Maximum Permissible Pipe Loadings

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Abstract

Adequate pipe cover is important for buried pipes to provide protection from surface loads. During construction and earthworks by others around Water Corporation pipe assets, the cover of these pipes may be affected such that relaxations in requirements or engineering solutions are proposed. For any such measures to be approved, knowledge of the contributing risk factors is fundamental. Establishing the barrel strength of pipes made from cast iron, cement lined mild steel and PVC of differing nominal diameters and estimating the buried cover depth necessary to protect them will provide a contribution to the knowledge base used in this decision making. With cast iron pipes of sizes DN 100 and DN 150 tested in a laboratory, it has been found that such pipes can quite adequately withstand expected vehicle loading conditions, but as with all engineering applications these results must be considered alongside a broad range of contributing factors.

1. Introduction

The Water Corporation protects its buried pipe assets from imposed surface loads primarily by ensuring they have sufficient cover between the surface and the pipe buried below. A pipe is provided adequate protection at installation through either sufficient cover or via an engineering solution. This might take the form of a trench, tunnel, bridging slab, sleeve or concrete encasing to strengthen the pipe (Water Corporation, 2018). Issues arise where earthworks may disrupt or remove the effectiveness of some of these measures. During such scenarios, the buried depth cover of a pipe may be reduced, introducing the risk of the pipe asset becoming damaged. The Water Corporation is seeking to increase overall knowledge of the cover requirements for their pipe assets to provide additional information when pipe cover requirements are being considered.

A relaxation regarding the cover requirements may allow construction works to continue, but any decision regarding relaxations or engineering solutions must be made with the knowledge of likely outcomes. Factors which affect any proposed relaxation of cover requirements include the expected magnitude of surface loads within the vicinity of the pipe, the material of the pipe and the size of the pipe. Of great interest to the Water Corporation are the properties of "legacy" pipes including cast iron (CI) and cement lined mild steel (MSCL), as well as the more modern polyvinyl chloride (PVC) pipes.

1.1 Current Water Corporation Practices

The cover requirements for pipe assets as currently required may be found in Water Corporation Design Standards, including DS 60, DS 63, DS 66 and DS 51, providing guidance for non-reticulation pipelines, reticulation pipelines smaller than DN250, urban drainage pipes and wastewater pump stations and pressure mains respectively. Further guidance on pipe bedding, laying, fill and appurtenances is located in the Water Supply Code of Australia (Water Services Association of Australia, 2011).

The development of these cover values is drawn from a design approach that also incorporates accessibility of appurtenances, allowances for erosion effects, risk based considerations for hazardous material transport, and other influences from lessons learned through experience. They are of conservative nature, to ensure a consistent construction standard for all installed pipes, which will allow for predictable location and behaviour for future activities.

1.2 Pipe Testing Scope

To fulfill the Water Corporation's wishes to test legacy pipes, the samples have been sourced from recent removal of such pipes from service. Apart from the benefit of replicating any effect that aging or fatigue may have on the properties of collected pipe samples, it is entirely possible that they are no longer available in new condition. While pipes made from polyvinyl chloride (PVC), polyethylene (PE) and steel (including MSCL) are currently being installed, asbestos cement (AC), reinforced concrete (RC) and cast iron (CI) are no longer being installed. Sample collection thus relies on the collection of recently removed pipe assets for older pipe materials.

The scope of this investigation will be limited to failure of the pipe barrel section under bearing stress. As used in Technical Basis of Austroads Guide to Pavement Technology (Jameson, 2013), a surface load replicating what is called "full standard axle loading" for trucks will be adopted as the imposed surface load. This axle configuration is a dual-tyred single axle carrying a total load of 80kN, defined by individual wheels producing a surface stress profile of circular radius 92.1mm and vertical contact stress of 750kPa (Jameson, 2013).

2. Process

To investigate cover requirements and the effect that modifying cover depth has on load transferal to a buried pipe, soil and buried pipe loading theories are utilised to link laboratory experiments to expected buried behaviour in the field. Made available for the purpose of this task is the Baldwin static loading machine for compression tests, meaning that the experiment phase of this research will not involve the effects of burying a pipe, and is adapted to reflect the condition of pipes found in service.

2.1 Truncated Cone/Pyramid Soil Theory

Also known as the Approximate Method (Budhu, 2015), the truncated cone/pyramid theory will provide a representation for sandy soil behaviour in minimum-cover analysis. It simplifies a surface load to a circular or rectangular shape, producing a truncated cone or truncated pyramid soil structure respectively in showing how the surface load is distributed through the soil. For minimum cover analysis, self-weight of the soil is negligible compared to the load required for pipe failure (Moser & Folkman, 2008). By using the standard axle loading defined in (Jameson, 2013), a benchmark for surface loading is used in the development of the cover requirements. This truncated cone will develop vertically downwards with the cone radius increasing 1 for every 2 descended (Moser & Folkman, 2008). The purpose of this theory is to find a depth that the pipe is able to withstand as the soil cone structure dissipates vertical stress. This soil structure requires a development depth approximately equal to the width of the surface load (Budhu, 2015), and so the shallow limit on the cover depth can be set at 200mm.

