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MECHANICAL CHARACTERISTICS OF REINFORCED CONCRETE COLUMN AFFECTED BY ALKALI AGGREGATE REACTION

Kazuo Takemura*, Ei-ichi Tazawa**, Asuo Yonekura** and Yasutomo Abe*

* Dep. of Civil Engineering, Kure College of Technology
Kure, Hiroshima 737, Japan
** Dep. of Civil Engineering, Hiroshima University
Higashi-Hiroshima, Hiroshima 724, Japan

1. ABSTRACT

This paper describes the test results of spirally reinforced concrete column affected by alkali aggregate reaction which is subjected to axial load. Variables are axial reinforcement, spiral reinforcement and water-cement ratio. The results are compared with those of Expansive concrete and Normal concrete.

2. INTRODUCTION

Recently, the early deterioration of concrete structures due to alkali aggregate reaction (ASR) has been a social problem in Japan. Many studies on reinforced concrete beam affected by ASR, subjected to bending moment, have been reported. However, there are few researches on reinforced concrete column subjected to axial load.

In these members, expansion of concrete is restrained with reinforcing bars, and so the self stress in compression may be induced in concrete. The main objective of the work described herein is to investigate the effects of expansion of concrete on mechanical properties of spirally reinforced concrete column. Expansive concrete and Normal concrete are also used in this study.

3. EXPERIMENTAL PROCEDURES

3.1 Materials and concretes

Ordinary portland cement having alkali content of 0.62 % was used. A calcium sulpho-aluminate based expansive admixture was used for Expansive concrete. Pit sand and river sand were used as fine aggregate. Reactive crushed chert was used as coarse aggregate of ASR concrete (Fig.1). Coarser portion of sand (2.5-5.0 mm) in ASR concrete was reactive aggregate obtained from the crushed chert. Non-reactive crushed stone was used in Expansive concrete and Normal concrete. Sodium hydroxide was used as addition-al alkali. Mix design is shown in Table 1.

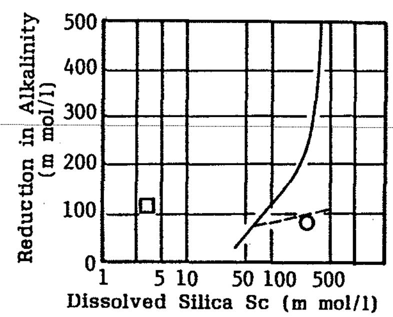

Fig.1 Results from ASTM chemical method

Table 1 Mix design and compressive strength of concrete

Mix No.	W/(C+E) (%)	Ex.Ad. (kg/m³)	Na_2Oeq. (kg/m³)	f_c' (kgf/cm²)	
				Unrestrained	Restrained
N1	58.8	0	2.11*	374	334
N2	50.0	0	2.42*	432	-
N3	50.0	0	5.00	333	-
N4	50.0	0	7.00	285	-
N5	74.6	0	1.16*	227	219
N6	94.1	0	1.32*	140	138
A1	65.0	0	7.00	150	155
A2	58.8	0	7.00	190	195
A3	50.0	0	7.00	222	261
A4	40.0	0	7.00	319	339
E1	54.8	70	1.19*	301	340
E2	67.1	85	1.41*	26	219
E3	54.8	85	1.83*	141	325
E4	41.0	85	2.59*	257	528

*From alkalinity of cement and expansive admixture
N;Normal, A;ASR, E;Expansive concrete

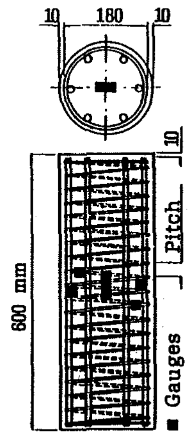

Fig.2 Size of column

3.2 Specimens and tests

Six ϕ10x20 cm size cylindrical specimens were prepared for each mix. Three of them were demoulded at the age of 2 days (unrestrained) and the others were cured within the steel mould just before the test (restrained). Spirally reinforced concrete columns 20 cm in diameter and 60 cm in height were prepared according to the test program shown in Table 2 (Fig.2). The specimens with column for the half length and with the same reinforcement (referred as Test Unit) were prepared in order to estimate expansion and actual compressive strength of core concrete confined within the spiral reinforcement. Free expansion of ASR concrete was measured with 10x10x40 cm size prismatic specimen.

ASR concretes were cured under ambient condition of 38 °C, 100 % RH.. Specimens with Expansive and Normal concrete were cured in the 20°C water tank.

