

# SEISMIC RETROFIT TECHNIQUES FOR REINFORCED CONCRETE BRIDGE COLUMNS WITH COMBINATION OF FRP SHEET AND STEEL JACKETING

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## Abstract

With the purpose to provide a seismic retrofit method with good workability for reinforced concrete (RC) highway bridge columns under severe construction work conditions, a retrofit method with combination of carbon fiber reinforced polymer (CFRP) sheet and steel jacketing has been proposed in the previous researches of this research project. In this research, bonding behavior between CFRP sheet and steel plate was investigated experimentally in order to establish a rational design method for the CFRP-steel bonded connection. This paper provide an introduction of the proposed seismic retrofit method companying with descriptions of the tests on CFRP-steel bonded connection and test on RC bridge column specimen for examining the retrofit effectiveness of the proposed retrofit method.

## Introduction

Attributing to the merits of high strength, light-weight and outstanding workability, fiber reinforced polymer (FRP) sheet has been widely used in repairing or strengthening reinforced concrete (RC) members in the recent decades. As for seismic retrofit of RC highway bridge columns in Japan, FRP sheet is usually used to retrofit columns with premature termination of longitudinal reinforcements without enough development length at the midheight. Figure 1 shows an example of RC bridge being under retrofitted with Carbon FRP (CFRP) sheet. CFRP sheet was jacketed around the termination sections of the longitudinal reinforcements in the longitudinal direction and circumferential direction to reinforce flexural and shear strength. In some other cases, FRP sheet is also used to reinforce ductility of the columns by jacketing around the plastic hinge in the circumferential direction.

However, it is not an effective method to reinforce the flexural strength of the column base by jacketing FRP sheet in the longitudinal direction. Generally, high elongation is required locally in both of the longitudinal and circumferential directions at the base. Enhancement of ductility capacity of the base can not be obtained because elongation of the FRP sheet is rather lower before breaking. From the point of view, a

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method with using combination of CFRP sheet and steel jacketing has been proposed in the previous researches (Zhang and Unjoh, 2009). It should be noted for the retrofit method that bonding behavior between CFRP sheet and steel plate is a key issue, because the longitudinal force induced from the additional anchor bolts must be transmitted to CFRP sheet and thus the steel plate should be bonded with CFRP sheet in the inelastic response of the column.

This paper provide an introduction of the proposed seismic retrofit method accompanying with descriptions of the tests on CFRP-steel bonded connection and test on RC bridge column specimen for examining the retrofit effectiveness of the proposed retrofit method.



**Fig. 1** Retrofit of RC bridge columns with CFRP sheet

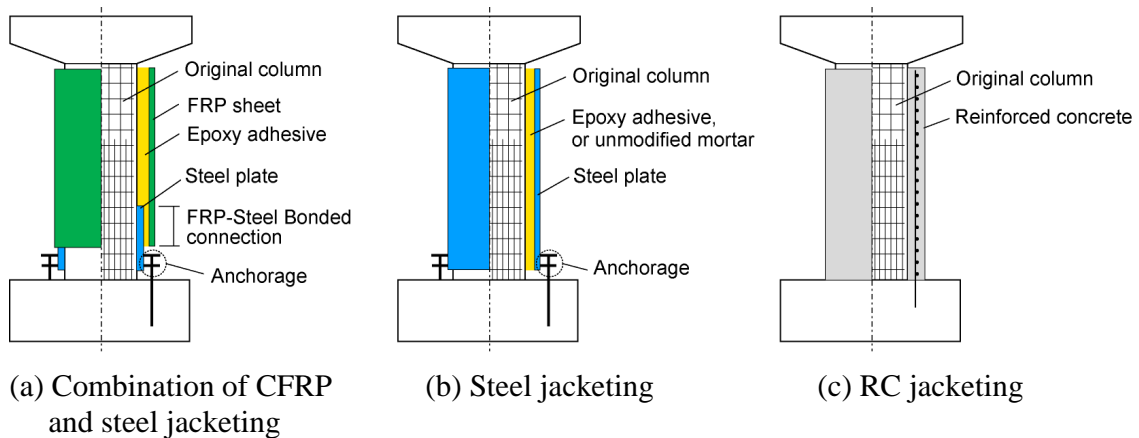
### **Overview of Seismic Retrofit methods**

