
Projection	Negative	Negative	Negative	Negative	Negative	Negative	Negative
Projection Ratio	0.5	1.0	1.0	2.0	2.0	2.0	2.0
Bedding Type	HS3	HS3	HS3	HS3	HS3	HS3	HS3
Soil Type	Wet Clay	Wet Clay	Wet Clay	Wet Clay	Wet Clay	Clayey Sand	Sand & Gravel
Load on Pipe kN/m	327.4	279.5	327.7	268.6	301.4	272.2	295.4
Pipe Class	**10**	**8**	**10**	**8**	**8**	**8**	**8**
AS/NZS 4058:2007 Minimum Test Proof Load of 2400 mm Pipes (Serviceability Limit) kN/m		**Class 6**	234	**Class 8**	312	**class 10**	390

The maximum embankment depth possible for wet clay embankment fill with a negative projection installation is around 35 m for the pipe strength classes available. This can be increased to 45 m if the embankment fill is changed to clayey sand or sand and gravel.

4 FACTORS AFFECTING CULVERT PIPE DESIGN

4.1 DEPTH AND MATERIALS OF EMBANKMENT FILL

The worked example illustrates that Class 8 SRCP can be safely used for culverts under embankments up to 45 m high, and possibly more with Class 10 pipes, provided the right conditions are applied.

As the depth of embankment fill increases, the effect of type of fill becomes more critical, and determines whether a safe design is possible.

The traditional equations used to calculate the load on the buried pipes include the fill material properties that affect the final working dead load on the pipes. These are:

- Density: Working dead load is directly proportional to the density of the embankment fill material.
- Soil Parameter $K\mu$: This parameter is derived from the soil angle of internal friction and influences the working dead load on pipes in both negative and positive projection installations; however, the traditional negative projection calculations are based on one conservative value of soil parameter $K\mu=0.13$.

It should be noted that both PipeClass software and the design equations and graphs in the Standard allow for the use of soils properties other than the default types listed. Designers should refer to both tools if the proposed embankment fill has substantially different properties to the default fill properties. Changes from the default values may not always result in a safer design, so Designers need to consider the effect of the fill properties on their design output and make sure to optimise their design safety options.

The change of type of embankment fill significantly changes the load on pipes installed under the same boundary conditions. The results for the Worked Example shown in *Tables 3 and 4,* illustrate that it may be possible to increase the embankment depth without the need to change the class strength of the pipes, subject to availability of alternative materials and the practicality of such changes.

Table 3: Loads on Pipes Installed in Various Types of Embankment Fill (Positive Projection)

Depth of pipe m	**15**	**15**	**15**	**18**
Projection	Positive	Positive	Positive	Positive
Projection Ratio	0.5	0.5	0.5	0.5
Bedding Type	HS3	HS3	HS3	HS3
Soil Type	Wet Clay	Clayey Sand	Sand & Gravel	Sand & Gravel
Load on Pipe kN/m	291.8	276.2	252.4	305.4
Pipe Class	**8**	**8**	**8**	**8**

Table 4: Loads on Pipes Installed in Various Types of Embankment Fill (Negative Projection)

Depth of pipe m	**35**	**35**	**35**	**48**
Projection	Negative	Negative	Negative	Negative
Projection Ratio	2.0	2.0	2.0	2.0
Bedding Type	HS3	HS3	HS3	HS3
Soil Type	Clay	Clayey Sand	Sand & Gravel	Sand & Gravel
Load on Pipe kN/m	301.4	272.2	243.0	311.1
Pipe Class	**8**	**8**	**8**	**8**

4.2 PIPE PROJECTION

The natural ground topography of the proposed culvert alignment and its hydraulic design typically dictate whether the pipes will be laid with their tops projecting above the natural ground level (positive projection) or below the adjacent natural ground level (negative projection).

The settlement ratios r_s for positive and negative embankment conditions respectively, are shown in *Figure 4* below (FIGURE C3 in AS/NZS 3725 Supplement 1:2007).

