



Engineering

Technical Standard

TS 0711.4 – Concrete Remedial Works: Structural Bonding and Strengthening

Version: 1.0

Date: 16 September 2022

Status: Final

Document ID: SAWS-ENG-0711.4

© 2022 SA Water Corporation. All rights reserved. This document may contain confidential information of SA Water Corporation. Disclosure or dissemination to unauthorised individuals is strictly prohibited. Uncontrolled when printed or downloaded.



**Government of
South Australia**

Copyright

This Standard is an intellectual property of the South Australian Water Corporation. It is copyright and all rights are reserved by SA Water. No part may be reproduced, copied or transmitted in any form or by any means without the express written permission of SA Water.

The information contained in this Standard is strictly for the private use of the intended recipient in relation to works or projects of SA Water.

This Standard has been prepared for SA Water's own internal use and SA Water makes no representation as to the quality, accuracy or suitability of the information for any other purpose.

Application & Interpretation of this Document

It is the responsibility of the users of this Standard to ensure that the application of information is appropriate and that any designs based on this Standard are fit for SA Water's purposes and comply with all relevant Australian Standards, Acts and regulations.

Users of this Standard accept sole responsibility for interpretation and use of the information contained in this Standard. Users should independently verify the accuracy, fitness for purpose and application of information contained in this Standard.

Only the current revision of this Standard should be used which is available for download from the SA Water website.

Significant/Major Changes Incorporated in This Edition

This is the first issue of this Technical Standard. However, it supersedes the following SA Water documents:

- SAW-ENG-STR-TEM-TSB-005 Technical Specification - Concrete Repair Works: Fibre Reinforced Polymer Composite Strengthening
- TS137 – Rehabilitation of Concrete Wastewater Manholes.

Document Controls

Revision History

Revision	Date	Author	Comments
1.0	16/9/2022	H Habib	First issue

Template: Technical Standard Version 6.00, 10/05/2016

Approvers

Role	Signature and Date
Principal Engineer, Civil and Structural Hany Habib	28/09/2022 X <i>Hany Habib</i> ----- Signer's Name Signed by: HA003047
Manager Engineering Quality and Innovation Matthew Davis	28/09/2022 X <i>MD</i> ----- Signer's Name Signed by: DA003681
Senior Manager Engineering Services Richard Gray	29/09/2022 X <i>RG</i> ----- Signer's Name Signed by: GR001964

Reviewers

Role	Name	Revision	Review Date

Contents

1	Introduction.....	7
1.1	Purpose	7
1.2	Concrete Remedial Works Technical Standard Suite	7
1.3	General Requirements	7
1.4	Concrete Strengthening Requirements	7
1.5	Abbreviations	8
1.6	References	8
1.7	Definitions	8
2	Concrete Strengthening System Selection.....	10
2.1	Strengthening Systems.....	10
2.2	Type of Structures.....	10
2.3	Strengthening Design	10
2.3.1	General	10
2.3.2	FRP Composite Strengthening.....	11
2.4	Submission: Design Report.....	12
3	Materials.....	13
3.1	General Requirements	13
3.2	Approved Repair Materials.....	13
3.3	Materials Testing.....	13
3.4	Fibre Reinforced Polymer System	13
3.4.1	FRP Laminate	13
3.4.2	FRP Reinforcement Fabric	14
3.4.3	Resin General Requirements	14
3.4.4	Concrete Surface Primer	14
3.4.5	Fabric Saturant	14
3.4.6	Epoxy Resin Adhesive.....	14
3.4.7	Protective Coating.....	14
3.4.8	Fabric Application Tolerances	15
3.4.9	Laminate Application Tolerances.....	15
3.5	Materials Submissions - Fibre Reinforced Polymer	15
4	Workmanship - General.....	16
4.1	Standards and Codes	16
4.2	Concrete Repair Constructor Competency	16
4.2.1	Approved FRP Applicators	16
4.3	Quality Assurance	16
4.3.1	Hold Points and Witness Points	16
4.3.2	Inspection and Test Plans	16
4.3.3	Pre-Start Meeting.....	16
4.3.4	Daily Records.....	17
4.3.5	As-Repaired Report.....	17
4.4	Health and Safety Requirements.....	17

4.5	Environmental Requirements	18
4.6	Construction Requirements.....	18
4.7	Temporary Works.....	18
4.8	Pre-Work Survey	18
4.9	Material Transport, Handling and Storage.....	19
4.9.1	FRP Reinforced Reinforcement	19
4.9.2	Resins	19
4.10	Trial Repairs	19
4.10.1	Reference Profile	20
4.10.2	Trial Application	20
5	FRP Installation	21
5.1	Environmental Conditions	21
5.2	Concrete Surface Preparation	21
5.2.1	General	21
5.2.2	Near Surface Mounted FRP bars.....	22
5.2.3	Concrete Surface Profile	22
5.2.4	Substrate Flatness	22
5.2.5	Soundness of the Prepared Substrate	22
5.2.6	Concrete Moisture Level.....	22
5.3	Cutting Laminate/Fabric	23
5.4	Application of Primer, Adhesive, Saturant and FRP Reinforcement.....	23
5.4.1	Cleaning Prior to FRP Application	23
5.4.2	Handling Resins.....	24
5.4.3	FRP Laminate Application	24
5.4.4	FRP Fabric Application.....	24
5.4.5	Near Surface Mounted FRP	25
5.5	Curing	25
5.6	Protective Coating	25
5.7	Cleaning	26
5.8	Inspection and Testing	26
5.9	Non-Compliant Work.....	26
5.10	Repair of Defects	26
5.10.1	Minor Defects	26
5.10.2	Major Defects	26
5.10.3	FRP Defect Repair	27
6	Quality Control Testing	28
6.1	General.....	28
6.2	List of Quality Control Tests.....	28
6.3	Test Method – Substrate Flatness	29
6.3.1	Method	29
6.3.2	Acceptance Criteria.....	29
6.4	Test Method –Soundness of Substrate	29
6.4.1	Method	29

6.4.2	Acceptance Criteria.....	29
6.5	Test Method - Adhesive Bond Capacity of Substrate.....	29
6.5.1	Method	29
6.5.2	Acceptance Criteria.....	29
6.6	Test Method - Concrete Moisture Level.....	30
6.6.1	Method	30
6.6.2	Acceptance Criteria.....	30
6.7	Test Method – Adhesive Wet Film Thickness	30
6.7.1	Method	30
6.7.2	Acceptance Criteria.....	30
6.8	Test Method - Soundness of FRP Repair	31
6.8.1	Method	31
6.8.2	Acceptance Criteria.....	31
6.9	Test Method – FRP Laminate Bond Strength	31
6.9.1	Method	31
6.9.2	Acceptance Criteria.....	32
Appendix A : Schedules of Hold Points, Witness Points and Identified Records 34		
A1	Schedule of Hold Points.....	34
A2	Schedule of Witness Points.....	34
A3	Schedule of Identified Records	34

List of figures

Figure 1: In-situ Direct Pull-off Test Failure Modes	33
--	----

List of tables

Table 1: Definitions of Terms Used in this Technical Standard.....	8
Table 2: Exposure Classes by Structure Type and Micro-Environment	11
Table 3: Fabric Application Tolerances	15
Table 4: Laminate Application Tolerances.....	15
Table 5: Concrete Moisture Test Criteria for “Dry” Concrete.....	23
Table 6: FRP Concrete Repairs Quality Control Tests and Frequency	28
Table 7: In-situ Direct Pull-off Test Failure Modes	32
Table 8: Example Tensile Bond Strength Data.....	32

1 Introduction

1.1 Purpose

The purpose of this section of the Concrete Remedial Works Technical Standard is to detail SA Water's minimum technical requirements for the supply of materials, surface preparation, material application, inspection and testing for structural bonding and strengthening of reinforced concrete water and wastewater assets using Fibre Reinforced Polymer (FRP) strengthening systems.

