Foundation considerations for buried rigid pipes in soft ground

B. Look[1,] PhD, FIEAust and V. Tandjiria[2], PhD, MIEAust

[1]Principal Geotechnical Engineer, Sinclair Knight Merz Pty Ltd, 32 Cordelia St, South Brisbane; PH: 617-30267173 ; email: blook@globalskm.com
[2]Principal Geotechnical Engineer, Sinclair Knight Merz Pty Ltd, 100 Christie St, St Leonards, NSW 2065 Australia; PH: 612-99282575 ; email: vtandjiria@globalskm.com

ABSTRACT

Foundation assessment involves ensuring the ground below can carry the load without bearing failure or excessive deformation. Deepening foundations or the use of piles is commonly used when the soil condition near surface does not have enough strength or rigidity. When the structure is a buried pipe, compressible soils may influence the hydraulic performance of the pipe. Based on usual foundation practices, the designer may place the buried pipe on a “competent” foundation such as on piles or deepening to place the pipe on to rock. While this may satisfy hydraulic gradients, a “settlement” induced load above the pipe now needs to be considered. This paper presents case studies for pipelines placed on rigid supports due to the soft ground. This increased rigidity of the system now attracts greater load to this buried pipe as the adjacent soft ground settles, while the pipe on a rigid support has negligible movement. Australian Standard provides little guidance on the loads in such circumstances. The principles of pipe - soil interaction are discussed to show how the effects of foundation improvement, pipe bedding, and compaction influence the load on the buried pipe. Without these principles being understood and applied there is a significant scope for the Australian Standards for buried pipes to be applied inappropriately.

Keywords: buried concrete pipes, compressible clays, rigid foundation, pipe installations

1 INTRODUCTION

There are two basic types of pipes – rigid and flexible. For rigid pipes the pipe itself is the structure while for flexible pipe the “structure” consists of the pipe and stiffened soil surrounding the pipe. Thus flexible pipes require wider trench widths to carry out compaction at the sides while rigid pipes may have narrower trenches for installation.

Concrete pipes are considered rigid while steel or PVC pipes are flexible. In both cases the interaction of the underlying soil, the bedding, the trench wall (if any), the surrounding soil, and the soil above (thickness and type) all contribute to the load on the pipe. However the flexible pipes require greater design emphasis on the side support while the rigid pipes require emphasis on the bedding and foundation to perform satisfactorily.

Rigid pipe design is discussed in this paper with respect to the application of the Australian Standard AS 3725 (2007) on “Design for installation of buried concrete pipes” for varying foundation conditions.

There are four common types of installations of buried rigid (concrete) pipes which influence earth loads transmitted to a pipe. In each case, the load imposed on the pipe is much more than the weight of the sol prism directly over the pipe in a trench (Handy and Spangler, 2007). The embankment attracts more load than the trench. A rigid pipe also attracts significantly more load than a flexible pipe. Thus the maximum load path is illustrated on the left most side of Figure 1. This concept is explained further, as it represents the basis of understanding and applying the Australian Standard. The type of installation affects the load imposed as follows:-

Narrow Trench – This type of installation is installed in a relatively narrow trench excavated in undisturbed soil and then covered with backfill extending to the ground surface.

Wide Trench - As the trench width increases the fill loading imposes more load on to the pipe. The embankment loading condition is reached when the trench walls are too far away from the pipe to help support the soil immediately adjacent to it. Calculations on load on to a pipe in a ditch with sloping side must therefore be based on the ditch width (B) and not the pipe diameter (D).

