CONTINUOUS FILAMENT WOUND GRP PIPE FOR USE IN JACKING APPLICATIONS

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ABSTRACT

The use of trenchless applications continues to increase with a range of technologies available for the installation of new or refurbished pipelines. At the larger end of the diameter scale pipe jacking can be used for the installation of pipelines as an alternative to trenching.

A number of materials are available for use in jacking applications including traditional rigid pipes, such as clay and concrete, as well as glass reinforced polyester (GRP) pipes. Continuous filament wound (CFW) GRP pipes provide a number of benefits over the heavier rigid alternatives.

ISO 25780 is the international standard for glass reinforced thermosetting plastic pipes intended to be installed using jacking techniques. The standard addresses the requirements for the manufacture of GRP jacking pipes as well as a methodology for calculating the allowable jacking loads for a pipe.

CFW GRP jacking pipe is currently being used in the largest GRP jacking pipe project to date in Australasia and includes the longest single drive. The evaluation process for this project included verification of material properties and large scale prototype testing to validate the design. This paper will review the performance of the GRP jacking as compared to the theoretical performance including verification testing of the pipes.

KEYWORDS

GRP jacking pipe, design, installation, trenchless, micro-tunneling

1 INTRODUCTION

Glass reinforced polyester (GRP) jacking pipe has been available for a number of years but produced by methods other than continuous filament winding (CFW). Before the advent of CFW GRP jacking pipe, GRP jacking pipes were limited in diameter and length by the available moulds. The introduction of CFW GRP pipe has meant a significant increase in the flexibility available to the customer in regards to pipe diameters and also significantly shorter production lead times.

CFW GRP jacking pipes have the benefit of being lighter and more compliant than rigid options enabling them to accommodate changes in direction and bends without the need to introduce compressible material between the pipes. Their high compressive strength allows for a reduced wall thickness compared with other pipe materials, maximizing cost savings and optimizing the ratio between price and performance.

This paper will review the requirements of ISO 25780 in regards to the manufacture of CFW GRP jacking pipes including short and long term testing. This paper will also explain the calculation method used for determining the allowable jacking force for a CFW GRP pipe.

2 DESIGN REQUIREMENTS

An ideal jacking pipe has high compressive strength but must also be compliant enough to cope with the eccentric loading expected when installing around a curve. CFW GRP pipes are suited to jacking pipe applications as they inherently have these properties. Rigid jacking pipes introduce compressible material, such as chip board, between successive pipes in order to create some compliance. These chip board packer rings remain in the pipe after installation until they rot and fall out. These packers are not needed with CFW GRP pipes.

A jacking pipe also needs a consistent outside diameter with a flush fitting joint. CFW GRP has the advantage over other GRP products in that the outside diameters of the pipes and couplings can be tailored to the project requirements. Moulded or cast GRP pipes are subject to differential shrinkage between the pipe and coupling during manufacture which results in the couplings being larger in diameter and can be damaged during installation.

3 MANUFACTURING PROCESS

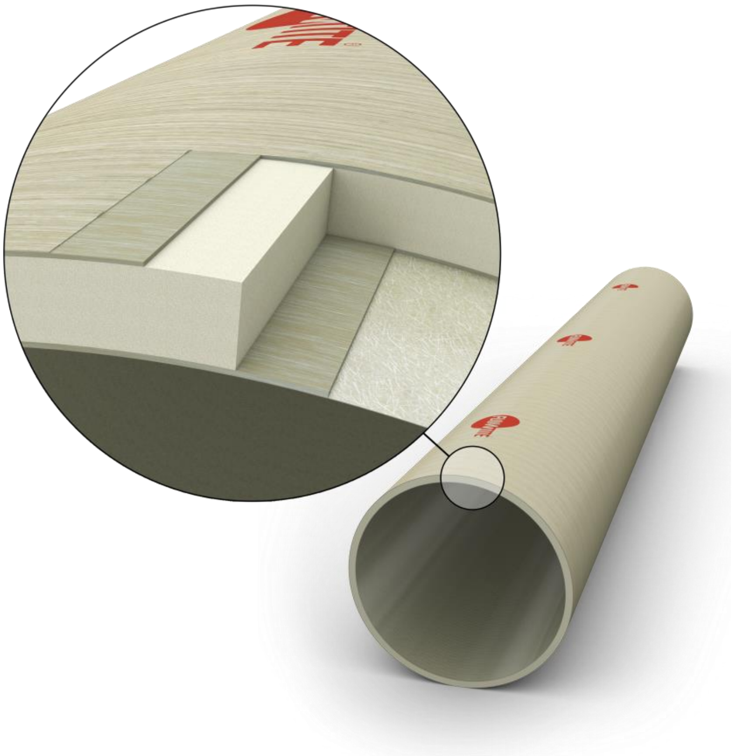
Continuous filament wound glass reinforced polyester (CFW GRP) pipes are manufactured using the continuous advancing mandrel process developed by Vera Fabrikker and Drostholm originally marketed under the Veroc brand and more recently as Flowtite®.

