# SPRAYED-UP FRP STRENGTHENING FOR REINFORCED CONCRETE BEAMS

Dr. Tomoki Furuta, Bando Chemical Industries, LTD., Kakogawa, Japan
Dr. Toshiyuki Kanakubo, University of Tsukuba, Tsukuba, Japan
Takeshi Nemoto, Showa Highpolymer Co., LTD., Tokyo, Japan
Keisuke Takahashi, Mitsubishi Chemical Functional Products, Inc., Tokyo, Japan
Kouichi Itoh, Constec Engi, Co., Toyko, Japan
Hiromi Minamihara, Mitsubishi Corporation, Tokyo, Japan

## Introduction

Nowadays, strengthening by post casting concrete, steel plate jacketing, fiber reinforcements such as carbon, aramid, and glass are utilized as seismic strengthening methods for concrete structures. Recently, a seismic strengthening method by wrapping continuous fiber sheets has often been used, since the constructibility and durability is superior. However, materials using continuous fibers are expensive. On the spread of seismic strengthening for buildings and infrastructures in future, simple methods of strengthening with low cost should not only be suggested, but also seismic behaviors should be cleared.

In this study, a new, inexpensive, and simple strengthening method for concrete structures is discussed and suggested in order to improve future seismic strengthening. This method using short fibers with vinyl ester is a new combination of materials as seismic strengthening. Chopped short fibers of carbon and glass with vinyl ester resin are sprayed in place on the concrete structures. It is called "Sprayed-Up FRP (Fiber Reinforced Polymer)." Benefits of using vinyl ester resin in this strengthening method are that it takes shorter time to harden the resin than epoxy resin. In addition, the mechanical properties of vinyl ester resin are the same as the one of epoxy resin.

In this paper, the outlines of this method and the results of T-shape beam test under the anti-symmetrical loading are reported. In addition, the bonding and anchoring behavior between FRP and concrete using slit (groove) are reported.

## Outline of Sprayed-up FRP Strengthening Method

**Figure 1** illustrates the idea of the sprayed-up FRP strengthening method for reinforced concrete buildings. **Photo 1** shows the construction site of sprayed column specimens. In this method, resin is carried through a narrow hose by an air compressor. The resin is mixed with short fibers such as carbon or glass at a tip of the narrow hose. The mixed materials are sprayed directly on a surface to be reinforced. After that, the surface is made flat by a roller. The resin will be hardened and the whole sprayed structure will be reinforced with FRP. This method makes seismic strengthening possible that all structure members, which are columns, beams, walls, and slabs, are monolithic since it is possible to reinforce an entire interior structures in building structures.

The installing procedure of the sprayed-up strengthening is as follows;

Step 1. Base arrangement; Surface of concrete is polished by a disc-sander and cleaned by air.

Step 2. Primer resin coating; Primer resin is applied to the surface in order to make highly adhesive between concrete and putty/resin.

Step 3. Putty arrangement; Dent areas and steps on concrete surface are filled with putty and make the surface flat in order to prevent from partial stresses of FRP and air voids on concrete. After putty dried, the surface is sanded.

Step 4. Resin coat; In order to make fibers more adhesive, resin is coated first by a spray gun.

Step 5. Spraying (Photo 1); Resin and short fiber are sprayed on concrete at a same time by a spray gun. The lengths of the carbon fiber and glass fiber are 2.0 inches and 1.5 inches, respectively.

Step 6. Impregnation (Photo 2); Entrapped air is rolled out.

In this study, in order to compare structural behaviors of sprayed-up FRP to the ones of continuous fiber sheet strengthening, preliminary arrangements as Step 1 through 3 are done. However, it is a goal to obtain sufficient seismic behaviors by taking only after Step 4.

