3. TEST METHOD FOR BOND PROPERTIES OF CONTINUOUS FIBER SHEETS TO CONCRETE (JSCE-E 543-2000)

1. Scope

This specification describes the method used to test the bond properties to concrete of the continuous fiber sheets used for upgrading of concrete members.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JSCE-E 541	Test method for tensile properties of continuous fiber sheets
JIS K 7100	Plastics-standard atmospheres for conditioning and testing
JIS B 7721	Verification of the force measuring system of the tensile testing machine
JIS Z 8401	Guide to the significant digits

3. Definitions

The following are the definitions of the major terms used in this specification in addition to the terms used in the "Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets" published by the Japan Society of Civil Engineers and JSCE-E 541.

a) Concrete block

A rectangular concrete block used to study the bond properties of continuous fiber sheets to concrete. Steel reinforcement or steel bars are embedded in the axial direction at the center of the cross-sectional area of the concrete block in order to transmit tensile strength. Concrete blocks are made up of a test block and an anchorage block.

b) Test block

The block used to study the bond properties of continuous fiber sheets

c) Anchorage block

The counterpart block to the test block prevents the bond failure of the continuous fiber sheet. An additional continuous fiber sheet jackets the block with the sheets to be tested circumferentially to provide higher bond resistance for the sheets.

d) Interfacial fracture energy

The amount of energy per unit of bond area necessary to produce interfacial fracture

e) Effective bond length

The length of the portion in which the bond stress between the continuous fiber sheet and the concrete acts effectively at the maximum load before the continuous fiber sheet comes loose from the concrete

f) Effective bond area

The area derived from the effective bond length and the bond width of the continuous fiber sheet

g) Bond strength

The strength calculated by dividing the maximum load by the effective bond area

4. Test specimens

4.1 Types and dimensions

There shall be two types of test specimens as described below.

a) Type A test specimen

Type A test specimens shall consist of two separate concrete blocks manufactured in accordance with the method described in Section 4.3.1 a). The shape and dimensions of Type A test specimen are shown in Figure 1 and Table 1, respectively.

b) Type B test specimen

Type B test specimens shall be a single concrete block manufactured in accordance with the method described in Section **4.3.1** b). The shape and dimensions of Type B test specimen are shown in Figure 2 and Table 1, respectively.

Table 1 Dimensions of test specimens (unit: mm)

Type of test specimen	Type A (separate block type)	Type B (single block type)
Block length	300 min.	600 min.
Block cross-sectional area	100 x 100	
Bond length	200 (not including section cut away from edge)	
Distinguishing characteristics	Test specimen consisting of two matching concrete blocks with the block length and cross-sectional area above	Single concrete block with the block length and cross-sectional area above and a 20 mm deep notch in the center on either side