Figure 4: Settlement Ratio

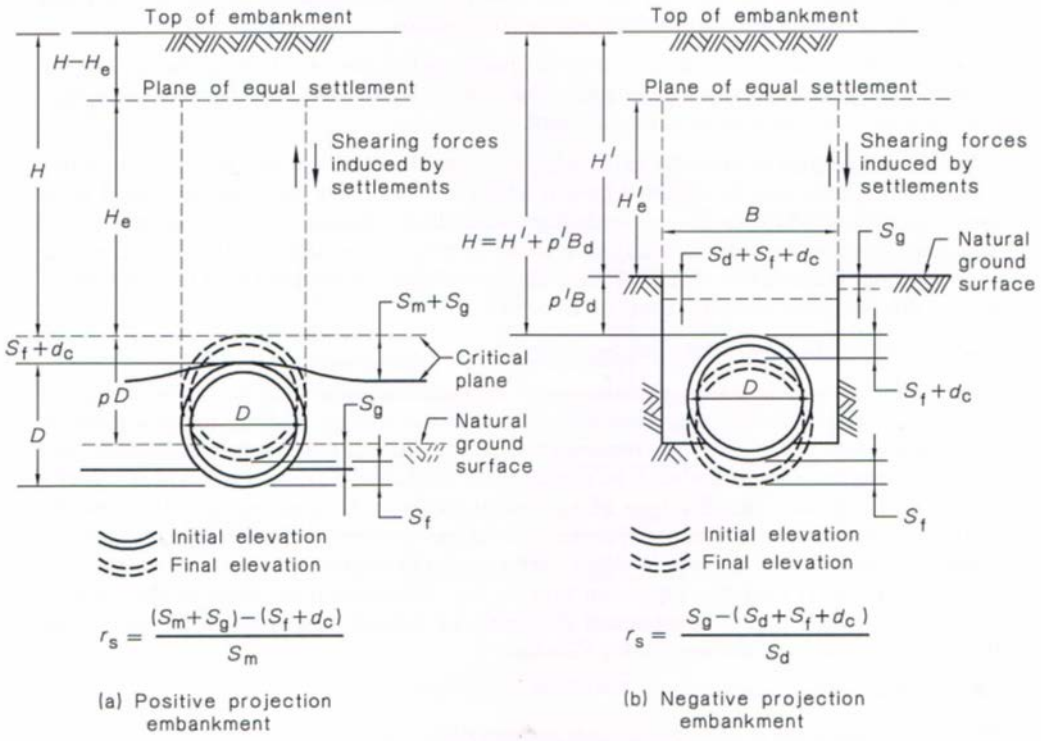


FIGURE C3 SETTLEMENT RATIO TERMS

C6.3.3.5 *Settlement ratio*

Settlement ratio refers to embankment conditions and is defined by the following equations:

$r_s = [(S_m + S_g) - (S_f + d_c)]/S_m$ for positive projection; or ...C6

$r_s = [(S_g - (S_d + S_f + d_c)]/S_d$ for negative projection ...C7

where

S_m = compression of the side column of soil of height D

S_g = settlement of the natural ground surface adjacent to pipes

S_f = settlement of the pipes into their foundation

S_d = compression of the fill material in the trench within the height—$p'B$

d_c = deflection of the vertical diameter of the pipes (see Figure C3)

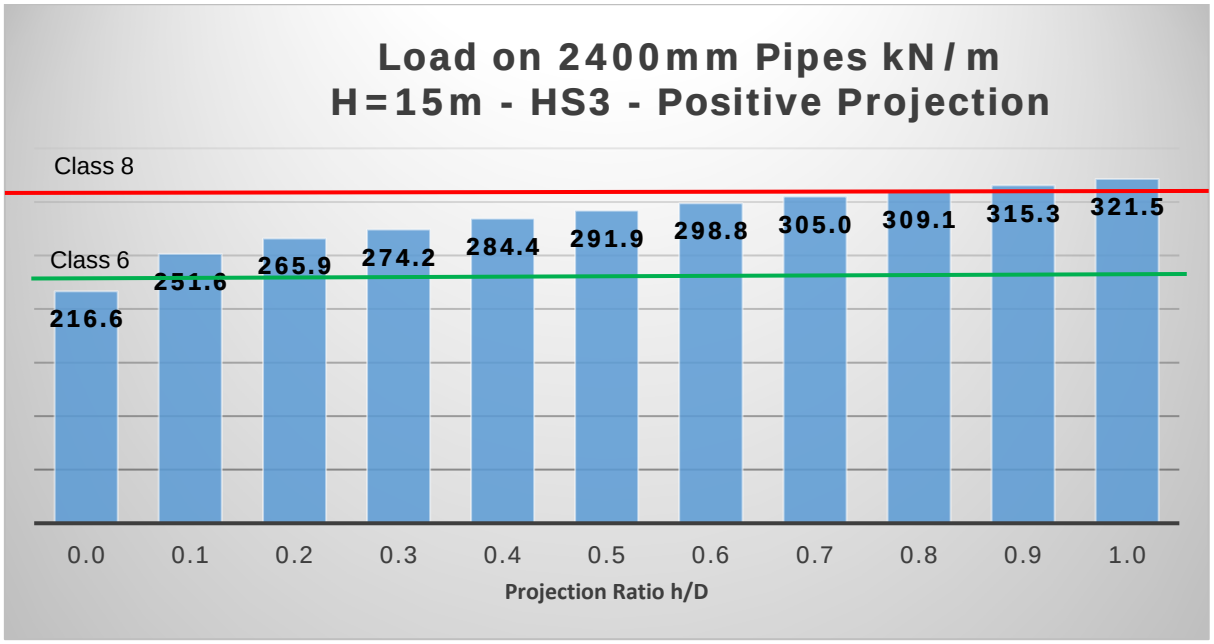
Depending on whether *"The Settlement Ratio r_s"* is positive or negative, the shear stresses between the soil prism above the pipe and the adjacent soil columns will be acting downwards or upwards on the prism.

