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1. Scope

- 1.1 This Austroads Technical Specification ATS 5380 sets out the requirements for the strengthening of concrete structures using Fibre Reinforced Polymer Composite (FRPC) strengthening systems, including supply and quality of materials, surface preparation, trial and permanent installation, relevant inspection and testing and acceptance criteria.

2. Definitions

- 2.1 The following definitions apply to this Specification:

Fibre Reinforced Polymer (FRP):

Carbon, aramid or glass fibres which are used to produce the various types of fibre reinforced polymer plates, strips, rods, sheets and fabric materials by impregnating or saturating them with epoxy resins or other adhesive materials.

Fibre Reinforced Polymer Composite (FRPC):

FRPC systems are a combination of fibre reinforcing materials and adhesive materials (such as resins and epoxies) which act in composite to strengthen a concrete structure.

Resin: The polymeric material used to bind together the reinforcing fibres in FRP.

3. Referenced Documents

- 3.1 The following documents are referenced in this specification:

Australian /New Zealand Standards

AS 1012.14	Method for securing and testing cores from hardened concrete for compressive strength and mass per unit volume
AS 1012.24	Determination of the Tensile Bond Strength of Concrete - Repairs and Strengthening Systems
AS 1627	Metal finishing - Preparation and pretreatment of surfaces – Method selection guide
AS/NZS 2312	Guide to the protection of structural steel against atmospheric corrosion by use of protective coatings
AS 5100.8	Bridge design Part 8: Rehabilitation and strengthening of existing bridges
AS/NZS 5131	Structural steelwork—Fabrication and erection

British Standards

BS 6319	Testing of resin and polymer/cement compositions for use in construction.
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Austroads

ATS 5340	Cementitious Patch Repair of Concrete
ATS 5341	Repair of Concrete Cracks
ATS 5343	Coating of Concrete

4. Quality System Requirements

- 4.1 The Contractor must prepare and implement a Quality Plan that includes:
- a) details the proposed materials, including resins, primers, putty fillers, saturants, adhesives and reinforcing fibres;
 - b) evidence of that the materials comply with this Specification, including relevant test results and certificates of compliance, which must not be more than 24 months old;
 - c) proposed methods of obtaining access to the site;
 - d) proposed methods to ensure that vehicles and pedestrians are adequately protected during the installation of the FRPC;
 - e) Work Method Statements / Procedures and Inspection and Test Plans for the application of strengthening system, including information on the proposed substrate preparation, method of application, equipment, and operators; and
 - f) details of the experience and training of the FRPC site supervisor and key personnel.
- 4.2 The Work Method Statement / Procedures and Inspection and Test Plans must:
- a) cross reference all applicable Specification clauses; and
 - b) identify all performance requirements and Hold Points.

HOLD POINT 1.

Process Held	Commencement of FRPC work on site.
Submission Details	The Quality Plan must be provided at least 14 days prior to the commencement of FRPC work on site.

5. Contractor Competency

- 5.1 The Contractor warrants that it (or the subcontractor, if the FRPC work is being undertaken by a subcontractor) is:
- a) suitably skilled and experienced in undertaking the application of FRPC systems; and
 - b) holds all approvals from the FRPC materials manufacturer that are necessary to ensure that the manufacturer's warranties are not voided.
- 5.2 The FRPC supervisor must be suitably trained and qualified on all aspects of application techniques and must be present at each stage of both the trial and permanent FRPC strengthening installation works.
- 5.3 Personnel applying the FRPC system must be suitably trained and skilled in the application of coatings to concrete.

6. Material Properties

- 6.1 The constituent materials of FRPC strengthening systems includes all compatible resins, primers, putty fillers, saturants, adhesives and reinforcing fibres as required. All property and strength requirements of resin and adhesive materials must be determined from testing in accordance with BS 6319.
- 6.2 All FRP materials must be used in accordance with the manufacturer's recommendations, material safety data sheets, and as specified in this Specification.
- 6.3 Material details must include documented evidence of previous performance, relevant test results and certificates of compliance traceable to the proposed FRPC strengthening system(s), which must not be more than 24 months old. If not provided with the Quality Plan, this evidence must be provided to the Principal at least 21 days prior to the commencement on work on site.
- 6.4 The FRP materials must comply with Clause A2 Materials of AS 5100.8 Appendix A Fibre Reinforced Polymer (FRP) Strengthening.

