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AN EXPERIMENTAL STUDY ON REINFORCED CONCRETE CIRCULAR COLUMNS HEAVILY CONFINED BY SPIRAL REINFORCEMENT

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ABSTRACT

An experimental study was conducted to investigate the behavior of reinforced high strength concrete circular columns heavily confined by spiral reinforcement, which were subjected to high intensity reversed cyclic lateral load and constant high axial load. In this paper, the experimental work and a part of experimental results are described and discussed, which include the failure process, the lateral deflection characteristics, the axial displacement characteristics, the ultimate moment and the ultimate deflection capacity.

KEYWORDS

Reinforced concrete; circular columns; cyclic load; spiral reinforcement; properties; high strength.

INTRODUCTION

The design of columns at the lower-story of high-rise building is very important, because the columns are subjected to high axial load, which results in the deterioration of ductility of columns. Generally, using high strength concrete is a way to reduce the axial load ratio of the columns and to cut down the section size of the columns, however, higher strength concrete shows more brittle behavior, which necessarily leads to deterioration of ductility of the columns. The ductility of reinforced concrete columns is important in evaluating their aseimicity behavior, because the column with excellent ductile behavior should be capable of absorbing and dissipating seismic energy. Reinforced concrete circular columns show almost the same behavior in every direction, and the ductility behavior of the columns can be markedly improved by providing the circular spiral reinforcement to confine the concrete in compressive zone, which has been proved by author's former experimental study (Suzuki et al., 1985) and practical earthquake damage. It can be regarded as reasonable to apply this column form in lower-story columns of high-rise building.

The object of this study is to investigate the basic mechanical properties of reinforced high-strength concrete circular columns with heavily confined by circular spiral reinforcement, which are subjected to scores of high intensity reversed cyclic lateral load and constant axial load.

EXPERIMENT

Figure 1 shows a typical test specimen, its dimension and bar arrangement. Details of column sections and

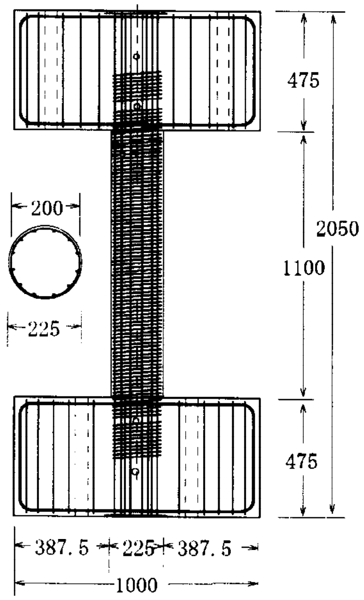

Fig. 1. Typical test specimen

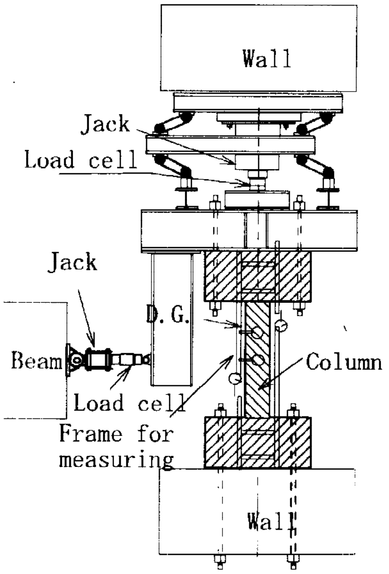

Fig. 2. Loading and measuring arrangement

strength of material used are given in Table 1. All specimens were designed to have higher beam strength capacity than that of column and have higher shear capacity than that of flexural capacity of column to assure that the flexural failure only occurred in the column. The main variables, as shown in Table 1, were the amount and the yield strength of circular spiral reinforcement, the axial load ratio and the strength of concrete.

Loading and measuring arrangement is shown in Figure 2. Reversed lateral load was applied alternately by a 1000 kN hydraulic jack through a "L" form rigid frame. The axial load was kept constant by adjusting the axial loading hydraulic jack (2000 kN capacity). The tests were carried out by deflection controlled method, and consisted of 5 cycles for each planned relative rotation angles of column (θ) such as 1/100, 1/50, 1/30, 1/20 and 1/15. In order to investigate the behavior of specimen No.6 , which was extremely heavily confined, the loading cycles was increased to 30 at θ=1/15.