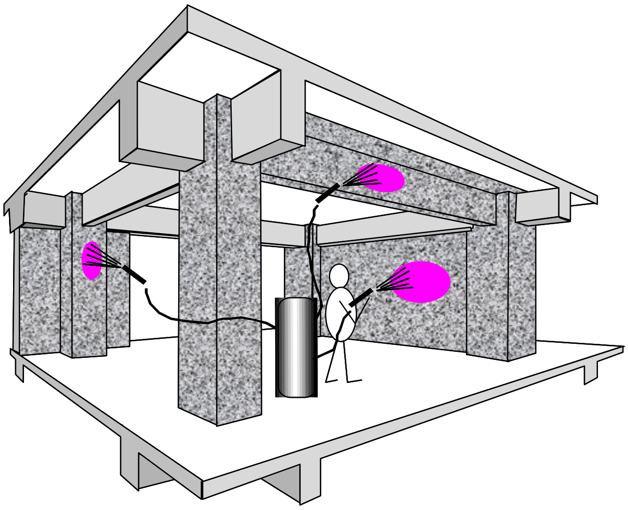


**Figure 1.** Sprayed-up FRP strengthening

**Photo 1.** Construction site of sprayed-up FRP

## Mechanical Properties of Sprayed-up FRP

Five coupon specimens of sprayed-up FRP were prepared as Type A (JIS K7054) test pieces. The conditions of making coupon specimens are exactly the same conditions with the beam specimens. The specified thickness of FRP was set to 3.0mm by controlling spraying time to have an equal rigidity of carbon fiber sheet of 200g/m$^2$ ($t_f$=0.115mm, $E_f$=230GPa). Based on a tensile test method for plastics reinforced by glass fiber (JIS K7054), a tensile test was carried out for these Type A test pieces.

**Table 1** summarizes the tensile test results. The measured sectional areas including resin are applied in calculating stress. The tensile strength of sprayed-up FRP is about 70MPa, and unit width strength is almost 270N/mm. The elastic modulus is 8GPa and rigidity of sprayed-up FRP is 24kN/mm. This value is almost the same with that of carbon fiber sheet (200g/m$^2$) of 26kN/mm.

**Table 1.** Tensile test results for test pieces

| Width (mm) | Thickness (mm) | Tensile strength (MPa) | Elastic modulus (GPa) | Elongation (%) |
|---|---|---|---|---|
| 24.8 | 3.99 | 67.2 | 8.02 | 1.24 |

## Bond Test between FRP and Concrete

Sprayed-up FRP has flexibility for the concrete surface at the construction site. It is known that structural behaviors of beams strengthened by fiber sheets are influenced by conditions of sheet anchoring at the meeting corner between beam and slab[1]. In this study, it is proposed that sprayed-up FRP is anchored at the meeting corner using "FRP filled slits". **Figure 2** shows an image of FRP anchoring method at the meeting corner. In this method, there is a merit that steel materials are not utilized.

In this study, bond test by double shearing type specimens are conducted in order to investigate the effectiveness of FRP filled slits. The test variables are size of slits.

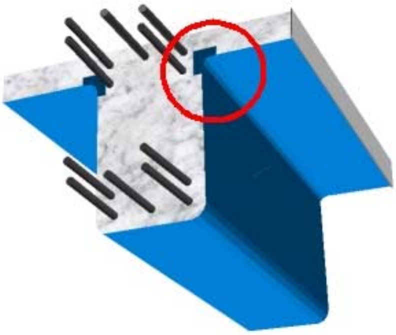


**Figure 2.** FRP filled slit anchoring

### *Specimens for Bond Test*

Specimens for bonding between FRP and concrete were prepared as shown in **Figure 3**. The specimen consists of a concrete prism (100 x 100 x 600mm) cracked at the center, using a hammer on the notch, after the reinforcing with FRP. The two steel bars also have no connection, which means that the two prisms are connected only through the FRP. Specimens No.1 had no slits in order to investigate pure bonding strength between FRP and concrete. Specimens No.2 through No.4 had FRP filled slits. The FRP at the slits was expected mechanical bearing to concrete. The parameters of specimens were depth of slits (5, 10, 20mm). The list of specimens is shown in **Table 2** with test results. Three specimens were tested for one test variables.