Table 2 Experimental program in column test

Test series	Mix No.	Axial reinforcement		Spiral reinforcement	
		Dia.(mm)	Number	Dia.(mm)	Pitch(cm)
A	N1,A2,E1	D10	0,4,6,8	ϕ6	3
		D13	6	ϕ6	∞,5,3,2
B	N1,A2,E1	D10	6	ϕ6	3
C	N1,N5,N6 A1,A2,A3,A4 E2,E3,E4	D10	6	ϕ6	3
D	A2	ϕ6	4	ϕ6	5
		D16	8	ϕ9	3

4. RESULTS AND DISCUSSION

4.1 Mechanical properties of concrete

4.1.1 Expansion of ASR concrete

The expansion with time elapsed of ASR concrete in which total alkali content is Na_2O eq. 7 kg/m^3, is shown in Fig.3. The expansion may be subjected to the influence of the surface area of reactive aggregate. As the weight of aggregate increases with water-cement ratio, the surface area of reactive aggregate increases with the water-cement ratio. The expansion at 16 weeks is divided by unit weight of reactive aggregate (ε/Ag.re.). The expansion increases lineally with water-cement ratio.

Alkalinity by weight of cement, however, decreases with water-cement ratio, because alkali content of concrete is constant. No effect of water-cement ratio is observed on the expansion per alkalinity by weight of cement (Fig.4).

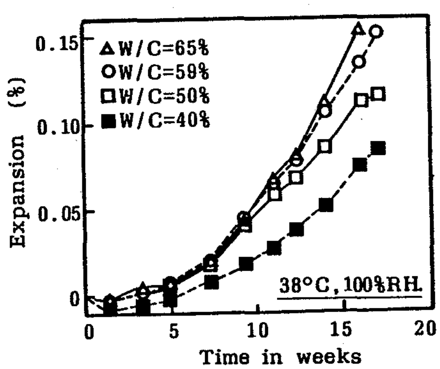

Fig.3 Expansion of ASR concrete

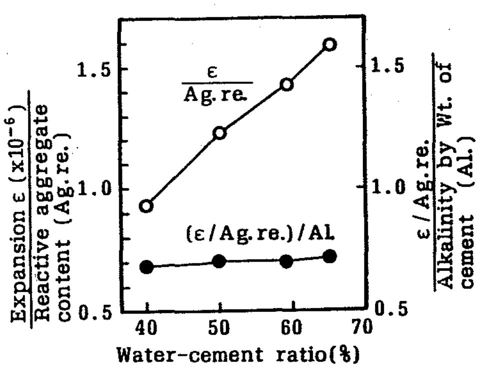

Fig.4 Effect of water-cement ratio on expansion of ASR concrete

4.1.2 Compressive strength

The compressive strength of concrete is one of the most important factor for estimating the characteristics of reinforced concrete column. Strength test results are shown in Table 1.

The compressive strengths of ASR concrete are approximately one half of those of Normal concrete. About 75 % of this reduction in strength, however, may be caused by addition of alkali NaOH.

Loss of compressive strength of Expansive concrete due to excessive expansion can be prevented by restraint afforded by steel mould as shown in Table 1.

4.2 Behavior of reinforced concrete column

4.2.1 Expansion

Axial and horizontal expansions of the center of column are shown in Fig.5 and 6. In case of Expansive concrete, axial expansion decreases remarkably with axial reinforcement ratio P. Axial reinforcement has little effect on horizontal expansion. Increment of spiral reinforcement ratio Ps is effective to restrain those expansions in both directions (Fig.5).

In case of ASR concrete, axial reinforcement is effective to restrain axial expansion, and spiral reinforcement is effective to restrain horizontal expansion (Fig.6).

The expansive strain measured within the test unit are shown in Fig.7 and 8. Axial reinforcing bar is set 2 cm from the circumferential surface. Concrete in the vicinity of reinforcing bar is well restrained. The expansion of inner concrete decreases with reinforcement ratios P or Ps. The expansion of unrestrained plain concrete unit with ASR concrete, however, decreases toward inside.

4.2.2 Ultimate load capacity of column

Calculation of ultimate load capacity of the column is performed in accordance with the equations specified in Japanese concrete specifications.