Figure 2(a) shows schematic of the proposed retrofit method. It adopted a combination of CFRP sheet jacketing and steel plate jacketing (hereinafter, combination of CFRP and steel jacketing) taking advantage of the merits of both of the CFRP and steel. Considerations of this technique are to use different methods to retrofit the base and the other parts of a column. A method same as the normal steel jacketing is used to retrofit the base where upgrading of the strength and the ductility are required. A FRP jacketing is used to retrofit the other parts to provide high strength. Transmit of force between the steel plate and the CFRP sheet is accomplished by FRP-steel bonded connection with a certain bond length.

Comparing to the normal steel jacketing and RC jacketing as shown in figure 2(b)

and (c), the proposed method is complicated because it needs to design the details of the bonded connection. The merits of the proposed method are the high performance of construction and that increasing of the dead weight after retrofit is very limited. The proposed method be suitable for the situations such as the followings: 1) bridges located in a place where no enough construction space can be ensured for building a large scale scaffolding or for the working of the construction machines and equipments; 2) bridges crossing a river or bridges located in a heavy snows region where construction period is short, etc.

Because this method employs a FRP-steel bonded connection to transfer the strength upgraded by the anchor bolts to the CFRP sheet, it is important to ensure the bonding capacity and certainty of the bonded connection. In this research, bonding behavior between CFRP sheet and steel plate was investigated intensively with shear bond tests in order to establish a rational design method for the bonded connection. Furthermore, a RC bridge column specimen was tested under cyclic loading method to inspect the retrofit effectiveness of the proposed retrofit method.



**Fig. 2** Schematics of seismic retrofit methods for RC bridge columns

### **Tests on Bonding Behavior between CFRP Sheet and Steel Plate**

Four series of double-lap shear bond tests were carried out taking the bonded layers of CFRP sheet as parameter. Three specimens were tested for each series. Table 1 shows a list of the specimens.

Figure 3 shows the details of the double-lap shear specimens. CFRP sheet of  $600 \text{ g/m}^2$  and ss400 steel plates were used. A long bond length of 600 mm was set in the tests in order to inspect the progress of debonding between CFRP sheet and steel plate. Surface of steel plate to be bonded with CFRP sheet was grinded with disc sanding machine. All

the specimens were cured for 7 days at ambient temperature. The tests were performed using a universal testing machine with a loading speed of 0.5-1.0 mm per minute.

Table 2 shows the test results of material properties of CFRP sheet and epoxy adhesive.

Table 1 List of Specimens

Series	Bond length (mm)	Bonded layers of CFRP	Numbers of specimens for each series
1-layer	600	1	3 (No.1, No.2, No.3)
2-layer	600	2	3 (No.1, No.2, No.3)
3-layer	600	3	3 (No.1, No.2, No.3)
4-layer	600	4	3 (No.1, No.2, No.3)

Table 2 Material Properties

Materials	Items	Values
CFRP sheet	Mass per area ( $\text{g}/\text{m}^2$ )	600
	Design thickness (mm)	0.333
	Young's modulus ( $\text{N}/\text{mm}^2$ )	$2.60 \times 10^5$
	Tensile strength ( $\text{N}/\text{mm}^2$ )	3,400
Epoxy adhesive	Young's modulus ( $\text{N}/\text{mm}^2$ )	$2.202 \times 10^3$
	Compressive strength ( $\text{N}/\text{mm}^2$ )	71.8
	Tensile strength ( $\text{N}/\text{mm}^2$ )	47.0
	Tensile shear strength ( $\text{N}/\text{mm}^2$ )	17.6