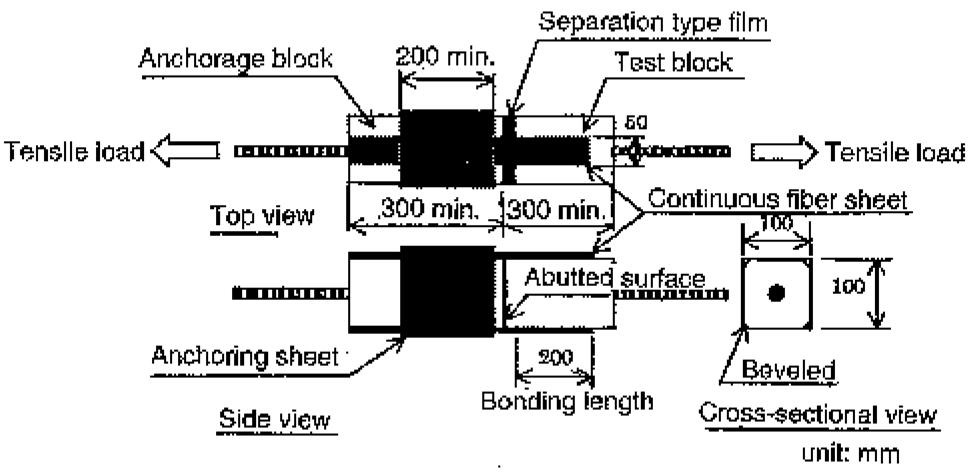

Figure 1 Shape of Type A test specimen

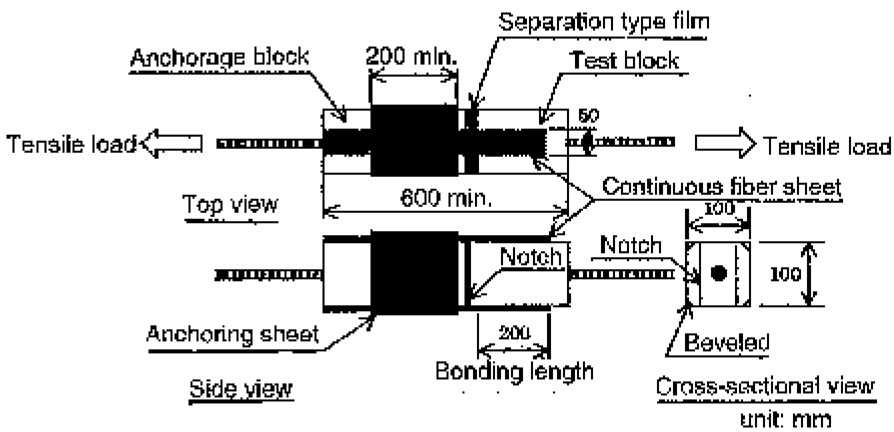

Figure 2 Shape of Type B test specimen

4.2 Quality of concrete and steel bars

4.2.1 Concrete

The standard quality of concrete shall be ordinary aggregate with maximum coarse aggregate diameter of 20 or 25 mm, slump 10 ±2 cm, and compressive strength of 30 ±3 N/mm^2 at an age of 28 days. When members to be actually upgraded are available, concrete of equivalent quality to the members may be used.

4.2.2 Steel bars

Steel bolts or bars used to transmit a tensile force shall have a strength and diameter sufficient to prevent yielding or pull-out from the concrete block before the continuous fiber sheet comes to the ultimate stage, in order to enable the load to be properly transmitted to the concrete block.

4.3 Preparation of test specimens

4.3.1 Concrete blocks

a) Type A test specimen (separate blocks)

(1) Prepare a pair of molds for concrete blocks with a cross-sectional area of 100 x 100 mm and a length of 300 mm. The dimensional error of the molds should be no more than 1/100 of the length of each side. To ensure precision, the molds should be made of steel. The four corners in the longer axis direction should be beveled using chamfering strips.

(2) The steel bolts or bars for applying tensile force should be positioned at the center axis of the concrete blocks and placed so that the ends of the bolts or bars are matched to the abutted surfaces of the concrete blocks during the test. The edge on the other side of the abutted surface should have a grip allowance long enough[1] to enable the steel bolt or bars to be gripped securely by the chuck of testing machine.

(3) Pour the concrete and cure it in the appropriate manner.[2]

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[1] The grip allowance for the tension steel bolts or bars shall be at least 200 mm from the edge of the concrete block.

[2] The concrete should be cured to give it the required strength.

(4) The steel bolts or bar should be placed so that they are not eccentric with respect to the center of the cross-sectional area. Make sure that no slippage or twisting occurs in the surfaces of the concrete blocks.

b) Type B test specimen (single block)

(1) Prepare a mold for a concrete block with a cross-sectional area of 100 x 100 mm and a length of 600 mm. The dimensional error of the mold should be no more than 1/100 of the length of each side. To ensure precision, the mold should be made of steel. The four corners in the longer axis direction should be beveled using chamfering strips. Wooden pieces for making notches on concrete surfaces after stripping off the mold should be placed on the two sides of the mold. The notch depth should be 20 mm.

(2) A pair of steel bolts or bars should be placed at the center axis of the concrete blocks so that they are abutted in the center of the longer axis. The positions of the steel bolts or bars should be placed so that they are not eccentric with respect to the center of the cross-sectional area. The edge on the other side of the abutted surface should have a grip allowance long enough[1] to enable the steel bolts or bars to be gripped securely by a chuck of testing machine.

