TEST METHOD FOR BOND STRENGTH OF CONTINUOUS FIBER REINFORCING MATERIALS BY PULL-OUT TESTING (JSCE-E 539-1995)

1. SCOPE

This standard specifies mainly the test method of determining the bond strength of CFRM used in place of steel reinforcement or prestressing tendon in concrete by pull-out testing.

2. DEFINITIONS

The following terms are defined for general use in this Standard, in addition to the terms used in the "Recommendation for Design and Construction for Concrete Structures using Continuous Fiber Reinforcing Materials" and the "Quality Specifications for Continuous Fiber Reinforcing Materials":

Nominal peripheral length: The peripheral length of the CFRM which forms the basis for calculation of bond strength; determined separately for each CFRM

3. TEST PIECES

3.1 Fabrication of test pieces

Test pieces shall normally be cube-shaped, fabricated by pouring concrete around a central CFRM. The bonded length of the CFRM shall be a typical section of the surface of the CFRM set up in the free end side. The length shall normally be 4 times the diameter of the CFRM. If the bonded length as defined above is thought not to represent the bonding characteristics of the CFRM, the bonded length may be extended as appropriate. In order to equalize the stress from the loading plate on the loaded end side, sections other than the bonded section shall be sheathed with PVC etc. to prevent bonding.

3.2 Dimensions of test piece

The dimensions of the test piece shall be determined according to the dimensions of the CFRM, as shown in **table 1**:

Table 1: Dimensions of test pieces

CFRM nominal diameter	Length of one face of test piece (cm)	Bonded length	External diameter of spiral hoop reinforcement (cm)
Less than 17 mm 17 ~ 30 mm	10×10×10 15×15×15	4×nominal diameter 4×nominal diameter	8 ~ 10 12 ~ 15

3.3 Dimensions of CFRM tendon

The CFRM tendon shall be allowed to protrude by around 10 mm at the free end side, and the end face must be structured so as to allow access for a dial gauge etc., used to measure the length of pull-out. The loading end side of the CFRM tendon must be long enough to allow the performance of the pull-out test, and must be fitted with an anchoring section, gripping device or similar apparatus to allow transmission of loads.

3.4 Arrangement of CFRM tendons

CFRM tendons shall be arranged horizontally in the center of the test piece.

3.5 Reinforcement of test pieces

Test pieces shall be reinforced with spiral hoops centered at the test piece to prevent splitting failure while the test is in progress. Spiral reinforcement hoops shall be 6 mm in diameter, with a spiral pitch of 4 cm. The ends of the spiral hoops shall be welded, or 1.5 times extra turns shall be provided.

3.6 Number of test pieces

The number of test pieces shall not be less than three. If the test piece is found clearly to have failed at the anchoring section, or to have slipped out of the anchoring section, an additional test shall be performed on a separate test piece taken from the same lot.

4. FORMS

Forms shall conform to the JSCE "Test method for bond strength of concrete by pull-out testing" (JSCE-G 503-1988).

5. CONCRETE QUALITY

The concrete shall be made with normal aggregates, with coarse aggregates having a maximum dimension of 20 or 25 mm. The standard concrete shall have slump of 10±2 cm, and the compressive strength at 28 days shall be 30±3 N/mm^2.

6. PLACING OF CONCRETE

6.1 The bonding section of the CFRM tendon shall be cleaned and rendered free from any grease, dirt etc.

6.2 Suitable measures shall be taken before placing to prevent bonding of the non-bonding sections of the tendon, and the CFRM tendon shall be placed horizontally in the form, perpendicular to the loading face.

6.3 The opening in the form through which the CFRM tendon is inserted must be sealed to prevent ingress of water etc. using oil putty or similar.

6.4 The form must be kept horizontal from the time of placing the concrete until the form is removed.

6.5 After placing, the test piece shall be smoothed off by scraping any excess concrete off the top, repeating this process again after around 2 hours to ensure that a test piece of the proper dimensions is obtained.

7. REMOVAL OF FORMS AND CURING

Forms shall be removed after 2 days, and the test pieces cured thereafter in water at a temperature of 20±3°C until the time of testing.

8. TESTING MACHINE AND DEVICES

8.1 Testing machine

The testing machine for pull-out tests must be capable of applying the prescribed load accurately.

8.2 Loading plate

The loading plate shall have a hole through which the CFRM tendon shall pass. The diameter of the hole in the loading plate shall be around 2~3 times the diameter of the continuous fiber tendon.

8.3 Anchorage

The loading end side of the CFRM tendon shall be fitted with an anchorage capable of transmitting loads accurately until the tendon pulls out due to bond failure, or because of splitting or cracking of the concrete. The load transmission device shall transmit axial loads only to the CFRM tendon, without transmitting either torsion or flexural force.

8.4 Dial gauge

The displacement meter fitted to the free end of the CFRM tendon shall be a dial gauge or similar apparatus, giving readings accurate to around 1/1000 mm.

9. TEST METHOD

9.1 Mounting of test piece

The test piece shall be placed correctly on the loading plate, with a spherical plate underneath to prevent eccentric loads from acting on the test piece.

9.2 Loading rate

The standard loading rate shall be such that the average tensile stress of the CFRM tendon increases at a rate of 10~20 N/mm^2 per minute. The loading rate must be kept as constant as possible, not subjecting the test piece to shock.

9.3 Scope of test

The slippage of the free end and the load applied shall be recorded in the increments shown in **table 2**, until either the continuous fiber tendon pulls out of the concrete, or the load decreases significantly due to splitting or cracking of the concrete.

Table 2: Measurement increments

Slippage of free end	Measurement increment
~0.1 mm	every 0.01 mm
0.1 mm ~ 0.2 mm	every 0.02 mm
0.2 mm ~ 0.5 mm	every 0.05 mm
0.5 mm ~	every 0.1 mm

9.4 Age of test piece

The age of the test piece at the time of testing shall be 28 days.

10. CALCULATION AND EXPRESSION OF TEST RESULTS

10.1 Handling of data

In cases where a test piece is judged to have undergone tensile failure at the anchoring section, or to have slipped out of the anchoring section before the CFRM has slipped from the concrete or the load is significantly reduced due to splitting or cracking of the concrete, the data shall be disregarded and additional tests shall be performed until the number of test pieces slipping from the concrete or where the load is significantly reduced due to splitting or cracking of the concrete is not less than three.

10.2

The bond strength shall be calculated according to Eq. (1) and rounded off to 3 significant digits and the curve for the pull-out load or bond stress versus slippage displacement for each test piece shall be plotted.

$$t = \frac{P}{ul} \qquad (1)$$

where

τ = bond stress (N/mm^2)
P = tensile load (N)
u = nominal peripheral length of CFRM (mm)
l = bonded length (mm)

10.3

The average bond stress causing slippage at the free end of 0.05 mm, 0.10 mm and 0.25 mm, and the maximum bond stress at the failure load shall be calculated.

11. TEST REPORT

The test report shall include the following items:
(1) Name of CFRM
(2) Type of fiber and fiber binding material, volume ratio of fiber, type of surface treatment of fibers
(3) Numbers or identification marks of test pieces
(4) Designation, nominal diameter, nominal cross sectional area
(5) Date of test, test temperature, loading rate
(6) Dimensions of test pieces, bonded length of CFRM
(7) Concrete mix, slump, and compressive strength at time of testing
(8) Average bond stress causing slippage at the free end of 0.05 mm, 0.10 mm and 0.25 mm for each test piece
(9) Maximum bond stress, failure mode and averages for each test piece
(10) Bond stress - slippage displacement curve for each test piece