It is intended that repairs completed in accordance with this Technical Standard are of consistent high quality and attain the specified durability and service life.

1.2 Concrete Remedial Works Technical Standard Suite

This Technical Standard is one, that comprises:

- TS 0711.0: General Requirements
- TS 0711.1: Concrete repairs (structural and non-structural repairs)
- TS 0711.2: Joint sealant replacement
- TS 0711.3: Concrete crack repair
- **TS 0711.4: Structural bonding and strengthening (This Document)**
- TS 0711.5: Surface protection and lining of concrete

Read TS 0711.4 in conjunction with TS 0711.0: General Requirements.

1.3 General Requirements

TS 0711.0 General Requirements apply to all aspects of the work:

1. Introduction: Purpose, references
2. Scope: Types of structure and repair methods, exclusions, and technical dispensation
3. Using the technical standard
4. General project requirements
5. Quality requirements
6. Health and safety requirements
7. Environmental requirements
8. Construction requirements

Appendix A : Schedules of hold points, witness points and identified records.

1.4 Concrete Strengthening Requirements

Carry out all remediation of concrete in accordance with the requirements as specified in TS 0711.0, the project contract documents, the requirements specified in this Technical Standard and the repair material manufacturer's instructions.

Request written advice from SA Water's Representative to resolve any conflict between this Technical Standard and any manufacturer's instructions.

Make no deviation from this Technical Standard without written approval from SA Water's Representative.

The technical requirements of this Technical Standard include:

1. Type of repair and materials
2. Pre-work survey to identify mark out and record the location of concrete defects
3. Installation of temporary propping
4. Trial repair to verify materials and workmanship
5. Removal of defective concrete to provide a sound substrate
6. Installation of the FRP strengthening system
7. Quality control testing to verify compliant repair works
8. Submission of an As-Repaired report.

Undertake additional remedial works if required (concrete repair, crack injection, joint sealant, surface protection) in accordance with TS 0711.1 to TS 0711.5.

If required, undertake demolition of complete structural components in accordance with TS 0711.0 Clause 6.4.5.

1.5 Abbreviations

Abbreviations used in this document are defined in TS 0711.0 Clause 1.2.

1.6 References

Australian and International Standards, SA Water Standards, Industry Technical Guidelines and other documents referenced in this Technical Standard are defined in TS 0711.0 Clause 1.3.

1.7 Definitions

The terminology and technical definitions applicable to this Technical Standard are defined in TS 0711.0 Clause 1.4.

A selection of key technical terms relevant to this Technical Standard are defined in Table 1.

Table 1: Definitions of Terms Used in this Technical Standard.

Term	Definition
Blowholes	Small regular or irregular cavities, usually not exceeding 15 mm in diameter or 5 mm in depth, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation.
Bond	The chemical and/or mechanical adherence between a repair material or coating and the existing concrete substrate.
Bond strength (or pull-off strength)	The resistance to separation of an adhered repair material or coating from a concrete substrate via the mechanical application of a tensile stress.
Delamination	The separation of a section of one material from another which is identified by a drummy or hollow sound instead of a clear ringing sound when the material is tapped.
Dry surface	Concrete residual moisture after surface preparation does not exceed the limits for successful coating application, bonding and curing in ASTM D4263, ASTM F1869 or ASTM F2170.
Fibre fabric	A material formed of fibres orientated in the required direction in a woven or non-woven form and made available in blankets or various widths, weights, thicknesses, and lengths

Term	Definition
Fibre laminate	Fibre-reinforced polymer composite comprising two or more layers of fibres, bound together in a resin matrix, and produced in the form of a sheet, plate of required widths, thicknesses, lengths and physical properties,
Fibre-reinforced polymer (FRP)	Composite material comprised of a resin matrix such as epoxy or other adhesive materials reinforced with high strength fibres such as carbon, aramid, or glass, moulded and hardened to form the required shape including fibre fabric and laminates, which can act in composite to enhance the structural capacity of concrete structures.
Moist surface	Concrete surface has a matt moist appearance with no shiny water film, the pores are not water saturated, indicated by a drop of water being readily absorbed, restoring the surface to a matt appearance.
Near surface mounted FRP	FRP laminate that is installed into slots that have been prepared in the cover region of a concrete component.
Resin	A resin system based on epoxy materials comprising a thermosetting polymer that is the reaction of an epoxy resin and amino hardener, including primer, saturant, adhesive and putty filler in a FRP system.
Saturated surface dry (SSD)	The concrete substrate pores are saturated with water to a depth of several millimetres, the concrete surface may have a wet sheen, but there is no dripping/ ponded/free water on the surface, as if it had been dried with a cloth.
Spall	A fragment of concrete broken off or detached from the edge of solid concrete due to the corrosion of steel reinforcement or due to accidental, physical, or mechanical damage.
Surface bonded FRP	FRP that is directly bonded to the outside surface a concrete component.
Surface Imperfections	Surface voids or cavities not exceeding 5 mm in depth left on the concrete surface (in the form of surface honeycomb), due to failure of the mortar to effectively fill the spaces among coarse aggregate particles during placement and consolidation.
Wet surface	The concrete surface has dripping or standing water.

2 Concrete Strengthening System Selection

2.1 Strengthening Systems

This Technical Standard sets out the requirements for fibre-reinforced polymer (FRP) composite structural strengthening systems for application to deteriorated or underperforming concrete structures or members, which might include one or more combinations of concrete repair type as listed in TS 0711.1 Table 2.

Structural strengthening of concrete structures can also be undertaken by using other materials and techniques including:

1. Install additional thickness of reinforced concrete or sprayed concrete to beams, columns, crossheads, and walls
2. Supplementing or replacing embedded steel reinforcement in the concrete repair
3. Install additional members such as beams, columns, cross-bracing and walls to support, supplement or make redundant the damaged structural members
4. Install additional external reinforcement, encased and exposed, such as reinforced concrete deck/slab overlay or column jacket/collar
5. External/transverse post tensioning (steel rods or tendons).

Methods 1 and 2 are covered in TS 0711.1.

Methods 3 to 5 are not included in this Technical Standard. General guidance on these strengthening methods is provided in ACI 546 Chapter 7. Such works should be undertaken using other relevant SA Water Technical Standards such as TS 0710 or project specific Specifications.

2.2 Type of Structures

The types of structures covered by this Technical Standard are outlined in TS 0711.0 Clause 2.1 and exclude structural steel construction.

