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# Standard Test Method for Bond Strength of Fiber-Reinforced Polymer Matrix Composite Bars to Concrete by Pullout Testing[1]

This standard is issued under the fixed designation D7913/D7913M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers the determination of the bond strength of fiber-reinforced polymer (FRP) composite bars used as reinforcing bars or pre-stressing tendons in concrete.

1.2 Two procedures for casting test specimens are provided. The first procedure aligns the bar with the concrete casting direction. The second procedure aligns the bar's transverse to the concrete casting direction.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

A944 Test Method for Comparing Bond Strength of Steel Reinforcing Bars to Concrete Using Beam-End Specimens

C33/C33M Specification for Concrete Aggregates

C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens

C143/C143M Test Method for Slump of Hydraulic-Cement Concrete

C150/C150M Specification for Portland Cement

C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory

C293/C293M Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading)

C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

C617/C617M Practice for Capping Cylindrical Concrete Specimens

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D883 Terminology Relating to Plastics

D3878 Terminology for Composite Materials

D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials

D7205/D7205M Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

D7705 Test Method for Alkali Resistance of Fiber Reinforced Polymer (FRP) Matrix Composite Bars used in Concrete Construction

E4 Practices for Force Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

E83 Practice for Verification and Classification of Extensometer Systems

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

E456 Terminology Relating to Quality and Statistics

E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

F2203 Test Method for Linear Measurement Using Precision Steel Rule

## 3. Terminology

3.1 Terminology in D3878 defines terms relating to high modulus fibers and their composites. Terminology in D883

[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.10 on Composites for Civil Structures.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

defines terms relating to plastics. Terminology in E6 defines terms relating to mechanical testing. Terminology in E456 and in Practice E122 define terms relating to statistics and the selection of sample sizes. In the event of a conflict between terms, Terminology in D3878 shall have precedence over the other terminology standards.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *anchor, n*—a protective device placed on one end of a bar, between the bar and the grips of the tensile testing machine, to prevent grip-induced damage. Usually used on bars with irregular surfaces. **D7205/D7205M**

3.2.2 *bar, n*—a linear element, often with surface undulations or a coating of particles that promote mechanical interlock with concrete.

3.2.3 *bonded length, n*—the length of the test bar that is in contact with concrete.

3.2.4 *effective circumference, n*—a geometric value representing the circumference of a circle which has an enclosed area equal to the nominal cross-sectional area of a bar.

3.2.5 *effective diameter, n*—a geometric value representing the diameter of a circle which has an enclosed area equal to the nominal cross-sectional area of a bar.

3.2.6 *nominal cross-sectional area, n*—a measure of cross-sectional area of a bar, determined over at least one representative length, used to calculate stress.

3.2.7 *nominal value, n*—a value, existing in name only, assigned to a measurable property for the purpose of convenient designation. Tolerances may be applied to a nominal value to define an acceptable range for the property.

3.2.8 *representative length, n*—the minimum length of a bar that contains a repeating geometric pattern that, placed end-to-end, reproduces the geometric pattern of a continuous bar (usually used in reference to bars having surface undulations for enhancing interlock with concrete).

3.2.9 *surface undulation, n*—variation in the area, orientation, or shape of the cross-section of a bar along its length, intended to enhance mechanical interlock between a bar and concrete, made by any of a number of processes such as, for example, indentation, addition of extra materials, and twisting.

3.3 *Symbols:*

3.3.1 $A$—nominal cross-sectional area of a bar

3.3.2 $d_b$—effective bar diameter per Test Method D7205/D7205M

3.3.3 $C_b$—effective circumference of FRP bar

3.3.4 $CV$—sample coefficient of variation

3.3.5 $E_{CHORD}$—tensile chord modulus of elasticity in the test direction per Test Method D7205/D7205M

3.3.6 $F$—tensile force in bar

3.3.7 $f_c'$—compressive strength of concrete

3.3.8 $l$—bonded length

3.3.9 $L$—free length of the loaded-end of the bar

3.3.10 $L_c$—length from the top of the embedded bar to the point of attachment of the slip measuring device

3.3.11 $n$—number of specimens

3.3.12 $r$—repeatability limit, the value below which the absolute difference between two individual test results obtained under repeatability conditions may be expected to occur with a probability of approximately 0.95 (95 %)

