USE OF CFRP ANCHORS TO STRENGTHEN LAP SPLICES OF RECTANGULAR RC COLUMNS

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1 INTRODUCTION

In many reinforced concrete structures built in the 1970's and earlier, lap splices in column longitudinal reinforcement were based on compression loads only. The length of splice and the amount of transverse reinforcement are inadequate if the lap splices are subjected to different types of loading or if ductility is needed. If an earthquake occurs, performance of the structure may be less than desired. The jacketing of the reinforced concrete columns using Carbon Fiber Reinforced Polymer (CFRP) material may provide a solution for improving the lap splice behavior. However, the CFRP jacketing of rectangular reinforced concrete columns is not as efficient as it is for circular or square columns. While the corner bars in CFRP jacketed rectangular columns can benefit from the confinement provided by the CFRP jacket, the benefits of confinement may be marginal for bars not located at or near a corner. By providing CFRP anchors, the efficiency of the confinement provided by a rectangular CFRP jacket can be increased and the behavior of lap splices away from the corners can be improved. In addition, CFRP anchors may be used without CFRP jackets in strengthening lap splices in rectangular columns with walls.

The objective of this study was to develop effective methods of strengthening deficient lap splices in rectangular reinforced concrete columns by a combination of CFRP jackets and CFRP anchors or using CFRP anchors only. Three rectangular (460 mm x 910 mm) columns were fabricated and strengthened by CFRP anchors with or without CFRP jackets. Column 1 was tested as-built under monotonic loading, and Column 2 and 3 were tested after strengthening with CFRP under cyclic loading.

2 EXPERIMENTAL STUDY

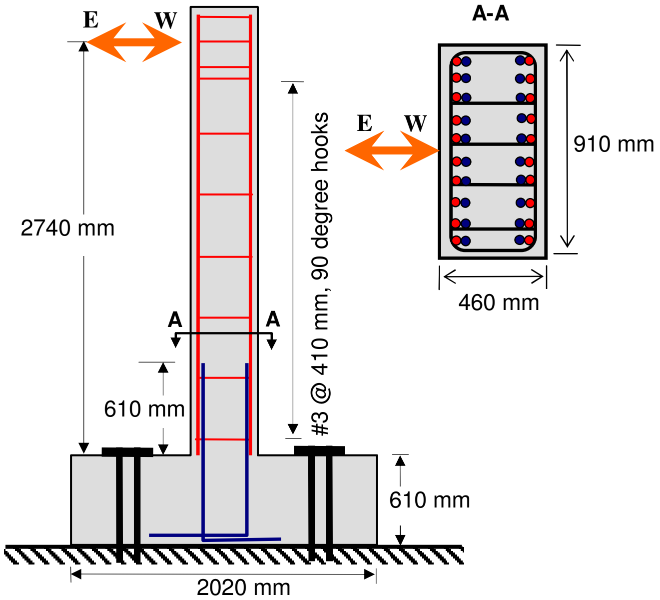
2.1 Test setup and test specimens

The geometry and loading configuration for the test specimens are provided in Figure 1. The longitudinal bars in the column and the bars from the footing were lap spliced above the construction joint between the column and the footing. The footing was fixed to a strong floor by threaded rods and lateral load was applied to the column at 2740 mm from top of the footing. No axial force was applied to the columns. To minimize effect of shear, the columns were designed to have higher nominal shear strength than flexural strength.

The test columns had twenty lap splices (10 on each face). The length of the #8 (25mm) lap splices was 610 mm. In the lap spliced region, transverse reinforcement was provided by #3 (10mm) bars at 410 mm spacing with the first tie at 100 mm from the footing. Design of columns was based on provisions of the ACI 318-63 [1].

2.2 Material Properties

Design compressive strength of concrete was 28 MPa, typical of construction in the 1970's, . The measured compressive strengths of concrete at the day of the test are shown in Table 1. The steel reinforcement used for the tests was GR60 (414 MPa, tensile yield strength) and the measured tensile yield strength was 434 MPa for all the longitudinal reinforcement. One mm thick CFRP sheet (Tyfo® SCH-41 composites with Tyfo® S Epoxy) was used in column strengthening. The ultimate tensile strength was 990MPa at a strain of 0.01.



- Longitudinal reinforcement: #8 (25 mm dia.), GR60, f_y= 434 Mpa
- Ties: #3 (10 mm dia.), GR 60, f_y = 455 Mpa ~510 Mpa

Fig. 1 Test setup and specimen

Table 1 Specimens and strengthening methods

Specimen	Test Condition		CFRP Jacket	Number of CFRP anchors, (A)	Diameter of anchor hole	Width of CFRP in an anchor, (B)	Total Width of CFRP anchors, (AxB)
Column 1 (f_c' = 32 MPa)	As-built (Monotonic loading)						
Column 2 (f_c' = 39 MPa)	Strengthening (Cyclic loading)	West	Fully wrapped	8	19 mm	180 mm	1440 mm
		East	Fully wrapped	16	13 mm	90 mm	1440 mm
Column 3 (f_c' = 39 MPa)	Strengthening (Cyclic loading)	West	None	20	16 mm	130 mm	2600 mm
		East	Partial	16	13 mm	90 mm	1440 mm

2.3 Strengthening methods

Different strengthening methods were used on the east and west face of a column to evaluate more variables of the strengthening methods with CFRP.

