ICC EVALUATION SERVICE®

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March 1, 2024

TO: PARTIES INTERESTED IN FIBER-REINFORCED POLYMER (FRP) ANCHORS FOR EXTERNALLY BONDED FRP COMPOSITE STRENGTHENING SYSTEMS FOR CONCRETE

SUBJECT: Proposed Revisions to the Acceptance Criteria for Fiber-Reinforced Polymer (FRP) Anchors For Externally Bonded FRP Composite Strengthening Systems for Concrete, AC557-0324-R1 (MS/MC)

Dear Colleague:

We are seeking your comments on proposed revisions to the acceptance criteria, AC 557, as presented in the enclosed draft. The proponent of these revisions is Simpson Strong-Tie. The revisions, which are being posted on the ICC-ES web site for 30 days of public comment, may be summarized as follows:

1. The criteria has been revised to include through FRP anchors. In the criteria, the strength of the through anchors will be conservatively limited to the strength of the bent FRP anchors as determined by the criteria. See Sections 1.2, 1.4.6, 1.4.6.5 and 6.1.10.

   See letter from Simpson Strong-Tie, dated February 27, 2024, appended to this memo, for justification.

2. The criteria has been revised to include use of prescriptive design and detailing in accordance with ACI PRC 440.2-23 *Design and Construction of Externally Bonded Fiber-Reinforced Polymer (FRP) Systems for Strengthening Concrete Structures—Guide*. For use of FRP anchors in prescriptive design, the criteria has been revised to require FRP anchors comply with additional ACI PRC 440.2-23 requirements. See Sections 1.2, 1.3.5, 3.8 and 6.1.11.

   See letter from Simpson Strong-Tie, dated February 27, 2024, appended to this memo, for justification.

3. Minor editorial revisions have been made to the criteria, as noted:
   a) Referenced codes and standards editions have been added under Table 6 of the criteria. In addition, Section 1.3 has been modified to reference Table 6.
   b) The footnotes under Table 5 have been updated to correct previously mis-referenced sections.

Should the Evaluation Committee approve the proposed revisions to the criteria, no mandatory compliance date will be required.

While the Evaluation Committee will be voting on the revised criteria during the 30-day comment period, we will seriously consider all comments from the public and will pull the criteria back for reconsideration if public comments raise major issues. In that case, we would seek a new committee vote; further revise the draft and post it for a new round of public comments; or put the revised criteria on the agenda for a future Evaluation Committee hearing.

If they are of interest, please review the proposed revisions and send us your comments at the earliest opportunity.

To submit your comments, please use the form on the web site and attach any letters or other materials. If you would like an explanation of the "alternate criteria process," under which we are soliciting comments, this too is available on the ICC-ES web site.

Please do not try to communicate directly with any Evaluation Committee member about a criteria under consideration, as committee members cannot accept such communications.

Thank you for your interest and your contributions. If you have any questions, please contact me at (800) 423-6587, at extension 3691, or Manuel Chan, S.E., Principal Structural Engineer, at extension 3288. You may also reach us by e-mail at es@icc-es.org.

Yours very truly,

Melissa Sanchez

Melissa Sanchez, SE, LEED AP
Principal Structural Engineer

MS/ls

Encl.

cc: Evaluation Committee

February 27, 2024

Melissa Sanchez, S.E., LEED AP
Principal Structural Engineer
ICC Evaluation Service, LLC
Western Regional Office
3060 Saturn Street, Suite 100
Brea, CA 92821

Subject: AC557 Revision

Dear Melissa,

The proposed revision to ICC-ES AC557 includes two main items; specific language stating that bent and through anchors are in the scope of this document and a reference to ACI PRC-440.2-23: Design and Construction of Externally Bonded Fiber-Reinforced Polymer (FRP) Systems for Strengthening Concrete Structures—Guide. Justification for each of these proposed revisions is discussed below:

1. Through FRP anchors are now proposed to be included in the scope, along with bent FRP anchors. These two FRP anchor types are now explicitly stated within the scope section. The current version of the document only provides testing and design provisions for bent FRP anchors, but this was not clear in the scope section. The inclusion of through FRP anchors into the scope is justified and conservative, based on the following points. Per ICC-ES AC557 Equation 19, the three failure modes of bent FRP anchors are bent FRP anchor rupture, dowel bond, and splay bond. The three possible failure modes of through FRP anchors are bent FRP anchor rupture (for 'bent' through anchor ends), straight FRP anchor rupture (for 'straight' through anchor ends), and splay bond. Dowel bond, or concrete-side failures, are precluded in through FRP anchors as no force is transferring to the concrete. The only possible additional failure mode of through FRP anchors, which is not tested within the bent FRP anchor testing included within this AC, is straight FRP anchor rupture. Straight FRP anchor rupture occurs at a higher load than bent FRP anchor rupture, as demonstrated by the design equations from del Rey Castillo et al (2019)[(1)]. The design equation for straight FRP anchor rupture is:

$$N_{fr}^{95\%} = 3.1 E_a \varepsilon_a 10^{-3} A_{dowel}^{0.62} \left(\frac{90 - \alpha}{90} \right) \tag{5}$$

   While the design equation for bent FRP anchor rupture is:

$$N_{fr}^{95\%} = 2.2 E_a \varepsilon_a 10^{-3} A_{dowel}^{0.62} \left(\frac{90 - \alpha}{90} \right) \tag{7}$$

   Therefore, assuming the bent FRP anchor rupture strength for straight FRP anchor rupture will be conservative.

2. ACI PRC-440.2-23 contains prescriptive provisions for FRP anchors for anchoring U-wraps for shear strengthening. These provisions may be used in lieu of ICC-ES AC557 “Section 3.7: FRP Anchor Strength and Design” to design FRP anchors evaluated per ICC-ES AC557. The prescriptive provisions of ACI PRC-440.2-23 use a different design approach than ICC-ES AC557, but the two documents can be used together.

Please contact me with any questions you may have regarding this subject.

Sincerely,

Griff Shapack, P.E.
Senior Product Engineer
Simpson Strong-Tie Company Inc.

dw/MB

Reference:

(1) del Rey Castillo, Enrique & Kanitkar, Ravi & Smith, Scott & Griffith, M. & Ingham, Jason. (2019). Design approach for FRP spike anchors in FRP-strengthened RC structures. Composite Structures. 214. 10.1016/j.compstruct.2019.01.100.

PROPOSED REVISIONS TO ACCEPTANCE CRITERIA FOR FIBER-REINFORCED POLYMER (FRP) ANCHORS FOR EXTERNALLY BONDED FRP COMPOSITE STRENGTHENING SYSTEMS FOR CONCRETE

AC557

Proposed March 2024

Previously approved October 2023

PREFACE

Evaluation reports issued by ICC Evaluation Service, LLC (ICC-ES), are based upon performance features of the International family of codes. (Some reports may also reference older code families such as the BOCA National Codes, the Standard Codes, and the Uniform Codes, or other codes as designated by the ICC-ES president.) Section 104.11 of the *International Building Code®* reads as follows:

> **The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.**

ICC-ES may consider alternate criteria for report approval, provided the report applicant submits data demonstrating that the alternate criteria are at least equivalent to the criteria set forth in this document, and otherwise demonstrate compliance with the performance features of the codes. ICC-ES retains the right to refuse to issue or renew any evaluation report, if the applicable product, material, or method of construction is such that either unusual care with its installation or use must be exercised for satisfactory performance, or if malfunctioning is apt to cause injury or unreasonable damage.

Acceptance criteria are developed for use solely by ICC-ES for purposes of issuing ICC-ES evaluation reports

PROPOSED REVISIONS TO ACCEPTANCE CRITERIA FOR FIBER-REINFORCED POLYMER (FRP) ANCHORS FOR EXTERNALLY BONDED FRP COMPOSITE STRENGTHENING SYSTEMS FOR CONCRETE (AC557)

1.0 INTRODUCTION

1.1 Purpose: The purpose of this acceptance criteria is to establish requirements for fiber-reinforced polymer (FRP) composite anchors for externally bonded FRP composite strengthening systems for concrete to be evaluated in an ICC Evaluation Service, LLC (ICC-ES) evaluation report for use under the 2021, 2018, 2015 and 2012 *International Building Code*® (IBC) and 2021, 2018, 2015 and 2012 *International Residential Code*® (IRC). Bases of evaluation are IBC Section 104.11 and IRC Section R104.11.

The reason for the development of this criteria is to provide guidelines for the evaluation of alternative systems, where the codes do not provide requirements for testing and determination of structural capacities, reliability, and serviceability of these products.

1.2 Scope: This acceptance criteria applies to FRP composite anchors embedded in concrete with epoxy resin, with the opposite end to be used in conjunction with externally bonded FRP composite strengthening systems for concrete. FRP anchors shall be produced in a manufacturing facility. Evaluation of field-produced fiber anchors are outside the scope of this criteria.

This criteria contains provisions for the evaluation of material and durability properties, and structural capacity of bent FRP anchors and through FRP anchors with optional tests for seismic and sustained loading. FRP anchors evaluated under this criteria are intended to be used ~~for~~with ~~the development of~~ externally bonded FRP laminates evaluated under AC125. Alternatively, FRP anchors complying with this criteria may also be used prescriptively as provided in ACI PRC-440.2

1.3 Referenced Codes and Standards: Where standards are referenced in this acceptance criteria, the standards shall be applied consistently with the IBC edition upon which compliance is based (See Table 6).

1.3.1 2021, 2018, 2015 and 2012 *International Building Code*® (IBC), International Code Council.

1.3.2 2021, 2018, 2015 and 2012 *International Residential Code* (IRC), International Code Council.

1.3.3 ACI 211.1, Selecting Proportions for Normal-Density and High-Density Concrete-Guide, American Concrete Institute.

1.3.4 ACI 318, Building Code Requirements for Structural Concrete, American Concrete Institute.

1.3.5 ACI PRC-440.2, Design and Construction of Externally Bonded Fiber-Reinforced Polymer (FRP) Systems for Strengthening Concrete Structures—Guide, American Concrete Institute.

