Design, Specification and Selection of Concrete Jacking Pipes
– Who Decides? What Really Matters?

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ABSTRACT

Inadequate or incomplete specifications for jacking pipes often lead to purchasing decisions being made by installers that may not be in the best interest of the asset owner or in some instances the installer themselves. The absence of an appropriate Australian Standard has led designers to use overseas (mainly European) standards. What are the implications of this for both the asset owner and installer? This paper details the design requirements for concrete jacking pipes from the perspective of the asset owner and the installation contractor. In particular, it contains a review of requirements of existing Australian, European and Japanese standards and specifications, their respective strengths and weaknesses with respect to jacking pipes, and what it means if these specifications are used. Joint performance is a key to both a successful jacked pipeline installation and long asset life, and the results of joint testing in accordance with existing specifications along with other suggested testing requirements are included. In conclusion, suggested amendments and additions to the existing Australian Standard for precast concrete pipes are presented as a guide to both specifiers and installers of concrete jacking pipes.

1. INTRODUCTION

Trenchless methods of pipe installation are becoming more common for a host of economic, environmental and other reasons. In most traditional pipeline contracts the designer and/or asset owner will specify the type of pipe to be used. If however the pipe is to be installed using trenchless methods, the design and specification of such pipes become far more complex. Not only do the pipes have to meet the design requirements for the intended application but they have to meet the often complex requirements of the installation contractor. As such, in many projects the purchasing decisions for the jacking pipes is often left to the installation contractor. In many of these projects the single largest variable cost of the installation for the contractor is the purchase of the pipe. In a competitive tendering situation this cost pressure can lead to the selection of pipes based on cost alone which may or may not be in the best interest of the asset owner and pipe installation contractor.

Reinforced concrete jacking pipes are one of the most commonly used materials used for jacked pipe installations. The existing Australian / New Zealand Standard (AS/NZS 4058:2007) for concrete pipes has little or no relevance to jacking pipes. This has forced specifiers, at best, to use overseas publications, or, at worst, include no specification at all. The lack of relevance of the existing local standard combined with the lack of understanding of the overseas standards can mean that purchasing decisions are being made for the wrong reasons. At the end of the project, when all the impressive tunnelling machines and temporary works have been removed, the asset owner is being with only one thing, the installed pipeline. Is it suitable for the intended application? Has the installation contractor been forced to make a hasty decision in an attempt to win a project? Is this really all fair?

This paper examines some of the key design issues associated with the selection of concrete jacking pipes and includes a comparison of a number of overseas standards which are sometimes used in local specifications. It concludes with some suggested changes to the existing local standard in an attempt to give certainty to asset owners that the installed pipeline will provide the expected asset life and provides the installation contractor with a pipe that will significantly increase the chances of a successful installation.

2. REQUIREMENTS FOR CONCRETE JACKING PIPES

Any jacking pipe must be capable of performance through 2 distinct phases, the first being the relatively short period of its installation followed by typically a much longer service life. James Thomson (1993) included an excellent summary of fundamental requirements for pipes, which were:

- Resistance to internal and external corrosion.
- Capacity to withstand static and dynamic loadings.
- Capacity to withstand internal and external pressures.
- Good flow characteristics.
- Satisfactory whole-life costs.

Thomson went on to further detail specific design features for jacking pipes, which were:

- High axial load capacity.
- Close dimension tolerances.
- Squareness of ends.
- Straightness along the length.
- A watertight joint made within the pipe wall, without internal or external projection.
- Joints capable of transmitting axial loads while remaining water tight under angular deflection.

The American Society of Civil Engineers (*ASCE*, 2001) also included some general requirements for microtunnelling pipes, which are:

- Circular shape with a flush outside surface (including at the joints).
- Strength sufficient to withstand both the installation loads and the in-place, long term service loads.
- Dimensional tolerance on length, straightness, roundness, end squareness, and allowable angular deflection.
- Durability for service exposure (internal and external corrosion resistance).
- Joints capable of the specified level of water-tight performance and transfer of jacking loads between pipes.

There is much in common with these requirements. The most important aspects of these are discussed below and include specific comment from an Australian perspective. Designers, asset owners and installers should be aware of these requirements when designing or planning a jacked pipe installation.