Minimum concrete requirements for FRP strengthening:

1. Concrete substrate minimum pull off strength 1.5 MPa as measured by AS 1012.24
2. Minimum compressive strength 17 MPa, as measured by AS 1012.14
3. Maximum compressive strength 100 MPa, as measured by AS 1012.14.

2.3 Strengthening Design

2.3.1 General

The strengthening design shall be prepared by a chartered professional structural engineer who is eligible for Corporate Membership of the Institution of Engineers, Australia, and who is a member of the Consult Australia, with appropriate experience in structural design, safety, scaffolding, and composite strengthening design.

Base the structure strengthening design on a structural analysis undertaken to determine the level of overloading or under-design for the in-service load conditions, to ensure that the strengthened structure meets the minimum requirements for serviceability, strength, and durability in AS 3600, AS 5100 and AS 3735.

The structural analysis is to consider any load redistribution in the strengthened structure for the in-service load conditions to prevent any overstressing of unstrengthened sections.

Repair and reinforce the existing concrete structure with FRP reinforcement in a safe manner, using methods complying with the standard industry practice for strengthening and the requirements of the relevant codes for design, materials, construction, fabrication, and erection.

Make use of any available Manufacturer's special design programme for its FRP reinforcement system.

2.3.2 FRP Composite Strengthening

Design and install FRP strengthening in accordance with AS 5100.8 Appendix A.

Assume that the FRP strengthening does not contribute to the capacity of a member subject to fire.

Apply the environmental reduction factors in AS 5100.8 Table A5.4 in accordance with AS 3735 Table 4.1 exposure classifications, as listed in Table 2, where exposure conditions B2, C and D are "Aggressive" exposure conditions, and exposure conditions A or B1 are "Exterior" exposure conditions.

Take into account and make provision for moisture transmission in the design of the FRP system.

Select a protective coating for the FRP system in accordance with this Technical Standard and TS 0711.5.

Table 2: Exposure Classes by Structure Type and Micro-Environment

Structure Type	Environment	AS 3735 Table 4.1 Exposure Condition	AS 5100.8 Table A5.4 Exposure Condition	Coatings Exposure Class (TS 0711.5 Table 4)
Fresh Water Storage/ Transmission Assets	Submerged/splash	B2	Aggressive	Moderate
	Atmospheric - internal	B1	Exterior	Moderate
	Atmospheric - external	B1-C	Exterior/ Aggressive	Moderate
All Assets	Chemical exposure	B2-D	Aggressive	High / Extreme
Waste Water (Sewage) Assets	Continuously Submerged > 0.5 m below min. level, < 4m/s velocity	B2	Aggressive	Moderate
	Continuously Submerged > 0.5 m below min. level, > 4m/s velocity	B2	Aggressive	High
	All internal areas above (0.5 m below min. sewage level) - open to air, fresh sewage	B2	Aggressive	Moderate
	All internal areas above (0.5 m below min. sewage level) - open to air, stale sewage	D	Aggressive	High
	All internal areas above (0.5 m below min. sewage level) - enclosed, fresh sewage	D	Aggressive	High

Structure Type	Environment	AS 3735 Table 4.1 Exposure Condition	AS 5100.8 Table A5.4 Exposure Condition	Coatings Exposure Class (TS 0711.5 Table 4)
	All internal areas above (0.5 m below min. sewage level) - enclosed, stale sewage	D	Aggressive	Extreme
	Atmospheric - external	B1-C	Exterior/ Aggressive	Moderate
	Emergency Storage Tank	B2	Aggressive	Moderate
General Environments	Internal/external marine - aerosol and splash	C	Aggressive	High
	Buried	B1-D	Exterior/ Aggressive	Low to Extreme

2.4 Submission: Design Report

Provide a design report by a chartered professional structural engineer in a format acceptable to SA Water's Representative for review that includes:

1. Design calculations
2. Drawings of the proposed work (including Shop drawings) indicating:
 - a. Limits of strengthening
 - b. Details of any additional epoxy injection crack repair or epoxy resin patching (to comply with TS 0711.3), or concrete repair/replacement (to comply with TS 0711.1)
3. Complete description of the FRP Reinforcing system materials, primer, resin, and protective coating, surface preparation, application procedures, application rates, and cure times
4. Safety-in-Design assessment.

HOLD POINT

3 Materials

3.1 General Requirements

Comply with general materials requirements detailed in TS 0711.0 Clause 8.4 and 8.5:

1. General
2. Repair systems
3. Proprietary items
4. Manufacturer's recommendations
5. Product Supplier
6. Compliance with TS0800 (containing SA Water requirements for AS/NZS 4020) - when used in drinking water supplies
7. Materials submissions
8. Storage of materials
9. Trials.

3.2 Approved Repair Materials

Products not having prior documented SA Water approval shall not be used until approval has been obtained from SA Water's Representative.

HOLD POINT

3.3 Materials Testing

Undertake materials testing in accordance with TS 0711.0 Clause 5.9.

List all tests proposed to be undertaken to demonstrate compliance with the Technical Standard.

HOLD POINT

3.4 Fibre Reinforced Polymer System

The Fibre Reinforced Polymer (FRP) System shall be a proprietary system that includes all resins, primers, saturants, adhesives, reinforcing fibres, reinforcing laminates and protective coatings as required that are fully compatible with each other and are tested to recognised Australian or International Standards.

3.4.1 FRP Laminate

FRP Precured Strip shall be high strength, high modulus, unidirectional pultruded carbon fibre reinforced polymer (CFRP) specifically designed for adding strength as part of a load bearing bonded system.

CFRP materials shall comply with the minimum properties in AS 5100.8 Table A2.2.1. CFRP precured strips are to be of the type, size, layer, and location as indicated on the Drawings.

3.4.2 FRP Reinforcement Fabric

FRP Reinforcement fabric shall be high strength, high modulus, glass, aramid, or carbon fibre fabric that may be unidirectional or woven textile (bi-directional in various fibre architectures) to suit specific repair needs, designed for adding strength as part of a load bearing bonded system taking into account the fabric's tensile strength, creep rupture and elastic modulus properties.

Fabric materials shall comply with the minimum properties in AS 5100.8 Tables A2.2.2, A2.2.3, and A2.2.4.

FRP Reinforcement fabric shall be of the type, size, layer, and location as indicated on the Drawings.

3.4.3 Resin General Requirements

The resins shall have the following characteristics:

1. Compatible with and adherent to each other, the substrate, and the fibre
2. Resistant to the service environment
3. Workability, filling ability, pot life consistent with the application requirements
4. Suitable mechanical properties for the cured FRP.

3.4.4 Concrete Surface Primer

The concrete surface primer shall be a two component, low viscosity, moisture/tolerant, high modulus, high strength epoxy or as recommended by the manufacturer.

The surface primer material shall comply with the minimum properties in AS 5100.8 Table A2.3.4.

WITNESS POINT

3.4.5 Fabric Saturant

Saturant resin shall be two component, low viscosity, moisture tolerant, high strength, high modulus epoxy or as recommended by the manufacturer.

The saturant material shall comply with the minimum properties in AS 5100.8 Table A2.3.4.

3.4.6 Epoxy Resin Adhesive

Epoxy resin repair mortar/putty filler/adhesive shall be non-sag thixotropic paste or putty as recommended by the manufacturer.