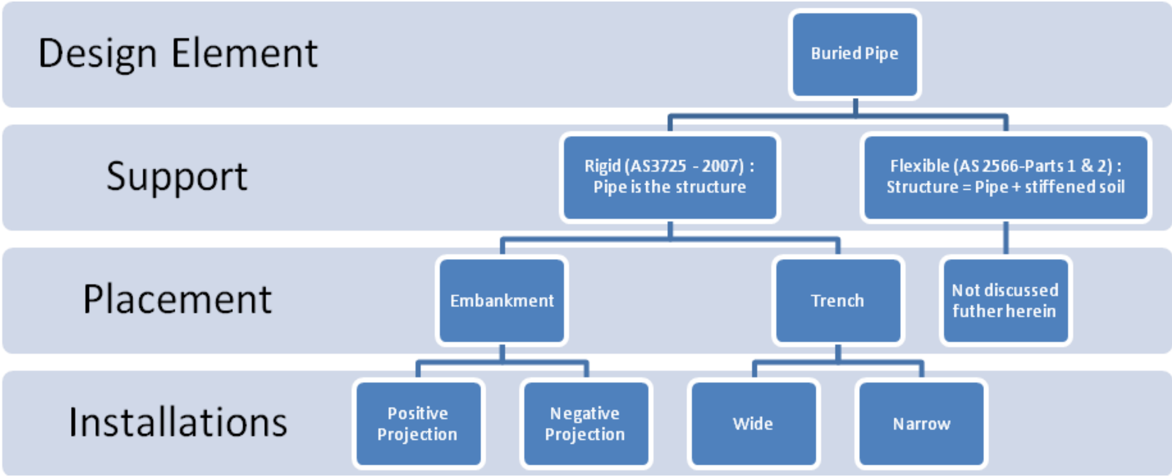


Figure 1. Pipe Installations

Positive Projecting Embankment – The pipe is installed on the original ground or compacted fill and then covered by an earth fill or embankment. This has the maximum load attraction of the 4 installations described.

Negative Projecting Embankment – The pipe is installed in a shallow trench of such depth that the top of the pipe is below the natural ground surface or compacted fill and then covered with an earth fill or embankment which extends above the original ground level.

The positive projecting embankment has the maximum load attraction due to arching effects. This arching movement of fill above culvert for each type of installation is illustrated in Figure 2.

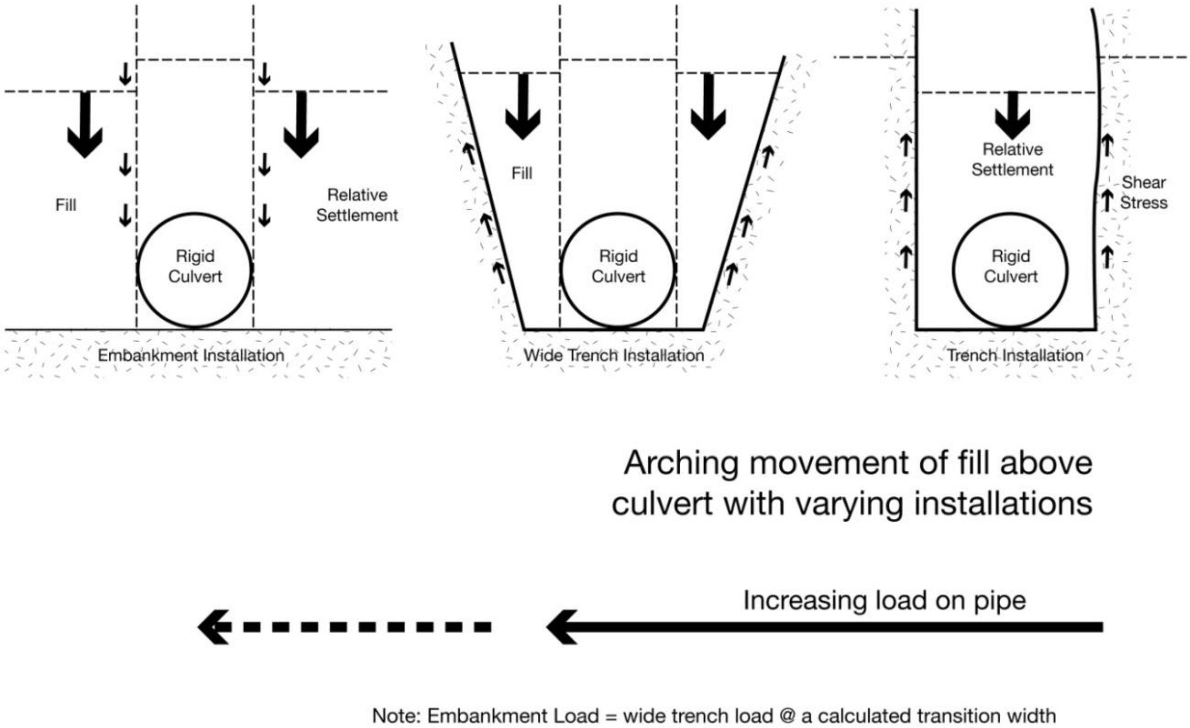


Figure 2. Influence of arching on load transfer to pipe for trench and embankments