2.2 Two-Edge Bearing Test

The test using the Baldwin static loading machine is adapted from a method used to determine the bearing strength of concrete pipes. This is found in AS4058 Appendix C (Standards Australia, 2007), and involves loading pads on the crown invert of the pipe. While in concrete the failure point is when significant cracks occur, the different pipe materials in this project will require differing indicators for critical failure. For example, if the pipe has a brittle failure (such as CI), the complete failure will provide an obvious end of loading, while the failure point of MSCL could be the destruction of the internal cement lining, and PVC the decreased flow capacity. The data collected during these lab experiments include the imposed load and the change in vertical height of the pipe, as well as any other observations during the course of the loading.

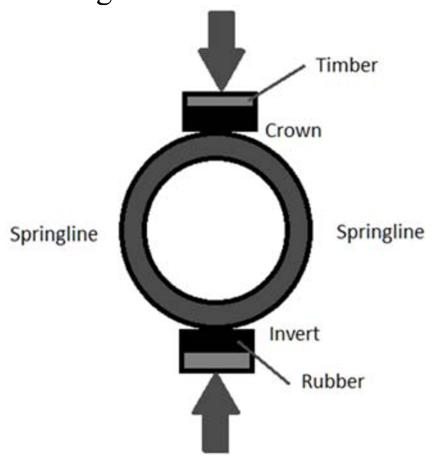

Figure 1 (a) Diagram of two-edge bearing method as found in AS4058 (Standards Australia, 2007)

Figure 1 (b) Set-up of the two-edge bearing method at the UWA structural lab

2.3 Bedding and Impact Factors

A buried pipe will not have a force concentrated on solely on the crown and invert, but will experience a distributed load on the top surface, with the surrounding soil supporting and strengthening the pipe against bearing failure along the bottom. To account for this, a modifying factor is adapted from a buried concrete pipe scenario using the live load bedding factor of 1.5 (Concrete Pipe Association of Australasia, 2013) due to the similar rigid properties of the pipes being tested, and with vehicle loads being live loads.

An impact factor must also be applied to account for the dynamic loading nature of vehicle tyre loads across buried pipes. For a shallow application, this is taken as a 1.5 multiplier on the imposed load (Moser & Folkman, 2008).

2.4 Combining the Theories

A representation of these theories based on AS3725 Cl. 10.2(a) (Standards Australia, 2007):

$$\{T_c F_B\}_{pipe\ strength} \geq \left\{P \times \frac{\pi R^2}{\pi\left(R+\frac{z}{2}\right)^2} F_I B\right\}_{transferred\ load}$$

Where $T_c = experimental\ pipe\ strength\ (kN/m)$
$F_B = live\ load\ bedding\ factor = 1.5$
$P = vertical\ spressure\ of\ tyre\ on\ surface\ (kPa)$
$R = surface\ contact\ radius\ of\ tyre\ (m)$
$z = vertical\ distance\ between\ surface\ and\ top\ of\ pipe\ (m)$
$F_I = impact\ factor = 1.5$
$B = pipe\ width\ (m)$

3. Results and Discussion

At this point, only CI samples of sizes DN100 and DN150 have been tested. They produce a strength failure point brittle in nature, roughly longitudinal, following crown, invert and springlines. Experiments were conducted on samples of length 250mm and the results for both CI sizes are shown below.