4.2.1 POSITIVE PROJECTION

Figure 5 shows the effect of varying the projection ratio from 0.0 to 1.0 on the design load of the 2400 mm pipe under a 15 m fill (Wet clay embankment fill as per the worked example previously detailed).

PipeClass was used for load calculations for Projection Ratios p>0.5, and AS/NZS 3725:2007 graphs for Projection Ratios p<0.5.

Figure 5: Load on Pipes at Various Positive Projection Ratios

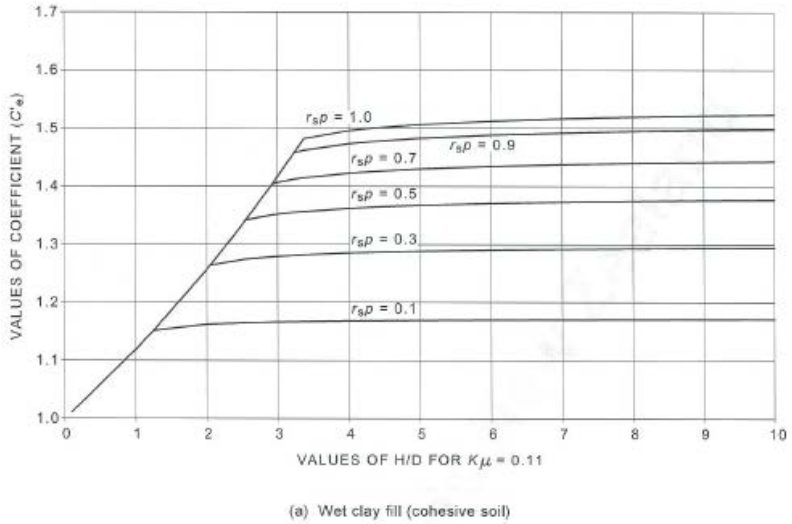


There is a reduction in positive shear stresses between soil prisms, over and adjacent to the pipe, as the projection ratio decreases from 1.0 to 0.0. S_m, the compression of the side (adjacent) column of soil reduces with the reduction in projection ratio reflecting the decrease in the settlement of the side soil prism.

Since AS/NZS 3725 specifies a constant value of 1.0 for Positive Projection Settlement Ratio r_s, the value of C'$_e$ (also known as Spangler's Coefficient) which is function of r_s x p (projection and settlement ratios) will be the highest at full pipe projection and lowest when the top of the pipe is level with the natural or equivalent ground.

Figure 6 below(FIGURE 7 in AS/NZS 3725:2007) shows the change in values of C'$_e$ for the positive projection case for wet clay that been used in the worked example.

Figure 6 – Graph of C'$_e$ for Positive Projection wet clay fill



(a) Wet clay fill (cohesive soil)

The decrease in the value of C'_e (Spangler's Coefficient) with the decrease of the projection ratio results in the decrease in the load on the pipe in the worked example (*Figure 5* above) since the load due to fill is calculated using equation 2 in the Standard:

$$W_g = C'_e wDH$$

Designers should note that AS/NZS 3725:2007 defines the pipe projection as being above or below "Natural ground surface or compacted select fill" (FIGURE 1 (a) in AS/NZS 3725), whilst the traditional definition of pipe projection is the projection above or below "Natural Ground". This variation from the traditional theories allows Designers to account for both natural projection and for an artificial projection. The latter could be created by building the embankment to higher level than the bottom of the pipe, and then installing the pipe in a trench in the compacted embankment.

The AS/NZS 3725:2007 acceptance of compacted embankment fill, as "equivalent surface" to "natural ground" is unlikely to affect the safety in design due to the following reasons:

a) SRC pipes in Australia and New Zealand are typically manufactured with thinner walls than those produced overseas. This lower wall/diameter ratio allows pipes to deflect marginally more under load leading to higher values of d_c (see *Figure 4*) that might compensate for some of the settlement variance for projected pipes.

b) AS/NZS 3725:2007 uses a conservative single value of Settlement Ratio r_s of 1.0, while the traditional solutions are generally based on various values of Settlement Ratios with a value of 0.5 usually used for Normal Soil with controlled compaction of pipe bedding as shown in *Figures 7 & 8*. Since the value of *C'e* is dependant of the $r_s\rho$ (Projection Ratio multiplied by Settlement Ratio), the outcome will remain conservative in most cases.

   The values of Settlement Ratios specified by AS/NZS 3725:2007 and the American Concrete Pipe Association (ACPA) are shown in *Figures 7 and 8* respectively.