7. Handling and Storage of Materials

- 7.1 All FRP system materials must:
 - a) be stored, Handled and applied in accordance with the manufacturer's instructions;
 - b) be used in the order of manufacture;
 - c) be clearly identifiable on site with the manufacturer's name, product type, reference number and batch number;
 - d) be kept clean and free of contamination;
 - e) be checked for possible damage resulting from transportation, handling or incorrect cutting prior to use; and
 - f) not be used if it is with within 30 days of its expiry date and/or shelf life.
- 7.2 Where FRPC system material is supplied in protective wrapping, it must be kept in that wrapping until immediately prior to application.
- 7.3 Where FRPC system material is supplied in containers, it must be stored in dry conditions, not exposed to direct sunlight and remain in the original, sealed containers until time of use
- 7.4 Any FRPC system material surface which is not clean or has been contaminated may only be used if it is thoroughly cleaned without degrading its properties.
- 7.5 FRP plates, laminates, strips or rods must:
 - a) be supplied and stored on site in a manner that prevents damage or contamination;
 - b) be free from unintended curves, bows, wraps, undulations or twists;
 - c) be handled with clean gloves under dry conditions and touching of ready for bonding surfaces without protective plastic must be avoided.
- 7.6 FRP fabric sheets or rolls must be:
 - a) handled carefully and free from wraps, twists or fibre misalignment;
 - b) stored either by being rolled to a diameter greater than or equal to the original roll packaging or by being dry stacked after cutting; and
 - c) protected from dust and moisture.

- 7.7 The Contractor must provide, for each batch of FRPC system material, a copy of the manufacturer's information as specified below:
- a) manufacturer's name and address;
 - b) product reference;
 - c) batch number of identification;
 - d) quantity manufactured in the batch;
 - e) certificate of date of manufacture.
- 7.8 The Contractor must maintain traceability records showing which elements were treated with each batch of FRPC system material.

8. Environmental Constraints

- 8.1 FRPC strengthening systems must not be applied under any of the following conditions:
- a) windy conditions where over spray and/or spatter may be generated;
 - b) when wind-borne debris is likely to contaminate the uncured surface of the freshly applied coating;
 - c) when the ambient temperature exceeds 30°C or is below 5°C unless otherwise agreed to in writing by the manufacturer;
 - d) when the concrete surface temperature exceeds 35°C;
 - e) when the concrete surface temperature is below 8°C unless an appropriate heating method is in place;
 - f) when the surface temperature of the substrate is less than 3°C above the dew point calculated in accordance with AS 2312;
 - g) when the relative humidity exceeds 85% unless an appropriate drying method is in place;
 - h) when rain spatter or run-off, including leakage through deck joints, contaminating the surface and adversely affecting the adhesion to the substrate, may occur;
 - i) when the moisture content of the concrete or cementitious repairs exceeds 10%; and
 - j) when the surface moisture condition of the concrete is not dry and/or it does not satisfy the manufacturer's recommendations.
- 8.2 The environmental conditions must be measured, recorded and assessed against the above requirements once every four hours of each shift or more frequently during periods when the weather is rapidly changing. A calibrated commercially available hygrometer (psychrometer) or electronic climatic measuring gauge must be used to determine the parameters which require readings.
- 8.3 The Contractor's procedures must include provisions for the management of adverse environmental conditions, including the suspension of work where appropriate.
- 8.4 The Contractor must adhere to the manufacturer's instructions regarding drying and curing requirements, and overcoating time intervals, for the prevailing environmental conditions. If any of the prevailing on site environmental conditions stated in this Clause retard the curing and strength development of the adhesive, the Contractor must implement accelerated curing measures, which must include as a minimum the use of heating enclosures, covering with heating blankets and preheating of the adhesive prior to mixing, to ensure timely setting and satisfactory curing and strength development of the adhesive.

9. Trial Application

- 9.1 As a condition precedent to the commencement of full scale FRPC work, the Contractor must complete a trial application of the FRPC strengthening system which demonstrates that the FRPC work will comply with this Specification.

WITNESS POINT 1.

Process Held	Commencement of the full scale FRPC works
Submission Details	Notification of the proposed date for trial application, include details of the test areas, must be provided at least 14 days beforehand.

- 9.2 At a minimum, the test area must not be less than 1.5 m² for each type of concrete surface.
- 9.3 The surface layer of the concrete must be prepared in accordance with the requirements of Clause 11.
- 9.4 During the trial application, actual coverage rates of adhesives and other resins must be recorded, in order that due allowance may be made in the full-scale application for rough, irregular or highly absorbent concrete substrate. Additional requirements or observations must be recorded and considered for the full-scale application.
- 9.5 If a trial application is successful, the FRPC strengthening system must be the same as that used in the trial.
- 9.6 If the trial application does not satisfy all applicable requirements of this Specification:
- the non-compliant work must be removed;
 - a proposal for a new trial application which rectifies the deficiencies of the earlier trial must be submitted; and
 - the trial application is repeated until the trial satisfies all applicable requirements of this Specification.

HOLD POINT 2.

Process Held	Commencement of the full scale FRPC works.
Submission Details	A trial application which demonstrates that the proposed FRPC work complies with this Specification must be completed at least 14 days prior to the commencement of full scale FRPC work.

10. Protection of Works and Property

- 10.1 The Contractor must:
- protect already completed works during abrasive blasting operations or any other surface preparation process and during FRPC system application processes;
 - ensure that the FRPC works are protected from adverse conditions, dust and debris during the curing period of the FRPC system;
 - implement suitable protective measures and methods during the installation of the FRPC system to ensure that vehicles and pedestrians are adequately protected from these works; and
 - remove all adhesive residues, droppings and smudges from all surfaces, including surfaces not being treated.
- 10.2 At all times while work is underway on site, the Contractor must remove all waste (including spent abrasive, liquids, packaging and general rubbish) from the site on a daily basis. Waste must be handled, transported and disposed of in accordance with any environmental requirements / regulations applicable to the works.