2.1 Corrosion Resistance

From the asset owner’s perspective, this is a fundamental requirement. The corrosion mechanism of the concrete in precast concrete pipes is relatively well understood due to the long history of performance and existing publications and standards (e.g., AS/NZS 4058). Most concrete pipe manufacturers are able to offer a range of design solutions for different environments including increased cover to reinforcement and thermoplastic internal lining for aggressive sewerage environments. The almost universal use of steel collared jacking pipes is a potential issue with asset life. This is not well documented although, like concrete, the corrosion mechanism of steel is well understood. A detailed discussion of the corrosion resistance of steel collars on jacking pipes is beyond the scope of this paper. It is however, recommended that the following should be considered by the designer:

a) It is important to consider the different environments that will exist inside and outside the pipeline.

b) On the outside (soil side) chemical analysis of native soil and groundwater should indicate whether there is likely to be constituents present which may be harmful to steel. From this it should be possible to determine a potential rate of corrosion.

c) Post installation grouting of the exterior annulus between the jacking pipe and the soil is likely to significantly reduce the likelihood of corrosion occurring.

d) A secondary sealant can be incorporated into the joint design that may isolate the collar from the interior environment.

e) The use of stainless steel is likely to eliminate most of the risk of corrosion although in certain soils the selection of the grade of stainless steel may be important.

Figure 1 - Jacking Pipes with Stainless Steel Collars & Thermoplastic Lining

2.2 Loading and Strength Requirements

Loads acting on jacking pipes will include both permanent and installation loads. Permanent loads (earth and live loads) can be calculated using AS/NZS 3725:2007. From this calculation the minimum strength requirement for the permanent installation can be determined. For reinforced concrete pipes this will be in the form of a minimum proof and ultimate load for a pipe with the capacity then proven by external load testing (see Figure 2).

Strength requirements for installation during jacking are, however, quite a different matter. The two main loads to consider are axial loads applied via the jacks and lateral loads as a result of a reaction from contact between the pipe and the tunnel wall. The axial load capacity or maximum allowable forces are calculated in accordance with method detailed in the Concrete Pipe Association of Australasia publication, Pipe Jacking (CPAA -1990). Independent research at Oxford University (Norris – 1992, p 8.3) concluded that:

> "*the linear stress approach of the Australian CPA can adequately match the measured stresses, and could be used to define jacking loads on pipes on the basis of pipe size, packer properties, concrete strength and angular misalignment.*"

As Norris points out, there are a number of factors which need to be considered including the stress history of the packer during possible repeated loading cycles. The author suggests that this stress history is of particular importance if considering possible curved alignments with different curve directions. In such instances, alternative packer arrangements may be necessary.

Lateral loads as a result of reactions between the pipe and excavated tunnel are not well understood and are difficult to predict. As shall be discussed later in the paper, the industry to date has largely relied on a minimum strength based in historical strength classes which have proven to provide quite reliable performance.

2.3 Internal and External Hydrostatic Pressure Capacity

For most jacked pipe installations internal hydrostatic pressure is not a significant design parameter. However for sewerage applications hydrostatic testing in accordance with AS/NZS 4058 could be appropriate for a jacked installation. This testing involves an internal hydrostatic test of 90 kPa which is suitable for maximum working pressures of 60-70 kPa. For particularly deep sewers, which are likely to be installed by microtunnelling, the designer needs to consider maximum working pressures which may occur and this may require the pipes to be classified and tested as pressure pipes.

Jacking pipe capacity to withstand external hydrostatic pressures is however a significant and often overlooked issue. External hydrostatic pressure will occur due to external groundwater but during installation this pressure may be significantly higher due to slurry or lubrication injection. Stein (2005) suggests that these pressures can reach up to 5 bar (500 kPa). External hydrostatic pressure can result in the pipe seal being forced inside the pipe joint which will result in an almost complete loss of connection between adjacent pipes and of the jacked pipeline. Installation contractors are making increased use of sophisticated lubrication systems which significantly reduce jacking forces but the pipe joints used with such systems need to be compatible.

The capacity of a pipe joint (jacking or otherwise) to withstand external pressure is best determined by external hydrostatic testing. There are very few published test methods in existing standards and specifications for external hydrostatic testing. This is mainly due to the difficulty in applying an external hydrostatic pressure to a joint. Many specifications refer to both pipe and joint testing with the application of internal hydrostatic pressure; however, this is of limited relevance for this application, as very few pipe joints are symmetrical and tend to have a better capacity to withstand internal rather than external hydrostatic pressure. External hydrostatic testing can be carried out by pressurisation of an external testing band that seals around the pipe joint as shown in Figure 3.