Figure 7 – Settlement Ratios - AS/NZS 3725 (Table 4)

SETTLEMENT RATIOS

Projection type	Foundation type	Settlement ratio (r_s)
Positive projection	Any	+1.0
Negative projection	Earth	−0.5
	Rock	−1.0

Figure 8 – Settlement Ratios – (ACPA 1998)

Table 4.2. Design Values of Settlement Ratio.

Installation and Foundation Condition	Settlement Ratio r_{sd}	
	Usual Range	Design Value
Positive Projection	0.0 to +1.0	
Rock or Unyielding Soil	+1.0	+1.0
*Ordinary Soil	+0.5 to +0.8	+0.7
Yielding Soil	0.0 to +0.5	+0.3
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

**The value of the settlement ratio depends on the degree of compaction of the fill material adjacent to the sides of the pipe. With construction methods resulting in proper compaction of bedding and sidefill materials, a settlement ratio design value of +0.5 is recommended.*

c) AS/NZS 3725:2007 Clause 9.3.1 specifies the following condition for the side zone support properties:

> The side zones shall not be considered to be effective in supporting the pipes unless the trench walls or surrounding embankment have a density and stiffness not less than those of the adjacent compacted fill, to a height of $0.5D$ above the bottom of the pipe and for a lateral distance from the pipe outside springline of not less than 1.5 times the pipe outside diameter (D), or D beyond the trench wall, whichever is the lesser.

Although the statement above refers pipe support, compaction of the side zone to achieve similar stiffness to HS2 or HS3 supports typically used for embankment installations will eventually reduce the compression of the fill in the lower portion of the side prism. This will allow for the compacted embankment fill in this lower portion to be considered equivalent surface in the projection calculations.

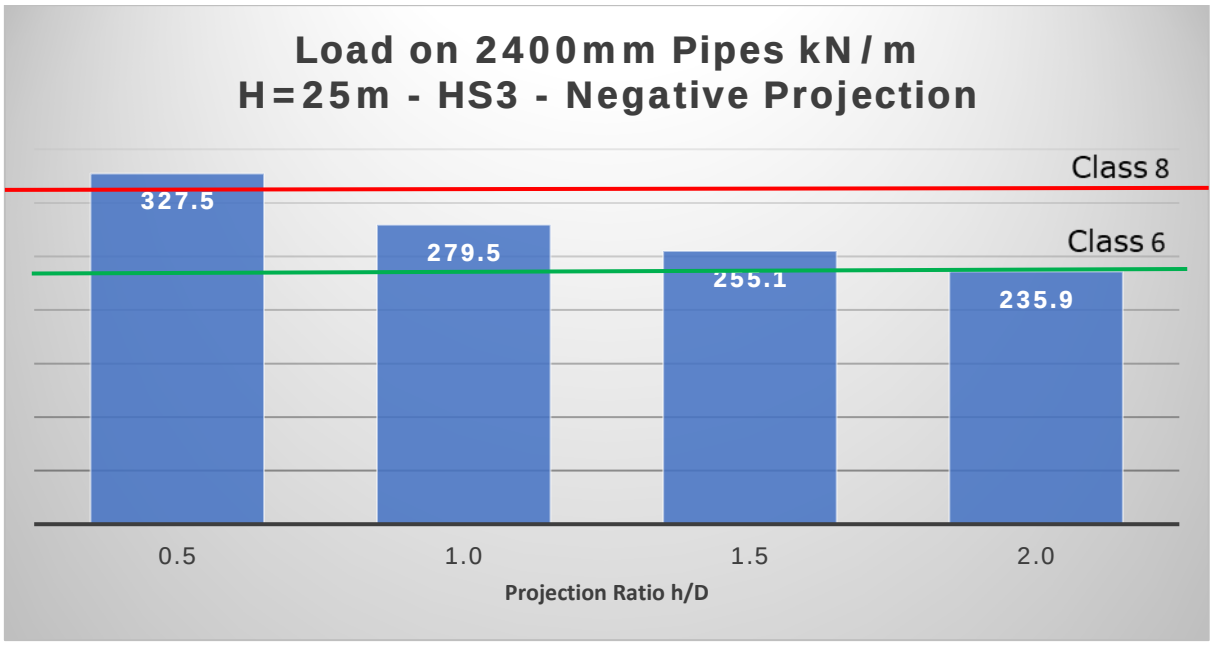
4.2.1 NEGATIVE PROJECTION

The diagram on the right of *Figure 4* clearly shows that the deeper internal prism will settle at the foundation more than the shallower side prism. Combining the effect of the compression of the internal prism and the deflection of the pipe, the internal prism will tend to deform downwards, creating upward shear forces along the edge of the internal prism reducing the load on the pipe.