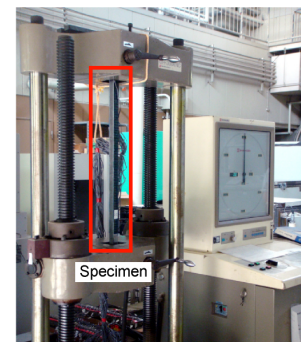
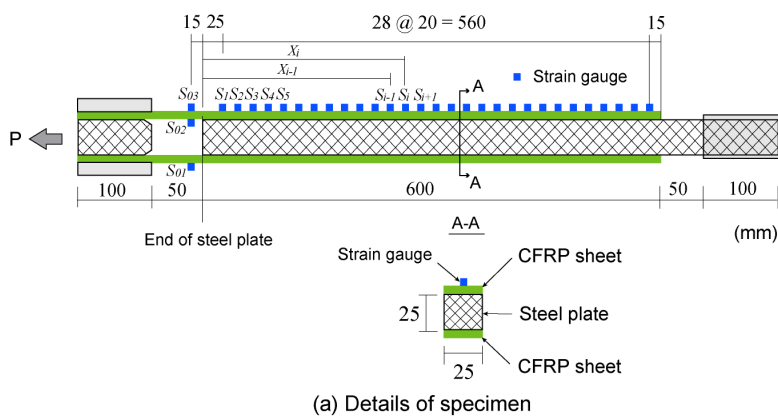
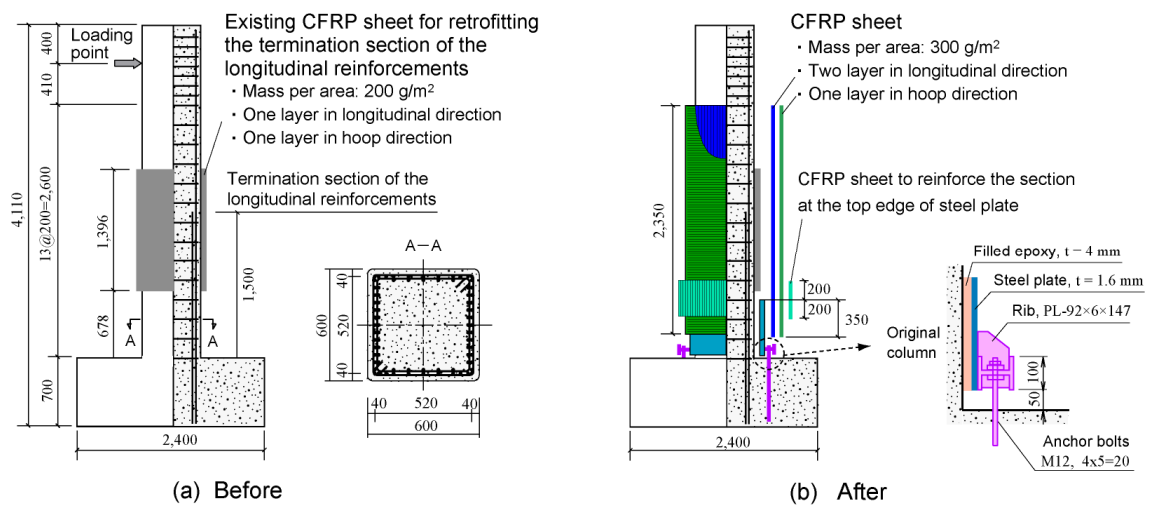


Fig. 3 Details of specimens and setup of test





**Fig. 5** Details of RC bridge column specimen before and after retrofit with combination of CFRP and steel jacking

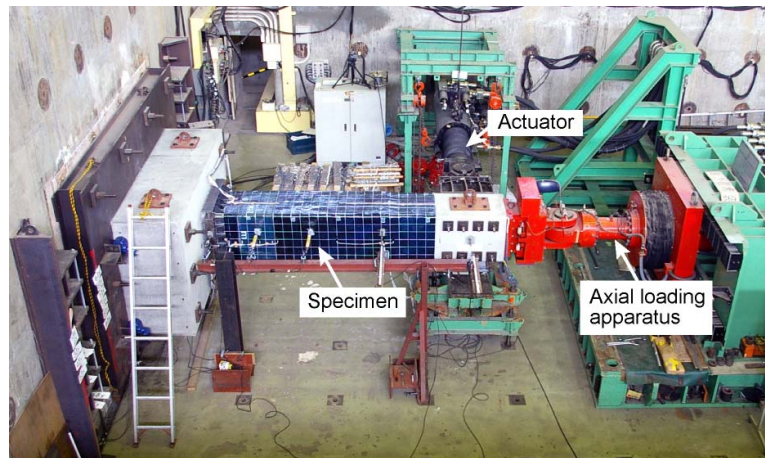
### **Cyclic Loading Test on RC Bridge Column Specimen**

A RC bridge column specimen was tested under cyclic loading method to inspect the retrofit effectiveness of the proposed combination of CFRP and steel jacking method. The specimen was a scaled model of a RC bridge column with premature termination of longitudinal reinforcements at the midheight but retrofit of the termination section of the longitudinal reinforcements was already performed. Retrofit of the termination section of the longitudinal reinforcements was designed to prevent failure at this section period to flexural failure of the base. Therefore, it can be considered that the specimen before retrofitted with the proposed method is equivalent to a column with a failure mode of flexural failure of the base.