The process allows for the continuous and accurate placement of raw materials to optimise the laminate design and rate of production. A very dense laminate is created that maximises the contribution of the three basic raw materials, namely glass fibre, polyester resin and silica aggregate. Both continuous glass fibre rovings and chopped glass are incorporated for high hoop strength and compressive strength. The raw materials are placed on the continuously advancing mandrel to ensure optimum strength with minimum weight.

Once the materials have been applied the laminate is cured completely and cut to length as required in a continuous process. Once the pipes have been cut to length the pipe ends are machined to accept the flush mounted couplings.

Where required lubrication ports are fitted to allow the pumping of lubricant into the annular space during tunneling. These ports can later be used for the pumping of grout into the same annular space to complete the installation process.

Figure 1: Typical cross-section of CFW jacking pipe



Photograph 1: The manufacturing process

4 STANDARD REQUIREMENTS

A number of standards are used for jacking pipe but most do not address the specific requirements for GRP jacking pipe. ISO 25780 was published in 2011 for GRP jacking pipes and forms part of a suite of standards for GRP pipe including ISO 10467 and ISO 10639. The full titles of the standards appear below.

ISO 25780-2011 Plastics piping systems for pressure and non-pressure water supply, irrigation, drainage or sewerage – Glass-reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin – Pipes with flexible joints intended to be installed using jacking techniques

ISO 10467-2004 Plastics piping systems for pressure and non-pressure drainage and sewerage — Glass-reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin

ISO 10639-2004 Plastics piping systems for pressure and non-pressure water supply — Glass reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin

ISO 25780 provides guidance on the pipe properties including raw materials, pipe construction and joint design. The standard also provides the allowable tolerances for straightness of the pipe and squareness of the end faces which are critical for a pipe under high axial compressive load.

In regards to long term material properties, such as creep stiffness and resistance to strain corrosion, ISO 25780 references ISO 10467. ISO 25780 considers the results from testing of similar CFW GRP pipes which comply with ISO 10467 to be representative of those for the heavier walled jacking pipe as long as the pipes have a wall structure that gives equivalent or higher strain in areas of similar material composition.

Longitudinal compressive strength and initial longitudinal compressive modulus is addressed and will be covered later in this paper.

5 RAW MATERIALS

Continuous filament wound GRP jacking pipes are constructed using chopped and continuous glass fibres, polyester resin and a silica aggregate. Compatibility of the raw materials with each other is essential for the long term performance of the pipe. To ensure their compatibility and performance, raw materials used for all types of GRP pipes must be qualified using an accredited laboratory to show compliance with the standards.

The polyester resin in a GRP pipe serves the purpose of keeping the glass fibres and silica aggregate in the proper position to be able to withstand the applied loads. In addition, the resin distributes the load through the composite pipe wall and controls the chemical resistance properties of the pipe. The adhesive bond strength of the polyester resin to the glass fibres is very important (Peters et al., 1991) and very much influenced by the type and quality of the glass fibres and their coatings. Short and long term testing must be performed on all raw materials intended for the manufacture of GRP pipe.

