論文 Shear Resisting Capacity of a Reinforced Concrete Pier Retrofitted with Carbon Fiber Sheet

Gabriel SÎRBU*1, Torii YOSHIHIRO*2, Yasuhiko SATO*3, Tamon UEDA*4

ABSTRACT: This paper presents the study results of a reinforced concrete pier with carbon fiber sheet (CFS) retrofitting. Plain reinforced concrete specimens were used for comparison. The experimental variables are: type of loading, ratio of CFS reinforcement. Specimens were subjected to static monotonic lateral loading or static cyclic lateral loading.
KEYWORDS: carbon fiber; reinforced concrete pier; shear reinforcement.

1. INTRODUCTION

The application of the Fiber Reinforcing Plastics (FRP) to improve the capacity of reinforced concrete elements, creates a great issue in the field of civil engineering. For the elements which do not have enough ductility, studies about the retrofitting effect of FRP materials have been carried [1, 2]. The main target of these studies was to find the relation between the amount of retrofitting material and the increase in ductility and shear capacity. However, the predicted values do not reflect with enough accuracy the shear capacity and ductility after retrofitting. This paper presents the influence of different loading conditions on the shear capacity using CFS as retrofitting material.

2. EXPERIMENTS

Because the target of this study was the study of the shear capacity of reinforced concrete piers retrofitted with CFS, the test specimens have been designed in such way that they fail in shear. For this purpose the relationships from "Standard Specifications for Design and Construction for Concrete Structures - 1986(Part 1-Design)"[3] were used.

Each specimen was a single prismatic column plus a strong footing ensemble. The column had a rectangular cross-section of 25×25 cm with rounded corners (R=3.5cm), and a total length of 100 cm. The point of application of the lateral load was at 65cm from the base. All specimens had the same reinforcement detailing. For the strengthened test specimens, the CFS was bonded to the concrete surface and impregnated with epoxy resin. During the tests, displacements of the loading point and strains in the reinforcing bars and CFS were measured in detail.

*1. Graduate Student, Hokkaido University, Department of Civil Engineering,
*2. Undergraduate Student, Hokkaido University, Department of Civil Engineering,
*3. Research Associate, Hokkaido University, Department of Civil Engineering,
*4. Associate Professor, Hokkaido University, Department of Civil Engineering,

2.1 MATERIALS

The steel reinforcement was five D25 (SD345) for longitudinal reinforcement (symmetric reinforcement), and round bar Ø6 for transverse reinforcement at 15cm spacing. The resulting reinforcement ratio was 4.68% and 0.15% for longitudinal and for transverse reinforcement respectively. The mechanical properties of the reinforcement are shown in **Table 1**. The stress-strain relationship for the Ø6 transverse reinforcement for monotonic loading is a linear-elastic until yielding and goes afterwards to a strain hardening curve up to 343 MPa (3500kgf/cm^2). This relationship was determined from a series of coupon tests. In addition, a cyclic test was conducted to investigate the behavior of the transverse reinforcement in cyclic conditions and to calibrate the calculation of the stress from each stirrup using Aktan, Karlson, Sozen's model[4]. The stress-strain relationship for longitudinal reinforcement is a bilinear relationship. The CFS was provided by TONEN Corporation; the stress-strain relationship is linear-elastic until failure. The details of specimens and the concrete strength measured on cylinders immediately after the test for each specimen are given in **Table 2**.

