www.icc-es.org | (800) 423-6587 | (562) 699-0543 *A Subsidiary of the International Code Council®*

ACCEPTANCE CRITERIA FOR FIBER-REINFORCED POLYMER COMPOSITE OR UNREINFORCED POLYMER CONNECTORS ANCHORED IN CONCRETE

AC320

Approved October 2015

(Editorially revised September 2017)

Previously approved July 2014, June 2006

(Previously editorially revised November 2009)

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.) 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.**

This acceptance criteria has been issued to provide interested parties with guidelines for demonstrating compliance with performance features of the codes referenced in the criteria. The criteria was developed through a transparent process involving public hearings of the ICC-ES Evaluation Committee, and/or on-line postings where public comment was solicited.

New acceptance criteria will only have an "approved" date, which is the date the document was approved by the Evaluation Committee. When existing acceptance criteria are revised, the Evaluation Committee will decide whether the revised document should carry only an "approved" date, or an "approved" date combined with a "compliance" date. The compliance date is the date by which relevant evaluation reports must comply with the requirements of the criteria. See the ICC-ES web site for more information on compliance dates.

If this criteria is a revised edition, a solid vertical line (│) in the margin within the criteria indicates a change from the previous edition. A deletion indicator (→) is provided in the margin where any significant wording has been deleted.

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.

ACCEPTANCE CRITERIA FOR FIBER-REINFORCED POLYMER COMPOSITE OR UNREINFORCED POLYMER CONNECTORS ANCHORED IN CONCRETE (AC320)

1.0 INTRODUCTION

1.1 Purpose: The purpose of this criteria is to establish requirements for recognition of fiber-reinforced polymer composite or unreinforced polymer connectors cast into concrete in ICC Evaluation Service, LLC (ICC-ES), evaluation reports under the 2015, 2012, and 2009 *International Building Code*® (IBC), 2015, 2012, and 2009 *International Residential Code*® (IRC) and the 1997 *Uniform Building Code*™ (UBC). Bases of recognition are IBC Section 104.11 and UBC Section 104.2.8.

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

1.2 Scope: Connectors recognized under this criteria are limited to allowable stress design applications in uncracked normal-weight concrete as an alternative to what is required under Section 1901.3 of the 2015 IBC, Section 1908 of the 2012 IBC, and Section 1911 of the 2009 IBC or Sections 1923.1 and 2107.1.5 of the UBC. The connectors are intended for multiple installations and function by anchorage into concrete and resistance of the connector body. Connections formed by the connectors may either be of two rigid elements in direct contact or two rigid elements spaced apart by nonrigid material. Interior or exterior exposures are allowed. The connectors may also be used where an engineering design is submitted in accordance with Section R301.1.3 of the IRC.

1.3 Codes and Referenced Standards:

1.3.1 2015, 2012 and 2009, *International Building Code*® (IBC), International Code Council

1.3.2 2015, 2012 and 2009, *International Residential Code*® (IRC), International Code Council

1.3.3 1997 *Uniform Building Code*™ (UBC).

1.3.4 ACI 211.1-91 (2002), Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete, American Concrete Institute.

1.3.5 ACI 318-14 for the 2015 IBC, 318-11 for the 2012 IBC, and 318-08 for the 2009 IBC, Building Code Requirements for Structural Concrete, American Concrete Institute.

1.3.6 ASTM C31-12 (2015 IBC), -08b (2012 IBC) and -06 (2009 IBC), Standard Practice for Making and Curing Concrete Test Specimens in the Field, ASTM International.

1.3.7 ASTM C33-08, Standard Specification for Concrete Aggregates, ASTM International.

1.3.8 ASTM C39-03, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM International.

1.3.9 ASTM C42-04, Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete, ASTM International.

1.3.10 ASTM C581-03, Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service, ASTM International.

1.3.11 ASTM D638-10, Standard Test Method for Tensile Properties of Plastics, ASTM International.

1.3.12 ASTM D790-03, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM International.

1.3.13 ASTM D2247-02, Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity, ASTM International.

1.3.14 ASTM D3039/D 3039M-00(2006), Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM International.

1.3.15 ASTM E119-12a (2015 IBC), -08a (2012 IBC) and -07 (2009 IBC), Standard Test Methods for Fire Tests of Building Construction and Materials, ASTM International.

1.3.16 ASTM E488-96, Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements, ASTM International.

1.3.17 EB001, Design, Control of Concrete Mixtures, 14th edition, 2002, Portland Cement Association.

1.3.18 UL 263-11 (2015 IBC) [-03 with revisions through 07 (2012 IBC), -03 (2009 IBC)], Standard for Fire Tests of Building Construction and Materials, Underwriters Laboratories, Inc.

1.4 Definitions:

1.4.1 Connector Test Series: A group of identical connectors tested under identical conditions. “Identical conditions,” for purposes of this criteria, include diameter, length, embedment, spacing, edge distance, concrete density or weight, test member thickness and concrete compressive strength.

1.4.2 Edge Distance:

1.4.2.1 Edge Distance (c): The measure between the connector centerline and the free edge of the concrete member.

1.4.2.2 Critical Edge Distance (c_{cr}): The least edge distance at which the allowable load capacity of a connector is applicable without reductions.