The effect of the increase in the values of the Negative Projection on the load on the pipes is shown in *Figure 9* for the worked example of the 2400 mm Ø pipe under 25 m wet clay embankment fill.

The load on the pipe exceeds the capacity of a Class 8 pipes when installed with a projection Ratio of 0.5 but decreases as the projection ratio increases from 1.0 to 2.0, reducing to just Class 6 at Projection Ratio of 2.0.

Figure 9: Load on Pipes at Various Negative Projection Ratio

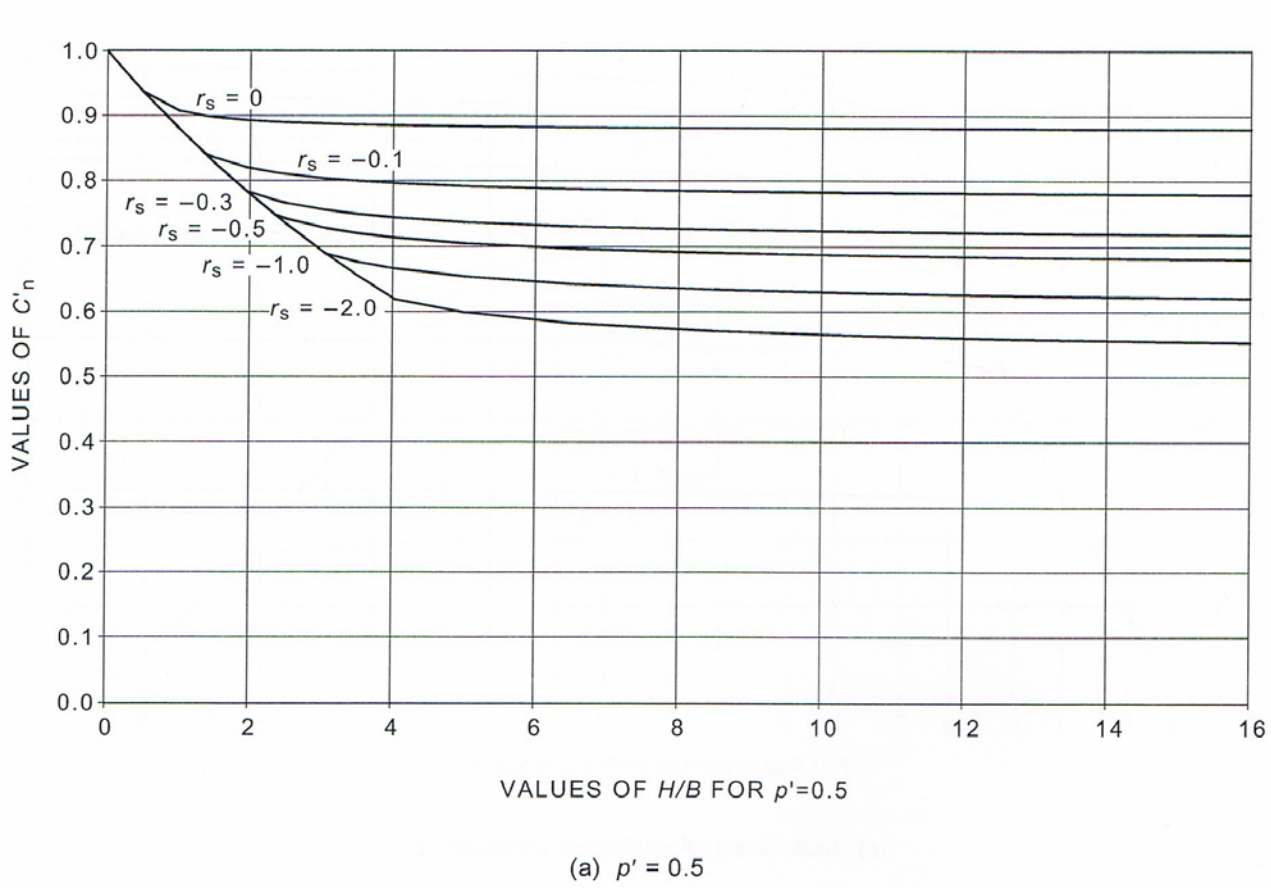


Similar to positive projection, AS/NZS 3725:2007 allows the pipe projection to be within "Natural Ground" or "Equivalent Surface". However, it requires the use of compressible fill on top of the pipe and a higher value of Settlement Ratio (r_s=-0.5 for earth foundations) as compared to that used in the traditional design approach for similar cases, as shown in *Figure 7 & 8.* This generally results with a higher value of C'_n (see *Figure 10*), and hence, maintains the conservative traditional design approach.

Clause 9.2.3.1 in AS/NZS 3725: 2007 for HS support requires that the trench walls of the natural soil have a density or stiffness not less than the compacted fill. It is unlikely that the natural soil will have similar stiffness to compacted granular fill specified for HS2 and HS3 bedding.