Table 1 Mechanical properties of reinforcement

Material	Type	Cross-sectional area (cm^2)	Young's modulus (GPa)	Yield strength (MPa)	Tensile strength (MPa)
Steel	Ø6	0.28	196	226	343
	D25	5.067	188	382	-
CFS	FTS-C1-20	0.111 for 10cm width	230	-	3480

Table 2 Details of the specimens

Specimens	f'c (MPa)	Concrete Young's modulus (GPa)	Concrete shear modulus (GPa)	CFS (stripes of 2cm width)	Lateral displ. (mm)	Peak value of shear force (kN)	Test type
SS1	25.7	19.0	11.60	No	10.4	143.1	Monotonic
SC1	28.4	20.8	12.90	No	16.0	142.6	Cyclic
SS2	22.7	19.6	9.80	5/9.50cm spacing	12.6	157.9	Monotonic
SC2	29.0	21.7	10.90	5/9.50cm spacing	10.0	125.4	Cyclic
SS3	29.6	21.5	10.60	9/4.75cm spacing	14.0	192.9	Monotonic
SC3	29.3	21.0	10.50	9/4.75cm spacing	22.0	191.3	Cyclic

2.2 TEST SETUP

A rigid steel reaction frame was used to test all specimens. The specimen was connected to this reaction frame by 4 Ø22mm high-strength steel rods, which were prestressed at 294kN each. A ±294 kN (±15cm maximum displacement range) actuator was used to apply the lateral load. **Figure 1** shows the test setup. **Figure 2** indicates the arrangement of strain gauges for steel reinforcement and displacement transducers. Each stirrup that was observed during tests had 6 strain gauges and for the longitudinal bars, the middle one had 4 strain gauges at 15cm spacing starting from the base. All data was scanned and recorded immediately after each step in loading. **Figure 3** is showing the position of the strain gauges on CFS stripes for specimens SS2 and SC2, and SS3, SC3 respectively. **Figure 4** presents the shear crack pattern for specimens SS1, SC1 and SS3, SC3 respectively.

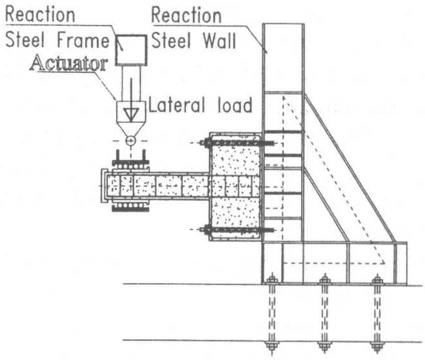

Figure 1 Test setup

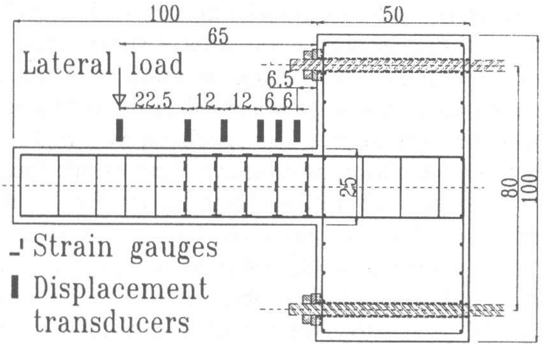

Figure 2 Strain gauges and transducers arrangement

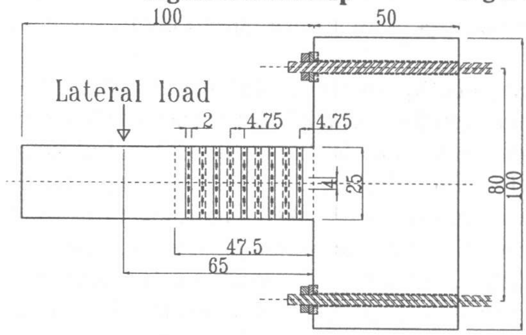

Figure 3 CFS strain gauges in specimens SS2, SC2 and SS3, SC3 respectively

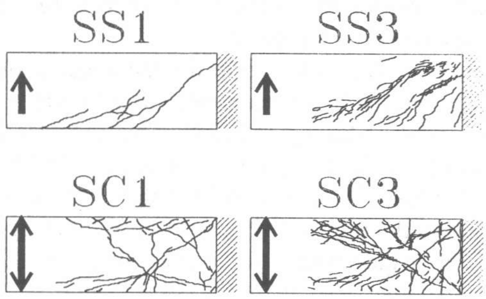

Figure 4 Crack pattern for specimens SS1, SC1 and SS3, SC3 respectively

3. TEST RESULTS

3.1 LOADING HISTORY

Specimens SS1, SS2 and SS3 were statically and monotonically loaded until failure. The yielding of longitudinal bars for specimen S1 occurred at the lateral displacement of 11mm. Specimens SC1, SC2 and SC3 were subjected to the loading history presented in **Figure 5**. For this loading history, $0.2\delta_y$ of SS1 was chosen as step for each 4 cycles series.

