Improving Seismic Performance of Deficient Columns with Reinforced RC using Fiber-Reinforced Composite

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SUMMARY:
Many efforts have been poured into retrofitting existing RC columns since the number of earthquakes has increased worldwide. In particular, the occurrence of earthquakes in the area surrounding the Korean Peninsula has dramatically increased. For this reason, much interest has focused on retrofitting Korean school buildings as refuge facilities. Since the school buildings in Korea have not been designed to carry the lateral and shear force caused by earthquakes, such buildings will experience massive damage, even in moderate earthquakes. However, most retrofitting systems developed so far result in unintentional physical damage to other structural components and to the columns themselves. To overcome such problems, a new retrofitted system has been developed in this study. It uses a composite material, which is made of fiber reinforced plastic with glass fiber, to provide strength as well as ductility enhancement. An in-site connecting device is also developed to reduce the construction period and physical damage to the other structural components. Through experimental tests, the performance of the proposed retrofitting system has been investigated. The results show that the proposed system increases ductility and delays shear failure of the RC columns.

Keywords: RC-Column, FRP composite, Ductility, Seismic Retrofitting, Glass Fibre.

1. INSTRUCTIONS

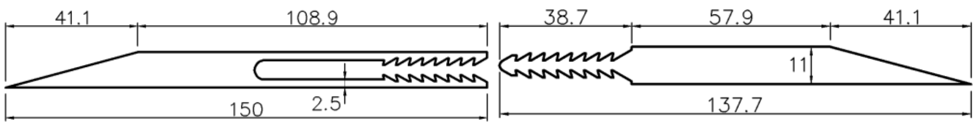
The Korean Peninsula is located close to Japan and a number of sever earthquakes have occurred recently. Such devastating events force the Korean government to earmark more funds for improving the performance of public facilities; in particular, school buildings would be used as earthquake refugee centres. Considering limited available funding, strengthening techniques have taken precedence. Many researchers have showed that composite materials are very versatile in the strengthening of existing columns with respect to ductility and strength. Most of the strengthening methods, however, are based on the wrapping of circular as well as rectangular columns on a construction site. Because of this, the quality control becomes a very difficult issue. Furthermore, there is no consideration of other adjacent structural components such as walls and beams.

In this study, the primary objective is to develop a new strengthening method that is able to reduce construction time and damage to walls adjacent to columns using prefabricated composite sheets. The quality control of composites becomes more reliable because it is prefabricated in the factory. It is proposed that the prefabricated composite sheet is consisted of two pieces with connectors. Hence, the composite sheet is easily constructed as a connecting of two connectors on-site, which also reduces damage to adjacent walls.

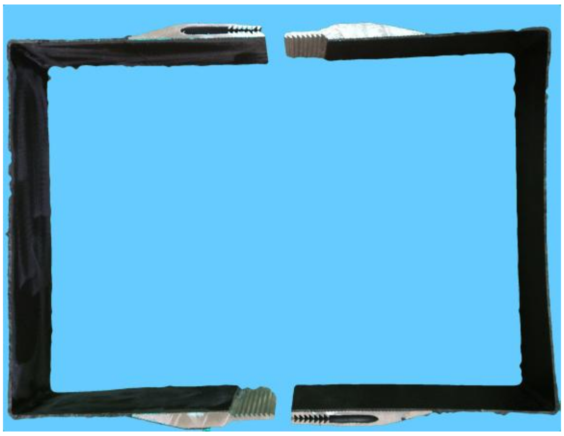
Based on a number of numerical simulations, the best shape of the connection part was first determined and designed. Four RC column specimens were constructed. Those columns were representative RC columns of school facilities in Korea, 75% scaled down. The strength and ductility of the proposed strengthening device were verified and discussed through the experimental works.

2. GFRP SHEET WITH CONNECTION PART

The GFRP composite sheet was made of glass fibers and epoxy. Each ply had 0.25 mm thickness and 12 plies were used in the GFRP sheet. The total thickness was 3 mm. 80 % of fibers were distributed in the hoop direction and 20% of fibers were placed in the longitudinal direction.
The connector of the composite sheet is basically designed in two parts. Specific dimensions are shown in Figure 1. With the proposed connector, the strengthening of columns is easily performed on-site without complicated devices such as winding machines. Also, the damage to existing walls of structure can be reduced along with the reduced width of the GFRP sheet.