1.3.6 ASTM C31, Standard Practice for Making and Curing Concrete Test Specimens in the Field, ASTM International.

1.3.7 ASTM C33, Standard Specification for Concrete Aggregates, ASTM International.

1.3.8 ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM International.

1.3.9 ASTM C150, Standard Specification for Portland Cement, ASTM International.

1.3.10 ASTM D7205, Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars, ASTM International.

1.3.11 ASTM D8337, Standard Test Method for Evaluation of Bond Properties of FRP Composite Applied to Concrete Substrate using Single-Lap Shear Test, ASTM International.

1.3.12 ASTM E488, Standard Test Methods for Strength of Anchors in Concrete Elements, ASTM International.

1.3.13 ICC-ES Acceptance Criteria for Quality Documentation (AC10), ICC Evaluation Service.

1.3.14 ICC-ES Acceptance Criteria for Test Reports (AC85), ICC Evaluation Service.

1.3.15 ICC-ES Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber-Reinforced Polymer (FRP) Composite Systems (AC125), ICC Evaluation Service.

1.3.16 ICC-ES Acceptance Criteria for Inspection and Verification of Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-Reinforced Polymer (FRP) and Steel-Reinforced Polymer (SRP) Composite Systems (AC178), ICC Evaluation Service.

1.3.17 ICC-ES Acceptance Criteria for Inspections and Third-Party Inspection Agencies (AC304), ICC Evaluation Service.

1.3.18 ISO 21930-2017 Sustainability in Buildings and Civil Engineering Works - Core Rules for Environmental Product Declarations of Construction Products and Services, International Organization for Standardization (ISO).

1.4 DEFINITIONS

1.4.1 Composite Material: A combination of high-strength fibers and polymer matrix material. This FRP composite may be applied either during manufacture of the structural element or at the project location.

1.4.2 Design Values: The FRP composite material's load and deformation design capacities based on ultimate strength methods.

1.4.3 Epoxy Resin: Polymer matrix resin used to saturate FRP fabrics or FRP anchors to create an FRP composite, or to form an adhesive bond between an FRP anchor dowel and the surrounding concrete.

1.4.4 Fiber Volume Fraction: Ratio of the volume of fibers to the volume of the composite containing the fibers.

1.4.5 Field-Produced Fiber Anchors: Fiber anchors produced on a project site from a bundled tow fiber spool, rolling or cutting FRP fabrics into an anchor, or any other field-fabricated process that requires the amount of fiber per unit length and/or the length of the anchors to be determined manually in the field by installation personnel.

1.4.6 FRP Anchor: An anchor made from composite material consisting of a dowel portion~~,~~ to be installed into concrete, and a ~~fan, or~~ splay~~,~~ portion on ~~the other~~one or both ends, to be attached to an FRP laminate. FRP anchor splays fan out in a sector of a circle in the primary fiber direction of the laminate. The dowel portion of the FRP anchor may be precured in the manufacturing facility or field-saturated.

1.4.6.1 Bent FRP Anchor: FRP anchor installed with the dowel embedded into concrete at an angle between 90° to 135° with respect to the FRP anchor splay attached to the FRP laminate.

1.4.6.2 Field-saturated FRP anchor: FRP anchor that is delivered to the project site dry, or unsaturated, but is produced in a controlled manufacturing facility with a determined amount of fiber per unit length and is cut to length as specified by the FRP designer. Both the dowel and splay portion of the anchor must be saturated during installation in the field.

1.4.6.3 Precured FRP Anchor: FRP anchor that is partially precured with epoxy resin at the dowel end only during manufacturing. The splay portion of the anchor remains unsaturated and must be saturated and cured in the field within the FRP laminate.

1.4.6.4 Straight FRP Anchor: FRP anchor installed with the dowel embedded into concrete in line with the FRP anchor splay attached to the FRP laminate.

1.4.6.5 Through FRP Anchors: FRP anchor installed with the dowel portion embedded completely through a concrete member with anchor splays on both ends of the FRP anchor.

1.4.7 FRP Anchor Dowel: Embedded portion of the FRP anchor installed into the concrete substrate using epoxy resin.

1.4.8 FRP Anchor Dowel Angle: The inside angle between the FRP anchor dowel and the splay (refer to Figure 2).

1.4.9 FRP Anchor Splay: Fan portion of the FRP anchor that is installed in a sector of a circle configuration onto the FRP composite laminate.

1.4.10 FRP Anchor Splay Angle: The inside angle of the FRP anchor splay at the dowel (refer to Figure 1).

1.4.11 FRP Anchor Splay Length: The length of the FRP anchor splay in the direction of fibers (refer to Figure 1).

1.4.12 FRP Anchor Splay Width: The maximum distance across the extreme fibers of the FRP anchor splay, measured perpendicular to the primary fiber direction of the laminate (refer to Figure 1).

1.4.13 Pot Life of the Epoxy: Time it takes the epoxy to set after mixing is completed.

1.4.14 Wet Lay-up: A manufacturing process where dry fiber is impregnated on-site with a saturating resin matrix and then cured-in place.

1.5 NOMENCLATURE

A_{fa} = $d_a^2 * \pi/4$ = nominal cross-sectional area of FRP anchor after saturation, in^2 (mm^2).

A_{splay} = surface area between the FRP anchor splay and the FRP composite laminate, in^2 (mm^2).

a = constant determined by regression analysis in accordance with Section 3.6.4.

b = constant determined by regression analysis in accordance with Section 3.6.4.

c = FRP anchor edge distance, in. (mm).

c_{min} = minimum FRP anchor edge distance, in. (mm).

d_a = nominal diameter of FRP anchor, in. (mm).

d_o = diameter of FRP anchor hole, in. (mm).

F_i = test result normalized to consider concrete strength, lb (N).

F_k = characteristic value (5 percent fractile) from testing, lb (N).

$F_{k,ASB}$ = characteristic value (5 percent fractile) of FRP anchor splay bond testing result, lb (N).

$F_{k,BAB,cr}$ = characteristic value (5 percent fractile) of bent FRP anchor bond testing result, cracked concrete, lb (N).

$F_{k,BAB,un}$ = characteristic value (5 percent fractile) of bent FRP anchor bond testing result, uncracked concrete, lb (N).

$F_{k,BAR}$ = characteristic value (99.7 percent confidence) of bent FRP anchor rupture testing result, lb (N).

$F_{k,SAB,un}$ = characteristic value (5 percent fractile) of straight FRP anchor bond testing result, uncracked concrete, lb (N).

F_N = characteristic value (99.7 percent confidence) from testing, lb (N).

$F_{N,CAT}$ = characteristic value (99.7 percent confidence) of composite axial tension testing result, lb (N).

$\bar{F}_{test,x}$ = mean of test results for test series x, lb (N).

$F_{u,test,x}$ = test result from test series x, lb (N).

f'_c = specified compressive strength of concrete, psi (MPa).

$f_{c,\ test}$ = concrete compressive strength as measured at the time of testing, psi (MPa).

$f_{c,test,x}$ = mean concrete compressive strength measured with standard cylinders, per Section 3.3.3, of the test members used for test series x, psi (MPa).

$f_{c,\ test,i}$ = concrete compressive strength corresponding to the tests used to establish $\bar{N}o, i$, psi (MPa).

f_d = dowel rupture strength of composite FRP anchors, psi (MPa).

h = member thickness, in. (mm).

h_{ef} = embedment depth of straight FRP anchor, inches (mm).

h_{efb} = embedment depth of bent FRP anchor, in. (mm).

h_{min} = minimum member thickness, in. (mm).

K = tolerance factor corresponding to a 5 percent probability of non-exceedance with a confidence of 90 percent derived from a noncentral t-distribution for which the population standard deviation is unknow (values for specific samples size n are provided in Table 2.

l_a = length of FRP anchor, in. (mm).

N_{asb} = FRP anchor splay bond strength, lb (N).

$N_{bs,b}$= bent FRP anchor bond strength, lb (N).

N_{et} = mean tension capacity of an anchor at elevated temperature, lb (N).

$N_{k,et}$ = characteristic tension capacity at elevated temperature, lb (N).

$N_{k,o}$ = characteristic tension capacity of an anchor in reference test series lb (N).

N_{red} = reduced sustained load applied in the sustained load test as required to satisfy displacement or residual strength criteria, lb (N).

$N_{sust,lt}$ = sustained tension load applied in reliability testing, lb (N).

$\bar{N}o,i$ = mean tension capacity of FRP anchor in reference bond tests in low-strength concrete, lb (N).

n = 0.5 for concrete breakout and splitting failure or when failure is characterized by pullout or when tests are performed as confined tests.

s = FRP anchor spacing, in. (mm).

s_{min} = minimum FRP anchor spacing, in. (mm).

$stdv$ = standard deviation, lb (N).

t = time related to the total recorded displacement, in hours.

$t_{service}$= intended FRP anchor service life, in hours, (assumed to be 50 years under standard conditions).

V_{ar} = bent FRP anchor rupture strength, lb (N).

V_{eq} = maximum shear load to be applied in the simulated seismic shear test, lb (N).

$V_{eq,reduced}$ = reduced maximum shear load at which the anchor successfully completes the simulated seismic shear test, lb (N).

V_{fa} = design shear strength of composite bent FRP anchor, lb (N).

V_i = intermediate shear load to be applied in the simulated seismic shear test, lb (N).

$V_{i,reduced}$ = reduced intermediate shear load to be applied in the reduced simulated seismic shear test, lb (N).

V_m = minimum shear load to be applied in the simulated seismic shear test, lb (N).

$V_{m,reduced}$= reduced minimum shear load to be applied in the reduced simulated seismic shear test, lb (N).

$\bar{V}o,i$= mean shear capacity of FRP anchor in reference bond tests in uncracked low-strength concrete with $h_{ef} = 4d_a$, lb (N).

V_{sb} = splay bond strength of the FRP anchor, psi (MPa).

$v_{test,x}$ = coefficient of variation of the population sample corresponding to test series x, percent.

w_{fa} = splay width of FRP anchor, in. (mm).

α_a = full splay angle of FRP anchor, degrees.

$\alpha_{ar,b}$ = bent FRP anchor rupture strength coefficient.

$\alpha_{b,et}$ = reduction factor for FRP anchor from elevated temperature loading.