- ***Column 1*** No CFRP jackets were applied to Column 1.
- ***Column 2*** The CFRP jackets for Column 2 is shown in Figure 2. One layer of CFRP sheet was used to provide confinement to the 610 mm lap spliced region (Two 305 mm wide CFRP sheets were used). The CFRP sheet was overlapped by 130 mm on one side face of column after wrapping (Fully wrapped CFRP jacket).
- ***Column 3*** It was assumed that 305 mm wide walls framed into the north and south faces of the column. The walls were even with the west face of the column. Therefore, CFRP jackets could not be wrapped around the column. One layer of CFRP covered the east face and 150 mm of the north and south face up to the wall. The short sides of the jacket were anchored by four CFRP anchors (Partial CFRP jacket). On the west face, one layer of CFRP was applied to the face before applying the anchors to provide a more uniform distribution of confining force from the anchors but this sheet by itself did not provide any confinement to the splices. Figure 3 shows the jacket details.

The concrete surface of a column where CFRP jackets were applied was ground to remove cement paste. The corners of all the test columns were also rounded to 50 mm radius to make a smooth transition of CFRP around a corner.

CFRP anchor

A CFRP anchor is shown in Figure 2. A CFRP anchor consists of a roll of CFRP, fabricated by cutting a specified width of a CFRP sheet and inserting it into a 230 mm deep hole drilled into the concrete .The CFRP protruding from the hole was splayed out over the CFRP jackets. The anchors were installed on at least one side of every lap spliced longitudinal bar except for the corner bars. A summary of CFRP anchor in the test columns is shown in Table 1 and the geometry of CFRP anchors in the tested columns is shown in Figures 2 and 3.

No anchors were applied to Column 1. For Column 2, the total width material in the CFRP anchors in both sides of column was the same. However, 16 anchors were applied to the east face while 8 anchors were applied to the west face. The width of CFRP per anchor in the west side was twice that in the east side. The geometry of CFRP anchors on the east face of Column 3 was identical to that of Column 2. However, 20 CFRP anchors were applied to the west face of Column 3 since there was no confinement provided by wrapping a sheet around a corner.

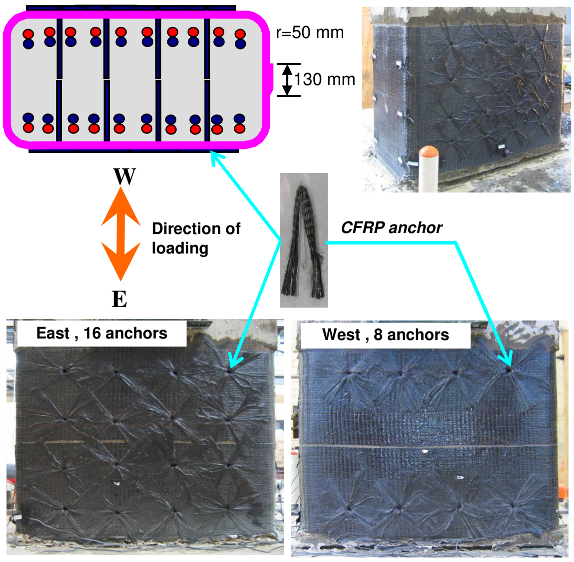


Fig. 2 Strengthening method, Column 2

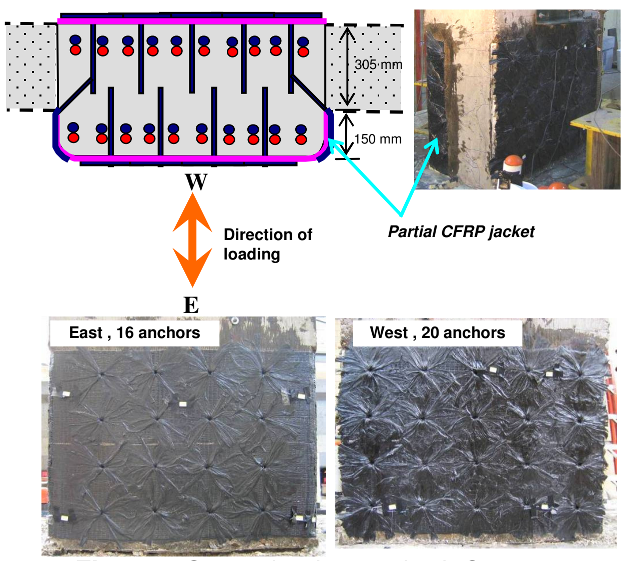


Fig. 3 Strengthening method, Column 3

2.4 Test results

Figure 4 and 5 show drift ratio vs normalized load responses. The lateral load applied to the test columns was normalized using the computed nominal strength (250 kN) of the column. The nominal strength was calculated using the design strength of the concrete and reinforcement. Column 1 was tested as-built under monotonic loading to determine the strength of the test specimen without strengthening. The response of Column 1 is plotted with the cyclic responses of Column 2 and 3 in Figure 4 and 5.

