Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 999 (1997)

Artikel: Shear strengthening of RC columns by carbon fiber sheet
Autor: Joh, Osamu / Kitano, Atsunori
DOI: https://doi.org/10.5169/seals-1117

Shear Strengthening of RC Columns by Carbon Fiber Sheet

Osamu JOH
Professor
Hokkaido University
Sapporo, Japan

Osamu Joh, born 1943, graduated from Hokkaido University, received Dr. degree of Engineering from the University.

Atsunori KITANO
Lecturer
Hokkaido University
Sapporo, Japan

Atsunori Kitano, born 1966, graduated from Hokkaido University, received M.S. degree of Engineering from the University.

Summary

This paper describes an experimental study on the use of carbon fiber sheet for seismic retrofit of non-ductile reinforced concrete columns. Fifteen column specimens designed originally to be failed in shear were tested under some variables which are shear span ratio, axial stress level, quantity of sheet reinforcement and etc. The test results show the effectiveness of carbon fiber sheet bound up column faces for improving the strength and ductility of columns. Shear strength evaluation formula using of an effective coefficient for sheet reinforcement are proposed.

1. Introduction

A carbon fiber sheet was developed as a new material for repairing and strengthen of reinforced concrete members. The sheet is arranged with long carbon fibers in one way. Consequently, it has high strength in one way, and has good workability because of light weight, flexibility and no use of concrete. The sheet is used in real structures for increase of flexural strength of beams, stiffening of slabs with bending cracks, repairing of columns failed in shear and so on. There are many studies of effects on flexural performance, but few studies on shear strength. The paper was an experimental study on shear performance of normal steel reinforced concrete columns bandaged with carbon fiber sheet. Especially the experiment focused to obtain relationships between the shear strength of such columns and some factors: shear span ratio, quality of carbon fiber sheet, axial stress ratio and so on.

2. Experimental Work

Twelve specimens provided originally had a column with a square cross section of 300 mm x 300 mm and two loading stabs at the top and bottom of the column. Reinforcement ratios of column axial bars and of hoop with 150 mm spacing were 2.65 % in gross and 0.124 %, respectively, for all columns. The specimens consisted of four variables: shear span ratio, reinforcement quality of carbon fiber (hereafter CF) sheet, column axial stress and repaired/strengthened. This variable of 'repaired' means a reloading test of the specimens which were repaired with CF sheet after failing in shear as original RC columns (CS2, CM2 and CL2, see Table). Then total number of test units was fifteen.

The arrangement of sheet reinforcement was the way which CF bandages cut out with 30 mm width from the sheet were bound up the column faces in every 50 mm pitch with one or three layers. This striping was to observe easily development of cracking on the columns. Each bandage had a lap joint of about 100 mm length at the ends, and was glued concrete with epoxy adhesive. The properties of CF sheet were thickness of 0.111 mm, tensile strength of 3.55 GPa, Young's modulus of 235 GPa, elongation of 1.5 %. The specimens were subjected to constant axial load in stress ratio of 0, 0.2 or 0.4 and lateral load reversals in drifts angles of 1/500, 1/200, 1/100x2, 1/50x2, 1/33x2, 1/25x2 and 1/20x2. Moment diagram of column was a point symmetry about the column midhight.

Table Summary of test results and analyses note: S=Shear, B=Bond unit: V (kN), R (10^{-3}rad.)