$\alpha_{b,seis}$ = reduction factor for bent FRP anchor under seismic loading.

α_{COV} = reduction factor for larger coefficients of variation.

$\alpha_{p,sust}$ = reduction factor for FRP anchor in sustained loading.

β = dowel angle of FRP anchor, degrees.

γ_{wt} = FRP Anchor dry fiber weight per unit length, oz/in. (g/cm).

$\sigma_{bs,b,cr}$ = bent FRP anchor bond strength in cracked concrete, psi (MPa).

$\sigma_{bs,b,un}$ = bent FRP anchor bond strength in uncracked concrete, psi (MPa).

$\sigma_{bs,s,un}$ = straight FRP anchor bond strength in uncracked concrete, psi (MPa).

$\Delta(t)$ = overall displacement of the test recorded at time t, in. (mm).

Δ_{lim} = mean maximum displacement measured immediately before failure from the reference bond tests from Section 4.3.1.

$\Delta_{t=0}$ = initial displacement under sustained load, in. (mm).

$\Delta_{service}$ = projected total displacement over the intended service life of the FRP anchor, in. (mm).

2.0 BASIC INFORMATION

2.1 General: The following information shall be submitted:

2.1.1 Product Description: A detailed description of the FRP anchor system is needed, including the following items:

1. **FRP anchor:** The FRP anchor specifications, including dowel rupture strength (f_d), diameter, fiber volume fraction, weight per unit length, minimum and maximum tested splay width, minimum and maximum tested splay length, dowel angle, cross sectional area, minimum and maximum tested embedment depth.
2. **FRP Composite Laminate and Epoxy Resin**: The FRP composite laminate material and epoxy resin shall comply with ICC-ES Acceptance

Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber-Reinforced Polymer (FRP) Composite Systems (AC125) and be evaluated under a valid ICC-ES evaluation report.

3. **Epoxy Resin**: The epoxy resin properties shall be provided, including packaging system, mixing instructions, mixing ratios, pot life, storage information and shelf life, if applicable.

2.1.2 Manufacturer's Published Installation Instructions: Manufacturer's Published Instructions for Installation (MPII) shall be submitted. At minimum, it shall include the following items.

1. Description of how the product or system will be used or installed in the field, including FRP anchor hole diameter, cleaning and curing.
2. Procedures establishing quality control in field installation.
3. Requirements for product handling and storage.

2.1.3 Packaging and Identification: Product identification shall be in accordance with the product identification provisions of the ICC-ES Rules of Procedure for Evaluation Reports. A description of the method of packaging and field identification of FRP anchors shall be submitted to ICC-ES. The ICC-ES mark of conformity, electronic labeling, and/or the evaluation report number (ICC-ES ESR-XXXX) along with the name, registered trademark, or registered logo of the report holder [and/or listee] must be included in the product label. Additionally, each container of FRP anchors shall bear a label which clearly identifies the product name, model, and size.

2.2 Testing Laboratories: Testing laboratories shall comply with Section 2.0 of the ICC-ES Acceptance Criteria for Test Reports (AC85) and Section 4.2 of the ICC-ES Rules of Procedure for Evaluation Reports.

2.3 Test Reports: Test reports shall comply with AC85 and include the following:

1. Identification of the test standard used and the date of issue of the standard, and other relevant information concerning the test procedure, justification for any deviations from the referenced test standard, and any critical information relevant to the specific test.
2. Description of the sample selection method in accordance with Section 2.4 of this criteria.
3. Description of installation of FRP anchor.
4. Description of test setup.
5. Rate and method of loading.
6. Loading steps and measurements.
7. Deformation and strain measurements.
8. Modes of failure.
9. Comparison of test results and nominal design values.

2.4 Product Sampling: Sampling of FRP anchors for tests under this criteria shall comply with Section 3.1 of AC85.

2.5 Qualification Test Plan: A qualification test plan shall be submitted to and approved by ICC-ES staff prior to any testing being conducted.

3.0 TEST AND PERFORMANCE REQUIREMENTS:

3.1 General: The specimens shall be constructed under conditions specified by the manufacturer, and should simulate installation (including curing), anticipated loading conditions and load levels of the FRP anchor system in the field.

3.2 Physical Properties of FRP Composite Materials: Evaluation of environmental durability exposure resistance of the FRP anchor materials shall be achieved in accordance with ICC-ES AC125 Sections 5.9 through 5.16 and 5.18, as applicable. Composite coupon specimens used for testing shall be made from the same components as the FRP anchors being evaluated. The FRP anchors shall have a fiber volume fraction greater than or equal to the composite coupon specimens tested.

FRP anchors that are made with the same FRP composite system components that have been evaluated in a published ICC-ES evaluation report in accordance with AC125, with fiber volume fractions greater than or equal to those of the laminates evaluated under AC125, do not require the testing listed above in this section.

3.3 Concrete:

3.3.1 General: The concrete used to produce test members shall comply with the following:

Concrete mix design shall follow recommendations for proportioning in ACI 211.1 or ACI 318. Portland Cement shall comply with ASTM C150. Coarse and fine aggregate in concrete shall comply with ASTM C33 for normal-weight concrete.

Concrete test cylinders shall be prepared in accordance with ASTM C31. Cylinders shall be stored and cured in accordance with Section 10.2 of ASTM C31 (field cure). To determine the compressive strength of test members, cylinders shall be tested in accordance with ASTM C39.

3.3.2 Test members: Test members shall be prepared in accordance with Section 6.4 of ASTM E488.

3.3.3 Compressive Strength Determination: Reported concrete compressive strength for any test series shall be determined from tests in this section.

Test members shall be cured a minimum of 28 days prior to beginning of tests.

Concrete compressive strength at time of tests for low-strength concrete shall be between 2500 psi (17.2 MPa) to 4000 psi (27.6 MPa). Compressive strength at time of tests for high-strength concrete shall be between 6500 psi (44.8 MPa) to 8500 psi (58.6 MPa).

Two tests of two cylinders, or cores, shall be performed at the beginning and end of testing. The beginning of the compressive strength tests shall be concurrent with the initiation of FRP anchor load testing. The beginning and ending strength results shall be averaged (four cylinders or cores, total) to establish the strength of the test members during the test period.

For concrete aged 90 days or more, the compressive strength test may be determined by taking the average of three cylinders or cores tested on a single day, performed within 30 days of the FRP anchor load testing.

3.4 FRP Anchor System Test Program: Tests for FRP anchors assessed in uncracked and cracked concrete conditions shall be in accordance with Table 1 and Section 4.0 of this criteria.

3.4.1 Requirements for Test Specimens: Install FRP anchors according to the Manufacturer's Printed Instructions for Installation (MPII). FRP anchors shall be installed in test specimens in the same manner they are installed in the field.

If the tested portions of the FRP anchors are installed in a wet layup process without precuring in the field, they shall be installed the same way in test specimens. The time between initial saturation of the FRP anchor dowel and installation of the FRP anchor dowel into concrete shall be less than the pot life of the epoxy used.

When FRP anchor dowels are installed with an epoxy thickened with fumed silica, the maximum allowable ratio of fumed silica to epoxy must be used in testing, and reported in the test report for quality control documentation purposes.

3.4.2 Test Results: Test results shall be analyzed in accordance with Section 3.6 of this criteria and shall be reported in accordance with Table 4 and Table 5 of this criteria. The format in Table 4 and Table 5 may be modified as appropriate provided that the basic intent of the content of these tables is met.

3.5 Test Assessment Report: The report shall include a complete analysis and interpretation of the test results. FRP anchor design strength shall be specified based on analyses and testing but shall not be higher than as specified in Section 3.7.

Design strength shall be based on a characteristic value approach as defined in Sections 3.6.1.2 and 3.6.1.3.

3.6 Test Data Assessment:

Design parameters shall be calculated in accordance with this section and reported for each test series. Design parameters shall be used for design in accordance with Section 3.7.

3.6.1 Normalization and Statistical Evaluation:

3.6.1.1 Normalization of FRP anchor capacities for concrete strength: For all test series in Sections 4.3, 4.4.2 and 4.4.3, the test result, F_i, shall be normalized to 2500 psi (17.2 MPa) concrete strength using Equation (1).

$$F_i = F_{u,test,x}\left(\frac{2500}{f_{c,test,x}}\right)^n \quad (1)$$

3.6.1.2 Characteristic Values from Testing (5 percent fractile): For test series in Sections 4.3, 4.4 and 4.5, the characteristic value, F_k, shall be calculated using Equation (2).

$$F_k = \alpha_{COV}[\bar{F}_{test,x}(1 - K \times v_{test,x})] \quad (2)$$

where K values for specific sample sizes, *n,* are provided in Table 2.

3.6.1.3 Characteristic Material Property Values (99.7 percent confidence): For test series in Section 4.2, the characteristic value, F_N, shall be calculated using Equation (3).

$$F_N = \alpha_{COV}[\bar{F}_{test,x} - 3\text{stdv}] \quad (3)$$

3.6.1.4 Requirement on Coefficient of Variation for Reference Tests: For each test series, excluding reliability and service-condition tests, the coefficient of variation (COV) of the peak load shall not exceed 15 percent. For test series where $(COV)v_{test,x}$ exceeds 15 percent, determine a reduction factor α_{COV} with Equation (4).

If COV ≤ 15: (4)
$\alpha_{COV} = 1$

if COV > 15:
$\alpha_{COV} = \frac{1}{1+0.03(v_{test,x}-15)} \leq 1.0$

3.6.1.5 Requirement on Coefficient of Variation for Reliability and Service-Condition Tests: For reliability and service-condition test series, the coefficient of variation (COV) of the peak load shall not exceed 20 percent. For test series where $(COV)v_{test,x}$ exceeds 20 percent, determine a reduction factor α_{COV} with Equation (5).