(3) Place the concrete and cure it in the appropriate manner.[2]

4.3.2 Concrete surface treatment

The surfaces of concrete shall be given standard surface treatment using the following procedure. When a member to be actually upgraded is available, surface treatment equivalent to the actual work shall be conducted.

a) Scour the surface of concrete using a grinder to remove laitance and dirt.

b) Using a rag, wipe away powder and dust from the concrete surface. If there are oils on the surface, wipe them away using acetone.

c) Coat with primer and let it harden until it does not stick to the fingers when touched.

d) Coat with putty or other smoothing agent to even out the unevenness and bubbles on the surface, then wait for it to harden until it does not stick to the fingers when touched.

4.3.3 Attaching and anchoring continuous fiber sheets

Use the following procedure to attach the continuous fiber sheets. When a member to be actually upgraded is available, a method equivalent to the actual work shall be used.

a) Attach the separation film[3] along the abutted surfaces of the concrete blocks (for the Type A test specimen) or along the notch in the concrete block (for the Type B test specimen) to prevent between concrete and the continuous fiber sheet .

b) After coating both sides of the conc rete block with resin, attach a 50 mm wide continuous fiber sheet along the axis of the steel bolts or bars as shown in Figure 1[4, 5] and then impregnate resin into the sheet without cut bubbles. During this process, adjust the length from the end of the separation film to the end of the continuous fiber sheet so that the bond length on the test block is 200 mm. On the anchorage block, extend the continuous fiber sheet to the end of the block.

c) Apply the resin on the top.

d) Cure the test specimen at the prescribed temperature and humidity for the prescribed period of time.

e) Wind a continuous fiber sheet of at least 200 mm in width once around the anchorage block perpendicular to the longer axis within 15 mm of the abutted surfaces or notch, as shown in Figure 1.

f) Cure the test specimen at the prescribed temperature and humidity for the prescribed amount of time.

4.4 Conditioning the test specimen

As a rule, test specimens shall be conditioned for at least 48 hours before testing in a Class 2 standard atmosphere (temperature 23 ±2°C and humidity 50 ±10%) as described in JIS K 7100.

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[3] To prevent spalling off of corners of the concrete blocks, attach a thin layer of separation film around the ends to prevent bond between the continuous fiber sheet and the concrete.

[4] When bonding the continuous fiber sheets, make sure the impregnation resin does not come out too much from the surface. If this happens, wipe it away completely.

[5] No more than three plies of continuous fiber sheets should be used.

4.5 Number of test specimens

A number of test specimens suitable for the test objective shall be determined. However, it shall be no fewer than three.

5. Testing Machine and Measuring Devices

5.1 Testing machine

The testing machine shall conform to JIS B 7721 and must be capable of applying the prescribed load properly.

5.2 Chucks

The chucks shall be capable of transmitting loads appropriately so that no eccentricity is created in the test specimen.

5.3 Strain gauges

The strain gauges shall be capable of recording variations during testing with an accuracy of 10×10^{-6}.

6. Test Method

6.1 Dimensions of test specimen

The width of the bonded continuous fiber sheet shall be measured, at the slit on Type A test specimens and at the notch on Type B test specimens, as well as in three additional locations on both test specimens (in the center of the bonded portion and at the ends).

6.2 Mounting the test specimen

Both Type A and Type B test specimens shall be mounted onto the testing machine so that an eccentric load is not applied by matching the center axis of the test specimen to the center axis of the testing machine.

6.3 Mounting the strain gauges

In order to measure the strain distribution in the bonded portion, strain gauges must be mounted properly on the continuous fiber sheet on the test block. The size of strain gauge and the gauge interval shall be determined to match the objective of strain measurements.[6]

6.4. Loading rate

The standard loading rate shall be at a rate of 2-5 kN per minute.

6.5 Test temperature

The test temperature shall be 20 ±5°C. However, if the test specimen is not sensitive to changes in temperature, the test may be conducted at a temperature of 5-35°C.

6.6 Scope of test

The loading test shall be performed up to the ultimate stage of the continuous fiber sheet. Measurements of load, strain and displacement shall be made and recorded continuously or at regular intervals until maximum capacity.

Reference: When strain gauges are mounted, measurements should be made about every 1 kN load.

7. Calculation and Expression of Test Results

7.1 Handling of data

The test data shall be assessed on the basis only of test specimens whose ultimate are observed as peeling off or failure of the continuous fiber sheet. In cases where

[6] The interval between strain gauges should be no more than 20 mm.

failure has clearly taken place at the anchorage portion, the data shall be disregarded and additional tests shall be performed using test specimens from the same lot until the number of test specimens experiencing failure in the test portion is not less than the prescribed number.

