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TTC EVALUATION REPORT

Report No. TTC-2003.02

PREPARED FOR:

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EVALUATION SUBJECT:

TEST DATA ON THE RIB LOC MACHINE SPIRAL WOUND LINING SYSTEM AND MATERIALS

PREPARED BY:

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DATE:

August 15, 2003

DISCLAIMER: This report is limited to the data and test reports submitted by the company requesting this report. No independent tests were performed by the TTC and the TTC does not make specifically any warranty, either expressed or implied, as to any finding or other matter in this report.

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A. EXECUTIVE SUMMARY AND CONCLUSIONS

SUMMARY

Ten different test reports were submitted by RePipe, Inc and Rib Loc Australia Pty Ltd to the TTC for the purpose of preparing this report. These test reports have been reviewed in terms of the standards under which the tests were conducted and their conduct either by, or in the presence of, independent parties. The tests provide results addressing the major design issues for pipe lining systems and include one set of evaluations on earlier Rib Loc installations after nine years in service.

CONCLUSIONS

It is concluded that there is documentation to the effect that the tests have been properly conducted in accordance with the standards listed for each test, or in comparison with prior tests in the absence of standards, and that the results are consistent with the nature of the lining system and its component material.

Testing regarding the issue of annular space leakage for the Rib Loc system (which has been the subject of competitive discussion among liner providers) indicates that the flows expected through the annular space of the Rib Loc liner decrease significantly with distance traveled along the pipe because of the long helical flow paths followed between the liner ribs. Tested flow levels for the circumstances of the comparative tests indicated that the flow levels for the Rib Loc liner were at a similar level to those for the deform-reform liners in prior testing. The results provide a way of comparing flows under defined test conditions but do not provide a good means of comparing actual performance in practice where inlets and outlets may vary in location and proximity. For this reason, it would be helpful to develop information on the efficiency of local seals at manholes and lateral reconnections. When these seals are effective, the issue of annular flow is not important relative to sewer infiltration or exfiltration in lined sewers.

No long-term (10,000 hour) buckling test data for complete liners was provided for review but the long-term test data compiled to date is consistent with the parameters used in design to achieve a 50-year design life for the liner.

The test data provided for the Rib Loc system covers a wide range of design and performance issues relating to the use of the Rib Loc system for relining sewer pipes and indicates satisfactory performance relative to the related North American and international standards.

B. BACKGROUND

IMPETUS FOR THIS REPORT

The review of existing test data relating to the performance of Rib Loc Expanda Pipe that is described in this report was carried out at the request of rePipe, Inc and Rib Loc Australia Pty Ltd. The report reviews existing test data carried out in Australia, Germany and the U.S. and summarizes the results of that test data and the quality control procedures and standards used in the testing. The report also summarizes the design and performance issues that need to be addressed when using a liner system such as Rib Loc for the rehabilitation of pipes and comments on the extent to which the provided test data address these design and performance issues.

CONDUCT OF THE STUDY

The review was carried out in March and April of 2003 by Dr. Ray Sterling, P.E. and Jadranka Simicevic, BS, MS, both from the Trenchless Technology Center at Louisiana Tech University. The review began with the test data and documents provided by Rib Loc. Further documentation and referenced standards were obtained as necessary to gain a full understanding of the test procedures and the extent to which the testing conformed to the established standards for those tests. It was documented in the contract for the review that Rib Loc/rePipe must accept and make available the report in total and not abstract only portions of the review. The draft report was prepared without any review or comments on the findings by rePipe/Rib Loc personnel. The draft report was then submitted to rePipe/Rib Loc for their review.

C. DESIGN AND PERFORMANCE ISSUES FOR SPIRAL WOUND PIPE LINERS

In order to determine whether the existing test results adequately reflect the design and performance issues for spiral wound pipe liners, it is worthwhile reviewing the potential risks for inadequate performance of such liners when used in sewer pipe rehabilitation. The more common potential risks are listed in this chapter.

CONSTRUCTION/INSTALLATION FAILURES

Potential risks

- Inability to install the system within the existing pipe (due to sharp offsets or lack of access)
- Inability to obtain a tight fit with the existing pipe due to irregularities, sharp bends and offsets in the existing pipe, which leads to an unacceptable loss of cross section
- Lack of adequate quality control of field processes

Discussion

Any lining system has field conditions for which it is not suitable and these must be determined during the planning and design process. The Rib Loc system can deal with changes in direction of sewers within reasonable limits but will have difficulties in dealing with highly irregular cross-sections unless the irregularities are dealt with before lining.

The system has an advantage in terms of field quality control since it uses a factory manufactured profile extrusion and a simple mechanical process for installation. A new installation option with a profile winder that moves inside the pipe allows accommodation of changes in pipe diameter within a single liner installation.

Relevance to test results

Tests T1, T2 and T10 test the extent to which the edge seal of the liner profile strips is affected by bends in the host pipe. The other construction problems are planning, design or procedural issues, and no standard tests are used to control such occurrences.

STRUCTURAL FAILURE

Potential risks

- Radial liner deflection to a degree that compromises the function of the pipe
- Failure of the liner caused by exceeding permissible strains or stresses in the liner material
- Failure of the liner through buckling caused by external water pressure acting between the host pipe and the liner

Discussion	The liner may be subject to a variety of stress conditions over its lifetime. The most common conditions are likely to be: ▪ Local or general deformation of the host pipe that will transmit loads to the liner from the surrounding soil or live loads from the ground surface. This may result from changes in ground conditions or from continued deterioration of the host pipe. ▪ Internal water pressure resulting from surcharge conditions in the lined pipe ▪ External water pressure within the annular space that acts on the liner (resulting from the defects in the host pipe and the presence of a temporary or permanent groundwater level above the host pipe The design of liners against structural failure is covered in various international and ASTM standards. The provisions of such standards give guidance on the design loading conditions to used, the analysis techniques that can be used to determine the required thickness and material properties for the liner, and the testing requirements to make sure that the product in question will meet the requirements. Failure due to external groundwater pressure acting between the host pipe and the liner is usually caused by local buckling of the liner and the buckling pressure is affected by the effective thickness of the liner (moment of inertia against local bending of the liner), the long-term modulus of the liner material, the annular space gap between the liner and the host pipe, and any initial imperfections in the shape of the liner.
Relevance to test results	Tests T8 and T9 were conducted to determine the short-term and long-term modulus of the liner material and to assess the buckling pressure for the liner when the annular space is pressurized. Strains at failure of the liner material also were determined. These tests provide the necessary physical properties to allow the liner to be structurally designed in a similar fashion to other lining methods and in accordance with ASTM procedures.
	LINER MATERIAL DEGRADATION OVER TIME **(Leading to one of the other failure modes)**
Potential risks	▪ Deterioration of the liner material in the presence of chemical or biological agents likely to be found in the service environment ▪ Deterioration or erosion of the liner due to abrasion from flowing particles within the operating sewer ▪ Physical damage to the liner from maintenance operations within the sewer, e.g. cleaning
Discussion	It is necessary to know whether the material used for the liner is adequate for the expected service life of the relined pipe. If the liner material were to deteriorate in the service environment of the sewer – either through chemical/biological action or through physical damage from abrasion/maintenance – then it could become too weak or to thin to withstand the stresses imposed on it (leading to collapse) or could be punctured in local areas (leading to renewed infiltration or exfiltration).