1.4.2.3 Minimum Edge Distance (c_{min}): The least edge distance at which the connectors are tested for recognition.

1.4.3 Connector: The product is a mechanical fastener that is either a fiber-reinforced polymer composite or unreinforced polymer, cast-in-place into concrete. The connectors are intended to develop tension, shear or combined tension and shear loads.

1.4.4 Embedment Depth (h_v): Distance from test member surface to the installed end of connector.

1.4.5 Spacing:

1.4.5.1 Connector Spacing (s): The measure between connectors, centerline-to-centerline distance.

1.4.5.2 Critical Spacing (s_{cr}): The least connector spacing distance at which the allowable load capacity of a connector is applicable such that the connector is not influenced by adjacent connectors.

1.4.5.3 Minimum Spacing (s_{min}): The least connector spacing at which the connectors are tested for recognition.

1.4.6 Test Member: The concrete slab receiving the connectors to be tested.

1.4.7 Uncracked Concrete: Concrete element where analysis indicates no cracking ($f_t < f_r$) due to service loads or deformations. The modulus of rupture, f_r, is defined in ACI 318-14, Section 19.2.3.1, or ACI-318-11 and -08, Section 9.5.2.3 (IBC), or UBC Section 1909.5.2.3.

2.0 BASIC INFORMATION

2.1 Connectors:

2.1.1 Connectors shall be described as to:

a. Generic or trade name.

b. Manufacturer's catalog number.

c. Nominal connector dimensions and geometry.

d. Connector length.

e. Permitted manufacturing tolerances.

f. Basic materials, including appropriate physical properties before and after manufacture, and protective coatings. If the connectors consist of component parts involving different materials, differences shall be noted.

g. Appropriate national standard for the materials. Reports of physical properties for materials used in test specimens shall be submitted. These reports shall be generated by a testing laboratory. Where no physical property specifications exist, acceptable properties shall be established by physical property tests.

h. Manner of field identification prior to and/or after installation. Each connector packaging unit shall be marked with the manufacturer's name or insignia; connector type, diameter and length; and the evaluation report number.

i. Recommended installation procedures. Manufacturer's published instructions for installation, application, and design shall be submitted.

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:

2.3.1 Test reports shall comply with AC85 and include information specified in Section 13 of ASTM E488, and the following:

a. Mode of failure for each test (e.g., substrate cracking, substrate spalling, connector pull-out, shear, connector failure, etc.). Location of connector fracture failures shall be noted.

b. Photographs of test equipment and typical failure.

c. Report sealed by a registered design professional.

d. Report of connector sampling at manufacturer's facilities by a testing laboratory. See Section 2.4 of this criteria.

2.3.2 Concrete Properties: The test reports shall describe the concrete properties as set forth in Sections 3.1 through 3.4 of this criteria.

2.4 Product Sampling: Composite connectors used in tests shall be sampled in accordance with Section 3.1 of AC85.

2.5 Data Analysis: The documentation containing analysis of data shall be sealed by a registered design professional.

2.6 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 Concrete:

3.1.1 Concrete mix design shall follow recommendations for proportioning in EB001; ACI 211.1; IBC Chapter 19 (ACI 318); or UBC Chapter 19, Division II. Proportions may be varied to meet local requirements and to achieve desired nominal compressive strength. The reason for any variation shall be explained in the test report.

3.1.2 Coarse and fine aggregate in concrete shall comply with ASTM C33 for normal-weight concrete. The aggregate description shall include the rock and mineral components, shape, hardness, maximum size and grading specification.

3.1.3 Concrete test cylinders shall be prepared according to ASTM C31. Cylinders shall be stored and cured according to Section 10.2 of ASTM C31 (field cure). Cylinders shall be tested in accordance with ASTM C39 and Section 3.2 of this criteria to determine the strength of test members.

3.1.4 When no test cylinders are available, compressive strength shall be determined using drilled cores from test members. Cores shall be obtained, prepared and tested in accordance with ASTM C42 and Section 3.2 of this criteria.

3.1.5 Reinforcement may only be used to stabilize test members during transportation. Reinforcing elements in concrete test members shall be outside the potential failure region of each test connector or connector group. The testing laboratory shall verify location of reinforcing.

3.2 Strength Determination:

3.2.1 Test members shall be aged a minimum of 21 days prior to the beginning of connector tests.

Exception: Tests to determine performance in high early strength or uncured concrete.

3.2.2 For concrete less than 90 days old, two tests of two cylinders or cores each, prepared according to Section 3.1 of this criteria, shall be performed at the beginning and ending of connector testing according to Table 3 of this criteria. The beginning test shall be concurrent with the initiation of connector 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 connector test period.

3.2.3 For concrete aged 90 days or more, the compressive strength shall be the average of the results for a single test of three cylinders or cores determined after at least 90 days and within 30 days of connector testing.

3.2.4 Reported concrete strength for any connector test series shall be determined from the tests in this section within the time limitations of Table 3 of this criteria.

3.3 Allowable Loads:

3.3.1 General: The information in Sections 3.3.2, 3.3.3, 4.4.4 and 6.6.4 shall be applied in determining allowable service loads. The adjustment for wind or seismic load set forth in Section 6.6.4 is permitted in accordance with Section 1612.3.2 of the UBC if cyclic tests described in Section 4.7 of this criteria are conducted.