Table 1. Details of column sections and mechanical properties of material

Specimen	f_c	N	N/(Af_c)	Spiral reinforcement			Main rein.
	(MPa)	(kN)	η	Pitch	p_v (%)	f_{sy}(MPa)	f_y (MPa)
No.1	50.5	960	0.48	D6@25	2.56	385	357
No.2	49.5	1225	0.62	D6@25	2.56	385	357
No.3	55.8	686	0.31	D6@25	2.56	385	357
No.4	58.8	1460	0.62	D6@25	2.56	921	357
No.5	51.5	1245	0.61	D6@15	4.26	385	357
No.6	60.1	1431	0.60	D6@6.4	10.0	385	357
No.7	31.1	1245	1.01	D6@15	4.26	385	357

Lateral deflections and axial compressive displacement of columns were measured by displacement transducers attached to the measuring small light-steel rigid frame. The strain distribution of longitudinal and spiral reinforcement of columns were measured by electrical resistance strain gages.

FAILURE CHARACTERISTICS OF COLUMNS

Since columns were heavily confined by enough spiral reinforcement, the shear capacity of columns was fully

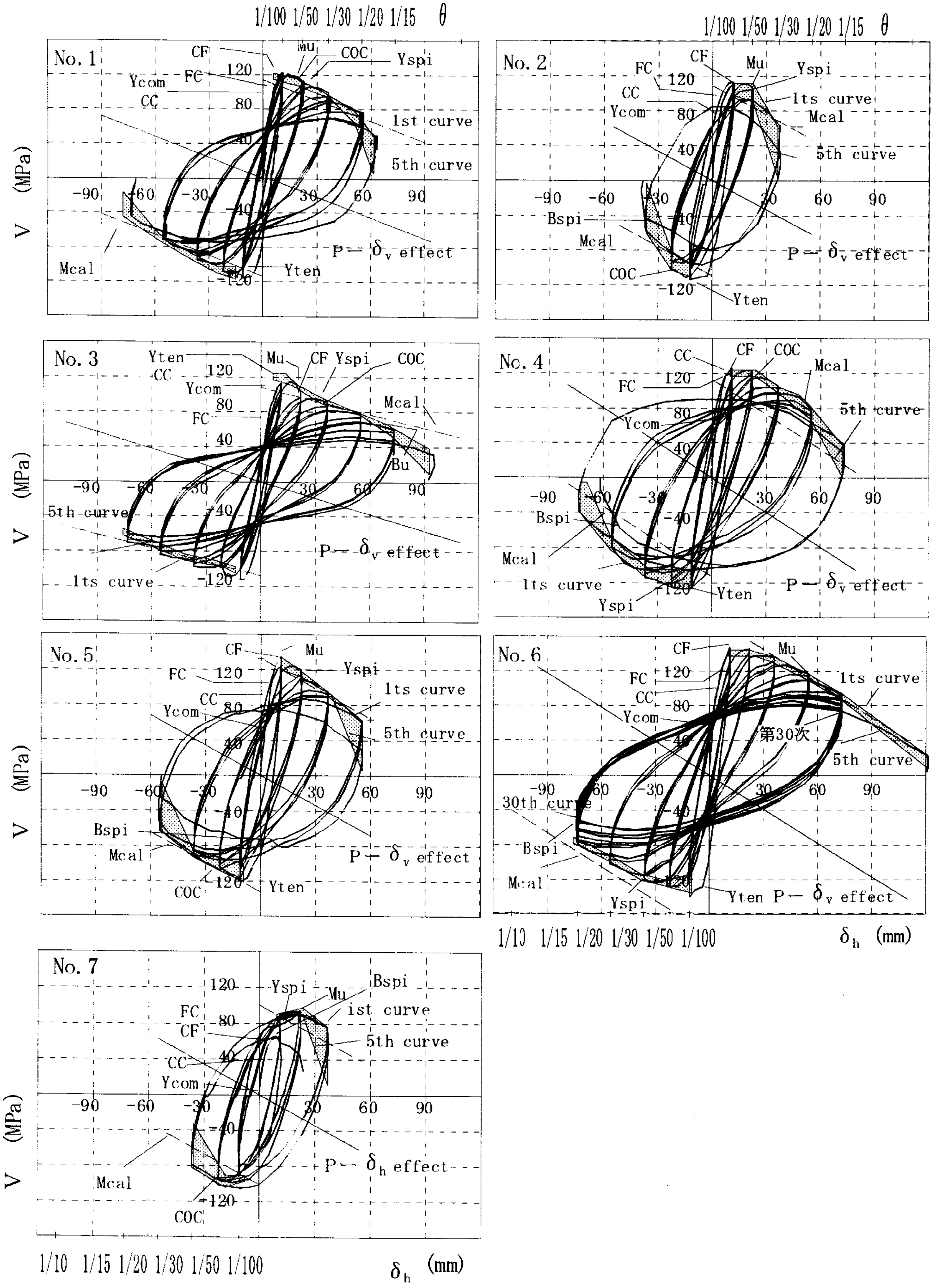

Fig. 4 Lateral load-deflection relations

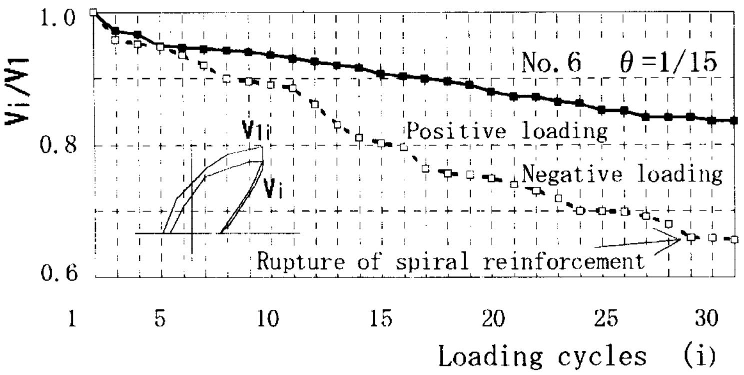

Fig. 5 Reduction ratio of load capacity of No.6 under cyclic load

of load capacity of No.6 at $\theta=1/15$. It can be seen that the load capacity of No.6 descends greatly since the 10th cyclic loading in negative loading process, but it descends slowly and tends to converge with increase of loading cycles in positive loading process.

Specimen No.5 and No.7 were subjected to same axial load and confined with same spiral reinforcement, but they have different strength of concrete. Due to using high strength of concrete. No.5 has a smaller axial load ratio and shows larger deflection than No.7.

CHARACTERISTICS OF AXIAL COMPRESSIVE DISPLACEMENT

Figure 6 shows the results of specimens of the axial compressive displacement (δ_v)-relative lateral deflection (δ_h) of column ends. It can be seen that, with the increase of δ_h, δ_v increases, and that leads to unrecoverable axial compressive residual displacement. The residual displacement would constantly accumulate and enlarge due to the cyclic loading at each loading datum θ . These phenomena are more pronounced for the specimen with larger axial load ratio and less spiral reinforcement. Furthermore, specimens (No.1~No.5, No.7) which failure due to severe fracture and scaling of core concrete has remarkable development of δ_v in several cycles of loading just before their failure. It can be considered that a rapid increase of δ_v designates that the failure of column is upcoming.

ULTIMATE MOMENT

Table 2 shows the comparison of experimental maximum moments (M_{exp}) of specimens and calculated ones by using different methods (Suzuki et al., 1985, Suzuki et al., 1991). In the calculation of M_{cal1} and M_{cal2}, the core concrete area