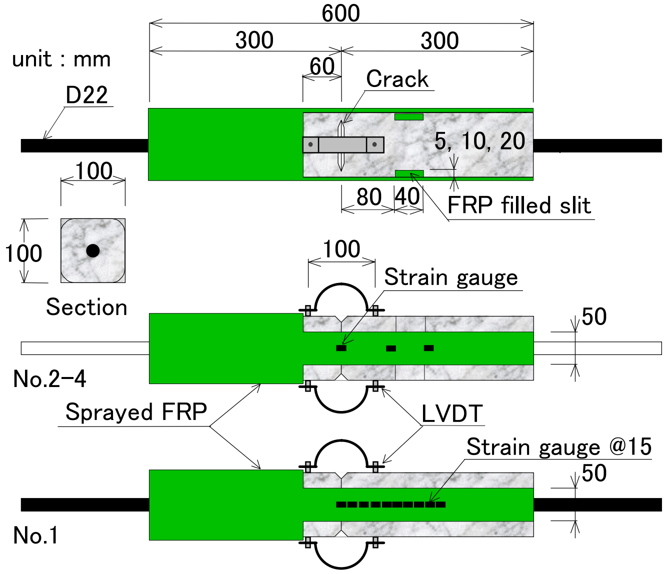


**Figure 3.** Specimens for bond test

Concrete for bond specimens was normal weight concrete with compressive and tensile strength of 32.8MPa and 2.70MPa, respectively. Static tensile load was applied at the both steel bar ends with displacement controlled 2MN loading machine. Load and crack width of notch at the center of specimens were measured. FPR strains were measured by strain gages as shown in **Figure 3**.

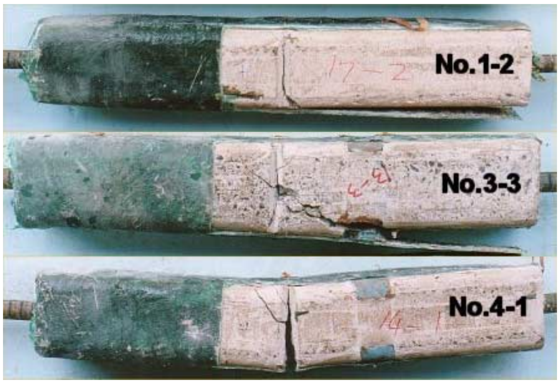
**Table 2.** List of bond specimens

| Specimen | Slit | | At maximum load | | Failure type |
|---|---|---|---|---|---|
| | Width (mm) | Depth (mm) | Load (kN) | Crack width (mm) | |
| No.1-1 | No slit | | 20.8 | 1.13 | Bond failure |
| -2 | | | 26.3 | 1.48 | Bond failure |
| -3 | | | 14.8 | 0.75 | Bond failure |
| No.2-1 | 40 | 5 | 24.1 | 1.22 | Concrete shear |
| -2 | | | 24.2 | 1.78 | FRP rupture |
| -3 | | | 27.1 | 1.41 | Concrete shear |
| No.3-1 | | 10 | - | - | FRP rupture |
| -2 | | | 23.0 | 1.21 | Concrete shear |
| -3 | | | 31.2 | 1.78 | Concrete shear |
| No.4-1 | | 20 | 30.2 | 1.46 | FRP rupture |
| -2 | | | 16.9 | 0.79 | FRP rupture |
| -3 | | | 26.3 | 1.37 | FRP rupture |

***Failure Type and Maximum Load***

Specimens No.1 without slit failed by debonding of FRP from concrete. Specimens from No.2 to No.4 failed by FRP rupture or concrete shear failure. Typical failures are shown in **Photo 2**. The maximum load for specimens No.1, i.e., bond strength between sprayed-up FRP and concrete is 20.6kN in the average of three specimens. Comparing with the bond strength of carbon fiber sheet having same rigidity, the bond strength is almost 80% of analytical bond strength by literature 2) of 25.7kN.

The anchoring strength of FRP filled slit is not clear, because specimens from No.2 to No.4 failed by FRP rupture or concrete shear failure. However, the slit depth of 5mm is sufficient to cause rupture of FRP itself. The average of maximum load of three specimens of No.2 is 97% of tensile strength obtained by coupon tensile specimens.



No.1-2 : Bond failure

No.3-3 : Concrete shear

No.4-1 : FRP rupture

**Photo 2.** Bond specimens after loading

***FRP Strain Distributions***

**Figure 4** shows strain distributions of FRP for each specimen. X-axis indicates the distance from the center of specimens. The slits locate between 80mm and 120mm for specimens No.2 through No.4. In specimen No.1, it is observed that a section having the slope of strain distribution moves from the center toward the end of the specimen as increasing the load. This phenomenon is caused by debonding of FRP. In specimens No.2 – No.4, the strains in the range beyond the slits is very small. From these results, it is recognized that the FRP filled slits have efficiency to anchor the FRP.