3.3.2 Allowable Service Load Determination:

3.3.2.1 For tension and shear, the allowable service load shall be calculated using the average adjusted or unadjusted ultimate load, as applicable, and a factor of safety in accordance with Table 7 of this criteria.

3.3.2.2 For tension and shear, the displacement at the allowable design load shall be determined, and the average displacement for each test series shall be calculated.

3.3.3 Adjustment Factor Considerations:

3.3.3.1 Installation Parameters: When the load test program evaluates the connector with variations in installation parameters such as spacing, edge distance, embedment, and slab thickness, allowable loads may need corresponding adjustment factors to reflect capacity reductions. Test load results shall be analyzed by comparing loads corresponding to the various installation parameters and developing appropriate load adjustment factors, which are applied to the optimum allowable connector load.

When more than one load adjustment factor is applied, the product of the factors is used to determine design loads. Examples include connectors installed at reduced spacings and reduced edge distances.

3.3.3.2 Compressive Strength: Where connector values are desired in concrete of varying compressive strengths, such values may be derived by interpolation from test results for two concrete compressive strengths, providing the range in mix design strength from one group of tests to another does not exceed 2,000 psi (13.8 MPa).

3.3.3.3 Capacity Reductions: In lieu of direct testing, to determine service conditions for tension capacity where edge distance is less than embedment length, Eq-1 shall be used to determine the capacity reduction factor to be multiplied by the mean seismic tension loads determined in Section 4.7 of this criteria if seismic recognition is desired. Otherwise average static tension loads can be used:

$$C_{es} = \frac{d_e}{h_v} \leq 1.0 \qquad \text{(Eq-1)}$$

where:

C_{es} = Capacity reduction factor to be multiplied by cyclic tension load for seismic recognition under the UBC, or static tension load if only static recognition is desired.

d_e = Distance from centerline of connector to concrete edge measured perpendicular to edge.

h_v = Connector embedment length.

To determine critical edge distance for shear capacity, Eq-2 shall be used:

$$d_e = \left(\frac{\varphi \cdot V_c}{\varphi \cdot 12.5 \cdot \sqrt{f'_c}} \right)^{2/3} \qquad \text{(Eq-2)}$$

where:

d_e = Distance from centerline of connector to concrete edge measured perpendicular to edge.

φ = Concrete strength reduction factor = 0.85.

V_c = Average shear strength of connector obtained from cyclic shear testing for seismic recognition under the UBC, or static shear load if only static recognition is desired.

f'_c = Concrete strength for which testing was performed and recognition is desired.

The resultant edge distance will be multiplied by a factor of 4.0 to obtain the critical edge distance of the connector for shear capacity. If this result is greater than h_v then the procedure in this section can be ignored and h_v shall be the critical edge distance. If recognition for a smaller critical edge distance is desired, tension testing must be conducted to determine critical edge distance.

3.3.3.4 Adjustment of Shear Values Due to Bending of Connector: The fiber-reinforced polymer composite or unreinforced polymer connector used in the intended application resists shear loads in bending rather than pure shear. Therefore, a limiting displacement value of 0.1 inch (2.54 mm) due to gravity loads is placed on the connector. When the connector displacement exceeds the limiting value of 0.1 inch (2.54 mm) due to gravity loads, the free end of the connector shall be supported by other means. The displacement shall be calculated in accordance with Eq-3 (neglecting any contribution from the insulation in the intended application):

$$\Delta_g = \frac{Q_g \cdot d^3{}_A}{12E_{Ab} \cdot I_A} \qquad \text{(Eq-3)}$$

where:

Δ_g = Displacement due to gravity load, inch or mm

Q_g = Gravity load on the connector, typically the weight of the fascia layer of the tributary area for the connector, lb or kg = tabγ.

where:

t = Thickness of the fascia layer, feet or mm.

a = Horizontal spacing of the connector, feet or mm.

b = Vertical spacing of the connector, feet or mm.

γ = Density of concrete, lb/ft^3 or kg/mm^3

$$d_A = d_d + \frac{2h_v}{3}\left[1 - \frac{1}{1 + h_v / d_d}\right]$$

where:

d_A = Connector bending length, a function of insulation thickness and embedment, inch or mm.

d_d = Insulation thickness, inch or mm.

h_v = Embedment length of the connector in the concrete, inch or mm.

E_{Ab} = Flexural modulus of elasticity as determined in Section 4.1.3, psi or pa.

I_a = Moment of Inertia of the connector, in^4 or mm4.

The deflection of the connector can be reduced by decreasing the connector spacing, with a minimum spacing of 8 inches (203 mm) on center each way.

3.3.4 Combined Loads: Allowable load for connectors subjected to combined shear and tension forces can be determined by Eq-4:

$$(P_s/P_t) + (V_s/V_t) \square 1 \qquad \text{(Eq-4)}$$

where:

P_s = Applied service tension load.

P_t = Service tension load.

V_s = Applied service shear load.

V_t = Service shear load.

