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ASSESSING TRANSVERSE REINFORCEMENT FOR ENHANCED PERFORMANCE OF 200MPA ULTRA-HIGH-STRENGTH CONCRETE COLUMNS

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ABSTRACT

This paper presents an experimental study of the behavior of 200MPa UHSC columns confined by rectangular ties subjected to concentric compression. Twelve large scale columns (220*220*1000mm) were tested in order to recognize the effects of the main variables such as the concrete compressive strengths, tie configurations, amount of the transverse reinforcement. The behavior of UHSC columns are characterized by sudden spalling of concrete cover and extremely brittle behavior, unless the columns are confined with transverse reinforcement that can provide sufficient high lateral confinement pressure. Therefore, more confinement is required in a column with higher concrete strength than in a column with lower concrete strength to achieve the same amount of strength enhancement in both columns.

Keywords: ultra-high-strength concrete columns, uniaxial compressive behavior, transverse reinforcement

1. INTRODUCTION

The technology of ultra-high-strength concrete (UHSC) as a primary structural material in high-rise building construction has greatly improved over the last decade and currently compressive strength 200MPa UHSC with improved field applicability by atmospheric curing has been developed in Korea. However, there have been some problems and special considerations to use UHSC for the structural member of high-rise building, e.g., extremely brittle failure, early cover spalling, and so on. It is well-known that the increase in strength and ductility of reinforced concrete columns are afforded by enough confinement reinforcement (e.g., Sheikh and Uzumeri 1980, 1982; Mander et al. 1984, 1988; Razvi and Saatcioglu 1994, 1999; Cusson and Paultre 1994, 1995; Han et al. 2003; Légeron and Paultre 2003, 2008; Sharma et al. 2005; Hong et al. 2003; Xie et al. 1995; Liu et al. 2000). However, current code provisions for confining reinforcement of concrete columns are the results of tests

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done on reinforced concrete columns with normal strength concrete and these provisions may neither be adequate nor safe for UHSC columns (ACI 2011). Therefore, the research reported in this paper is aimed at investigating the confining effect of transverse reinforcement in 200MPa UHSC columns subjected to monotonic axial compressive loading.

2. EXPERIMENTAL PROGRAM

Twelve large-scale UHSC columns, with 220 square section and 1000 mm overall were constructed and tested under concentric compressive loading. All specimens were constructed using D10 (d_b = 9.5 mm, A_s = 71 mm^2) transverse reinforcement but various volumetric ratios and configurations of transverse reinforcement were used. Ratios of the transverse reinforcement in the specimen to the lateral reinforcement required by the ACI code clauses (ACI, 2011) for seismic design ranged from 55% to 125%. Four different configurations of transverse reinforcement such as type A, B, C, and D were considered in this experimental program. Figure 1 shows the geometry and reinforcement layout of the specimens and Table 1 shows the details of test parameter for investigation.

Specimens CC-1~CC-8, CC-10 and CC-12, CC-9 and CC-11 were constructed with a specified 98-day compressive strength of 200, 100, 50MPa, respectively. Table 2 summarizes the concrete properties.

All specimens were tested under monotonically increasing concentric compressive loading using a 11400 kN capacity universal testing machine, as shown in Figure 2. A loading rate of 3 kN per second was used up to 6000 kN and then displacement control at a rate of 0.0018 mm per second was used.

The testing was continued until the specimen's resistance dropped to twenty percent of the peak load or the compressive displacement reached 25 mm. The internal load cell of the testing machine was used to measure the axial loads that were applied to the column specimens.

Table 1: Details of test parameter

Specimens	concrete	Longitudinal reinforcement			Transverse reinforcement				
	f'_c (MPa)	No.-Size	f_{yl} (MPa)	ρ_l (%)	Type (ABCD)	Spacing (mm)	f_{yh} (MPa)	ρ_{sh} (%)	$\rho_{sh} / \rho_{sh(ACI)}$
CC-1	200	8-D16	497.5	3.233	A	40	549.5	3.6	0.55
CC-2	200	8-D16	497.5	3.233	B	40	549.5	5.3	0.82
CC-3	200	8-D16	497.5	3.233	C	35	549.5	6.9	1.07
CC-4	200	12-D13	479.6	3.141	D	35	549.5	8.1	1.26
CC-5	200	8-D16	497.5	3.233	A	23	549.5	6.2	0.96
CC-6	200	8-D16	497.5	3.233	B	35	549.5	6.1	0.94
CC-7	200	8-D16	497.5	3.233	C	40	549.5	6.1	0.94
CC-8	200	12-D13	479.6	3.141	D	47	549.5	6.1	0.94
CC-9	50	8-D16	497.5	3.233	B	100	549.5	2.1	0.93
CC-10	100	8-D16	497.5	3.233	B	60	549.5	3.6	0.98
CC-11	50	8-D16	497.5	3.233	A	40	549.5	3.6	1.22
CC-12	100	8-D16	497.5	3.233	A	40	549.5	3.6	0.98

