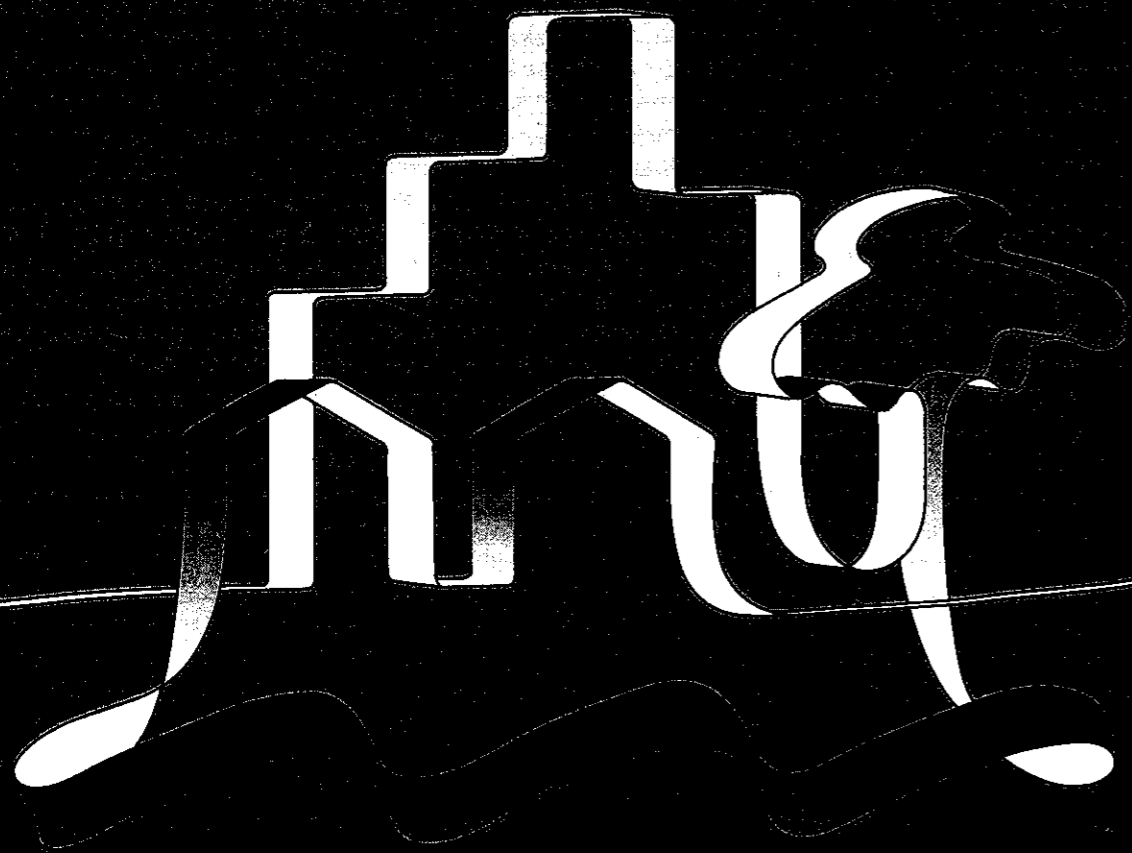


Water Research Association of Australia

Performance Requirements for
Elastomeric Sealing Pipe Joints -
Water Supply and Sewerage



Report No. WRA/198/80

URBAN WATER RESEARCH ASSOCIATION OF AUSTRALIA (UWRAA)

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Urban Water Research Association of Australia

Performance Requirements for Elastomeric Sealing Pipe Joints – Water Supply and Sewerage

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CSIRO Building, Construction and Engineering, Melbourne

**Research Report No 138
July 1998**

FOREWORD

This report is based on UWRAA Research Project No AM-18: 'Performance Requirements for Elastomeric Sealing Pipe Joints; Water Supply and Sewerage' which was commenced in July 1993. Organisational responsibility for the project was as follows:

Sponsoring Authority:	Melbourne Water Corporation
Research Agency:	CSIRO Building, Construction and Engineering Highett, Vic 3190 - Australia
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The project was funded by Melbourne Water Corporation, CSIRO and the Urban Water Research Association of Australia.

SYNOPSIS

Poor performance of pipe joints in water and sewerage pipelines means that water authorities unnecessarily spend millions of dollars annually in treatment and maintenance work, such as clearing root intrusions and blockages. Some of this poor performance occurs because of the lack of adequate joint performance requirements in Australian pipe standards. The current performance requirements given in standards for elastomeric sealing rings used in pipe joints have a number of inconsistencies across the different pipe material types. They are either currently unnecessarily restrictive through the use of prescriptive property requirements or inadequate in that they define minimal or no performance requirements. These problems increase costs, reduce freedom to take advantage of developments in technology and adversely affect competitiveness in export markets.

In this report, previous and current research on the performance and evaluation of elastomeric joints is reviewed and the inconsistencies across the different pipe material types are discussed. To establish a background to the development of pipe and pipe joint systems, with a focus on elastomer joint design, a survey was conducted among a range of rubber manufacturers, pipe manufacturers and water authorities. Based on the information from both the survey and a literature review, the ability of elastomeric joints to resist root intrusion has been highlighted as the main performance requirement necessary for sewerage pipelines. Experimental assessment of root intrusion using sewerage pipe materials such as vitrified clay, plastic and fibre-reinforced cement has been undertaken using various types of common joints, with different levels of interface pressure. A finite element modelling technique is described for evaluating whether the interface pressure between rubber ring and spigot and socket, under shear load conditions, is adequate to stop sewer infiltration and exfiltration. Finally, uniform performance requirements for elastomeric pipe joints for pressure and non-pressure pipeline system components are proposed.

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1 INTRODUCTION

It has been known for some time that inadequate jointing performance of pipe joints can lead to problems such as root intrusion, and infiltration and exfiltration through pipe joints, and that rectification of these problems absorbs a significant part of water authorities' maintenance budgets. Root intrusion through pipe joints has been of major concern throughout most of Australia, and causes significant maintenance costs for sewerage systems. Infiltration through pipe joints results in silting of pipelines, possible contamination of potable water and increases the load on sewage treatment plants. Exfiltration through pipe joints from sewerage systems can lead to contamination of groundwater and waterways, and increased public health hazards.

Although pipe joints have undergone development and improvement over the years, the performance requirements needed for pipe joints have not necessarily been fully researched or comprehensively defined within Australian Standards. This has resulted in the current standards having a number of inconsistencies in performance requirements, for different pipe materials. Certainly, the widespread adoption of rubber seals for sewer pipe joints in the 1970s dramatically reduced leakage and root invasion through the joints. However, root systems are still found to penetrate sewerage pipe joints, and there is limited research into the long-term sealing performance of elastomeric seals in both water and sewerage pipelines.

Existing standards for elastomeric sealing rings used in pipe joints for water and sewage conveyance are currently poorly defined or unnecessarily restrictive through the use of prescriptive property requirements. With the objective of allowing the property requirements of elastomeric seals to be defined comprehensively by performance tests, a survey of relevant Australian and overseas standards, publications and industry correspondence has been undertaken. Results of the survey have been taken into account in establishing the uniform performance requirements necessary for rubber ring joints associated with pipes and fittings, for all available piping materials, to ensure that satisfactory field performance will be met in the long term.

As part of the process for determining the long-term performance requirements of rubber ring joints, the long-term properties of ring elastomers have also been investigated, particularly how they perform under stress, their biodeterioration and their support of microbiological growth.

2 CURRENT PERFORMANCE REQUIREMENTS

The performance requirements of pipes and fittings are generally controlled in the long term by the performance of the elastomeric joints between pipes and fittings. The major method of assessment in current standards is pressure testing, with less emphasis being placed on other performance requirements. The performance requirements may be grouped as follows:

- (a) Pressure tests for pipes, joints and fittings.
- (b) Pressure tests in conjunction with mechanical performance requirements for joint systems, i.e.:
 - deflection,
 - straight draw,
 - shear resistance, and
 - resistance to root penetration.
- (c) Interfacial sealing pressure requirements for rubber rings.

2.1 Pipes and Fittings

Pipes and fittings used for the transport of water are classified by Australian Standards as either pressure or non-pressure, with the exception of glass-reinforced polyester and precast concrete pipes, which are classified in their respective standards for use in both pressure and non-pressure applications. This pressure distinction is most significant when the effect of a positive internal pressure on the interfacial sealing pressure in a rubber ring jointed system is considered. High internal pressures produce high interfacial pressures, which are currently considered necessary for the prevention of tree root intrusion between the rubber ring and the pipe surface. It is therefore convenient to separate the pressure performance requirements for all of the pipes and fittings used with rubber ring joints, in terms of pressure and non-pressure test criteria.

2.1.1 Pressure applications

The current performance requirements for pressure and dual pressure/non-pressure pipes, fittings and elastomeric sealing joints are summarised in Appendix 1 from the relevant standards. Pipes and fittings classified for pressure use are generally assessed using hydrostatic pressure assessment, which consists of a short-term pressure test for a period ranging from 15 seconds up to 24 hours at pressures between 0.9 and 7.4 MPa, or by the development of hydrostatic pressure failure curves

out to times of 10 000 hours which are then extrapolated out to 50 years. However, in many cases where there is a performance requirement for the pipe there is often a lesser or in some case no performance requirement for the fitting. This is obviously an area that needs addressing if the overall performance of the system is to be uniform.

2.1.2 Non-pressure applications

The current performance requirements for pipes and fittings classified for non-pressure use are summarised in Appendix 2 from the relevant standards. In most cases there is no pressure assessment requirement for pipes, and pressure requirements on the fittings are generally to ensure that inspection openings do not leak under a positive or negative pressure varying between 80 and 90 kPa. Uniform requirements are again needed here and discussions with water authorities have indicated that an 85 kPa requirement would meet the field performance needs, where pipes of this type can be buried up to 8.5 m. For deeper installations pressure pipes would generally be specified.

2.2 Joints

Referring to Appendices 1 and 2, the performance requirements for joints can be divided into three categories:

- (a) Joints that are subject to an application of pressure only:
 - internal pressure,
 - external pressure, and
 - internal vacuum.
- (b) Joints that are subject to both pressures and the combination or one of the following additional mechanical load conditions:
 - a deflection test in which two lengths of pipe, axially aligned through a joint, are deflected by a particular angle about a fulcrum that is located within the joint,
 - a straight draw test in which two lengths of pipe, axially aligned through a joint and fully engaged, are separated longitudinally by a particular displacement,
 - a shear resistance test in which two lengths of pipe, axially aligned through a joint, are subject to a shear load perpendicular to the axis at the joint, and

- a deformation test in which two lengths of pipe, axially aligned through a joint, are subject to a deformation such that the spigot is deformed in relation to the socket.

(c) Joints that have a performance requirement for resistance to tree root penetration. The objective of this performance requirement is to produce a standard average interface pressure between the rubber ring and the pipe surface, so that the interface pressure can be estimated at 50 years after jointing, taking into account stress relaxation, creep and joint movement.

The performance requirements for joints, as detailed in Appendices 1 and 2, vary from no requirement to a simple hydrostatic pressure requirement as detailed in (a), through to more complex testing assessments utilising deflection, draw and shear in combination with hydrostatic pressure. Again, consistent performance requirements need to be developed so that pipes and fittings can be assessed against standard requirements that reflect the performance needed in field applications. For non-pressure applications, root penetration is only perceived to be a problem with uPVC and vitrified clay, no performance requirements being specified for other pipe materials. This area also needs addressing as root intrusion is known to be a problem for other pipe materials.

2.3 Rubber Rings

To ensure the adequate jointing performance of rubber ring joints, it is important to investigate the long-term performance requirements and the long-term properties of elastomers used in pipe jointing, particularly how they perform under stress, their resistance to biodeterioration and their tendency to support microbiological growth.

The current performance requirements for elastomers used in the manufacture of pipe sealing rings are summarised in Table I. The full details of rubber ring performance requirements for each standard are given in Appendix 3.

As detailed in Appendix 3, the elastomer performance requirements specified in the Australian (AS 1646), European (prEN 681-1), British (BS 2494) and American (ASTM F477) Standards vary significantly. The Australian Standard groups the physical properties of elastomeric compounds by elastomer type and hardness, the European and British Standards group the same compounds according to their application and hardness, and the American Standard groups the elastomer according to low and high pressure usage.