Eq-5 may be used when substantiated by test results from Series 19 and 20 in Table 4 of this criteria:

$$\left(\frac{P_s}{P_t}\right)^{5/3} + \left(\frac{V_s}{V_t}\right)^{5/3} \leq 1 \qquad \text{(Eq-5)}$$

3.3.5 Concrete Test Compressive Strength: Where average concrete compressive strength test results are within 10 percent of the nominal specified concrete compressive strengths, connector capacity values shall be reported at the nominal specified concrete compressive strength without adjustment. Where average concrete compressive strength test results are up to 500 psi (3.44 MPa) greater than the nominal specified strength, test results for connector capacities shall be adjusted by the following factor and reported at the nominal specified concrete compressive strength:

$$\sqrt{\frac{\textit{Nominal Specified Concrete Compressive Strength}}{\textit{Actual Concrete Compressive Strength}}}$$

3.3.6 Extrapolation of test data for additional connector sizes, embedments and/or concrete strengths is prohibited.

3.4 Fiber-reinforced Polymer Composite and Unreinforced Polymer Properties: Physical, mechanical and environmental properties of the fiber-reinforced polymer composite and unreinforced polymer shall be determined in accordance with Section 4.1 of this criteria and comply with the associated conditions of acceptance.

4.0 TEST METHODS AND ANALYSIS

4.1 Material Suitability Requirements:

4.1.1 General Requirements: Required physical, mechanical, and environmental properties of the fiber-reinforced polymer composite and unreinforced polymer material used in the connectors are given in Table 1 and 2. Physical, mechanical, and environmental tests are described in these criteria as well as other ASTM standards as noted.

4.1.2 Physical and Mechanical Properties of the Fiber-reinforced *Polymer* Composite or Unreinforced Polymer Material: Tensile strength shall be determined in accordance with ASTM D3039 (fiber-reinforced polymer composite), or ASTM D638 (unreinforced polymer), excluding the strain measurement and modulus. Also, the specimens shall be cut from the rod stock from which the connectors are manufactured. Gripping shall be such that it will not damage the specimen and cause premature failure of the specimen in the gripping location. The test schedule shall comply with Table 1.

4.1.3 Flexural Properties of the Fiber-reinforced Polymer Composite or Unreinforced Polymer Material:

4.1.3.1 Procedure: Fiber-reinforced polymer composite or unreinforced polymer materials' flexural properties, including flexural strength, deflection, and flexural modulus, shall be determined in accordance with ASTM D790, Procedure B. The test specimens shall be cut from the rod stock from which the connectors are manufactured.

4.1.3.2 Conditions of Acceptance: The flexural modulus of elasticity, E_{Ab}, to be used in the design equations shall be no greater than 0.95 times the mean of the test results.

4.1.4 Environmental Properties of the Fiber-reinforced Polymer Composite or Unreinforced Polymer Material: The fiber-reinforced polymer composite and unreinforced polymer material's response to moisture, wet concrete environment, and aging shall be determined as follows:

4.1.4.1 Effects of Moisture and Aging: Testing shall be conducted in accordance with ASTM D2247, Section 7. Tensile strength testing of the material, conducted in accordance with Section 4.1.2 of this criteria, shall be determined after exposure of the material to 100 percent humidity at 100 ± 4ºF (37 ± 2ºC) for 1,000 and 3,000 hours.

4.1.4.2 Effects of Wet Concrete Environment and Aging: Testing shall be conducted in accordance with ASTM C581, Section 7.2. Tensile strength testing of the material, conducted in accordance with Section 4.1.2 of this criteria, shall be determined after the material has been exposed to an alkali solution with a pH of 12 at 73 ± 3ºF (23 ± 1.6ºC) for 1,000 and 3,000 hours.

4.1.4.3 Conditions of Acceptance: The conditions of acceptance for environmental properties are shown in Table 2 of this criteria.

4.2 Connector Installation:

4.2.1 Each type of connector to be recognized shall be tested. Connectors having different style anchorage zones on each end shall be tested for each embedment.

4.2.2 Connectors shall be installed into the test members in accordance with the manufacturer's published instructions, including instructions regarding embedment depth and consolidation techniques. Only tools typically used in field installations are permitted. The brand, model number and size of vibrator or other tool shall be reported.

All procedures shall be conducted or directly verified by the testing laboratory.

4.2.3 All test connectors shall be installed perpendicular to the surface of the test member with a 6-degree tolerance, in a manner representative of actual field installations.

4.2.4 Installation of connectors shall comply with published recommendations of the manufacturer. Pertinent data such as connector embedment, depth, nominal torque, etc., shall be observed and reported by the testing laboratory.

4.3 Load Tests for Service Conditions:

4.3.1 The service conditions of connectors installed in concrete are determined by testing that investigates the effects of several factors, including:

a. Connector materials.

b. Direction of loading.

c. Concrete strength.

d. Connector location: spacing and edge distance.

e. Connector embedment and thickness of attached and receiving materials. Section 4.2.1 describes embedment qualification criteria.

4.3.2 Table 4 summarizes connector test requirements for service conditions.

4.4 Testing and Equipment:

4.4.1 Test equipment for tension and shear loading shall be adequate to impose anticipated ultimate loads and shall comply with Sections 5 and 6 of ASTM E488. If loading is not carried to failure, the highest value achieved shall be considered the ultimate load.

4.4.2 Direction of loading for all tensile testing shall be coaxial with the embedded connector.

4.4.3 Test equipment cannot impose pullout or shear-reaction loadings on the surface or edge of the concrete member within the distance specified in Table 2 of ASTM E488. Equipment used to apply shear loads shall be designed to minimize frictional resistance, using a surface finish specified in Section 6.4.3 of ASTM E488.