This issue is addressed in Clause C6.3.3.2 of the AS/NZS 3725 Supplement where there is a requirement to apply the induced trench approach for both cases of a trench in natural soil or equivalent embankment fill by using compressible material over the pipe to assure development of upward shear stresses on the internal soil prism on top of the pipe.

Figure 10: *Values of Spangler's Coefficient C'$_n$ (Fig 8 AS/NZS 3725 Negative Projection Embankment Condition)*



The conditions stated in Clause C6.3.3.2 of the Supplement are summarised below. This consideration of the Standard might also explain why the Standard selects higher value for Settlement Ratio, which typically results in higher calculated load on the pipes.

a) If the trench is filled with compressible material such as Straw Bales (recent research and installation overseas and New Zealand indicates that High Density Polystyrene can be used as alternative to Straw Bales) (Siquera & Al-Saleem 2018), then full values of reduction of load on pipes is allowed by the using C'_n factors at their typical value of less than unity.
b) If the trench is filled with loose uncompacted fill, then the installation should be treated as Positive Projection with C'_e = 1.0.

4.3 TRENCH WIDTH

Trench width do not affect the values of load on pipes installed in positive projection. Therefore, Designers considering a positive projection installation to calculate loads on pipes installed in wide trenches may specify any trench width that suits the proposed installation procedures. Designers may also note that any trench width arrived at during construction to reach sound ground will be acceptable.

Trench width should also been selected so that the support for the side zone meets the requirements of Clause 9.2.3.1 of the Standard.

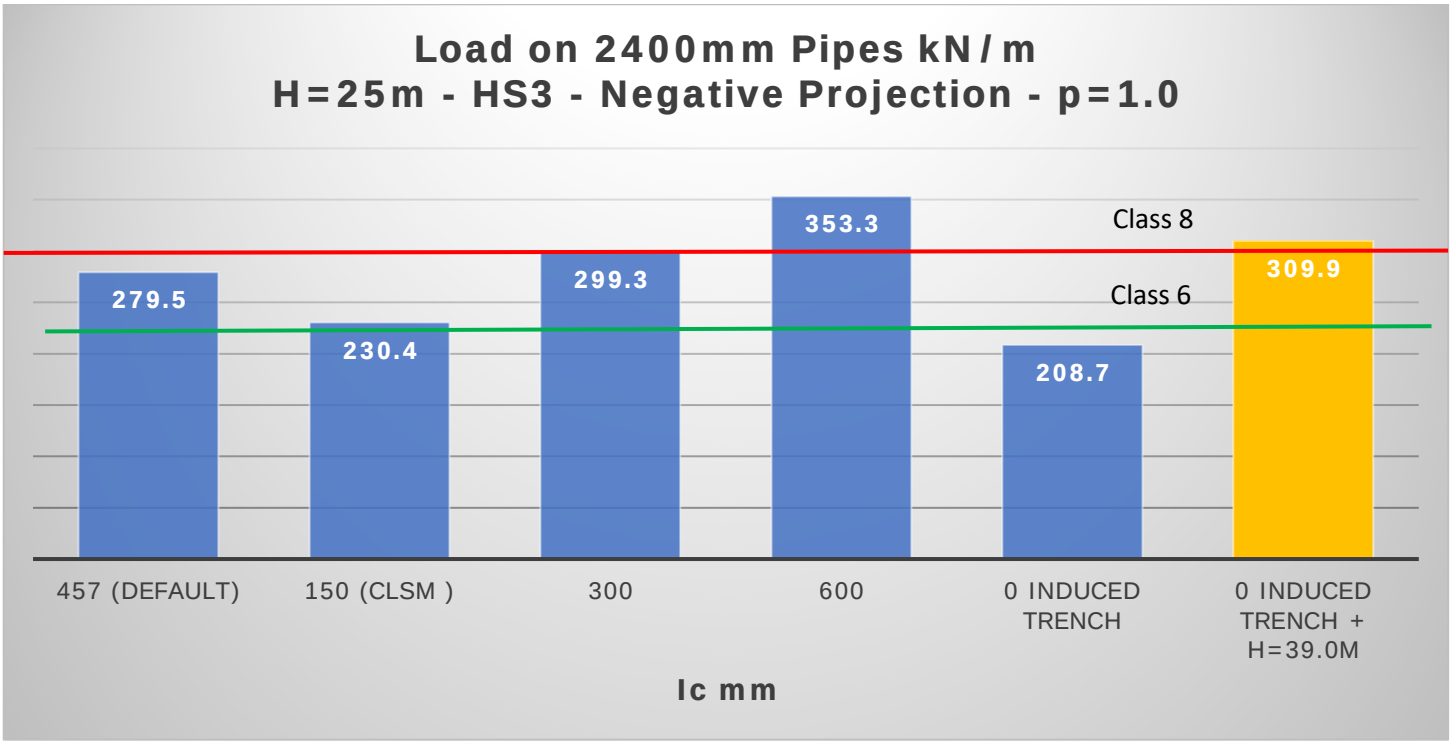
Trench widths in negative projection installations have a significant effect on the loads on the pipe.

