INTERNATIONAL

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Standard Test Method for Evaluation of Performance for FRP Composite Bonded to Concrete Substrate using Beam Test[1]

This standard is issued under the fixed designation D7958/D7958M; 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 describes the apparatus and procedure for evaluating the performance of wet lay-up or pultruded Fiber-Reinforced Polymer (FRP) composite systems adhesively bonded to a flat concrete substrate. The test determines the maximum force that an FRP system can bear before detaching from a concrete beam tested in flexure. Failure will occur along the weakest plane within the system composed of the FRP composite, adhesive, and concrete substrate.

1.2 This test method is used for assessment and comparison of FRP systems subject to environmental conditioning. This test method is not intended for job approval or product qualification purposes.

1.3 This test method is intended for use with adhesive-applied FRP systems and is appropriate for use with FRP systems having any fiber orientation or combination of ply orientations comprising the FRP composite, although the test condition only considers forces in the direction parallel to the beam longitudinal axis.

1.4 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 exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.4.1 Within the text, the inch-pound units are shown in brackets.

1.5 *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.*

1.6 *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:*

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field
C33/C33M Specification for Concrete Aggregates
C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens
C42/C42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C125 Terminology Relating to Concrete and Concrete Aggregates
C150/C150M Specification for Portland Cement
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
C617 Practice for Capping Cylindrical Concrete Specimens
D883 Terminology Relating to Plastics
D3039 Test Method for Tensile Properties of Polymer Matrix Composite Materials
D3878 Terminology for Composite Materials
D7565 Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

[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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E251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages
E456 Terminology Relating to Quality and Statistics

3. Terminology

3.1 Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. Terminology C125 defines terms relating to concrete. Terminology E456 and Practice E122 define terms relating to statistics. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other standards.

3.2 *Definitions:*

3.2.1 *detach, v*—The FRP system pulling off of or breaking away from the concrete substrate. Detachment may result from cohesive failure in the FRP laminate, adhesive or substrate concrete or from adhesive failure between any components of the FRP system. Detachment corresponds to the peak force carried by the FRP.

3.3 *Symbols:*

3.3.1 A—lower bound rate coefficient: A = 0.50 MPa/min [72 psi/min]

3.3.2 B—upper bound rate coefficient: A = 0.69 MPa/min [100 psi/min]

3.3.3 C—resultant force of compression block

3.3.4 b—width of test beam

3.3.5 CV—sample coefficient of variation

3.3.6 d—overall depth of test beam

3.3.7 E_c—modulus of elasticity of concrete

3.3.8 E^{chord}—tensile chord modulus of elasticity of FRP (D3039)

3.3.9 f_c'—compressive strength of concrete (C39/C39M)

3.3.10 F—maximum force in FRP

3.3.11 h—thickness of FRP (D3039)

3.3.12 K^*—FRP tensile stiffness per unit width (D7565)

3.3.13 n—number of specimens

3.3.14 P—maximum applied force indicated by testing machine

3.3.15 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 %)

3.3.16 r_P—rate of application of load P, N/min [lbf/min]

3.3.17 S_{n-1}—sample standard deviation

3.3.18 S—bonded length of FRP

3.3.19 w—bonded width of FRP

3.3.20 $\bar{x}$—sample mean

3.3.21 x_i—measured or derived property

3.3.22 α—ratio of neutral axis depth measured from compression face of specimen to overall depth of specimen

3.3.23 β—ratio of axial stiffness of FRP to that of concrete specimen

3.3.24 ε—strain at debonding recorded from strain gage

4. Summary of Test Method

4.1 This test is conducted by loading simply supported concrete beam specimens having a load located at the center of the beam span to failure. The beams are reinforced on their soffit (tension face) with bonded FRP reinforcement. The specimen configuration and testing procedures are similar to those used to determine modulus of rupture of concrete (see Test Method C78).