Relevance to test results	Tests T3, T4 and T5 were conducted to assess the long-term behavior of the liner material and its resistance to erosion.
	HYDRAULIC INADEQUACY
Potential risks	▪ The flow characteristics of the lined pipe are not adequate for the service conditions of the pipe. This depends on the smoothness of the lined pipe and the loss of cross-section through the lining process.
Discussion	It is inevitable that a liner installed within an existing host pipe (that is not in itself enlarged) will reduce the cross-sectional area of the pipe available for flow. This may or may not be important for a particular pipe depending on the expected flows relative to its current capacity. The reduction of cross-section is usually offset in terms of flow characteristics by the improvement in the roughness coefficient of the pipe when using a liner with a smooth interior surface in comparison with the deteriorated surface condition of the host pipe. Whether the flow capacity is actually enhanced or not depends on the thickness of the liner, the diameter of the host pipe, and the change in roughness coefficient.
Relevance to test results	Test T6 was conducted to determine the hydraulic roughness coefficient for the Rib Loc liner. This information can then be used for the comparison of the before/after flow characteristics if the roughness of the host pipe in its current condition can be estimated or measured.
	FAILURE TO ADEQUATELY ADDRESS INFILTRATION **(When reduction of infiltration is an objective of the relining project)**
Potential risks	▪ Leakage through the liner material itself ▪ Leakage through the joints in the liner material ▪ Leakage into or out of the lined pipe at lateral connections ▪ Leakage into or out of the sewer system at manholes or similar pipe terminations
Discussion	Relining projects may have two or more complementary objectives such as stabilizing structural deterioration of a sewer pipe or reducing infiltration into the sewer system. When infiltration reduction is a goal of the relining, it is necessary to understand the potential paths for water to enter the sewer system either through the liner or around the installed liner. No in-situ lining methods for sewers currently provide a liner with no annular space that is fully adhered to the inside of the host pipe. In the absence of this condition it is possible for groundwater to enter the annular space through failures in the host pipe. This water can then migrate along the annular space and enter the sewer system at places where lateral reconnections are made or at the ends of the liner at manholes. It is preferable to seal these locations but, if they are not sealed, then the potential flow into the sewer will be dependent on the characteristics of the annular space.

Relevance to test results	Test T7 conducted annular space leakage tests similar to studies performed earlier on CIPP and deform-reform lining materials. Tests T1, T2 and T4 present water and air pressure testing results that provide information on the joint seals for the liner and on the lack of defects or permeability in the liner material itself.
	LONGITUDINAL LINER MOVEMENT
Potential risks	▪ Expansion or shrinkage of the liner causing movement with respect to the host pipe and misalignment of lateral connections ▪ Sliding of the liner within the host pipe due to drag forces on the liner
Discussion	Lining systems may be installed by dragging a liner within the host pipe, by curing the liner at high temperatures or by other procedures that may affect the longitudinal strain conditions within the liner. If these thermal or mechanical strains are not released or allowed to dissipate before the lateral reconnections are made, then problems due to misalignment of the connections may occur. Likewise, if the lining is not well fixed within the host pipe, it could become dislodged and moved longitudinally at a later date.
Relevance to test results	No specific tests related to this issue are included in the test set provided but the nature of the installation process (winding the profiles at ambient temperature at a smaller diameter and then expanding against the wall of the host pipe) means that later thermal or installation process induced movements are highly unlikely. The expansion of the liner against the host pipe by winding also should provide a mechanical contact with the host pipe in places that will help to prevent longitudinal sliding of the liner.

D. REVIEW OF SUBMITTED REPORTS

	This chapter outlines tests performed on Rib Loc Expanda Pipe that were submitted to the TTC for evaluation, and conveys whether the tests were done by an independent testing laboratory or were in-house testing.

T1. Test Report on Joint Tightness Testing of Rib Loc Expanda Pipe (1999)

- Leak-tightness

PROPERTY TESTED

Rib Loc Expanda Pipe is a field-fabricated liner produced from extruded PVC profile strip with male and female edges. During spiral winding process, the male and female edges self-interlock and form a leak tight joint. The objective of this test was to prove that the formed joint meets requirements for leak tightness in gravity sewers and conduits. This was not a routine quality control test, but a test of reliability and performance requirements.

6 liners wound and tested in laboratory conditions

SCOPE

Rib Loc Expanda Pipe is typically installed in sewer pipes with ID between 6-in and 30-in, although larger diameters are also possible. For this test, six liners were spirally wound[1] with the following dimensions:

OD:	Length – STRAIGHT ALIGNMENT TESTS:	Length – CURVED ALIGNMENT TESTS:
$5^{5}/_{16}$- in (135mm)	6 ft (1.83 m)	20 ft (6.10 m)
8-in (203mm)	6 ft (1.83 m)	25 ft (7.62 m)
18-in (457mm)	10 ft (3.05 m)	50 ft (15.24 m)

ASTM F1697-1996

TEST DESIGN

Design of this test is based with some modifications on ASTM F1697-96[2]. The modifications are:

- The 10° sharp bend in curved alignment is replaced with a 10° arc bend, which reflects better field application of the product and has now been incorporated into the ASTM;
- Instead of testing one liner for each pipe size under three settings, two liners are fabricated for each pipe size (one tested for two straight alignment settings and the other for curved alignment setting);
- The vacuum testing[3] is omitted and only the pressure testing is performed.

USA, 1998

TIME AND LOCATION

The test was conducted on 09/03/98 in Paramount, CA (in the laboratory of Ramtech Laboratories).

[1] During the winding process, GE silicone was applied to the primary lock area to act as lubricant.

[2] ASTM F1697-96 covers requirements and test methods for materials, dimensions, workmanship, stiffness factor, extrusion quality, and form of marking for extruded PVC profile strips used for spirally wound pipe liners. Part of this standard refers to the testing of joint tightness.

[3] The ASTM standard requires both the pressure and the vacuum test be performed in three settings in following order (1) Pipe straight alignment; (2) Pipe straight alignment with shear deflection set-up; (3) Pipe curved alignment with sharp 10° bend.