6 QUALIFICATION TESTING

Qualification testing is used to determine the long term performance of GRP pipes. Qualification testing must be performed on pipe samples using the same materials, design, composition and manufacturing processes as will be sold to customers. Long term qualification testing consists of testing multiple samples at a variety of strain levels over a period of at least 10,000 hours (approximately 14 months). The results of the testing are analysed using the methods prescribed in the standards and extrapolated to 50 years. The value of 50 years is used for the purposes of statistics and does not mean the pipes only have a 50 year life. Extrapolating test results to 50 years and then applying the required factors of safety results in products which should perform for well over 100 years.

6.1 STRAIN CORROSION

For pipes subject to sanitary sewage there is the potential for the pipes to be exposed to sulphuric acid. This is generated from the hydrogen sulphide gas produced as bacteria decompose the sewage in anaerobic conditions. Plastics are inherently more robust than both concrete and metals in acidic conditions. However, standardised long term test methods have been adopted where a number of pipe samples are exposed to sulphuric acid over an extended time period while subjected to artificially high tensile strain.

Photograph 2: Strain corrosion testing

Over 30 years Flowtite® has tested samples collected from all the Flowtite® manufacturing facilities. Analysis of the data has shown an estimated lifespan of 150 plus years. (Jonsson, 2007)

6.2 LONG TERM STIFFNESS

The long term stiffness of a plastic pipe is a measure of the pipes ability to resist ongoing deflection under a constant load. This is also called the creep stiffness or creep factor. The long term stiffness is a measure of the pipes ability to resist vertical loads from back fill in combination with the soil embedment. For buried flexible pipes, the higher the pipe stiffness, the higher the allowable cover height.

Long term stiffness testing consists of applying a predetermined constant load to a pipe submerged in water and measuring deflection with time. The test must continue for at least 10,000 hours (approximately 14 months). The 50 year stiffness calculated from the 10,000 hour testing should be between 60% and 75% of the initial stiffness for a correctly manufactured continuous fibre wound GRP pipe. GRP pipes made without continuous fibres and only short chopped fibres, such as centrifugally cast pipes, can have values as low as 30% of the initial stiffness.

6.3 COMPRESSIVE STRENGTH

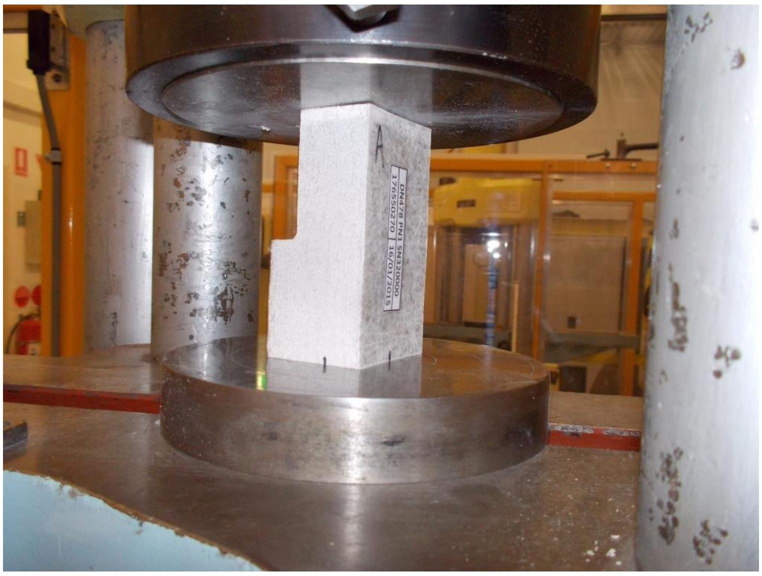
The compressive strength of the CFW GRP jacking pipe is determined through compressive testing of both representative pipe sections and test pieces cut from the pipe wall. In regards to the test pieces, ISO 25780 requires testing at both the pipe ends and in the middle of the pipe. An advantage of the continuous filament winding process is consistency along the entire pipe length as the pipe is made continuously. Moulded or cast pipes can have inconsistencies in the distribution of raw materials from spigot to barrel with a subsequent variation in mechanical properties which is not seen in CFW GRP pipes.