If COV ≤ 20: (5)
$\alpha_{COV} = 1$

if COV > 20:
$\alpha_{COV} = \frac{1}{1+0.03(v_{test,x}-20)} \leq 1.0$

3.6.2 Composite Axial Tension Tests (Ultimate Tension Strength): For each test series completed in accordance with Section 4.2, the dowel rupture strength of composite FRP anchors, f_d, shall be calculated in accordance with Equation (6).

$$f_d = \frac{F_{N,CAT}}{A_{fa}} \quad (6)$$

3.6.3 FRP Anchor Dowel Bond Shear Strength: For each test series completed in accordance with Section 4.3.1, the FRP anchor dowel bond strength of straight FRP anchors, $\sigma_{bs,s}$, shall be calculated using Equation (7).

$$\sigma_{bs,s,un} = \frac{F_{k,SAB}}{d_a \pi h_{efs}} \quad (7)$$

(Straight FRP anchor – uncracked concrete)

For FRP anchors to be qualified, the minimum straight FRP anchor dowel bond strength shall exceed 670 psi.

3.6.4 Bond Strength Coefficient of FRP Anchors under Sustained Loading (Creep Test): The overall displacement under sustained load, which accounts for both the initial elastic displacement at the onset of loading and the creep displacement from long term loading, shall be estimated for each member tested per Section 4.3.2. A logarithmic trendline shall be established to project displacements over the service life of the FRP anchor with a minimum of 20 data points from the last 20 days of the creep test by computing a least-squares fit through the data points using Eq. (8).

$$\Delta(t) = \Delta_{t=0} + at^b \quad (8)$$

The projected displacement of each FRP anchor under sustained load for the intended service life shall be computed for each test per Equation (9).

$$\Delta_{service} = \Delta_{t=0} + a(t_{service})^b \quad (9)$$

The average of the projected displacements over the FRP anchors intended service life $\Delta_{service}$ shall not be greater than Δ_{lim}. Δ_{lim} shall be taken as the average of the maximum displacement measured immediately before failure in the reference bond tests from Section 4.3.1. Additionally, the calculated projected displacement $\Delta_{service}$ for individual tests shall not be greater than $1.2\Delta_{lim}$.

If the required displacements above are not achieved, perform the testing in Section 4.3.2 under a reduced sustained load until the requirements are achieved. Once acceptable displacement performance is achieved, calculate the reduction factor $\alpha_{\rho,sust}$ in accordance with Equation (10).

$$\alpha_{\rho,sust} = min\left[\frac{N_{red}}{N_{sust,lt}}\right] \leq 1.0 \quad (10)$$

The average value of the residual tension capacity tests shall be at least 0.90 of the average reference bond strength value from the testing performed per Section 4.3.1. If this residual strength threshold is not met, reduce the sustained load for the testing in Section 4.3.2 until the requirement is met and calculate the reduction factor $\alpha_{\rho,sust}$ in accordance with Equation (10).

3.6.5 Bond Strength Coefficient of FRP Anchors at Elevated Temperature: For each test series completed in accordance with Section 4.3.3, the reduction factor for FRP anchor from elevated temperature loading, $\alpha_{b,et}$, shall be calculated using Equation (11).

$$\alpha_{b,et} = min\left[\frac{N_{et}}{\overline{N}o}; \frac{N_{k,et}}{N_{k,o}}\right] \leq 1.0 \quad (11)$$

3.6.6 Bent FRP Anchor Rupture Strength Coefficient: For each test series completed in accordance with Section 4.4.1, the bent FRP anchor rupture strength coefficient of the bent FRP anchors, $\alpha_{ar,b}$, shall be calculated using Equation (12).

$$\alpha_{ar,b} = \frac{F_{k,BAR}}{f_d A_{fa}} \leq 1.0 \quad (12)$$

3.6.7 Bent FRP Anchor Dowel Bond Shear Strength: For each test series completed in accordance with Section 4.4.2, the FRP anchor dowel bond tensile strength of bent FRP anchors, $F_{k,BAB}$,, shall be calculated using Equation (2).

The minimum dowel bond tensile strength value for a given dowel angle (β) shall be used to compute the characteristic dowel bond strength, $\sigma_{bs,b}$, per Equations (13) and (14).

$$\sigma_{bs,b,un} = \frac{\min(F_{k,BAB,un})}{d_a \pi h_{efb}} \quad (13)$$

(Bent FRP anchor – uncracked concrete)

$$\sigma_{bs,b,cr} = \frac{\min(F_{k,BAB,cr})}{d_a \pi h_{efb}} \quad (14)$$

(Bent FRP anchor – cracked concrete)

Where: min ($F_{k,BAB}$) is the minimum of $F_{k,BAB}$ for low and high strength concrete and various embedment depth test series, per Table 1.

For FRP anchors to be qualified, the minimum bent FRP anchor dowel bond strength shall exceed 670 psi.

3.6.8 Bond Strength Coefficient of Bent FRP Anchors under Seismic Loading:

3.6.8.1 Test Requirements: Simulated seismic-shear load shall be applied on all FRP anchors in the test series as specified in Section 4.4.3.2. Any failure of a member to maintain adequate capacity in completing the required loading cycles shall be considered an unsuccessful test. Following the cyclic load program, the average residual capacity of the FRP anchors in the test series shall be at least 1.6 times V_{eq}. If the test series passes the loading history and residual capacity criteria, $\alpha_{b,seis}$ shall be taken as 1.0.

3.6.8.2 Condition of Acceptance: If a test member fails the requirements in Section 3.6.8.1 at the V_{eq} load level, the test may be repeated with reduced cyclic loads in accordance with the loading history specified in Section 4.4.3.2, replacing V_{eq}, V_i, and V_m, with $V_{eq,reduced}$, $V_{i,reduced}$, $V_{m,reduced}$, respectively. The cyclic load history regime shall be completed for all FRP anchors in the test series. Any failure of a member to maintain adequate capacity in completing the required loading cycles shall be considered an unsuccessful test. The average residual capacity of the FRP anchors in the test series shall be at least 1.6 of the reduced peak load, $V_{eq,reduced}$. Successful completion of the reduced cyclic loading history and residual capacity shall be recorded along with the bent FRP anchor seismic reduction factor, $\alpha_{b,seis}$, in accordance with Equation (15).

$$\alpha_{b,seis} = \frac{V_{eq,reduced}}{V_{eq}} \quad (15)$$

3.6.9 FRP Anchor Splay Bond Strength: For each test series completed in accordance with Section 4.5, the FRP anchor splay bond strength of bent FRP anchors, V_{sb}, shall be calculated in accordance with Equation (16).

$$V_{sb} = \frac{F_{k,ASB}}{A_{splay}} \quad (16)$$

where, A_{splay} shall be calculated using Equations (17) and (18).

$$A_{splay} = \frac{\pi l_a^2 \alpha_a}{360} \quad (17)$$

$$\alpha_a = \sin^{-1}\left(\frac{w_{fa}}{2l_a}\right) \times 2 \text{ (degree)} \quad (18)$$

Each V_{sb} value shall be published in Table 5 with the corresponding tested splay configuration parameters also provided. Where FRP anchors are tested with multiple laminate types, the minimum splay bond strength shall be published for each set of tested splay configurations.

3.7 FRP Anchor Strength and Design: FRP anchor strength and detailing are determined based on the data assessment addressed in Section 3.6 and reported as design values per Section 3.4.2. The design values are calculated directly from test results. All strength reduction factors used to calculate the capacity of the FRP laminates, per AC125, that are bonded to the FRP anchors, must also be applied to the FRP anchor strengths calculated in this section.

3.7.1 Data Interpolation and Extrapolation: Interpolation between and extrapolation beyond test results is not allowed. For FRP anchors with design parameters (diameter, splay angle or splay length) matching tested parameters reported per Section 3.4.2, the design value (coefficient or bond strength) for those parameters may be used for design. For untested anchors with parameters (diameter, splay angle or splay length) that lie between two tested anchors with adjacent parameters (diameter, splay angle or splay length), the design value shall be the lesser design value (coefficient or bond strength) of the tested anchors with adjacent parameters.

All dowel angles to be included in the report shall be tested; no intermediate angles are allowed. Minimum required test parameters are listed in Table 1. Additional tests may be conducted to provide additional design values.

3.7.2 Strength of Bent FRP Anchors: FRP anchors installed in bent configuration with dowel angle between 90° to 135° from the composite FRP laminate(s) shall be evaluated based on bent FRP anchor capacity, as defined in Equation (19), taken as the minimum of value corresponding to the three failure modes calculated using Equations (20), (21), and (22).

$$V_{fa} = min(V_{ar}, N_{bs,b}, N_{asb}) \tag{19}$$

The FRP anchor rupture strength, V_{ar}, of the bent FRP anchor shall be calculated using Equation (20).

$$V_{ar} = \alpha_{ar,b} f_d A_{fa} \tag{20}$$

FRP anchor strength based on the dowel bond failure, $N_{bs,b}$, shall be calculated using Equation (21).

$$N_{bs,b} = \alpha_{b,seis}\alpha_{b,et}\alpha_{p,sus}\sigma_{bs,b(uc,cr)}\pi d_a h_{efb} \tag{21}$$

Where, $\alpha_{b,seis}$ is 1.0 when the FRP anchor is used in non-seismic applications, $\alpha_{b,et}$ is 1.0 when elevated temperature exposure is not anticipated throughout the service life of the FRP anchor, and $\alpha_{p,sus}$ is 1.0 when sustained loading on the FRP anchor is not anticipated throughout the service life of the FRP anchor. Otherwise, the variables shall be as determined as defined in Section 1.5 and Section 3.6.

The FRP anchor dowel bond capacity calculated from Equation (21) may be used for either uncracked or cracked concrete applications, as appropriate. Where one or two FRP anchors are installed into concrete where cracking is anticipated, and where FRP anchors are designed to fully develop an FRP laminate, the cracked concrete bond strength shall be used in design. For applications where a minimum number of three anchors share load to develop a given width of FRP laminate, uncracked concrete dowel bond strength may be used in design.