Preussag Pipe Rehabilitation	**REQUEST FOR TESTING** Preussag Pipe Rehabilitation (Santa Ana, CA) was a licensee for Rib Loc products and technologies at the time of testing.
Ramtech Laboratories, Inc	**COMPANY CONDUCTING TESTING** Ramtech Laboratories is a testing laboratory that performs engineering testing, inspections, consulting, ICBO/CABO[4] approvals and QC. It is a recognized testing laboratory with ICBO Evaluation Service, Inc.[5] (TL-167) and City of Los Angeles (RR23840).
Municipal representatives	**TEST WITNESSING** Eight representatives from five municipalities witnessed the testing: City of Long Beach (1), City of Santa Monica (1), County Sanitation District of Los Angeles (1), City of Los Angeles (3), and City of San Diego (2).
	SIGNATURE ON REPORT COPY OR TRANSMITTAL Ronald A. Macey, David R. Macey, and Steven M. Berggren (Ramtech Laboratories Inc.)
	TEST PROCEDURE Tested pipe liners were fabricated in lengths well above the minimum specified by the ASTM standard. Preparation of samples (fabrication by spiral winding, mounting of end seals) and internal pressure testing (amount of pressure and duration of test) were performed according to the standard.
No leaks	**RESULTS** According to ASTM F1697, visible leaks in the joint constitute failure. No leaks were observed indicating that all pipe samples passed the test requirements.
	COMMENTS The ASTM standard was followed with some modifications and the performed testing confirms the leak-tightness of new Rib Loc Expanda Pipe installed in gravity sewer pipelines within the boundaries of the testing (liner OD between 6-in and 18-in and curvature of pipe alignment up to 10° arc bends). Because the process of fabrication does not change with the liner size, it is reasonable to expect that Rib Loc Expanda Pipes with OD larger than 18-in will be leak-tight as well.

[4] ICBO stands for International Conference of Building Officials; CABO - Council of American Building Officials
[5] ICBO Evaluation Service, Inc is a subsidiary of the International Code Council.
TL indicates an accredited testing laboratory. RR indicates research report.

T2. Internal Pressure Test and Vacuum Test (2000)

▪ Leak-tightness	**PROPERTY TESTED** This test evaluates the same property of Rib Loc Expanda Pipe as test T1.
2 liners wound and tested in laboratory conditions	**SCOPE** This test evaluates two liners with the following dimensions: OD: / Length: / Profile $15^3/_4$-in (400 mm) / 34-ft (10.46 m) / 126 Ex $8^5/_8$-in (220 mm) / 19-ft (5.75 m) / 85 Ex2
ASTM F1697-1996	**TEST DESIGN** This test is based on the same ASTM F1697-96 standard as test T1. The 10° sharp bend in curved alignment is again replaced with a 10° arc bend, which reflects better field application of the product. This has now been incorporated into the ASTM. However, the vacuum testing is not omitted and is performed together with the pressure testing.
Australia, 2000	**TIME AND LOCATION** The test was conducted on 08/31/00 in Gepps Cross, South Australia (in the testing laboratory of Rib Loc Australia Pty Ltd).
Rib Loc Australia Pty Ltd	**COMPANY REQUESTING AND CONDUCTING TESTING** This was in-house testing under surveillance of an independent testing laboratory.
Amdel Limited	**TEST WITNESSING** At the time of testing, Amdel Limited[6] was one of 13 laboratories of Amdel, the largest independent laboratory group in Australia, whose numerous accreditations and permits authorize development and provision of various testing services.
	SIGNATURE ON REPORT COPY OR TRANSMITTAL Damien Lynch (Amdel Limited)
	TEST PROCEDURE Testing was carried out as specified in the referenced ASTM standard.

[6] Amdel Limited was purchased by Gribbles Group Limited in March 2002.

Allowable pressure drop

No leaks

RESULTS

According to ASTM F1697 standard, the allowable pressure change after the test period is 17 kPa in the vacuum test. With pressure drop 3 kPa in straight alignment setting and 17 kPa in curved and 5 % deflected alignment, both liners passed the test requirements.

According to ASTM F1697, visible leaks in the joint constitute failure in the water pressure test. No leaks were observed indicating that both liners passed the test requirements.

COMMENTS

The submitted report clearly portrays the testing procedure and presents the results of testing in a test data sheet.

This test is conducted one year after test T1 following more closely the ASTM standard requirements. The results are in accordance with the earlier test, both tests confirming leak-tightness of Rib Loc Expanda Pipe.

T3. Test Certificate No. 22 0134 0 88 (1988)

- Abrasion resistance
- Resistance to impact load at low temperatures
- Leak-tightness

PROPERTY TESTED

The objective of this test was to prove that Rib Loc Expanda Pipe manufactured from PVC resin meets or exceeds specified requirements for selected material properties to be used as protective liner in sanitary and combined sewer pipelines made of concrete. This is a test of reliability and performance requirements.

3 half-shells of liner wound in concrete pipe[7]

6 test pieces of liner strips cemented and anchored to the concrete slabs[8]

SCOPE

This test evaluates the following test pieces:

ID	Length	Profile
$11^{3}/_{4}$ in (300mm)	3.3 ft (1 m)	Ribton 1-140-5

Width × Length	Profile
113/4 in ×113/4 in (300mm × 300mm)	Ribton 1-140-5

[7] All 3 half-shells tested for abrasion

[8] 2 test pieces tested for impact strength under low temperatures and 4 test pieces tested for leak-tightness

German guidelines	**TEST DESIGN** Guidelines by the German Institute for Civil Engineering (DIBt, 1982) specify tests and minimal requirements the PVC material used for relining of sewer pipelines must satisfy. Tests for resistance to abrasion and impact load at low temperatures, as well as for leak-tightness, are designed in accordance with these guidelines.
Germany, 1988	**TIME AND LOCATION** Testing was conducted between March and September 1988 in Dortmund, Germany (in the laboratory of MPA NRW).
Ferdinand Stuekerjuergen	**REQUEST FOR TESTING** Ferdinand Stuekerjuergen GmbH was an early German licensee for Rib Loc products and technologies.
MPA NRW	**COMPANY CONDUCTING TESTING** MPA NRW[9] is a German material testing authority that provides services of accredited test and calibration laboratories, certification bodies for products and a certification body for quality management systems. The institute has various acknowledgements/accreditations, one of which is DAP-PL-2600.99 – the accreditation in compliance with DIN EN ISO/IEC 17025 (*General requirements for the competence of testing and calibration laboratories*) and the DIN EN ISO 9001:1994 (*Quality management*) from the German Accreditation System Inspection Department GmbH.
	SIGNATURE ON REPORT COPY OR TRANSMITTAL Paul Fülling (MPA NRW)
	TEST PROCEDURE <u>Abrasion resistance</u> The abrasion test follows the Darmstadt rocker test method. A semicircular channel pipe, closed by end plates and filled with a sand/gravel/water mixture, is tilted alternatively in the longitudinal direction ±22°. The depth of abrasion is measured along the pipe invert in 20 points, omitting 6-in (150mm) sections at each end of channel after large number of cycles. Mean value measured after 200,000 cycles is used as the result. <u>Impact strength at low temperatures</u> Impact strength is tested by applying impact load on the concrete/liner test pieces after having them stored at 32°F ±4°F (0°C ±2°C) for 16 hours. The load is applied by dropping a 2-in (50mm) steel ball from a height to create 7.4 lb·ft (10 N·m) impact energy. Tested are both zones with and without Rib Loc joint.