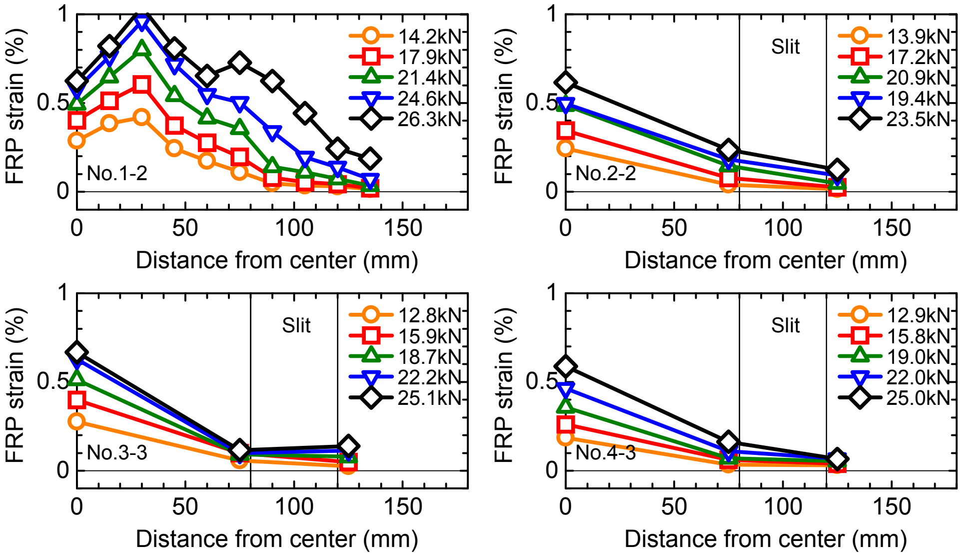


**Figure 4.** Strain distributions of FRP

## Antisymmetrical Loading Test for T-Shape Beams

### *Specimens for Beam Test*

**Figure 5** shows the dimensions and the details of beam specimens. The specimens are modeled in 1/3 scale of actual beams with slabs. The dimension was 300mm wide and 200mm deep and the shear