TABLE I
STANDARD ELASTOMER PERFORMANCE REQUIREMENTS

Property	AS 1646	prEN 681-1	BS 2494	ASTM F477
Elastomer hardness	•	•	•	•
Low temperature elastomer hardness	◦	◦	•	•
Tensile strength	•	•	•	•
Percentage elongation at break	•	•	•	•
Compression set	•	•	•	•
Low temperature compression set	•	•	◦	◦
Accelerated aging	•	◦	◦	•
Liquid immersion	•	•	•	•
<i>Water immersion (volume change)</i>	•	•	◦	◦
<i>Oil resistance</i>	•	•	◦	◦
Ozone resistance	•	•	•	•
Rate of compression stress relaxation	•	•	•	◦
Effect on water quality (contamination)	•	•	•	◦
Microbiological deterioration resistance	◦	•	•	◦
Dimensional tolerances	•	•	•	•
Imperfections and defects	•	•	◦	◦
Accelerated aging	◦	•	•	◦
Tear strength for joint seals for hot water supply	◦	•	◦	◦
Desorption test	◦	◦	•	◦
Splice strength (where applicable)	◦	◦	•	•
Moulding integrity (T type where applicable)	◦	◦	•	◦

- Indicates the property is addressed by the standard.
- Indicates the property is not addressed by the standard

The features common to all standards are elastomer hardness, tensile strength, percentage elongation at break, compression set, ozone resistance and dimensional tolerances. AS 1646 does not address microbiological deterioration resistance of elastomeric compounds, which is an important factor for evaluating the various compounds used in the making of ring seals. This problem is addressed in the British Standard and now needs to be addressed in the Australian Standard, because microbiological performance is currently being used by water authorities to permit the use of different elastomers for different applications. For example, Sydney Water approves of natural rubber rings for water supply, sewerage and drainage purposes, and Melbourne Water and its three retail arms approve of natural rubber for water supply, and styrene butadiene and polychloroprene for sewerage.

2.3.1 Performance of rubber rings

The long-term performance of a rubber ring joint depends on the appropriate selection of the type of rubber from which the joint is manufactured. As early as 1963, Leeftlang reported that the failure

of rubber rings was caused by micro-organisms of the streptomyces genus. By examining more than 50 samples of rings or sediments from different parts of the Netherlands and Belgium, the author managed to isolate a strain of streptomyces bacteria as the cause of the failure of rubber rings. By investigating the extent to which the degradation of the rubber rings in the joint was promoted by the compression of the ring, he discovered that the stress on the ring was unrelated to deterioration of the rubber. The author's test results of resistance to attack showed that all natural rubber (NR) compounds were attacked within 2-3 months, but none of the synthetic rubber compounds tested were attacked during a prolonged stay in the test basin lasting at least one year and often two years or longer. It was also shown that mixtures of NR with synthetic rubber (styrene butadiene rubber (SBR), acrylonitrile butadiene rubber (NBR) and polychloroprene rubber (CR)) were not attacked when the proportion of NR in the total polymer was less than 40 or 50%.

Five years later, Leeftang (1968) studied different conditions in water utility practice between countries. He concluded that the greater resistance of American rubber rings to biological attack in comparison to the gaskets, formerly used in the Netherlands, was due to differences in the recipes and curing methods. Furthermore, the quality of the water and its ability to provide streptomyces with mineral nutrients would have a marked influence upon the rate of growth of the bacteria. The surface area of the ring exposed to the water appeared to be an important factor. It was large in Dutch joints of asbestos-cement pipes and much smaller in many American types of joints. To avoid all risks of biological degradation, the author suggested the use synthetic rubber gaskets instead of NR gaskets.

McKenna and Kallis (1964) investigated the different behaviour of natural and synthetic rubber compounds resulting from bacteriological attack, based on the utilisation of various aliphatic hydrocarbons by bacteria. By testing the viability of different organisms (micrococcus, pseudomonas, mycobacterium and nocardia) to grow, they found that where I-phenyldecane was utilised, growth was restricted to mycobacteria and nocardia when a hydrogen atom at the fourth carbon atom was substituted by a methyl group.

Hills and Airi (1967) observed the deterioration of pipe-joint rings which appeared to be consistent with microbiological degradation. They listed the following three types of attack which primarily occurred inside the joint:

- Attack spread around the ring – when liquid levels are constantly varying from full to empty, or when the pipe is kept completely full of water containing dissolved oxygen, e.g. in a water main.
- Attack spread around an arc – when the liquid level varies constantly between two levels (full and part-full, or empty and part-full).
- Attack at two points on opposite sides of the ring – when the liquid level is relatively static and little oxygen is present in the material passing through the pipe, e.g. in a sewer.

By conducting a test similar to that described by Leeftang (1963), Hills and Airi (1967) showed that natural rubber was particularly susceptible to biological attack. Of the synthetic rubbers or blends tested, only CR, NR-CR and NR-SBR would appear to possess suitable mechanical properties for forming adequate pipe-joint rings in addition to being resistant or reasonably resistant to microbiological degradation of the type observed in the case of NR compounds. They concluded that the choice of compounding ingredients of all types had a marked effect on the resistance of NR. However, the addition of fungicides or bactericides to the rubber compound was of no use.

Hodgson (1984) reported an investigation into the deterioration of jointing rings manufactured by Reidrubber and Empire Rubber in the Christchurch district of New Zealand. He stated that the greatest deterioration was from a microbiological source (actinomycete) and that microbiological attack was observed in a wide range of soil types and conditions, on the internal side and the external side of the ring for different pipe types, i.e. ceramic, concrete and asbestos cement pipes. Ring deterioration also occurred in stormwater lines and in some cases the deterioration in these lines was as rapid as in sewer lines. It was observed that the deterioration was greatly affected by the pH values and temperature range of the water. It was also found that the microbiological organism consumed the rubber ring at 0.012 inches/year, with the attack being at the rubber surface. The time for the rubber to be removed was related to the actual contact area of the ring with the pipe surface, because as the ring was compressed, less ring was exposed to the attack medium. That is, a joint which had only 20% compression of the original chord diameter would fail much sooner than the same ring compressed to 45%.

Bolin and Camnerin (1986) conducted an investigation into the long-term properties of rubber such as volume increase, weight increase, hardness, tensile strength, tensile stress at 100% elongation and elongation at break. Thirty-three different types of rubber were exposed for various periods of

time up to five years in water (at two different temperatures), in oil (three different oils at 70°C) and in air at 10 different temperatures. It was shown that chloroprene rubber with lead oxide in the vulcanising system had greater durability than a corresponding material with zinc oxide. At the temperature of 95°C in water, the best materials were ethylene propylene terpolymer rubber (EPDM) and fluorinated rubber, but SBR and butyl rubber (IIR) had a greater durability at 125°C than at 95°C.

Seregely *et al.* (1988) investigated in detail the influence of heat-activated oxidative aging, oil, hydrogen-sulfide containing gaseous oil, sea water and steam on the physical properties such as tensile strength, elongation at break and hardness, of compounds based on various elastomers. It was found that the most sensitive properties of the tested NR compound decreased to approximately 50% of their initial value after 27 years at 20°C and that a log/log plot of physical property changes of the rubber versus time was approximately linear.

In Australia, limited work has been reported. Melbourne and Metropolitan Board of Works (MMBW) (1966) conducted an extensive investigation into the service requirements and mechanics of rubber ring joints for use in 4" diameter vitrified clay sewers. A series of tests was carried out using rubber rings of varying composition and materials in a series of dummy joints constructed of steel spigots and sockets. The stress-relaxation tests showed that both NR and CR gave a satisfactory result, polyurethane failed by breaking up immediately at 33% compression and at 25% compression failed after three months. Serious attack on NR from groundwater was reported by Hunter District Water Board (MMBW 1966). Therefore, CR was regarded as the most suitable material for chord rings. It was capable of holding 60% of its initial compressive strength over an estimated 200-year period, regardless of ring sizes or initial compressive stress in the ring.

Mitchell (1970) presented the relaxation test results for different rubber rings, as shown in Figure 1. All of the equivalent rates of compression stress relaxation (*Rt*) for the tested results were better than those required in the current AS 1646, i.e. the rate of compression stress relaxation of the elastomeric material shall not exceed 6% for a nominal hardness of 75, and 7% for a nominal hardness of >75.

Based on the above information, it seems appropriate to conclude that in general synthetic rubbers are superior to natural rubbers for applications in contact with sewage, particularly with respect to their resistance to degradation from bacterial attack.

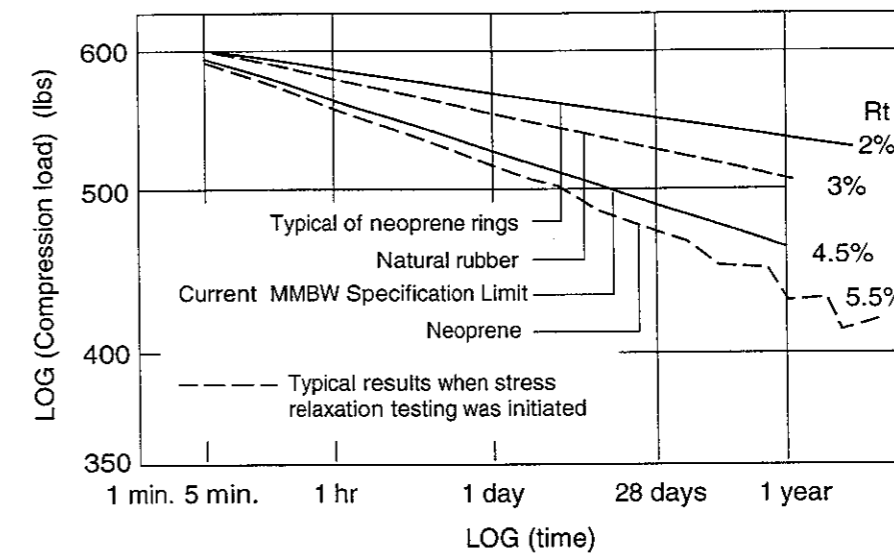


Figure 1. Relaxation test results (from Mitchell, 1970)

2.4 Root Penetration

For rubber ring joints to resist plant root penetration, it has been reported and promulgated into Australian standards that a sufficiently high interface pressure between the rubber and pipe must be maintained, even though high interface pressures can make jointing of the spigot and socket difficult. Evaluation of the appropriate interfacial pressure to be used has been under discussion for some time and different values are used in different standards, as shown in Table II.

TABLE II
INTERFACE CHARACTERISTICS REQUIRED FOR RUBBER RING JOINTS

Performance requirement	AS 1260-1984	NZS 7649	AS/NZS 1260-1996	AS 1741	ASTM C425
Minimum initial interface pressure (MPa)	0.55	0.4	0.4	0.55	0.21
Minimum 50-year interface pressure (MPa)	0.35	NS*	NS	0.35	NS
Minimum width over which the minimum pressure must apply (mm)	7	4	4	7†	NS
Minimum cross-sectional area (mm ²)	100 (for pipe of nominal diameter DN 100) 150 (for all other sizes)	NS	NS	NS	NS

* Not specified.

† AS 1741 requires a minimum contact width of 7 mm, and a minimum contact pressure of 0.55 MPa, but it does not specify a width over which that minimum contact pressure applies. It might be just a peak and the contact pressure for the rest of the 7 mm might be far less. This is another example of inconsistency between standards which are presumably trying to achieve the same thing.

Steele (1971) reported trials from 1962 to 1970 on 150 mm clay pipes laid 1.8 m deep, directly below trees with known aggressive root systems (*Fraxinus oxycarpa* and *Eucalyptus cladocalyx*). The pipes were joined using laterally unrestrained O-ring joints and an interface pressure range of 0.34–0.41 MPa. Steele reported that root penetration occurred in 90% of cases, however root penetration occurred in only 4% of cases when the interface pressure was increased in the range of 0.55–0.61 MPa. He therefore concluded that a minimum interface pressure of 0.69 MPa was necessary to ensure reasonable protection against root intrusion.

LeHunt (1979) suggested that the figures quoted in Steele's report may be regarded as conservative. In an attempt to further define an adequate minimum interface sealing pressure, LeHunt performed a series of root tub experiments using uPVC joints surrounded by soil. Rye-grass was planted in the tubs so that the root zones grew around the pipe socket. Root penetration was observed in those joints with an interface pressure of 0.4 MPa, while no penetration was observed in the 0.6–1.10 MPa range. LeHunt suggested that 0.55 MPa may be used as an initial minimum interface pressure to apply over a single continuous width of 6 mm. Values similar to these have been adopted by both uPVC and vitrified clay standards and with these values, no evidence of root penetration has been reported in uPVC joints.

Hodgson (1979) reported the results of field work on ceramic, rubber ring jointed pipes carried out in Christchurch. This work indicated that a minimum interface sealing ring pressure of 0.345 MPa was required to withstand root penetration. However, the example presented in his report revealed that severe root penetration occurred with 100 mm ceramic pipes with contact pressures as high as 0.46 MPa, estimated by using Lindley's (1966) formula (equation 1, where E is the Young's modulus of the rubber ring, and the other symbols used are defined in Figure 2 (from Freakley and Payne, 1978)).

$$F' = dE \left[1.25 \left(\frac{x}{d} \right)^{3/2} + 50 \left(\frac{x}{d} \right)^6 \right] \quad (1)$$

In order to evaluate the suitability of Hepsleve joints for use in the Melbourne sewerage system, and to assess the effect of different percentage compressions on this joint's ability to exclude roots, MMBW (1980) conducted tests on 16 standard unglazed vitrified clay pipe rubber ring joints (as controls) and 16 Hepsleve joints over straight barrelled vitrified clay pipes. The pipe joints were tested in horizontal troughs (soil boxes) with two vigorous plants (river red gum and pampas

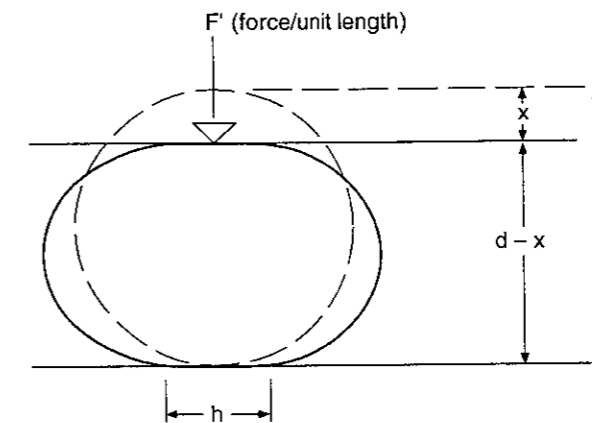


Figure 2. Compression of toroidal rubber ring between plane surfaces and cross-section

grass) growing in soil in the troughs. It was found that the Hepsleve joint was inferior to the currently used socket/spigot rubber ring joint, particularly with regard to denying root access from two very aggressive plant species. By using Lindley's (1966) formula for calculating interface pressure of laterally unrestrained toroidal rubber rings, we have estimated the interface pressure of standard VC joints based on the ring compressions and rubber ring chord diameters used in the test. Once again, contrary to Steele's (1971) reports, no root penetration was observed in these joints with an interface pressure of 0.37–2.24 MPa for 100 mm pipes and 0.37–1.58 MPa for 150 mm pipes.