3.7.3 FRP Anchor Splay Strength of Bent FRP Anchor: FRP anchor splay strength for bent FRP anchor, N_{asb}, shall be determined based on the characteristic bond strength between the FRP anchor splay and the FRP composite laminate using Equation (22)

$$N_{asb} = V_{sb}(A_{splay}) \tag{22}$$

3.7.4 Embedment Depth Requirement for Bent FRP Anchors:

Minimum embedment, $h_{efb,min}$, for bent FRP anchors shall be calculated using Equation (23).

$$h_{efb,min} = \text{max. of} \begin{cases} 4d_a \\ 2'' \end{cases} \tag{23}$$

Maximum embedment, $h_{efb,max}$ for bent FRP anchors shall be calculated using Equation (24).

$$h_{efb,max} = \text{min. of} \begin{cases} 20d_a \\ 24'' \end{cases} \tag{24}$$

3.7.5 Hole Preparation: The diameter of the hole in the concrete (d_o) shall be drilled to no less than 1/8 inch (3.2 mm) larger than d_a, and no greater than 3/8 inch (9.5 mm) larger than d_a.

The drilled hole shall match the specified FRP anchor dowel angle (β) to a tolerance of ± 6 degrees.

All edges of drilled holes that will have splays bent over them shall be rounded or chamfered to a minimum radius as provided in the manufacturer's installation instructions, but no less than 0.5 in. (12.7 mm).

3.7.6 FRP Anchor Splay Width: The maximum width of FRP anchor splay, w_{fa}, shall be 12 in. (305 mm).

3.7.7 FRP Anchor Splay Length: The maximum and minimum length of FRP anchor splay, l_a, shall be as selected and tested by the manufacturer, but no less than 6 in. (152 mm).

3.7.8 FRP Anchor Splay Angle: The maximum angle of FRP anchor splay, α_a, shall be 60°. The minimum angle of FRP splay, $\alpha_{a,min}$, shall be tested and reported in the manufacturer's evaluation report.

3.7.9 FRP Anchor Spacing: The minimum FRP anchor spacing, s_{min}, (center-to-center) shall be limited to the greater of $3.0h_{efb}$ and $6d_a$.

3.7.10 FRP Anchor Edge Distance: The minimum edge distance of FRP anchor, c_{min}, shall be $1.5h_{efb}$.

3.7.11 Splay Coverage and Lateral Overlap: FRP anchor splay width shall be equal to FRP anchor spacing for the width of the FRP laminate. When multiple FRP anchors are installed, lateral overlap of FRP anchor splays is not required.

3.8 Prescriptive FRP Anchor Design: FRP anchors complying with this criteria can be used prescriptively as provided in ACI PRC-440.2, provided the laminate and FRP anchor comply with ACI PRC-440.2, including material~~and~~, stiffness, testing and evaluation requirements under Chapter 4 and Section 14.1.4 of ACI PRC-440.2, as applicable.

4.0 TEST METHODS

4.1 Limitations:

1) FRP anchors shall not be used in gravity strengthening applications unless optional testing

and assessment per Sections 4.3.2 and 3.6.4, respectively, are conducted.

2) FRP anchors are limited for use in Seismic Design Categories A and B under the IBC unless optional seismic testing and assessment per Sections 4.4.3 and 3.6.8, respectively, are provided. If optional seismic testing is provided, FRP anchors may be used in Seismic Design Categories A through F.

4.2 Composite Axial Tension Tests (Ultimate Tension Strength):

4.2.1 Configuration: FRP anchor specimens shall be configured as cured composite FRP anchors to induce dowel rupture failure. Specimen cross-sections shall be the same as typical FRP anchor dowels. Extremes of FRP anchor diameter shall be considered, as specified in Table 1. FRP anchor dowel specimens shall be fabricated prior to testing. FRP anchors shall be saturated with epoxy resin and supported from a rigid frame during epoxy curing to maintain straightness as a rod. After curing, bond both ends of the FRP anchor dowel into steel pipes with an adhesive sufficient to develop the rupture strength of the dowel. Testing criteria of the tension test shall be per ASTM D7205.

4.2.2 Procedure: The load shall be applied monotonically in the direction of the fibers until the failure mode is observed, its capacity reached, or desired limit states are achieved. The load or displacement rate shall be adjusted so that peak load occurs between 1 to 3 minutes from the start of testing.

4.3 Straight FRP Anchor Tests:

4.3.1 Confined Direct Axial Tension Tests (Reference Test – Bond Failure):

4.3.1.1 Configuration: FRP anchor specimens shall be configured to be embedded straight into the restrained substrate in uncracked concrete to induce bond shear failure to obtain the FRP anchor bond strength. Specimens shall be embedded with a wet layup installation process. If FRP anchor dowels are field saturated, the time between initial saturation of the FRP anchor dowel and installation of the FRP anchor dowel into concrete must be less than the pot life of the epoxy used. FRP anchor shall be vertically aligned over anchor hole and supported from a rigid frame during epoxy curing. FRP anchor diameter shall be 0.5 inch (12 mm) and concrete shall be low strength. The minimum embedment depth (h_{ef}) of the FRP anchor shall not be less than four diameters ($4d_a$), or 1-5/8 in. (41 mm), and the minimum spacing to adjacent tested FRP anchors shall be 1.5 times greater than the embedment depth (h_{ef}). The minimum thickness of the tested member shall be greater of 1.25 inches (32 mm) or 2 times FRP anchor diameter more than the FRP anchor embedment depth. The substrate surface shall be restrained within a radius of 1 inch (25 mm) of the FRP anchor perimeter. The testing specimen shall be unreinforced in the projecting failure mode area. Testing criteria of the confined test shall be per ASTM E488.

4.3.1.2 Procedure: The load shall be applied monotonically with either displacement-control or force-control in the direction of the FRP anchor embedment until the failure mode is observed, its capacity reached, or desired limit states are achieved. The load or displacement rate shall be adjusted so that peak load occurs between 1 to 3 minutes from the start of testing.

4.3.2 Direct Axial Tension Tests with Sensitivity to Sustained Loading (Reliability Test) – (Optional)

4.3.2.1 Configuration: The testing configuration shall be in accordance with Section 4.3.1 in uncracked concrete. This test is used to evaluate the shear bond capacity and performance of FRP anchors under sustained loads. All FRP anchors shall be installed and cured, following the recommended cure period provided by the manufacturer's instruction. Each test shall have a minimum duration of 42 days. The temperature of the test member shall remain stabilized at 73°F ± 8°F for the entire test duration.

4.3.2.2 Procedure: Tests shall be sustained tension tests in uncracked concrete, followed by confined tension tests to failure. Preload the FRP anchor not to exceed 5 percent of $N_{sust,lt}$ or 300 lb. (1.33 kN), then zero the displacement readings, then increase to a constant tension load $N_{sust,lt}$, per Equation (25).

$$N_{sust,lt} = 0.55\bar{N}o,i\left(\frac{f_{c,test}}{f_{c,test,i}}\right)^n \quad (25)$$

The applied load is maintained during the entire testing duration. Anchor displacements are to be measured and recorded throughout testing per the following schedule:

a) Every 10 minutes for the first hour
b) Every hour for the next 6 hours
c) Every day for the next 10 days
d) Every 5 to 7 days in the following days

Following the sustained loading, unload the anchor prior to performing the residual strength test. A confined tension test is then conducted to failure with continuous measurement of load and displacement. The load shall be applied monotonically with either displacement-control or force-control in the direction of the anchor embedment. The load or displacement rate shall be adjusted such that the peak load occurs between 1 to 3 minutes from the start of testing.

4.3.3 Confined Direct Axial Tension Tests at Elevated Temperature (Service-condition Test)

4.3.3.1 Configuration: Testing configuration shall be in accordance with Section 4.3.1 in uncracked concrete. This test is used to assess the sensitivity of the anchor shear bond capacity of the adhesive material to applications in concrete with elevated temperatures. All anchors shall be installed and cured at standard temperature, following the recommended cure period provided by the manufacturer.

4.3.3.2 Procedure: Before testing, heat and maintain the test members at the desired temperature for a minimum of 24 hours. Remove each test member from the heating chamber and perform the test in a confined tension test prior to the member temperature dropping below the desired qualification temperature. The load shall be applied monotonically with either displacement-control or force-control in the direction of the anchor embedment until the failure mode is observed, its capacity is reached, or desired limit states are achieved. The load or displacement rate shall be adjusted so that peak load occurs between 1 to 3 minutes from the start of testing. The minimum required temperature is 110°F. The elevated temperature used for testing shall be reported by the manufacturer.

4.4 Bent FRP Anchor Tests:

4.4.1 Tension Tests on Bent FRP Anchors (Rupture Failure):

4.4.1.1 Configuration: FRP anchor specimens shall be configured with the splay bonded to composite FRP laminate(s) to induce FRP anchor tensile rupture failure at, or near, the bend of the dowel in uncracked concrete. The composite FRP laminate is intentionally debonded from the concrete substrate to avoid fabric debonding and emphasize the failure mode in the FRP anchor bend and dowel. If FRP anchor dowels are field saturated, the time between initial saturation of the FRP anchor dowel and installation of the FRP anchor dowel into concrete must be less than the pot life of the epoxy used. Extremes of FRP anchor size, layout, and concrete strength parameters shall be considered. FRP anchor installation and splay detailing shall reflect field configurations and installation procedures for the system. The dowel portion shall be installed at a dowel angle between 90° and 135° into the substrate. Each selected dowel angle shall be tested separately. The minimum FRP anchor spacing shall be 1.5 times greater than the embedment depth (h_{efb}) in all directions. The minimum thickness (h_{min}) of the tested member shall be 1.25 in. (32 mm) or 2 times the FRP anchor diameter more than the FRP anchor embedment depth. Figure 2 presents the configuration of the bent FRP anchor. Figure 3 shows the typical test setup of bent FRP anchors to induce rupture failure.

4.4.1.2 Procedure: The load shall be applied to the FRP laminate(s) monotonically until the failure mode is observed, its capacity is reached, or desired limit states are achieved. The load or displacement rate shall be adjusted so that peak load occurs between 1 to 3 minutes from the start of testing.

