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Seismic behavior of corrosion-damaged reinforced concrete columns strengthened using combined carbon fiber-reinforced polymer and steel jacket

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SUMMARY

The results of a research program aimed at investigating the effectiveness of simultaneous application of carbon fiber-reinforced polymer (CFRP) sheets and steel jacket to upgrade corrosion-damaged reinforced concrete (RC) columns was presented. A total of 14 RC columns were tested under combined lateral cyclic displacement excursions and constant axial load. The variables studied in this program included effectiveness of different strengthening techniques, as well as effects of degree of rebar corrosion, axial load, CFRP sheets and steel jacket. It was showed that strengthening corroded RC columns with combined CFRP sheets and steel jacket was effective in enhancing the seismic performance of the columns and resulted in more stable hysteresis curves with lower strength degradations as compared with the un-strengthened ones. Additionally, it was also found that the corroded RC columns strengthened with combined CFRP sheets and steel jacket behaved better than those strengthened only with the single material. Analytical study was conducted and compared with the experimental results. A good agreement was observed.

1. Introduction

Chloride-induced corrosion of steel bars in reinforced concrete exposed to marine environments and de-icing salts has become one of the major causes of deterioration in many existing reinforced concrete (RC) structures. It can lead to further structural distress due to the loss of the reinforcing steel cross-sectional area as well as loss of bond along the steel–concrete interface. As a result, the RC structure damaged by corrosion may have inadequate seismic performance, many of these structures suffered extensive structural damage and even collapse when subjected to a strong ground motion [1–3]. Therefore, it is necessary to investigate the technique to strengthen the corroded column in order to upgrade the seismic performance.

There are many solutions to strengthen reinforced concrete (RC) columns. Externally bonded fiber-reinforced polymers (FRP), as a promising rehabilitation system to upgrade RC columns, has been examined in many literatures [4–14]. It is proved that although FRP system improved the ductility and energy absorption capacity of the RC columns, but no significant improve in strength. Steel jacketing, as a conventional strengthening technique, improved the flexural strength, shear capacity, stiffness, ductility and axial load carrying capacity [15–18], but it is not suitable for corroded RC columns because the steel jacket may be damaged by marine environments and de-icing salts.

Until now, rare attempt is made to strengthen corroded RC columns with combined CFRP sheets and steel jacket. Thus, a study was made in the program in order to make full use of advantages of the two kinds of materials in improving seismic performance of RC column. The objectives of this program are (1) to clarify the effectiveness of combined strengthening techniques; (2) to evaluate the effects of the rebar corrosion; (3) to study the effects of the layers of the CFRP; (4) to investigate the effects of axial load level and (5) to determine the effects of strengthening steel jacket.

2. Experimental program

2.1. Specimen details

Fourteen RC columns were constructed and tested under combined axial load and reversed cyclic lateral displacement excursions. As shown in Fig. 1, the original columns had a clear height of 1500 mm with a cross-section of 200 mm by 200 mm. Four 14 mm diameter bars were used as longitudinal reinforcement, stirrups of 8 mm diameter bars were spaced at every 100 mm and had 135° hooks in the ends. The clear concrete cover to the hoops was 22 mm. Three 150 × 150 × 150 mm cubes were cast along with the specimens, the 28-day mean cube compressive strength was 44.8 MPa, the consumption of the material of the concretes is given in Table 1. The other details of the specimens are shown in Fig. 1. The black region which length is 500 mm in Fig. 1a and c is the regions wrapped with CFRP sheets, the repair procedure of the specimens in Fig. 1c consisted of bonding steel jacket first and then wrapping CFRP sheets.