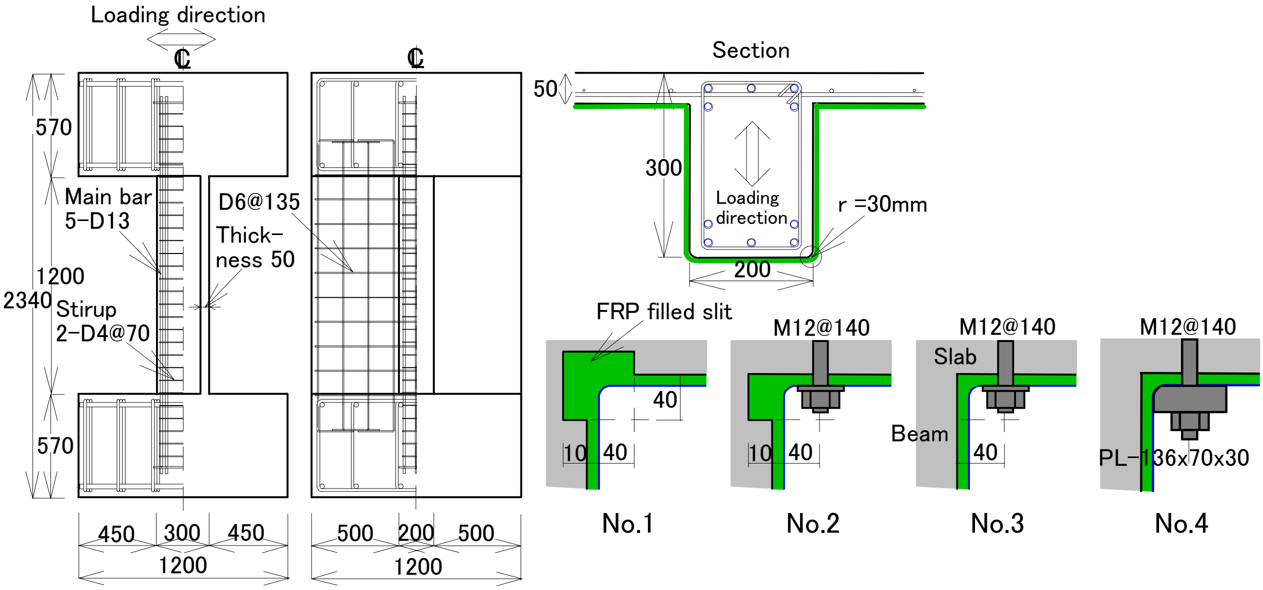


**Figure 5.** Beam specimen

span ratio is 2.0. The width and thickness of slabs are 500mm and 50mm, respectively. The test variable is type of FRP anchorage at the meeting corner of beam and slab. In specimen No.1 and No.2, FRP is anchored by FRP filled slits. In specimen No.2, anchor bolts M12 are also set to slab surface. In specimen No.3, FRP is anchored by only M12 bolts to slab surface. Steel blocks are also used to anchor the FRP in specimen No.4.

The thickness of FRP are designed to 3mm so as for the FRP rigidity (elastic modulus times thickness) to be equal with the carbon fiber sheet strengthening of specimen No.22 and No.23 of literature 1). Deformed rebars D13 (yield strength = 324MPa) and D4 (yield strength = 218MPa) were used as main bars and stirrups, respectively. The designed normal weight concrete strength was 24MPa. The maximum diameter of the aggregates was 15mm. The measured compressive and tensile strength at the loading age is 26.9MPa and 2.02MPa, respectively.

### *Loading System and Measurements*

Each specimen was subjected to anti-symmetrical bending moment in a cyclic manner. The drift angles were from 1/400rad to 1/20rad. Measuring items were horizontal and vertical displacements between the top and bottom stubs, and strains of main bars, stirrups and FRP.

### *Failure Progress*

Specimens after loading are shown in **Photo 3**. All specimens had flexural yielding at the loading cycle of 1/100rad. At the loading cycle of 1/50rad., small cracks of FRP took place. Finally, the load decreased by rupture of FRP.

In specimen No.3, cracks of FRP around the anchor bolts took place at the first loading cycle of 1/50rad. At the second loading cycle, FRP rupture at the meeting corner was observed, and FRP had debonding on the sides of beam. In specimen No.4, FRP cracked around the steel blocks at the second loading cycle of 1/50rad. After that, rupture of FRP expanded along the shear cracks of concrete. In specimen No.1 and No.2, cracks of FRP around the beam corner at the end of beam took place at the second loading cycle of 1/50rad. At the loading cycle of 1/33rad., FRP ruptured along the beam corner toward the axial direction. Failure of FRP at the meeting corner was not observed.

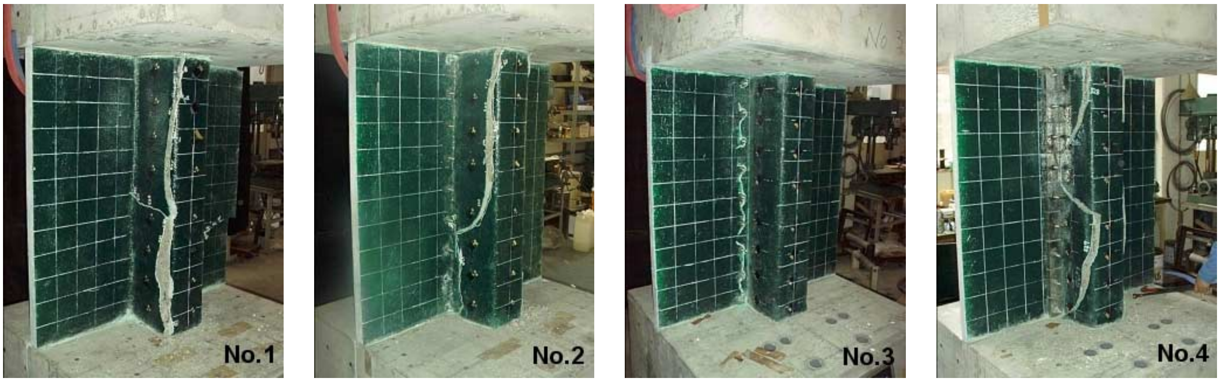


**Photo 3.** Beam specimens after loading

Shear force versus translational angle (drift angle) relationships are shown in **Figure 6**. The angle in which the remarkable decrement of shear force was observed is in the order of specimen No.2 > No.1 > No.4 > No.3. The effectiveness of FRP filled slit for anchoring of FRP is also recognized in the beam test.