2 EFFECT OF FOUNDATION ON LOAD CARRIED BY RIGID PIPE

The common practice is to consider a rigid foundation as better than a "soft" foundation and compaction is always better than no compaction. Australian Standard 3725 (2007) refers to rock foundations requiring 75mm minimum for a Type U support – but not mentioned in H supports. Additionally the bedding directly below the pipe invert should not be compacted. The American Concrete Pipe Association (2000) specifies not less than 150mm bedding for rock foundation. The philosophy of above (although not stated) is to not have a rigid foundation directly below the pipe.

The foundation supporting a rigid pipe has a significant effect on the loads carried by the pipe. In the case of a rock foundation, the rigidity of the underling ground would introduce significant stress on the pipe unless an increase of bedding is adopted. Where soft soils are adjacent to the pipe (on a rigid "rock" foundation), then an increased pipe stress is also experienced as settlement occurs.

Heger and Selig (1994) investigated the rigid pipe distress in high embankments over soft soil strata. The load acting on the rigid pipe increases with increasing settlement occurring in the soft soil beside the pipe. Soft soil that is not removed for at least 1 pipe diameter adjacent to the rigid pipe supported on rock has a significant effect on the loads carried by the pipe.

Matyas and Davis (1983) for a concrete pipe supported on piles in soft soils also emphasise the increased stress effect on the pipe, and recommends using the complete projection values for the loading coefficients.

The more rigid the foundation below the pipe, the higher stress which the pipe experiences as relative settlement between the fill above the rigid pipe and the fill surrounding the pile is also larger. The arching movement of fill above the pipe for three different foundations – firm ground, rock and pile is presented in Figure 3 and compares the typical embankment condition with such conditions.

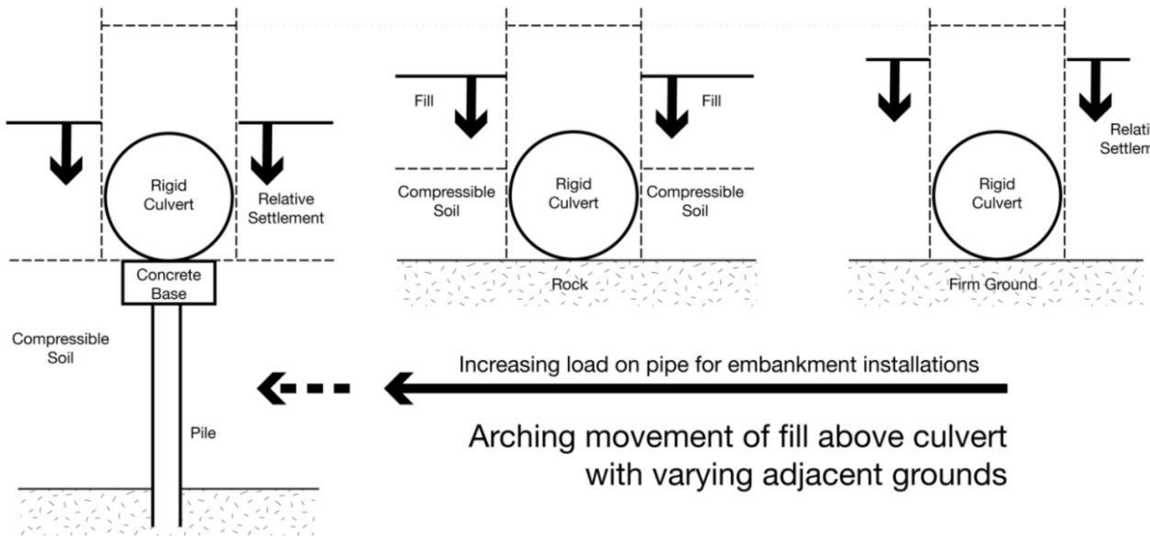


Figure 3. Influence of arching where the relative movement increases

3 SETTLEMENT RATIO AND COMPLETE PROJECTION

AS3725 does not discuss the effect of settlement of compressible soil adjacent to the pipe to the load acting on the pipe. The effect of foundation types is defined in terms of the Settlement ratio (r_s). The settlement ratio for a positive projection is +1.0 for all fill materials while r_s for negative projection is -0.5 for earth foundation and -1.0 for rock foundation. The AS3725 Standard intent has to be read with the supplement "Design for installation of buried concrete pipes – Commentary (Supplement to AS