[9] MPA NRW stands for Materialprüfungsamt Nordrhein-Westfalen, i.e. Office for Material Testing of North Rhine Westphalia

Leak-tightness

Leak tightness is tested on the concrete/liner test pieces by applying external water pressure to the space between the liner and the concrete slab. For this purpose, nine $^{3}/_{16}$-in (5mm) holes have been drilled through concrete to expose but not penetrate the internal liner. In three short-term tests, water overpressure of 72.5 psi (5 bars or 500 kPa) is applied for 1 hour and afterwards increased in 2-min intervals until the liner rupture. In one long-term test, water overpressure of 43.5 psi (3 bars or 300 kPa) is applied for 1,000 hours (almost 42 days).

RESULTS

Abrasion loss is 0.22mm @ 200,000 cycles

Abrasion resistance

Average abrasion loss was 0.22 mm after 200,000 cycles.

No visible damage

Impact strength at low temperatures

No external damage was visible after the testes.

No leaks

Leak-tightness

Neither the short-term tests nor the long-term test generated any leaks or worked the anchoring loose. Leak started at the glued joint when the overpressure reached 128 psi (880 kPa or 8.8 bars), however the anchoring was still tight.

COMMENTS

In its appendix, the submitted report includes a test certificate (by Deutche Solvay-Werke GmbH) with values of selected properties for tested material, among others tensile properties and corrosion resistance.

The report concludes that the "Ribton" (now Rib Loc) meets the requirements of the "Guideline for Selection and Application of Internal Linings with plastic components for single and combined sewers – Requirements and Tests," September 1982 version and that proof of the fulfillment of the minimum requirements set for rigid PVC lining materials has been furnished.

The result about abrasion resistance is consistent with other testing on PVC pipes that show that PVC as a material is resistant to abrasion. (Gabriel, 1990)

Water leakage noted at an external water pressure of 8.8 bar (approximately 294 ft head of water) is well outside the range of application of the product.

A comment that the material tensile strength of 48.5 N/mm^2 was below the 50 N/mm^2 requirement in Germany is not relevant for the U.S. where the minimum tensile strength requirement according to Greenbook SSPWC 210-2.5, 2000[10] is 44 N/mm^2 (6,500 psi).

[10] See test T5.

T4. Testing of 9 Year Old Rib Loc Expanda Liner (1999)

- Long-term abrasion resistance
- Long-term leak-tightness

PROPERTY TESTED

The objective of this testing is to demonstrate that Rib Loc Expanda Pipe installed in gravity sewers and conduits is resistant to abrasion and continues to be leak-tight over time. Two separate tests, one of abrasion resistance and the other of leak-tightness, performed on a liner having been in service for several years, were conducted as quality control testing.

1 liner tested several years after installation both in the laboratory and in-situ

SCOPE

Both tests evaluate one Rib Loc Expanda Pipe wound into a vitrified clay sewer pipe with the following dimensions:

OD	Length	Profile
$11^3/_4$ in (300mm)	150 ft (45 m)	85 Ex[11]

The host sewer pipe is in sandy soil conditions with high groundwater table and infiltration to the system, which causes a large amount of sand to be transported by the sewer and thus exposes the sewer pipe to abrasion. The pipe has no lateral connections and is therefore very suitable for pressure testing. The age of liner at the times of testing is seven and nine years.

TEST DESIGN

Abrasion resistance
Resistance to abrasion is tested by measuring and comparing the thickness of two samples removed from the installed liner: one removed from surface exposed to abrasion over the years (invert) and the other from the surface not exposed to abrasion (crown).

Leak-tightness
Three separate in-situ tests are based on the following standards:

EN 1610: 1997

(1) EN 1610: 1997 (European Standard), which requires the leak-tightness be tested with either air or water pressure test.

AS 2032:1997

(2) AS 2032:1997 (Australian Standard), which requires the leak-tightness be tested with either a hydrostatic test or an air test.

Greenbook SSPWC 306-1.4: 1994

(3) Greenbook SSPWC 306-1.4 (APWA Southern Californian Chapter), which requires that gravity sewer pipelines 24-in or less in diameter be tested for leakage depending on the difference in elevation between inverts of adjacent manholes:

- If difference is less than 10-ft, water exfiltration test or water infiltration test should be used, but air pressure test may be used instead.
- If difference is greater than 10-ft, air pressure test or water infiltration test should be used.

[11] The lock was lubricated and sealed with GE SC2000 silicone.

TIME AND LOCATION

Australia, 1997 & 1999

The host sewer pipe with installed Rib Loc Expanda Pipe liner is located in a suburb of Adelaide, South Australia (Kiama Avenue, West Lakes Shore, South Australia).

Testing of abrasion resistance was conducted on the material samples in the laboratory of Duncan Tool & Gauge Pty Ltd in October 1997. Testing of leak-tightness was conducted in-situ on July 15, 1999.

COMPANY REQUESTING AND CONDUCTING TESTING

Rib Loc Australia Pty Ltd
United Water

This was mostly in-house testing, with the assistance from the following companies:

United Water provided assistance with the removal of samples from liner, which were tested for abrasion resistance. United Water is the largest private water company operating in Australia and New Zealand, providing water and wastewater services to more than one million people.

Duncan Tool & Gauge Pty Ltd

Duncan Tool & Gauge Pty Ltd conducted laboratory testing on the samples. This is a recognized testing laboratory in Australia with the NATA [12](Accreditation No.778). The laboratory complies with the requirements of ISO/IEC 17025 (1999).

TEST WITNESSING

Amdel Limited

Amdel Limited[13] witnessed the testing of *leak-tightness*, and a separate report was prepared by this company to attest to it.

SIGNATURE ON REPORT COPY OR TRANSMITTAL

Mark A. Robinson (Rib Loc Australia Pty Ltd)
L. A. Duncan (Duncan Tool & Gauge Pty Ltd) - Appendix E
Jeremy V. Pickering (Amdel Limited) - Appendix C

TEST PROCEDURE

Abrasion resistance
Preparation of samples was satisfactory: the location selected for sample removal identified appropriately based on the liner color (gray color in the invert due to exposure to sewerage, original white color in the crown for not being exposed to sewerage), and cleaning of samples done non-destructively (soaking in domestic grade disinfectant and using a stiff plastic brush).

For each sample, a reading of thickness was taken in two common grooves in sets (three sets of six readings). The mean was calculated for each six-reading set, and overall mean calculated subsequently.