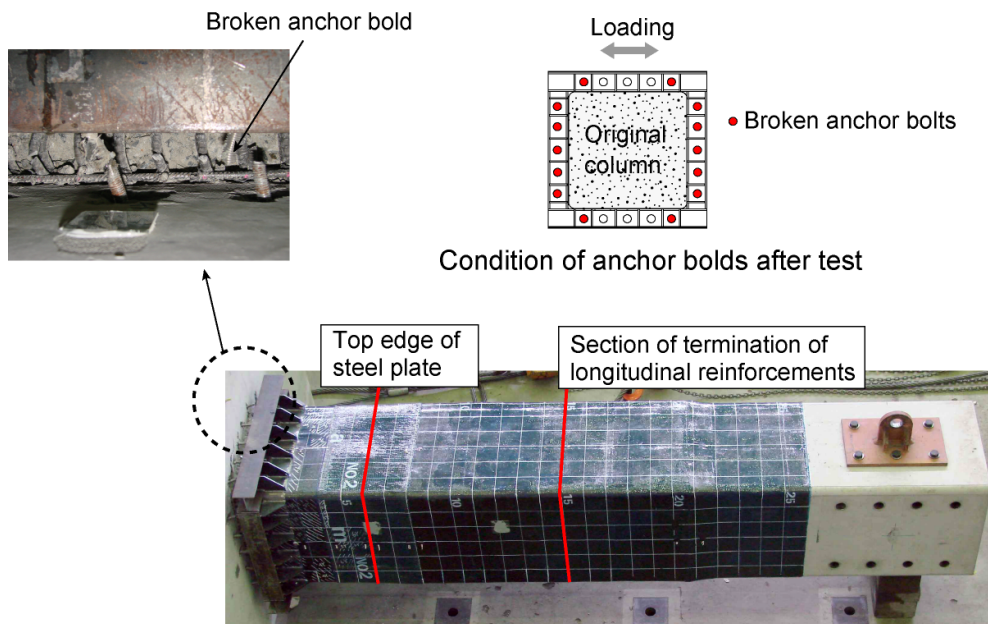
Figure 5 shows the details of the specimen. Cross section of the original column was 600×600 mm. The height of the loading point was 3,100 mm with an aspect ratio of 5.0. SD295-D10 and SD295-D3 was used as longitudinal reinforcements and hoop ties, respectively. Reinforcement ratio was 1.58%. Retrofit with the proposed retrofit method was designed to upgrade the flexural strength with an increase of 30 percent. Bond length of 350 mm was applied between CFRP sheet and steel plate.

Figure 6 shows setup of the cyclic loading test. Axial force of 539 kN was applied during the loading to provide an axial stress of about 1.5MPa. Loading was performed under displacement control and the loading speed was 10 mm/sec. Cyclic number was 3 for each loading step.