The intrusion of plant and tree roots into sanitary drains in South Australia has always been a problem because of the long periods of dry weather experienced throughout the year. To tackle this problem and also to assess different joint types (open, semi-open and encapsulated joints), Martin (1989–90) undertook an accelerated root intrusion assessment of rubber ring joints in a sanitary drainage system. Joint assemblies covering a range of products in the marketplace were prepared with a pot being constructed or fitted around the actual joint area with the collar uppermost. Two plant species (rye-grass and *Melaleuca armillaris*) were chosen for the assessment. The interior of each pipe containing a joint was filled with hydroponic nutrient throughout the duration of the 'growth period' of 10 months. It was observed that no roots had penetrated beyond the rubber ring seal, except for the joints of the encapsulated type which had a gap exceeding 0.5 mm between the inside of the socket and the spigot of the pipe. Table III presents the approximate interface pressure (F'/lb) for vitrified clay samples estimated by applying Lindley's (1966) formula based on information supplied by Martin (1989–90), and it can be seen that the calculated interface pressures vary between 0.60 and 1.11 MPa.

TABLE III
VITRIFIED CLAY SAMPLES — ROOT PENETRATION TESTS (FROM MARTIN, 1989-90)*

Label	Socket diameter		Spigot diameter		Mean compression of rubber ring (%)	d (mm)	X (mm)	b (mm)	F' (N/mm)	F'/b (MPa)
	Min. (mm)	Max. (mm)	Min. (mm)	Max. (mm)						
DN150										
A	217	218.6	195.5	196	36.2	17.28	6.26	15.01	14.63	0.97
B	217.5	218	195.5	196	36.6	17.35	6.35	15.24	15.15	0.99
C	217	218.5	192	194.5	29.1	17.28	5.03	12.07	8.61	0.71
D	217	219	193	194	27.2	16.83	4.58	10.98	7.31	0.67
E	217	219.2	193	193	31	18.19	5.64	13.53	10.41	0.77
F	216	218.5	193.8	194	29.1	16.47	4.79	11.50	8.21	0.71
DN100										
A	158	159	139.4	140.2	35.4	14.47	5.12	12.30	11.52	0.94
B	158.5	159.2	139.2	140.5	34.3	14.46	4.96	11.90	10.58	0.89
C	158	158.5	140.2	140.8	38.7	14.48	5.60	13.45	14.94	1.11
D	159.6	161	139	139	27.9	14.77	4.12	9.89	6.75	0.68
E	158	158.7	139	139	33	14.44	4.77	11.44	9.58	0.84
F	160.5	161	139	139	24.3	14.37	3.49	8.38	5.06	0.60

* The symbols used in the table are defined in Figure 2.

As discussed above, root penetration into vitrified clay joints of higher or as high interface pressure as those given in the current codes has been reported. This indicates that it is necessary to further define the interfacial pressure needed to exclude root penetration in order to achieve a uniform and relevant range of test requirements for the different water and sewer pipes currently in use. Consequently, further research is being conducted at CSIRO BCE to establish the necessary requirements.

2.5 Infiltration/Exfiltration

The current performance requirements detailed in standards to enable pipe joints to resist infiltration and exfiltration are specific, and include assessment procedures such as diametrical distortion, shear, draw and deflection, as shown in Figure 3. There are a number of performance requirements necessary for a pipe to be assessed against if it is going to show good long-term performance. For example, diametral distortion can be used to demonstrate that elastomeric joints perform satisfactorily at the recommended maximum vertical deflection whilst the pipe is under pressure. Tests that assess for diametrical distortion include the British Standard (BS 4346) and ISO methods (ISO/DIS 4435) in which the spigot is compressed between two beams. Different values of diameter distortion (% of OD) are used in different standards: 7.5% in NZS 7648 and NZS 7649, 10% in BS4 346 and BS4 660, and 5% in ASTM D3212 and ISO/DIS 4435. Shear is also

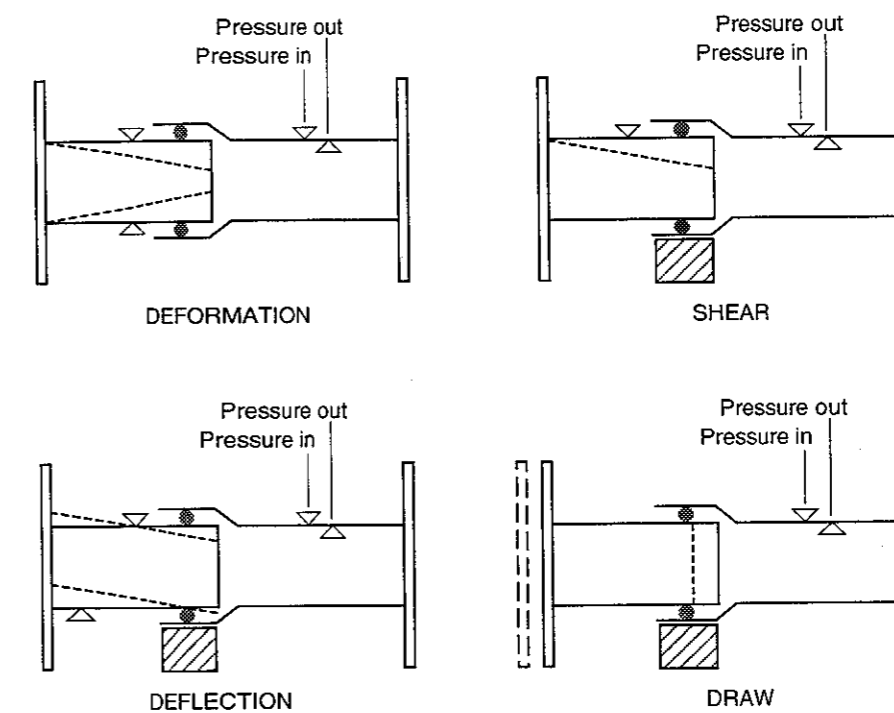


Figure 3. Parameters determined using the infiltration/exfiltration test apparatus

assessed in the ASTM method (ASTM D3212) in which the distorting load is applied as a shear load to the top of the spigot.

Deflection tests are not generally specified and although draw is required in some Australian Standards (AS 1741, AS 3571), CSIRO experience shows that large diameter pipes are not easily joined, and that applying draw in these cases is very difficult. A large number of terracotta spigots and sockets have been joined and they are extremely difficult to separate once joined. This would suggest that the assessment of pipes with draw, as detailed in the ASTM standard, is not practicable especially if high interface pressures are also required. With lower interface pressures, assessment with draw may be possible.

3 PIPE JOINT PERFORMANCE SURVEY

3.1 Survey Format

To establish a background to the development of pipe and pipe joint systems, with a focus on elastomer joint design, a survey of a range of rubber manufacturers, pipe manufacturers and water authorities was conducted.

For rubber manufacturers, the following information was requested, as detailed in Appendix 4:

- rubber type,
- material properties,
- aging properties, and
- design factors.

For pipe manufacturers, the following information was requested, as detailed in Appendix 5:

- pipe type,
- pipe material,
- type and manufacturer of rubber ring currently used,
- details of joint design,
- joint design pressure,
- maximum field operating pressure, and
- other comments.

For water authorities, the following information was requested, as detailed in Appendix 6:

- pipe type,
- rubber ring performance requirements for different pipe types,
- required design pressures,
- maximum operating pressures, and
- other factors affecting selection for pipe/joint combinations.

3.2 Summary of Survey Results

In general, most of the responses were received from water authorities. Only limited responses were received from rubber and pipe manufacturers. Apart from the information given in Table IV on commonly used pipe types with different applications, the key points from the survey can be summarised as follows:

- angular deflections for both rigid and flexible pipes are at manufacturer's maximum recommendation,
- root inhibitor is used for prevention of root intrusion, and
- performance characteristics of different pipe materials comply with the relevant standards.

TABLE IV
COMMONLY USED PIPES WITH DIFFERENT APPLICATIONS

State	Pipe types and applications			
	Sewer	Soil, waste & vent	Pressure	Stormwater
Tasmania	uPVC VC GRP RC		uPVC DICT DI MSCL	uPVC VC GRP RC
Western Australia	uPVC FRP DI MSCL	uPVC DI	uPVC FRP DI MSCL	uPVC DI MSCL
New South Wales	uPVC DI RC GRP VC	uPVC	uPVC DI GRP MSCL	
Victoria	uPVC RC DI VC HDPE GRP	uPVC DI	uPVC RC DI MSCL GRP	uPVC VC RC HDPE

uPVC = unplasticised PVC; VC = vitrified clay; DICT = ductile iron cement lined; GRP = glass filament-reinforced thermosetting plastics; DI = ductile iron; RC = reinforced concrete; MSCL = mild steel cement lined; FRP = fibre-reinforced polyester; HDPE = high density polyethylene.

4 DISCUSSION

From the review of the current performance requirements in Australian standards, it is seen that the current performance requirements for pipes, fittings and joints given in the standards have the following inconsistencies across the different pipe material types:

- performance requirements are not uniform across different pipe materials,
- the appropriate performance requirements for resisting root penetration are varied and the values required in some standards are questionable,
- pressure ranges for hydrostatic pressure tests vary significantly, and
- long-term hydrostatic pressure tests are not required by many Australian standards.

In the case of joints, the ability of the elastomer to resist root intrusion appears to be the main performance requirement necessary in standards for sewerage pipelines. Previous research on root intrusion resistance using simulated installation conditions was either inconclusive or restricted to specific materials and joint types. Furthermore, no interface pressures or contact length between

the rubber ring and the pipe were measured in the majority of cases. To allow a consistent assessment of the effect of rubber ring interface pressure on the resistance to root intrusion for different pipe materials, it was therefore necessary to undertake some additional work on the range of materials currently used, such as vitrified clay, plastic and fibre-reinforced cement, the commonly used joints and a range of levels of interface pressure.

5 INTERFACIAL SEALING PRESSURE ASSESSMENT

5.1 Rubber Ring Performance

To assess the effect of interface pressure, pipe porosity, pipe material and joint design on the propensity to allow root penetration past the rubber ring joint, a number of assessments were carried out on pipes of PVC, vitrified clay and fibre-reinforced cement. Interface pressures were assessed in accordance with NZS 7649:1988 (the 1 mm hole test) and then the pipe assemblies were assessed by 'accelerated horizontal root ingress' at Adelaide Botanic Gardens. This assessment is currently underway.

5.1.1 Pipe types and interfacial sealing pressure

For all pipe assemblies assessed, the rubber ring joint tested was manufactured to meet the requirements of the relevant Australian Standards, as shown in Table V, except that in each case, special rubber rings free from chemical root inhibitors were manufactured (it should be noted that in many instances the presence of root inhibitor is a requirement of the standard).

TABLE V
SPECIMEN DETAILS FOR RUBBER RING JOINTS USED IN
INTERFACIAL SEALING PRESSURE (IFSP) EVALUATION

Pipe type	Outside diameter (mm)	Australian Standard
uPVC	110.0	1254
uPVC	110.0	1260
uPVC	110.0	1415
uPVC	110.0	1273
uPVC	114.1	1477
uPVC	121.7	2977
FRC	123.1	4139
VC	138.5	1741

For PVC assemblies, three rubber seals were evaluated. These included a high interface pressure ring (Sewer), a slip coupling ring (SWV) and a lip-seal ring (NZ), and as shown in Figure 4. A further variation for the SWV and NZ series was the size of the gap between the pipe spigot and the socket mouth, as detailed in Table VI.