4.4.4 Displacement due to shear and tension shall be recorded for each test specimen. The displacement shall be indicated as a function of load and direction of load application. The load-displacement curve shall show no fall or plateau until 150 percent of allowable service load is reached. Refer to Section 5.5 of ASTM E488 for measurement procedures.

4.4.5 The testing schedule shall comply with Table 4 of this criteria. Characteristics to be evaluated include service conditions, spacing distance and edge distance. Edge distance may be established without testing in accordance with Section 3.3.3.3. The following parameters will be established by the load test program as they apply to the connector systems:

a. Embedment depth(s).

b. Critical edge distance.

c. Minimum edge distance with appropriate load reduction factor (optional).

d. Critical spacing.

e. Minimum spacing with appropriate load reduction factor (optional).

4.4.6 The minimum allowable slab thickness shall be $1^1/_2$ times h_v, unless other thicknesses are substantiated with acceptable test data. Section 6.4.1 of ASTM E488 specifies minimum test member thickness. Supplemental connector test series using varying parameters may be considered to establish connector efficiency, with appropriate load capacity adjustment factors.

4.4.7 Group tests will establish spacing. Recognition will be based on the number, edge distance and spacing of connectors tested. Groups of connectors shall consist of two to four connectors with a connector spacing less than four times the embedment. Table 4 of this criteria and Section 5.5.1.2 of ASTM E488 contain additional guidelines.

4.4.8 Group tests shall be conducted on the same nominal size of connectors used in shear and pullout tests.

4.4.9 All connectors in group tests shall be loaded equally and simultaneously by a common fixture. Shear load shall be co-linear with the connector group.

4.4.10 Connector tests shall be conducted on fibered concrete test members if recognition in fibered concrete is desired.

4.5 Static Tests: A minimum of five samples per size of connector is required for tension and shear tests. Static load test procedures for tension and shear shall comply with this criteria and Section 8 of ASTM E488.

4.6 Creep Tests:

4.6.1 Procedure: Unless otherwise noted, all tests are to be performed in accordance with ASTM E488. Where differences occur, this criteria shall take precedence over ASTM E488.

4.6.1.1 Creep Test Series at Elevated Temperature: Thermocouples shall be embedded a maximum of $2^1/_2$ inches (63 mm) from the surface of the concrete into which the connectors are installed. The thermocouples shall be cast-in-place or installed into maximum $^1/_2$-inch-diameter (12.7 mm) holes drilled into cured concrete, with the holes sealed in a manner to ensure that temperature readings reflect the concrete temperature. After the anchor curing period, the temperature of the specimens shall be increased until the temperature, as determined from the thermocouples, is stabilized for at least 24 hours at the minimum elevated temperature of 150ºF ± 3ºF (65.55ºC ± 1.67ºC). A preload not exceeding 5 percent of the sustained creep load shall be applied before zeroing displacement readings. Sustained creep load is defined as 40 percent of the average ultimate load determined by Section 4.5 of this criteria. The remainder of the sustained creep load shall then be applied. The initial elastic displacement (additional displacement after the preload) shall be measured within three minutes of application of the sustained creep load. The concrete specimen temperature shall be recorded at maximum one-hour intervals. As an alternative, the concrete specimen temperature can be recorded at maximum 24-hour intervals, provided the heat chamber temperature necessary to maintain the required concrete temperature is maintained and is recorded at maximum one-hour intervals. For a smooth displacement-versustime curve, displacements shall be measured at least hourly for the first six hours, and daily for the duration of the test. If the concrete test temperature falls below the minimum specified temperature (including tolerances) for over 24 hours, the creep test duration shall be extended to account for the total period below the minimum specified temperature. Creep tests shall continue for a minimum of 42 days. The total displacement at 600 days, which includes the initial elastic displacement plus the creep displacement, is determined for each specimen by projecting a logarithmic trendline (determined by calculating a least-squares fit through the data points, using the equation $y = c * lnx + b$), constructed from data from not less than the last 20 days (minimum of 20 data points) of the creep test, forward to 600 days.

4.6.1.2 Conditions of Acceptance: The average total displacement at 600 days of the creep test series, described in Section 4.6.1.1 of this criteria, shall be less than the average displacement at ultimate load determined from Section 4.5 of this criteria or less than 0.15 inch (3.81 mm), whichever is less.

4.7 Cyclic Tests in Concrete (Optional):

4.7.1 General: Under a cyclic test program, tests shall be performed to determine the seismic tension and shear capacity of connectors for recognition under the UBC. Use of connectors to resist seismic loads under the IBC is prohibited. Section 6.6 of this criteria contains additional limitations.

4.7.2 Procedure: The connectors shall be subjected to a simulated pulsating sinusoidal seismic cycle, detailed in Figure 3 of this criteria, for tension; and a simulated alternating sinusoidal seismic cycle, detailed in Figure 4 of this criteria, for shear loading. The frequency of the loading shall be within the range of 0.1 to 2 Hz. Each seismic cycle test shall consist of at least five connectors. The median diameter or next-larger diameter of each connector type to be recognized shall be tested at the shallowest and deepest embedments for which seismic recognition is desired.

Connectors shall be installed in accordance with the manufacturer's recommendations.