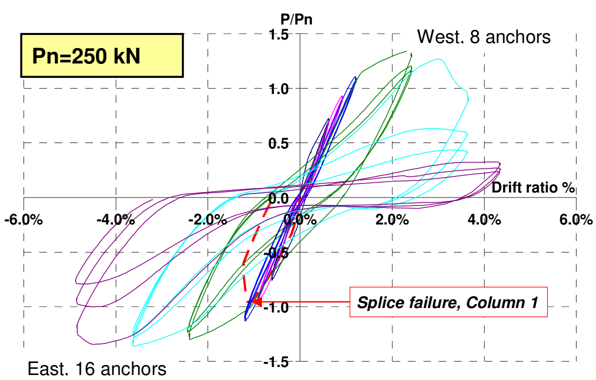


Fig. 4 Drift ratio vs normalized load, Column 2

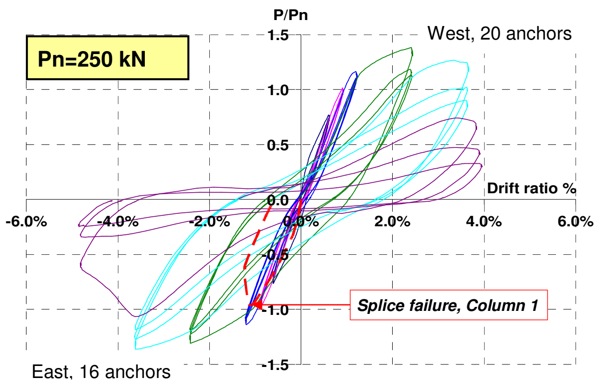


Fig. 5 Drift ratio vs normalized load, Column 3

A summary of the column test results is shown in Table 2. The failure mode of Column 1 was brittle splice failure before the nominal strength of the column was reached. A sudden drop of strength was observed at a drift ratio of 1.1% and the measured peak strength did not reach the nominal strength of the column. However, the failure mode of the columns after strengthening was yielding of tension reinforcement. Significant improvement of strength and deformation capacity under cyclic loading was observed on the east (16 anchors, fully wrapped jackets) and west (8 anchors, fully wrapped jackets) faces of Column 2 after strengthening with CFRP. The strength increased by 42 % for the east face and by 41 % for the west face after strengthening compared with the as-built strength of Column 1. The drift ratio corresponding to the peak strength of Column 2 was 3.6 % on the east face and 2.4 % on the west face. Improvement of strength and deformation capacity was also observed on the east (16 anchors, partial jackets) and west (20 anchors, no jackets) faces of Column 3 after strengthening with CFRP under cyclic loading. The strength increased by 42 % for the east face and by 44 % for the west face after strengthening compared with the as-built strength of Column 1. The drift ratio corresponding to the peak strength of Column 3 was 3.6 % for the east face and 2.4 % for the west face.

Table 2 Specimens and summary of test results

Specimen	Test condition		CFRP jacket	No. of CFRP anchors	Measured peak strength, P/P_n	Drift at measured peak strength
Column 1	As-built				0.96*	1.1 %
Column 2	Strengthening	West	Fully wrapped	8	1.35	2.4 %
		East	Fully wrapped	16	1.36	3.6 %
Column 3	Strengthening	West	None	20	1.38	2.4 %
		East	Partial	16	1.36	3.6 %

*Splice failure

3 CONCLUDING REMARKS

A brittle splice failure occurred in the as-built rectangular column which was designed based on provisions of the ACI 318-63. The as-built column exhibited little or no ductility before splice failure occurred. However, the columns strengthened with CFRP showed a significant increase in strength and deformation capacity under cyclic loading. CFRP jackets and anchors effectively confined lap splices and changed the failure mode of a rectangular column from brittle splice failure to yielding of column reinforcement.

A decrease in the number of CFRP anchors improved the strength of the splice if total width of CFRP anchors was maintained. However, deformation capacity was improved by using a larger number of smaller anchors. The strengthening method using partial CFRP jackets or a CFRP sheet on one face can be applied to a column with walls. Such strengthening improved the deformation capacity less than when using fully wrapped CFRP jackets. However, the same improvement in the strength was achieved using partial jackets.

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