SEMI RIGID PIPES - RESEARCH & DESIGN

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Abstract

FRC Pipe satisfying the requirements of AS 4139, 1993 is installed as a rigid pipe according to the design principles of AS 3725 “Loads on buried concrete pipes”. It has been observed that the FRC Pipe in a buried installation is able to sustain loads substantially in excess of the design code requirement. James Hardie R&D team were asked to investigate this and undertook a detailed investigation and experimental programme of soil box testing. The 1993 AS 4139 Standard required FRC pipe to have sufficient strength to resist failure after 50 years of sustained three edge bearing loading equivalent to 1.5 times the design cracking load of an equivalent class of steel reinforced concrete pipe. The proposed revisions to the Standard recognises that the FRC pipe may exhibit flexible properties and that in-ground deflections are significantly lower than those exhibited by the pipe in the unrestrained condition.

Key Words: semi-rigid pipe, rigid pipe, creep, soil boxes, soil support, FRC pipe, AS 4139, ring bending, deflection

Introduction

This paper discusses the principles applied in the proposed revisions of AS 4139 - Fibre Reinforced Concrete Pipes and Fittings to permit the classification of semi-rigid pipes. The proposed revisions still require the pipe to be designed into a pipe installation as a rigid pipe using the design principles of AS 3725 – Loads on Buried Concrete Pipes.

When a semi-rigid pipe is designed into a pipeline installation using rigid pipe design principles the factor of safety of the pipe may be far higher than that predicted by the rigid installation design of Marston[7] which is embodied in AS 3725.

The Concept of a Semi-Rigid Pipe

A rigid pipe is assumed to gain increased load bearing capacity from the soil pressure around the pipe but it is incapable of having sufficient deflection to gain added passive support from the surrounding soil thus it must have sufficient ring bending strength to support the full soil prism load if it is to maintain its integrity for its full service life. Semi-rigid pipe must have sufficient ring bending strength to initially support the full soil prism load, and also have sufficient capability to deflect as its stiffness reduces with time and it needs to obtain additional support from the surrounding soil to maintain its integrity for its full service life. A flexible pipe has insufficient ring bending strength to support the full soil prism load and relies totally on support from the surrounding soil to maintain its integrity for its full service life.

Semi—rigid pipes are acknowledged in the South African Bureau of Standards document SABS 0102:PartI-1987 Code of Practice for the Selection of Pipes for Buried Pipelines. This code defines the semi-rigid pipe according to the pipe – soil interaction rather than an arbitrary deflection capability. The code defines a flexural stiffness ratio (Y) of the pipe – soil system for semi-rigid pipes as lying between 10 and 10^3 where:

$$S = \frac{E_e I}{B_c^3}$$

$$Y = \frac{E_s}{S}$$

Where : E_e = plane strain elastic modulus of the pipe material, MPa

E_s = plane strain elastic modulus of the soil, MPa

I = moment of inertia per unit length of the pipe wall, m^4

B_c = outside diameter of the pipe, m

Semi-rigid pipes are also acknowledged in the British Standard document EN 1295-1: 1998 "Structural Design of Buried Pipelines Under Various Conditions of Loading". This document does not give a criteria for the classification of semi-rigid pipes but accepts ductile iron pipes as semi-rigid when the installation is designed according to the standard, and accepts asbestos cement pipes as semi-rigid when the installation is designed according to ISO 2785 "Directives for the Selection of Asbestos Cement Pipes Subject to External Loads With or Without Internal Pressure". EN 1295-1 provides a design procedure for the pipeline installation which is in essence the Spangler[11] modified Iowa equations used in AS/NZS 2566.1:1998 Buried Flexible Pipelines Part1: Structural Design.

The German Association for Water Pollution Control (ATV) Standard A 127 Standard for the Static Calculation of Drainage Sewers and Pipelines provides an installation design procedure which is far more complex than the Spangler modified Iowa equations and permits the specifier to design pipes such as asbestos cement and ductile iron as either rigid pipes or as flexible pipes and make his final choice according to the design outcome.