Testing shall be performed with a concrete compressive strength of 3,000 ± 500 psi (20.68 ± 3.45 MPa) at the time the cyclic load tests are conducted, which will qualify the connector system for resisting wind loads within the range of concrete strengths for which the connectors are recognized. A test series consisting of five connectors, installed in concrete having the same design mix and materials as that used for the cyclic test connectors, is used to establish the reference ultimate static load values, T_{ref} and V_{ref}, for tension and shear.

After the test cycles have been completed, each connector shall be loaded in tension or shear, as applicable, to ultimate capacity.

4.7.3 Tension Procedure: The maximum tension load, N_s, shall be 1.5 times the allowable design tension value for which recognition is desired. The value for which recognition is desired shall be no larger than 133.33 percent of the allowable static load assigned to connectors installed under the same conditions (conditions such as concrete strength, embedment and connector diameter). The minimum load value for each load level shall not be greater than five percent of the ultimate static capacity in same-strength concrete. For all tension cyclic qualification tests, data recording shall include, at a minimum, the peak values of each load cycle applied to the connector, together with corresponding connector displacements in the direction of the load. The load cycle is given in Table 5 and Figure 1 of this criteria.

4.7.4 Shear Procedure: The maximum shear test load, V_s, shall be 1.5 times the allowable design shear value for which recognition is desired. The value for which recognition is desired shall be no larger than 133.33 percent of the allowable static load assigned to connectors installed under the same conditions (conditions such as concrete strength, embedment and connector diameter). For shear loading, the load-displacement results shall be plotted as hysteretic loops. The load cycle is given in Table 5 and Figure 2 of this criteria. Alternating shear loading may be approximated by the application of two half-sinusoidal load cycles at the desired frequency, connected by a reduced-speed ramped loading, as shown in Figure 3.

4.7.5 Conditions of Acceptance:

4.7.5.1 Each connector shall withstand the loading cycles without failure.

4.7.5.2 The average load in the tests performed on the connectors after the cyclic testing shall be at least 80 percent of the average ultimate static load, T_{ref} or V_{ref}, for connectors installed in the reference concrete.

Exception: Where individual ultimate loads differ by more than 15 percent from the average of the results, all ultimate loads shall be at least 80 percent of the average ultimate static load, T_{ref} or V_{ref}.

4.7.5.3 The maximum displacement during all phases of the seismic tests shall satisfy Eq-6 or Eq-7:

$$\Delta_{ns} \le \frac{N_s}{T_{ref}} \Delta_{ult} \qquad \text{(Eq-6)}$$

where:

T_{ref} = Average ultimate tension load based on tests described in Section 4.7.2 or Test Series 1, Table 2, whichever is greater (pounds-force or N).

Δ_{ns} = Measured maximum displacement during seismic tension test (inches or mm).

Δ_{ult} = Displacement limitation for ultimate tension and shear loads.

= 0. 10 inch (2.54 mm) for tension.

= 0.15 inch (3.81 mm) for shear.

N_s = Maximum tension load in seismic tests, described in Section 4.7.3 (pounds-force or N).

$$\Delta_{vs} \le \frac{2V_s}{V_{ref}} \Delta_{ult} \qquad \text{(Eq-7)}$$

where:

V_{ref} = Average ultimate shear load based on tests described in Section 4.7.2 or Test Series 12, Table 4, whichever is greater (pounds-force or N).

Δ_{vs} = Measured maximum displacement during seismic shear test (inches or mm).

V_s = Maximum shear load in seismic tests, described in Section 4.7.4 (pounds-force or N).

4.8 Fire Resistance (Optional): Recognition of connector use in fire-resistive construction shall be evaluated for load resistance during fire exposure. General guidelines for fire exposure are in ASTM E119, UL263 or UBC Standard 7-1.

5.0 QUALITY CONTROL

5.1 The products shall be manufactured under an approved quality control program with inspections by ICC-ES or by a properly accredited inspection agency that has a contractual relationship with ICC-ES. The quality control program shall verify continued connector compliance with specifications in Section 2.1.

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

5.3 A qualifying inspection shall be conducted at each manufacturing facility when required by the ICC-ES Acceptance Criteria for Inspections and Inspection Agencies (AC304).

6.0 EVALUATION REPORT RECOGNITION

The evaluation report shall include the following:

6.1 Basic information required by Section 2.1 of this criteria, including product description, installation procedures, packaging, and identification.

6.2 Allowable loads for each connector as determined by Section 3.3 of this criteria.

6.3 Exposure: Connectors are recognized for exterior exposure or damp environments.

6.4 Treated Wood: Materials are not permitted in contact with preservative-treated and fire-retardant-treated wood.

6.5 Special Inspection: Special inspection shall apply to the installation of the connectors. Special inspection shall conform to either Section 1704 of the IBC or Section 1701 of the UBC.

6.6 The connectors may also be used where an engineering design is submitted in accordance with Section R301.1.3 of the IRC (Only if recognition under the IRC is requested).

6.7 Evaluation Report Conditions of Use:

6.7.1 Fatigue and Shock Loading: Since an ICC-ES acceptance criteria for evaluating data to determine the performance of connectors subjected to fatigue or shock loading is unavailable at this time, the use of these connectors under these conditions is beyond the scope of this report.