The process for determination of compressive properties of pipe samples is defined in Annex B of ISO 25780. An initial type test shall be conducted on pipe spools prepared with the same production method and tolerances, including rebated spigots and grooves, as used for production of the related pipes.

Photograph 3: Compression testing of pipe spool

Prism test pieces taken from a similar pipe are also tested and used to determine both the compressive strength at break and the intial longitudinal compressive modulus. This is described in detail in Annex A of ISO 25780.

Photograph 4: Compression testing using prism test pieces



Typical material properties for a continuous filament wound GRP jacking pipe are a longitudinal compressive strength of 90 MPa and a longitudinal compressive modulus of 11,000 to 16,000 MPa.

6.4 JOINT PERFORMANCE

The joint performance requirements for a GRP jacking pipe are similar to those for other rubber ring jointed pipes. However, the angular deflection requirement is significantly lower than you would find for a buried rubber ring jointed GRP pipe. The maximum allowable angular deflection should not be less than the values shown in Table 1.

Table 1: Maximum Angular Deflection (ISO 25780 Table 2)

External Diameter d_{OD} mm	**Maximum allowable installed deflection** a mm/m	**Maximum allowable installed deflection** δ degrees
$d_{OD} \leq 200$	20	1.1458
$200 < d_{OD} \leq 500$	15	0.8594
$500 < d_{OD} \leq 1000$	10	0.5729
$1000 < d_{OD}$	$a = 10 \times \frac{1000}{d_{OD}}$	Derive from value of a

Joint designs, whether stainless steel or GRP, need to be qualified. The performance of the coupling design is verified through type testing. A range of tests are conducted on the joints and must be representative across the entire diameter range. Testing is conducted with the joint in a number of configurations including angular deflection and draw as well as with a simulated misalignment. The joint must be able to resist angular deflection and draw at twice the design pressure for a minimum of 24 hours.

Angular deflection between successive jacking pipes has an influence on the allowable jacking force due to eccentricity of load. This will be discussed in more detail in this paper.

7 DESIGN

The permissible jacking force on a CFW GRP jacking pipe can be calculated from the material properties and the geometry of the pipe cross-section.

The pipes ultimate longitudinal load, F_{ult}, is calculated using the following equation. This is the expected failure load of the pipe under compressive load where $\sigma_{b,s,min}$ is the manufacturer's stated minimum compressive strength at break and A_s is the minimum pipe cross-sectional area. This will be at the pipe spigot and will take into account any rebates for gaskets.

$$F_{ult} = \sigma_{b,s,min} \times A_s$$

The maximum jacking load a pipe can withstand during the jacking operation is the theoretical design jacking load, $F_{j,calc}$. The theoretical jacking load assumes the jacking load is concentric and perpendicular to the pipe end with no angular deflection. This is calculated from the ultimate longitudinal load by applying a material safety factor, γ.

$$F_{j,calc} = \frac{F_{ult}}{\gamma}$$

The material safety factor, γ, should not be less than 1.75 and this value is typically used.

The theoretical jacking load, $F_{j,calc}$, does not take into account any eccentric loading on the pipe due to angular deflection. The permissible eccentric jacking load on the jacking pipe, $F_{perm,p}$, can be calculated based on the estimated angular deflection and the resultant distribution of compressive stresses across the end of the pipe.

$$F_{perm,p} = \frac{F_{ult}}{\gamma \times S_a}$$

The stress eccentricity dependence, S_a, is the ratio of the maximum compressive stress, σ_{max}, to the average compressive stress, σ_0. The method used to calculate S_a depends on the extent of the angular deflection between pipe ends.

Two angular deflection design cases exist. These are the closed joint or open joint cases. The closed joint design case exists for smaller deflection angles when the two pipe ends remain in contact for the full circumference even though there is an angular deflection between pipes. The pipes remain in contact due to the compliance of the pipes. For CFW GRP pipes the open joint design case doesn't occur as the bend angle required to cause the pipe ends to separate is larger than is allowed by ISO 25780. Therefore only the closed joint case will be discussed here.