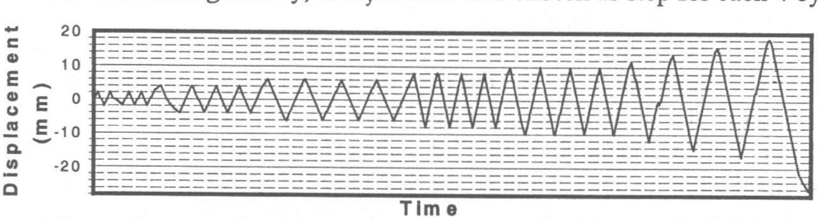

Figure 5 Displacement history for cyclic tests

3.2 TEST OBSERVATIONS

For specimen SS1 after the first shear crack formed, with the increase of the lateral load additional shear cracks formed. These cracks extended and became a major shear crack that can be represented by a line that links the loading point with the opposite point at the base of the column. Specimen SC1 had a similar behavior and a symmetric crack pattern formed. For specimen SS2 after a shear crack formed, delamination of CFS stripes in the vicinity of the shear crack occurred with the increase of the load until the failure. The delamination could be observed in the epoxy resin layer, which presented very fine cracks near the CFS stripes. The specimen SC2 had a different behavior and did not present very clear delamination phenomena. Due to this fact, very localized stress could develop in the CFS stripes. Therefore, they broke almost along the same line that the shear cracks intersected them. Same symmetric crack pattern was observed.

Specimen SS3 presented very clear delamination phenomena in the vicinity of CFS stripes. Also it could be observed that a finer mesh of small cracks in the epoxy resin layer formed as the load increased. For specimen SC3 the same symmetric crack pattern was observed but in this case the delamination occurred clearly. The CFS stripes that failed first were in the region where the two symmetric main shear cracks intersected. Also the delamination phenomena observed in this case occurred with a lower speed compared with the case of specimen SC2.

The peak value for the shear resisting force for specimen SS1 was 143.1kN. For specimen SC1 the peak value was 142.6kN. Specimen SS2, which had 5 stripes of CFS, had the peak value of 163.2kN. This increase in the peak value is due to the CFS retrofitting. Specimen SS3 that had 9 stripes of CFS had the peak value for the resisting shear force at 192.9kN. For specimen SC3 the peak value increased up to 191.3kN. These increases were due to the bigger CFS reinforcing ratio. Specimen SC2 had the lowest peak value. After the CFS stripes broke, the peak value was 125.4kN. Until now, we cannot explain why this value was less than the peak value of specimen SS1 or SC2. The values for lateral displacement presented in **Table 2** correspond to the peak value of the shear resisting force.

Using the maximum strains recorded in stirrups during the experiment, and the stress-strain relationship of Ø6, the tensile force in each stirrup was calculated. Then, the shear force carried by stirrups was computed. **Figure 6** presents the total shear force measured during tests versus calculated shear force carried by the four stirrups which were observed. The difference between specimen SS1 and peak values for specimen SC1 is not so significant. We can observe a reduction in the shear force carried by the stirrups within the same series of cycles of same amplitude, but for the next step in the amplitude of the lateral displacement, the peak value is reaching the value of specimen SS1. In case of specimens SS2 and SC3 the peak values within the same series of cycles of same amplitude for specimen SC3 are always greater than the value of specimen SS3. In case of specimens SS3 and SC3 the same behavior is observed, but in this case the difference is much greater and the values of the shear force carried by stirrups of specimen SC3 are almost double than the corresponding values calculated for specimen SS3.