[12] National Association of Testing Authorities
[13] Amdel Limited is already referenced in test T1.

	Leak-tightness All three tests were performed in accordance with the related standards. All specified procedures were followed properly, i.e. both the procedures for: ▪ Increasing the internal air pressure in the pipeline (by introducing constant air flow to reach specified target value and maintaining it at that constant value for a specified time interval), ▪ Decreasing the internal air pressure in the pipeline (by discontinuing air flow to let internal air pressure in the pipeline drop either to the specified target value or during specified time interval).
Unchanged thickness regardless of abrasion Air-pressure maintained	**RESULTS** Abrasion resistance The liner had the same thickness in the crown and in the invert within the uncertainty of measurement, which shows that aggressive sewage flow had no noticeable effect on the liner after seven years of service. Leak-tightness In all three air-pressure tests, the tested liner satisfied the requirements set by the standards. In particular, in the third test based on Greenbook SSPWC 306-1.4, at least 180 seconds was required to pass after discontinuing the constant air flow to the pipeline before the internal air pressure was to drop from 2.5 psi to 1.5 psi. In fact, internal air pressure remained unchanged and the test was declared completed when 180 seconds passed with no drop at all in internal air pressure.
	COMMENTS The submitted report describes fairly well the design, the testing procedure, and the results related to testing of leak-tightness. Amdel's witnessing report is brief but exact and informative. However, a supplementary report by Duncan Tool & Gauge Pty Ltd is a test data sheet, which is too concise to evaluate the details of the laboratory testing.

T5. Test of "Expanda-Pipe" PVC Liner System (1995)

▪ Chemical resistance ▪ Tensile properties	**PROPERTY TESTED** The objective of this test is to demonstrate that the PVC material used for Rib Loc Expanda Pipe meets or exceeds specified requirements for chemical resistance and physical properties to be used as protective liner in sewer pipelines. This is a test of reliability and performance requirements.

Material samples	**SCOPE** This test evaluates material samples with the following dimensions: The samples were supplied by Hancor Inc, the Rib Loc's installation licensee at the time of testing.

Width × Length	Profile
1 in ×1 in (25mm × 25mm)	Cell Class 13454-C[14], gray colored

Greenbook SSPWC 210-2.3: 1994	**TEST DESIGN** Greenbook SSPWC 210-2.3:1994 states that a plastic liner manufactured from PVC resin may be tested for chemical resistance and physical properties at any time during the manufacture or prior to the final acceptance. In particular, requirements to be met or exceeded are given for: ▪ Chemical resistance: max permissible percent weight change determined in the "Pickle Jar Test" ▪ Tensile strength and break elongation: minimum required when determined as in ASTM D 412 (Die B) ▪ Indentation hardness: max permissible when determined as in ASTM D 2240 (Type D durometer)
USA, 1995	**TIME AND LOCATION** The test was conducted in the Fall of 1995 in Los Angeles, CA (in the laboratory of Standards Division within the City of Los Angeles General Services Department).
	REQUEST FOR TESTING Rib Loc Australia Pty Ltd
City of Los Angeles Standards Testing Lab	**COMPANY CONDUCTING TESTING** City of Los Angeles Standards Testing Laboratory is a licensed materials testing agency specializing in quality control, acceptance testing and engineering services. Tests are performed in strict compliance with ASTM, ACI, AASHTO, EPA Greenbook, California Test Methods, or other relevant procedures and specifications as required by the individual project. Plastic pipe products are on the list of materials routinely tested by this laboratory.
	TEST WITNESSING This is a long-term test (about four months) performed by an independent testing laboratory and no additional eyewitnesses were involved.

[14] Per ASTM D 1784, material properties of this cell class are:

- Base resin: (1) PVC homopolymer
- Min impact strength: (3) 1.5 ft·lb/in
- Min tensile strength: (4) 7,000 psi (48.3 MPa)
- Modulus of elasticity: (5) 400,000 psi (2,758 MPa)
- Min deflection temp under load 1.82Mpa: (4) 158°F (70°C)

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Papkin K. Kovasapian (City of Los Angeles, Dept. of General Services)

TEST PROCEDURE

Details missing

The submitted report contains only a reference to the Greenbook standard specifications and the results of the testing, but does not give any description of test conducting such as exact dates, number of specimens, test conditions, etc.

RESULTS

Referenced 1994 Greenbook standard covers only flexible PVC liners, whereas the 2000 edition of this standard covers also rigid PVC liners.

Determined values and standard requirements before and after immersion test are as follows:

		Rib Loc SPECIMENS	SSPWC 210-2.3:1994 **FLEXIBLE PVC LINERS**	SSPWC 210-2.5:2000 **RIGID PVC LINERS**
Weight change:	INITIAL	-	-	
	FINAL	≤ (±0.109%)	≤ (±1.5%)	≤ (±1.5%)
Tensile strength:	INITIAL	≥ 6,904 psi	≥ 2,200 psi (ASTM D 412)	≥ 6,500 psi (ASTM D 638)
	FINAL	≥ 6,748 psi	≥ 2,100 psi (ASTM D 412)	≥ 80 % of INITIAL
Break elongation:	INITIAL	9.9 – 25.5 %	≥ 200 % (ASTM D 412)	≥ 25 % (ASTM D 638)
	FINAL	9.8 - 24.9 %	≥ 200 % (ASTM D 412)	NA
Hardness, Durometer D:	INITIAL	74	≤50-60 (ASTM D 2240)	≤70 (ASTM D 2240)
	FINAL	-	≤ INITIAL ± 5	NA

Note: ASTM standards in parenthesis specify standard procedures used to determine the material properties.

COMMENTS

Chemical resistance of PVC material used for Rib Loc Expanda Pipe is satisfactory.

Tensile properties and hardness are clearly in the region of requirements for rigid PVC liners, however, it is not explicit as to whether the material does or does not satisfy the requirements. Namely, the submitted report gives only the range of determined values, but does not specify the number of tested specimens, the average value and the standard deviation.

T6. Determination of Hydraulic Roughness of PVC Expanda Pipe (1991)

- Hydraulic roughness

PROPERTY TESTED

Some unevenness in wall roughness can be found in all commercially available pipes, but in spirally wound pipes there is also irregularity of surface due to the joint connecting the PVC profile strips. The objective of this test is to determine the hydraulic roughness parameters to be used for calculating hydraulic capacity of Rib Loc Expanda Pipe.

1 liner wound and tested in laboratory conditions

SCOPE

The test evaluates one Rib Loc Expanda Pipe spirally wound in laboratory conditions with the following dimensions:

ID	Length	Profile
$8^7/_8$ in (225 mm)	105 ft (32 m)	85 Ex[15]

Testing procedure by the Utah State University

TEST DESIGN

The Utah State University developed a test procedure for determination of fluid frictional head loss in spirally wound ribbed PVC pipes (Utah Water Research Laboratory, 1985).