11. Concrete Surface Preparation

- 11.1 The Contractor must provide the Principal with at least 14 days prior notification of its proposed date for commencing work on site.

WITNESS POINT 2.	
Process Held	Commencement of surface preparation.
Submission Details	Notification of the proposed date for commencing work on site be provided at least 14 days beforehand.

- 11.2 Concrete surfaces must be dry, and be free from all dust, oil (e.g. from form release oils), grease, laitance and loose particles, remnants of curing compounds, waxes, coatings, impregnations, organic contaminants (i.e. moss, algae etc.) and other bond inhibiting materials. Methods used to prepare the concrete surface include wet or dry abrasive blasting, wire brushing, abrasion with angle grinder, or by high pressure water jet blasting as required to provide a clean sound surface.
- 11.3 Areas of persistent contamination must be removed from the surface by the use of appropriate solvents or detergents followed by washing with potable water in accordance with AS 1627.1. The surfaces must then be allowed to dry thoroughly.
- 11.4 The surface preparation process must be managed to ensure that all abrasive materials and debris emissions are contained, collected, removed from site and disposed of in compliance with applicable environmental regulations.
- 11.5 Abrasive blast cleaning must be carried out in accordance with AS 1627.4. Dust from the surface preparation must be removed by blowing with dry and oil free compressed air or other suitable means. The surface must be vacuumed before the application of the FRP material.
- a) The surface layer of the concrete must be removed to expose small particles of well-bound aggregate such that the roughness to be achieved lies between an amplitude of 0.5 mm to 1 mm, with a surface presenting similar to 60 grit sandpaper. The surface must not be roughened excessively.
 - b) The following must be filled with a suitable epoxy putty adhesive, compatible with the FRPC strengthening system:
 - i) blow holes;
 - ii) areas of honeycombing;
 - iii) loose surface layers and weak concrete;
 - iv) cracks of width less than 0.20 mm for reinforced concrete members;
 - v) cracks of width less than 0.10 mm for pre cast prestressed elements and reinforced concrete structures located in marine or other saline environments; and
 - vi) other defects, either revealed by a grinding process or exposed by other surface preparation methods.
- 11.6 Any cracks present must be repaired by pressure injection of low viscosity epoxy resin in accordance with the requirements of ATS 5341, as follows:
- a) cracks of width equal to or greater than 0.10 mm for all pre-cast pre-stressed concrete elements;
 - b) cracks of width equal to or greater than 0.20 mm for reinforced concrete elements, except that for reinforced concrete elements located in marine and other saline environments epoxy injection shall be for all cracks of width equal to or greater than 0.10 mm.
- 11.7 If the surface of the concrete is weak, more material must be removed, and the amount removed and refilled must be sufficient to result in a strong, sound substrate suitable for the intended FRPC strengthening system. Where necessary, projecting fins, rough spots, sudden steps or other surface irregularities must be ground to less than 1 mm by light abrasion with an angle grinder or filled with a suitable epoxy putty adhesive to provide a smooth concrete surface.

- 11.8 The cored holes must be cleaned and repaired with a suitable shrinkage compensating cementitious repair material to the original surface profile in accordance with the requirements of ATS 5340. The exposed surface of the repaired breakouts or core holes must be similar in texture and colour to the surrounding concrete.
- 11.9 The Contractor must determine the moisture content of each type of concrete surface to be strengthened with FRP using a commercially available calibrated moisture meter. At least one test per sample must be carried out immediately prior to the commencement of each day's FRPC strengthening works to ensure that the concrete moisture content is less than 10%.
- 11.10 Where fibre fabric is to be wrapped around corners, the corners must be rounded to a minimum radius of 25 mm to avoid local damage to the fabric.
- 11.11 The unevenness of the concrete substrate surface must be such that the gap under a 2 m straightedge does not exceed 4 mm. The general unevenness with respect to a 0.3 m straightedge must not exceed 1 mm. Any out of tolerance areas must be rectified with a suitable rapid setting levelling putty filler.
- 11.12 Any cementitious repairs undertaken in accordance with the requirements of ATS 5340 must be cured for at least 14 days prior to undertaking any FRPC strengthening application.
- 11.13 FRPC strengthening system application may be undertaken earlier than 14 days, but no earlier than 7 days, if it can be established using a commercially available calibrated moisture meter that the moisture content of cementitious repairs is less than 10%, and provided the concrete surface is dry at the time of application.
- 11.14 The concrete surface requirements of this Clause apply to all types of FRPC strengthening systems including FRP plate, laminate, strip, fabric sheets and near surface mounted (NSM) FRP rods or strips.