C'_n is dependent on H/B (Depth of fill/Width of trench), p' (negative projection ratio) and r_s (negative projection settlement ratio).

The graph shown in *Figure 10* above illustrates the values for C'_n for $\rho'=0.5$ load case in the worked example

Since the load is directly proportional to the width of trench at high H/B ratios, *Figure 11* illustrates how the load on pipes in the worked example change as the trench width varies (commonly chosen trench widths are used to illustrate the effect).

Figure 11: Load on Pipes at Various Trench Widths

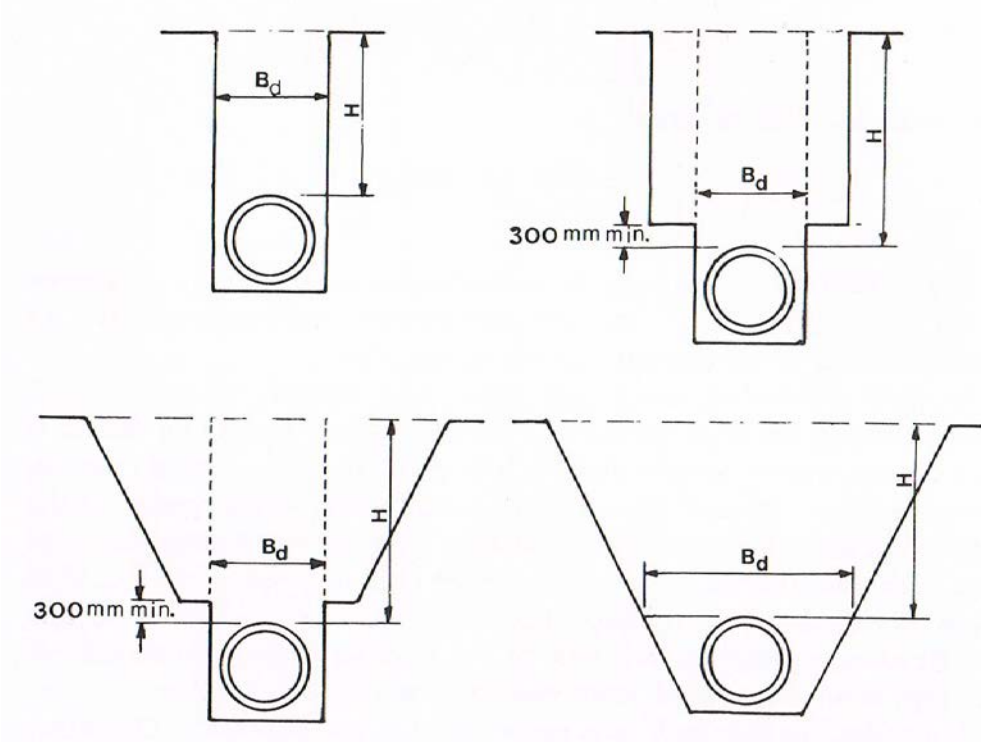


The example above shows the importance of specifying trench width in design drawings and specifications, and the need to revisit these during preconstruction and construction stages, to ensure that the design meets expectations. Incorrect trench width may result in an inadequate strength pipe being installed.

Designers should note that the trench width used in design is the width at the top of the pipe. *Figure 12* illustrates locations where trench width B should be considered for various trench configurations. (Young & Trott 1984)

Health and Safety requirements might dictate sloping or stepping of the trench side at levels lower than the top of the pipes; such requirements should be carefully investigated and accounted for during design stages.

Figure 12: Width of Trench for Various Common Trench Geometries



4.4 PIPE SUPPORT AND BEDDING FACTOR

Safe installation of pipes under deep embankments requires adequate side support for the pipes to achieve the highest Bedding Factor (for maximum reduction loads on the pipes).

AS/NZS 3725:2007 includes a conservative approach to ensure safety in design by considering installation selection, laying, compacting and testing of various embedment layers to achieve the targeted design bedding factors. The AS/NZS 3725 Supplement 1:2007 also includes further clarification of factors that should be considered in design of pipe support.

The CPAA has published an Engineering Guideline “Selecting Materials for Bedding Steel Reinforced Concrete Pipe” to clarify issues arising from difficulties in sourcing the selected fill materials specified in AS/NZS 3725 in some instances or locations. The document provides guidance for use of locally available selected fill materials to achieve the Standard Bedding Factors based on the materials and site compaction meets certain specified conditions.