A pair of linear variable differential transducers (LVDTs) were placed on the front and on the back faces of each specimen, over a gage length of 700 mm, to measure the shortening at the four corners. Strains in the steel reinforcement were measured using electrical resistance strain gages glued to the hoops, crossties and vertical bars near the mid-height of the specimens, as shown in Figure 1. Especially, a pair of electrical resistance strain gauges, with one gauge on the inside of the bar and the other on the outside of the bar, were glued on the longitudinal reinforcement to capture the onset of bar buckling.

Table 2: Concrete properties

	Fresh concrete			Hardened concrete				
Mix	Air content (%)	Slump-flow (mm)	T50-60 (sec)	f_c' (3day) (MPa)	f_c' (28day) (MPa)	f_c' (98day) (MPa)	ε_c' (98day) (mm/mm)	E_c (MPa)
200MPa	1.4	800/800	2.5/5.5	95.6	187.7	199.8	0.0042	50853
100MPa	1.8	670/670	1.6/5.2	48.9	91.8	110.8	0.0032	39556
50MPa	1.2	680/670	-	40.3	61.1	70.4	0.0028	33416

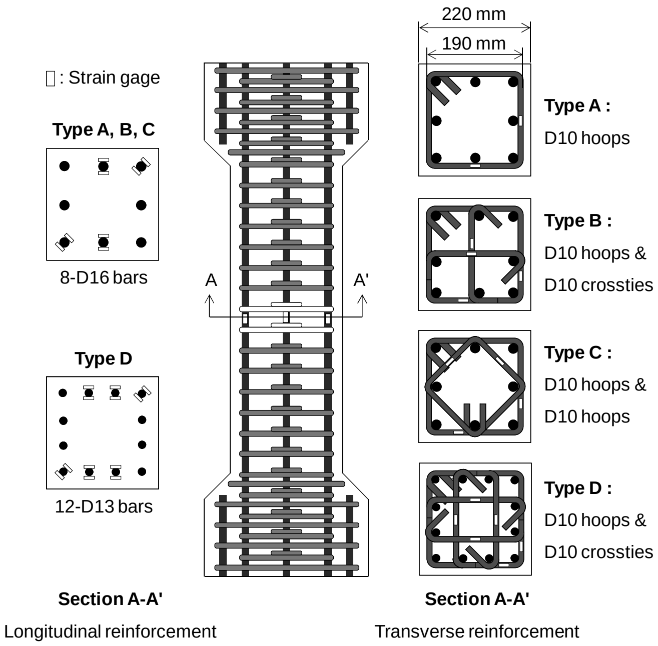


Figure 1: Specimen details and instrumentations.

Figure 2: Test setup.

3. TEST RESULTS

Table 2 summarizes the experimental results obtained for all of the specimens. The results of axial loads, P_{max}, P_c, and P_{cc}, are compared with their corresponding predicted axial capacities, computed according to the ACI Code clauses (ACI 2011) as:

$$P_o = 0.85 f_c'(A_g - A_{st}) + f_y A_{st} \tag{1}$$

$$P_{oc} = 0.85 f_c'(A_g - A_{st}) \tag{2}$$

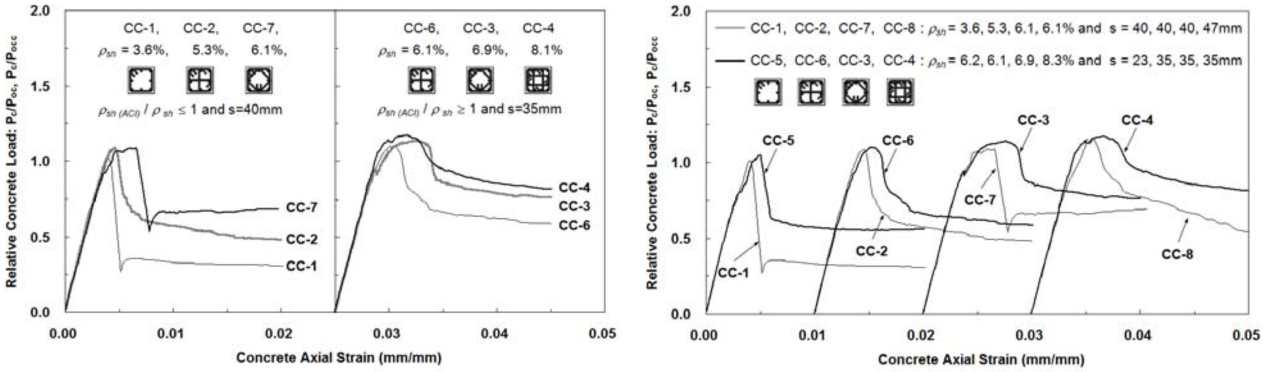
$$P_{occ} = 0.85 f_c' A_{cc} \tag{3}$$

Table 2: Summary of experimental results

Specimens	Type	Axial loads						Axial strains			
		$P_{\max}$ (kN)	$\frac{P_{\max}}{P_o}$	P_c (kN)	$\frac{P_c}{P_{oc}}$	P_{cc} (kN)	$\frac{P_{cc}}{P_{occ}}$	$\varepsilon_{cP\max}$ (%)	$\frac{\varepsilon_{cP\max}}{\varepsilon_c'}$	ε_{cc} (%)	$\frac{\varepsilon_{cc}'}{\varepsilon_c'}$
CC-1	A	6898.0	0.79	6119.5	0.77	5325.2	1.01	0.0033	0.79	0.0042	0.99
CC-2	B	8009.4	0.92	7230.9	0.91	5717.1	1.09	0.0040	0.94	0.0046	1.10
CC-3	C	7300.6	0.84	6522.1	0.82	5994.3	1.14	0.0033	0.79	0.0074	1.77
CC-4	D	7502.7	0.86	6773.5	0.85	6189.8	1.17	0.0034	0.82	0.0067	1.60
CC-5	A	7231.2	0.83	6452.7	0.81	5567.3	1.06	0.0036	0.85	0.0050	1.19
CC-6	B	8002.4	0.92	7223.9	0.91	5805.3	1.10	0.0038	0.91	0.0051	1.22
CC-7	C	7610.3	0.87	6831.8	0.86	5730.2	1.09	0.0035	0.84	0.0059	1.42
CC-8	D	7720.3	0.89	6991.1	0.88	6219.5	1.18	0.0037	0.89	0.0052	1.23
CC-9	B	3633.7	1.01	2855.2	1.02	2298.8	1.24	0.0033	1.19	0.0044	1.59
CC-10	B	5530.9	1.07	4752.4	1.08	3904.1	1.34	0.0035	1.11	0.0041	1.29
CC-11	A	4182.4	1.17	3403.9	1.21	2762.1	1.49	0.0034	1.23	0.0048	1.71
CC-12	A	5402.4	1.04	4623.9	1.05	4091.6	1.40	0.0032	1.01	0.0038	1.19

3.1. Volumetric ratios of transverse reinforcement

The lateral confining pressure that can be developed in a column is directly related to the amount of transverse reinforcement. Figure 3(a) illustrates the response of confined concrete with same tie spacing but different transverse reinforcement ratio. Figure 3(b) summarizes the response of four different pairs of specimens, and within each matched pair, two specimens differing only in their ratio of transverse reinforcement are compared. Test results indicated that both strength and ductility of confined concrete were improved with increased amounts and of transverse reinforcement. The column specimens with $\rho_{sh} \leq \rho_{sh(ACI)}$ exhibit brittle behavior, showing faster rate of strength decay after the peak, whereas the specimens with $\rho_{sh} \geq \rho_{sh(ACI)}$ exhibit ductile behavior.



(a) with same tie spacing **(b) with same tie configuration**

Figure 3: Effect of transverse reinforcement ratio.

3.2. Configurations of transverse reinforcement

The configuration of transverse reinforcement determines the effectively confined area, which increases with a better distribution of longitudinal reinforcements. Figure 4 illustrate the response of equally confined specimens with different tie configuration. Strength and ductility of specimens CC-7 (8 bar arrangement) and CC-8 (12 bar arrangement) improved compare with specimens CC-5 (8 bar arrangement) and CC-6 (8 bar arrangement), respectively. Especially, specimens with type A configuration showed poorest behavior in terms of strength, ductility, and toughness gains.