Figure 2 - Pipe External Load Testing

Figure 3 - External Hydrostatic Testing

2.4 Geometric Requirements and Tolerances

The pipeline designer is usually most interested in the internal diameter for hydraulic or other reasons. The installer is, however, much more interested in a number of geometric parameters, with external diameter and overall pipe length being two of the most significant. The issues associated with various geometric parameters are discussed in more detail later in the paper.

2.5 Jacking Pipe Joints and Performance Requirements

As any pipeline designer or asset owner knows, pipe joints and pipe joint performance is one of the most important design considerations. These are particularly important for jacking pipes which in addition to normal pipeline requirements also need to be capable of transferring high axial loads. In Australia, as with other locations, early jacking pipes were modified trench pipes. Current industry publications (CPAA-1 and CPAA-2) still refer to pipe joints that are largely based on these modified trench pipe joints. These joints are referred to, in these publications, as a butt end or butt joint and the in-wall rubber ring joint (see Figure 4).

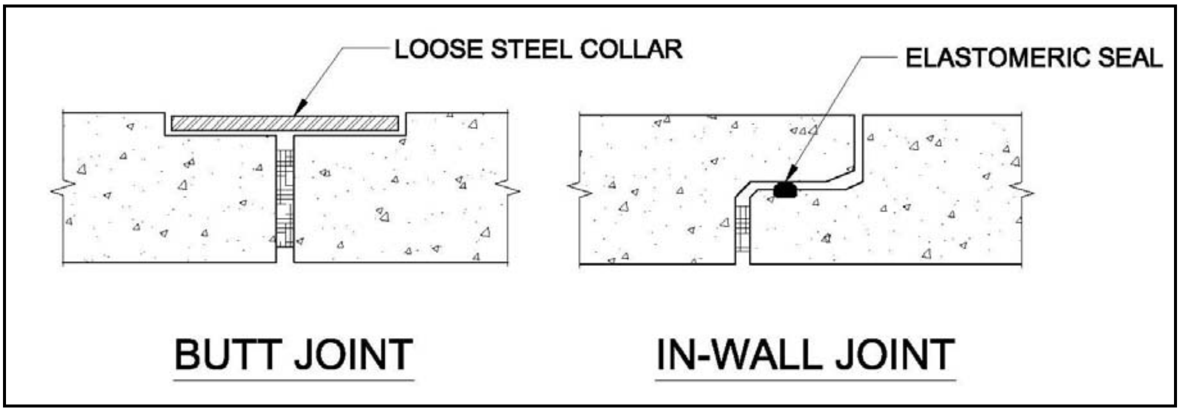

Figure 4 - Modified Trench Pipe Joints

The butt joint jacking pipe is still popular with many pipe jacking contractors due to its ready availability and having an external diameter that matches their installation equipment, but has limited flexibility and does not provide a water or soil tight joint. As such, this pipe is generally not suitable for installation with modern microtunnelling equipment as slurry and / or lubricants end up inside the pipe. Similarly in drainage applications there is a risk that infiltration and exfiltration of stormwater or groundwater could erode the surrounding soil, leading to formation of voids under road pavements or other important infrastructure.

The in-wall or rebated joint (as referred to in some overseas publications) has been successfully used on a number of sewer installations in Australia, but has also experienced some installation issues. These issues include cracking of the concrete collar and seals being forced inside the pipe. The cracking of the concrete collar can be overcome by inclusion of an external steel band cast onto the outside of the collar.

The most common jacking pipe joint used throughout the world is a pipe which has a collar (usually steel) flush with the pipe barrel with an elastomeric seal. Thomson (1993) stated that this is now “the most commonly used type of joint worldwide”. Sixteen years later this is still very much the case. Figure 5 shows two variations of the collar joint, with the fixed collar by far the most common, due to the leading edge of the collar being flush with and positively connected to the pipe barrel.