7.2 Failure categories

Table 2 shows the categories for test specimen failure.

Table 2 Categories for test specimen failure

Code	Type of failure
BF	Interfacial failure
SF	Base material failure

7.3 Interfacial fracture energy

The interfacial fracture energy between the bonded surfaces G_f shall be calculated using Eq. (1) and rounded off to three significant digits in accordance with JIS Z 8401.

$$G_f = \frac{P_{max}^2}{8b^2 \cdot E_f \cdot t} \quad \text{.......................(1)}$$

where

G_f : Interfacial fracture energy (N/mm)
P_{max} : Maximum load (N)
b : Average width of continuous fiber sheet (mm)
E_f : Young's modulus of continuous fiber sheet (N/mm^2)
t : Thickness of continuous fiber sheet (mm))(= n•w/p)
n : No. of ply of continuous fiber sheet
w : Fiber mass per unit area of continuous fiber sheet (g/mm^2)[7]
r : Density of continuous fiber sheet[7]

[7] Nominal fiber weight provided by material manufacturer may be used.

7.4 Bond strength

The bond strength $\tilde{t}_u$ shall be calculated using Eq. (2) and rounded off to three significant digits in accordance with JIS Z 8401.

$$\tilde{t}_u = \frac{P_{max}}{2b \cdot l} \qquad \text{(2)}$$

where

$\tilde{t}_u$: Bond strength (N/mm^2)

P_{max} : Maximum load (N)

b : Average width of continuous fiber sheet (mm)

l : Effective bond length in test portion of continuous fiber sheet (mm)[8]

7.5 Strain distribution diagram

When strain measurements are done, a strain distribution diagram may be drawn at each loading step.

8. Report

The report shall include the following items:

a) Name of continuous fiber sheet
b) Type of continuous fiber sheet and impregnation resin
c) Fiber mass per unit area and density of continuous fiber sheet
d) Fabrication date, fabrication method and curing period for test specimens
e) Temperature, humidity and duration of test specimen conditioning
f) Identification of test specimen
g) Test date, test temperature and loading rate
h) Test specimen dimensions and fiber mass per unit area, width, length and number of plies for continuous fiber sheets
i) Concrete mixture, slump and compressive strength at testing

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[8] Effective bond length l is determined by the number of continuous fiber sheet layers, Young's modulus and the type of impregnation resin.

j) Interfacial fracture energy and bond strength for each test specimen and averages for these values

k) Type of failure for each test specimen

COMMENTARY ON TEST METHOD FOR BOND PROPERTIES OF CONTINUOUS FIBER SHEETS TO CONCRETE

Introduction

Determination of the bond properties of continuous fiber sheets to concrete is crucial for upgrading design. Conducting test to obtain accurate information on bonding behavior that matches the actual members would be ideal. Nevertheless, to specify a standard test method, it is necessary to simplify the dimensions of test specimens and the test method and to minimize the effect of differences in test conditions and human error on the evaluation results. Here a method of evaluating the bond properties of continuous fiber sheets to concrete using a uniaxial tensile strength test is adopted. This uniaxial tensile strength test method has been used by many research organizations in the past and the test can be conducted with comparative ease. The test method referenced here is "Test method for bond properties of continuous fiber sheets to concrete using tensile testing" published by the Japan Concrete Institute.

1. Scope

In this test method, the maximum load is measured in order to evaluate the bond strength, which is calculated by dividing the maximum load by the interfacial fracture energy for the bonded surfaces and the given effective bonding area (continuous fiber sheet width x effective bond length). The interfacial fracture energy derived with this test method can be used in upgrading design as the peeling resistance for flexural behaviors. It is also an important parameter determining the constitutive law of bond of continuous fiber sheets for use in calculating shear capacity. Bond strength may be used to evaluate the relative bond strengths of continuous fiber sheets and concrete, and to make comparisons with old materials when different or new continuous fiber sheet impregnation resins are used for particular applications.

2. Normative References

3. Definitions

(e)

Previous research has shown that, in the uniaxial tensile strength test method for bond strength, the maximum load at failure does not increase so much if the bond length of the continuous fiber sheet is greater than a certain level. The reason is assumed that the bond stress occurs not over the entire bonded area of the continuous fiber sheet but only in a certain limited area. Since this area is seen to be essentially the effective area for bond between the continuous fiber sheets and concrete, it was defined as the effective bond length.