In **Figure 7** is presented the calculated shear forces carried by CFS stripes for specimens SS2, SC2, SS3 and SC3. For the case of specimen SS2 and SC2 there is almost no difference between the shear forces calculated for each specimen until $0.8\delta_y$. At $0.8\delta_y$ the CFS stripes broke. For specimens SS3 and SC3 the calculated shear force carried by CFS for SC3 is almost equal with the one calculated for SS2 until $0.8\delta_y$. After $0.8\delta_y$ the peak value is increasing but is decreasing when the displacement's amplitude is reaching $1.0\delta_y$. Also, it

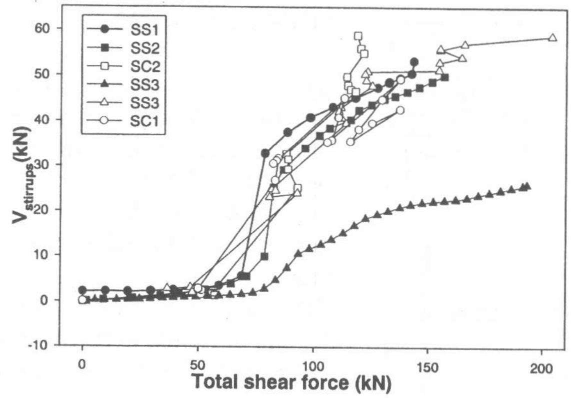

Figure 6 Shear force carried by stirrups

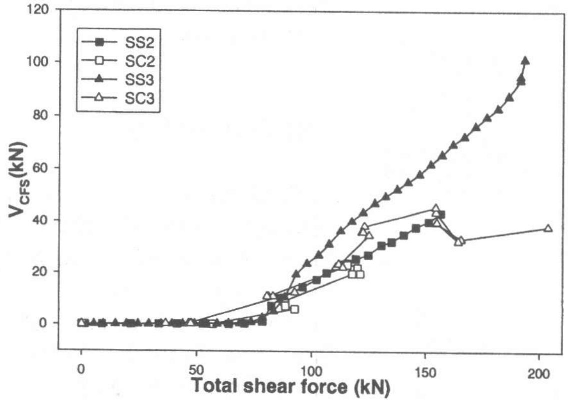

Figure 7 Shear force carried by CFS stripes

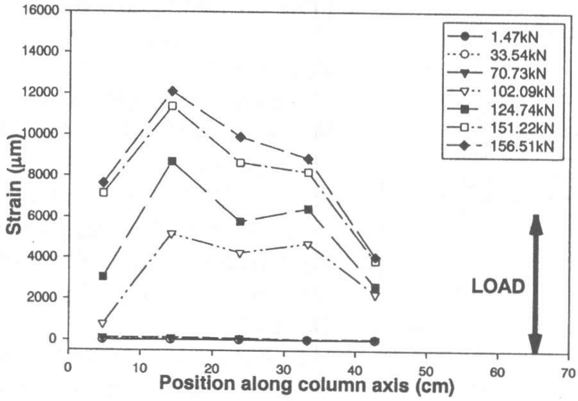

Figure 8 Strain distribution in CFS stripes-SS2

can be observed that the values calculated for SS3 reached only 1.5 of the SS2 value for the same total shear force even if the amount of CFS is double. **Figure 8** and **Figure 9** are presenting the strain distribution in CFS stripes along the column axis for specimen SS2 and SS3 respectively. **Figure 10** and **Figure 11** are presenting the strain distribution in CFS stripes along the column axis for specimen SC2 and SC3 respectively. It can be observed that for the case of monotonic loading the strain distribution along the column axis is maintaining the same shape and the maximum strain recorded range between 12000 to 14000μm. In the cyclic loading case, for specimen SC2 until the maximum strain reached 6000μm the strain distribution is similar to the monotonic case. After this step, the first three CFS stripes closest to the loading point broke suddenly. The video records indicate that the stripe, which was located at 23.75cm from base, broke the first one. For specimen SC3 the distribution of the strain along the column axis has a wave aspect because the shear crack formed exactly at the location of the strain gauge. For the other stripes which indicate a lower value the shear crack formed between the location of the strain gauges. In this case, also after reaching 6000μm the CFS stripes start to break but not more that one for each time when the displacement was increased. The predicted maximum shear force carried by CFS stripes was 44.1kN for specimen SS2 and 98.1kN for specimen SS3. The experimental value for maximum shear force carried by CFS stripes was 43.6kN for specimen SS2, 101.83kN for specimen SS3, 23.73kN for specimen SC2 and for specimen SC3 was 45.84kN.