4.4.2 Tension Tests on Bent FRP Anchors (Reference Test – Dowel Bond Failure):

4.4.2.1 Configuration: FRP anchor specimens shall be configured with the splay bonded to composite FRP laminate(s) to induce dowel bond failure in uncracked and cracked concrete. The composite FRP laminate is intentionally debonded from the concrete substrate to avoid fabric debonding and emphasize the failure mode in the FRP anchor bend and dowel. If FRP anchor dowels are field saturated, the time between initial saturation of the FRP anchor dowel and installation of the FRP anchor dowel into concrete must be less than the pot life of the epoxy used. Extremes of FRP anchor size, layout, and concrete strength parameters shall be considered. FRP anchor installation and splay detailing shall reflect field configurations and installation procedures for the system. The dowel portion shall be installed at a dowel angle between 90° and 135° into the substrate. Each selected dowel angle shall be tested separately. The minimum embedment depth (h_{efb}) of the FRP anchor shall not be less than four diameters ($4d_a$), or 2 in. (50 mm), and the minimum FRP anchor spacing shall be 1.5 times more than the embedment depth (h_{efb}) in all directions. The minimum thickness (h_{min}) of the tested member shall be 1.25 in. (32 mm) or 2 times the FRP anchor diameter greater than the FRP anchor embedment depth. Figure 3 and Figure 4 show the typical test setup of bent FRP anchors to induce bond failure in uncracked and cracked concrete, respectively.

4.4.2.2 Procedure: The load shall be applied to the FRP laminate(s) monotonically until the failure mode is observed, its capacity is reached, or desired limit states are achieved. The load or displacement rate shall be adjusted so that peak load occurs between 1 to 3 minutes from the start of testing.

4.4.3 Seismic Tension Tests on Bent FRP Anchors (Dowel Bond Failure – Service-condition Test) – (Optional)

4.4.3.1 Configuration: Testing configuration shall be in accordance with Section 4.4.2. This test is used to evaluate the performance of bent FRP anchors subjected to seismic tension loads. Extremes of FRP anchor sizes shall be considered. The dowel portion shall be installed at a dowel angle between 90° and 135° into the substrate. Each selected dowel angle shall be tested separately.

4.4.3.2 Procedure: All FRP anchors shall be installed in uncracked concrete. Subject the FRP anchors to the sinusoidal (tension only) shear loads in three stages, V_{eq}, V_i, and V_m, in 10, 30, and 100 cycles, respectively, under a frequency of 0.1 to 2 Hz. See Table 3 and Figure 5. The value of the three seismic tension loading stages, V_{eq}, V_i, and V_m is given in Equations (26) – (28).

$$V_{eq} = 0.5\bar{V}o,i\left(\frac{f_{c,test}}{f_{c,test,2}}\right)^{n}\ lb \qquad (26)$$

$$V_m = \frac{V_{eq}}{2} \qquad (27)$$

$$V_i = \frac{V_{eq} + V_m}{2} \qquad (28)$$

The FRP anchor displacement and applied tension load shall be recorded throughout the testing. After the simulated seismic-shear cycles are complete, load the test member to failure and record the residual capacity. The load for the residual strength test shall be applied to the FRP laminate(s) monotonically with either displacement-control or force-control until failure occurs.

4.5 FRP Anchor Splay Bond Tests:

4.5.1 Configuration: FRP anchor specimens shall be configured with the splay portion bonded onto composite FRP laminate(s) to induce debonding failure between the FRP anchor splay and the FRP laminate(s). All tests shall be single lap shear tests with the FRP laminate bonded to one side of the FRP anchor splay. Extremes of FRP anchor size, and splay width, length, and angle shall be considered. Splay detailing shall reflect field configurations and installation procedures onto the FRP laminate(s). When FRP anchors are qualified for use with multiple composite laminate types, the extremes of FRP laminate stiffness shall be tested for each tested splay configuration, where the laminate stiffness is measured by (E_{lam}*t_{lam}), with E_{lam} being the laminate modulus of elasticity and t_{lam} being the FRP laminate thickness per AC125. The width of the FRP laminate shall be at least the width of the FRP anchor splay. Figure 6 shows typical test setups for FRP anchor splay bond tests.

4.5.2 Procedure: The load shall be applied to the composite FRP laminate(s) monotonically until the failure mode is observed, its capacity is reached, or desired limit states are achieved. The load or displacement rate shall be adjusted so that peak load occurs between 1 to 3 minutes from the start of testing.

5.0 QUALITY CONTROL

5.1 Manufacturing: The FRP composites shall be manufactured under an approved quality control program with inspections by ICC-ES. A qualifying inspection shall be conducted at each manufacturing facility in accordance with the requirements of the ICC-ES Acceptance Criteria for Inspections and Inspection Agencies (AC304).

Quality documentation complying with the ICC-ES Acceptance Criteria for Quality Documentation (AC10) shall be submitted.

5.2 Installation: All installations shall be done by applicators trained and approved by the manufacturer of the system. The quality assurance program shall be documented and comply with ICC-ES Acceptance Criteria for Inspection and Verification of Concrete Reinforced and Unreinforced Masonry Strengthening Using Fiber-Reinforced Polymer (FRP) and Steel-Reinforced Polymer (SRP) Composite Systems (AC178).

Special inspection under the IBC is required, including hole cleaning and FRP anchor installation, and shall comply with Section 1704 and 1705 of the IBC and other sections of the applicable code.

6.0 EVALUATION REPORT REQUIREMENTS:

6.1 The evaluation report shall include the following information:

6.1.1 Basic information required by Section 2.1, including product description, installation procedures and identification information.

6.1.2 FRP anchor data shall be published as indicated in Section 3.4.2.

6.1.3 Language that the construction documents, prepared or reviewed by a registered design professional where required by the statutes of the jurisdiction in which the project is to be constructed, specifying the FRP anchors, must indicate compliance with this evaluation report and applicable codes and must be submitted to the code official for approval.

6.1.4 Where acceptable test data is not submitted in accordance with the optional sensitivity to Sustained Loading tests under Section 4.3.2, the evaluation report shall include a statement that FRP anchors subjected to sustained loads are outside the scope of this report.

6.1.5 Where acceptable test data is not submitted in accordance with the optional Seismic Tension Tests under Section 4.4.3, the evaluation report shall include a statement that FRP anchors are limited for use in Seismic Design Categories A and B under the IBC.

6.1.6 The FRP anchors evaluated under this ESR are intended for use with FRP laminates evaluated to ICC-ES acceptance criteria for concrete and reinforced and unreinforced masonry strengthening using externally bonded fiber-reinforced polymer (FRP) composite systems (AC125) under ICC-ES evaluation report ESR-XXXX.

6.1.7 FRP anchors are limited in use to the installation orientations tested. The installation orientations (ie. overhead, horizontal, etc.) included in the scope of the evaluation report shall be described in detail in the report.

6.1.8 FRP anchors are limited to installation in concrete made with Portland cement complying with ASTM C150.

6.1.9 The evaluation report shall contain language that protection of the composite materials in areas where they may be subject to impact loading is outside the scope of this report.

6.1.10 The evaluation report shall contain language that the strength of through FRP anchors shall be limited to the strength of the bent FRP anchors.

6.1.11 Where evidence is submitted showing compliance with Section 3.8 of this criteria, the evaluation report shall contain language that FRP anchors evaluated under the ESR report may alternatively be designed and detailed prescriptively in accordance with ACI PRC-440.2 Section 14.1.4.

7.0 ENVIRONMENTAL PRODUCT DECLARATION (Optional):

Environmental impacts shall be assessed via an Environmental Product Declaration (EPD) based on a Life Cycle Assessment (LCA). The LCA and EPD shall be conducted in accordance with ISO 21930 and the appropriate Product Category Rule(s) for the product type.■

TABLE 1 - TEST PROGRAM FOR EVALUATING FRP ANCHOR SYSTEMS OR UNCRACKED AND CRACKED CONCRETE

Test No.	Test Ref.	Purpose	Testing Parameters	Minimum Protocol[1]	Crack width, Δ_w, in.	Assessment	f_c	h_{ef}	Minimum Sample Size, n_{min}
1	4.2	Ultimate Tension Strength: Composite Axial Tension Tests[2]	Tension, single FRP anchor	(4) diameters[3]	--	3.6.2	--	--	Twenty (5 per unique lot)
Straight FRP Anchor Tests									
Reference Tests									
2	4.3.1	Bond Failure: Confined Direct Axial Tension Tests	Confined tension on straight single FRP anchor away from edges	½” diameter[4]	--	3.6.3	low	min. [11]	Five
Reliability Tests									
3	4.3.2	Axial Tension Tests with Sensitivity to Sustained Loading (Optional)	Tension on straight single FRP anchor away from edges	½” diameter[4]	--	3.6.4	low	min. [11]	Five
Service-Condition Tests									
4	4.3.3	Confined Direct Axial Tension Tests at Elevated Temperature[5]	Confined tension on straight single FRP anchor away from edges	½” diameter[4]	--	3.6.5	low	min. [11]	Five
Bent FRP Anchor Tests[6]									
5	4.4.1	Rupture Failure: Tension Tests on Bent FRP Anchors	Tension, single FRP anchor away from edges, FRP laminate unbonded to the substrate, FRP anchor installed sandwiched by the fabric	(4) diameters[3], max α_a[7], min hole chamfer	--	3.6.6	high	≥ $8d_a$[8]	Five
Reference Tests									
6	4.4.2	Dowel Bond Failure: Tension Tests on Bent FRP Anchors in uncracked concrete[9]	Tension, single FRP anchor away from edges, FRP laminate unbonded to the substrate, FRP anchor installed sandwiched by the fabric	(4) diameters[3]	--	3.6.7	low high	$4d_a$[10] $6d_a$[10] min.[11]	Five
7	4.4.2	Dowel Bond Failure: Tension Tests on Bent FRP Anchors in cracked concrete[9]	Tension, single FRP anchor away from edges, unbonded fabric to the substrate, FRP anchor installed sandwiched by the fabric	(4) diameters[3]	0.020	3.6.7	low high	min.[11]	Five
Service-Condition Tests									
8	4.4.3	Dowel Bond Failure: Seismic Tension Tests on Bent FRP Anchors (Optional)	Tension, single FRP anchor away from edges, unbonded fabric to the substrate, FRP anchor installed sandwiched by the fabric	(3) diameters[12]	--	3.6.8	low	min. [11]	Five
FRP Anchor Splay Tests									
9	4.5	FRP Anchor Splay Bond Tests	Tension in FRP laminate, failure in bond between FRP anchor splay and FRP laminate	(3) diameters[12], min α_a @ min & max l_a, max α_a @ min l_a, max w_{fa} @ max l_a[13]	--	3.6.9	High (conc. optional)	max.	Five