(a) Proposed Details of Connector



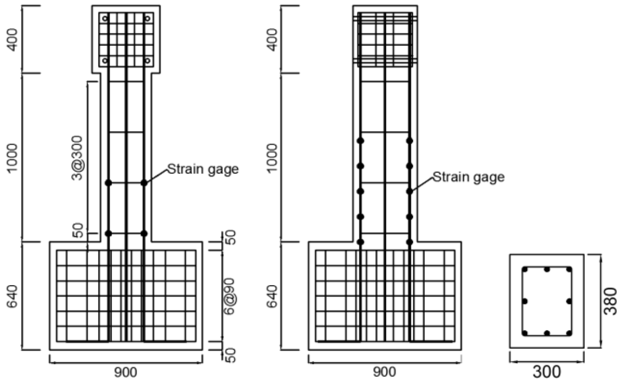
(b) GFRP Sheet with Connectors

Figure 1. Details of Proposed Connectors of GFRP Sheet

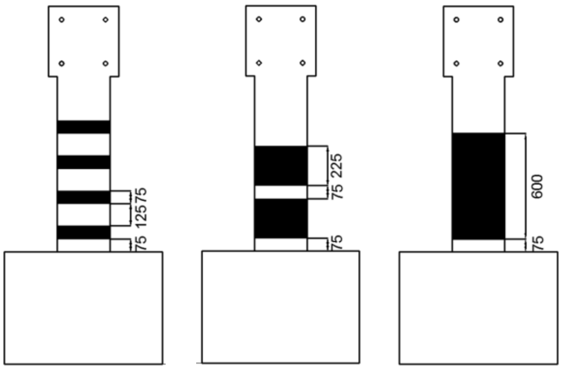
3. EXPERIMENTAL PROGRAM FOR RC COLUMNS

3.1. Test Specimens

The specimens were designed as 75% scaled down representative RC columns of school facilities in South Korea. A total of four RC columns were constructed. The specimens had dimensions of 300 x 380 x 1000 mm and they were connected to a stub of 900 x 900 x 640 mm. The top of the column had a loading block that had dimensions of 400 x 380 x 400 mm. The details of the specimens are shown in Figure 2 and in Table 1.
Specimens were constructed vertically with ready-mixed concrete with nominal 28-day target strength of 24 MPa. The compressive strength of the concrete was 25.5 MPa. Reinforcement bars had 300 MPa yield strength. Four 22 mm and 19 mm reinforcing bars were placed in the longitudinal direction and 10 mm reinforcing bars were used as the transverse reinforcement. The reinforcing cage of the column loading block and the base stub were constructed using 10 mm bars. One specimen were tested without strengthening under monotonic loads; these specimens were identified as ORC-1. The rest of the specimens were strengthened by GFRP sheets with spacings of 75 mm, 225 mm, and 600 mm, respectively, as shown in Figure 2 (b); these specimens are identified as GLRC-1, GLRC-2, and GLRC-3.



(a) Details and Instrument Position



(b) Detailed Dimensions of GFRP Sheet

Figure 2. Details of the RC Column Specimens including Instrument Location

Table 1. Details of Specimens

Specimen	Load Type	GFRP Sheet	
		Height (mm)	Thickness (mm)
ORC-1	Monotonic Load	-	-
GLRC-1	Cyclic Load	75	3
GLRC-2	Cyclic Load	225	3
GLRC-3	Cyclic Load	600	3

3.2. Instruments and Test Setup

Before carrying out the test, the stub of the column was fixed on the reaction floor of the laboratory. LVDT was placed on the end of the loading block in order to measure the lateral displacement. Ten steel strain gauges were attached evenly on the longitudinal reinforcing bars and four steel strain gauges were attached on the transverse reinforcing bars. Details of the instruments are shown in Figure 4 (a). Using a 500-kN hydraulic actuator, lateral load was applied by displacement control. The axial force was applied by two servo-type-hydraulic jacks with a keeping force of 285 kN, which is equivalent to $0.1A_g f_{ck}$. The test setup is shown in Figure 3. Based on the test results for the column without strengthening under monotonic load, yield displacement was assumed as a displacement at 80% of maximum strength. Using the obtained yield displacement, the loading protocol was generated up to μ =5, 18 cycles, as plotted in Figure 4. The experiment was started by applying an axial force; horizontal load was applied by displacement control while keeping the axial force constant.