In the USA AWWA Manual M9 Concrete Pressure Pipe embraces the concept of semi-rigid pipe in relation to steel cylinder concrete pressure pipe manufactured in accordance with AWWA C303. This pipe is considered semi-rigid in larger diameters because it develops its ability to support external loads both from its inherent strength and from the support of the surrounding soil as it deflects. This manual uses the Spangler modified Iowa equations to predict and limit the deflection of the pipes.

The Creep Characteristics of Semi-rigid Pipe

All concrete based material are subject to creep when loaded to high levels of stress. Neville[7] states that dry concrete should not be stressed to more than 70% of its ultimate stress if failure due to creep is to be avoided, and a lower stress level will apply for saturated concrete.

The proposed revisions of AS 4139 require that a rigid pipe must be able to withstand a sustained saturated load in ring bending for 50 years of 1.5 times Tc. In the case of semi-rigid pipe the revisions take into account the soil support of the pipe and the creep characteristics of the pipe are accounted by means of determining the reduction in stiffness with age of the pipe and determining the long term installed deflection of the pipe.

The reduction in stiffness of the pipe is determined by means of stress relaxation testing where the pipe is held at a constant deflection in a saturated condition and the reduction in the reaction force of the pipe is measured with time. This reduction in force with time enables the long term stiffness of the pipe to be determined at a future time period of 2 years. Extensive research of installed pipelines by De Putter and Elzink (1981)[2], Janson (1981)[3], Molin (1981)[8], Bishop (1981)[1], Joekes and Elzink (1985)[5], Joseph (1985)[6], Molin (1985)[9] and Janson (1990)[4] shows that the deflection of installed flexible pipelines and the surrounding soil stabilises within 2 years of installation.

The Factors of Safety of Semi-rigid Pipe

The proposed revisions of AS 4139 require the semi rigid pipe to be designed into an installation as a rigid pipe using the provisions of AS 3725. These revisions take the creep characteristics of the pipe material into account by determining the long term stiffness of the pipe and its long term deflection in the ground. The proposed revisions also require a fully saturated semi-rigid pipe to have an in-ground long term deflection no greater than 50% of its deflection at the point of maximum load capacity in ring bending.

By means of a calculated example based on experimental data the factors of safety of a semi-rigid pipe installation will now be demonstrated. In this example a specific pipe is chosen as an FRC pipe at 375 mm diameter Class 2. The pipe is designed to have a dry test load capability of 2 times Tc rather than the required 3 times Tc under the existing AS 4139 which requires the pipe to be able to sustain a load in saturated ring bending for 50 years to take into account the creep characteristics of the pipe material.

The pipe is to be designed into an embankment condition at the maximum burial depth permitted by AS 3725 for an H2 installation.

The backfilling of the trench is to be to the minimum requirements of AUSPEC Development Construction Specification C220 Storm Water Drainage which specifies fine grained soil to be compacted to at least 95% dry density ratio or 70% density index. AS 2566.1 Table 3.2 gives a soil modulus of 3 MPa for this soil and compaction.

The material properties, principal dimensions and mechanical properties of the pipe are given in the following tables:

90% LCL Saturated Strain at Maximum Load		1.05%
90% LCL Initial Modulus of Elasticity	MPa	10,018
90% LCL Long Term Modulus of Elasticity	MPa	5,009
95% LCL Dry Ultimate Stress	MPa	28.8

Table 1. FRC pipe Material Properties

Inside Diameter (d_i)	mm	379
Wall Thickness (t)	mm	21
Outside Diameter (d_o)	mm	421
Moment Inertia (I)	mm^4	792
Initial Stiffness (S_{DI})	N/m/m	123,957
Long Term Stiffness (S_{DL2})	N/m/m	61,979
Tc	kN/m	17
Minimum Dry Load Capacity	kN/m	34
Minimum Saturated Load Capacity	kN/m	25.5

Table 2. FRC Pipe Mechanical Properties

The pipe stiffness is given by :

$$S = \frac{E\,I \times 10^6}{(d_i + t)^3}$$

$$I = \frac{t^3}{12}$$

Where :

S = pipe stiffness, N/m/m

E = material modulus of elasticity, MPa

I = pipe wall moment of inertia, mm^4

d_i = internal diameter, mm

t = wall thickness, mm

The soil pressure over the pipe at maximum burial depth in the chosen installation is given by AS 3725 as :

$$w_g = \frac{T_c\,F_b \times 10^3}{C_e^{/}\,d_o}$$

Where :

w_g = soil dead load on pipe, kPa

T_c = long term design load, kN/m

F_b = pipe bedding factor (maximum value 2 for H2 installation)

$C_e^{/}$ = Spangler coefficient (maximum value 1.68 for $H/d_o > 8$)

d_o = pipe external diameter, mm

H = pipe burial depth, m

The solution of this equation yields a maximum soil pressure over the pipe of 48.1 kPa.