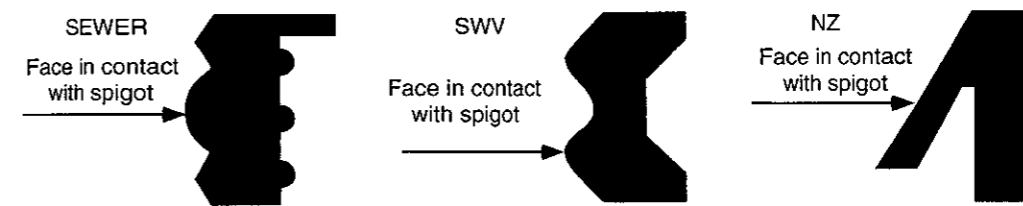
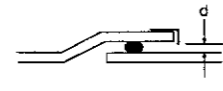


Figure 4. Cross-section of rubber ring types assessed

TABLE VI
TEST RESULTS FOR IFSP

Pipe type	Joint type	 average (d)* (mm)	Contact length (mm) when IFSP > 0.4 MPa	Interfacial pressure (MPa)	
				Min.	Max.
	Slip coupling (SWV)	0.2	<1	0.37	0.543
		0.7			
		2.2			
		3.7			
uPVC	NZ joint	0.2	7.54		0.82
		0.7			
		2.2			
		3.7			
VC	Australian sewer joint	0.2	4.5	0.44	>0.8
		—			
VC	Maximum collar	—	7.84		>0.8
		—			
VC _{coated}	Minimum collar	—	9.46		>0.8
		—			
FRC	Maximum collar	—	16		0.73
		—			
FRC _{coated}	Minimum collar	—	14		0.915
		—			
FRC _{coated}	Maximum collar	—	16.25		0.77
		—			
FRC _{coated}	Minimum collar	—	13.9		0.9
		—			

* Tolerances on d were always negative so that the gap could be up to 0.2 mm less than stated above; the values in the table are the average of two samples for fibre-reinforced cement (FRC) and vitrified clay (VC) joints, and five samples for PVC joints, and the contact length is the sum of all the contacts between the rubber and pipe.

To examine the effect of eliminating moisture transmission through the porous pipe materials, the external surface of two sets of VC and FRC pipes was coated with two-part epoxy resin (40% diluted with solvent; Intergard Ez Epoxy and En-cap Ac Sealer, in a ratio of 4:1).

The initial interfacial pressure results are summarised in Table VI, where the minimum pressure relates to the pressure measured at one of the minor profiles for either the SWV or Sewer ring, as shown in Figures 5 and 6. Typical graphs for the other ring profiles are given in Figures 7, 8 and 9 and indicate the maximum pressures and the contact area for the range of pressures measured.

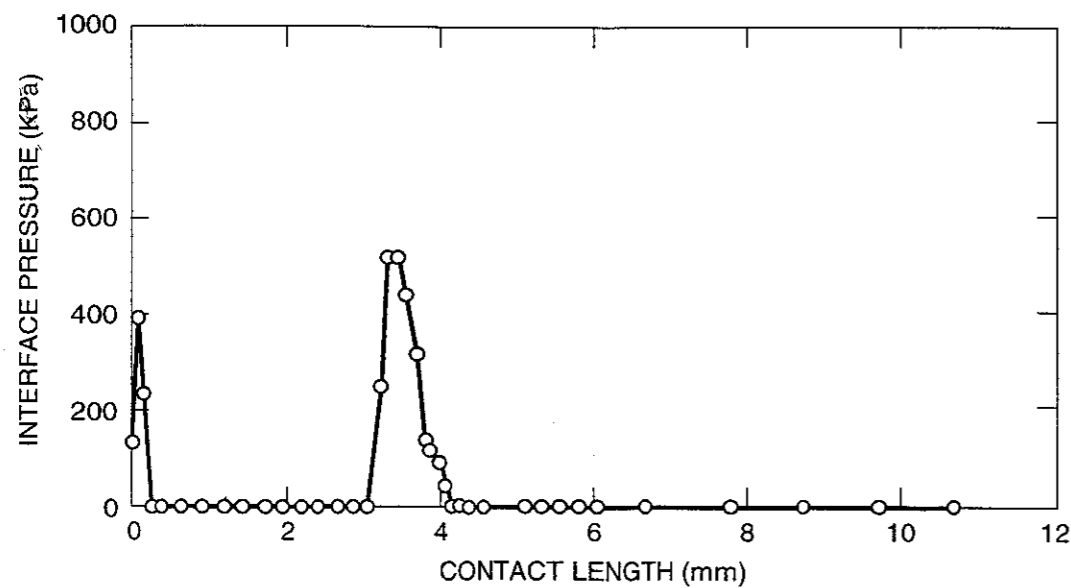


Figure 5. Interfacial sealing pressures for Australian PVC SWV joint

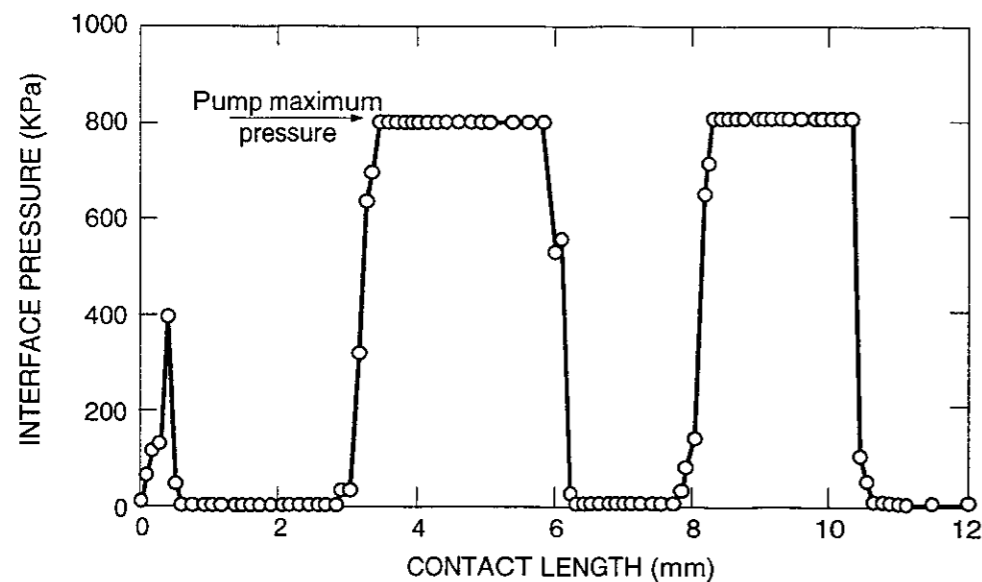


Figure 6. Interfacial sealing pressures for Australian PVC Sewer joint

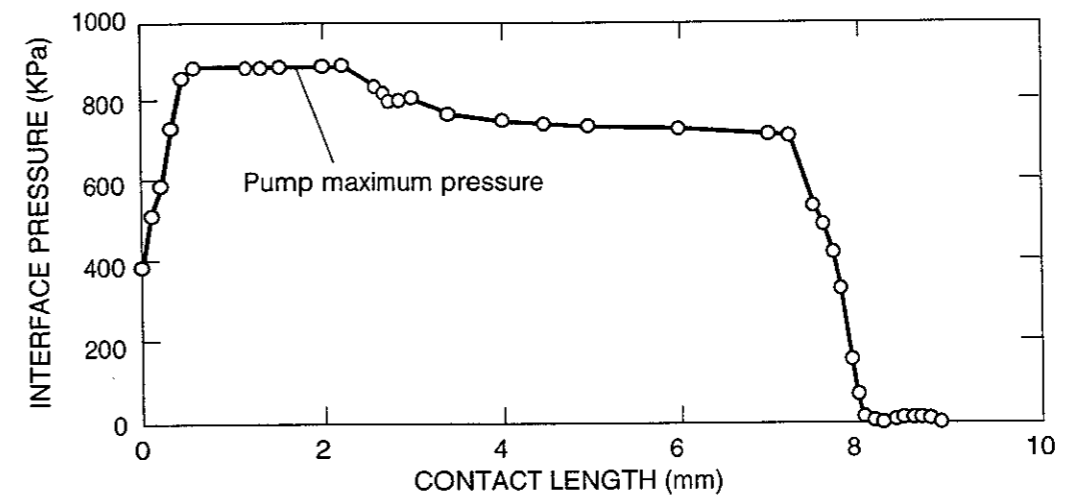


Figure 7. Interfacial sealing pressures for New Zealand PVC lip-seal joint

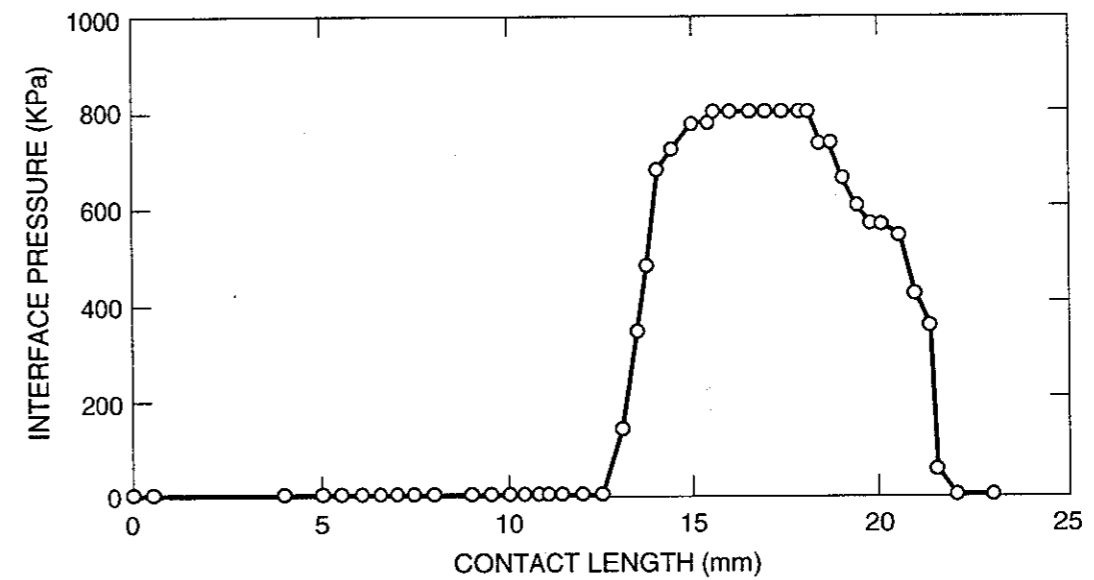


Figure 8. Interfacial sealing pressures for VC joint

5.2 Accelerated Root Intrusion Test

5.2.1 Horizontal pipes and fittings

The range of pipes specified in Table V was assessed for root intrusion by installing an assembled pipe containing a rubber ring joint in a 200 L translucent PVC tub (two samples per tub), as shown in Figure 10. The horizontal pipes were then buried under potting soil, which was steam sterilised before use.