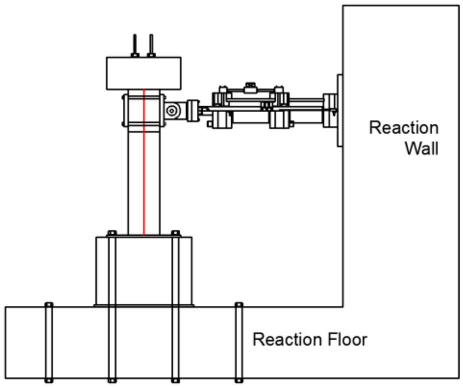


Figure 3. Test Setup

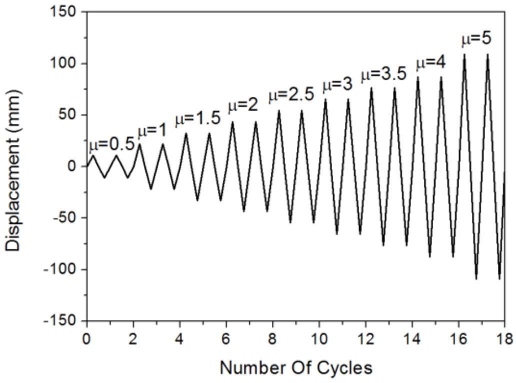


Figure 4. Loading Protocol

4. RESULTS OF EXPERIMENTS

The load-displacement relationship of column GLRC-1 is depicted in Figure 5. For the purpose of comparison, the load-displacement relationship of ORC-1 was designed to overlap. First yielding of the longitudinal bar occurred at a displacement of 16 mm (μ =1); yielding of the transverse reinforcing bar occurred at the displacement of 37.5 mm (μ =2.5). Because the GFRP sheet was placed in the form of a strip, as shown in Figure 4 (b), the strengthening was found to contributed more to the shear behavior than did the flexural strength. The peak strength of the column was observed as 155 kN and corresponding displacement was observed to be 29 mm (μ =1.5). However, the strength of the column was kept almost constant at 153 kN until the displacement reached 64 mm (μ =4). Due to the strengthening, the strength and the peak displacement were increased by 6% and 50%, respectively. It can be clearly seen that the GFRP sheet contributed to delaying of the shear failure of the column. The failure of the GFRP sheet was initiated at a displacement of 66 mm (μ =3) and two of the four GFRP sheets were broken at the final stage. As expected, the failure of the GFRP sheet was found to occur at the sheet rather than at the connector, as depicted in Figure 8 (b). This figure also shows that the diagonal shear cracks were dramatically decreased.

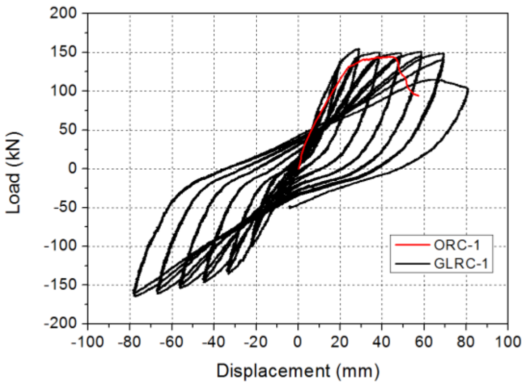


Figure 5. Lateral Load vs. Displacement of Column (GLRC-1)

Figure 6 shows the load-displacement relationship of column GLRC-2. The longitudinal reinforcing bar yielded at the displacement of 17 mm (μ =1). The transverse steel bar yielded at the displacement of 36 mm (μ =2). Because the width of GFRP sheet became larger than that of GLRC-1, as shown in Figure 4 (b), the strengthening was found to contribute to both the shear behavior and the flexural strength. The peak strength of the column was observed to be 165 KN and the corresponding displacement was observed to be 74 mm (μ =3.5). The strength and the peak displacement were increased by 14% and 72% respectively. The failure of the GFRP sheet was initiated at the corner of the bottom of the column when the lateral displacement was 76 mm (μ =3.5). As expected, the failure of the GFRP sheet was found to occur at the corner of the sheet rather than at the connector.