The predicted deflection of the saturated pipe at installation is given by the Spangler modified Iowa equation from AS 2566 which appears in the proposed revision of AS 4139 as :

$$\frac{\Delta y}{d_i + t} = \frac{K \times 10^{-3}\,w_g}{8 \times 10^{-6}\,S + 0.061\,E^{/}}$$

Where :

$\frac{\Delta y}{d_i + t}$ = pipe diametral deflection ratio

K = bedding factor (typically 0.1)

S = pipe stiffness, N/m/m

$E^{/}$ = effective combined soil modulus, MPa

These deflection ratios may now be used to calculate the maximum strain in the pipe wall. The maximum strain is given by :

$$\varepsilon = \frac{dy \times 4.279\, t}{(d_i + t)^2}$$

Where :

ε = maximum strain in the pipe wall and other units are as previously defined

The solution of these equations using the data listed above gives :

	Deflection Ratio	Material Strain	Strain Capability	Factor of Safety
Initial Installation	0.41%	0.093%	1.05%	11.3
Long Term	0.71%	0.160%	1.05%	6.5

Table 3. Pipe Deflections & Factor of Safety

In the above example the pipe has a load factor of safety of 1.5 where it is designed into the installation as a rigid pipe.

When the soil support is taken into account the long term factor of safety rises to 6.5 which is over 4 times that predicted by rigid pipe theory.

Confirmation Soil Box Testing

Over the past two years the R&D Team at James Hardie has carried out an extensive programme of soil box testing in order to confirm that the theory and assumptions concerning semi-rigid pipes are correct.

A novel flexible soil box was designed which has spring loaded sides and permits a range of installation conditions to be simulated by adjusting the spring rate at the box sides and the modulus of the soil used to bury the pipes.

Fig 1. James Hardie Flexible Soil Box

The following describes two series of tests carried out using a low modulus soil and a high modulus soil on saturated FRC pipes to the design listed above and dry steel reinforced concrete pipes (SRC) manufactured to AS 4058.

The Series A tests used single 8mm springs at the box sides and the sand selected for the soil box was very fine grained and of a soil group of mixed cohesive soils. From previous work this sand is known to have a very low modulus and give very poor support to the pipes.

The Series B tests used double 8mm springs at the box sides and the sand selected for the soil box was coarse grained and of a soil group of non cohesive soils which meet the specification of Select Fill in Table 3 of AS 3725.

During the tests the loads, pipe deflections, soil box side deflections and test machine crosshead displacements were all monitored. This data was used to calculate the forces within the soil box and to estimate the effective modulus of the soil within the soil box.

The soil below the pipe and in the haunch zone of the pipe was compacted by means of tamping with a block of timber. The estimated modulus of the soil due to its compaction is less than 5MPa. The soil at the sides of the pipe and above the pipe was simply tipped into the soil box and was not compacted by means of tamping. When the box was filled the sand was pressed down by hand at a pressure estimated to be in the order of 5kPa.

During the testing of the pipe the soil modulus is not constant, it increases as the test load increases and compacts the soil.

Failure of the saturated FRC pipe was deemed to occur when the inner surface of the pipe showed the first sign of any disruption. Failure of the SRC pipe was deemed to occur when the pipe cracked and the crack width was estimated at 0.25 mm.

A typical load – deflection trace for FRC pipe is given in Appendix A Figure A1. A typical load – deflection trace for SRC pipe is given in Appendix A Figure A2. An estimate of the soil modulus at the side of the pipe for the Series B tests is given in Appendix a Figure A3.

The test results for Series A which had low modulus soil in a box with weak springs are given in Table 4. The test results for Series B which had a higher modulus soil and stiffer springs are given in Table 5.