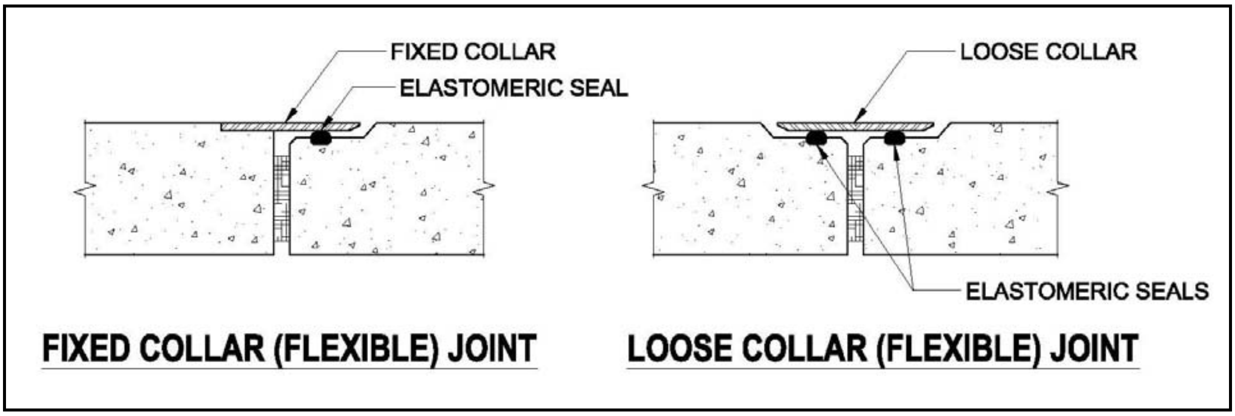

Figure 5 - Collared Jacking Pipe Joints

3. EXISTING STANDARDS AND SPECIFICATIONS

The existing Australian Standard for precast concrete pipes AS/NZS 4058:2007 makes very limited reference to jacking pipes and on its own has very limited value as a specification document for either the asset owner or installation contractor looking to purchase concrete jacking pipes. A number of overseas publications, however, are far more relevant. These are:

- BS 5911-1:2002 Concrete pipes and ancillary concrete products – Part 1: Specification for unreinforced and reinforced concrete pipes (including jacking pipes) and fittings with flexible joints (complementary to BS EN 1916:2002).
- EN 1916:2002 Concrete pipes and fittings, unreinforced, steel fibre and reinforced.
- JSWAS-A2-1991 Jacking reinforced concrete pipes for sewerage.

The British Standard BS 5911 is complementary to European Standard EN 1916 which basically means it contains additional or different requirements to the EN 1916. These standards are included here as it has been common practice in a number of Australian and New Zealand projects for them to be used as the main specification for the jacking pipes. These standards are relevant for a range of concrete pipe applications including jacking pipes.

The Japanese specification JSWAS-A2 is published by the Japanese Sewerage Works Agency and is included here for comparison purposes as Japan has a long and successful history in jacking pipe manufacture and trenchless installation. This specification is specific for jacking pipes only. This specification is also prescriptive in that it includes detailed dimensions for all aspects of the pipe including internal & external diameters and joint dimensions for both standard and intermediate jacking station pipes. It is assumed that most installation contractors would look with envy at this type of specification with specified dimensions, rather than having to deal with the vast range of external diameters for jacking pipes offered by Australian and other jacking pipe suppliers.

Table 1 shows a comparison between a number of the more significant requirements of AS/NZS 4058, BS 5911/EN 1916 and JSWAS-A2. This should be treated as high level summary. Direct comparisons cannot be made due to different test methods (e.g. water absorption) included in each of the standards. A number of these requirements are self explanatory; however the most significant issues are discussed below:

- **Strength Requirements –** All three standards have a common requirement for defining pipe strength. All include a non-destructive proof load test and an ultimate (failure) load test. The requirements for the proof test vary, however, a failure load is easy to compare. BS 5911 includes only one strength class for jacking pipes whereas JSWAS-A2 includes 2 strength classes. Figure 6 includes a comparison of the ultimate test loads in BS 5911 with Class 4 pipes to AS/NZS 4058 and the higher strength Class 2 from JSWAS-A2. There is quite reasonable correlation between these loads classes with Class 4 of AS/NZS 4058 being either consistent with or in between the values of the established British and Japanese publications. It is suggested that a Class 4 strength class to AS/NZS 4058 would appear to be an appropriate choice for reinforced concrete jacking pipes.
- **Joint Types**. AS/NZS 4058 contains no details of joint types for jacking pipes. Both EN 1916 and JSWAS-A2 only include joints with flexible water tight joints. EN 1916 includes a greater range including a fixed collar, loose collar and rebated joint. JSWAS-A2 only includes one joint type, being a fixed collar which is fabricated from mild steel with a coal tar epoxy coating.
- **Joint Design / Performance Requirements.** This is probably one of the most fundamental differences between all 3 standards. AS/NZS 4058 contains no

requirements for joint design and only limited performance requirements with regards watertightness of the joint. EN 1916 contains significant joint design and joint design criteria although, like all standards, fails to include any requirement for external hydrostatic testing. The joint design and performance criteria of EN 1916 are relevant to all pipes including jacking pipes and ensure a minimum compression in the elastomeric seal at extremes of tolerance and hydrostatic testing of the pipe joint with the application of a shear load and deflection of the joint. The test pressure is relatively low, however, which may not be suitable for all applications.