5. Significance and Use

5.1 This test method serves as a means for uniformly preparing and testing standard specimens suitable for being subject to environmental conditioning and subsequently used

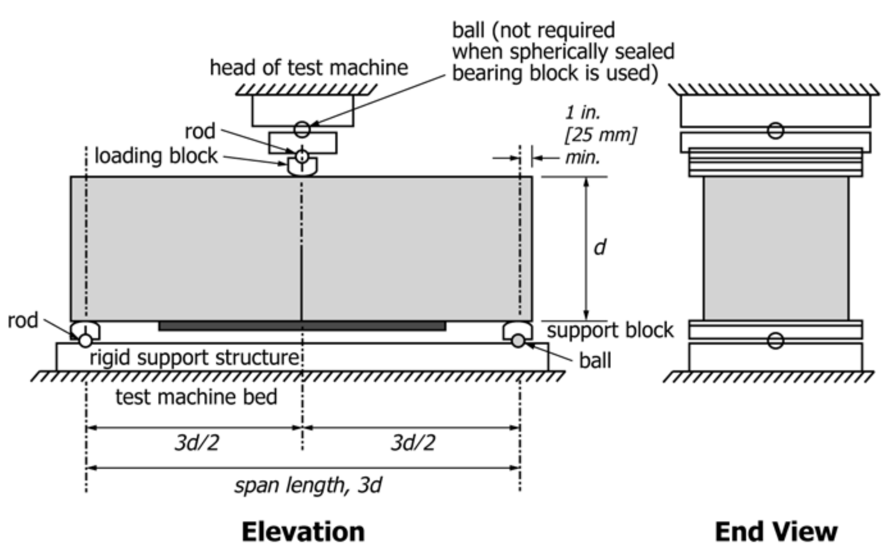

FIG. 1 Schematic of Suitable Apparatus for Flexure Test by a Single Load at the Center of the Span. All Parts of Apparatus are Made of Steel.

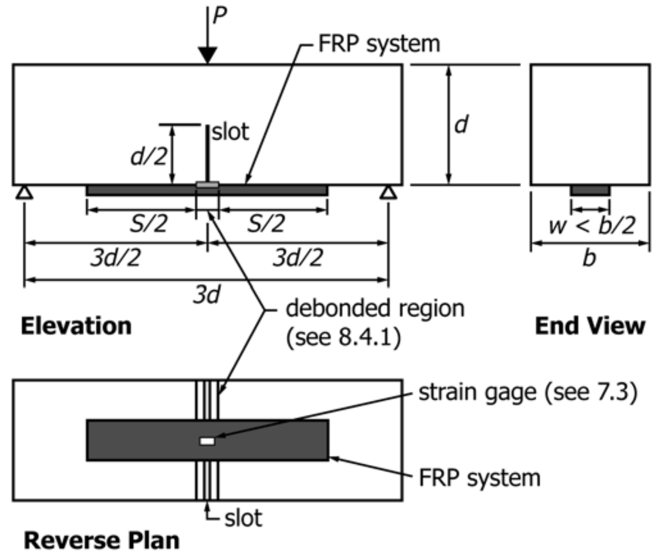

FIG. 2 Specimen Dimensions and Details of Bonded FRP System

to evaluate FRP-bonded-to-concrete system performance, and evaluating and reporting the results.

5.2 This test method is intended for use in the laboratory.

5.3 The comparison of results from this test method conducted on identical specimens subject to different environmental conditioning protocols can be used to evaluate the effects of environmental exposure on the bond performance of FRP systems.

6. Interferences

6.1 *Material and Specimen Preparation*—Non-uniform FRP or FRP-to-substrate adhesive thickness can affect an individual test result. Variation in FRP or adhesive thickness between specimens can cause biased or scattered test results.

6.2 *Specimen Dimensions*—This method calculates a value of maximum force resisted by the FRP system, as such, results are dependent on the specimen dimensions. Values calculated using specimens having different dimensions should not be compared.

6.3 *FRP Reinforcement*—Use of excessive FRP reinforcement, sufficient to cause a diagonal shear failure mode in the concrete beam (as shown in Fig. 3(c)), results in an invalid test.

6.4 *FRP Reinforcement*—Use of very flexurally stiff FRP reinforcement, sufficient to cause a debonding failure at the termination of the FRP, results in an invalid test.

6.5 *Concrete Strength and Modulus of Elasticity*—Variation due to aging and/or conditioning affects the concrete strength and modulus which may affect the assumed distribution of stress in the cross section which affects Calculation Method 2.

