SARUCTURAL RERPERMANCE OF WELDED BUILT-UP SQUARE CFT COLUMN WITH STEEL FIBER

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ABSTRACT

Welded built-up square CFT columns are widely employed in construction field thanks to their structural safety because the bent steel plate mitigates stress concentration, improves workability and maximizes the composite effect enabled by the bent ribs. The anchor effect of the ribs in the columns enables more efficient and economic design using thin steel plates when compared with generic square CFT columns. We suggest the advanced method of using steel fibers to improve structural stability and ductility. The main parameters in the experiment are mixing ratio of steel fibers and loading method.

Keywords: Concrete filled steel tube (CFT), Steel-fiber reinforced concrete (FC), Advanced Technology Construction (ACT) Column, Aspect ratio.

1. INTRODUCTION

Many studies have been made on concrete filled steel tube columns in Korea and abroad and the columns are employed in wide range of structures from buildings and bridges to underground facilities. When the columns under axial force partially deal with lateral force, they are often subject to axial force and moment simultaneously depending on boundary condition. In this case, the concrete inside the steel tube provides tensile force and the steel tube deals with most of the lateral force. Reinforcement with bars or steel fibers has been suggested in some studies to mitigate this problem. The load capacity of steel fibers varies significantly depending on mixing ratio and aspect ratio. Previous studies found that mixing ratio over 2% is not economically desirable and leads to fiber balling. In this study, the biaxial behavior and hysteresis of the interior anchor type CFT columns reinforced with a small amount of steel fibers are analyzed through structural test. Figure 1 shows the concept of the column to be analyzed in the study.

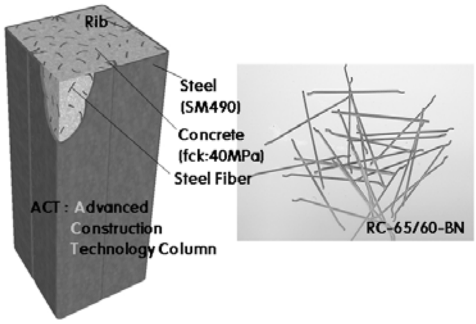

Figure 1: Concept of advanced construction technology column

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2. RESEARCHS OF STEEL FIBER REINFORCED CFT COLUMN

Giusppe Campione(2000) suggested moment-axial force relationship in order to improve the load capacity and ductility of circular CFT columns reinforced with steel fibers. S.R. Gopal and P.D. Manoharan (2006)conducted structural performance test of generic circular columns and those reinforced with steel fibers(aspect ratio:60, volume mixed: 1%). The compressive strength of the concrete was 42MPa. Another parameter was slenderness ratio, which ranged between 13 and 28. The circular columns in the test had identical cross-section (76x2$_{mm}$) and different lengths ranging from 988 to 2128$_{mm}$. The tests showed that the CFT columns reinforced with steel fibers had a great deal of ductility and controlled lateral displacement effectively. Zhong Tao(2007) analyzed the hysteresis and behavior of square CFT column which was filled with normal concrete and had interior stiffeners (a) and that which was reinforced with steel fibers and did not have stiffeners (b). The hooked-ended steel fibers were 30mm in length and 0.5mm in diameter and the mixing ratio was about 2%. The cross section of the columns(□-200x2.5mm), Fy of the steel (270MPa) and compressive strength of the concrete (59MPa) were identical among the columns. It was observed from the test that although initial stiffness and axial strength were higher in (a) by 5%, (b) was superior to (a) in terms of ductility after yield strength as much as 150%. As shown in the above-mentioned studies, while the reinforcement with steel fibers does not improve load capacity under pure axial load, it provides a great deal of ductility and toughness under flexural force. In order to avoid economically undesirable design, it is required to find optimal amount of steel fibers based on the cross-section of the column, aggregate and the aspect ratio of the fibers.

3. STRUCTURAL TEST OF CFT COLUMNS REINFORCED WITH STEEL FIBERS

For the sake of convenience in the test, eccentric load was applied to create the state of biaxial stress as shown in figure 2. As shown in table 1 of specimen list, parameters were mixing ratio and eccentric ratio.