3725)". Figure C3 from that commentary is replicated here as Figure 4, with the symbols defined as follows:

S_m = Compression of the side column of soil of height D
S_g = Settlement of natural ground surface adjacent to pipes
S_f = settlement of the pipes into their foundation
d_e = deflection of the vertical diameter of the pipe

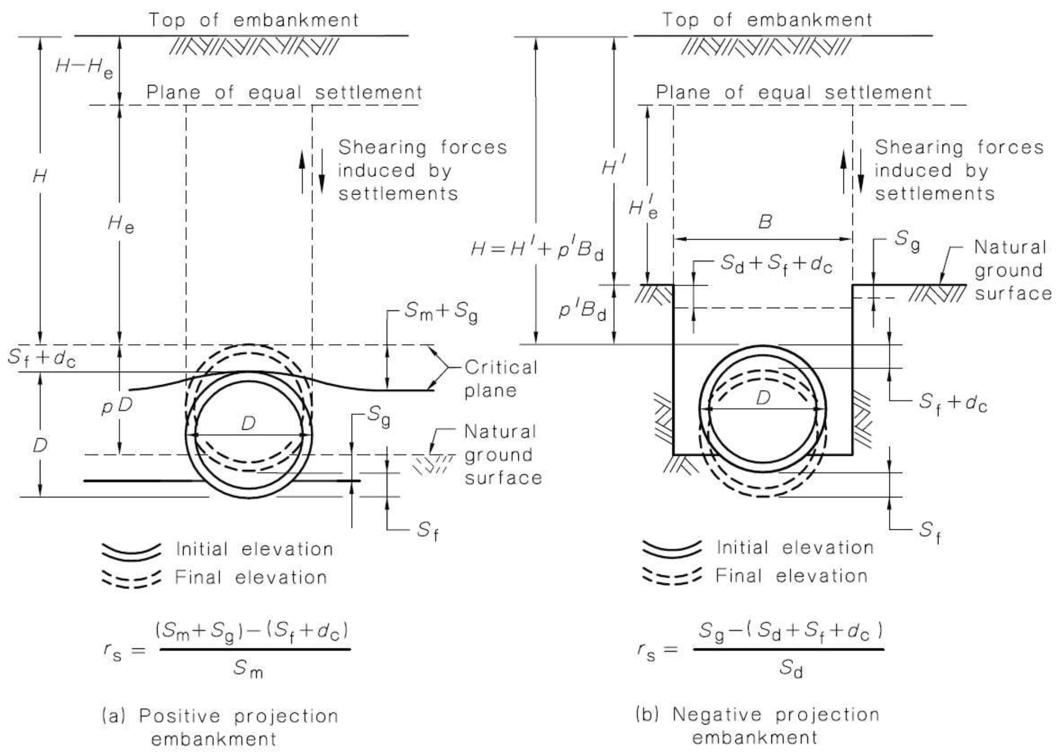


FIGURE C3 SETTLEMENT RATIO TERMS

Figure 4. Settlement Ratio

Where a pipe is founded on a rock or solid concrete foundation, there is negligible settlement of the pipes into their foundation (S_f ~ 0). Where soft clays and /or high embankment loading occur, the settlement of the natural ground surface adjacent to pipes (S_g) can be significant. The r_s values in the Standard has a maximum value of +1.0, yet in the case of a rigid foundation and/or soils compressing adjacent to the pipe the "complete projection" as required to be satisfied is not covered in the AS 3725. However, using some of the references mentioned in AS3725 would show the complete projection condition having up to 170% above the maximum AS3725's coefficient.