- **Geometric Characteristics.** From the installation contractor's perspective these aspects of any jacking pipe are often the most important. From a pipe manufacturer's they are also significant as they are representative of a considerable investment in pipe manufacturing equipment. Pipe external diameter is possibly the most important criteria as far as the installation contractor is concerned because of its compatibility, or otherwise, with installation equipment. Both the British and Japanese standards include a range of nominal diameters which are based on "hard metric" range (e.g., DN400, 500, 600, 700 etc.) compared to the traditional "soft metric" range offered in Australia (e.g., 525, 600, 675, 750 etc.). Figure 6 also contains a summary of nominal diameters included in each of the existing standards. These nominal sizes are relevant as much of the installation equipment used is manufactured in either Japan or Europe.

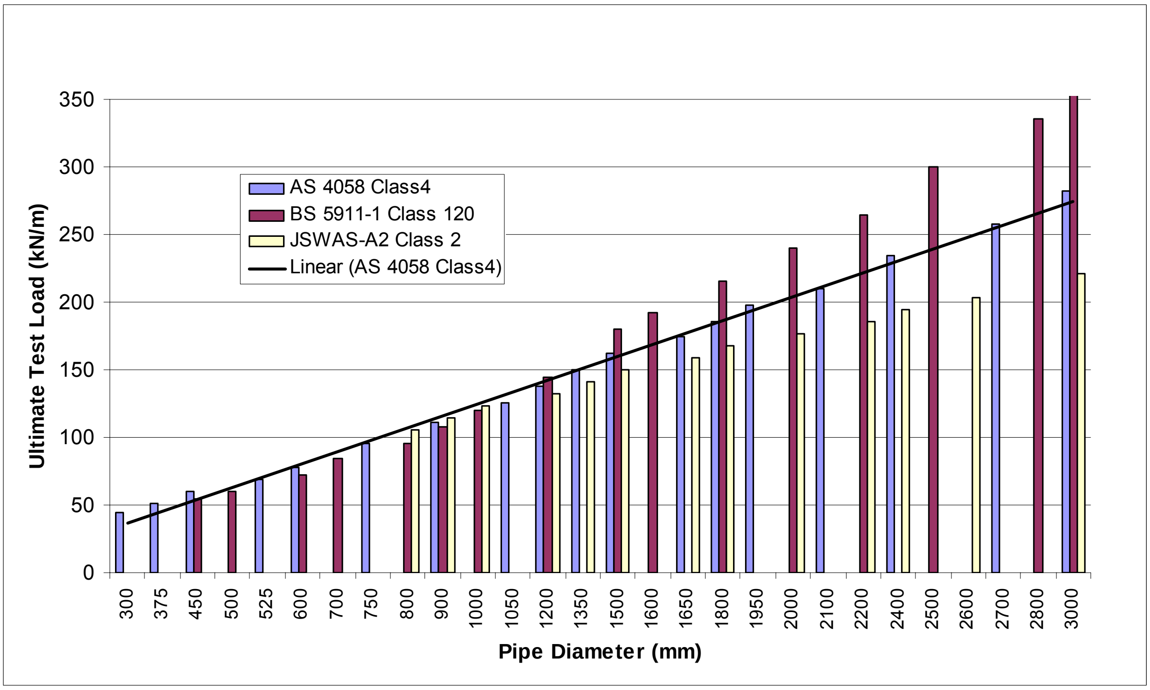

Figure 6 - Comparison Ultimate Test Loads between Different Pipe Standards

Table 1 - Comparison Australian and some International Concrete Pipe Standards

Requirements		AS/NZS 4058:2007	BS 5911-1:2002/EN 1916:2002	JSWAS-A2 1992
Resistance to Internal & External Corrosion	**Cover to reinforcement**	Includes different values for different manufacturing methods and exposure classifications. Varies between 10-35 mm	Minimum cover of 15 mm + an additional 5 mm on the external surfaces for jacking pipes	No requirement specified
	Minimum cementitious content / concrete strengths	No requirement specified	Varies between 340 and 400 kg/m^3	No requirement specified
	Minimum concrete strengths	For wet cast concrete – 50 MPa.	Minimum 40 MPa. Jacking capacity to be based on core tests from actual product pipe	Minimum concrete strengths vary between 50 and 70 MPa approx.
	Water absorption	6%	6%	No requirement specified
Strength	**Strength requirements (see also Figure 8)**	Determined by load testing. Strength classes vary between Class 2 and 10. No specific requirement for jacking pipe.	Determined by load testing. Single strength Class 120 for jacking pipes.	Determined by load testing. Two strength classes Class 1 and Class 2.
	Allowable jacking forces / capacity	No requirement specified	Detailed method of calculation of allowable jacking forces	No requirement specified
Internal & External Pressure	**Joint type**	No requirement specified for jacking pipes	Fixed collar, loose collar or rebated – all with elastomeric seal	Fixed steel collar with elastomeric seal
	Joint design	No requirement specified	Significant requirement in EN 1916 to ensure minimum compression in seal under shear load	No requirement specified (although most joint dimensions are specified)
	Internal Hydrostatic Testing	90 kPa for Sewerage and min. 1.2 x max. working pressure	50 kPa at extremes of tolerance (type test) under shear load and/or max. draw	100 kPa applied either internally or externally
	External Hydrostatic Testing	No requirement specified	No requirement specified	100 kPa applied either internally or externally
Geometric Characteristics	**Nominal internal diameter (see also Figure 5) / Size Range**	Nominal internal diameters based on “soft conversion” of imperial sizes (e.g. 375, 450, 525, 600, 750 etc.) / Size range DN100 – DN4200	Nominal sizes based on hard metric sizes (e.g. 500, 600, 700, 800 etc.) / Size range DN450 – DN3000 for jacking pipes	Nominal sizes typically based on multiples of 100 mm but some exceptions / Size Range DN800 – DN3000