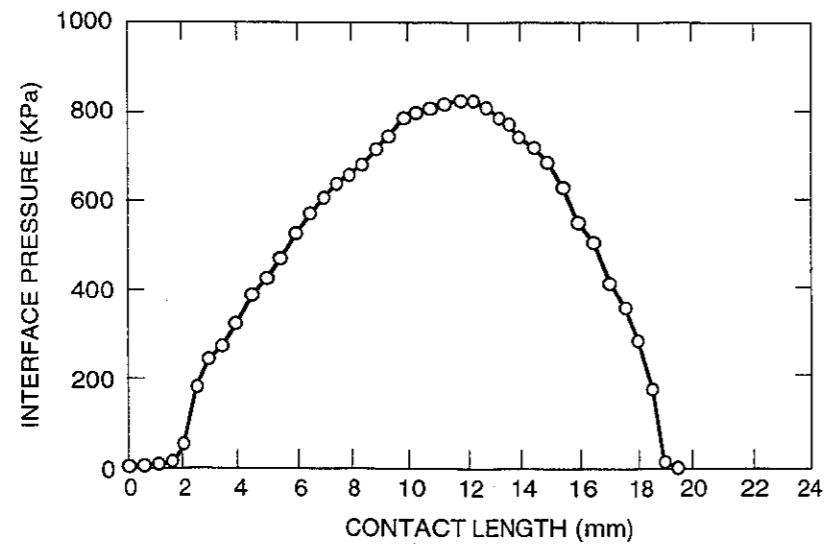


Figure 9. Interfacial sealing pressures for FRC joint

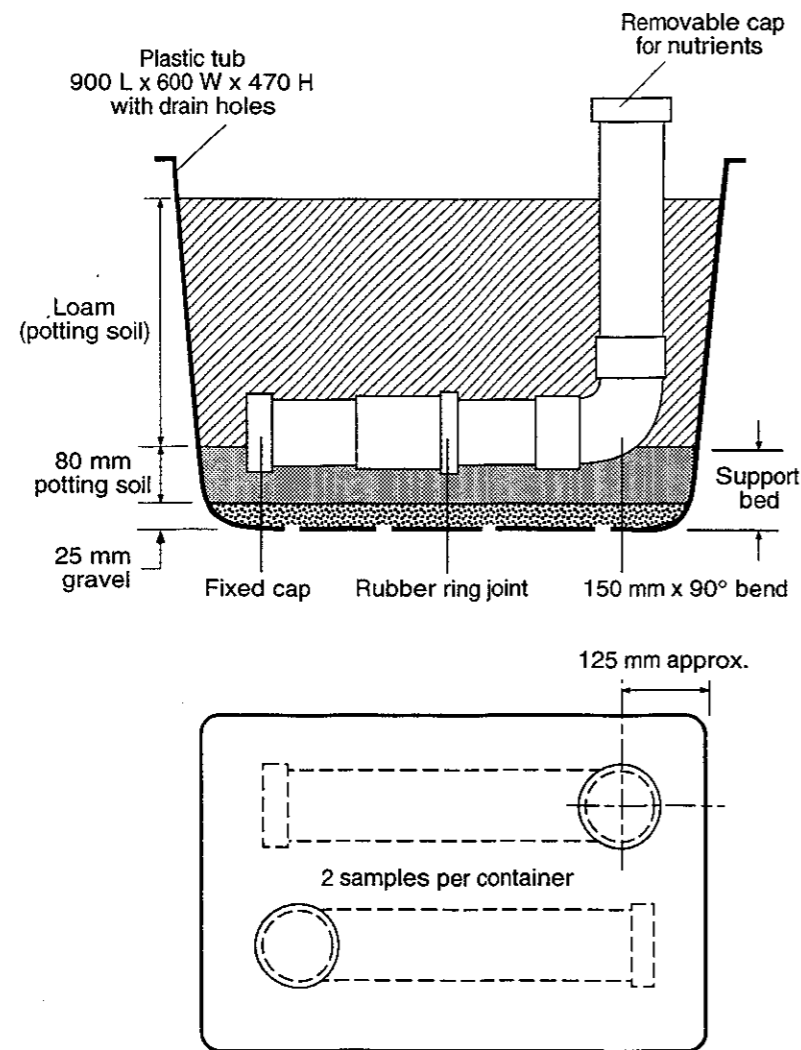


Figure 10. Schematics showing placement of various pipes and joints in tubs

Two plant species (rye-grass and *Melaleuca armillaris*) were selected for assessment of the rubber ring joint. According to M. Jusaitis (Chief Scientist in Conservation Biology and Horticultural Research, Black Hill Flora Centre, South Australia, pers. comm., 1996), rye-grass characteristically has a fibrous root system with many fine, long and aggressive roots, and *Melaleuca armillaris* is a woody plant with a taproot system which has the potential to enter small cracks and expand them through secondary growth.

On 22 March 1996, half of the tubs for PVC pipes were sown with rye-grass seeds, and the remaining tubs for PVC and the tubs for FRC and VC were planted with *Melaleuca armillaris* seedlings (eight per tub) transplanted from propagating tubes. A drip-irrigation system was fitted for ongoing watering (six drippers per tub) and liquid fertilisers were applied to the soil as needed during the course of the assessment to encourage plant growth. One month later, all pipes were filled with full strength Top® hydroponics nutrient solution to encourage roots to seek nutrients from within the pipes. Levels of nutrient solution were maintained during the course of the assessment.

The growing period for the rye-grass was six months and the tubs containing the rye-grass have now been withdrawn and inspected, however the *Melaleuca armillaris* tubs with a 13-month growing period are still under assessment due to inadequate root growth after one season's growth.

At the end of the growing period, the nutrient solution in the tubs containing rye-grass were emptied and the assemblies dissected in a vertical plane using a bandsaw. The two halves of each assembly were then inspected. In all cases the development of the root system had been prolific, as shown in Figure 11. However, inspection of the bisected pipes showed that no roots had penetrated into the pipes.



Figure 11. Rye-grass root formation in horizontal tubs

Contrary to Martin's (1989-90) finding that roots had penetrated beyond the rubber ring seal for the joints having a gap exceeding 0.5 mm between the pipe spigot and the socket mouth, the current results show that no roots had penetrated into the pipes with a gap size as great as 3.7 mm.

5.2.2 Vertical pipes and fittings

Interfacial sealing pressure tests were also performed on six joints assembled from DN100 PVC pipes and fittings, after these joints had been tested for accelerated vertical root ingress in Adelaide Botanic Gardens (Whittle *et al.*, 1997). Again three styles of rubber ring seals, i.e. slip coupling (SWV), lip-seal (NZ) and a high interface pressure ring (Sewer), were evaluated. Joints of both DN100 and DN150 nominal diameter were tested in triplicate. Thus a total of 36 assemblies were evaluated.

Rye-grass (*Lolium rigidum*) and *Melaleuca armillaris* were planted in separate pots, and during the growing period the nutrient level was monitored and the joints inspected at regular intervals. The growing period for the rye-grass was seven months, whilst for the *Melaleuca armillaris* the period was 14 months.

At the end of the growth period, for DN100 joints, two of the triplicates with respect to joint types and plant species were dissected to examine the root system, and the other one was used for measuring the interfacial pressure. For DN150 joints, all of the assemblies were dissected to observe the outcome. It was found that the root systems from both plants grew round and round the pot innumerable times and bound up the pot soil into a compact mass, however, no roots had penetrated beyond the rubber ring seal. The maximum interfacial pressures (average) were: 0.725 MPa, 0.625 MPa and 0.3 MPa for Sewer, SWV and NZ joints respectively.

The first lip of the profile for the rubber ring used for SWV and the one first able to be penetrated by roots, has a low interfacial sealing pressure of around 0.4 MPa as well as an interfacial sealing length of less than 1 mm. In both the vertical and horizontal studies, where the pipe was correctly installed, inspection showed that no roots had managed to penetrate past this first seal. This would indicate that an interface pressure of 0.4 MPa with a low interface length is satisfactory to exclude roots from intruding into sewer pipes. This observation, however, does not take into account the possibility of failure from badly manufactured or damaged rings, or rings that have been poorly

installed. As installation is the major area where problems can occur, use of rubber rings such as the NZ flap joint would minimise the possibility of failure occurring from bad installation practice.

It should be noted that the sockets used in NZ joints were different from the normal ones and this may explain the low interface pressure of 0.3 MPa. It should be noted that even at such a low interfacial pressure, no root intrusion past the rubber ring was observed.

5.3 Long-term Interface Pressure Evaluation of Assembled Rubber Ring Joints

To measure the effects of creep of the pipe material and relaxation of the rubber ring, interface pressures at ten different time intervals (up to a period of 10 000 hours) are currently being measured on assembled joints. In general, for periods up to 5000 hours, under the tested conditions, there is no significant reduction of the interface pressure and the contact length when IFSP is greater than 0.4 MPa over the duration of the test period.

6 FEA MODELLING OF RUBBER RING JOINTS

Whilst the ability to resist root penetration is an important property for rubber ring joints, the ability to stop infiltration or exfiltration whilst under a range of distortions or deflections that could occur in practice is also important. To evaluate performance of rubber ring jointed pipelines at the maximum vertical deflection, a finite element package (STRAND 6) was employed to model the joint under a distorting load applied as a shear load to the top of the spigot (in accordance with ASTM D3212; see shear example in Figure 3). In this analysis, because of the symmetry only half of the structure needs to be considered. To model the PVC pipes, 396 three-dimensional, eight-node brick elements were used, and another 24 similar elements were used to model the rubber ring. The linear material properties used in the analyses were as detailed in Table VII.

TABLE VII
MATERIAL PROPERTIES USED FOR FINITE ELEMENT ANALYSIS

	PVC	Rubber
Young's modulus E	1930 MPa	2.2 MPa
Poisson's ratio ν	0.37	0.5
Density ρ	1200 kg/m ³	940 kg/m ³

The results from the finite element method demonstrate that as the point of load application moves the top of the pipe outside diameter downward 5% (ASTM D3212), the thickness of the rubber ring at the top of the joint (loading application side) increases by 0.18 mm whilst at the bottom of the joint it reduces (compresses) by 0.15 mm.

Using Lindley's (1966) formula for calculating interface pressure of laterally unrestrained toroidal rubber rings (equation 1), it is estimated that the interface pressure is reduced at the top of the joint by 0.17 MPa and increased at the bottom of the joint by 0.15 MPa. Subtracting the reduced interface pressure due to the shear load (the most adverse case) from the interface pressure without a distorting load, the interface pressure remaining between the rubber ring and the pipes can be determined. This can be used to evaluate whether the maintained interface pressure is sufficient between rubber ring and PVC pipes to exclude sewer infiltration and exfiltration. If a minimum level of interface pressure of 0.4 MPa is specified, a distortion of 5% could reduce this pressure down to 0.23 MPa at the top of the pipe.

It should be noted that the analysis was done with the rubber ring being treated as elastic and not as hyper-elastic, also the interface pressures due to the shear load are only rough estimates by approximating the ring profile as an O-ring. The above example is merely to illustrate that the modelling technique described can be used to evaluate the performance of rubber ring joints under a distorting load. For obtaining accurate results, the real profile of the sealing ring should be used and the rubber should be modelled with the complex material properties such as near incompressibility, large strains and displacements, and generalised strain energy functions. If tests of this type are adopted into Australian Standards, the effect of this distortion on the minimum level of interfacial sealing pressure selected will need to be considered.

7 UNIFORM JOINT TEST PROCEDURES

7.1 Performance Requirement

Because of the diversity of joint test procedures that exist across Australian pipe and fittings standards, a uniform method of assessment needs to be established. It is recommended that the performance requirements for elastomeric pipe joints for pressure and non-pressure pipeline systems be assessed in terms of two pipe type categories – rigid and flexible materials – as given in Table VIII. One possible test method for assessing the elastomeric joint performance at the recommended

TABLE VIII
TEST REQUIREMENTS FOR DIFFERENT WATER/SEWER PIPES

Test		Pressure pipe application		Non-pressure pipe application	
Rigid material	Flexible material	Test pressure	Time (hours)	Test pressure	Time (hours)
—	Hydrostatic pressure & diametral distortion	$\beta \times P_w^*$ $\alpha \times P_w$	1 1000	$\alpha \times P_w$	1
—	Negative pressure & diametral distortion	-85 kPa	2	-85 kPa	1
Hydrostatic pressure & angular deflection	Hydrostatic pressure & angular deflection	$\beta \times P_w$ $\alpha \times P_w$	1 1000		
Negative pressure & angular deflection	Negative pressure & angular deflection	-85 kPa	2	-85 kPa	1
Rubber ring initial interface pressure	Rubber ring initial interface pressure	Not required		0.4 MPa	

* P_w is the rated pressure of the pipe joint from the relevant standards. The coefficients α and β are the multipliers for test pressure which are defined in Appendix 7.

maximum deflection is given in Table IX and is based on the ASTM D3212 method, using the apparatus illustrated in Figure 12. It should be noted that different values of diametral distortion ($\gamma\%$ of OD) are used in different standards; γ is 7.5 in NZS 7648 and NZS 7649, 10 in BS 4346 and BS 4660 and 5 in ASTM D3212. The values given in Table IX are taken from the Standards Australia Committee WS/28 draft for AS 2566.1. The coefficients to determine the actual test pressures to be used are calculated according to the method given in Appendix 7. This method takes into account stress relaxation of the pipe and rubber ring and allows calculation of one- and 1000-hour test values that will ensure satisfactory performance at the 50-year extrapolated value.

In addition, for non-pressure pipes, there is a need for a performance requirement for resistance to tree root penetration. Current work indicates that the minimum requirement of a contact width of 4 mm and an interface pressure of 0.4 MPa is satisfactory for uPVC. These values are the same as specified in AS/NZS 1260-1996. However, it should be noted that work is currently being undertaken to clarify these values for different pipe materials.

TABLE IX
JOINT DEFLECTIONS

Pipe material	Pressure application		Non-pressure application	
	Angular deflection ϕ (°)	Diameter distortion γ (% of OD)	Angular deflection ϕ (°)	Diameter distortion γ (% of OD)
Rigid (e.g. VC, concrete)	At manufacturer's maximum recommended deflection	NA	At manufacturer's maximum recommended deflection	NA
Flexible (e.g. plastics, steel, ductile iron)	At manufacturer's maximum recommended deflection	3	At manufacturer's maximum recommended deflection	7.5

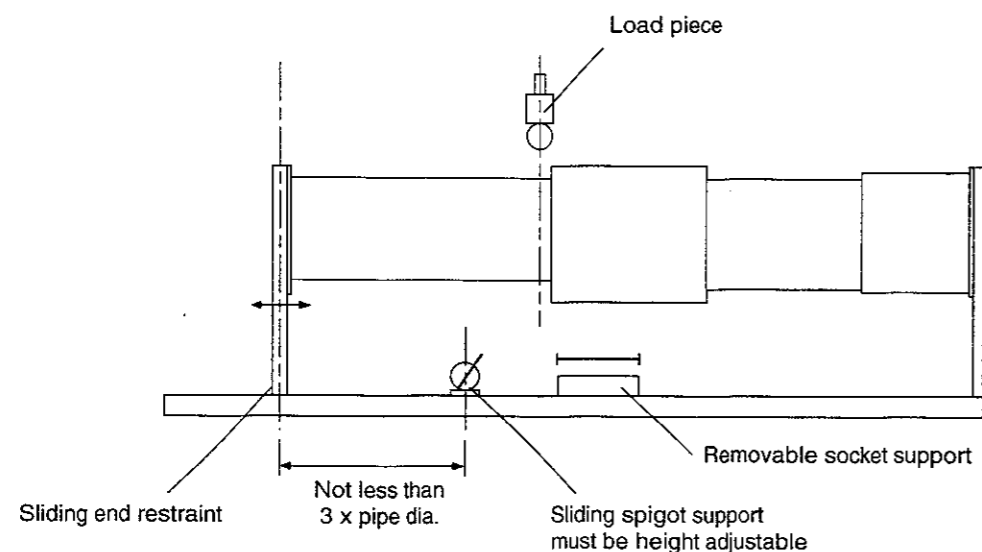


Figure 12. Test apparatus

7.2 Permissible Working Pressure

Assessment of pipe joints to the procedure given in Table VIII gives only a pass/fail assessment and does not take into account the variability of pipe manufacture and performance. An alternative to assessing joints to Table VIII at a specific pressure would be to test joints until failure occurred and then apply statistical analysis to establish a permissible working pressure. Utilising this method would allow manufacturers who produced joints of a consistent standard to specify higher working pressures for their joints.