3.3.13 $Sc$—elastic elongation

3.3.14 $s_{n-1}$—sample standard deviation

3.3.15 $\bar{x}$—sample mean

3.3.16 $x_i$—measured or derived property

3.3.17 $w/c$—water to cement ratio

3.3.18 $\tau$—average bond stress

## 4. Summary of Test Method

4.1 FRP bars are cast in concrete prisms in one of two orientations and the concrete is allowed to cure for 28 days. Cured specimens are placed in a test fixture consisting of a compression platen at one end. The loaded-end of the bar is gripped in a tension anchor and loaded in tension until failure. The average bond stress is calculated as the maximum force observed during the test divided by the surface area of the bar bonded to the concrete prism.



## 5. Significance and Use

5.1 The behavior of the bond between concrete and FRP reinforcing bars is an important performance aspect that has been used in material specifications and design standards. This test method serves as a means for uniformly preparing specimens and testing FRP bar-to-concrete bond, and for providing a standard method to calculate, evaluate and report bond strength.



5.2 This test method for measuring bond strength by pullout testing is intended for use in laboratory tests in which the principal variable is the size or type of FRP bars.

NOTE 1—This test method should not be used to establish design bond values and development lengths for FRP bars embedded in concrete, as it does not represent the state of bond stress observed in concrete flexural members reinforced with FRP bars. See Test Method A944 for a beam-end test configuration, used for determining bond stress in steel bars.

5.3 This test method is intended to determine the bond behavior for material specifications, research and development. The bond behavior will be specimen-configuration dependent, which may affect both analysis and design. The primary test result is the bond strength of the specimen to normal weight concrete.

5.4 This test method may also be used to determine the conformance of a product or a treatment to a requirement relating to its effect on the bond developed between FRP bar and concrete. The result obtained from this test method should be used only for comparative purposes to compare parameters or variables of bond strength. The method may be used as part of a protocol to establish long-term environmental effects on bond to concrete, including environmental reduction factors for FRP bars embedded in concrete.

## 6. Interferences

6.1 The results from the procedures presented are limited to the material and test factors listed in Section 5.

6.2 *Gripping*—The method of gripping has been known to cause premature tensile failures in bars. Anchors, if used, should be designed in such a way that the required tensile capacity can be achieved without slip throughout the length of the anchor during the test.

6.3 *Concrete Cover Splitting*—The concrete prism may split during the test, an indication that the force in the bar is too high for the given specimen configuration. It may be necessary to decrease the bonded length or increase the prism size for bars with unusually high bond strength. A prism dimension of 300 mm [12 in.] is suggested in situations where prism splitting occurs.

6.4 *Bar Surface Characteristics*—The average bond strength is related to the surface characteristics of the bar. Modifications to this texture are likely to affect bond strength and any such modifications made during specimen preparation should be reported. If the bar has a representative length that is greater than the bonded length, the bond strength may vary depending on the location of the bonded section in relation to the representative length.

6.5 *Concrete Prism Flatness*—Flatness of the bearing surface of the concrete prism where it meets the steel loading plate (Fig. 1) should be ensured. Non-flat surfaces or lack of perpendicularity between the concrete surface and the FRP bar may lead to premature fracture of the concrete prism due to stress concentrations and may increase the displacement readings at the loaded-end of the bars due to deformation of the concrete prism. For horizontally cast specimens, a rigid mold with smooth interior surfaces should be used. A compliant plate such as a sheet of plywood or a thin overlay of high-strength cement or plaster material may be used to accommodate uneven surfaces, see Section 8.6.7.