6.7.2 Fire-resistance-rated Construction: (*This version applies where acceptable test data is not supplied*:) Connectors are not permitted for use in conjunction with fire-resistance-rated construction. Exceptions would be:

- Connectors resist wind loading only
- For other than wind loading, special consideration is given to fire exposure conditions.

(*This version applies where acceptable test data is suppled*:)

Connectors are qualified for use within ____-hour fire-resistance-rated construction when complying with Section ____ of this report.

6.7.3 Cracked Concrete: Since an ICC-ES acceptance criteria for evaluating the performance of fiber-reinforced polymer composite or unreinforced polymer connectors in cracked concrete is unavailable at this time, the use of the connectors is limited to installation in uncracked concrete. Cracking occurs when $f_t > f_r$ due to service loads or deformations.

6.7.4 Seismic or Wind Load:

6.7.4.1 IBC: (*This version applies where acceptable test data is supplied under the IBC*:) Use of the connectors to resist seismic loads is beyond the scope of this report. When using the basic load combinations in accordance with IBC Section 1605.3.1.1, allowable loads are not permitted to be increased for wind loading. When using the alternative basic load combinations in IBC Section 1605.3.2 that include wind loads, the allowable shear and tension loads for connectors are permitted to be increased.

(*This version applies where acceptable test data is not supplied*:) Use of the connectors to resist seismic loads is beyond the scope of this report.

6.7.4.2 UBC: (*This version applies where acceptable test data is supplied under the UBC*:) When using the basic load combinations in accordance with UBC Section 1612.3.1, allowable loads are not permitted to be increased for wind or seismic loading. When using the alternative basic load combinations in UBC Section 1612.3.2 that include wind or seismic loads, the allowable shear and tension loads for connectors are permitted to be increased by $33^1/_3$ percent.

(*This version applies where acceptable test data is not supplied*:) Use of the connectors to resist wind or seismic loads is beyond the scope of this report. The allowable loads or load combinations for the connectors shall not be adjusted for connectors subjected to wind loads.■

TABLE 1—PHYSICAL PROPERTIES

PROPERTY	TEST METHOD	NUMBER OF SPECIMENS[1]
Tensile strength	ASTM D3039 or D638	20
Flexural properties	ASTM D790	20

[1]Specimen sets shall exhibit a coefficient of variation (COV) of 6 percent or less. Outliers are subject to further investigation according to ASTM E178. If the COV exceeds 6 percent, the numbered specimens shall be doubled.

TABLE 2—ENVIRONMENTAL DURABILITY TEST MATRIX

ENVIRONMENTAL DURABILITY TEST	RELEVANT SPECIFICATIONS	TEST CONDITIONS	TEST DURATION	MINIMUM NUMBER OF SPECIMENS	PERCENT RETENTION OF TENSILE STRENGTH Hours 1,000	PERCENT RETENTION OF TENSILE STRENGTH Hours 3,000
Water resistance	ASTM D2247	100 percent, 100 ± 4ºF	1,000 and 3,000 hours	20 for each duration	90	85
Alkali resistance	ASTM C581	Immersion in alkali solution of pH = 12 at 73 ± 3ºF	1,000 and 3,000 hours	20 for each duration		

For **SI:** 1℃ = 5/9(TºF - 32).

TABLE 3—STRENGTH TEST TIME LIMITATIONS

AGE OF CONCRETE AT BEGINNING OF CONNECTOR TEST	MAXIMUM TIME BETWEEN STRENGTH TESTS (Test Period)	COMMENTS
Less than 21 days	3 days	Per Section 3.2.1 for special tests only
21 - 35 days	7 days	—
36 - 56 days	14 days	—
57 - 90 days	30 days	—
More than 90 days	—	See Section 3.2.3

TABLE 4—TESTING SCHEDULE

TEST SERIES NUMBER	TEST	ASTM E488 CRITERIA SECTION	ICC-ES ACCEPTANCE CRITERIA SECTION(S)	CONCRETE COMPRESSIVE STRENGTH[1]	NUMBER OF TESTS				REMARKS[3]
					All Diameters	Small	Medium	Large	
Service Conditions (Direction of loading: axial tension)									
1	Single connectors	8.4.1	—	Min.	5	—	—	—	Mandatory test
2	Single connectors	8.4.1	—	Med.	5	—	—	—	Optional test
3	Single connectors	8.4.1	—	Max.	5	—	—	—	Optional test
4	Single connectors, critical edge distance	—	3.3.3 & 4.4	Min.	—	5	5	5	Optional test[3]
5	Single connectors, minimum edge distance	—	3.3.3 & 4.4	Min.	—	5	5	5	Optional test[3]
6	Single connectors, critical edge distance	—	3.3.3 & 4.4	Max.	—	5	5	5	Optional test[3]
7	Single connectors, minimum edge distance	—	3.3.3 & 4.4	Max.	—	5	5	5	Optional test[3]
8	Group of 2 connectors, critical spacing	—	3.3.3 & 4.4	Min.	—	5	5	5	Optional test[3,5]
9	Group of 2 connectors, minimum spacing distance	—	3.3.3 & 4.4	Min.	—	5	5	5	Optional test[3]
10	Group of 4 connectors, minimum spacing distance	—	3.3.3 & 4.4	Min.	—	5	5	5	Optional test[3,6]
11	Group of 4 connectors, minimum spacing distance	—	3.3.3 & 4.4	Min.	—	5	5	5	Optional test[3]
Service Conditions (Direction of loading: shear)									
12	Single connectors	8.4.2	—	Min.	5	—	—	—	Mandatory test[2]
13	Single connectors, critical edge distance	—	3.3.3 & 4.4	Min.	—	5	5	5	Optional test[3]
14	Single connectors, minimum edge distance	—	3.3.3 & 4.4	Min.	—	5	5	5	Optional test[3]
15	Single connectors, critical edge distance	—	3.3.3 & 4.4	Max.	—	5	5	5	Optional test[3]
16	Single connectors, minimum edge distance	—	3.3.3 & 4.4	Max.	—	5	5	5	Optional test[3]
17	Group of 2 connectors, critical spacing	—	3.3.3 & 4.4	Min.	—	—	5	—	Optional test[3.7]
18	Group of 2 connectors, minimum spacing distance	—	3.3.3 & 4.4	Min.	—		5	—	Optional test[3]
Service Conditions (Direction of loading: oblique tension 45 degrees)									
19	Single connectors	—	3.3.4	Min.	3	—	—	—	Optional test[4]
20	Single connectors	—	3.3.4	Max.	3	—	—	—	Optional test[4]