12. Properties of Existing Concrete

General

- 12.1 Unless the Principal has provided the properties of the existing concrete beforehand, the Contractor must determine the in situ compressive strength and the direct tension (pull off) strength for each type of concrete surface to be strengthened with FRP.

HOLD POINT 3.

Process Held	Coring of concrete.
Submission Details	The proposed location of concrete cores must be provided at least 7 days prior to the commencement of coring.

- 12.2 The minimum acceptable in situ concrete compressive strength determined in accordance with AS 1012.14 is 17 MPa and the minimum acceptable concrete pull-off strength is 1.5 MPa as measured in accordance with AS 1012.24.
- 12.3 The Contractor must provide a copy of all test results including photographic records to the Principal within one week of undertaking such testing and prior to proceeding with the FRPC strengthening works.

In situ Compressive Strength as determined from Concrete Cores

- 12.4 Concrete test cores must be cut from a structural element representing a group of elements and each type of concrete surface to be strengthened with FRP. A minimum of three cores per sample must be tested in accordance with AS 1012.14. Each core must be 75 mm diameter and a minimum of 150 mm long. All cores must be clearly labelled to identify them with the structural element and location they represent.
- 12.5 Core samples must be located with a calibrated cover meter capable of detecting the presence of steel reinforcement with an accuracy of ± 1 mm at a depth of 25 mm, to avoid cutting through the reinforcing steel. Drilling cores in areas of high stress, or creating core holes below the waterline must be avoided. Where cores are cut from concrete decks and slabs, core locations must be remote from wheel paths. Cores containing steel reinforcement must not be tested.

Concrete Pull-Off Strength

- 12.6 The Contractor must conduct partially cored direct pull off tests of a structural element representing a group of elements and each type of concrete surface to be strengthened with FRP. A minimum of three tests per sample must be tested.
- 12.7 The pull off testing must be undertaken in accordance with the requirements of AS 1012.24 using 50 mm diameter aluminium dollies only. Dollies with a diameter smaller than 50 mm must not be allowed.
- 12.8 The cored holes must be cleaned and repaired with a suitable shrinkage compensating cementitious repair material to the original surface profile in accordance with the requirements of ATS 5340. The exposed surface of the repaired breakouts or core holes must be similar in texture and colour to the surrounding concrete.

13. System Installation

Primer and Epoxy Putty Requirements

- 13.1 A primer must be applied to the prepared concrete substrate. The primer must be uniformly applied to all areas of the prepared concrete surface using brush or roller, in accordance with the manufacturer's recommendations and specified rate of coverage. Airless spray equipment can be used provided thorough back rolling is undertaken to work the primer into the concrete surface.
- 13.2 Compatible epoxy putty must only be used to fill voids, smooth surface discontinuities and treat minor imperfections prior to the application of other materials. Rough edges or lines of cured putty must be ground smooth prior to proceeding with the installation. The putty must have rapid strength gain characteristics which enable over-bonding to be carried out after a short time and must be capable of being applied in thin layers where required
- 13.3 Prior to applying the adhesive or the saturating resin the primer and putty filler must be allowed to cure for the required period in accordance with the material manufacturer's specified requirements, to ensure satisfactory adhesion at the interface of the two materials. Where the primer and putty filler are completely cured, additional surface preparation may be required prior to the application of the saturating resin or adhesive consistent with the FRPC strengthening system compatibility requirements.

Mixing of Resins

- 13.4 The mixing of resins must be in accordance with the FRPC system manufacturer's recommended procedures including recommended batch sizes, mix ratios, mixing methods, mixing times, current material safety data sheets, and as specified in this Specification. The temperature of all resin components must be between 10°C and 30°C at the time of mixing. Resin and hardeners must be mixed together in accordance with manufacturer's recommended proportions and required mixing times until there is a uniform, homogeneous mixing of components and colour streaks are eliminated. No excess material must be left in the individual component containers.
- 13.5 Resin components must be mixed using slow speed electrically powered mixing paddles. All mixed resin must be used within the specified pot life. Any resin remaining at the end of the specified pot life must be discarded. Scales or volumetric equipment used must be calibrated at 3 monthly intervals.

Drying and Curing Requirements

- 13.6 The Contractor must adhere to the manufacturer's instructions regarding drying and curing requirements, re application time intervals for adhesives and other resins, and prevailing weather conditions.