[1]This is the minimum testing protocol. Additional testing may be conducted and reported if desired.
[2]Dowel rupture strength is used in capacity calculations per Section 3.7.2 and shall not be used directly for design.
[3]If fewer than four diameters are included in the evaluation report, all diameters shall be tested. The four diameters shall include the minimum diameter, two intermediate diameters, and the maximum diameter.
[4]Test nominal 1/2 in. diameter or the closest nominal diameter to 1/2 in. under evaluation. An alternate diameter may be tested if approved by ICC-ES.
[5]The minimum required temperature is 110°F. A higher temperature may be tested and reported if desired. Multiple temperatures may be tested and reported if desired. The elevated temperature used for testing shall be reported by the manufacturer in Table 4.
[6]For an FRP anchor to be qualified at a specific dowel angle, all tests in this section must be completed and reported at the specific dowel angle. FRP anchors may only be designed at the dowel angles tested, no intermediate angles are allowed.
[7]Additional splay angle test series may be tested, if desired; but the maximum splay angle must be tested for each FRP anchor diameter tested.
[8]Embedment depth shall be chosen to induce an FRP anchor rupture failure. The required depth will vary based on the test parameters.
[9] Multiple test series are required for a given diameter and dowel angle, in varying concrete strength and/or embedment depths, as noted.
[10]The embedment depth for this test series may be varied if required to achieve the desired failure mode.
[11]Report minimum tested embedment depth in Table 4.
[12]If fewer than three diameters are included in the evaluation report, all diameters shall be tested. The three diameters shall include the minimum diameter, one intermediate diameter, and the maximum diameter.
[13]Minimum and maximum splay lengths may be controlled by anchor geometry. Limits are set in 3.7.7. Additional intermediate splay lengths may be tested if qualification is desired. Minimum splay angle may be controlled by anchor geometry. Limits are set in 3.7.8. Maximum FRP anchor splay width shall be chosen by manufacturer, not to exceed the limit in 3.7.6. Each tested splay parameter must be reported in Table 5.

TABLE 2 - K VALUES FOR 5 PERCENT PROBABILITY OF NON-EXCEEDANCE WITH A CONFIDENCE OF 90 PERCENT

Number of test *n*	K	Number of test *n*	K
3	5.311	21	2.190
4	3.957	22	2.174
5	3.400	23	2.159
6	3.092	24	2.145
7	2.894	25	2.132
8	2.754	26	2.120
9	2.650	27	2.109
10	2.568	28	2.099
11	2.503	29	2.089
12	2.448	30	2.080
13	2.402	35	2.041
14	2.363	40	2.010
15	2.329	45	1.986
16	2.299	50	1.965
17	2.272	60	1.933
18	2.249	120	1.841
19	2.227	240	1.780
20	2.208	∞	1.645

TABLE 3 – REQUIRED LOADING HISTORY FOR SEISMIC TENSION TEST

Load level	V_{eq}	V_i	V_m
Number of cycles	10	30	100

TABLE 4 - SAMPLE FORMAT FOR REPORTING FRP ANCHOR DOWEL BOND AND RUPTURE DATA

FRP Anchor manufacturer	FRP Anchor name	Epoxy resin name	Criteria and code(s)	Symbol	Units	FRP Anchor nominal diameters			
FRP nominal anchor diameter				d_a	in.				
FRP anchor nominal saturated cross-sectional area				A_{fa}	in.^{2}				
FRP Anchor dry fiber weight per unit length				γ_{wt}	oz./ in.				
FRP anchor fiber volume fraction				--	%				
Composite FRP anchor tensile rupture strength[1]				f_d	psi				
FRP anchor splay angle[2]				α_a	degree				
FRP anchor dowel angle[3]				β	degree				
Hole diameter				d_o	in.				
Minimum embedment depth of bent FRP anchor[4]				$h_{efb,min}$	in.				
Bent FRP anchor rupture strength coefficient				$\alpha_{ar,b}$	--				
Bent FRP anchor dowel bond strength in uncracked concrete[5]				$\sigma_{bs,b,un}$	psi				
Bent FRP anchor dowel bond strength in cracked concrete[5]				$\sigma_{bs,b,cr}$	psi				
FRP anchor sustained loading bond coefficient				$\alpha_{p,sus}$	--				
FRP anchor elevated temperature bond coefficient				$\alpha_{b,et}$	--				
FRP anchor elevated temperature				--	F°				
Bent FRP anchor seismic bond coefficient				$\alpha_{b,seis}$					

[1]Dowel rupture strength is used in capacity calculations per Section 3.7.2 and shall not be used directly for design.
[2]The maximum splay angle must be tested. Other splay angles may also be tested.
[3]Each dowel angle used for design must be tested and reported separately.
[4]Report minimum tested embedment depth.
[5]Report minimum values from test series required in Table 1 per Section 3.6.7.

TABLE 5 - SAMPLE FORMAT FOR REPORTING FRP ANCHOR SPLAY BOND DATA

<table>
<tr><th colspan="10">Anchor qualified per TABLE 1 - TEST PROGRAM FOR EVALUATING FRP ANCHOR SYSTEMS FOR UNCRACKED AND CRACKED CONCRETE</th></tr>
<tr><td>FRP anchor manufacturer</td><td>FRP anchor name</td><td>Epoxy resin name</td><td>Criteria and code(s)</td><td rowspan="2">Symbol</td><td rowspan="2">Units</td><td colspan="4" rowspan="2">FRP anchor nominal diameters</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">FRP anchor nominal diameter</td><td>d_a</td><td>in.</td><td colspan="4"></td></tr>
<tr><td colspan="4">FRP anchor splay width</td><td>w_{fa}</td><td>in.</td><td></td><td></td><td></td><td>max.[1]</td></tr>
<tr><td colspan="4">FRP anchor splay length[2]</td><td>l_a</td><td>in.</td><td>min.</td><td>max.</td><td>min.</td><td>max.</td></tr>
<tr><td colspan="4">FRP anchor splay angle[3]</td><td>α_a</td><td>degree</td><td>min.</td><td>min.</td><td>max.</td><td></td></tr>
<tr><td colspan="4">Hole diameter</td><td>d_o</td><td>in.</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Area of FRP anchor splay</td><td>A_{splay}</td><td>in.[2]</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">FRP anchor splay bond strength</td><td>V_{sb}</td><td>psi</td><td></td><td></td><td></td><td></td></tr>
</table>

[1]Value chosen by manufacturer, not to exceed limit in 3.7.6~~5~~.
[2]Minimum and maximum values may be controlled by anchor geometry. Limits are set in 3.7.7~~6~~. Additional intermediate lengths may be tested if qualification is desired.
[3]Minimum value may be controlled by anchor geometry. Limits are set in 3.7.8~~7~~.

TABLE 6—APPLICABLE EDITIONS OF REFERENCED STANDARDS

REFERENCED STANDARD	STANDARD EDITION			
	2021 IBC	2018 IBC	2015 IBC	2012 IBC
ACI 211.1	2022	2022	2022	2022
ACI 318	2019	2014	2014	2011
ACI PRC-440.2	2023	2023	2023	2023
ASTM C31	2018B	2015	2012	2008b
ASTM C33	2018	2013	2013	2008
ASTM C39	2023	2023	2023	2023
ASTM C150	2018	2015	2012	2007
ASTM D7205	2021	2021	2021	2021
ASTM D8337	2021	2021	2021	2021
ASTM E488	2022	2022	2022	2022