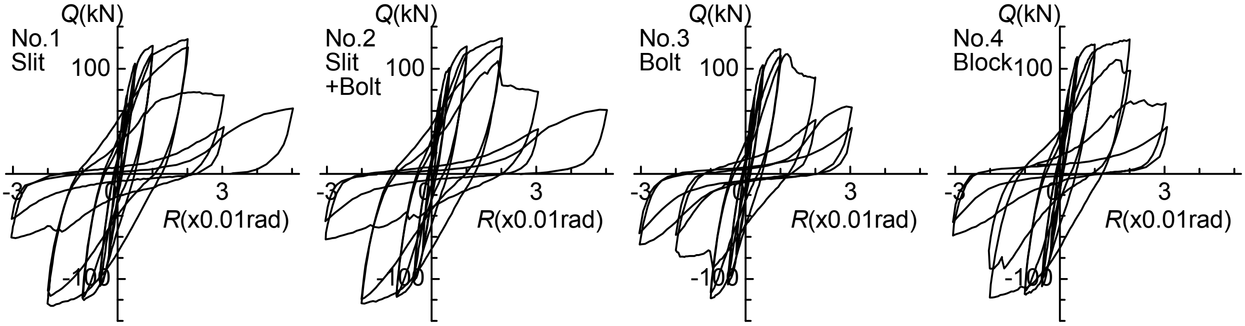


**Figure 6.** Shear force – translational angle curves

### *Comparison between Sprayed-Up FRP and Carbon Fiber Sheet Strengthening*

Shear force versus translational angle curves are compared with those of specimens strengthened by carbon fiber sheet. As reported in literature 1), T-shape beam specimens having same dimensions and material strength with this study have tested to investigate the efficiency of carbon fiber sheet strengthening. The specimen No.11 was not strengthened by sheet, and specimen No.22 and 23 were strengthened by 1 layer of carbon fiber sheet of 200g/m$^2$. In both specimen No.22 and No.23, fiber sheet was anchored at the meeting corner by steel angles and anchor bolts. In specimen No.22, the anchor bolts were set to both beam and slab faces. In specimen No.23, the sheet was anchored only to the slab face.

Skeleton curves for these specimens are shown in **Figure 7**. Specimen No.11 failed by shear without flexural yielding. All specimens No.1 – No.4 change failure mode to flexural yielding type. Strengthening effect by sprayed-up FRP is recognized. Comparing the specimens No.1 – No.4 with specimens No.22 and No.23, the behaviors are almost the same until 1/50rad. After the loading of 1/33rad., sprayed-up FRP strengthened specimens show brittle behavior rather than sheet strengthened specimens. This is caused by rupture of FRP itself at the corner of beam. The tensile strength per unit width of sprayed-up FRP and carbon fiber sheet is 268 and 541kN/mm, respectively.

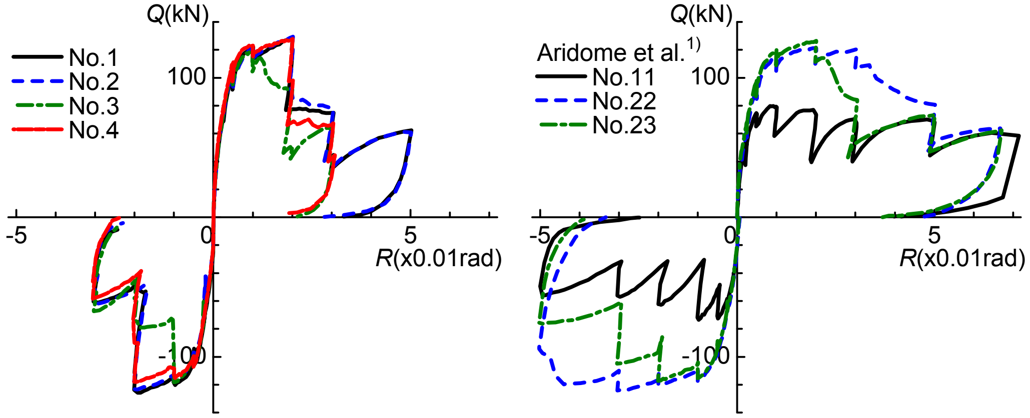


**Figure 7.** Comparing of skeleton curves between sheet strengthening

### *FRP Strain Distributions*

FRP strain distributions at the peak load of each loading cycle are shown in **Figure 8**. The left side diagrams show ones for specimen No.2, the right sides are for specimen No.3. The upper diagrams indicate the distributions at the side of beam, and the lowers are at the corner of beam. The maximum

FRP strain is about 0.3 to 0.4%. In specimen No.2, the strains of the corner at the ends of the beam are larger corresponding to actual failure mode, FRP rupture at the corner. In specimen No.3, negative strains take place because of FRP debonding from side of beam.