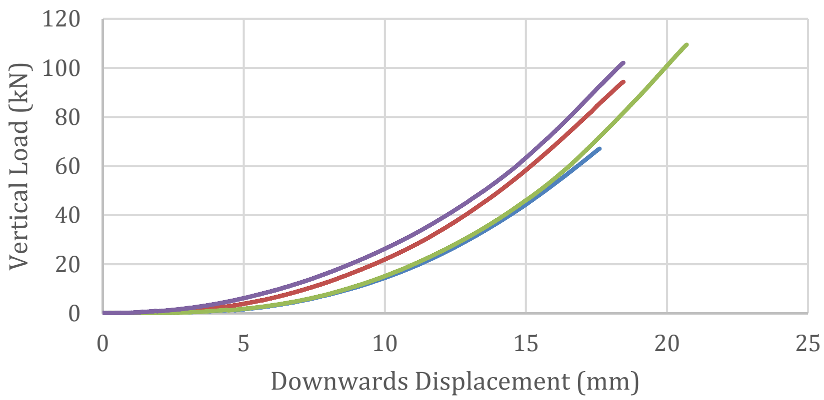

Figure 2 Load vs Displacement graph for CI DN100 Baldwin bearing tests

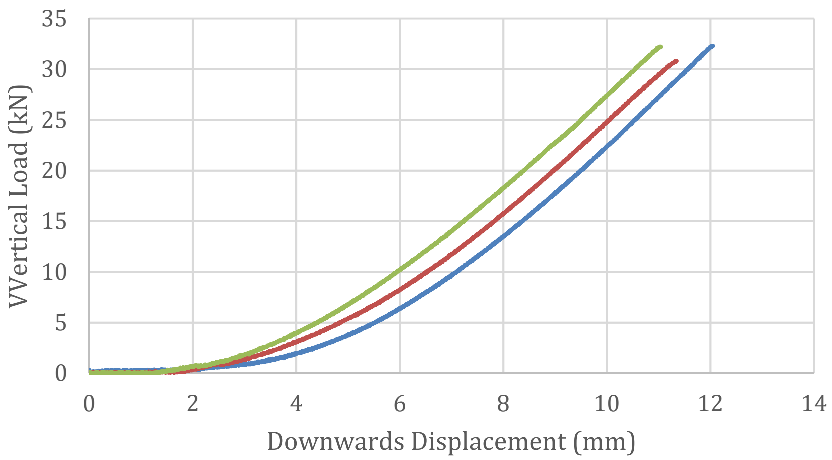

Figure 3 Load vs Displacement graph for CI DN150 Baldwin bearing tests

Pipe Specifications	Minimum Ultimate Strength	Minimum Ultimate Strength/m
DN 100 CI	67.1 kN	268.3 kN/m
DN 150 CI	30.8 kN	123.2 kN/m

Table 1 Converts the experiment ultimate strength load to a per-meter property

By using the standard axle load defined by a circle of 92.1mm radius and 750kPa pressure (Jameson, 2013), the equation becomes:

$$T_c \geq 750 \times \frac{0.0921^2}{\left(0.0921 + \frac{z}{2}\right)^2} B$$

Pipe Type	Bearing Strength/m	Z (m)	Transferred Load/m
DN 100 CI	268.3 kN/m	0	75 kN/m
DN 150 CI	123.2 kN/m	0	112.5 kN/m

Table 2 Compares the bearing strength of the pipe to the transferred standard axle load it would be resisting

3.1 Analysis and Recommendations

Based on the calculated strengths and transferred loads, both CI DN100 and DN150 are capable of carrying the standard axle load without requiring any additional burial depth. This does not however suggest that pipes placed on the surface will withstand the loading alone, instead that if the tyre pressure is distributed properly on the pipe then it will withstand the load. Thus, the minimum cover will be set by the depth required for the development of the truncated soil structure (Budhu, 2015) of 200mm. Buried at 200mm, the pipes will have the conditions:

Pipe type	Bearing Strength/m	Transferred Load/m	Factor of Safety
DN 100 CI	268.3 kN/m	17.2 kN/m	15.56
DN 150 CI	123.2 kN/m	25.9 kN/m	4.76

Table 3 Compares the strength of the pipe to a 200mm cover transferred load

The 200mm recommended pipe cover provides a high factor of safety, especially for the DN 100 CI pipe, but due to the brittle properties of the CI pipes it is important that unnecessary risks be avoided. Too shallow a cover may cause rocks to produce stress concentrations, and ruts may reduce the true cover with sufficiently loose soil and traversal (Moser & Folkman, 2008), so care must still be taken when working around these pipe types.

4. Conclusions and Future Work

For the pipes tested to date, a minimum cover recommendation of 200mm for each CI pipes of DN 100 and DN 150 may appear overly conservative, with factors of safety 15.5 and 4.7 respectively. However, the testing to date has been conducted on a small sample size of 4 x DN 100 and 3 × DN 150, so some work must still be done to develop a full picture of the representative strength of these particular pipes. If additional samples can be obtained within the project timespan there will be benefits not just to provide additional strength values, but to provide a more accurate observation of how age and wear affect the pipes that were in service.

It should be noted that any samples capable of being tested produce knowledge bias towards higher pipe strength results, since any pipes too deteriorated or damaged to be tested will not become tested samples and will therefore not appear in any results. Such a study on the full condition of in-service or recently in-service pipe assets would provide knowledge of great significance, however that is outside the scope of this project.

For the remainder of this study, a focus will shift to MSCL and PVC pipes, with the intent to observe and measure their behaviours under loading and how this compares to pipes of differing sizes and materials. Additional loading scenarios may also be considered, with heavy rollers, cranes or other heavy vehicles of interest.

Recommendations for future studies to complement the information covered in this project include additional pipe materials and sizes, fatigue loading effects, vibration effects, alternative failure modes such as socket failure or pipe beam failure, testing with a pressurised pipe barrel, more accurate laboratory replications of buried pipe loading conditions, and investigating the effect that soil properties have on loading assumptions.

5. Acknowledgements

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