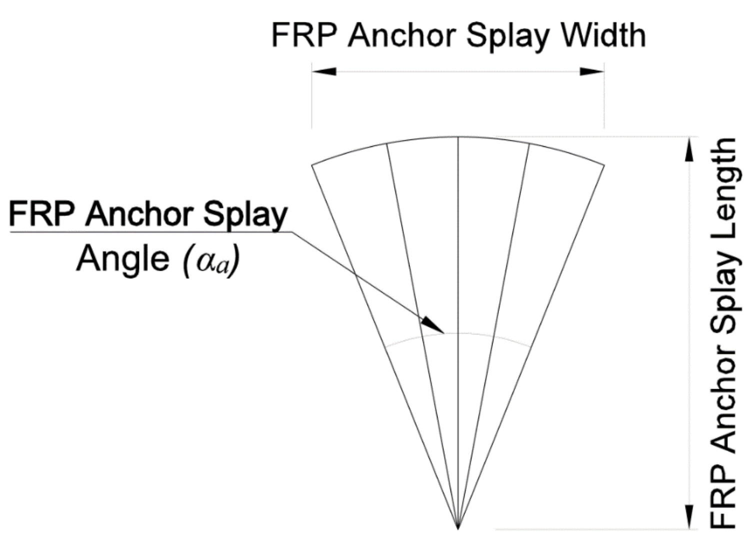


FIGURE 1: FRP ANCHOR SPLAY

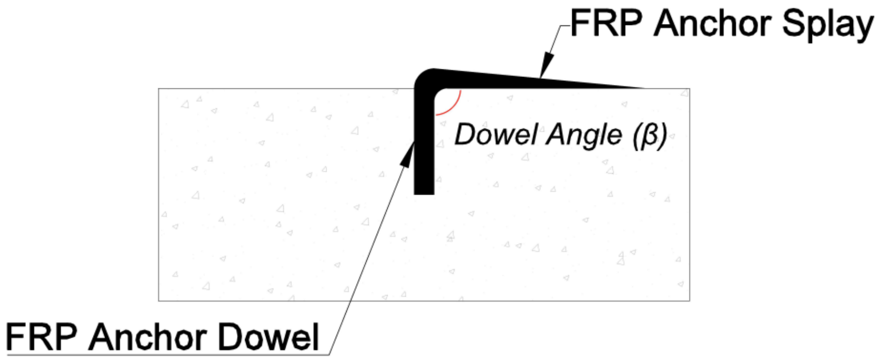


FIGURE 2: BENT FRP ANCHOR

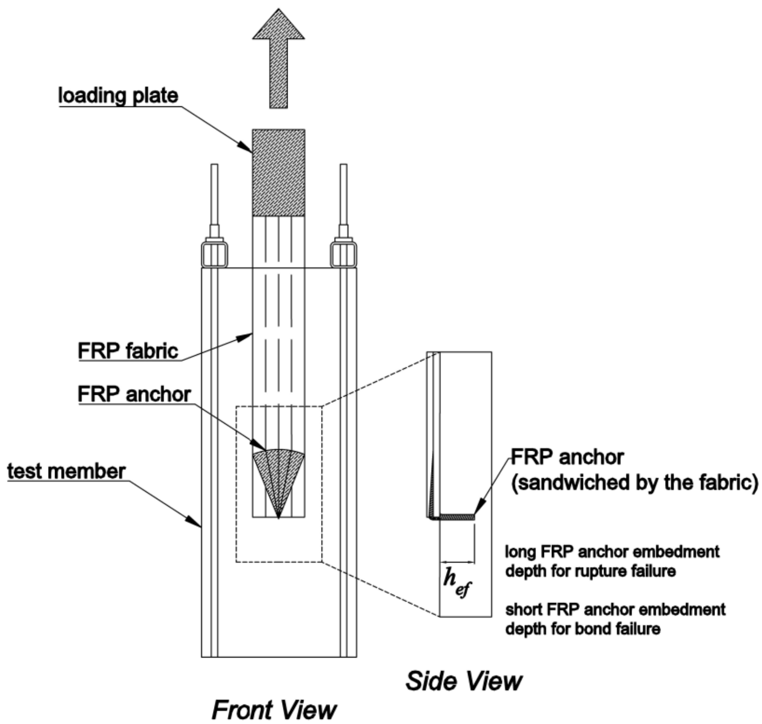


FIGURE 3: BENT FRP ANCHOR IN UNCRACKED CONCRETE TO INDUCE RUPTURE FAILURE OR BOND FAILURE.

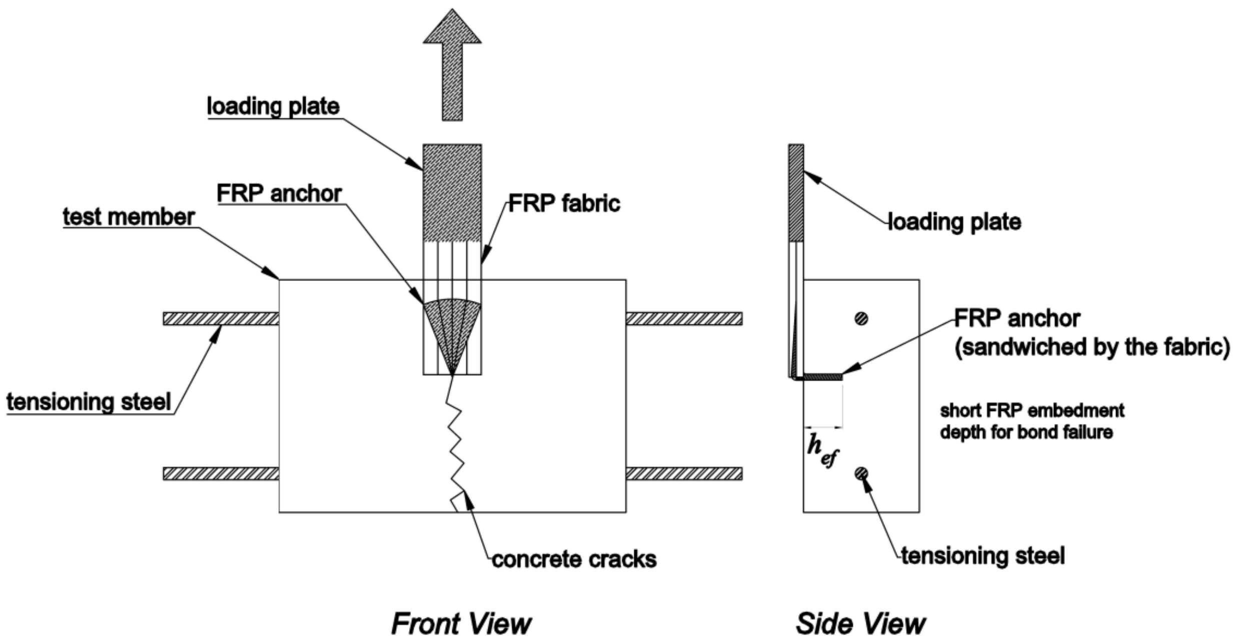


FIGURE 4: BENT FRP ANCHOR IN CRACKED CONCRETE TO INDUCE BOND FAILURE.

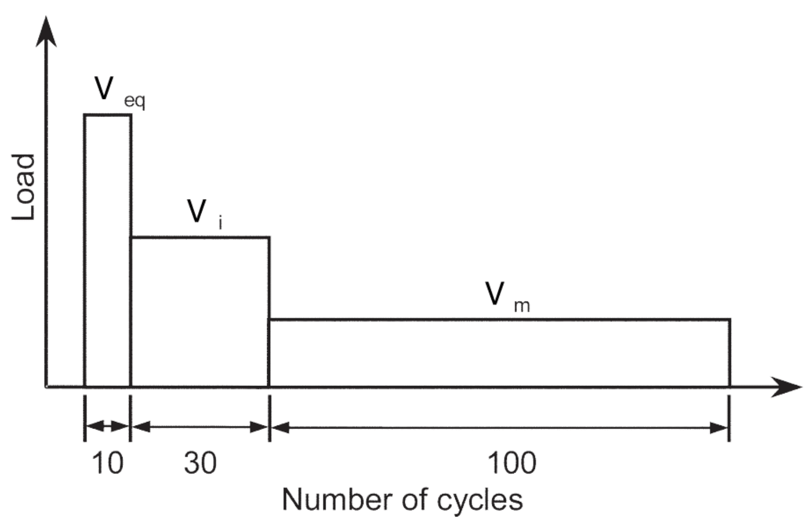
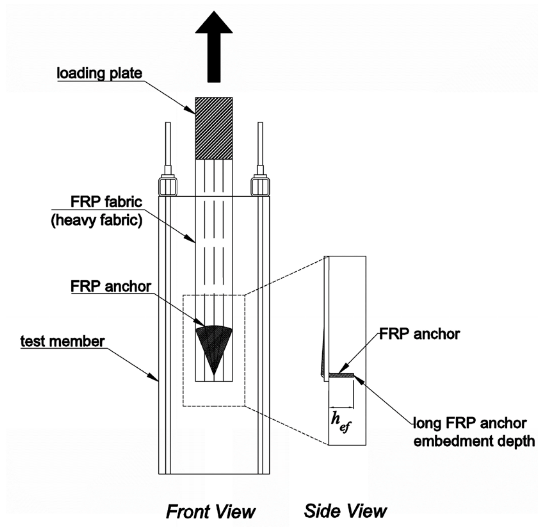
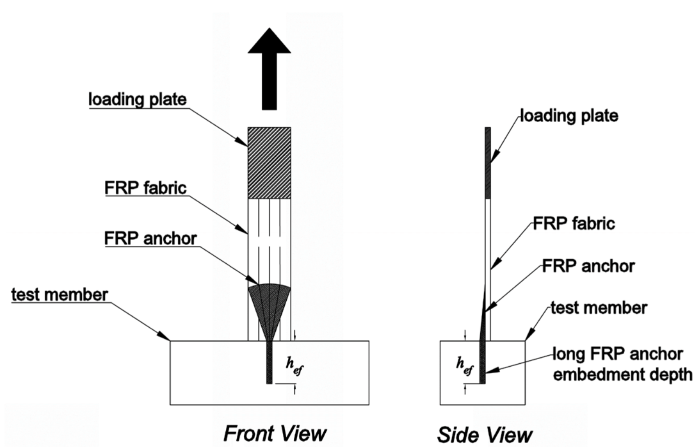


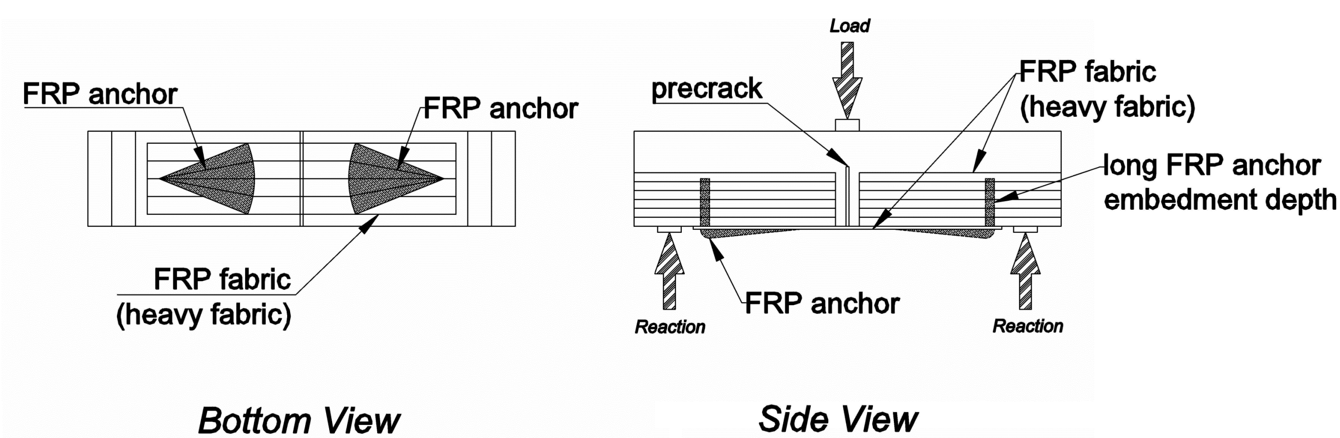
FIGURE 5: REQUIRED LOADING HISTORY FOR SEISMIC TENSION TEST



(a)



(b)



(c)

FIGURE 6: TYPICAL TEST SETUPS OF FRP ANCHOR SPLAY TESTING.