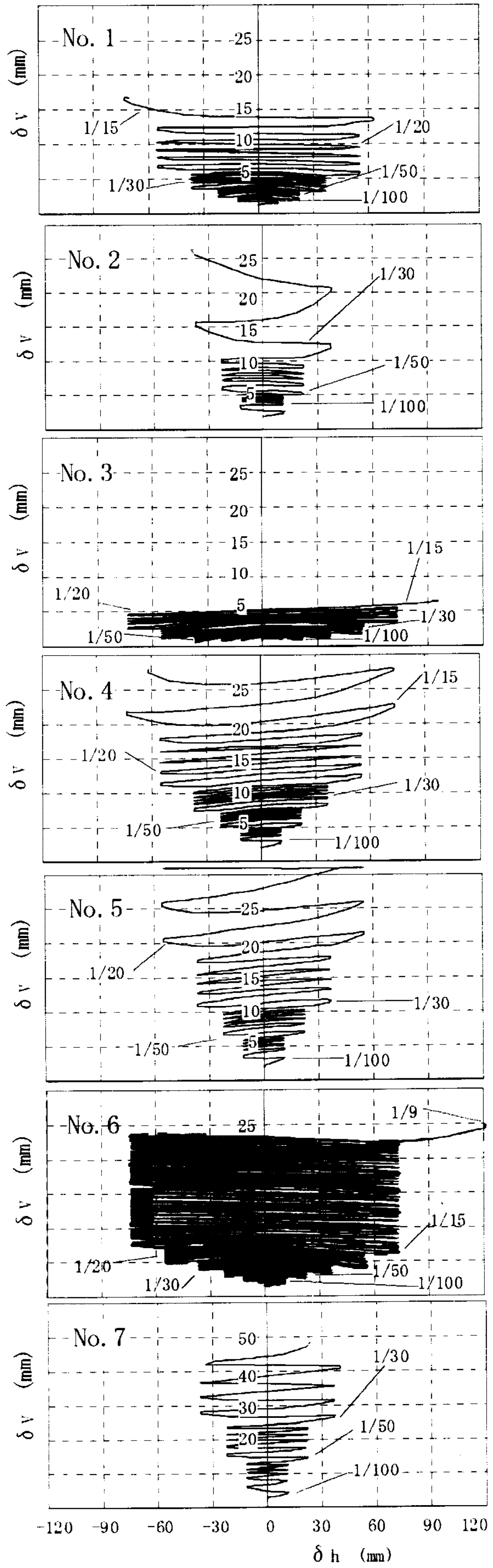

Fig. 6. Characteristics of axial compressive displacement

of calculated section is taken into consideration, according to the experimental results that cover concrete severely fractured and nearly scaled off before specimen reached its maximum moment, the compressive strength of core concrete is calculated by the strength formula (Suzuki et al., 1985) of confined concrete. From Table 2 it can be seen that the ratios of M_{cal1}/M_{exp} and M_{cal2}/M_{exp} are 0.832~1.012 (averaging 0.891) and 0.754~0.993 (averaging 0.821) respectively, both are in good agreement with experimental moments.

Table 2 Comparison between experimental ultimate momnets of columns and calculated ones

Specimen	M_{exp} (kN-m)	M_{cal1} (kN-m)	M_{cal2} (kN-m)	M_{cal1}/M_{exp}	M_{cal2}/M_{exp}
No.1	71.23	62.44	57.02	0.877	0.801
No.2	71.23	59.83	51.19	0.841	0.719
No.3	67.32	59.22	57.41	0.879	0.853
No.4	87.73	75.91	66.14	0.865	0.754
No.5	76.58	72.78	66.03	0.931	0.862
No.6	99.81	100.96	99.16	1.012	0.993
No.7	66.36	55.24	50.70	0.832	0.764
	Average			0.891	0.821

ULTIMATE DEFLECTION CAPACITY

Figure 7 shows the ultimate relative rotation angles of columns (θ u) versus the axial load (η) and the ratio of volume of spiral reinforcement (p_v). From Figure 8, it can be seen that the θ u increases with increase of the p_v and decreases with increase of the η . As to circular column specimens using high-strength concrete of f_c=50 MPa and f_c=30 MPa , though subjected to high axial load with axial load ratio up to 0.6 and 1.0 respectively, they still possessed large deflection capacity of θ u=1/50, showing excellent stability, under scores of high intensity reversed cyclic lateral load when heavily confined by spiral reinforcement D6@25 and D6@15 (p_v=2.56% and p_v=4.26% respectively). Moreover, θ u could be increased by 2~3.5 time if close spacing or high-strength spiral reinforcement be used.

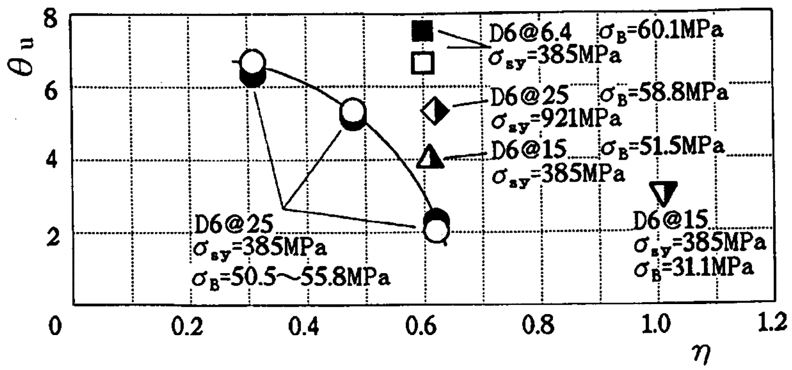

Fig. 7. Ultimate rotation angles of columns-axial load ratoi and amount of circular spiral confining reinforcement

CONCLUSIONS

From the investigations presented above, the following conclusions are made.

In this experiment, the final failure of columns results from the rupture of spiral reinforcement, or the buckling of compressive longitudinal bars, or the severe fracture of core concrete (see Figure 3).

The deflection capacity of columns decreases with increase of the axial load ratio (see Figure 4 and 7).

The column, which is heavily confined by spiral reinforcement, shows excellent ductile behavior even if it is subjected high intensity reversed cyclic lateral load and constant high axial load (Figure 4, 5 and 7).

The accumulation of axial deformation of columns progresses rapidly with increase of lateral deflection and numbers of lateral loading cycles (see Figure 6).

The ultimate moments can be calculated with satisfactory by using the proposed method (see Table 2).

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