4 CASE STUDY

The pile foundation of Figure 3 shows the situation investigated. The geometry is as follows:

- 1500 mm storm water pipe
- Foundation on a structural concrete slab of 1000mm wide x 400mm deep on timber piles at 4m spacing between the centres of the piles
- Thickness of fill studied was between 3m and 7m with bedding of 150mm thick sand material. The stress on the pipe generated by the fill embankment inducing 200mm settlement of soft clay materials surrounding the pipe

This pipe was placed in a natural drainage channel with a slope of 1.5 Horizontal: 1.0 Vertical. The effective width of the trench is 6.95m. Sand bedding was adopted in this analysis - but this does affect the results. A two-dimensional stress and deformation analysis was carried out using the Plaxis finite element software. The soil/rock and structural (concrete and timber) engineering properties adopted in the numerical analysis is presented In Table 1.

Table 1: Material properties used in plaxis analysis

Unit	Material	Elastic Modulus (kPa)	Poisson's Ratio	Unit Weight (kN/m^3)
1	Fill	25,000	0.3	20
2	Soft Clay	2,000	0.45	18
3	Weathered Rock	200,000	0.25	22
4	Bedding: Sand	50,000	0.3	20
5	Concrete	2E7	0.2	24
6	Timber Pile[1]	1E7	0.25	10

[1] Elastic modulus of timber pile adopted in the analysis adjusted (reduced) based on pile spacing and dimension.

5 RESULTS OF ANALYSIS

The stress distribution along the pipe is different for the pipe under the fill weight only and for pipe under fill settlement, as well as foundation type, bedding material and thickness. A smoother stress distribution is observed for the pipe supported on a soil foundation compared to the pipe supported on a slab on piles. For both cases, the stress is actually greater at the bottom side of the pipe especially for the pipe supported by rigid foundation (see figure 5). In general, the stress generated by settlement of the compressible clay is much larger than the stress generated by fill weight.

However, the Australian Standard computes the stress at the top of the pipe and assumes uniformity of that stress (for an earth foundation). This uniformity of stress on the pipe is not valid when a rigid foundation and/or compressible clays exist adjacent. Figure 6 shows the load (converted from stress for that 1500mm pipe size) vs. the height of fill above the pipe calculated using the method suggested in AS3725, a complete projection procedure, and the finite element analysis (Plaxis).

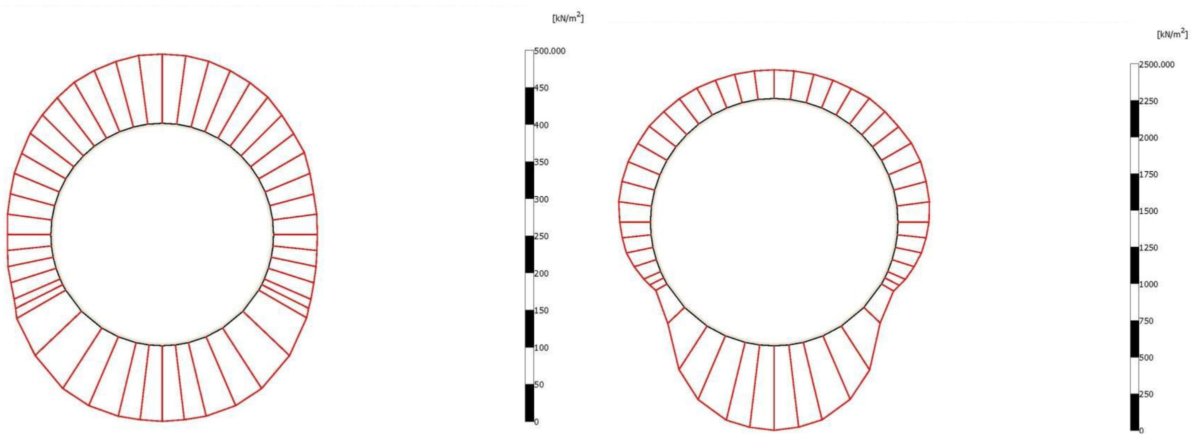
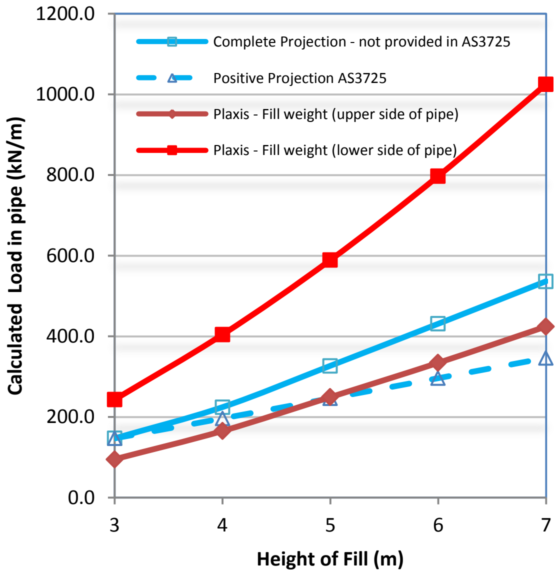