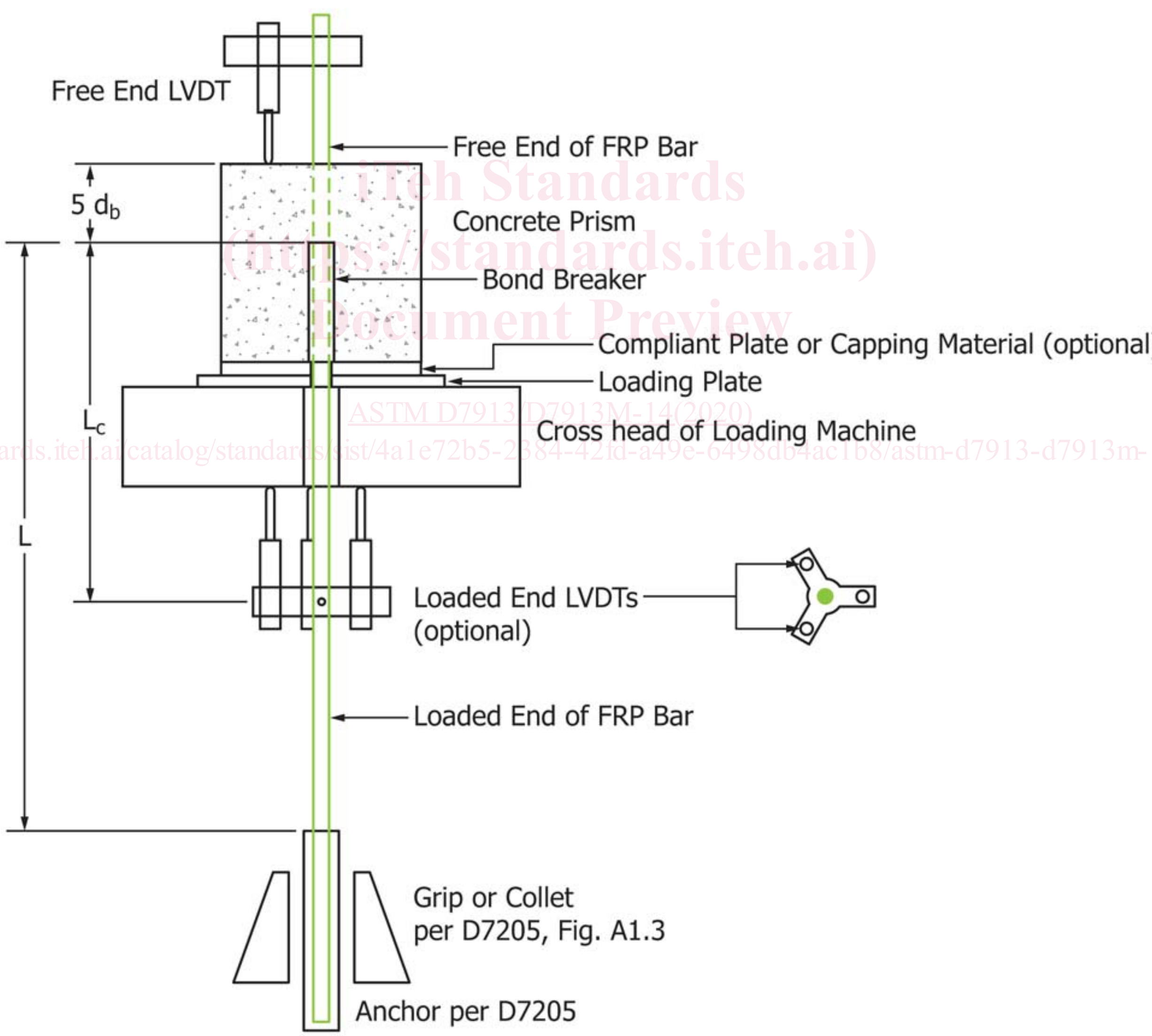




**FIG. 1**

6.6 *Concrete Strength*—The bond strength is related to the concrete compressive strength. Therefore the concrete must be composed of known constituents and the specimens must be cured in a controlled environment.

6.7 *System Alignment*—Excessive bending may cause premature failure, as well as a highly inaccurate bond stress determination. Every effort should be made to eliminate bending from the test system. Bending may occur due to misalignment of the bar within the anchor or grips or due to lack of perpendicularity between the face of the compression platen, the cast face of the prism that mates with the compression platen, and the bar. See Practice E1012 for verification of specimen alignment under tensile loading.

6.8 *Measurement of Cross-Sectional Area*—The nominal cross-sectional area of the bar is measured by immersing a prescribed length of the specimen in water to determine its buoyant weight per Test Methods D792 and D7205/D7205M. Bar configurations that trap air during immersion (aside from minor porosity) cannot be assessed using this method. This method may not be appropriate for bars that have large variations in cross-sectional area along the length of the bar.

6.9 *Environmental Conditions at Time of Testing*—Test results may be affected by the laboratory conditions. Test conditions shall be reported.