Equations for calculation of steady flows under pressure in pipelines used in professional practice today are (1) Darcy-Weisbach equation, (2) Hazen-Williams equation, and (3) Manning equation. This testing utilizes all three equations[16] to determine hydraulic roughness parameters: surface roughness, Hazen-Williams coefficient and Manning coefficient. Various hydraulics books offer tables in which hydraulic roughness parameters for assorted pipe materials are compiled from relevant references. This test takes values from two books (Kannen, 1986; Streeter and Wylie, 1981).

Australia, 1990

TIME AND LOCATION

The testing was conducted in December 1990 in Adelaide, SA (in the Water Engineering Laboratory of the University of South Australia - UniSA).

REQUEST FOR TESTING

Rib Loc Australia Pty Ltd

UniSA –
Water Engineering Lab
(Techsearch Inc.[17])

COMPANY CONDUCTING TESTING

The Water Engineering Laboratory of the UniSA is a facility specifically designed to test and evaluate the hydraulic performance of existing or planned stormwater drainage network details and other hydraulic devices.

[15] The lock lubricated and sealed with GE SC2000 silicone.

[16] Darcy-Weisbach equation is fundamentally sound and the most accurate. However, the empirical Hazen-Williams and Manning equations, the latter originally and primarily developed for open channel flows, have been used in pipeline calculations much longer and are still commonly used today.

[17] Until July 1995, Techsearch Inc. was the commercial arm of the UniSA, providing services to support staff in their external activities, ensuring that the commercial interests of the University were protected, and performing a research development role in support of the various University Centers.

TEST WITNESSING

There were no independent witnesses to the testing.

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Dr. John Argue (University of South Australia)

TEST PROCEDURE

A test rig has been constructed replicating the Utah tests, with 10 pressure tappings (assemblies to measure hydraulic grade line) positioned at approx 10-ft (3-m) intervals along the pipe length. Several preliminary tests were carried out to verify the headloss recording procedure, i.e. consistency in headloss reading between selected pairs of pressure tappings.

A total of 12 different flows were tested. For each flow, headloss between three pairs of pressure tappings and water temperature were recorded. Based on collected data, hydraulic roughness parameters of Rib Loc Expanda Pipe were calculated.

RESULTS

Surface roughness ≈0.045mm

Friction factor from the Darcy-Weisbach equation
Depending on Reynolds number, the friction factor is between 0.0130 (high flow, Re=1,354,000) and 0.0179 (low flow, Re=220,000). In the Moody diagram, these values fall between the curves for relative roughness 0.0001 and 0.0004. The curve in between is for relative roughness 0.0002, and its corresponding wall surface roughness is 0.045mm.

Hazen-Williams ≈143

Roughness coefficient from the Hazen-Williams equation
The roughness coefficient is in the range between 138 and 146, with an average value of 143.

Manning ≈0.0087

Roughness coefficient from the Manning equation
The roughness coefficient is between 0.0080 (high flow) and 0.0094 (low flow), with an average value of 0.0087.
Based on generally established (published) values of these parameters for different pipe types, Rib Loc Expanda Pipe has similar degrees of roughness as several pipe types (from commercial steel and wrought iron to smooth PVC).

COMMENTS

The testing has determined in a satisfactory way hydraulic roughness parameters for calculation of frictional loss in the equations mostly used in professional practice today.

In the Moody diagram, plotted friction factor values do not clearly identify one relative roughness curve. The accuracy of calibration, which depends on the flow rate and the performance of measuring devices and has not been considered in the report, is believed responsible for the range of results.

T7. Test for Evaluating Fluid Migration in the Rib Space of Rib Loc Expanda Pipe (2001)

- Flow properties of annular space

PROPERTY TESTED

All close-fit pipe liners create an annular space between the liner and the host pipe, and because of it, it is possible for fluid to flow between the liner and the host pipe. Entry/exit points for such flow may be cracks, joints or other defects in the host pipe; the holes cut in the pipe liner for reconnection at laterals; and the ends of the liner where the pipe terminates in a manhole or similar structure. If the lateral connections and the liner termination at manholes are properly sealed, then the existence of annular space will not result in infiltration or exfiltration. However, if either location is either not sealed or is improperly sealed, infiltration or exfiltration can occur. In this case, the volume of flow will be controlled by the pressure head causing the flow and the flow properties of the annular space.

The objective of this test is to evaluate the flow properties of annular space for the Rib Loc Expanda Pipe, i.e. the ease at which the fluid migrates through it under given pressure head. For this purpose, the reduction in flow rate over the pipe length with the annular space flow is determined. With respect to this index, the test compares Rib Loc Expanda Pipe with CIP liners and deform/reform liners previously tested in the Baton Rouge tests (Bakeer and Guice, 1997).

1 liner wound in a VCP pipe assembled above the ground for the purpose of testing

SCOPE

The test evaluates one Rib Loc Expanda Pipe spirally wound in a VCP pipe assembled above the ground for the purpose of this testing with the following dimensions:

OD	Length	Profile
8 in (203mm)	27 ft (8.23 m)	85-7 PVC

Testing procedure by the Louisiana Tech and the Tulane University

TEST DESIGN

The Louisiana Tech University and the Tulane University developed a test procedure for evaluation of fluid migration in the annular space of lined piping systems (Bakeer and Guice, 1997). That research was sponsored by the City of Baton Rouge, LA, and the tests in the study are referred to as the Baton Rouge tests. The design of Rib Loc liner testing closely follows the design of the Baton Rouge tests.

Australia, 2001

TIME AND LOCATION

The testing was conducted on 11/19/01 in Adelaide, South Australia (in the storage yard in front of Rib Loc workshop).

Rib Loc Australia Pty Ltd	**COMPANY REQUESTING AND CONDUCTING TESTING** This was in-house testing under surveillance of an independent testing laboratory.
Amdel	**TEST WITNESSING** All flow measurements were controlled and double-checked by an official independent witness from the Material Services of Amdel[18]. This division of Amdel provides a wide range of materials testing, analysis and consulting services for the construction and manufacturing industries and related areas.
	SIGNATURE ON REPORT COPY OR TRANSMITTAL The submitted report does not reference the author.
	TEST PROCEDURE The test setup was constructed replicating the Baton Rouge tests. However, because of the shorter length of the water supply line, for which a 5/8-in (16 mm) PVC pipe was used, a PVC-reducer was installed into the supply pipe and adjusted to make the initial flow rates comparable to those in Baton Rouge tests. Two external water pressure conditions were tested: 1. Water pressure head of 5-ft (1.52 m) 2. Water pressure head of 10-ft (3.05 m) One test was carried out for each water pressure condition in the same manner as the one-day Baton Rouge tests (1-D), i.e. each test took a total of 45 min, with conditions changing in 15 min intervals: Condition I - both laterals opened; Condition II - upstream lateral plugged; Condition III - downstream lateral plugged. In each test, the flow rate was measured at the end of water supply line before connecting with the pipe's annular space ("initial flow"), and after each 15 min period was completed. Flow rates measured at laterals were compared with initial flows and percentage of reduction calculated.
	RESULTS For the Rib Loc Expanda Pipe, Condition I and III are the same, i.e. all the flow goes through the upstream lateral if it is unplugged regardless of the downstream lateral. Flow rates measured for Rib Loc and the corresponding average[19] values for other liners from the Baton Rouge tests are as follows:

[18] Amdel is already referenced in test T1.