Table 1: Specimens list

Name	Eccentricity (mm)	Percent of steel fiber
C0000	0	0
C0020	0	0.25
C0030	0	0.375
E2520	75 (0.25B)	0.25
E2530	75 (0.25B)	0.375
E5020	150 (0.5B)	0.25
E5030	150 (0.5B)	0.375

(a) concentric load (b) eccentric load

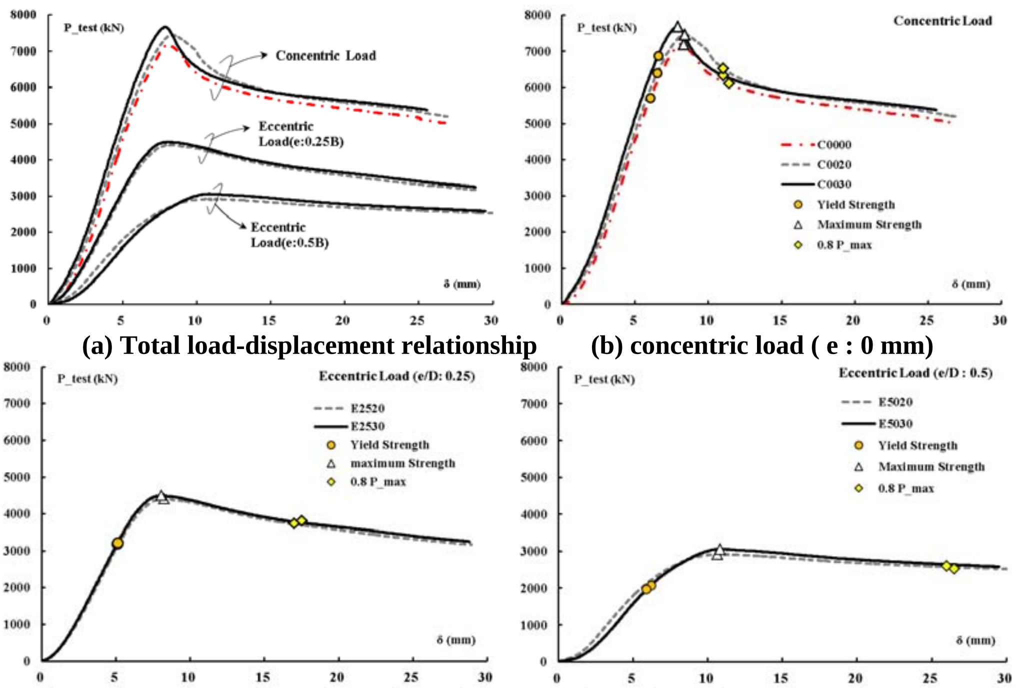
Figure 2: Test boundary condition

The yield strength of the 6mm steel and the compressive strength of the concrete were 325MPa and 40MPa, respectively. The specimens had identical cross sections (□-300×300×6) and lengths (1050$_{mm}$). The hook-ended fibers were 60mm in length (Lf) and 0.75mm in diameter (Df) and their aspect ratio was 80. In the specimens' names, C and E stand for concentric load and eccentric load, respectively. The first two digits after C or E show eccentric distance and the last two digits mean fiber contents (kg). In order to check the compressive strength of the reinforced concrete having different mixing ratios, material test was conducted for 21 samples of different ages. Steel fiber reinforcement factor (RI=vf(Lf/Df) was 20~30 and volume factor (RI*=3Vf(Lf/Df) was 60~90. The average compressive strengths of the concrete without steel fibers and that with 0.25% and 0.375% steel fibers were 41MPa, 42MPa and 46MPa, respectively as shown in table 2.