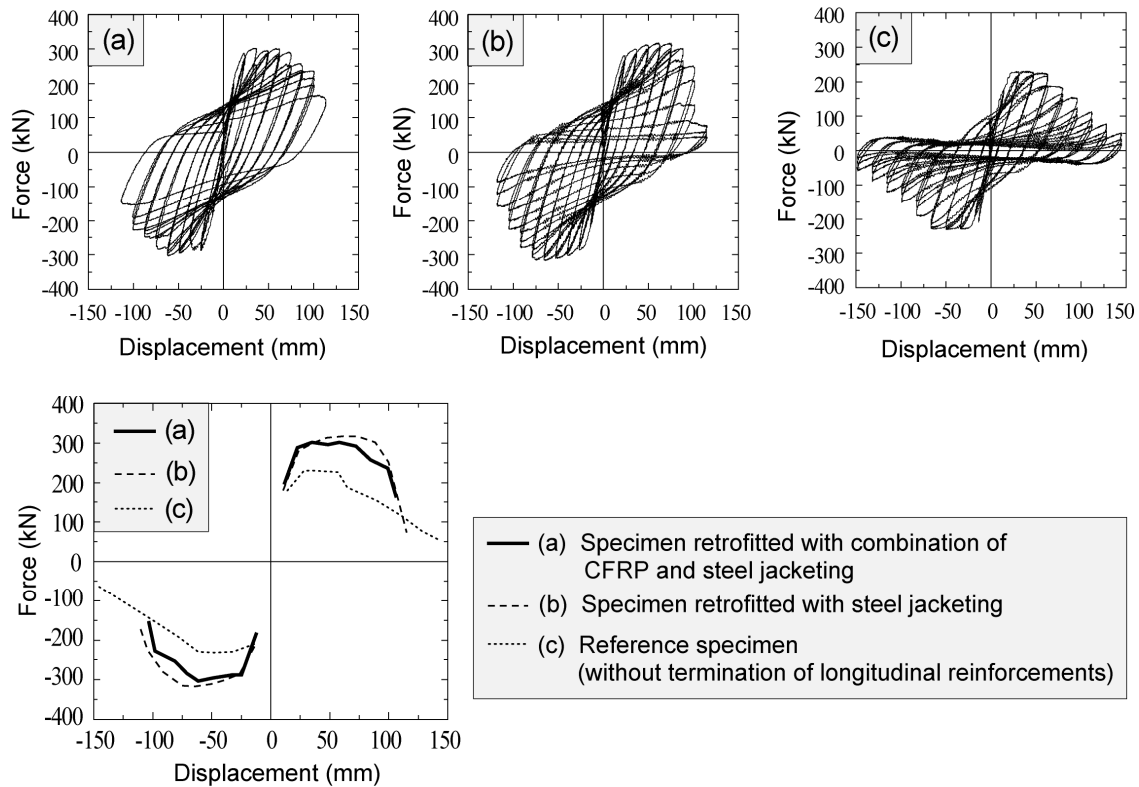


**Fig. 6** Setup of cyclic loading test



**Fig. 7** Conditions of specimen after test

Cyclic loading was surcharged until a loading step of  $9\delta_y$  with yield displacement  $\delta_y$  of 12.7 mm. Initiation of cracks at the base, breaking of anchor bolts, remarkable compressive failure of core concrete and breaking of longitudinal reinforcements were confirmed at a loading step of  $3\delta_y$ ,  $6\delta_y$ ,  $7\delta_y$  and  $8\delta_y$ , respectively. Bonding condition between CFRP sheet and steel plate was checked after each loading step by tapping the CFRP surface with a small hammer to detect voids. It is noted that no debonding area was detected till the test finished. Figure 7 shows the conditions of specimen after test.



**Fig. 8** Lateral force-displacement

Retrofit effectiveness of the proposed retrofit method was discussed by comparing the flexural strength and ductility with that of a specimen retrofitted with normal steel jacketing and that of a reference specimen (Hoshikuma, J. and Unjoh, S.). Here, design of the base section of the original column was the same for each of the three specimens. And design of the anchorage was the same for each of the two retrofitted specimen. Figure 8 shows lateral force-displacement hysteresees and envelope curves of the three specimens. It can be seen that retrofit effect of the proposed retrofit method was similar with the normal steel jacketing.

## **Conclusions**

Retrofit method with using a combination of CFRP sheet jacketing and steel jacketing was proposed in this research project with the purpose to provide a seismic retrofit method for RC bridge columns under severe construction work conditions. Bonding behavior between the CFRP sheet and steel plate was investigated experimentally in order to establish a rational design method for the bonded connection. It is found that the proposed retrofit method with necessary bonding connection details can provide a retrofit effect similar with the normal steel jacketing.



## **References**

Zhang, G.F. and Unjoh, S.: “A Retrofit Method for Upgrading Seismic Performance of RC Columns with Termination of Main Reinforcements”, *Proceedings of the 12th Symposium on Ductility Design Method for Bridges, JSCE*, pp.47-52, 2009.1 (in Japanese)

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