[1]Where connectors are evaluated at more than one concrete strength level, certain tests shall be repeated at each concrete strength.
[2]Tests for "single connectors, critical edge distance" (No. 13 series) should be run first. If fiber-reinforced reinforced composite or unreinforced polymer connector failure occurs, then tests for single connectors (No. 12 series) can be deleted.
[3]Spacings and edge distances are established by acceptable test results. Where acceptable test results are not available, spacings and edge distances shall comply with Section 3.3.3.
[4]Section 3.3.4 describes scope and recognition with and without acceptable test results.
[5]Average ultimate load obtained in this test shall be at least 90% of 2 times the load obtained in test series #4.
[6]Average ultimate load obtained in this test shall be at least 90% of 4 times the load obtained in test series #4.
[7]Average ultimate load obtained in this test shall be at least 90% of 2 times the load obtained in test series #13.

TABLE 5—TENSION CYCLIC LOAD PROGRAM

LOAD LEVEL	NUMBER OF CYCLES
N_s	10
Ni	30
Nm	100

where:

N_i = A load midway between N_s and N_m.
N_m = One-fourth the average ultimate tension load, T_{ref}, in concrete of the tested strength.
N_s = The maximum tension test load.

TABLE 6—SHEAR CYCLIC LOAD PROGRAM

LOAD LEVEL	NUMBER OF CYCLES
$\pm V_s$	10
$\pm V_i$	30
$\pm V_m$	100

where:

V_i = A load midway between V_s and V_m.
V_m = One-fourth the average ultimate shear load, V_{ref}, in concrete of the tested strength.
V_s = The maximum shear test load.

TABLE 7—FACTORS OF SAFETY

MATERIAL	TENSION		SHEAR	
	UBC	IBC	UBC	IBC
Concrete with special inspection	4	4	4	4

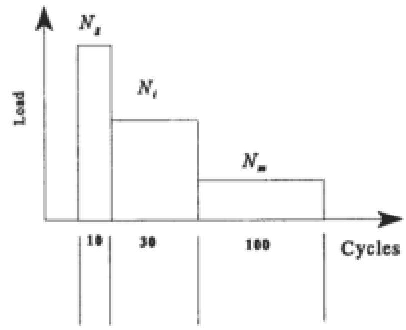

FIGURE 1—SEISMIC TENSION CYCLE

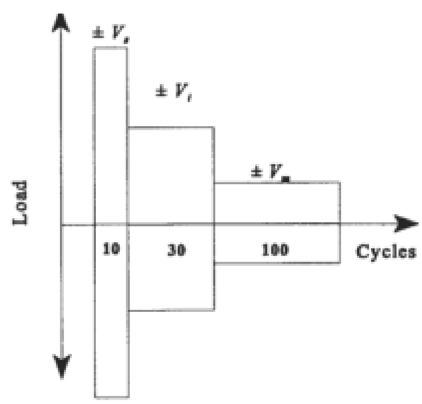

FIGURE 2—SEISMIC SHEAR CYCLE

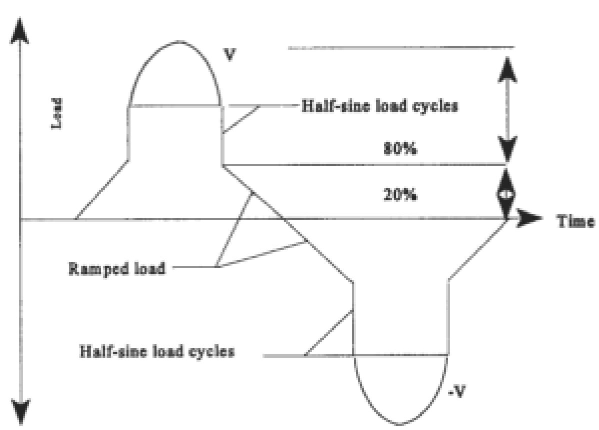

FIGURE 3—APPROXIMATION OF ALTERNATIVE SHEAR LOADING