	Minimum internal diameter / tolerance	No requirement specified / tolerance on design diameter varies but typically +/-7 for ≤ 600 and +/-13 for > 1650	Requirements for jacking pipes included (wide range) / Varies between ± 5 at DN450 and ± 15 at DN3000	Nominal ID = actual ID / Tolerance varies between +/-4 mm for DN800 to +/-12 for DN3000
	External Diameter / tolerance	No requirement specified / For jacking pipes suggested using ID tolerance	No requirement specified / Varies between ± 4 at DN450 and ± 7 at DN3000	ID & wall thickness specified / Tolerance on wall thickness included
	End Squareness	Varies between ± 2 and ± 7 depending on diameter	3 to 6 mm deviation across diameter depending on nominal diameter	No requirement specified

4. TOWARDS A NEW AUSTRALIAN / NEW ZEALAND STANDARD

The current standard AS/NZS 4058 was last published in 2007 and prior to that, previous revisions were AS 4058:1992 and AS 1342:1973. As such, one must be realistic about the likelihood of a new revision of the current standard within the next decade. There would be, however, a number of advantages to the industry if the local standard included more detailed minimum requirements for jacking pipes. These advantages are:

a) Asset owners would have confidence that pipelines installed using trenchless methods will provide the required performance during the required asset life.
b) Installation contractors would have confidence in products being supplied and will be under less pressure to offer the lowest cost pipe in competitive tendering situations.
c) Concrete pipe manufacturers would offer a relatively standard, well designed and cost effective product even in the absence of a project specification.

Development of a revised Australian / New Zealand standard needs to include all parties listed above and the development of such a standard needs to start perhaps through the leadership of the ASTT.

In the interim it is suggested that a combination of AS/NZS 4058 and BS 5911/EN 1916 is the best option available and any specification should include the following minimum requirements:

- Material and cover requirements of AS/NZS 4058:2007 are the most appropriate for Australian conditions with an additional 5 mm minimum cover to reinforcement for installation by pipe jacking.
- A flexible water tight joint is essential. Joint design and performance criteria of EN 1916 should be a minimum requirement.
- External hydrostatic testing to a pressure at least 20% above pressures that will exist during both installation and in service conditions. This should be a type test only and applied to pipe joints at extremes of tolerance and maximum joint deflection.
- All jacking pipes should be a minimum Class 4 strength class to AS/NZS 4058.
- Tolerances on geometric characteristics of BS 5911 are the most appropriate.
- A minimum (and perhaps maximum) actual internal diameter should be included due to the large range of nominal diameters offered in the market.

5. CONCLUSIONS

Well designed and manufactured reinforced concrete jacking pipes provide both the asset owner and installation contractor a product that can meet both their requirements. A revised Australian / New Zealand Standard for precast concrete pipes including detailed requirements for jacking pipes will provide many benefits to the industry. An industry group representing the interests of asset owners, installers and pipe manufacturers should work together to develop such a standard.

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