The stress eccentricity dependence, S_a, is calculated from the following formula where Z is the diametrical extent of compression in the joint segments and d_g is the spigot or groove diameter.

$$S_a = \frac{\sigma_{max}}{\sigma_0} = \frac{\frac{Z}{d_g}}{\frac{Z}{d_g} - 0.5}$$

Z is calculated from the axial compressive modulus, E_p, of the pipe, the pipe length, l, and the angular deflection, δ, using the following formula.

$$Z = \frac{\sigma_{b,s,min} \times l}{\gamma \times E_p} \times \frac{1}{tan\delta}$$

For the closed joint condition the value of S_a will vary from a value of 1.0 for two pipes in straight alignment with no angular deflection to 2.0 where the joint is at the brink of opening. For most closed joint designs a value of 2.0 is used as a default.

Figure 2: Closed joint condition

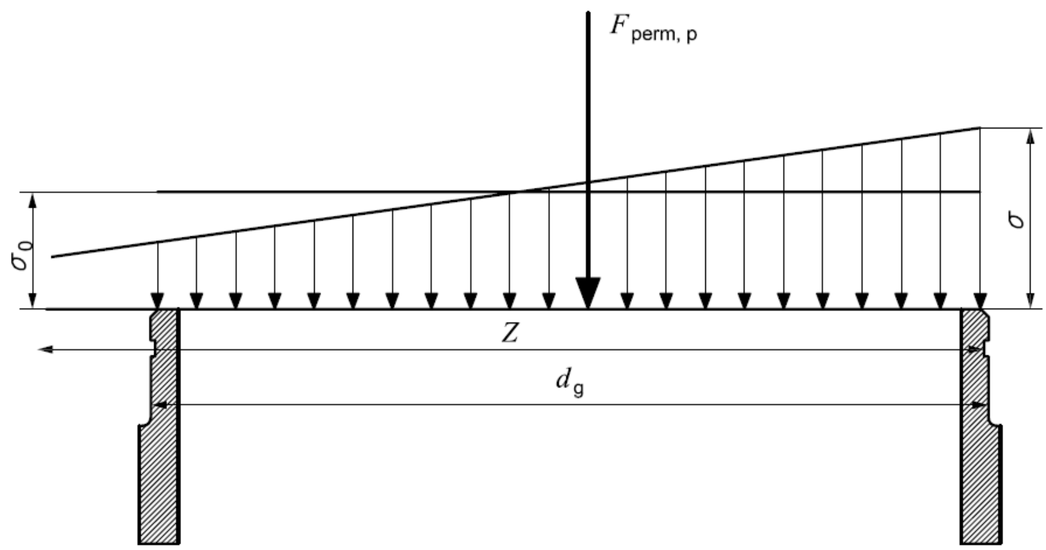
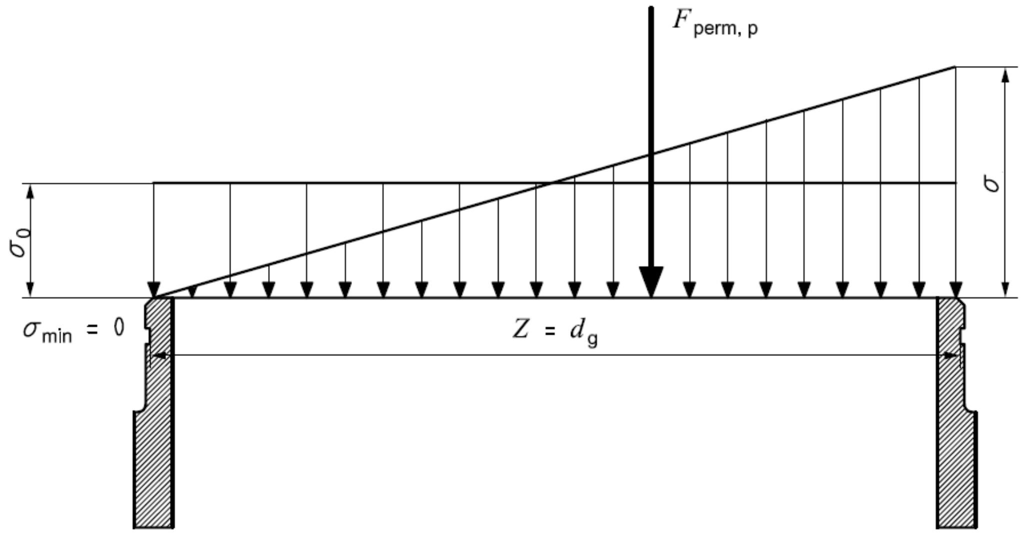