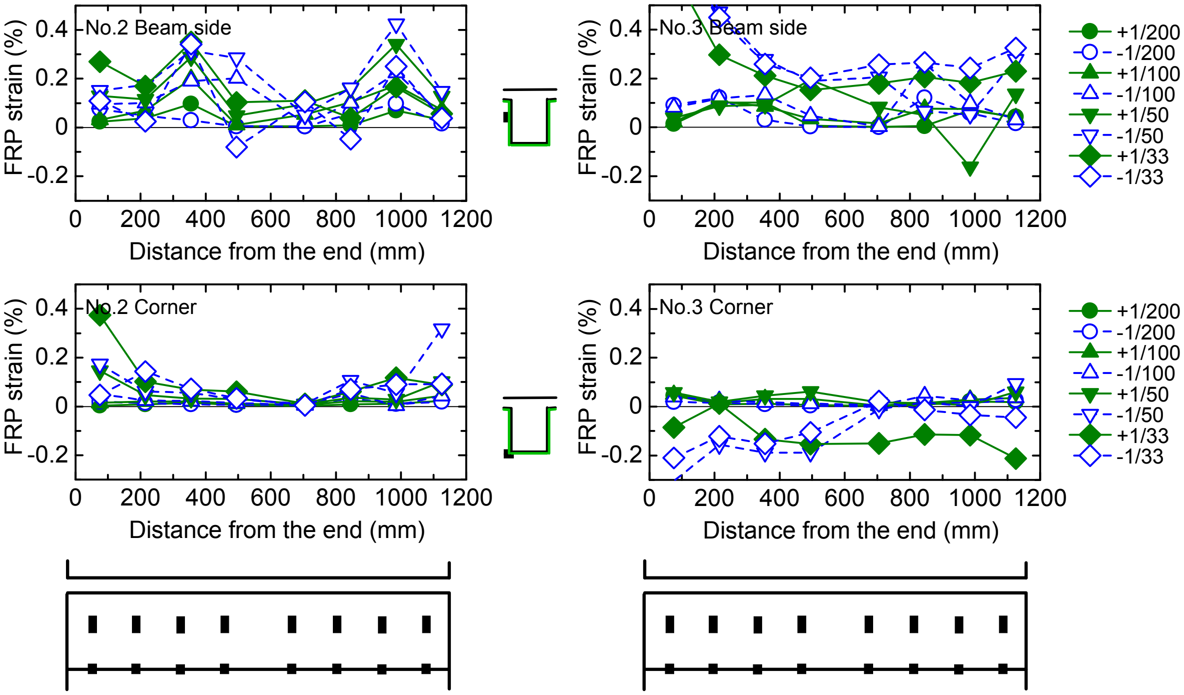


**Figure 8.** Strain distributions of FRP

## Conclusions

This strengthening method by sprayed-up glass fibers with vinyl ester resin is possible to apply to strengthen the reinforced concrete beams. The conclusions are summarized as follows;

(1) Both results of bond test and beam test indicate that FRP filled slit is effective for anchoring of FRP to concrete

(2) The slit depth of 5mm is sufficient to cause rupture of FRP itself.

(3) Failure of FRP at the meeting corner between beam and slab is not observed by FRP filled slit anchoring. FRP ruptured at the beam corner at the angle of 1/50rad.

## References

1) Yoshiro Aridome, Toshiyuki Kanakubo, Tomoki Furuta and Masaaki Matsui (1998), “Ductility of T-Shape RC Beams Strengthened by CFRP Sheet”, *Transactions of the Japan Concrete Institute*, Vol.20, pp.117-124

2) Kasumassa Nakaba, Toshiyuki Kanakubo, Tomoki Furuta and Hiroyuki Yoshizawa (2001), “Bond Behavior between Fiber-Reinforced Polymer Laminates and Concrete”, *ACI Structural Journal*, Vol.98, No.3, May-June, pp.359-367