Figure 5. Typical effective normal stresses on pipe due to fill weight for sand bedding on (a) earth foundation and (b) rigid foundation

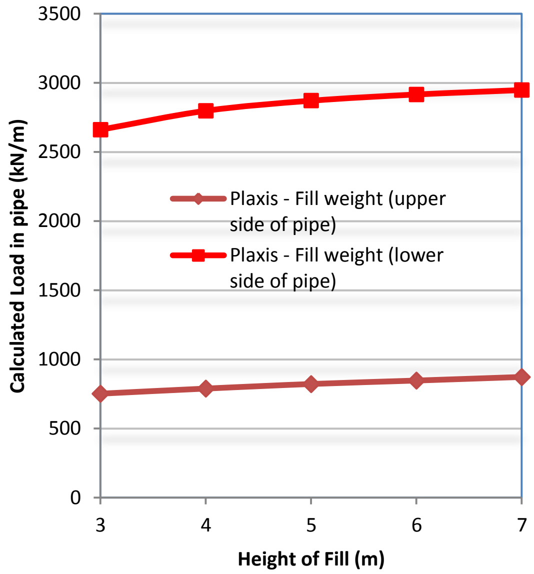
Key findings obtained from the results of the study are as follows:

- Increasing the thickness of embankment above the pipe moves towards the complete projection condition of the pipe.

- The recommended method in AS3275 using the positive projection condition underestimates the load in the pipe for the case where the pipe is supported by rigid foundation (i.e. a rock foundation and pile).
- A rigid foundation of the pipe (pile foundation on concrete slab) and settlement of the soil adjacent to the pipe significantly generates larger loads acting on the pipe than predicted by AS 3725.
- The proposed method by applying the complete projection condition of the pipe using some references mentioned in AS3275 improves the estimated load in the pipe, but the finite element analysis results predict a higher load at the pipe invert.
- The maximum compressive loads (bottom side of the pipe – invert) are significantly higher than at the top of the pipe (crown) where a rigid foundation is present.
- The load acting on the pipe generated by fill settlement is much larger than that generated by the weight of the fill.



(a)



(b)

Figure 6. Calculated load in pipe – (a) due to fill weight and (b) due to 200mm settlement

6 CONCLUSION

AS3725 does not cover the condition of rigid foundations below the pipe. Where the ground adjacent to the buried pipe settles due to compressible soils then the induced stress becomes even larger. The Standard should not be used in such conditions.

The pipe stress varies when the foundation or bedding conditions change. Where a rigid foundation occurs there is non-uniformity of the stress of the pipe between the crown and the invert level with the latter being significantly higher than predicted by AS 3725.

REFERENCES

Heger, F.J. and Selig, E.T. (1994). “Rigid pipe distress in high embankments over soft soil strata”. Transportation Research Record 1431, 46-52.

Matyas, E.L., and Davis, J.B. (1983), “Prediction of vertical earth loads on rigid pipes”, Journal of Geotechnical Engineering, Vol 109, No 2, ASCE.

AS/NZS 3725: 2007. “Design for installation of buried concrete pipes”, Australia/New Zealand Standards.

AS/NZ 3725 Supp 1: 2007. “Design for installation of buried concrete pipes – commentary (Supplement to AS/NZS 3725:2007)”. Australia/New Zealand Standards.

American Concrete Pipe Association, 1998. “Concrete Pipe Handbook”.

Handy, R.L. and Spangler, M.G. (2007). “Geotechnical Engineering: Soil and Foundation Principles and Practice”. McGraw Hill Publishers.

AS4058: 2007. “Precast concrete pipes (pressure and non-pressure)”. Australia/New Zealand Standards.

American Concrete Pipe (ACP) Association (2000), “Standard Installations and Bedding factors for the indirect design method”.