The epoxy putty material shall comply with the minimum properties in AS 5100.8 Table A2.3.3.

3.4.7 Protective Coating

The resin protective coating shall be:

1. UV resistant
2. Comply with the requirements of TS 0711.5 or as recommended by the manufacturer.

3.4.8 Fabric Application Tolerances

Application tolerances for fabric sheets shall be as listed in Table 3.

Table 3: Fabric Application Tolerances

Property	Requirement
Material length	+ 50 mm, - 10 mm
Application position	± 25 mm

3.4.9 Laminate Application Tolerances

Application tolerances for laminates shall be as listed in Table 4.

Table 4: Laminate Application Tolerances

Property	Requirement
Material length	± 20 mm
Application position	± 25 mm
Adhesive thickness to substrate	1 to 2 mm
Adhesive thickness to laminate	3 mm at centre to 1 mm at edge
Minimum spacing between adjacent parallel elements	5 mm
Final thickness of adhesive along the bond line	1.5 mm to 3.0 mm

3.5 Materials Submissions - Fibre Reinforced Polymer

Comply with all parts of TS 0711.0: Clause 8.4.7 Submissions and the following specific requirements.

Provide at least 28 days prior to the date on which the FRP composite system is to be used on site:

1. Samples of all materials to be used, each properly labeled
2. List of Specialist Applicator completed FRP Reinforcement projects, including size, location, owner, engineer/architect and contact numbers
3. Evidence of Specialist Applicator's qualification, training, and experience with the specific FRP manufacturers installation procedures
4. Independent NATA accredited test reports, as required, verifying the material properties and environmental durability of the proposed FRP system. Such reports shall include as a minimum the performance requirements listed in Clause 3.4 , and evidence of > 2 years performance of structural strengthening with FRP materials, confirmed by actual field tests for a minimum three successful installations
5. Shop drawings.

HOLD POINT

4 Workmanship - General

4.1 Standards and Codes

Comply with the standards, codes and guidelines referenced in this document and as defined in TS 0711.0: Clause 1.3 and reference standards as detailed in Section 1.6 of this document.

4.2 Concrete Repair Constructor Competency

Comply with all parts of TS 0711.0: Clause 4.1.

4.2.1 Approved FRP Applicators

Use an approved specialist FRP applicator, experienced with demonstrated competence in surface preparation and application of FRP systems:

1. The FRP composite applicator personnel shall be trained by the FRP System Manufacturer and shall have completed a program of instruction in the use of FRP Reinforcement
2. The FRP composite applicator's personnel shall have a minimum of 5 years' experience in FRP Reinforcement
3. The FRP composite supplier shall provide experienced field supervision personnel specifically trained in the installation of its FRP reinforcements to provide technical support during the installation.

4.3 Quality Assurance

Comply with all parts of TS 0711.0: Clause 5 Quality and the quality control testing requirements in Clause 6.

Provide identified records listed in Appendix A.

4.3.1 Hold Points and Witness Points

Comply with all mandatory quality control and audit hold and witness points, listed in Appendix A.

Advise SA Water's Representative when hold points are reached and ready for inspection.

4.3.2 Inspection and Test Plans

Comply with ITP requirements in TS 0711.0 Clause 5.6.

Show the type, sequence, and number of tests to be undertaken in each area and how the pass, rework or reject criteria will be determined on the ITP.

4.3.3 Pre-Start Meeting

Hold a pre-start meeting in accordance with TS 0711.0 Clause 8.6.

4.3.4 Daily Records

Comply with requirements in TS 0711.0 Clause 5.11 Site Records.

Maintain records of the work on a daily basis to enable traceability of workmanship and materials.

Provide the following minimum daily records:

1. Job Identification
2. Surface preparation method and equipment used
3. Application equipment used
4. FRP reinforcement and epoxy resin materials used, batch number, and areas treated with each batch and the date and time each item or area was treated
5. Application details including layer number/direction, wet film thickness
6. Any unusual events or behaviour associated with the FRP application work or materials or both
7. Weather conditions, ambient temperature, surface temperature, relative humidity, dew point and any other weather or site conditions such as dust, dirt, debris, etc. that may affect the specified finish at the start of each day's work then at a maximum of every 4 hours, or each change in weather conditions
8. Recording of any containment monitoring regime to confirm that abrasive blasting material has been contained within the works site boundary.

4.3.5 As-Repaired Report

Provide an As-Repaired Report in accordance with TS 0711.0 Clause 5.12.

4.4 Health and Safety Requirements

Comply with health and safety requirements in TS 0711.0 Clause 6:

- | | |
|------------|--------------------------|
| Clause 6.1 | General |
| Clause 6.2 | Works on existing sewers |
| Clause 6.3 | Lighting |
| Clause 6.4 | Concrete removal |
| Clause 6.5 | Diving |
| Clause 6.6 | Traffic management |
| Clause 6.7 | Barriers and signs |
| Clause 6.8 | Equipment |
| Clause 6.9 | Hazardous materials |

4.5 Environmental Requirements

Comply with health and safety requirements in TS 0711.0 Clause 7:

Clause 7.1	Noise emissions
Clause 7.2	Compressor silencing
Clause 7.3	Hand tools
Clause 7.4	Waste management/Disposal of contaminants
Clause 7.5	General cleaning and disposal of refuse
Clause 7.6	Dust and water
Clause 7.7	Existing flora.

4.6 Construction Requirements

Comply with the construction requirements in TS 0711.0 Clause 8:

Clause 8.1	Existing structures
Clause 8.2	Temporary works
Clause 8.3	Extent of works identification
Clause 8.4	Materials requirements
Clause 8.5	Trials
Clause 8.6	Pre-start meeting
Clause 8.7	Commissioning and water quality monitoring.

4.7 Temporary Works

Provide temporary works including propping, access systems and plant isolations in accordance with TS 0711.0 Clause 8.2.

4.8 Pre-Work Survey

Undertake the pre-work survey requirements of TS 0711.0 Clause 8:

1. Clause 8.1.1: Verify existing structures and the location of all services located outside or embedded within the concrete structure components
2. Clause 8.3 : Extent of works identification:
 - a. Mark up plan showing extent of work
 - b. Undertake and record pre-repair survey, submit Report
 - c. Undertake further testing if required
 - d. Mark out on the structure all defect areas for repair.

HOLD POINT

4.9 Material Transport, Handling and Storage

4.9.1 FRP Reinforced Reinforcement

FRP reinforcement may be ordered in continuous coils or rolls or custom cut lengths.

Store FRP material in its original packing box horizontally, in a cool dry area away from direct sunlight, flame, moisture, or other hazards.

FRP materials can be brittle and must be handled with great care.

Handle FRP laminates and fabric using clean gloves, mask and goggles at all times due to the risk of loose fibres.

Use a roller frame to manage coils of FRP. Comply with the manufacturer's minimum coil diameter at all times. Use two personnel to avoid uncontrolled uncoiling.

Do not use any FRP laminate that has split or cracked at the ends due to handling or cutting.

Avoid touching FRP surfaces without protective peel ply.

Only remove protective peel ply immediately before application of the laminate or fibre material, and do not touch the surface.