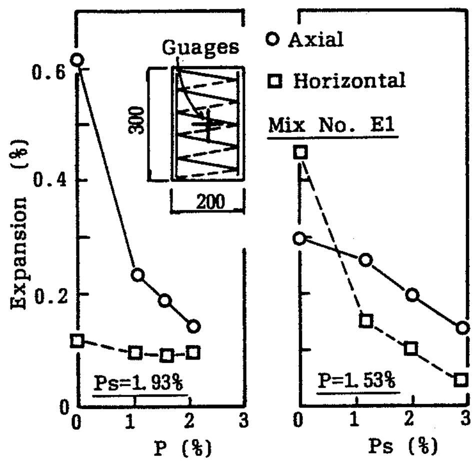

Fig.5 Effects of reinforcement ratios on expansion of center of column with expansive concrete

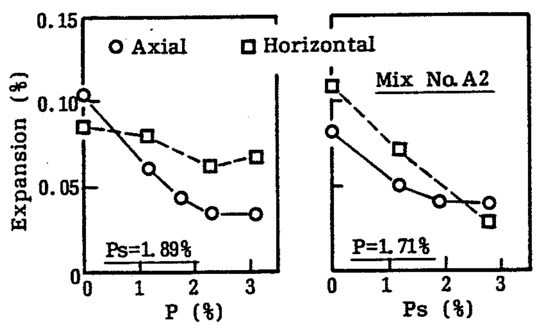

Fig.6 Effects of reinforcement ratios on expansion of center of column with ASR concrete

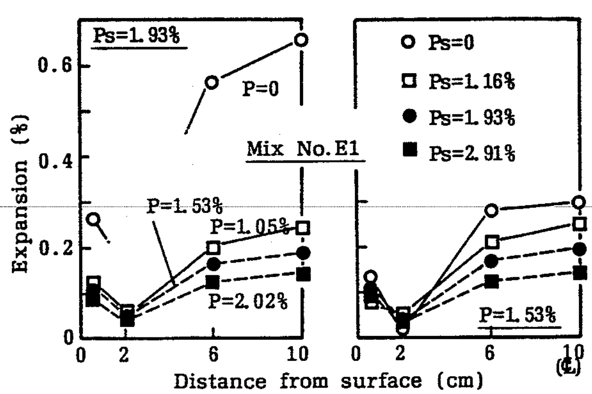

Fig.7 Distribution of expansion (Expansive concrete)

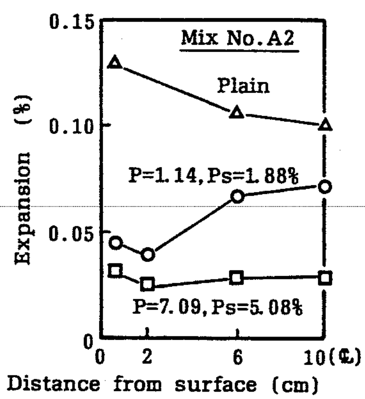

Fig.8 Distribution of expansion (ASR concrete)

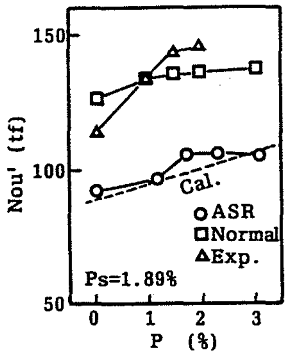

Fig.9 Effect of P on Nou' of column

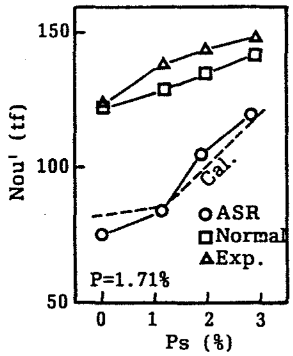

Fig.10 Effect of Ps on Nou' of column

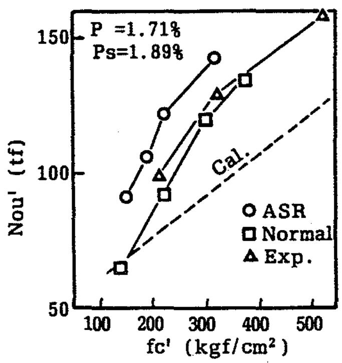

Fig.11 Effect of fc' on Nou' of column

The ultimate load capacity of the columns with any concrete tends to increase with reinforcement ratio P or Ps (Fig.9 and 10). Increment of ultimate load capacity of ASR concrete column with spiral reinforcement is larger than those of the other two concrete column. The ultimate load capacity of ASR concrete column is smaller than those of the others at the same reinforcement ratios because of lower compressive strength of concrete. At the same compressive strength, however, the ultimate load capacities of ASR concrete column are 15-30 % higher than those obtained from the other concretes (Fig.11).