Table 2: Material test result

No	V_f	Compressive Strength (MPa)			RI	RI*	f_{ck} (MPa)
		Days 7	Days 21	Days 28			
1	0	19	37	41	0	0	40
2	0.25	23	30	42	20	60	40
3	0.375	26	35	46	30	90	40

The graphs in figure 3 are load-displacement relationships obtained from 7 structural tests. The specimens displayed stable behavior and load capacity and displacement did not vary significantly depending on the mixing ratio of the steel fibers. The graphs of the specimens under eccentric loads maintain gradual slopes after maximum strength and show ductile behavior. Table 3 shows the initial stiffness, maximum strength, yield strength and displacement obtained from the tests. The 1/3 tangent method was used to evaluate yield strength. The average yield ratio(Pu/Py) of the specimens under concentric loads was approximately 1.18. Yield ratios of the specimens having the eccentric ratio of 0.25 and 0.50B were 1.38 and 1.47 on average, respectively, which were relatively higher than those under concentric loads. The average ductility ratio(δ 0.8P_{max}/ δ y) of the specimens under concentric loads was 1.75. However, the ductility ratio of the specimens under eccentric loads was significantly higher, which was the average of 3.41 for the specimens having eccentric ratio of 0.25D and 4.32 for 0.50D. When the eccentric ratios were identical, E5030 showed slightly higher ductile behavior than E5020 by 3%.



(a) Total load-displacement relationship **(b) concentric load (e : 0 mm)**

(c) eccentric load (e : 75mm) **(d) eccentric load (e:150 mm)**

Figure 3: Load-displacement relationship

Table 3: Specimens and analysis list

Name	Initial stiffness (kN/mm)	Py (kN)	δ_y (mm)	P_u(kN)	δ_u (mm)	$P_{0.8\ Max}$ (kN)	$\delta_{0.8Pmax}$ (mm)	P_u/P_y	δ_u/δ_y	$\delta_{0.8max}/\delta_y$
C0000	737	5699	6.04	7,204	8.69	6123	11.4	1.26	1.44	1.89
C0020	819	6403	6.50	7,460	8.38	6340	11.2	1.17	1.29	1.69
C0030	875	6873	6.57	7,682	7.89	6529	11.0	1.12	1.20	1.67
E2520	519	3195	5.05	4,405	8.23	3744	17.0	1.38	1.63	3.37
E2530	538	3220	5.09	4,491	8.04	3817	17.5	1.39	1.58	3.44
E5020	304	2068	6.23	2,920	10.63	2520	26.5	1.40	1.71	4.25
E5030	241	1970	5.92	3,060	10.82	2605	26.0	1.55	1.83	4.39

4. ANALYSIS AND FINDINGS

Figure 4 shows the comparison of axial strength associated with different mixing ratios. Under concentric load, the strength of the specimens reinforced with steel fibers was improved by 4~7%. The improvement in strength under eccentric load was approximately 2~5%. Although the reinforcement with steel fibers did not lead to noticeable improvement in axial strength, it should be viewed as effective considering the low mixing ratio of 0.375%. Since the steel fibers were suggested in order to delay deformation rather than improve axial strength of the ACT columns, the improvement should be evaluated quantitatively in terms of ductility.