4.5 CONSTRUCTION LIMITATIONS & H&S DURING CONSTRUCTION

Safety in design for installation of SRC culverts requires Designers to consider various construction limitations and H & S issues during design. These issues that are more prominent in a Negative Projection installation and involve, but not limited to the following:

a) Most Negative Projection culverts are installed to replace existing natural watercourses; therefore, designers should consider the importance of removing all unsuitable soil during trench excavation. New trench widths and projection ratios may apply once all unsuitable material has been removed.

b) Deep trenches will require the use of trench shields; methods for removing trench shields after pipe embedment compaction should be specified to ensure that pipe side support is not lost during shield removal.
c) Installation of large diameter, and heavy pipes in wide and stepped deep trenches as those shown in *Figure 9* might require special construction equipment. Accessibility and availability of such equipment should be considered at design stages.
d) Some installations of pipe culverts under deep embankments are considered complicated construction operations, which require Contractors to follow precise procedures and meet all specifications and detailed requirements. Safety in design of such structures requires Designers to produce comprehensive, clear and easy to understand drawings and specifications. Furthermore, a quality assurance program must be in place, for construction to meet all design targets and Contractors must understand the implications of any unforeseen construction issues. Designs and drawings might need regular updating to allow for various issues that may develop or become apparent during construction.

5 FINITE ELEMENT SOIL PIPE INTERACTION ANALYSIS

The methods of computing the external load of earth fill on the pipes for various installation conditions discussed earlier in this paper are all based on the requirements of AS/NZS 3725:2007. The Standard has adopted the theoretical solutions developed by Marston, Spangler, and their associates in the first half of the twentieth century and validated by many experimental testing mostly in that period.

Many experiments and the long period of successful use have demonstrated that these theories provide designs that sufficiently accurate, safe and economic for normal installation conditions.

Developments in finite element analysis of soil-structure interaction problems have given Designers an alternative tool to use to design culverts pipes under deep embankments. However, the use of such alternatives would only justified if shown to provide a design having appreciable savings in cost with adequate safety.

In the light of the previous discussions, the following cases might be a good example where more accurate finite element analysis might be justified:

a) When Standard analysis indicates pipe strength Class requirements slightly exceeding Class 8, which is typically the maximum strength class available in New Zealand at present.
b) When pre-design investigations indicates that it is impossible to install the pipes within some of the limitations of the Standard, such as stiffness of side zone, use of loose fill or compressible materials in the trench or any other construction limitations.
c) When the geometry of the proposed installation indicates that, there will be possible diversion from the assumptions of the Standard, such as the installation of adjacent pipelines at different levels, installation parallel to the side slope of embankment or the use of different materials in various layers of the embankment fill.
d) To check and review safety of installation when there is any possible non-compliance during construction.

Designers might use any finite element software available that has soil-structure interaction analysis capabilities, or a specialized culvert analysis software such as the American Concrete Pipe Association – PIPECAR or the American Association of State Highway Officials AASHTO – CANDE. The latter is available free for download at https://www.candeforculverts.com/home.html.

6 CONCLUSIONS AND RECOMMENDATIONS

The details of the worked design example, and the discussions presented in this paper indicate the following:

a) It is possible to use the Standard to safely design installations and install concrete pipe culverts with up to 18 meters of embankment fill (in Positive Projections) and up to 48 meters (in Negative Projections).
b) Safety in design of concrete pipe culverts can only been maintained if the design complies with all limitations of the Standard and the Supplement as discussed in detail in this paper.
c) Designers of culverts under Deep Embankments should be aware of all the theoretical background of the Standard, and requirements and limitations before deciding which site-specific conditions, and/or site-modified conditions are best suited for use in design to ensure the targeted safety in design.
d) Designers should note that the use of the induced trench option would result in a reduction in load on pipe as the load is based on the OD of the pipe *D* and not the trench width *B*.
e) Best practice to achieve safety in design is to specify clearly specify the type of materials selected in the design for pipe support in Project specifications and drawings, rather than only referring to the Standard and expecting the Contractor to select the appropriate value. This specification should be revisited at preconstruction and construction stages, and if necessary, a new set of drawings and specifications issued to reflect the actual conditions encountered in the construction phase.

REFERENCES

AS/NZS 3725: 2007 and As/NZS 3725 Supp 1:2007, Standards Australia

ACPA (1998), “Concrete Pipe Handbook”, American Concrete Pipe Association - 1998, Ch. 4, Page 4-15.

Siquera, A & Al-Saleem, H. I. (2018), “Collaboration Driven Innovation for Deep Concrete Culvert Design and Installation – an Example Of Safety in Design”, Water New Zealand, Stormwater Conference 2018.

Young, O. C. & Trott, J. J. (1984), “Buried Rigid Pipes – Structural Design of Pipelines”, Elsevier Applied Science Publishers, 1984, Page 34.