## 7. Apparatus

7.1 *Testing Machine*—The testing machine used shall conform to the requirements of the sections on Basis of Verification, Corrections, and Time Interval Between Verifications of Practices E4. Motorized pumps or hand operated positive displacement pumps shall be capable of applying forces at a uniform rate without shock or interruption. The testing machine shall have a force capacity in excess of the bond capacity of the test specimen.



7.1.1 The force indicator on the testing machine shall be calibrated to a range of not greater than 10 times the observed failure force of the specimen.

7.2 *Steel Rule*—Linear measuring device for measuring bonded length per Test Method F2203.

7.3 *Drive Mechanism*—The testing machine with either loading-rate or displacement-rate control. The testing machine drive mechanism shall be capable of imparting to the movable head a controlled force or displacement rate with respect to the stationary head. The rate of the movable head shall be capable of being regulated as specified in 11.2.4.

7.4 *Test Fixture*—The test fixture consists of a loading plate, anchor, free-end LVDT (linear variable differential transformer) clamp and optional loaded-end LVDT clamp (see Fig. 1). The loading plate should rest on a support that transfers the reaction from this block to the force indicator of the testing machine. As an alternative, the force indicator of the testing machine can be attached to the tension grip at the loaded-end of the bar.

7.4.1 *Loading Plate*—The loading plate should be a machined steel plate at least 200 mm [8 in.] square and the surface dimensions of the plate must be larger than the mating dimensions on the specimen. The plate shall be at least 20 mm [0.75 in.] thick with a surface finish of 1.6 µm [64 µin.] or better. The hole drilled through the loading plate should be 10 mm ± 5 mm [0.4 in. ± 0.2 in.] larger in diameter than the maximum transverse dimension of the FRP bar. The loading plate may be fabricated in two parts to accommodate the testing of specimens fitted with end anchors.

7.4.2 If used, the anchor on the loaded-end of the FRP bar shall conform to Test Method D7205/D7205M, and may be attached to a tension grip body, to a collet, or to the second head of the testing machine, if so equipped.

NOTE 2—The tensile forces transmitted through the anchor will be below those required to rupture the FRP bar in tension. Therefore, it may be appropriate to use v-groove tension wedge grips, instead of the anchor as recommended in Test Method D7205/D7205M. If excessive slip or rupture at the grip body occurs, then a suitable anchor should be used.

7.4.3 The free-end LVDT clamp shall accommodate one LVDT to measure the free-end slip of the FRP bar, relative to the end of the concrete prism, during the test.

7.4.4 The optional loaded-end LVDT fixture shall accommodate one or more LVDTs. An arrangement of three LVDTs arranged 120° apart is suggested to measure the loaded-end slip plus elastic elongation over the distance *Lc* and to characterize and account for bending in the specimen.

7.5 *Displacement Devices*—The displacement measuring devices fitted to both the free end and optionally at the loaded-end of the FRP bars shall be LVDTs or similar devices, reading accurately to 0.01 mm [0.0004 in.]. An extensometer corresponding to Type 2, Class B-2 of Practice E83 may be used to measure free-end slip.

7.6 *Concrete Molds*—Two types of molds for bond test specimens are described: for 200 mm [8 in.] concrete prisms, containing either a vertically or horizontally embedded bar; and for 200 × 200 × 400 mm [8 × 8 × 16 in.] prisms, containing two horizontally embedded bars.

7.6.1 The molds should be made of metal no less than 6 mm [0.25 in.] or rigid plastic or wood no less than 12 mm [0.5 in.] thick. The molds should be watertight and constructed for easy removal without disturbing the embedded bars. Mold surface treatments and oiling of surfaces to promote easy removal of the specimens from the molds are acceptable.

7.7 *Concrete Curing Apparatus or Chamber*—The pullout specimens and the concrete compression specimens should be cured according to Practice C192/C192M in a moist cabinet or water storage tank according to Specification C511.

## 8. Specimen Preparation and Sampling

8.1 Each FRP bar should be cut into lengths so that the loaded-end of the specimen, *L*, is 1200 mm ± 5 mm [47 in. ± 0.2 in.] (see Fig. 1). An anchor meeting the requirements of Test Method D7205/D7205M, Annex A, may be fitted to the loaded-end of the bar.

8.2 The test specimens should contain either one FRP bar embedded parallel or perpendicular to the direction of casting of the concrete (Fig. 2), or two FRP bars embedded perpendicular to the direction of casting of the concrete (Fig. 3). Five specimens of a given type providing valid test results constitute