6.6 *Calculation Method*—It is known that calculation methods 1 and 2 will yield different results. Method 1 relies on a measured value of stiffness per unit width obtained from another specimen using Test Method D7565 or D3039. Method 2 relies on a number of geometric and material simplifications. Method 2 is intended for use when direct strain measurements are not possible. Values calculated using Method 1 are not comparable to values calculated using Method 2.

7. Apparatus

7.1 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. Hand-operated testing machines having pumps that do not provide a continuous loading in one stroke are not permitted. Motorized pumps or hand-operated positive displacement pumps having sufficient volume in one continuous stroke to complete a test without requiring replenishment are permitted and shall be capable of applying loads at a uniform rate without shock or interruption.

7.2 *Loading Apparatus*—With the exception that the beam test is conducted with a single load at the center of the beam, rather than two loads at the third-points, the loading apparatus shall be the same as that used for Test Method C78.

7.2.1 The center-point loading method shall be used in making beam tests employing bearing blocks that will ensure that forces applied to the beam will be perpendicular to the face of the specimen and applied without eccentricity. A diagram of an apparatus that accomplishes this purpose is shown in Fig. 1.

7.2.2 All apparatus for making flexure tests shall be capable of maintaining the specified span length and distances between load-applying blocks and support blocks constant within ±1.0 mm [±0.05 in.].

7.2.3 The ratio of the horizontal distance between the point of application of the load and the point of application of the nearest reaction to the depth of the beam shall be 1.5 ± 0.03.

7.2.4 If an apparatus similar to that illustrated in Fig. 1 is used: the force-applying and support blocks shall not be more than 64 mm [2.50 in.] nor less than 25 mm [1 in.] high, measured from the center or the axis of pivot, and should extend entirely across or beyond the full width of the specimen. Each case-hardened bearing surface in contact with the specimen shall not depart from a plane by more than 0.05 mm [0.002 in.] and shall be a portion of a cylinder, the axis of

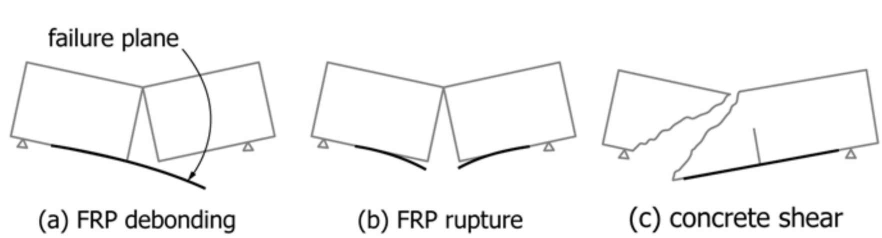

FIG. 3 Failure Modes for Beam Test

which is coincidental with either the axis of the rod or center of the ball, whichever the block is pivoted upon. The angle subtended by the curved surface of each block shall be at least 45°. The force-applying and support blocks shall be maintained in a vertical position and in contact with the rod or ball by means of spring-loaded screws that hold them in contact with the pivot rod or ball. The uppermost bearing plate and center point ball in Fig. 1 may be omitted when a spherically seated bearing block is used.

7.3 *Bonded Resistance Strain Gages*—FRP strain data, if required for Calculation Method 1, shall be determined by means of a bonded electrical resistance strain gage. Strain gage selection is a compromise based on the type of FRP material being tested. An active gage length of 6 mm [0.25 in.] is recommended for most materials. Active gage lengths should not be less than 3 mm [0.125 in.]. Gage calibration certification shall comply with Test Methods E251. When testing woven fabric composites, gage selection should consider the use of an active gage length that is at least as great as the characteristic repeating unit of the weave.

7.3.1 Bonded strain gages should be applied following environmental conditioning so as not to be affected by the conditioning. In some cases, bonding following environmental conditioning will not be possible; in these cases Calculation Method 2 may be used.

NOTE 1—Guidelines on the use of strain gages on FRP composites are provided in Test Method D3039.