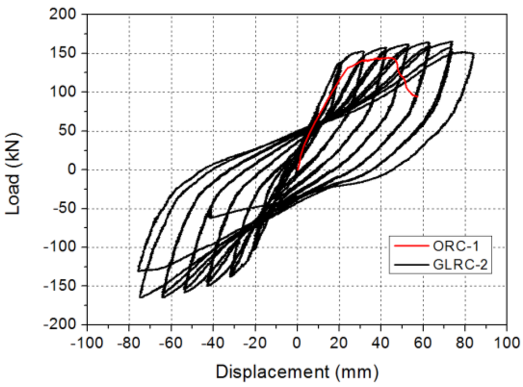


Figure 6. Lateral Load vs. Displacement of Column (GLRC-2)

The lateral load and displacement relationship of GLRC-3 is depicted in Figure 7. The yielding of the longitudinal and transverse reinforcing bars can be observed at the displacements of 18 mm (μ =1.0) and 58 mm (μ =3), respectively. The peak strength of the column was obtained at 160 kN when the lateral displacement was 49 mm (μ =2.5). However, the strength of the column was kept to an almost constant value at 157 kN until the displacement reached 71 mm (μ =3.5). The strength and the peak displacement were increased by 11% and 65%, respectively. The failure of the GFRP sheet at the bottom corner started at the displacement of 66 mm (μ =3). Even when the largest width of the GFRP sheet was used, the strength of the column was only slightly lower than that of the GLRC-2 column. This is mainly due to the failure mode of the GFRP sheet. Because the column was strengthened by a single GFRP sheet, the breaking of the GFRP sheet directly affects the strength of the column. As can be seen in the experimental results, the shear failure of the column was immediately followed by the failure of the GFRP sheet. The picture of the final loading step is given in Figure 8 (d). This image shows that the shear cracks for this column were reduced compared to those of the un-strengthened column.

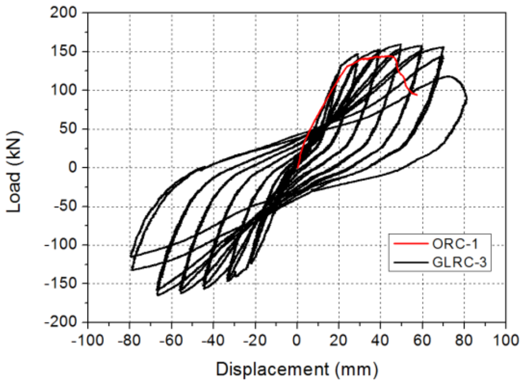


Figure 7. Lateral Load vs. Displacement of Column (GLRC-3)

(a) ORC-1 (b) GLRC-1 (c) GLRC-2 (d) GLRC-3

Figure 8. Failure Pictures of the Columns at the End of Test

Energy dissipation capacity has been widely used to evaluate the performance of structures during earthquakes because this value indicates the absorbability of the energy generated by an earthquake. The energy dissipation capacities and the accumulated energy dissipation capacities of the tested columns are arranged in Table 2. These show that the strengthened columns possess 2.3~2.6 times larger energy dissipation capacity than the original column. As discussed above, the energy dissipation capacity of GLRC-3 was smaller than that of GLRC-2 because a single GFRP sheet was used in the strengthening.

Table 2. Ductility Ratio and Energy Dissipation of Specimens

Specimen	$\mu=\Delta_u/\Delta_y$	Accumulated Energy Dissipation (kN-mm)
GLRC-1	3.90	154.74
GLRC-2	4.57	175.67
GLRC-3	3.42	158.47

5. CONCLUSIONS

A prefabricated GFRP sheet with a connector is developed in this study. It is very efficient to construct on-site thanks to the connector. It can also be used to strengthen existing column members with less damage to adjacent wall structures. The performance of the GFRP sheet was tested and verified through connector tension test and column tests.

The developed GFRP sheet was applied to representative columns of a school facility. Failure of all columns was initiated by breaking of the GFRP sheet rather than by the breaking of the connectors, as was the intent of the design. The strengthened columns basically show about two times greater ductility. The strength of the columns also increased by as much as 6~14%. The capacity of energy dissipation was increased as much as 2.6 times. The yielding of the reinforcing bars was also delayed due to the strengthening.

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