4. Test specimens

4.1

Here two types of test specimens are proposed: Type A, with two separate blocks, and Type B, a monolithic block. In the Type A test specimen, which is originally separated in the center, the load is applied directly to the continuous fiber sheet starting fom the initial loading step. In contrast, in the Type B test specimen, the concrete bears the tension load until the loading step at which cracks penetrate through to the notch. Accordingly, selecting the proper type of test specimen determines whether or not the consideration of the concrete contribution in tension is necessary.

4.2

Here the standard quality of concrete used specifies a slump of 10 ±2 cm and a compression strength of 30 ±3 N/mm^2 for a material age of 28 days. This quality of concrete is the standard type used in various test methods in the JSCE standards. This is done so that, by standardizing the quality of concrete, it would be easy to make relative comparisons of the test results obtained. However, if it is necessary to determine the bond properties of the actual members being studied for upgrading, concrete of the same quality as the actual members may be used for the test.

4.3

4.3.1

Eccentricity during the test has a great impact on the test results, so the test specimens must be accurately fabricated. Eccentricity during the test is affected by the positioning accuracy of the steel bolts or bars and the dimensional accuracy of the concrete test specimens themselves. Accordingly, for the Type A test specimens in particular, molds should be used so that the concrete for a pair of test specimens should be placed at the same time. The molds should be made from a thin steel plate with a guide placed in the center of the end of the test specimen, or similar measures taken, to enable the steel bolts or bars to be fastened in the proper positions in order to reduce the slippage when the blocks are fastened together. Also, since the accuracy of the molds directly affects the dimensional accuracy of the test specimens, the dimensional error of the molds should be no more than 1/100 of the side length.

For the Type B test specimens, the method calls for a notch with a depth of 20 mm to be made when the concrete is placed. However, the notch may also be made with a concrete cutter after the concrete has hardened.

4.3.2

The method noted here concerns the surface treatment that should be done in order to evaluate the standard bond properties of continuous fiber sheets. However, if a member to be actually upgraded is available, the same surface treatment may be used as that which is applied to this member.

4.3.3

The method of attaching continuous fiber sheets noted here is the one used in order to evaluate the standard bond properties. The separation film is wrapped around the ends of the test specimens to prevent the corners from being damaged. Normally a thin polyethylene film is used, but any material that does not stick to the resin that impregnates the continuous fiber sheet may be used. If a member to be actually upgraded is available, the same procedure may be used. No more than three plies of continuous fiber sheet may be used in the application of this test method. If the number of plies is greater than three, the effective bond length may exceed the bond length of 200 mm, and therefore a suitable bond length and effective bond length must be established separately.

The hardening time for the impregnation resin depends on the type of resin and the ambient temperature. Unless otherwise specified, the standard curing time is 7 days following attachment of the continuous fiber sheets to the concrete blocks, in a room with temperature and humidity regulated to 20°C ±5°C and 65% ±5%. If a member to be actually upgraded is available, curing may be done for the same duration and under the same environmental conditions as those applied under actual work conditions. However, before the test is begun, the test specimens must be conditioned for at least 48 hours at temperature 23 ±2°C and humidity 50 ±10% in accordance with JIS K 7100.

5. Testing Machine and Measuring Devices

5.1

As a rule, a tensile testing machine conforming to JIS B 7721 should be used. However, if a hydraulic jack is used to perform the test for convenience or due to difficulty in attaching test specimens, it must be confirmed that use of such methods will produce the same load control, test specimen mounting accuracy.

6. Test Method

6.3

This method notes that strain measurements should be conducted as needed. When the strain distribution is measured at each loading step, appropriate values for strain gauge length and the interval must be established to ensure that the desired data are obtained. The interval between strain gauges should be 20 mm or less.

7. Calculation and Expression of Test Results

7.3

The following values may be used for the effective bond length l when the carbon fiber sheets shown in Table C1 in JSCE-E 541 are used.

Carbon fiber sheets:

For single-ply bond	110 mm
For double ply bond	150 mm

For carbon fiber sheets other than the above and aramid fiber sheets, the effective bond length may be determined using the method prescribed in ¥the "Test method for bond properties of continuous fiber sheets to concrete using tensile testing" published by the Japan Concrete Institute.