Pipe Type	Spring (mm)	Sand	Crack Load (kN)	Pipe Deflection at Crack Load (mm)	Spring Deflection at Crack Load (mm)
FRC	8	Fine	51.0	19.64	3.23
FRC	8	Fine	49.0	18.00	3.17
FRC	8	Fine	36.0	14.65	1.63
FRC	8	Fine	38.8	23.75	2.30
FRC	8	Fine	37.0	13.68	1.80
FRC	8	Fine	41.0	11.98	1.98
Average			42.1	17.0	2.4
SRC	8	Fine	14.0	1.57	0.42
SRC	8	Fine	15.5	1.24	0.56
SRC	8	Fine	17.0	1.94	0.60
SRC	8	Fine	12.0	1.07	0.50
SRC	8	Fine	13.0	1.89	0.31
SRC	8	Fine	11.5	1.00	0.34
Average			13.8	1.5	0.5
Ratio FRC - SRC			3.0	11.7	5.2

Table 4. Series A Test Results

Pipe Type	Spring (mm)	Sand	Crack Load (kN)	Pipe Deflection at Crack Load (mm)	Spring Deflection at Crack Load (mm)
FRC	2x8	Coarse	76.0	13.34	2.52
FRC	2x8	Coarse	67.0	12.32	2.23
FRC	2x8	Coarse	66.0	11.30	2.55
FRC	2x8	Coarse	71.0	14.58	2.30
Average			70.0	12.9	2.4
SRC	2x8	Coarse	17.0	1.92	0.57
SRC	2x8	Coarse	17.0	0.30	0.18
SRC	2x8	Coarse	21.0	2.82	0.37
SRC	2x8	Coarse	13.0	1.33	0.33
Average			17.0	1.6	0.4
Ratio FRC - SRC			4.1	8.1	6.7

Table 5. Series B Test Results

The soil modulus of the Series A tests was estimated to be 0.2 MPa rising to a maximum of 0.4 MPa. For the series B tests the modulus was estimated to be 0.5 MPa rising to a maximum of 4 MPa.

These test results clearly show that the effect of soil support in increasing the load capacity of the semi rigid pipe. Assuming the FRC pipe and the SRC pipe both exceeded their minimum strengths by the same proportion, the expected result if the soil did not provide support to the pipes is that the FRC pipes should have tested 1.5 times higher than the SRC pipes

Conclusion

The experimental work has been used to verify the proposed amendments to AS 4139 and full details have been provided to the WS 008 committee.

In the case of the low modulus soil with minimal support the FRC pipes tested at 2 times expectation if the soil did not add support, and in the case of the higher modulus soil the FRC pipes tested at 2.6 times expectation.

The experimental work and theoretical analysis of the installed pipe shows that any pipe with deflection capability cannot possibly collapse due to creep failure of the pipe that occurs in unsupported ring bending.

In a pipe line installation the results are expected to be far higher due to the fact that the soil is compacted to its full modulus at installation and this compaction process is expected to deflect the pipes such that the final deflection after the addition of overburden will be less than the AS 2566 prediction.