For both pressure and non-pressure applications, the permissible working pressure P_{wp} of a rubber ring joint with different pipe material may be established by prototype testing to satisfy:

$$P_{wp} \leq \frac{P_{min}}{\beta\kappa} \quad (2)$$

where P_{min} is the minimum short-term failure pressure (positive internal pressure or vacuum), tested at the recommended maximum diameter distortion as given in Table IX, in a sample of N assemblies, where β is defined in Appendix 7 to allow for the effect of load duration and κ is a load factor defined in equation (A8.1) to allow for the variability of failure pressures. The factor κ is determined based on reliability studies (Leicester, 1987; Pham, 1993) by using the assumption of a two-parameter Weibull distribution for P_{min} which leads to the most conservative load factors, as discussed in Appendix 8. An example of the calculation to derive P_{wp} is also given in Appendix 8.

8 SUMMARY AND RECOMMENDATION FOR UNIFORM TEST REQUIREMENTS

The work undertaken in this study is summarised as follows:

- A literature search of standards, and previous and current research on the performance and evaluation of elastomeric joints has been carried out, and it is found that the current performance requirements given in the standards are not uniform, and the pressure ranges for hydrostatic pressure tests vary significantly across the different pipe material types.
- Long-term elastomer properties have been investigated and it is found from literature that the relaxation test results for different rubber rings support that specified in the current AS 1646; however microbiological performance requirements are not adequately specified in AS 1646.
- A survey of Australian water authorities and pipe and rubber ring manufacturers has been undertaken and the results indicate that water authorities essentially follow Australian standards when defining the necessary performance requirements for joints between pipes and fittings.
- Test procedures concerning root intrusion have been investigated and a laboratory test apparatus to determine elastomer interface pressure has been developed, and interface pressures of PVC, VC and FRC have been assessed. The interface pressures measured compare favourably with the current standard requirements.

- An accelerated root intrusion test has been carried out and it is seen that the requirement of a minimum interface pressure of 0.55 MPa and an interface length of 7 mm (where the interface pressure exceeds 0.55 MPa), specified in the superseded AS 1260-1984, and still required for utility infrastructure work and in AS 1741, is overly restrictive for plastics pipe applications. The minimum contact width of 4 mm and interface pressure of 0.4 MPa, as specified in AS/NZS 1260-1996, might also be conservative, but the final conclusion on these requirements cannot be reached until the end of the current accelerated horizontal root intrusion tests, which have now been expanded to incorporate ring interface pressures below 0.4 MPa. In the meantime, the values specified in AS/NZS 1260-1996 may be used for plastics pipes.
- A finite element modelling technique has been described for evaluating whether the remaining interface pressure, after considering the reduced pressure due to shear load, is sufficient between rubber ring and PVC pipes to exclude sewer infiltration and exfiltration.
- A uniform assessment procedure is recommended to allow uniform comparison of all pipe elastomeric joints, taking into account the creep properties of the pipe and the rubber ring, as well as the effect of pipe deflection and distortion.

9 ACKNOWLEDGMENTS

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APPENDIX 1 — PERFORMANCE REQUIREMENTS FOR PRESSURE AND DUAL PRESSURE/NON-PRESSURE PIPES, FITTINGS AND JOINTS WHERE ELASTOMERIC SEALS ARE USED

Pipe materials	Specifications																									
	Pipes	Pressure requirements																								
Grey iron (AS/NZS 2544)	Pressure	<table border="1"> <tr> <th colspan="2">Joints</th> <th colspan="2">Fittings</th> </tr> <tr> <td colspan="2"> <ul style="list-style-type: none"> 2 hrs @ 20°C, -80 to +4500 kPa for DN100 to DN300 2 hrs @ 20°C, -80 to +3600 kPa for DN375 to DN750 socketed joints shall maintain seal for deflections in accordance with table below </td> <td colspan="2"> <table border="1"> <tr> <th>Nominal size DN</th> <th>Test pressure (MPa)</th> </tr> <tr> <td>80-300</td> <td>2.5</td> </tr> <tr> <td>375-600</td> <td>1.6</td> </tr> </table> </td> </tr> </table>	Joints		Fittings		<ul style="list-style-type: none"> 2 hrs @ 20°C, -80 to +4500 kPa for DN100 to DN300 2 hrs @ 20°C, -80 to +3600 kPa for DN375 to DN750 socketed joints shall maintain seal for deflections in accordance with table below 		<table border="1"> <tr> <th>Nominal size DN</th> <th>Test pressure (MPa)</th> </tr> <tr> <td>80-300</td> <td>2.5</td> </tr> <tr> <td>375-600</td> <td>1.6</td> </tr> </table>		Nominal size DN	Test pressure (MPa)	80-300	2.5	375-600	1.6										
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Appendix 1 (continued)

Pipe materials	Specifications	
	Pipes	Fittings
PVC (AS/NZS 1477)	<p>Pressure</p> <p>Long-term hydrostatic pressure test</p> <ul style="list-style-type: none"> extrapolated mean hoop stress @ 50 yrs ≥23.6 MPa for DN ≤150 ≥26 MPa for DN ≤175 optional hoop stress of 12.5 MPa @ 60°C for 1000 hrs 	<p>Pressure requirements</p> <p>Hydrostatic pressure test</p> <ul style="list-style-type: none"> 24 hrs @ 2 × WP 1 hr @ 3.6 × WP <p>Vacuum test</p> <ul style="list-style-type: none"> vacuum of 85 +5, -0 kPa @ 202°C for 2 +0.1 hr <p>Long-term failure stress test</p> <ul style="list-style-type: none"> the firing material shall exhibit an extrapolated 50-yr UTS of not less than a value specified by the manufacturer, when tested according to one of the following alternative methods: <ol style="list-style-type: none"> long-term failure stress test of AS/NZS 1462.20 long-term hydrostatic test of AS 1462.6, using a tube test specimen produced from fitting material
uPVC (ISO/DIS 4422-5)	<p>Water supply</p> <p>(1) Long-term failure stress test</p> <ul style="list-style-type: none"> 1000 hr @ 1.7 × WP @ 20°C 1.45 × WP @ 40°C <p>(2) Short-term hydrostatic test</p> <ul style="list-style-type: none"> 1 hr @ 1.7 × WP @ 20°C 	<p>(2) Short-term hydrostatic test</p> <ul style="list-style-type: none"> 1 hr @ 3.6 × WP @ 202°C

Appendix 1 (continued)

Pipe materials	Specifications	
	Pipes	Fittings
Precast concrete (AS 4058)	<p>Pressure & non-pressure</p> <p>Hydrostatic pressure test</p> <ul style="list-style-type: none"> when tested in accordance with App. D, each pipe & joint combination shall be capable of sustaining either: <ol style="list-style-type: none"> for sewerage pipe & where specified, rubber ring jointed drainage pipe – a test pressure of 90 kPa w/o failure; or for pressure pipe – a specified test pressure, or if not specified, a test pressure not less than 1.2x the specified WP, w/o failure. In addition an ultimate test pressure equal to 1.25x the test pressure, or 75 kPa above the test pressure (whichever is smaller) w/o failure test pressures should be held constant for 1 min. plus 30 s for each 30 mm of wall thickness, or for twice that entire period if the pressure caused the formation of water beads on the pipe surface 	<p>No pressure requirement</p> <p>Hydrostatic pressure test</p> <ul style="list-style-type: none"> when tested in accordance with App. D, each pipe & joint combination shall be capable of sustaining either: <ol style="list-style-type: none"> for sewerage pipe & where specified, rubber ring jointed drainage pipe – a test pressure of 90 kPa w/o failure; or for pressure pipe – a specified test pressure, or if not specified, a test pressure not less than 1.2x the specified WP, w/o failure. In addition, an ultimate test pressure equal to 1.25x the test pressure, or 75 kPa above the test pressure (whichever is smaller) w/o failure test pressures should be held constant for 1 min. plus 30 s for each 30 mm of wall thickness, or for twice that entire period if the pressure caused the formation of water beads on the pipe surface <p>Deflection test</p> <ul style="list-style-type: none"> the assembled pipe & joint combination shall sustain deflection to the max. inter-axial angle recommended by the manufacturer for pipe & use, w/o damage to the pipe or loss of positive overlap of the socket inner face with the pipe spigot outside surface

Appendix 1 (continued)

Pipe materials	Specifications	Pressure requirements	
		Pipes	Fittings
PE (AS/NZS 4130)	Pressure	80°C test	No specification for elastomeric joints
		Compound classification	
		Applied stress (MPa)	
		Min. time to rupture (hrs)	
		PE 63	3.5 3.2 165 1000
		PE 80	4.6 4.0 165 1000
		PE 100	5.5 5.0 165 1000

ABS
(AS 3518)

Pressure

(1) Long-term hydrostatic pressure test

- extrapolated mean hoop stress @ 50 yrs ≥ 16 MPa

(2) Short-term hydrostatic test

- extrapolated mean hoop stress @ 1 hr ≥ 24 MPa

Appendix 1 (continued)

Pipe materials	Specifications	Pressure requirements	
		Pipes	Fittings
Glass filament reinforced thermosetting plastics, polyester based (GRP) (AS 3571)	Water, sewerage & drainage Pressure & non-pressure	(1) Long-term pressure test (for pressure pipes) • regression ratio used to calculate the quality control test pressure (2) Initial test pressure (for pressure pipes) • 24 hrs @ $P_{24h} = R_{24} \times P_{Lmin}$ $R_{24} = 24$ hr regression ratio $P_{Lmin} = WP \times \text{safety factor} - \text{min. long-term failure pressure in MPa obtained from the table below}$	No pressure requirement
		Nominal pressure class (PN)	
		P_{Lmin} (MPa)	
		Safety factor	
		1	2.1
		2.5	2.0
		4	1.9
		6	1.8
		10	2.25
		12.5	2.88
		16	3.60
		20	4.50
		25	1.8

Assembly condition	Pressure Clause	Pressure pipe applications		Non-pressure pipe applications	
		Test pressure (MPa)	Time	Test pressure (MPa)	Time
No deflection	Initial Static	0.005	15 min	0.005	15 min
	3xWP	0.0	24 hr	0.0	15 min
	Negative	-0.08	1 hr	-0.08	1 hr
Total draw	Initial Static	0.005	15 min	0.005	15 min
	2xWP	0.05	24 hr	0.05	15 min
	Negative	-0.08	1 hr	-0.08	1 hr
Maximum draw with shear load	Initial Static	0.005	15 min	0.005	15 min
	2xWP	0.05	24 hr	0.05	15 min
	Negative	-0.08	1 hr	-0.08	1 hr
Positive cyclic	5.6.4	0-15 xWP	10 cycles	Not required	
				15 min. each	

APPENDIX 2 — PERFORMANCE REQUIREMENTS FOR NON-PRESSURE PIPES, FITTINGS AND JOINTS WHERE ELASTOMERIC SEALS ARE USED

Pipe materials	Specifications		Pressure requirements	
	Pipes	Joints	Pipes	Fittings
Unplasticised PVC (uPVC) (AS/NZS 1260)	DWV		(1) Liquid infiltration • 1 +0.08, -0 hr @ -80 to -85 kPa @ 20 ± 2°C with a diametral distortion of 7.5% (2) Resistance to root penetration • contact width ≥ 4 mm • average interface pressure (minimum 4 mm width) ≥ 0.4 MPa	Moulded and fabricated fittings (with test openings only) (1) Hydrostatic pressure test • 1 +0.08, -0 hr @ 80 +5, -0 kPa (2) Liquid infiltration test • fitting tightened to a torque of 15 +1, -0 Nm • 1 +0.08, -0 hr @ 80 +5, -0 kPa • 1 +0.08, -0 hr @ negative pressure of 80 +5, -0 kPa No pressure requirement
Unplasticised PVC (uPVC) (AS 1273)	Rainwater		No pressure requirement • 1 hr @ 150 +5, -0 kPa	No pressure requirement
Cast grey & ductile iron (AS 1631)	Non-pressure		Hydrostatic pressure test • 15 s @ 0.35 MPa	See pipe requirements
High density sewer drainage polyethylene (HDPE) (BlackBrute) (ASTM F894-92)	Non-pressure		Pipe manufacturer's specification (Iplex) • 0.049 MPa	No pressure requirement supplied
Fibre-reinforced concrete (FRC) (AS 4139) (supersedes DR91056:R)	Non-pressure		Hydrostatic testing of drain pipe • 30 s @ 250 kPa, or • 1 min. @ 90 kPa + 30 s for every 10 mm of wall thickness	No pressure requirement