4.9.2 Resins

Store primer, saturant and protective coating under conditions as recommended by the Manufacturer in a cool dry place out of direct sunlight.

Add liquid material components and thoroughly mix prior to use, in accordance with the Manufacturer's recommendations and the approved Work Method Statement, to achieve a uniform consistency, colour and workability appropriate to the method of placing.

Use a stop watch or other timing device to ensure that the material is mixed for the correct amount of time.

Do not dilute resins with solvent.

Use the resin in accordance with the manufacturer's recommended pot life. Discard all resin that has exceeded its stated pot life or exceeds any stated workability parameter.

Take precautions to avoid damage to any surface near the work zone due to mixing and handling of the material.

Properly dispose of waste material and empty containers in accordance with TS 0711.0 Clause 7.4.

4.10 Trial Repairs

Undertake trial repairs for all types of specified repair in accordance with TS 0711.0 Clause 8.5.

Trial locations shall be as agreed with, or instructed by, SA Water's Representative.

HOLD POINT

4.10.1 Reference Profile

Prepare a representative minimum 0.5 m² concrete substrate area for FRP fabric or 0.5 m length for FRP laminate in accordance with Clause 5.2 for use as a reference standard demonstrating an acceptable prepared substrate for the duration of the works for approval by SA Water's Representative.

4.10.2 Trial Application

Undertake a trial FRP system application to a minimum 1 m² concrete surface area for fabric and 1 m for laminate and rod FRP, separate from the reference profile area.

5 FRP Installation

5.1 Environmental Conditions

Do not apply FRP Reinforcement materials under any of the following conditions:

1. if rain, wind, snow, or dew condensation conditions are predicted
2. The concrete substrate surface is not dry and does not meet the manufacturer's recommendations
3. The ambient temperature is outside the range $\geq 5^{\circ}\text{C}$ to $\leq 30^{\circ}\text{C}$
4. The concrete substrate surface temperature is outside the range $\geq 8^{\circ}\text{C}$ to $\leq 35^{\circ}\text{C}$.
5. The concrete substrate surface temperature is $\leq 3^{\circ}\text{C}$ above the dew point
6. Ambient relative humidity $\leq 85\%$.

5.2 Concrete Surface Preparation

5.2.1 General

Remove dust, laitance, grease, curing compounds, impregnations, waxes, foreign particles, disintegrated materials, and other bond inhibiting materials from the concrete surface using abrasive blasting or grinding methods.

Avoid using water based surface preparation methods unless adequate time is allowed for the substrate to dry.

These methods are detailed in ICRI Guideline No 310.2R-2013.

Be aware that aggressive methods may damage the concrete surface and require repair.

Use the blasting pressure, or mechanical effort, required to achieve the required surface profile for the specified system.

Acid etching is **NOT** an approved method to remove cement paste from the surface and surface pores of concrete. Do not use acid etching under any circumstances.

Remove all dust and debris arising from surface preparation using a vacuum method.

Inspect the prepared surface for defects and surface bruising (micro-cracked and fractured layer 3 mm to 10 deep). Remove any such weakened material that will reduce bond strength using abrasive blasting.

Repair all damaged areas (e.g. cracks, bug holes or uneven surface defects) with an epoxy resin repair mortar prior to placing FRP reinforcement.

Where required, undertake concrete repair to the concrete surface in accordance with TS 0711.1 as approved by SA Water's Representative prior to application of resin.

Repair cracks using a low viscosity structural injection resin in accordance with TS 0711.3.

Round external concrete corners to at least a 25 mm radius when perpendicular to fibre orientation. Smooth internal corners by trowelling epoxy mortar into the corners.

The concrete surface shall be clean and sound. It may be damp or dry, but free of standing water and frost.

5.2.2 Near Surface Mounted FRP bars

Undertake a survey to mark-out the location and depth of embedded reinforcement and check that it will not be cut or damaged.

Setout and cut slots in the concrete substrate for the near surface mounted FRP bar to depth/width as recommended by the material manufacturer, typically 6 mm wider and minimum 6 mm deeper than the laminate cross section.

Roughen the cut edges to comply with Clause 5.2.3.

5.2.3 Concrete Surface Profile

Prepare the concrete surface subject to FRP application to achieve the ICRI Technical Guideline No 310.2R, concrete surface profile range CPS 3, or as specified by the FRP material manufacturer.

Verify the achieved surface profile at all areas using the ICRI replica profiles.

5.2.4 Substrate Flatness

Do not apply FRP laminates to a surface that reverses curvature under load, or reverses the curvature of the laminate when under load.

Measure the substrate flatness and surface irregularities in accordance with Clause 6.3.

Grind flat uneven areas or fill using epoxy resin mortar (after primer application) to achieve the required flatness.

5.2.5 Soundness of the Prepared Substrate

Conduct soundness testing to all prepared surfaces in accordance with Clause 6.4.

Conduct surface bond strength testing to all prepared surfaces in accordance with Clause 6.5.

Repair the bond strength test areas using an epoxy resin mortar in accordance with Clause 5.4.5, other than no laminate bar is to be installed in the repair.

HOLD POINT

5.2.6 Concrete Moisture Level

Allow sufficient time for all concrete repair materials to cure, nominally a minimum 28 days for new concrete or as specified by the FRP system Manufacturer if the FRP System is part of its concrete repair system.

Before applying the FRP system, test the degree of concrete residual moisture in accordance with Clause 0 and ensure that the acceptance criteria in

Table 5 and the FRP system Manufacturer's specified substrate moisture limit values are complied with.

Concrete is considered "DRY" for application of epoxy resin when the concrete residual moisture after surface preparation does not exceed the limits for successful coating application, bonding and curing in

Table 5.

Table 5: Concrete Moisture Test Criteria for "Dry" Concrete

Moisture Test	Criterion for "Dry" Concrete
ASTM D4263 Plastic sheet method	No visible moisture
ASTM F1869 Calcium chloride test	$\leq 15 \text{ g}/24 \text{ hr}/\text{m}^2$
ASTM F2170 Relative humidity	$\leq 80\%$

Conduct this test after application of any cementitious rendering material.

Take due attention of moisture content along concrete surface due to, for example, dew fall.

HOLD POINT

5.3 Cutting Laminate/Fabric

Comply with the manufacturers recommendations for handling and cutting its FRP material.

Cleanly cut continuous coils or rolls on site to the required length taking care to support both sides of the laminate when cutting to avoid splintering.

Cut laminates and fabrics with tools using a "shearing" force (e.g. guillotine or heavy duty shears), a metal hand saw or using a diamond coated tool cutting method. Use masking tape prior to cutting by grinder to reduce splitting risk.

Manage the risk of exposure to airborne carbon or resin dust generated while cutting laminate.

Cut FRP fabric with shears or scissors.

Do not drill holes in FRP laminate plates, fabric, or rods.

Comply with the laminate and fabric application tolerances in Clauses 0 and 3.4.9.

5.4 Application of Primer, Adhesive, Saturant and FRP Reinforcement

5.4.1 Cleaning Prior to FRP Application

Use solvents to clean all concrete surfaces and FRP laminate materials without peel-ply immediately prior to application of a primer (where recommended by the FRP Manufacturer).