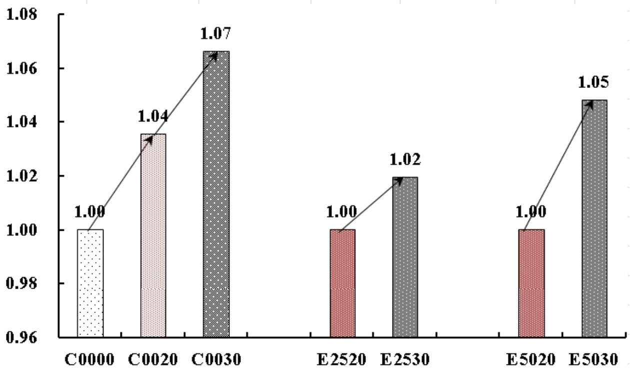
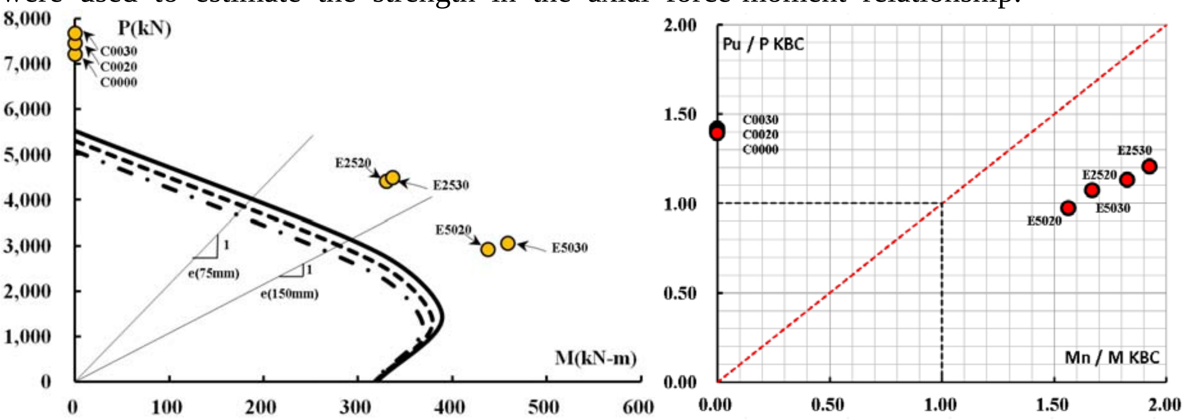


Figure 4: Comparison of strength associated with different mixing ratios

The result from the tests was compared with the design equation in Korean construction design codes. The average strength obtained from material test was used in the analysis. As shown in figure 5, three P-M curves were made due to the difference in the compressive strength of the concrete with different mixing ratios of steel fibers. Then, the eccentric slopes were used to estimate the strength in the axial force-moment relationship.



(a)P-M Curve (b)Non-dimensionalized axial force-moment ratio

Figure 5: Comparison between test & design equation

When compared with the test result, the design equation was found to be a lot more conse rvative in evaluating strength. The evaluation of the structural performance of the interior a nchor type CFT columns reinforced with steel fibers requires an appropriate amplification fa ctor. Under eccentric load, there was no big difference in axial strength between the test an d design equation, while bending strength in the test was 1.5 times higher than design stre ngth, which shows that even a little amount of steel fibers results in the composite effect with concrete. It is deduced that the steel fibers control the brittle behavior of the concrete and the interior anchors enable mutual reaction between the members.
Figure 6 shows the moment-curvature relationship of the specimens having different eccentri c ratios. On the assumption of flat cross-section and linear strain distribution, the strain me asured by the gauges at the both ends of the column center was used to calculate the curv ature at the column center. The bending moment of the cross-section was estimated as axial force multiplied by eccentric distance. In the moment-curvature relationship, the resistance to bending moment rose significantly until maximum strength. Elastic flexural rigidity was simi lar among the specimens, which was approximately 34,246kN-m2. Maximum bending strengt h was 0.02/m when the eccentric ratio was 0.5D and 0.017/m when 0.25D.

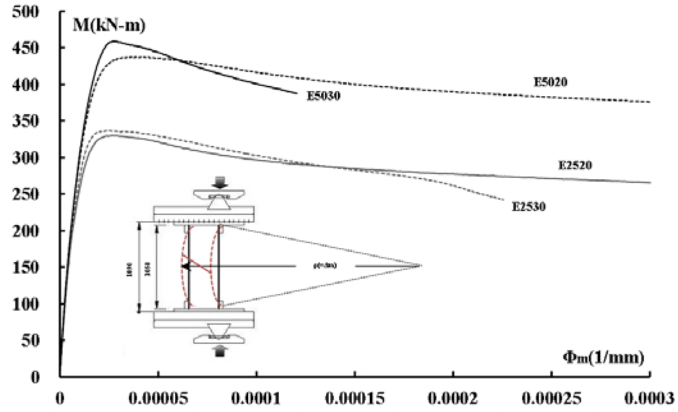
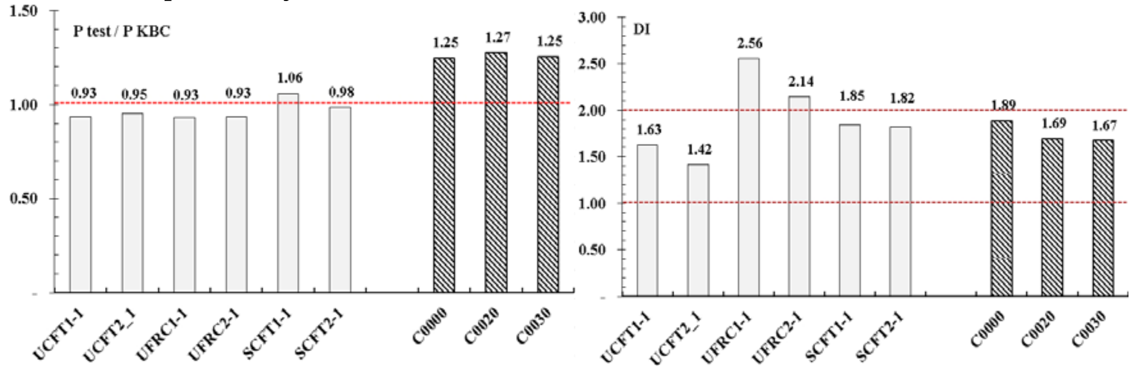