Application of Plates, Laminates or Strips

- 13.7 The bonding surface of the FRP plate, laminate or strip must be thoroughly cleaned and where required abraded lightly as per the manufacturer's recommendations prior to application. Where cutting of the FRP laminate is required, it must be installed securely to prevent any longitudinal splitting.
- 13.8 The adhesive must be applied to the prepared bonding concrete surface immediately after mixing as a thin layer by means of a notched steel trowel or equivalent. The adhesive must cover the whole of the bonding area and must be maintained at a thickness in the range of 1 mm to 2 mm. A further adhesive layer must be applied to the cleaned and fully dried FRP plate, laminate or strip to form a dome profile across the plate with 3 mm of adhesive material in the centre and 1 mm on the edges.
- 13.9 The FRP plate, laminate or strip must be brought into contact and lightly pressed with the fingers onto the prepared bonding area. The FRP material must be further pressed on with a hard rubber roller until the extra adhesive is squeezed out along the sides. The roller pressure must be applied from the centre going to the outer edge such that no voids are formed between the laminate and the concrete substrate surface. The excess adhesive must be removed. The layer thickness of the final adhesive along the bond line of the laminate must be a minimum of 1.5 mm and a maximum of 3 mm.
- 13.10 Adhesive residues on the laminate surface must be removed with a compatible chemical remover prior to hardening.
- 13.11 Where required, additional parallel FRP plates, laminates or strips must be applied at a minimum distance of 5 mm from the adjacent FRP material.
- 13.12 Where FRP plates, laminates or strips are lapped, the minimum overlap, in the longitudinal fibre direction, must be 300 mm.
- 13.13 If the FRP plate, laminate or strip requires temporary support during curing the FRPC system must be fully cured before the support is removed.

Application of Fabric Sheets

- 13.14 The saturating resin or bonding adhesive must be uniformly applied at the coverage rates specified in the material manufacturer’s data sheet to saturate the concrete surface using hand-held foam roller, brush or scraper to ensure adhesion of the fabric material. The fabric sheets must be cut to the prescribed sizes using suitable cutters. The FRP fabric sheets must be applied to the resin-saturated concrete surface by pressing manually onto the adhesive such that it is stretched in order to avoid wrinkles or the introduction of voids. The surface of the fabric must be rolled over the backing paper to force the impregnation of the resin into the fabric material. Rolling must be in the longitudinal direction of the fibres along the centreline and working outwards to expel excess adhesive at the edges to ensure the removal of any entrapped air and produce an even adhesive line. Any backing paper or other protective layer must then be peeled away.
- 13.15 Where subsequent layers of saturation resin are required as part of the FRPC strengthening system design, the Contractor must allow the specified minimum time to elapse before applying the second coat of resin in accordance with the material manufacturer’s data sheet. The time between mixing and application of the saturation resin must be in accordance with the material manufacturer’s data sheet.
- 13.16 Where FRP fabric sheets or strips are lapped the minimum overlap in the longitudinal fibre direction, must be 300 mm. Additional resin must be applied to the outer surface of the fabric layer to be overlapped. No lapping in the lateral fibre direction must be allowed. Any lifting or delamination that occurs during the application period must be corrected by pressing the fabric sheet using a foam roller or spatula.
- 13.17 Where multiple layers of FRP fabric sheet are required as part of the design of the FRPC strengthening system, these must be applied in accordance with the material manufacturer’s recommendations, data sheet, and as specified in this Specification.
- 13.18 Where the resin is factory applied or it is applied onto the fabric on site using hand held foam rollers, brushes or impregnation machines prior to application, the Contractor must develop additional procedures for the application process.

HOLD POINT 4.

Process Held	Application of resin.
Submission Details	Procedures for the application of resin must be provided at least 7 days prior to the commencement of coring.

Anchorage and Steel Protection Requirements

- 13.19 Where required, anchorage must be provided as detailed on the drawings.
- 13.20 Fibre anchors must not be fabricated on-site and must be manufactured and delivered directly from the manufacturer.
- 13.21 Fabrication and protective treatment of steel anchorage plates and bolts used as part of FRPC strengthening systems shall comply with the requirements of AS/NZS 5131.
- 13.22 Carbon based FRP materials must be isolated from galvanised or non-galvanised steel anchorages, steel reinforcement, steel bolts and other steel components such that galvanic corrosion is avoided.
- 13.23 Isolation measures must include the application of a 0.5 mm to 1 mm thick layer of epoxy coating, the placement of a non-conductive layer of glass fibre reinforced polymer (GFRP) fabric or the placement of a cementitious mortar as appropriate.

14. Application of Near Surface Mounted FRP Rods or Strips

Saw Cutting of Grooves

- 14.1 Grooves for Near Surface Mounted (NSM) FRPC must be saw-cut in a straight line and to the dimensions as shown on the drawings. The Contractor must implement controls such that the grooves are cut in a straight line. The tolerances for saw cutting of grooves must be as follows:
- Depth and width of groove 0 to + 2 mm
 - Longitudinal line tolerance of the groove, ± 5 mm in plan view.
- 14.2 The Contractor must take care to avoid existing steel reinforcement and must verify that there is adequate cover to existing steel reinforcement for the nominated groove depths by using a commercially available concrete cover meter. The cover meter must be supported with a current calibration certificate and must be capable of detecting the presence of reinforcement and indicating the depth from the concrete surface to the nearest point on the surface of the reinforcement with an accuracy of ± 1 mm at a depth of 25 mm.
- 14.3 The Contractor must avoid existing steel reinforcement by adjusting groove locations.
- 14.4 Any redundant grooves must be filled to the full depth with an epoxy adhesive in accordance with the requirements of Clause 6.
- 14.5 If reinforcing steel has been damaged, the Contractor must ensure that a structural assessment to evaluate the damage is undertaken and submit a rectification proposal. The structural assessment must be undertaken by the Professional Engineer who designed the strengthening system. An independent verification check (Proof-Engineering) of the effect of the damaged reinforcing steel must also be undertaken. Both the designer and the Proof-Engineer must be prequalified or registered in any applicable prequalification or registration scheme applicable to the jurisdiction where the works are taking place.