Solvent clean using two-cloths: cleaning the substrate with a solvent-saturated white cloth and dry the solvent-wet surface with a separate clean, dry cloth.

Use a water-soluble solvent, such as isopropyl alcohol (IPA) or Methyl Ethyl Ketone (MEK) and allow to flash off.

Repeat cleaning until the white cloth remains free of carbon dust, fibres, or other contaminants.

Replace used and dirty cloths frequently.

The prepared surfaces are to be clean, dust free and dry prior to application of a primer.

Re-clean the prepared surface, or a peel ply surface, if it becomes contaminated before the repair can proceed.

SA Water's Representative may inspect the concrete substrate preparation.

WITNESS POINT

5.4.2 Handling Resins

Mix and use epoxy resin components in accordance with Clause 4.9.1, and Clause 5.1.

Ensure that the concrete substrate moisture content for the application of the primer is in accordance with Clause 5.2.6.

Apply the primer uniformly by brush or roller and work well into the prepared concrete surface for all types of FRP applications.

Apply all subsequent layers of epoxy resin mortar, adhesive and saturant that form part of the FRP system onto a fresh tacky epoxy resin primer layer, within a suitable timeframe to ensure full intercoat adhesion. Apply primer to laminate without peel-ply.

If the epoxy resin primer, adhesive or saturant dries, re-prepare the surface to be coated by grinding to give a fully roughened surface to Clause 5.2.3, clean with solvent to Clause 5.4.1 and re-apply the primer before the next layer is applied.

5.4.3 FRP Laminate Application

Apply primer and whilst still tacky, level any remaining surface irregularities using epoxy resin mortar, ensuring the primer is tacky. Allow to cure and grind any rough edges smooth.

If required re-apply primer, and whilst still tacky, apply the epoxy resin adhesive to completely cover the concrete substrate using a notched steel trowel, checking thickness using a wet film comb in accordance with Clause 6.7.

Remove peel-ply and apply the epoxy resin adhesive to the laminate in a “V” profile, lift into place, bring into contact with the substrate and lightly press together.

Release or roll out entrapped air using a roller before the epoxy sets. Remove excess epoxy resin.

Comply with the manufacturers requirements for multiple laminate layers.

WITNESS POINT

5.4.4 FRP Fabric Application

If required cut fabric sheets to size.

Apply primer, and whilst still tacky, level any remaining surface irregularities using epoxy resin mortar. Allow to cure and grind any rough edges smooth.

Only roll epoxy resin saturant in the fabric longitudinal direction. Do not roll in the transverse direction.

Lightweight Fabric $\leq 400\text{g/m}^2$

If required re-apply primer, and whilst still tacky, apply a layer of epoxy resin saturant to the prepared concrete surface at the manufacturer's nominated wet film thickness or as determined in the trial application.

Apply and press the dry fabric into the saturant, stretch to avoid wrinkles, and roll to remove entrapped air.

If present, remove any fabric backing layer and re-roll to remove entrapped air, smooth and then de-foam the resin.

Apply second coat of epoxy resin saturant to the fabric whilst the first layer is still wet to touch at the manufacturer's nominated wet film thickness or as determined in the trial application.

If required apply additional fabric layers with minimum 300 mm overlap in the longitudinal direction to the same process, “wet on wet”. Correct any lifting or delamination by additional rolling.

Heavyweight Fabric > 400g/m²

Pre-apply the saturant resin to the fabric using rollers, brushes, or an impregnation machine to fully encapsulate all fibres.

If required re-apply primer, and whilst still tacky, apply a layer of epoxy resin saturant to the prepared concrete surface at the manufacturer's nominated wet film thickness or as determined in the trial application, and apply and press the wet fabric into the saturant, stretch to avoid wrinkles, and roll to remove entrapped air, smooth and then de-foam the resin.

Apply a second coat of epoxy resin saturant to the fabric whilst the first layer is still wet to touch at the manufacturer's nominated wet film thickness or as determined in the trial application.

If required apply additional wet fabric layers with minimum 300 mm overlap in the longitudinal direction to the same process, "wet on wet". Correct any lifting or delamination by additional rolling.

WITNESS POINT

5.4.5 Near Surface Mounted FRP

Apply primer to the slot surfaces and whilst still tacky, half fill the slot with epoxy resin adhesive via caulking gun ensuring no air voids.

Press the cleaned bar or laminate material into the wet adhesive.

Apply additional epoxy resin adhesive and tool to ensure no air gaps exist, to be flush with the concrete surface.

Broadcast clean kiln dried sand onto the wet adhesive surface if required.

WITNESS POINT

5.5 Curing

Undertake the following during curing of the FRP resin system:

1. Protect the finished installation from rain, sand, dust, etc. using protective sheeting or other barriers. Do not allow protective sheeting to come in contact with finished application
2. If required provide temporary support to the applied FRP material
3. Avoid vibration to the structure
4. Cure for a minimum of 48 hours.

Allow a two week curing period at an average ambient temperature of 20°C for full strength development before applying live loading.

5.6 Protective Coating

Apply a protective coating in accordance with the requirements in TS 0711.5 after a minimum 48 hour FRP curing period.

For laminates with a remaining peel-ply layer, remove before application of the coating, that may require a primer.

For laminates without a remaining peel-ply layer, carefully hand-sand the laminate surface taking care to not damage carbon fibres within the laminate. Clean the roughened surface in accordance with Clause 5.4.1 before application of the coating, that may require a primer.

For fabric layers, broadcast clean kiln dried sand onto the still wet saturant surface and allow to cure. Remove loose sand before applying the protective coating, that may require a primer.

Protect surfaces exposed to U.V. rays after two days (maximum seven days) with the selected protective coating.

HOLD POINT

5.7 Cleaning

Clean uncured saturants from tools with an approved solvent.

Remove cured saturants by mechanical means.

Dispose of waste materials in accordance with TS 0711.0 Clause 7.4.

5.8 Inspection and Testing

Undertake inspection and testing in accordance with Clause 6.

Assess and repair identified defects in the completed repair accordance with Clause 5.10.

HOLD POINT

5.9 Non-Compliant Work

If non-compliant work is identified during FRP application, stop work to verify the cause of failure. Once the cause of failure is identified, undertake corrective measures approved by SA Water or SA Water's Representative.

Identify by additional testing the portion of the works yielding unsatisfactory results (e.g. area of a floor/wall, works completed on a particular day or by a particular crew; or using a particular batch of materials).

Unless otherwise approved by SA Water's Representative, the entire portion of the works yielding unsatisfactory results or is otherwise non-compliant with this Technical Standard is to be removed and replaced in accordance with this Technical Standard.

5.10 Repair of Defects

5.10.1 Minor Defects

Minor defects are defined as follows:

1. Delamination or other defects in the range 25 mm x 25 mm up to 300 mm x 300 mm
2. FRP cracking, blistering, incomplete curing, incomplete wetting out of fabric, or air voids that affects its structural integrity
3. Coating damage.

5.10.2 Major Defects

Major defects are defined as follows:

1. Delamination or other defects of area greater than 300 mm x 300 mm
2. Peeling, debonding, cracking or excessive deflections.