Figure 6: Moment-curvatures curve

In the previous studies mentioned above, the tests of CFT columns reinforced with steel fib ers were conducted. Among them, the study made by Zhong Tao (2007) used similar mem bers with those in this study in terms of the shape of steel fibers and the strength of steel and concrete. Thus, the comparison was made in this study among the test results (UCFT: generic square steel tube + generic concrete, UFRC: generic square steel tube + concrete re inforced with steel fibers, SCFT: square steel tube with stiffeners + generic concrete). The l oad-displacement relationship of the columns under concentric load was identified to analyze axial strength and ductility. The KBC 2009 equation was non-dimensionalized for the comp arison with the previously conducted tests.



(a)Axial strength (b)Ductility

Figure 7: Comparison with previously conducted test

As shown in figure 7(a), Zhong Tao’s result seems to be underestimated because the width-thickness ratio of 80 in his test exceeded the allowable limit. The width-thickness ratio of the specimens in this test was 50. The displacement at yield was divided by that at 80% of maximum strength for non-dimensionalization as shown in figure 7(b). The ductility of UFRC specimens reinforced with 2% steel fibers was more than two times higher than others. Nevertheless, the fact that the ductility of the specimens in this test with the low mixing ratio of 0.25~0.375% was improved by as much as 1.67~1.89 times indicates that they are quite competitive. The interior anchors as well as the steel fiber reinforced concrete resulted in the improvement thanks to the composite effect between the members.

5. CONCLUSIONS

The following conclusions were drawn from the structural test of the built-up square CFT columns reinforced with a small amount of steel fibers for improving ductility.

(1) As the load-displacement relationship shows, the specimens displayed quite stable behavior and the ductility after yield remained high until failure. (2) When the concrete was reinforced with 0.25~0.375% steel fibers, the axial strength of the columns was improved by more than 5% because the composite effect between the fibers and the concrete was maximized. (3) The bending strength of the specimens under eccentric load was 1.5 times higher than bending moment because the steel fibers mixed in the concrete controlled the brittle nature of the cross-sections and improved ductility. (4) In the moment-curvature relationship, the resistance to bending moment rose significantly up to maximum strength and flexural rigidity was similar among the specimens. However, bending strength was improved by 1.3 times as the eccentric ratio increased. (5) It was found that only a small amount of steel fibers mixed in concrete resulted in the improvement in ductility as much as 1.7 times. The comparison with the result obtained from a previous test of the columns made of generic steel tube and steel fiber reinforced concrete showed that the improvement in structural performance observed from the specimens in this study was not attributable only to the steel fibers. The interior anchors and the reinforced concrete enabled composite effect between the members. Therefore, mixing a small amount of steel fibers in the concrete of interior anchor type built-up square columns can lead to efficient structural design and performance.

ACKNOWLEDGMENTS

This research was made possible by ABC SANGSA Company Limited and ACTPATNER Company Limited.

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