Figure 3: Maximum eccentricity by closed joint



For the case where S_a = 2 and γ = 1.75 the permissible eccentric jacking load can be calculated from the following formula.

$$F_{perm,p} = \frac{F_{ult}}{3.5}$$

8 PRACTICAL APPLICATION

Continuous filament wound GRP pipe is currently being used on Yarra Valley Water's Amaroo Sewer Main project in Victoria, Australia. The project is being managed by contractor John Holland and is the largest GRP jacking pipe installation ever undertaken in Australia. The project consists of 7.5km of OD1720 jacking pipe with the drive lengths varying from 161m up to 785m (Ferguson, 2016). The OD1720 jacking pipe has a permissible jacking load of 440 tonnes which had to be verified prior to installation beginning.

Photograph 5: Amaroo Sewer Main project

To evaluate the compressive strength of the CFW jacking pipes a full scale test was commissioned. The purpose of the test was to verify the performance of the OD1720mm SN55,000 jacking pipe manufactured by the continuous filament wound process at a jacking load of 500 tonnes. The performance of continuous wound jacking pipes had previously been verified through type testing at smaller diameters and numerous projects in Australia and overseas. The testing program verified the performance of the pipe under load with particular focus on any dimensional changes as well as confirming the compressive strength of the laminate through the prism testing.

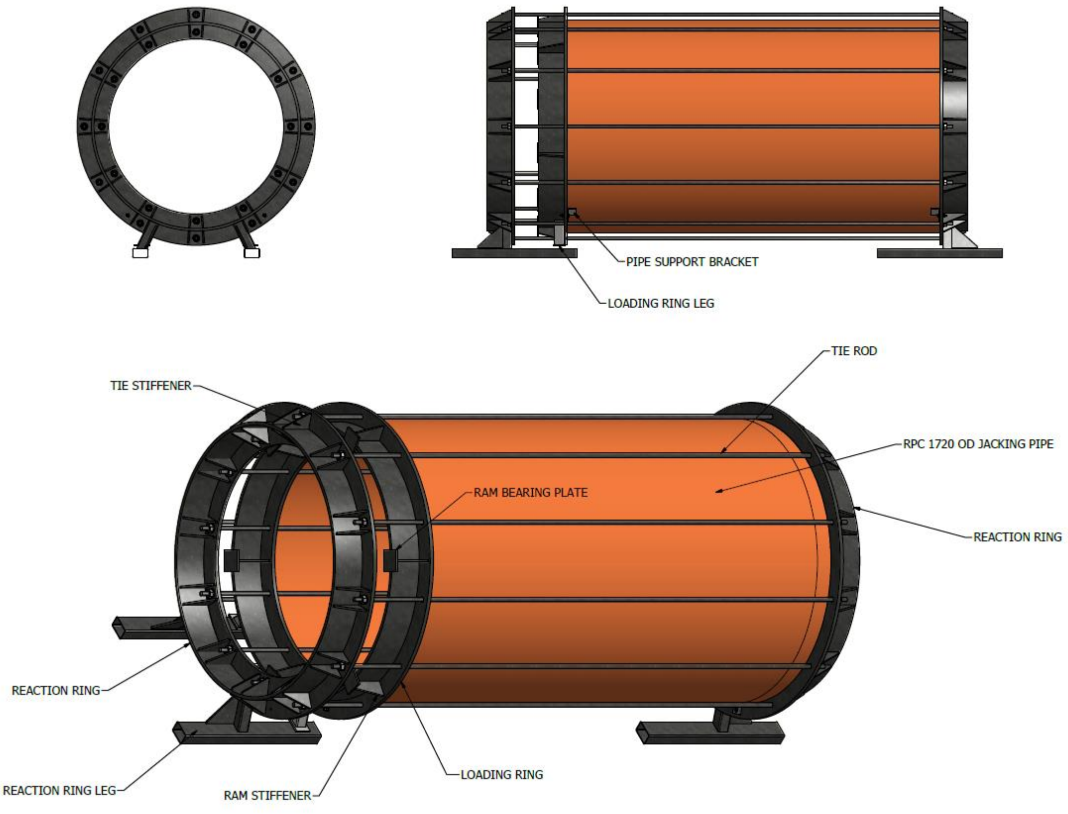
The expected maximum jacking load on the OD1720 SN55,000 jacking pipe was 440 tonnes as advised by John Holland Group. Testing facilities for an OD1720 jacking pipe were not available in Australia so a bespoke test rig was commissioned for testing by RPC Pipe Systems. This test rig was capable of applying a load of 5000 kN (approx. 510 tonnes) on the test pipe in an axial direction. To verify the ultimate compressive strength smaller prism test pieces were tested in accordance with Annex A of ISO 25780 on samples from both the pipe spigot and the barrel of the pipe.