5.10.3 FRP Defect Repair

Repair areas of minor defects or damage as follows:

1. Remove defective coating and assess the FRP substrate integrity. Re-apply defective coating
2. Do not repair areas smaller than 25 mm x 25 mm
3. Cut out cracked, or otherwise defective FRP by grinding and install an FRP patch, in accordance with relevant sections of Clause 5. The patch shall have the same characteristics as the original material such as laminate thickness and ply direction for each layer, with a minimum 150 mm overlap to the original material
4. Re-adhere delaminated FRP areas using epoxy resin injection undertaken in accordance with TS 0711.3.

Undertake a structural assessment of major defects that may require removal and replacement of the affected FRP, additional concrete repairs, propping or further structural assessment.

6 Quality Control Testing

6.1 General

Comply with all Quality Control Testing requirements in TS 0711.0 Clause 5 and this Technical Standard.

Use qualified and experienced inspectors to conduct all testing and quality control activities as required by this Technical Standard and the ITPs as the works proceed.

Allow for all samples, their production, retrieval and storage, testing and reporting required by the Contract.

Provide access, undertake sampling by coring (if requested by SA Water's Representative) and make good to reinstate to the profile of the surrounding surfaces using the approved repair materials and workmanship for any tests.

SA Water's Representative is at liberty to witness the carrying out of any test performed by the Constructor or its representative. The Constructor will be given one copy of any test result or report upon request.

Where testing is to be performed by a laboratory, supply one (1) copy of the laboratory report.

6.2 List of Quality Control Tests

The minimum testing requirements for FRP Application Works are listed in Table 6 and the test details follow. Additional testing may be included in the submitted ITP.

Table 6: FRP Concrete Repairs Quality Control Tests and Frequency

Test Required	Performed By	Procedure	Minimum Frequency of Testing
Concrete Surface Profile	QC Engineer	Clause 5.2.3	Each and every repair area
Substrate Flatness	QC Engineer	Clause 6.3	Each and every repair area.
Soundness of Concrete Surface	QC Engineer	Clause 6.4	Each and every repair area.
Adhesive Bond Capacity of Substrate	QC Engineer	Clause 6.5	3 tests per 10 m ² of FRP fabric repair area, or 3 tests per 50 m of FRP laminate repair area
Concrete Moisture Level	QC Engineer	Clause 0	Each and every repair area, one test per 5 m ² of FRP fabric repair area or one test per 10 m of FRP laminate repair area
Adhesive Wet Film Thickness	QC Engineer	Clause 6.7	Each and every repair area, 1 test per 5 m length of repair
Visual Inspection of Applied FRP	QC Engineer	Clause 0	Each and every repair area.
FRP Adhesion	QC Engineer	Clause 6.9	3 tests per 10 m ² of FRP fabric repair area, or 3 tests per 50 m of FRP laminate repair area

6.3 Test Method – Substrate Flatness

6.3.1 Method

Check the substrate surface for out-of-flatness at all treated areas using 0.3m and 2.0 m length flat edges laid in contact with the surface and resting under their own weight, or held against a vertical surface.

Measure the deviations of the concrete substrate from the underside of the straightedge, between the points which are in contact with the concrete substrate, by means of a slip gauge or other suitable accurate measuring device.

6.3.2 Acceptance Criteria

The acceptable out-of-flatness tolerance and surface irregularity are as follows:

Edges and surfaces in plan and level over 2 m distance: ± 3 mm.

Edges and surfaces in plan and level over 0.3 m distance: ± 1 mm.

6.4 Test Method – Soundness of Substrate

6.4.1 Method

Test all areas of prepared concrete substrate for soundness as follows:

1. Visually examine the repaired surfaces to confirm no defects including voids, honeycombing, segregation or cracking, or contamination
2. Test soundness of concrete by light tapping the surface using a light ballpeen hammer or delamination wand (metal bulb fixed to a fibre glass rod) to confirm nil delamination exists (solid versus hollow sounding).

6.4.2 Acceptance Criteria

No defects.

6.5 Test Method - Adhesive Bond Capacity of Substrate

6.5.1 Method

Test the adhesive bonding capacity of the prepared surface using a direct pull tensile test in accordance with AS 1012.24 at a rate not less than 3 tests per 10 m² of FRP fabric repair area or 3 tests per 50 m of FRP laminate repair.

6.5.2 Acceptance Criteria

The prepared concrete surface tensile capacity shall be greater than the minimum adhesion value 1.5 MPa for the specified repair material.

6.6 Test Method - Concrete Moisture Level

6.6.1 Method

Use ASTM D 4263 (Plastic sheet method) to determine if the concrete is sufficiently dry to apply the coating primer.

The test area is to be left open to ambient conditions for a minimum of 24 h prior to the placement of the test kit.

Conduct the test after the application of any cementitious rendering material.

If required by SA Waters Representative:

1. Assess the concrete vapour emission rate to ASTM F 1869 (Calcium Chloride Test)
2. Assess the concrete's internal relative humidity to ASTM F 2170 (In situ RH% probe test).

6.6.2 Acceptance Criteria

ASTM D 4263: No Visible moisture

ASTM F 1869: Maximum result of 15 g/24 hr/m²

ASTM F 2170: Maximum in situ relative humidity result of 80% or as otherwise specified by the coating Manufacturer.

Note: These limits apply in the absence of the coating Manufacturer's limits.

6.7 Test Method – Adhesive Wet Film Thickness

6.7.1 Method

Monitor the wet film thickness during application of the epoxy resin adhesive by use of a wet film thickness comb gauge as per AS 3894.3 Appendix C.

6.7.2 Acceptance Criteria

Where the minimum wet film thickness is less than or greater than that specified in Clause 3.4.9, reapply the adhesive to achieve the specified thickness.

6.8 Test Method - Soundness of FRP Repair

6.8.1 Method

Assess all areas with applied cured repair mortar for soundness as follows:

1. Visually inspect the repaired area immediately after application is complete and note any defects
2. Visually inspect the repaired area after curing is complete and note any defects such as incorrect fibre or laminate alignment, cracks, blisters, incomplete saturant curing, incomplete saturant wetting out/penetration of fabric, air voids or bubbles between layers, or between the FRP system and the concrete
3. Test soundness of the FRP material by light tapping of all repaired surfaces using a light ballpeen hammer or delamination wand (metal bulb fixed to a fibre glass rod) to confirm nil delamination exists (solid versus hollow sounding), taking care to not damage the applied FRP material, and record the size, location, and quantity of any delamination
4. Check the dimensional tolerance of applied FRP materials for compliance with the design drawings.

6.8.2 Acceptance Criteria

1. Achieve the required dimensional tolerance
2. Nil incomplete saturant curing or incomplete saturant wetting out/penetration of fabric
3. Nil cracking
4. Delamination in applied FRP (fabric, plates, single and multiple laminate layers):
 - a. Maximum allowable delamination size 25 mm x 25 mm
 - b. Maximum total allowable delaminated area $\leq 5\%$ of the total applied FRP area
 - c. For fabric FRP, ≤ 5 delaminated areas per 1 m² area
 - d. For laminate FRP, ≤ 1 delaminated areas per 2 m length
 - e. For a given FRP system cross section length, $\leq 25\%$ delamination
 - f. Nil delamination within 300 mm of a fabric/laminate/plate termination.