HOLD POINT 5.

Process Held	Rectification of damaged reinforcing steel.
Submission Details	A proposal, including supporting calculations, for rectification of damaged reinforcing steel must be provided at least 7 days prior to the commencement of the rectification.

Installation of Adhesive and FRP Rods or Strips

- 14.6 After priming, an initial portion of the epoxy adhesive must be paced into the prepared and clean groove to approximately mid-depth. The FRP rod or strip must be pressed into the adhesive followed by the remainder of the adhesive to fill the groove, while ensuring that the rod or strip is fully enveloped. The adhesive surface must be levelled, evenly finished and consolidated with a purpose built trowel such that any entrapped air bubbles are expelled. The NSM FRPC bonding operation must be completed within the allowable working time of the adhesive.
- 14.7 The Contractor must ensure that the NSM FRP rods or strips are centred within the groove such that a minimum of 3 mm adhesive thickness is left between the rod or strip and the sides and bottom of the groove.
- 14.8 The Contractor must ensure that the required surface preparation and roughness, cleanliness and drying out of the grooves such that the required mechanical interlock between the adhesive and the concrete substrate is achieved. Dust and other contaminants must be removed from the grooves immediately prior to filling with adhesive to prevent any adverse effects on the bond strength along the sides or bottom of the groove.

- 14.9 The adhesive must be well mixed to the correct proportions with the correct equipment in accordance with the requirements of Clause 13 and must be placed into the groove within the allowable gel or working time ensuring that air voids are eliminated.
- 14.10 If any of the prevailing on site environmental conditions stated in Clause 8 retard the curing and strength development of the adhesive, the Contractor must implement accelerated curing measures, including use of heating enclosures and preheating the adhesive resins, to accelerate strength development and prevent traffic-induced vibration effects on the NSM FRPC strengthening system.

15. Additional Requirements FOR FRPC Strengthening of Concrete Bridge Decks

- 15.1 Prior to undertaking design and installation works for FRPC strengthening of concrete bridge decks, the Contractor must undertake an investigation to determine both the depth of concrete cover to the steel reinforcement and the thickness of the existing asphalt, as affected by any variability that may exist in shape and profile of the concrete deck. These measurements must be allowed for in both the design and installation of the FRPC strengthening system.
- 15.2 Such measurements must be undertaken at 3 metre intervals and within a 3 metre grid over the whole area to be strengthened and over the whole area where cold milling (cold planing) of asphalt may be required.
- 15.3 The depth of concrete cover to the steel reinforcement must be determined by using a commercially available concrete cover meter. The cover meter must be supported with a current calibration certificate and must be capable of detecting the presence of reinforcement and indicating the depth from the concrete surface to the nearest point on the surface of the reinforcement with an accuracy of ± 1 mm at a depth of 25 mm. The thickness of asphalt must be determined by taking 25 diameter cores through to the top surface of the concrete deck.
- 15.4 Where cold milling is required, a milling procedure and ITP must be submitted a minimum of 7 days prior to the commencement of cold milling of asphalt over the concrete bridge deck, allowing for the planned base of cut to the top surface of the concrete deck. The milling procedure must include details on the type, mass and number of milling machine(s) and other equipment to be used and the proposed measures to control dynamic effects and proposed measures to avoid cutting damage to the concrete surface and steel reinforcement
- 15.5 Nil tolerance must apply on the depth of milling cut to the surface of the concrete deck. No grooving of the concrete surface must be allowed.
- 15.6 A milling machine with fine milling drum must be used on concrete bridge decks.
- 15.7 During the cold milling operation all necessary precautions must be taken to prevent the cutting teeth from contacting the concrete surface. The actual depth of cut must be measured on both sides of the cold milling machine at intervals not exceeding 3 metres.
- 15.8 All milling work must be subject to continuous observation for variability or change in cut surface appearance and all observations documented.
- 15.9 In the event that the cutting teeth contact the concrete surface the progress of the cold milling machine must cease immediately, any machine fault repaired, and the machine settings and controls readjusted.
- 15.10 Milling operators must have adequate training and experience in the operation of the cold milling machine and automatic sensing equipment. Relevant experience and training records of each operator must be included in the Quality Plan.

- 15.11 During milling operations, the Contractor must provide three suitably trained and skilled milling machine operators at the cold milling machine at all times, one on the driving platform and one on each side of the machine generally in the vicinity of the sensor/cutting mandrel.
- 15.12 At the completion of cold milling, all loose milled material must be removed and the concrete surface prepared in accordance with the requirements of this Specification.