Appendix 2 (continued)

Pipe materials	Specifications		Pressure requirements													
	Pipes	Joints	Pipes	Fittings												
Vitrified clay (AS 1741)	Sewer		Hydrostatic pressure test • 30 s @ 90 +5, -0 kPa	See pipe requirements												
			Burst strength • test pipes & fittings with integral sockets shall sustain either: (1) 30 s @ Nominal size DN Minimum bursting pressure (kPa) <300 3000 ≥300 2000													
			(2) burst pressure ≥ 125% max. design force due to max. compression & hardness of joint seals for integral sockets & sleeves													
			Mechanical tests (1) Deflection test • DN100 to DN1000 • 5 min. @ 60 kPa for conditions below													
			<table border="1"> <thead> <tr> <th>Nominal size DN</th> <th>Minimum deflection per metre of deflected pipe length (mm)</th> <th>Equivalent angular deflection (°)</th> </tr> </thead> <tbody> <tr> <td><225</td> <td>50</td> <td>2.9</td> </tr> <tr> <td>≥225</td> <td>30</td> <td>1.7</td> </tr> <tr> <td>>525</td> <td>20</td> <td>1.2</td> </tr> </tbody> </table>	Nominal size DN	Minimum deflection per metre of deflected pipe length (mm)	Equivalent angular deflection (°)	<225	50	2.9	≥225	30	1.7	>525	20	1.2	
Nominal size DN	Minimum deflection per metre of deflected pipe length (mm)	Equivalent angular deflection (°)														
<225	50	2.9														
≥225	30	1.7														
>525	20	1.2														
			(2) straight draw test • 5 min. @ 60 kPa with a longitudinal separation of 10 +1, -0 mm (3) shear resistance test • 5 min. @ 60 kPa with a longitudinal separation of 5 +1, -0 mm • vertical shear load equal to 25 N/mm of the max. ID													

APPENDIX 3 — PERFORMANCE REQUIREMENTS FOR RUBBER RINGS

TABLE A3.1
AS 1646 — PHYSICAL PROPERTIES OF ELASTOMERIC COMPOUNDS

Material properties & requirements	Requirements: nominal elastomer hardness, IRHD				
	36 to <45	45 to <55	55 to <65	65 to <75	75 to <85
NR and IR					
Tensile strength, min. (MPa)	18	21	21	16	13
Elongation @ break, min. (%)	600	500	500	280	200
Compression set @ 23 ± 2°C for 70 hr, max. (%)	12	12	12	15	15
Compression set @ 70 ± 2°C for 22 hr, max. (%)	25	20	20	20	20
Change on accelerated aging:					
(a) tensile strength, max. (%)	20	20	20	20	20
(b) elongation, max. (%)	20	20	20	20	20
(c) IRHD (max.)	5	5	5	5	5
CR					
Tensile strength, min. (MPa)	11	14	14	14	12
Elongation @ break, min. (%)	550	500	500	300	180
Compression set @ 23 ± 2°C for 70 hr, max. (%)	15	12	12	15	15
Compression set @ 70 ± 2°C for 22 hr, max. (%)	—	—	—	20	20
Compression set @ 100 ± 2°C for 22 hr, max. (%)	15	15	15	—	—
Change on accelerated aging:					
(a) tensile strength, max. (%)	20	20	20	20	20
(b) elongation, max. (%)	20	20	20	20	20
(c) IRHD (max.)	5	5	5	5	5
Oil resistance @ 100 ± 2°C for 70 hr, max. (%)	100	100	100	100	100
SBR					
Tensile strength, min. (MPa)	12	14	14	15	12
Elongation @ break, min. (%)	500	500	450	400	300
Compression set @ 23 ± 2°C for 70 hr, max. (%)	15	12	12	15	15
Compression set @ 70 ± 2°C for 22 hr, max. (%)	—	—	—	20	20
Compression set @ 100 ± 2°C for 22 hr, max. (%)	15	15	15	—	—
Change on accelerated aging:					
(a) tensile strength, max. (%)	20	20	20	20	20
(b) elongation, max. (%)	20	20	20	20	20
(c) IRHD (max.)	5	5	5	5	5
NBR					
Tensile strength, min. (MPa)	8	9	10	12	11
Elongation @ break, min. (%)	500	450	350	250	150
Compression set @ 23 ± 2°C for 70 hr, max. (%)	15	15	15	15	15
Compression set @ 70 ± 2°C for 22 hr, max. (%)	20	20	20	20	20
Change on accelerated aging:					
(a) tensile strength, max. (%)	20	20	20	20	20
(b) elongation, max. (%)	25	25	25	25	25
(c) IRHD (max.)	5	5	5	5	5
Oil resistance @ 100 ± 2°C for 70 hr, max. (%)	40	40	40	40	40
EPDM					
Tensile strength, MPa (min.)	11	11	12	11	9
Elongation @ break, min. (%)	450	400	325	200	125
Compression set @ 23 ± 2°C for 70 hr, max. (%)	15	15	15	15	15
Compression set @ 70 ± 2°C for 22 hr, max. (%)	20	20	20	20	20
Change on accelerated aging:					
(a) tensile strength, max. (%)	20	20	20	20	20
(b) elongation, max. (%)	30	30	30	30	30
(c) IRHD (max.)	5	5	5	5	5

TABLE A3.2
EUROPEAN STANDARD (PrEN 681-1:1992 E) — PHYSICAL PROPERTY REQUIREMENTS FOR MATERIALS USED IN COLD WATER SUPPLY AND DRAINAGE, SEWERAGE AND RAINWATER

Material properties & requirements	Requirements: nominal elastomer hardness, IRHD					
	40	50	60	70	80	90
Types WA, WC and WG						
Range of hardness (IRHD)	36-45	46-55	56-65	66-75	76-85	86-95
Permissible tolerance on hardness	5	5	5	5	5	5
Tensile strength, min. (MPa)	9	9	9	9	9	9
Elongation @ break, min. (%)	400	375	300	200	125	100
Compression set, max.						
72 hr @ 23°C	12	12	12	15	15	15
24 hr @ 70°C	20	20	20	20	20	20
72 hr @ -10°C	40	40	50	50	60	60
Aging, 7 days @ 70°C						
Hardness change, max. (IRHD)	+8/-5	+8/-5	+8/-5	+8/-5	+8/-5	+5/-5
Tensile strength change, max. (%)	-20	-20	-20	-20	-20	-20
Elongation change, max. (%)	+10/-30	+10/-30	+10/-30	+10/-30	+10/-40	+10/-40
Stress relaxation, max.						
7 days @ 23°C (%)	13	14	15	16	17	18
100 days @ 23°C	19	20	22	23	25	26
Stress relaxation per log. decade, max.	5.1	5.5	5.9	6.3	6.7	7.1
Volume change in water, 7 days @ 70°C, max. (%)	+8/-1	+8/-1	+8/-1	+8/-1	+8/-1	+8/-1
Ozone resistance	No cracking when viewed without magnification					
Optional requirements						
Compression set, max. (%)						
72 hr @ -25°C	60	60	60	70	70	70
Hardness change, max.						
168 hr @ -25°C	+18	+18	+18	—	—	—
Volume change in oil, max. (%)						
72 hr @ 70°C, No. 1	+10	+10	+10	+10	+10	+10
72 hr @ 70°C, No. 2	+50	+50	+50	+50	+50	+50
Types WB, WD and WF						
Range of hardness (IRHD)	—	46-55	56-65	66-75	76-85	86-95
Permissible tolerance on hardness	—	5	5	5	5	5
Tensile strength, min. (MPa)	—	9	9	9	9	9
Elongation @ break, min. (%)	—	250	200	200	100	100
Compression set, max.						
72 hr @ 23°C	—	15	15	15	15	15
24 hr @ 125°C	—	20	20	20	20	20
Aging, 7 days @ 70°C						
Hardness change, max. (IRHD)	—	+8/-5	+8/-5	+8/-5	+8/-5	+5/-5
Tensile strength change, max. (%)	—	-20	-20	-20	-20	-20
Elongation change, max. (%)	—	+10/-30	+10/-30	+10/-30	+10/-40	+10/-40
Stress relaxation, max.						
7 days @ 23°C (%)	—	15	15	15	18	18
7 days @ 125°C (%), (1)	—	30	30	30	30	30
Volume change in water, 7 days @ 95°C, max. (%), (1)	—	+8/-1	+8/-1	+8/-1	+8/-1	+8/-1
Ozone resistance	No cracking when viewed without magnification					
Tear strength, min. (N)	—	20	20	20	20	20
Compression set in water, (1), (2)						
70 days @ 110°C, max. (%)	—	30	30	30	30	30

TABLE A3.3
EUROPEAN STANDARD (PrEN 681-1:1992 E) — DESIGNATION OF ELASTOMERIC JOINT SEALS BY TYPE, APPLICATION AND REQUIREMENTS

Type	Application	Requirement
WA	Cold potable water supply up to 50°C	Cold water supply and drainage, sewerage and rainwater (Table 7) Effect on water quality Microbiological deterioration resistance
WB	Hot potable water (continuous supply up to 110°C)	Continuous hot water supply up to 110°C Effect on water quality Microbiological deterioration resistance
WC	Cold non-potable supply, drainage, sewerage and rainwater pipes (continuous flow up to 45°C and intermittent flow up to 95°C)	Table 7 Microbiological deterioration resistance
WD	Hot non-potable water (continuous supply up to 110°C)	Microbiological deterioration resistance
WE	Hot potable water (continuous supply up to 110°C) seals manufactured from isoprene-isobutylene copolymer	Effect on water quality Microbiological deterioration resistance Compression set in hot water
WF	Hot non-potable water (continuous supply up to 110°C) seals manufactured from isoprene-isobutylene	Microbiological deterioration resistance Compression set in hot water
WG	Cold non-potable supply, drainage, sewerage and rainwater pipes (continuous flow up to 45°C and intermittent flow up to 95°C) with oil resistance	Table 7 Microbiological deterioration resistance Oil resistance

TABLE A3.4
BS 2494 — PHYSICAL PROPERTIES OF ELASTOMERIC COMPOUNDS

Material properties & requirements	Requirements: nominal elastomer hardness, IRHD					
	36-45	46-55	56-65	66-75	76-84	85-91
<i>Type W (water)</i>						
Tensile strength, min. (MPa)	9	9	9	9	9	9
Elongation @ break, min. (%)	400	375	300	200	125	100
Hardness, IRHD (microtest)	Within 3 of specified hardness					
Compression set @ 23 ± 2°C for 70 hr, max. (%)	12	12	12	15	15	15
Compression set @ 70 ± 2°C for 22 hr, max. (%)	20	20	20	20	20	20
Stress relaxation, max. (%)	13	13	15	15	18	18
Water absorption, swell, max. (%)	8	8	8	8	8	8
Low temp. hardness change, max. from 23°C value, IRHD (normal test)	5	5	5	5	5	5
Ozone test	No cracking visible under 7× magnification					
Change on accelerated aging, 70°C, 168 hr:						
(a) tensile strength, max. (%)	20	20	20	20	20	20
(b) elongation, max. (%)	30	30	30	30	30	30
(c) hardness, IRHD (max.)	5	5	5	5	5	5
<i>Type D (drainage)</i>						
Tensile strength, min. (MPa)	9	9	9	9	9	9
Elongation @ break, min. (%)	400	375	300	200	125	100
Hardness, IRHD (microtest)	Within 3 of specified hardness					
Compression set @ 23 ± 2°C for 70 hr, max. (%)	12	12	12	15	15	15
Compression set @ 70 ± 2°C for 22 hr, max. (%)	20	20	20	20	20	20
Stress relaxation, max. (%)	13	13	15	15	18	18
Water absorption, swell, max. (%)	8	8	8	8	8	8
Low temp. hardness change, max. from 23°C value, IRHD (normal test)	5	5	5	5	5	5
Ozone test	No cracking visible under 7× magnification					
Change on accelerated aging, 70°C, 168 hr:						
(a) tensile strength, max. (%)	20	20	20	20	20	20
(b) elongation, max. (%)	30	30	30	30	30	30
(c) hardness, IRHD (max.)	5	5	5	5	5	5
<i>Type T (thermoplastic elastomer for above-ground use only)</i>						
Tensile strength, min. (MPa)	4	4	4	6	—	—
Elongation @ break, min. (%)	400	375	300	300	—	—
Hardness, IRHD (microtest)	Within 3 of specified hardness					
Compression set @ 23 ± 2°C for 70 hr, max. (%)	25	25	25	25	—	—
Compression set @ 70 ± 2°C for 22 hr, max. (%)	40	40	40	40	—	—
Stress relaxation, max. (%)	15	20	25	25	—	—
Water absorption, swell, max. (%)	6	6	6	6	—	—
Low temp. hardness change, max. from 23°C value, IRHD (normal test)	5	5	5	5	—	—
Ozone test	No cracking visible under 7× magnification					
Change on accelerated aging, 70°C, 168 hr:						
(a) tensile strength, max. (%)	10	10	10	10	—	—
(b) elongation, max. (%)	10	10	10	10	—	—
(c) hardness, IRHD (max.)	5	5	5	5	—	—