7.4 *Micrometers*—Micrometers used to determine specimen dimensions shall use a suitable size diameter ball-interface on irregular surfaces and a flat anvil interface on machined edges or very-smooth tooled surfaces. For typical specimen geometries, the accuracy of the instruments shall be suitable for reading to within 1 % of the intended measurement. The use of alternative measurement devices is permitted if agreed to by the test requestor and reported by the testing laboratory.

8. Test Specimen and Sampling

8.1 The concrete test specimen shall conform to all requirements of Test Method C42/C42M or Practices C31/C31M or C192/C192M applicable to beam specimens and shall have a test span within 2% of three times its depth as tested. The sides of the specimen shall be at right angles with the top and bottom. All surfaces shall be smooth and free of scars, indentations, holes, or inscribed identification marks.

8.1.1 The depth of the test specimen, *d*, shall be 102 mm [4.0 in.] or 152 mm [6.0 in.].

8.2 *Cast Specimens (Practices C31/C31M or C192/C192M)*—Cast specimen concrete mixture shall meet the following requirements:

8.2.1 *Aggregates*—Aggregates shall conform to Specification C33/C33M, and the maximum aggregate size shall be 9.5 or 12.7 mm [⅜ or ½ in.].

8.2.2 *Cement*—Use Type I/II portland cement conforming to Specification C150/C150M. The concrete mixture shall not include any other cementitious materials (for example, slag, fly ash, silica fume, or limestone powder) or chemical admixtures (for example, air-entraining agents, water reducers, high-range water reducers, shrinkage-compensating admixtures, corrosion inhibitors, set retarders, and set accelerators) unless the evaluation of these is an objective of the test program.

8.2.3 *Concrete Strength*—Cylinders should be cast and tested in accordance with Practice C31/C31M and Test Method C39/C39M. The 28-day compressive strength of the cylinders shall fall between 46 to 60 MPa [6500 to 8500 psi].

8.2.4 *Curing*—Cure cylinders and beam specimens for 28 days in water in accordance with Specification C511.

8.3 The tension face of the concrete test specimen shall have a slot at midspan to half its depth (i.e. to a depth of *d*/2 (±1.0 mm [±0.05 in.]). The slot should be vertical, perpendicular to the tension face of the specimen. The slot may be either sawcut or cast-in-place.

8.3.1 The width (kerf) of a saw-cut slot should be no greater than 3.2 mm [0.125 in.] and may be made using a diamond blade.

8.3.2 A cast-in-place slot should be created using a stiff shim embedded into the concrete mold. The shim should be no greater than 3.2 mm [0.125 in.] thick and be secured in the mold in such a way as to ensure its location and straightness. The shim must not adhere to the concrete.

8.3.3 When using molded specimens, the tension face of the test beam shall be one of the molded vertical sides of the specimen. When using sawed specimens, the tension face shall correspond to the top or bottom of the specimen as cut from the parent material.

8.4 Surface preparation of the tension face of the specimen to receive the FRP system shall be in accordance with the manufacturer's requirements of the FRP system being tested. Details of the surface preparation shall be recorded with the test data.

8.4.1 A bond-breaking layer, centered on the slot and extending across the entire width, *b*, of the beam shall be provided. The length of this debonded region should be the greater of 19 mm [0.75 in.] or the length of the strain gage (if used), see Fig. 2.

NOTE 2—Bond breaking is easily accomplished using masking tape spanning the slot.

8.5 The FRP system applied to the tension face of the specimen shall meet the following requirements as shown in Fig. 2:

8.5.1 The FRP system shall be applied in accordance with the manufacturer's recommended procedure. The manufacturer's instructions should be followed as to the minimum elapsed time between FRP system application and testing.

8.5.2 The width of the applied FRP system shall not exceed one half the width of the beam nor be smaller than one sixth the width of the beam. The FRP system shall be centered on the tension face of the beam.

8.5.3 The total bonded length of the FRP system, *S*, shall be greater than 2*d*, shall be centered on the slot and shall be less than the span length such that the end of the FRP system is not loaded (pinned) by the reaction supports.

NOTE 3—The FRP system effectively strengthens the beam in flexure. The dimensions and/or capacity of the FRP must not result in a shear failure of the specimen. Thus the applied test force, *P*, must not exceed the