16. Inspection and Testing

General

- 16.1 The Contractor must undertake all inspection and testing of the installed FRPC strengthening system with calibrated equipment as specified in this Clause. The Contractor must maintain all required documentation and results as specified in this Specification.
- 16.2 The work must be inspected by the Contractor at each stage of the FRPC strengthening operation as a minimum, i.e. after surface preparations, mixing of materials, prior to and after adhesive and resin application and any touch up that may be required and both during and after installation of FRP plates, laminates, strips or fabric sheets.

Testing for Drummy Areas

- 16.3 A visual inspection of the FRPC works must be conducted immediately after installation is complete and any defects recorded. The cured FRPC strengthening system must also be visually inspected and checked for delaminations, air voids, and bubbles between multiple layers or between the FRP material and the concrete, 7 days after completion of installation.
- 16.4 The drumminess test must be conducted along the whole length of each applied FRP plate, laminate, strip, rod or fabric sheet using a small hammer (or similar). Areas where the FRP material has not bonded correctly to the concrete or to subsequent layers will be characterised by a 'drummy' or hollow sound.
- 16.5 Delamination size, location, and quantity relative to the overall application area must be recorded and evaluated with respect to structural integrity and durability of the FRPC system. Small delaminations less than 25 mm x 25 mm do not require corrective action provided the total delaminated area is less than 5% of the FRPC strengthened area and provided that there are no more than 5 such delaminations per 1 m². Where these requirements are not complied with, the effective delaminated area must be considered as a large delamination area and repaired in accordance with the requirements of Clause 18. Individual or isolated delaminations, air voids or bubbles larger than 25 mm x 25 mm must be marked and repaired in accordance with the requirements of Clause 18.
- 16.6 Notwithstanding the requirements of this Clause, delaminations must not be present within 300 mm of the termination of FRP plates, laminate, strip, rod or fabric sheets

Testing for Flatness

- 16.7 The evenness of FRP plates, laminate, strip or fabric sheets must not deviate by more than 4 mm when checked with a 2 m straightedge. In addition, evenness must not deviate by more than 1 mm when checked with a 300 mm straightedge. If the requirements for flatness are not achieved, additional FRP plates, laminates, strips or fabric sheets must be fixed in locations to rectify the unevenness.

Adhesion (Pull-Off) Testing for FRP Plates, Laminates or Strips and Fabric

- 16.8 The Contractor must conduct partially cored direct pull-off tests of the fully cured FRPC system on sacrificial extensions of the permanent works to verify the tensile bond between the FRP material and the existing concrete substrate, 7 days after the completion of installation. The sacrificial extension of the FRP material must be installed at the same time and under the same application conditions as the permanent works in accordance with the requirements of this Specification.
- 16.9 The pull-off testing must be undertaken in accordance with the requirements of AS 1012.24 using 50 mm diameter aluminium dollies only. Dollies with a diameter smaller than 50 mm must not be allowed. Testing for FRP plates, laminates or strips must be carried out at a frequency of 3 tests per each 50 lineal metre run or part thereof of FRPC strengthened area. Testing for FRP fabric sheets must be carried out at a frequency of 3 tests per 5 m² of FRPC strengthened area. The mean bond strength at 7 days must be greater than 1.5 MPa, provided no individual result is below 90% of 1.5 MPa.
- 16.10 The mode of failure of the pull-off test must be in the concrete substrate. Mean bond strengths less than 1.5 MPa or failure between the FRP system and the concrete substrate or between layers of FRPC must be raised as a non-conformance
- 16.11 After the pull-off test is complete the cored holes must be filled and smoothed with a polymer modified cementitious material in accordance with ATS 5340 or with the FRPC system putty filler in accordance with Clause 6.

Testing and Inspection of Near Surface Mounted (NSM) FRP Rods or Strips

- 16.12 Testing and inspection of NSM rods or strips must be as follows:
- Undertake the adhesion (pull-off) test directly over the NSM FRP rod or strip area in accordance with test method AS 1012.24, with coring into the epoxy adhesive and surrounding concrete of up to 15 mm for the subsequent bonding of the 50 mm diameter aluminium dolly.
 - Testing for NSM FRP rods or strips must be carried out at a frequency of 3 tests per each 50 lineal metre run or part thereof of FRPC strengthened area. The mean bond strength at 7 days must be greater than 1.5 MPa, provided no individual result is below 90% of 1.5 MPa.
 - Upon completion of the adhesion (pull-off) test undertake a visual inspection of the dolly to visually verify the bond and integrity of the fractured concrete onto the sides of the split epoxy adhesive surfaces.
 - Visually verify the presence of any voids on the split surfaces of the epoxy adhesive both in situ and on the dolly. If voids are observed the work represented by the sample may be rejected and the Contractor must take additional measures as required to improve the placement and consolidation of the of the epoxy adhesive into the groove.
 - A 50 mm diameter core must be extracted from within the sacrificial extension to the full depth of the NSM FRP rod or strip installation, at the sampling frequency as specified in Clause 1616.12b) to visually verify the consolidation of the resin adhesive around the NSM FRP rods or strips and the sides of the groove. If voids or unsatisfactory consolidation or bond is observed the work represented by the sample may be rejected and the Contractor must take additional measures as required to improve the placement and consolidation of the epoxy adhesive into the groove.
 - Visual inspection and measurement must verify if the FRP rods or strips are centred within the groove and if a minimum of 3 mm adhesive thickness is left between the NSM FRP rod or strip and the sides and bottom of the groove, in accordance with the requirements of Clause 14.