Testing and reporting was conducted by the University of Adelaide. Testing was undertaken horizontally using a bespoke test rig. The overall specimen length was 3 m as used in the Amaroo project.

Four biaxial strain gauges were placed around the center of the pipe and four strain gauges placed on the inside of the rebated end section. The gauges continuously recorded axial and hoop strain for the duration of the testing. Additional strain gauges were fitted to the outside of the rebated sections in the gasket groove to better understand the strains in the pipe spigot after a first test was completed.

Coupons of pipe from the spigot and barrel of the pipe were tested to destruction in accordance with ISO 25780 Annex A and the results compared to those of the pipe sample. By comparing axial strain and stress of both the pipe and prism test pieces the factor of safety to failure was able to be determined. Samples were also fitted with strain gauges to provide a more accurate understanding of the behaviour of the pipe spigot under load.

Figure 4: Jacking pipe test rig



The objectives of the testing were to:

a) Confirm performance at a nominated jacking load of 500 tonnes.
b) Measure the axial deflection at operating load
c) Measure the increase in diameter at operating load
d) Determine any out of roundness at load and after removal of load
e) Calculate the factor of safety at 440 tonnes compressive load by comparing pipe test data to prism test data

The results from the test are summarised in Table 2.

Table 2: OD1720 SN55,000 CFW Jacking Pipe test results

Property	**Result**
Compressive strength of unrebated coupon cut from pipe barrel	127 MPa at failure
Compressive strength of rebated coupon cut from pipe barrel	112 MPa at failure
Compressive stress in full pipe section at 5000 kN axial load	24.3 MPa (Factor of safety of 4.6 based on rebated coupons)
Axial shortening at 5000 kN	4.37mm
Increase in diameter at 5000 kN	0.43mm
Out of roundness after load removal	0 mm

The resultant factor of safety significantly exceeded the value of 3.5 assumed in design. The compressive strength values were always expected to exceed the conservative value of 90 MPa typically used.

The longest drive installed to date at the Amaroo Sewer Main site is 695m. The pipe has performed well as was expected from the testresults.

9 CONCLUSIONS

Continuous filament wound jacking pipe is a legitimate alternative to existing rigid jacking pipes and other GRP jacking pipes. Through the use of ISO 25780 it is possible to safely design CFW GRP jacking pipe for tunneling applications with confidence.

CFW GRP jacking pipe provides a flexibility of design for jacking pipe not seen before. This gives the installer and the ultimate customer the opportunity to tailor a pipe to suit their specific requirements. Fast production rates gives the designer time to optimise the design rather than rush a decision based on the long lead times of traditional products.

As with all engineered products it is important to understand the underlying design requirements and material properties. Guidance is available from product manufacturers in regards to individual project designs.

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