[19] Baton Rouge tests involved two Def/Ref liners and two CIP liners. Each liner was tested on three pipes. Values shown in the table are average values calculated for each liner.

	FLOW RATE (gpm)					
CONDITION:	FLOW CALIBRATION[20]		CONDITION III		CONDITION II	
PIPE LENGTH:	0 ft		3 ¾ ft (114 cm)		13 ½ ft (411cm)	
PRESSURE HEAD:	5 ft	10 ft	5 ft	10 ft	5 ft	10 ft
Rib Loc	5.8	8.4	3.1	4.6	0.6	1.3
Def/Ref 1	5.3	7.5	2.8	4.2	1.4	2.1
Def/Ref 2	5.9	7.9	4.4	6.1	3.6	5.5
CIP 1	5.6	7.9	-	0.4	-	0.1
CIP 2	5.6	7.6	-	0.8	-	0.7

Reduction in flow rate achieved with Rib Loc liner is comparable or better than that achieved with deform-reformed liners and inferior to that achieved with CIP liners:

	REDUCTION IN FLOW RATE[21]					
CONDITION:	FLOW CALIBRATION		CONDITION III		CONDITION II	
PIPE LENGTH:	0 ft		3 ¾ ft (114 cm)		13 ½ ft (411cm)	
PRESSURE HEAD:	5 ft	10 ft	5 ft	10 ft	5 ft	10 ft
Rib Loc	-	-	46 %	45 %	90 %	84 %
Def/Ref 1	-	-	46 %	43 %	75 %	70 %
Def/Ref 2	-	-	24 %	23 %	39 %	30 %
CIP 1	-	-	-	95 %	-	99 %
CIP 2	-	-	-	89 %	-	91 %

COMMENTS

Basing obtained flow reductions on more than one test result would be desirable. The Baton Rouge tests tested three pipes for each liner under given test conditions.

It is correctly asserted that the Rib Loc liner fares better in terms of flow reduction with increased pipe length than deform/reform liners because the flow follows spiral path as opposed to going directly along the pipe (the spiral path in the test was 7.6 times longer than the straight path). It could also be added that not necessarily the entire annular space participates in flow. The ribs of Rib Loc profile used in the test divide the annular space into five separate areas and, with the liner rather tightly fitting the host pipe, the fluid flows only between two or three adjacent ribs (upstream lateral plugged) unless the flow enters the annular space at higher speed and manages to spread into all areas (upstream lateral opened).

CIP liners fare better than Rib Loc because they create a tight annular space and hence a significant resistance to water flow when trying to migrate into and through that space.

[20] Before connecting the water supply line to the annular space
[21] Reduction in flow rate is the difference between the flow rate at the lateral and the calibrated flow rate, divided by the calibrated flow

It should be noted, however, that each type of liner does allow leakage when laterals and liner terminations are not sealed and hence sealing of these junctions is recommended for all liner types in order to create a liner system with minimal infiltration or exfiltration.

T8. Report on Long Term Modulus of Rib Loc Expanda Profiles Based on Creep Test (1999)

Long-Term Modulus of Elasticity

PROPERTY TESTED

Rib Loc Expanda Pipe is made of flexible PVC material and its performance in relation to structural design of the pipe cross-section is generally limited by vertical deflection and buckling resistance. This test focuses on vertical deflection. Because PVC creeps, its stiffness and modulus of elasticity with respect to initial conditions appears to change when the pipe is exposed to a constant load over time (note, however, that its short-term modulus of elasticity with respect to short-term changes in loading remains the same). The objective of this test is to evaluate the modulus reduction factor that should be applied in 50-year liner design.

Three liners samples

SCOPE

The testing is performed on three Rib Loc Expanda Pipe liner samples:

ID	Length	Profile
$4^{3}/_{4}$-inch (120mm)	$11^{3}/_{4}$-inch (300mm)	56EX3

ISO 9967:1994

TEST DESIGN

ISO 9967 specifies the apparatus to be used for creep ratio tests on thermoplastic pipes, dimensions and conditioning of pipe samples, procedure of applying load and measuring deflection, and calculation of creep ratio. The design of this test follows the standard completely.

Australia, 1998

TIME AND LOCATION

The test was conducted in 1998 in Adelaide, South Australia (in the laboratory of Amdel Limited).

REQUEST FOR TESTING
Rib Loc Australia Pty Ltd

Amdel Limited

COMPANY CONDUCTING TESTING

Amdel Limited[22] conducted the testing.

[22] Amdel Limited is already referenced in test T1.

TEST WITNESSING

This was a long-term test performed by an independent testing laboratory and no additional witnesses were involved.

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Jeremy V. Pickering (Amdel Limited)

TEST PROCEDURE

The test was conducted in accordance with referenced ISO standard. The conditioning of pipe samples took 48 hours (2 days), application of both preloading force and the gradual increase to targeted load took 6 minutes. Pipe deflection was measured over next 2,016 hours (84 days) in exact times specified by the standard.

RESULTS

2-year creep ratio is 2.2

Two-year creep ratio
Extrapolating measured deflections to two-year deflections, the two-year creep ratio was calculated for each of three samples as in the referenced standard. Averaging these values, the two-year creep ratio of the tested pipe is determined to be 2.2.

50-year creep ratio is 2.7

50-year creep ratio
Using the same method of calculation, the 50-year creep ratio of the tested pipe is determined to be 2.7.

50-year modulus is 148,148

50-year modulus of elasticity
After 50 years, modulus of elasticity for cell classification 13354 (initially 400,000 psi) is 148,148 psi. This is 27% higher than the value used in the static design of the liner, which is 116,000 psi.

COMMENTS

Due to creep, the long-term modulus of elasticity of Rib Loc Expanda Pipe decreases with time as expected. This does not mean, however, that the short-term elastic modulus after years of service is similarly affected. The apparent long-term modulus of elasticity is important in the design of plastic pipe liners against buckling.

Extrapolation of the 1,000 hours creep data to 50 years (438,000 hours) goes beyond what is desirable. Generally, extrapolation of creep data should be limited to 10 times the duration of the creep test. However, this approach is a practical extension of the test data obtained on the product.

The value for the 50-year modulus extrapolated from the test results is 27% higher than that used in liner design, and hence the recommended design value is conservative relative to the ISO standard procedure for its calculation.