Table A3.4. (continued)

Material properties & requirements	Requirements: nominal elastomer hardness, IRHD					
	36-45	46-55	56-65	66-75	76-84	85-91
Type G (gas and hydrocarbon fluids)						
Tensile strength, min. (MPa)	9	9	9	9	9	9
Elongation @ break, min. (%)	400	300	200	150	100	100
Hardness, IRHD (microtest)	Within 3 of specified hardness					
Compression set @ 23 ± 2°C for 70 hr, max. (%)	8	8	8	8	8	8
Compression set @ 70 ± 2°C for 22 hr, max. (%)	12	12	12	12	12	12
Compression set @ -5°C for 22 hr, max. (%) after 30 min. recovery @ test temperature	20	20	20	20	20	20
Stress relaxation, max. (%)	10	10	10	10	10	10
Ozone test	No cracking visible under 7× magnification					
Liquid immersion tests						
Volume increase, max. (%)	30	30	30	30	30	30
Hardness change, IRHD, max.	16	15	15	14	12	12
Tensile strength, min. (MPa)	4.5	5	5	5	5	5
Elongation @ break, min. (%)	225	175	125	100	75	75
Desorption tests						
Volume loss, max.	15	12	10	10	10	10
Change on accelerated aging, 70°C, 168 hr:						
(a) tensile strength, max. (%)	10	10	10	10	10	10
(b) elongation, max. (%)	25	25	25	25	25	25
(c) hardness, IRHD (max.)	5	5	5	5	5	5
Type H (hot potable water) and Type S (hot non-potable water)						
Tensile strength, min. (MPa)	9	9	9	9	9	9
Elongation @ break, min. (%)	300	250	200	100	100	100
Hardness, IRHD (microtest)	Within 3 of specified hardness					
Compression set @ 23 ± 2°C for 70 hr, max. (%)	15	15	15	15	15	15
Compression set @ 70 ± 2°C for 22 hr, max. (%)	15	15	15	15	15	15
Stress relaxation, max. (%)	30	30	30	30	30	30
Water absorption, swell, % max.	8	8	8	8	8	8
Ozone test	No cracking visible under 7× magnification					
Change on accelerated aging, 125°C, 168 hr:						
(a) tensile strength, max. (%)	20	20	20	20	20	20
(b) elongation, max. (%)	20	20	20	20	20	20
(c) hardness, IRHD (max.)	5	5	5	5	5	5

TABLE A3.5
ASTM F477-90 — PHYSICAL REQUIREMENTS FOR ELASTOMERIC SEALS
FOR PLASTIC PIPES

Tests	Low-head application (below 150 kPa or 50-foot head)	High-head application (150 kPa or 50-foot head and above)
Original properties		
Tensile strength, min. (MPa)	8.3	13.8
Elongation, min. (%)	325	400
Hardness, Type A durometer	40-60	40-60
Low-temperature hardness, Type A durometer, max. increase, points	15	15
Compression set, max. (%)	25	20
Ozone resistance	No cracks	No cracks
Accelerated aging (air oven test)		
Decrease in tensile strength, max. of original (%)	15	15
Decrease in elongation, max. of original (%)	20	20
Hardness, Type A durometer, max. increase, points	8	8
After water immersion		
Change in volume, max. (%)	5	5

APPENDIX 4 — SURVEY FORM FOR RUBBER MANUFACTURERS

COMPANY/ORGANISATION:

DATA Ring merge names

APPLICATION

	Sewer	SWV	Pressure	Stormwater
RUBBER TYPE: _____ (e.g. SBR-styrene butadiene)				
Physical properties _____				
tensile strength				
elongation at break				
abrasion strength				
hardness				
tear strength				
Aging properties _____				
stress relaxation factor				
ozone resistance				
chemical resistance				
microbiological deterioration				
compression set				

Appendix 4 (continued)

	Sewer	SWV	Pressure	Stormwater
RUBBER TYPE: _____				
Design factors _____				
dimensional tolerances				
interaction with other components				
interfacial pressure for each joint design (acc. to AS 1462.13), plus • contact width • min. initial contact pressure • min. eventual contact pressure				
installation & assembly properties				
effect of the material on water quality				

APPENDIX 5 — SURVEY FORM FOR PIPE MANUFACTURERS

COMPANY/ORGANISATION: DATA Pipe merge names	APPLICATION			
	Sewer	SWV	Pressure	Stormwater
PIPE MATERIAL: (e.g. uPVC, ductile iron, GRP)				
Details of rubber ring • manufacturer • rubber type • details of ring cross-section				
Details of joint design* • rubber ring interfacial seal pressure • max. angular deflection • straight draw • max. joint shear • max./min. jointing forces to seat spigot in socket • max./min. deflection of pipe • joint dimensional tolerances • rubber ring dimensional tolerances				
Performance requirements of joint • max. internal design pressure • max. rec. field working pressure • max. rec. field operating pressure, if pipe class is not the determining factor (i.e. Class 20 + above)				
Details of failure assessment • laboratory failures • field failures				

* Please include drawings where available for joint design, as well as any additional comments you think may be relevant.

Appendix 5 (continued)

PIPE TYPE: _____	Sewer	SWV	Pressure	Stormwater
	Design factors _____			
G_{dmax} = max. design joint gap				
F_1 = force required to cause 5% diametral deflection of the pipe @ 10 min.				
G_{soil} = change in joint gap due to simulated soil loading				
G_{time} = change in joint gap due to time-dependant processes occurring in the joint components				
Stress relaxation factor				
P_{init} = initial contact pressure				
P_{resid} = residual contact pressure				

APPENDIX 6 — SURVEY FORM FOR WATER AUTHORITIES

COMPANY/ORGANISATION: DATA Water merge names	APPLICATION			
	Sewer	SWV	Pressure	Stormwater
PIPE MATERIAL: (e.g. UPVC, ductile iron, GRP)				
Rubber ring joint design details <ul style="list-style-type: none"> • type of joint • rubber ring manufacturer • rubber type • rubber ring geometry 				
Rubber ring joint performance details <ul style="list-style-type: none"> • max./min. field design pressure • max./min. field operating pressure • requirements for prevention of root intrusion 				
Rubber ring joint specifications <ul style="list-style-type: none"> • design factors required • performance factors required • other 				
Rubber ring purchasing specifications <ul style="list-style-type: none"> • design factors if different to above • performance factors if different to above • other factors 				

Please include any additional comments you think may be relevant.

APPENDIX 7 — DETERMINATION OF COEFFICIENTS FOR PRESSURE TESTS

The coefficients α and β are the test pressure multipliers which are defined in such a way that adequate performance of the assembled rubber ring joints can be ensured during the service life of 50 years. By multiplying the pipe working pressure by these factors, the test is carried out under such conditions that the expected rubber stress relaxation and the creep of the pipe material after 50 years is reached in 1000 hours (if other times are used, e.g. 24 hours or 100 hours, the principles for determining the multipliers as detailed in the following are still applicable). Based on either the rate of compression stress relaxation of rubber ring (defined in Table 3.2 in AS 1646-1992, denoted as R_r here) or the creep properties of pipe materials, α is defined as the larger of:

$$\frac{1 - 3 R_r}{1 - 5.64 R_r} \tag{A7.1}$$

which is

$$\left(\frac{\sigma_{1000}}{\sigma_{50years}} \right)_r$$

derived from $\sigma = \sigma_0 (1 - R_r \log t)$ for rubber, or

$$\left(\frac{\sigma_{1000}}{\sigma_s} \right)_p \tag{A7.2}$$

and β is defined as the larger of:

$$\frac{1}{1 - 5.64 R_r} \tag{A7.3}$$

which is

$$\left(\frac{\sigma_1}{\sigma_{50years}} \right)_r$$

derived from $\sigma = \sigma_0 (1 - R_r \log t)$ for rubber, or

$$\left(\frac{\sigma_1}{\sigma_s} \right)_p \tag{A7.4}$$

where t is the time in hours, σ_1 is the initial rubber or pipe stress (taken as the stress at 1 hour), σ_s is the design stress of pipe material, and σ_{1000} and $\sigma_{50years}$ are rubber or pipe stress at 1000 hours and 50 years respectively. The subscripts 'r' and 'p' stand for rubber and pipe respectively. These factors should be rounded to the next higher 0.05.

$$\left(\frac{\sigma_1}{\sigma_s}\right)_p \text{ and } \left(\frac{\sigma_{1000}}{\sigma_s}\right)_p$$

are determined based on the approach given in ISO/DIS 4422-5.

σ_1 and σ_{1000} are calculated to consider the creep strain at the operating stress, applied over the design life of the pipe as well as a safety factor. The strain in the pipe material after 50 years of operating at the design stress (σ_s) in the system, can be determined from isochronous stress/strain diagrams for the service temperature (Figure 3 from ISO/DIS 4422-5). To this strain value a safety factor of 50% is added. Using this new strain value, the test stress for 1 hour (σ_1) and 1000 hours (σ_{1000}) are determined from the isochronous stress/strain diagram.

A7.1 Calculation Example

A7.1.1 Rubber ring joined PVC pipe

Rubber: Take R_r as given in AS 1646-1992, i.e. 6%:

$$\alpha = \frac{1 - 3 R_r}{1 - 5.64 R_r} = 1.24$$

$$\beta = \frac{1}{1 - 5.64 R_r} = 1.51$$

PVC pipe: design stress $\sigma_s = 11.0$ MPa (AS 2566.1); strain (ϵ) at an induced stress equal to σ_s after 50 years = 0.483; additional strain safety factor for test (ϵ_A) which is equivalent to half (ϵ) = 0.242; strain value for test ($\epsilon_T = \epsilon + \epsilon_A$) = 0.725; test stresses (σ_1) and (σ_{1000}) at a strain value of $\epsilon_T = 22.75$ MPa and 18.3 MPa:

$$\alpha = \left(\frac{\sigma_{1000}}{\sigma_s}\right) = 1.7 \text{ and } \beta = \left(\frac{\sigma_1}{\sigma_s}\right) = 2.1$$

As the values of α and β calculated are larger for the PVC pipe than those for rubber, the multipliers for the test pressure shall be those from PVC, i.e. $\alpha = 1.7$ and $\beta = 2.10$.

A7.1.2 Rubber ring joined steel pipe

As creep does not greatly affect steel under normal service conditions, the multipliers shall be determined from rubber only. As calculated in the previous example, $\alpha = 1.25$ and $\beta = 1.50$.

APPENDIX 8 — DETERMINATION OF LOAD FACTOR (κ)

The value κ is calculated according to:

$$\kappa = \left[\frac{58}{N} \right] V_p \quad (\text{A8.1})$$

where N is the number of the assemblies tested and V_p is the coefficient of variation of the measured data computed directly from the data values P_i as follows:

$$V_p = \frac{1}{P_{mean}} = \sqrt{\frac{\sum_{i=1}^N (P_i - P_{mean})^2}{N - 1}} \quad (\text{A8.2})$$

where

$$P_{mean} = \frac{1}{N} \left(\sum_{i=1}^N P_i \right) \quad (\text{A8.3})$$

P_i = sample values.

Equation (A8.1) provides a 95% confidence limit in the fifth percentile value of the measured data.

A8.1 Example

Results of hydrostatic tests conducted on thickened PVC rubber ring jointed pipes are given in Table A8.1 (Michael Stahmer, Vinidex Tubemakers Pty Ltd, Melbourne, pers. comm., 1996) can be used to illustrate the above approach.

For PVC, the load duration factor β is determined to be 2.1 from Appendix 7. Substitution of β and the data shown in Table A8.1 into equations (2) to (A8.3) results in the following:

DN100: $P_{min} = 3.4$ MPa, $P_{mean} = 3.875$ MPa, $V_p = 0.125$, $\kappa = 1.397$ and $P_{wp} = 1.43$ MPa

DN150: $P_{min} = 1$ MPa, $P_{mean} = 1.75$ MPa, $V_p = 0.297$, $\kappa = 2.213$ and $P_{wp} = 0.27$ MPa

As seen in Table A8.1, the variation of results for the DN150 pipe is much greater than that for the DN100 pipe. The calculated permissible working pressures shown above reflect this variability.

TABLE A8.1
HYDROSTATIC TEST RESULTS ON PVC RUBBER RING JOINTED PIPES

Sample no. & size	Haul-off rate	Mean groove wall		Test conditions	Test result
		Pre-end-form	Post-end-form		
1/100	1.675	5.31	4.28	'Instantaneous' burst	Spigot fracture at 3.6 MPa
3/100	1.6	5.37	4.3	'Instantaneous' burst	Spigot fracture at 4.5 MPa
5/100	1.675	5.24	4.19	4 MPa, 30 minutes	Ring extruded
6/100	1.7	5.1	4.23	3.4MPa, 10 minutes	Ring extruded
1/150	1.15	4.33	3.69	'Instantaneous' burst	Pipe & socket fracture at 2.1 MPa
2/150	1.45	4.72	3.81	'Instantaneous' burst	Ring extruded at 2.1 MPa
3/150	1.35	4.13	3.44	'Instantaneous' burst	Joint leak at 1 MPa
5/150	1.2	4.68	3.98	1.8 MPa, 20 minutes	Spigot fracture

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