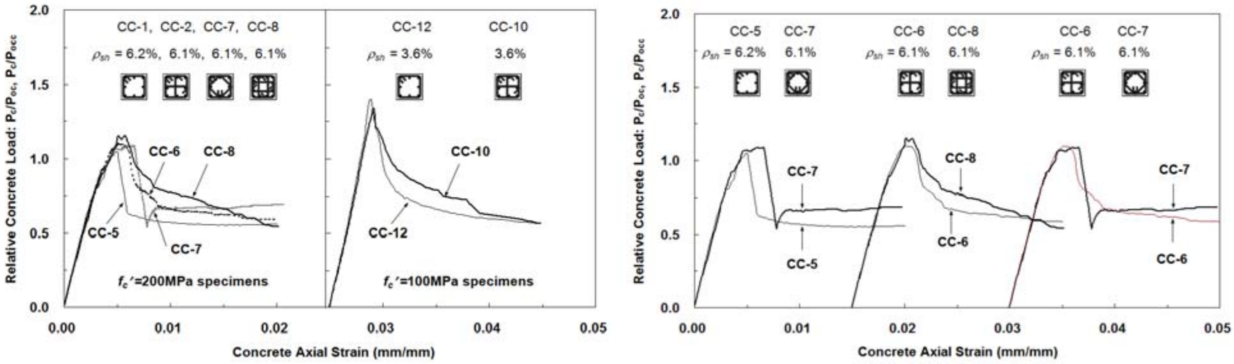
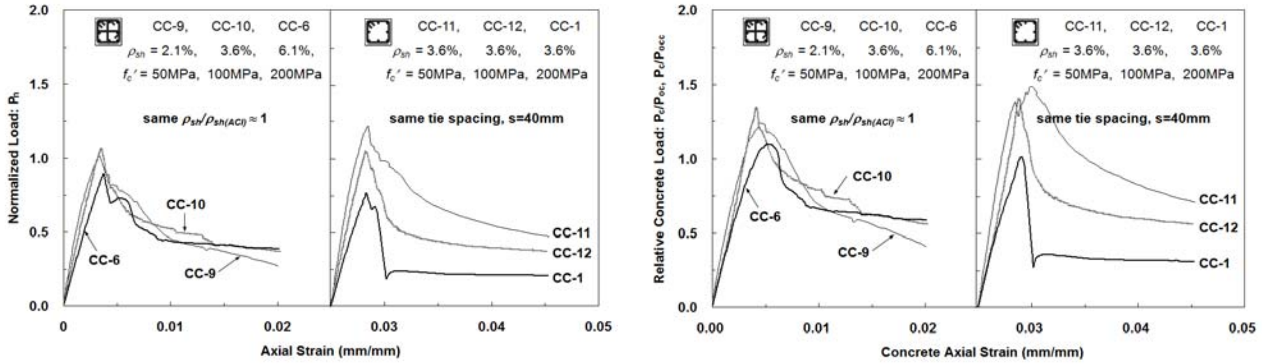


Figure 4: Effect of transverse reinforcement configuration.

3.3. Concrete compressive strength

Figure 5 illustrates the stress-strain curves of the column specimens with different concrete compressive strength. Specimens CC-9, CC-10 and CC-6 have same $\rho_{sh}/\rho_{sh(ACI)}$ ratio but different tie amounts and spacing according to the ACI code (ACI 2011) and specimens CC-11, CC-12 and CC-6 have exactly same tie amounts, configurations but different concrete compressive strength. 200MPa UHSC exhibits less lateral expansion than NSC and HSC and the efficiency of passive confinement of 200MPa UHSC would be reduced.



(a) P_n versus axial strain relationships (b) Relative concrete load versus axial strain relationships

Figure 5: Effect of concrete compressive strength.

The ratio, P_{max}/P_o, ranges from 1.01~1.17 in NSC and HSC specimens, whereas it ranges from 0.79~0.92 in UHSC specimens. This result indicated that more confinement is required in a column with higher concrete strength than in a column with lower concrete strength to achieve the same amount of strength enhancement in both columns.

4. CONCLUSIONS

The following conclusions arise from the research reported in this paper:

1) The behavior of UHSC columns are characterized by sudden spalling of concrete cover and extremely brittle behavior, unless the columns are confined with transverse reinforcement that can provide sufficient high lateral confinement pressure.

2) More confinement is required in a column with higher concrete strength than in a column with lower concrete strength to achieve the same amount of strength enhancement in both columns.

3) Volumetric ratio of transverse reinforcement has a more pronounced effect on the behavior of confined concrete columns than the other parameters like configuration of transverse reinforcement.

5. ACKNOWLEDGMENTS

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