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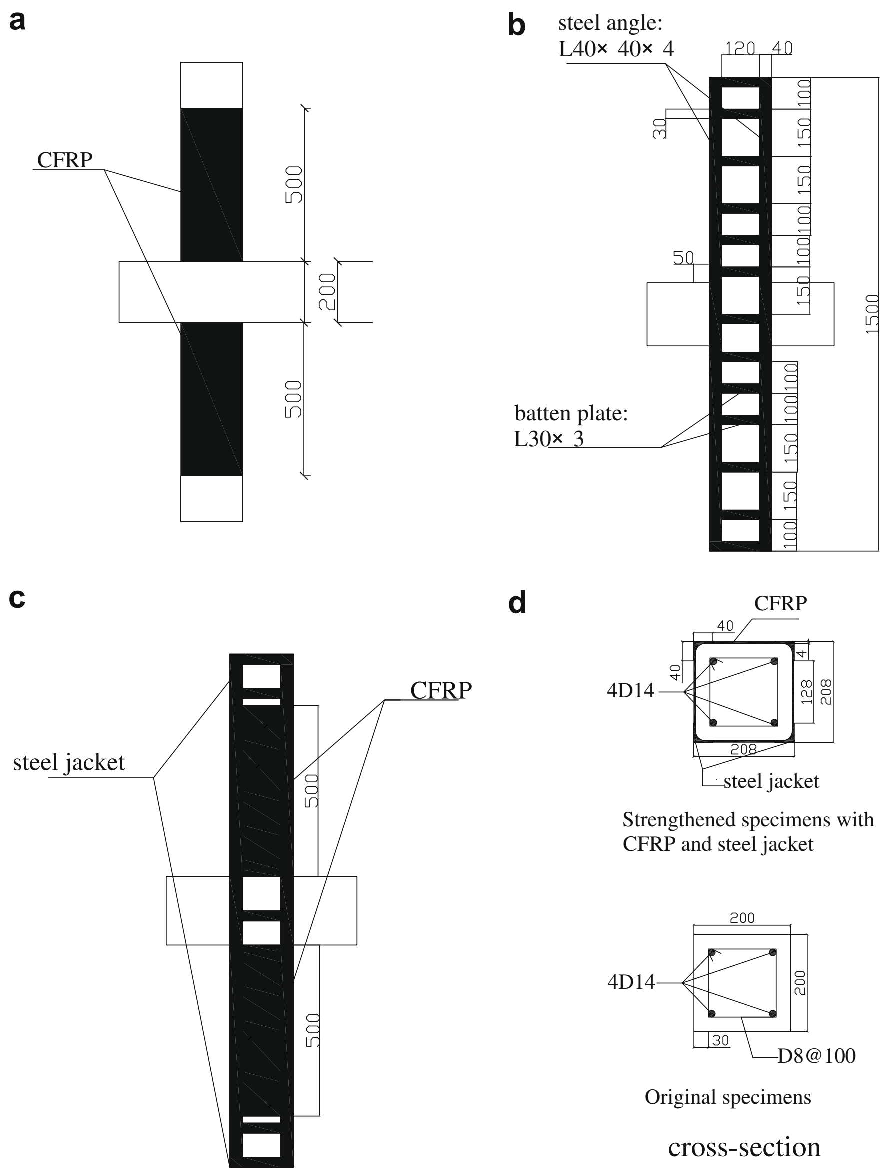

Fig. 1. Geometrical size of the strengthened column (note: units in mm, D = diameter).

2.2. Accelerated steel corrosion test

An external current technique was utilized in the present study to induce corrosion in test specimens within a reasonable time, as shown in Fig. 2. The specimens were placed in a water tank containing 3.5% salt solution, reinforcement cage of each specimen was used as the anode and corrosion resistant plates immersed in the bank was used as cathode, through which a constant current of 1.0 mA/cm^2 was applied. The level of corrosion was controlled by the volume of integrated electric current, the weight loss of the rebars corresponding to different corrosion degree are given in Table 2. Corrosion cracks observed in test specimens after carrying out electrolytic corrosion are shown in Fig. 3.

It can be seen from Table 2 that specimens B121, B2, B21, B22, B221, B222, B223, B3 and B321 are approximately same in corrosion ratio, i.e., in the range of 17–20%, in the corroded rebars. So they can be considered to have same degree of corrosion. Based on the same consideration, specimens C2, C21, C22 and C221 are also considered to have same degree of corrosion ratio.

Table 1
Details of mix concrete proportions.

Mix design	Water/cement ratio	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
Original concrete	0.46	205	446	526	1408
Retrofitted concrete	0.49	205	418	613	1164

In every case, the corrosion longitudinal cracks were running parallel to the steel reinforcing bars for all corroded specimens. In addition to the cracks, a lot of red–black corrosion products, which are concentrated on or close to the corrosion cracks, were observed leaching out of the cracks. This phenomenon implies that rendering the structural behaviors of the RC column have been damaged due to

Fig. 2. Setup of the accelerated.