Compressive Strength of Adhesives and Resins

- 16.13 The Contractor must take a sample of 3, 75 mm test cubes from the first batch of material mixed, then a sample of three 3, 75 mm cubes for every 100 kg of material used thereafter to test for compressive strength. The cubes must be cured for 7 days as per the material manufacturer's recommendations. Two cubes must be tested at 7 days and the third cube at 28 days, to confirm compliance with the minimum compressive cube strengths as specified in Clause 6. Test cubes must be made, cured and tested in accordance with BS 6319.
- 16.14 Test cubes must be made in rigid steel moulds which are provided with a rigid steel cover plate of similar dimensions to the base plate of the mould.
- 16.15 Following placement of the mixed adhesive or resin into the mould and striking of the surface, the cover plate must be placed and fully restrained by use of clamps or screws.
- 16.16 Test cubes smaller than 75 mm must not be allowed for compressive strength testing of adhesives and resins.

Adhesive Bond Line Thickness of FRP Plates, Laminates and Strips

- 16.17 The layer thickness of the final adhesive along the bond line of FRP plates, laminates and strips must be measured to confirm a minimum thickness of 1.5 mm and a maximum thickness of 3 mm in accordance with the requirements of Clause 13.

17. Application of Decorative/Anti-Carbonation Coating

- 17.1 The Contractor must apply two coats of a decorative/anti-carbonation coating to a total minimum dry film thickness of 150 micron, to both the FRPC strengthened and non-strengthened surfaces of the specified works in accordance with the requirements of ATS 5343. The coating must extend 500 mm onto the concrete surface beyond the FRPC strengthening.
- 17.2 Application of decorative/anti-carbonation coating must not be required for FRPC applications on the top surfaces of bridge decks.
- 17.3 The decorative/anti-carbonation coating must be alkali resistant and must be suitable for use on FRP material surfaces.

18. System Repairs

- 18.1 Non-compliant work includes:
- a failure to comply with any specified environmental constraint;
 - a failure to comply with the manufacturer's instructions or any requirement of this Specification;
 - delaminations, surface damage, air voids or bubbles larger than 25 mm x 25 mm; and
 - wrinkling of the FRP material or broken fabric.
- 18.2 Any non-compliant work must be repaired so that the work complies with this Specification. This may include removal of the FRPC areas concerned, followed by surface preparation and application of new layers of FRP material or NSM FRP rods.
- 18.3 Large delaminations greater than 300 mm x 300 mm must be repaired by selectively cutting away the affected FRP material, followed by surface preparation and application of overlapping FRP layers.

- 18.4 Delaminations, air voids or bubbles greater than 25 mm x 25 mm in size but less than 300 mm x 300 mm must be repaired by either resin injection or FRP layer replacement.
- 18.5 Wrinkling of the FRP material or broken fabric must be repaired by the application of additional layers.
- 18.6 Prior to commencement of the repair work, the Contractor must prepare a procedure for that repair work and provide details of the scope of the repair work.

HOLD POINT 6.	
Process Held	Commencement of repair work
Submission Details	Details of the scope of the repair work and a procedure for the repair work must be provided at least 7 days prior to the commencement of the repair work.

Annexure A: Summary of Hold Points, Witness Points and Records

The following is a summary of the Witness Points / Hold Points that apply to this specification and the Records that the Contractor must supply to the Principal to demonstrate compliance with this specification.

Clause	Hold Point	Witness Point	Record
4.2	1. Commencement of work on site.		Quality plan
7.7			Certificate from the manufacturer for each batch of materials
7.8			Traceability records
9.1		1. Notification of the proposed date for trial application	
9.6	2. Trial application		Evidence of successful completion of trial application
11.1		2. Notification of the proposed date for commencing surface preparation	
12	3. Coring of existing concrete		Proposed location of concrete cores.
12			Test results for concrete compressive strength and Pull-off strength
13.18	4. Application of resin.		Procedures for the application of resin
14.5	5. Rectification of damaged reinforcing steel		Proposal for rectification of damaged reinforcing steel
16.3			Test results for drumminess
16.7			Test results for flatness
16.8			Test results for Adhesion (Pull-Off) Testing
16.12			Test results for NSM FRP Rods or Strips
16.13			Test results for Compressive Strength of Adhesives and Resins
16.17			Test results for Adhesive Bond Line Thickness
18	6. Commencement of repair work		Proposal for repair work

Amendment Record

Amendment no.	Clauses amended	Action	Date
-	New specification	New	January 2020

Key

- Format Change in format
- Substitution Old clause removed and replaced with new clause
- New Insertion of new clause
- Removed Old clauses removed