Name of Specimen	Shear span ratio	Axial stress ratio	CF reinf. ratio%	Conc. f_c (MPa)	Experimental results: Stiffness reduct. expVr	expRr	Max. load expVu	expRu	Fail. mode	Calculated results: Shear calVs	Bond calVb	exVu/calV
CS2	1.11	0.2	0.0	28.7	287	2.00	293	2.00	S	303	(245)	0.99
CS2-ARe	1.11	0.2	0.0444	27.2	-	-	297	20.8	S	335	(269)	0.87
CS2-A	1.11	0.2	0.0444	27.2	297	2.90	305	10.4	S	326	(261)	0.92
CS2-3A	1.11	0.2	0.1332	30.7	323	3.50	340	8.92	S	376	(290)	0.87
CS0-3A	1.11	0.0	0.1332	32.9	242	4.20	350	30.0	S	342	(263)	0.98
CS4-3A	1.11	0.4	0.1332	24.0	304	2.87	320	5.29	S	371	(283)	0.83
CM2	1.68	0.2	0.0	29.9	264	6.20	264	6.20	B	(234)	213	1.24
CM2-ARc	1.68	0.2	0.0444	29.9	-	-	170	20.	B	(267)	235	0.83
CM2-A	1.68	0.2	0.0444	29.4	271	5.08	271	5.08	B	(265)	233	1.16
CM2-3A	1.68	0.2	0.1332	26.5	283	6.23	302	20.1	S+B	291	(265)	1.04
CM0-3A	1.68	0.0	0.1332	27.9	208	6.27	292	20.3	S+B	258	(243)	1.13
CM3-3A	1.68	0.3	0.1332	28.3	323	6.80	336	20.1	S+B	320	(288)	1.05
CL2	2.24	0.2	0.0	30.0	239	10.1	239	10.1	B	(199)	194	1.24
CL2-ARo	2.24	0.2	0.0444	30.0	-	-	156	20.1	B	(231)	215	0.73
CL2-A	2.24	0.2	0.0444	23.0	215	9.12	215	9.12	B	(204)	186	1.15

$$calVs = [0.115\, k_p k_u (180+\sigma_B)/(M/Vd+0.12) + 2.7\sqrt{(p_w \cdot \sigma_y + \alpha \cdot {}_f p \cdot {}_f\sigma_u)} + 0.1\,\sigma_0]\, b \cdot j \quad \text{(Eq.1)}$$

$$calVb = \tau_b [0.95 + 0.0018\,\sigma_0 - 0.066\, M/VD]\, n \cdot \phi \cdot d \quad \text{(Eq.2)}$$

where $\tau_b = [0.3+0.8C/\phi + 13\,\phi\, M/V]\sqrt{\sigma_B} + (a_w \cdot \sigma_y/\chi + \alpha \cdot {}_f a \cdot {}_f\sigma_u/{}_f\chi)/(11\, n\, \phi)$

3. Test Results and Discussion

Response performances of all test units is shown in the table. All columns of S-series (small shear span) were failed in diagonal compressive shear. Shear strength of column CS2-A with one-layer binding increased slightly comparing to that of column CS2 with no sheet, but ductility of the former was improved remarkably. Column CS2-3A with three-layer binding exhibited enhancements of shear strength and ductility. Columns of M-series (middle shear span) with no or one-layer binding were failed in bond split along column axial bars, and those with three-layer binding were failed in the mode mixed with shear and bond split. Columns CM2 and CM2-A failed in bond split had similar maximum strength and deformation at ultimate stage. High reinforcement with CF sheet can improve bond split strength more effectively than shear strength, judging from the fact as the failure mode was changed from the bond split failure to the mixed one. Columns CL2 and CL2-A of L-series (large shear span) showed similar characteristics to CM2 and CM2-A in the strength, ductility and failure mode.

To evaluate the shear strength of columns, Ohno-Arakawa Modified Equation (Eq.1) proposed for RC columns was used. In order to apply this equation to evaluate the shear strength of RC columns bound with CF sheet, the value of fiber reinforcement ratio ${}_f p$ multiplied by its tensile strength ${}_f\sigma_u$ was added in the second term of steel reinforcing effect in the equation. At this time, the use of a reduction factor α of about 2/3 needed to close the calculated values to the experiment values because CF fiber did not reach its tensile strength at the maximum strength of columns. The ratio of expVu/calVs was 0.99 for column CS2 with no sheet and 0.95 in average for columns failed in shear or mixed mode. This means it might be better to use a less value for the reduction factor. As for evaluating the bond split strength of columns, the same manner mentioned above was applied to Shibata-Sakurai Equation (Eq.2). The ratio of expVu/calVb was 1.24 and 1.25 for CM2 and CL2 with no sheet, respectively, and was 1.19 in average for columns failed in bond split or mixed mode. This means the reduction factor of 2/3 is almost an adequate value for evaluation of bond split strength.

4. Conclusion

Lateral load reversal tests of non-ductile R/C columns exhibited the following performances:
1) reinforcement by binding of one-layer carbon fiber sheet around column faces can improve the ductility only, 2) three-layer binding is required to increase not only the ductility but also the diagonal shear and bond split strengths, 3) effectiveness of carbon fiber sheet binding on shear strength decreases according to column axial stress level, and 4) the use of reduction factor for carbon fiber reinforcement is needed to evaluate the shear and bond split strengths.