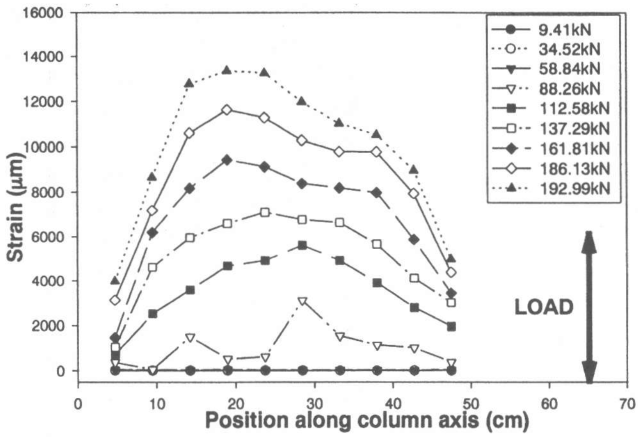

Figure 9 Strain distribution in CFS stripes-SS3

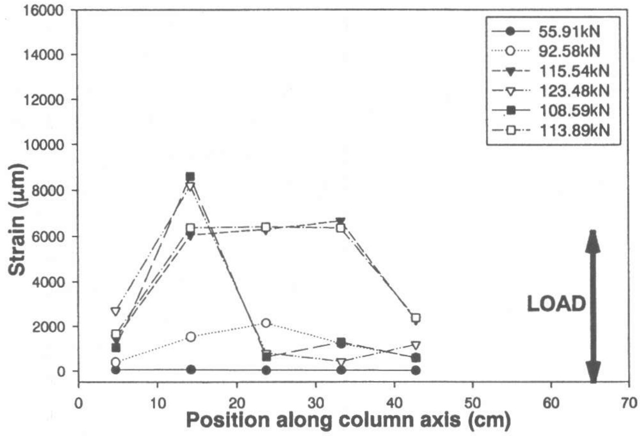

Figure 10 Strain distribution in CFS stripes-SC2

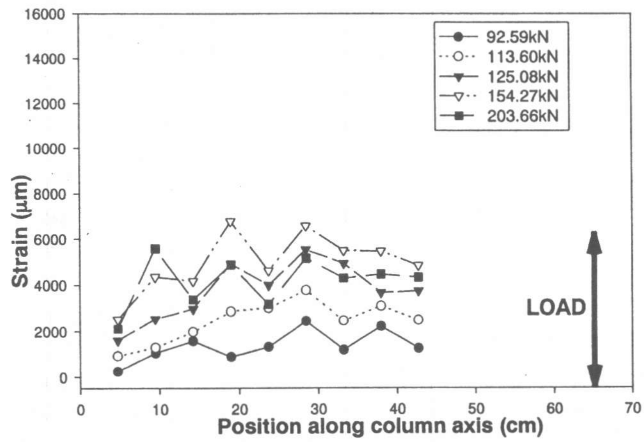

Figure 11 Strain distribution in CFS stripes-SC3

4.CONCLUSIONS

(1) For the static monotonic loading case, the ultimate shear force carried by the CFS stripes for the specimens considered in this study could be predicted with enough accuracy.

(2) For the static cyclic loading case, the experimental values recorded for the shear force carried by CFS stripes were reduced to a value, which range around half of the monotonic case.

5.REFERENCES

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