T9. Report on K Factor (Enhancement Factor) for Rib Loc Expanda Pipe (2001)

- K factor (Enhancement factor)

PROPERTY TESTED

This test focuses on resistance to pressure buckling of Rib Loc Expanda Pipe and its K factor (Enhancement factor[23]), which is the multiplier for the buckling pressure of a tight fitting liner over a free liner. The objective of this test is to determine a suitable K factor of Rib Loc Expanda Pipe for use in the design equations provided for pipe liners (e.g. ASTM F 1216) and thus ensure that the liner will be adequately designed to resist external fluid pressure buckling.

1 liner wound and tested in laboratory conditions

SCOPE

The testing is performed on one Rib Loc Expanda Pipe liner wound into a $17^{3}/_{4}$ in (450 mm) steel host pipe

ID	Length	Profile
$17^{3}/_{4}$ in (433 mm)	10 ft (3 m)	85-8PVCX7

TEST DESIGN

The report does not reference any standard with which the test is in accordance. However, the test design is similar to the short-term liner buckling tests carried out by the Trenchless Technology Center and others.

Unknown location, 2002

TIME AND LOCATION

The test was conducted on 12/07/02. The location is not referenced.

Rib Loc Australia Pty Ltd

COMPANY REQUESTING AND CONDUCTING TESTING

This was in-house testing under surveillance of an independent testing laboratory.

DLI Safety Services Pty Ltd

TEST WITNESSING

The testing was independently witnessed by DLI Safety Services Pty Ltd. DLI Safety Services Pty Ltd provide independent non-destructive testing of pressure vessels.

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The submitted report does not reference the author.

TEST PROCEDURE

The report does not provide details such as end sealing arrangements, annular space measurements, etc. It is only said that the steel pipe with

[23] The buckling pressure of a liner installed tightly within a host pipe is significantly larger than the buckling pressure of the same liner exposed to external fluid pressure without any host pipe support.

	installed liner is sealed and the pressure applied to the annular space is increased with time. The liner is observed for signs of bulging and final buckling.
K factor = 4.07	**RESULTS** Major bulging was observed at a pressure of 100 kPa at 4 o'clock and 8 o'clock positions in the cross section. Final buckling occurred at 105 kPa. The theoretical pressure capacity for an unrestrained liner calculated from the liner material properties is 24.55 kPa. Thus, the inferred K factor is 4.07.
Well Designed to Resist Fluid Pressure Buckling	**COMMENTS** The formula used to compute the buckling pressure of an unsupported pipe (or liner) is based on the neutral axis diameter of the liner, not the outer diameter of the liner. Moment of inertia for tested profile (85-8PVCX7) used in this formula is assumed to be correctly determined, but the source of its value is not included in the report. The collapse pressure of the liner is given as 105 kPa. A reasonable approach would be to base K on the collapse pressure, rather than the pressure at which a bulge was noticed (depending on the size of the bulge). If the actual collapse pressure is used (along with the neutral axis diameter), then K would increase to 4.28. Basing K on more than one test result would be desirable. When doing testing of a material, it is customary to test multiple samples. For example, when determining the flexural modulus of a polymeric material, the ASTM standards state that five specimens should be used. Overall, the Rib-Loc calculation of the enhancement factor K of 4.0 based on their test result is appropriate. This value is consistent with other liner bucking studies and the test confirms that the design procedures developed for avoiding liner buckling failure can be used for the Rib Loc liner with an appropriate value assumed for K.

T10. Installation of Rib Loc Expanda Liner in 7.5% Deflected Host Pipe (?)

▪ Closeness of fitting under deflection	**PROPERTY TESTED** Deflection of any buried pipe must be limited to a value that does not disrupt flow, cause joint leakage or creates excessive bending stress in the pipe, and typically the limit is 5% of pipe diameter maximum. Objective of this testing is to demonstrate that Rib Loc Expanda Pipe will remain a close-fit liner even if its host pipe undergoes deflection of 7.5% of its diameter after the liner installation.

1 liner wound and tested in laboratory conditions	**SCOPE** The testing is performed on one Rib Loc Expanda Pipe liner wound into an 8 in (450 mm) PVC pipe:

OD	Length	Profile
8 in (450 mm)	5-ft (152 cm)	85-7PVCX

	TEST DESIGN This testing does not follow any specified standard procedure.
Unknown	**TIME AND LOCATION** The submitted report does not reference the time and location of testing.
Rib Loc Australia Pty Ltd	**COMPANY REQUESTING AND CONDUCTING TESTING** This was in-house testing.
	TEST WITNESSING There were no independent witnesses to the testing.
	SIGNATURE ON REPORT COPY OR TRANSMITTAL The submitted report does not reference the author.
	TEST PROCEDURE The host pipe with installed liner was clamped at the crown and invert for a length of approximately 20-in (0.5 m). The pipe was deflected in the middle of clamped section by 7.5% of diameter, which is approximately $^{5}/_{8}$-in (15 mm). Windows were cut in the host pipe to allow visual inspection of the closeness of fitting.
Visible close-fit	**RESULTS** The report does not reference any measurements and only provides photographs that testify to the close fitting between the liner and the host pipe.
	COMMENTS It is expected but not confirmed that the windows were cut in the tight radius portion of the cross-section rather than the larger radius portion. Any lack of tightness would show up more in the tight radius portion than in the large radius portion of the cross-section.

REFERENCES

Standards

	AMERICAN SOCIETY FOR TESTING AND MATERIALS
ASTM D 412-98a	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers-Tension
ASTM D 638-02a	Standard Test Method for Tensile Properties of Plastics
ASTM D1784-02	Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds
ASTM D2240-02 b	Standard Test Method for Rubber Property—Durometer Hardness
ASTM F1216-98	F1216-98 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube
ASTM F1697-96	Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Strip for Machine Spiral-Wound Liner Pipe Rehabilitation of Existing Sewers and Conduits
	EUROPEAN STANDARDS
EN 1610: 1997	Construction and Testing of Drains and Sewers
	GERMAN STANDARDS
DIN/EN/ISO 9001:1994	Quality Management Systems - Requirements
DIN/ISO/IEC 17025	General Requirements for the Competence of Calibration and Testing Laboratories
	AUSTRALIAN STANDARDS
AS 2032:1997	Installation of uPVC Pipe Systems
	INTERNATIONAL ORGANIZATION FOR STANDARDS
ISO 9967:1994	Thermoplastics Pipes -- Determination of Creep Ratio
	AMERICAN PUBLIC WORKS ASSOCIATION SOUTHERN CALIFORNIAN CHAPTER
Greenbook SSPWC 210-2.3, 1994	Paint and Protective Coatings. Plastic Liner. Tests
Greenbook SSPWC 210-2.5, 2000	Paint and Protective Coatings. Rigid PVC Liners
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