6.9 Test Method – FRP Laminate Bond Strength

6.9.1 Method

Seven days after repair application on completion of curing, conduct in-situ direct tension pull-off testing in accordance with AS 1012.24 to verify that the tensile bond strength between the FRP material and the concrete substrate, and repair material integrity, is satisfactory at locations and rate approved by the SA Water's Representative, at a rate not less than 3 tests per 10 m² of completed FRP fabric repair area, or 3 tests per 50 linear meters of laminate repair.

Test dollies shall be 50 mm diameter and be designed for the specific pull-off test instrument. Ensure that the test dolly locations are greater than 100 mm apart.

Ensure during the partial coring of the substrate that the process has minimal effect on the bond between repair material and the substrate. Where reinforcement is encountered, move the location of the core by the minimum amount to avoid the reinforcement.

Repair the test locations in accordance with Clause 0.

Provide a test report in accordance with AS 1012.24.

6.9.2 Acceptance Criteria

Bond Strength

The mean bond strength at age 7 days shall be not less than 1.5 MPa, with no individual result less than 90% of the mean value.

Failure Mode

Visually inspect the test specimens and determine the mode of failure as categorised in Table 7 based and Figure 1 based on the cross sectional area at the failure plane.

Where a combination of modes of failure exist, record the percentage of each mode of failure to the nearest 10% based on the surface area of the failure face.

Record the results in a similar method as shown in Table 8.

Table 7: In-situ Direct Pull-off Test Failure Modes

Mode	Failure location/type
A	Tensile (cohesive) failure within the existing concrete substrate
B	Tensile (cohesive) failure within the FRP adhesive
C	Tensile (cohesive) failure within FRP layer
D	Tensile (cohesive) failure within an additional layer (i.e. a coating system if present)
Y	Tensile (cohesive) failure in the test adhesive layer
A/B	Bond failure at the interface between the existing concrete substrate and the FRP adhesive material
B/C	Bond failure at the interface between the FRP adhesive and FRP layer
C/D	Bond failure between additional layers if present
x/Y	Bond failure between the topmost layer (where x = B, C or D) and the adhesive layer
Y/Z	Bond failure between the adhesive layer and the dolly
Z	Failure of dolly or of the test apparatus

Table 8: Example Tensile Bond Strength Data

Test #	Bond Strength MPa	Failure Type Normal (Y/N)	A %	A/B %	B %	B/C %	C %	C/D %	D %	x/Y %	Y %	Y/Z %	Z %
1													
2													
3													
Mean													

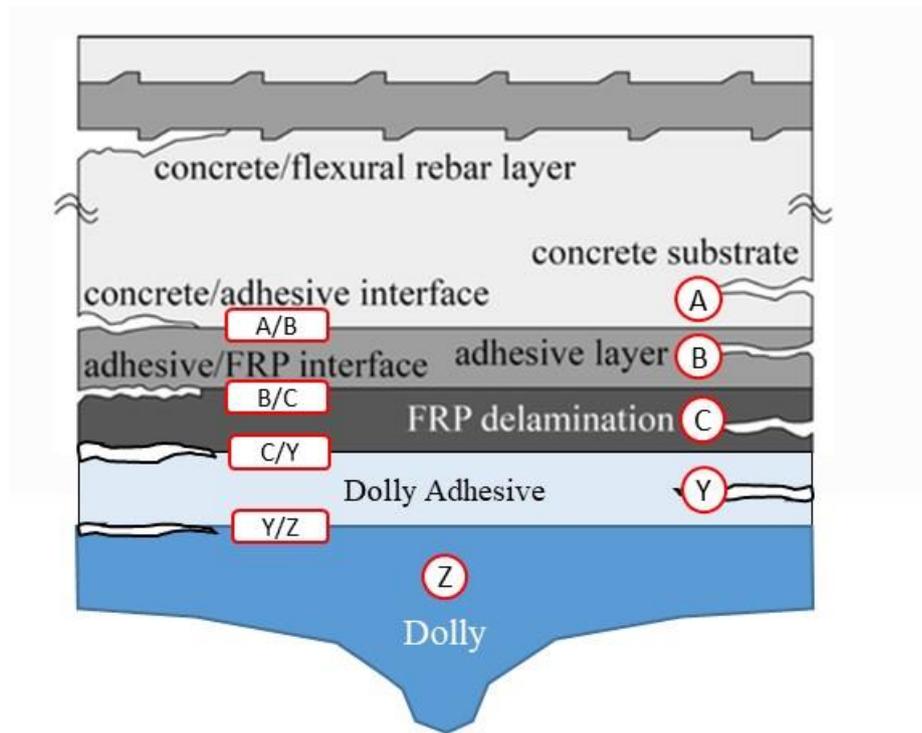


Figure 1: In-situ Direct Pull-off Test Failure Modes

Validity of Test Result

The load at failure is valid for all types and combinations of failure, except where an abnormal failure occurs. Raise as a non-conformance mean bond strengths less than 1.5 MPa.

An abnormal failure is where the adhesive layer fails (failure Types Y, x/Y and Y/Z), record the result, but exclude the result from calculation of the mean. Check the correct mixing ratio and application procedure of the adhesive, and that it is suited to the repair material under test. Undertake additional tests at alternative locations to achieve the minimum test frequency.

Where the bond strength at an individual test location is less than the minimum value required by this Technical Standard and the failure occurs within the substrate concrete (Type A failure mode), record the result, and count the test as a pass (repair system integrity and bond strength exceed the existing concrete substrate properties). SA Water's Representative may request additional testing in this situation to assess integrity of the existing concrete substrate.

Where the bond strength at an individual test location is less than the minimum value required by this Technical Standard and the failure occurs fully or partially within the FRP material (Type A/B or B failure mode), assess the possible cause such as misalignment of the dolly/test instrument, unusual/atypical presence of voids, or presence of coarse aggregate at the bond line. Undertake an additional set of three tests and exclude the non-confirming result from calculation of the mean bond strength.

WITNESS POINT

Appendix A : Schedules of Hold Points, Witness Points and Identified Records

A1 Schedule of Hold Points

Clause	Type	Description
2.4	Hold	Design Report submission
3.2	Hold	Approved repair materials
3.3	Hold	Material testing
3.5	Hold	Materials submissions
4.8	Hold	Pre-work survey – Mark defect on structure
4.10	Hold	Trial FRP application
5.2.5	Hold	Soundness of the prepared substrate
5.2.6	Hold	Moisture test of substrate
5.6	Hold	Completion of protective coating
5.8	Hold	Inspection and testing after FRP application

A2 Schedule of Witness Points

Clause	Type	Description
3.4.4	Witness	Concrete Surface Primer
5.4.1	Witness	Cleaning prior to FRP Application
5.4.3 5.4.4 5.4.5	Witness	FRP application
6.9.2	Witness	Acceptance criteria

A3 Schedule of Identified Records

Clause	Description
2.4	Design Report
3.5	Materials Submissions
4.3.3	Pre-start meeting record
0	Daily Records
4.8	Pre-work survey – Mark up plan of defects
6	Inspection and Test results
4.3.5	As-Repaired Report