7.5

Attaching strain gauges at appropriate intervals on the surface of the continuous fiber sheet and measuring the strain distribution enables the following method to be used to determine the bond constitutive law for the continuous fiber sheets.

7.5.1 Determining the relationship between bond stress and relative displacement

(1) From the strain distribution for the continuous fiber sheet at each loading step, determine the data after failure. Failure can be determined by the shape of the strain distribution. (Figure C1)

(2) Using the strain distribution for any loading step after failure, perform numerical integration and differentiation as shown in Figure C2 to calculate the bond stress $t_{(x)}$ and relative displacement $d_{(x)}$ between the continuous fiber sheet and the concrete at each point.

(3) Derive the relationship between the bond stress $t_{(x)}$ and the relative displacement $d_{(x)}$.

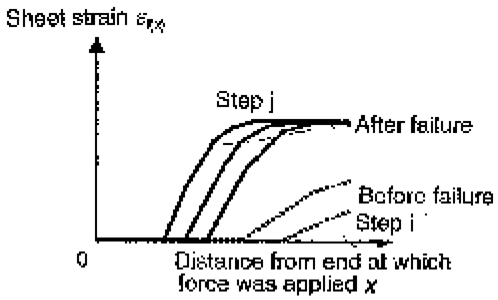

Figure C1
Calculated values for strain distribution of continuous fiber sheet

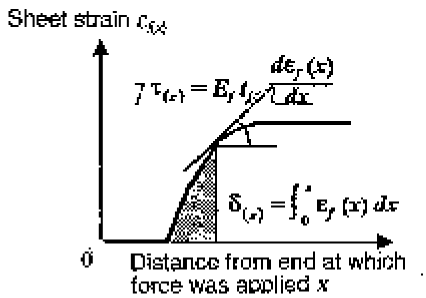

Figure C2
Calculation of bond stress and relative displacement

(4) Perform the aforementioned procedure at several load steps after failure and then average the data to determine the relationship between bond stress *t* and relative displacement *d* for the continuous fiber sheets and the concrete.

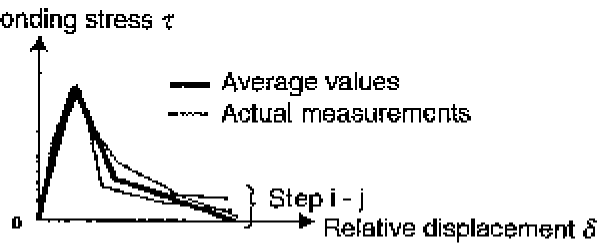

Figure C3 Relationship between *t* and *d* derived from strain distribution of continuous fiber sheets

7.5.2 Modeling the relationship between bond stress and relative displacement

Figure C3 shows the relationship between bond stress and relative displacement, derived from the actual measurements of the strain distribution of the continuous fiber sheets. As the figure shows, the area can be generally divided into an elastic domain and a softening domain. Modeling as shown below is done to make it easier to calculate the shear capacity of members reinforced with continuous fiber sheets.

(1) A bilinear model may be used to approximate the relationship between *t* and *d* obtained from the actual measurements (Figure C4).

(2) A cut-off model is identified so that the bilinear model and the fracture energy (the area enclosed by the *t* and *d* curves) are equivalent and the maximum bond stress is doubled (Figure C5).

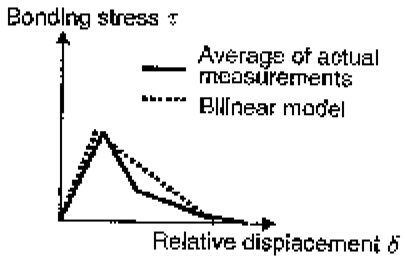

Figure C4 Bilinear model

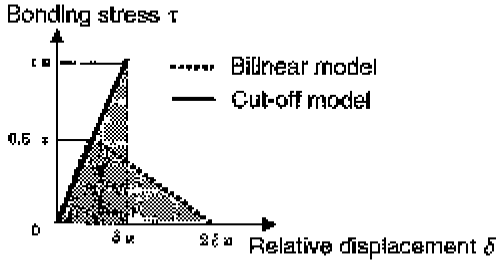

Figure C5 Cut-off model

8. Report