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Appendix A

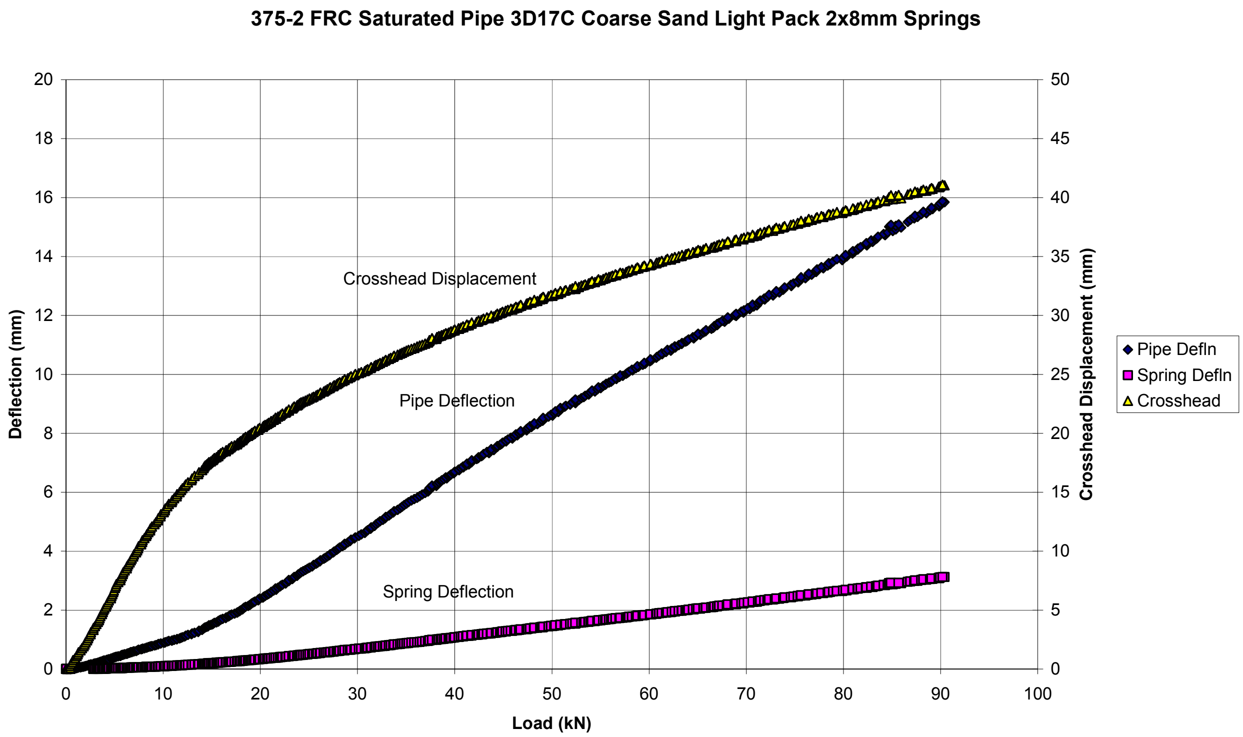

Fig A1. Typical load deflection trace for FRC pipe

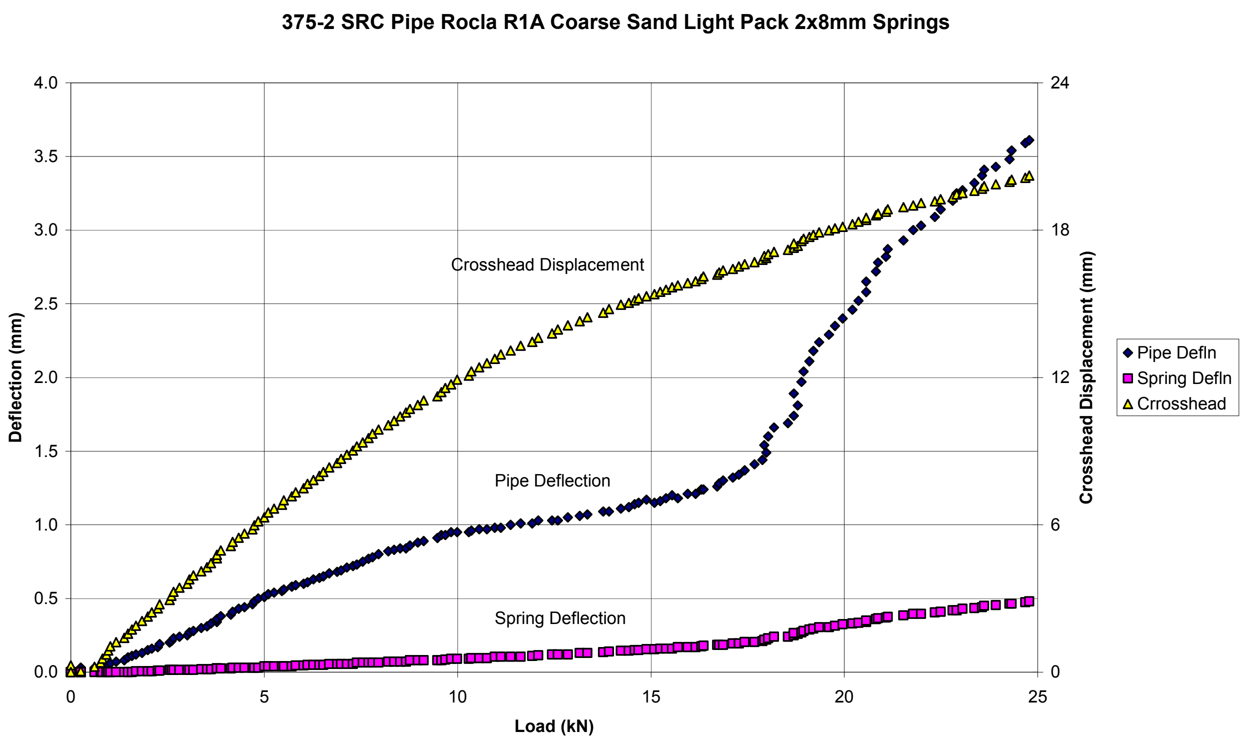

Fig A2. Typical load – deflection trace for SRC pipe

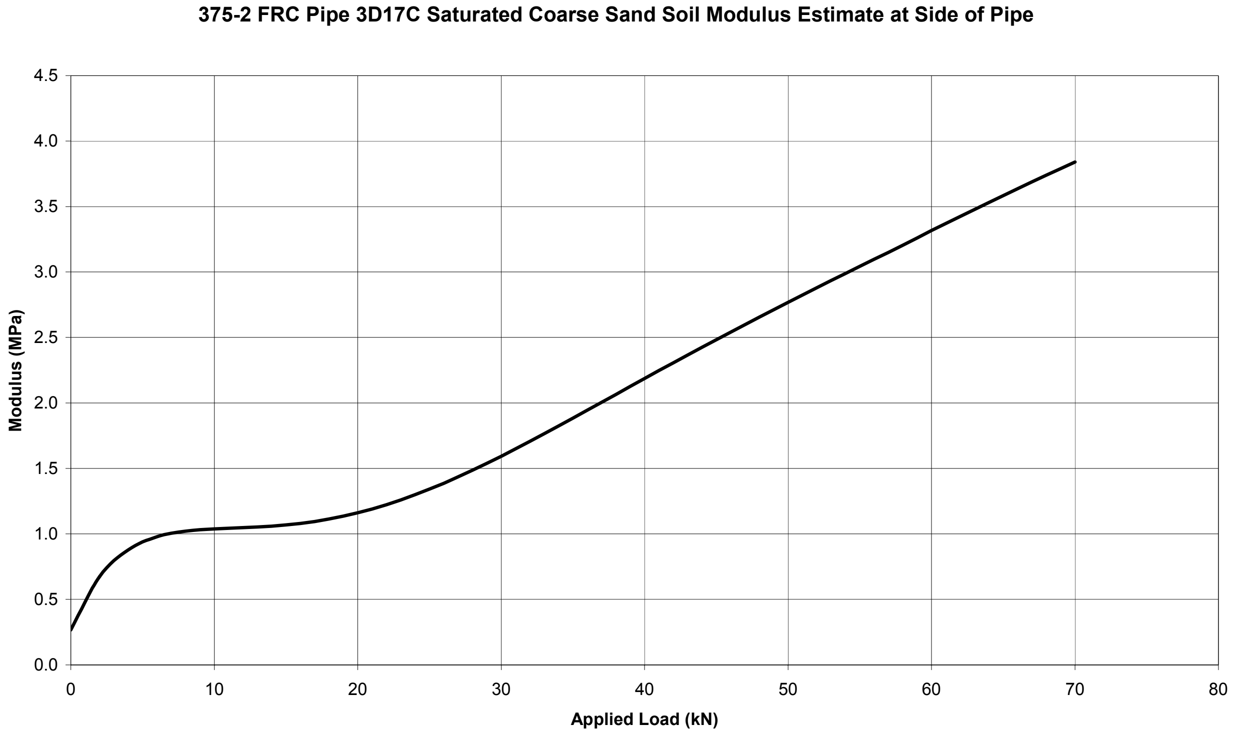

Fig A3. Estimated soil modulus at side of pipe

Author Biography

Peter Sutherland commenced his engineering career in 1969, initially working in local government on road and drainage construction. In 1972 he spent a year working in England on a series of bridges. Returning to Australia in 1974 he has worked in several technical sales and marketing positions allied to both the bridge and drainage industries.

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