Table 3 Correlation between Nou' and P or Ps

Concrete	Equations
ASR	Nou'= 93.0 + 4.79P (Ps=1.89%)
	Nou'= 71.5 + 16.8 Ps (P =1.71%)
Normal	Nou'= 128.4 + 3.40P (Ps=1.89%)
	Nou'= 120.9 + 7.42 Ps (P =1.71%)
Exp.	Nou'= 115.6 + 17.5 P (Ps=1.89%)
	Nou'= 125.9 + 8.79Ps (P =1.71%)

Correlations between the ultimate load capacity and reinforcement ratio P or Ps are obtained, on the assumption that the correlation is linear (Table 3, Fig.9 and 10). To ASR concrete column spiral reinforcement is more effective in increasing the ultimate load capacity and to Expansive concrete column axial reinforcement is more effective.

Contributions of axial reinforcement ratio P and spiral reinforcement ratio Ps to the ultimate load capacity of ASR concrete column are superposed in order to investigate the total effects of axial and spiral reinforcements. Those results are shown in Fig.12. Reinforcement in ASR concrete column is more effective in contributing to the ultimate load capacity of column than the others. The compressive strengths measured for internal concrete cored from the test units with the same section as column are shown in Fig.13.

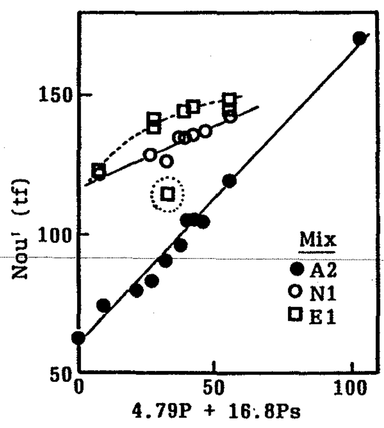

Fig.12 Relationship between 4.79P plus 16.8Ps and Nou' of colum

4.2.3 Displacement of column

Examples of load versus strain curve of the columns with the same reinforcement and nearly equal ultimate load capacity are shown in Fig.14. Strains of ASR concrete column at a certain axial load N' are higher than the others. As the Young's modulus of ASR concrete is smaller than the others, strains become high.

Ductility of column is affected by spiral reinforcement. Ductility of ASR concrete columns is larger than that of Normal or Expansive concrete (Fig.15).

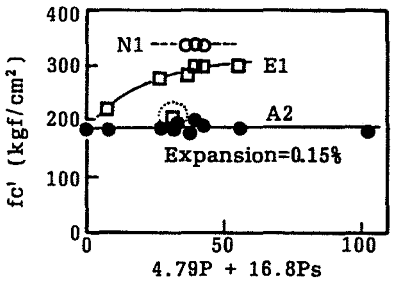

Fig.13 Compressive strength of cored specimen

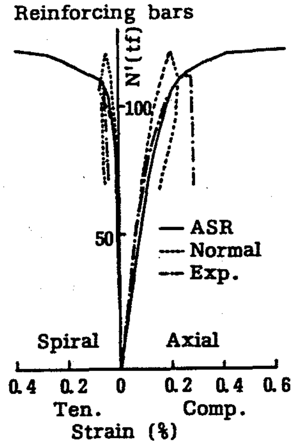

Fig.14 Examples of load versus strain curves

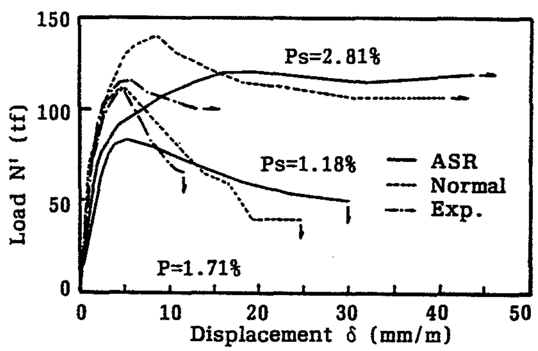

Fig.15 Examples of load versus displacement

5. CONCLUSIONS

Conclusions are summarized as follows within the scope of this experimental work.

(1) Axial reinforcement is effective to restrain the axial expansion of concrete caused by ASR or expansive component enclosed by spiral reinforcement but it is hardly effective to restrain the horizontal expansion. Spiral reinforcement is effective to restrain horizontal and axial expansion of the concrete.

(2) ASR concrete columns have 15-30 % higher ultimate load capacity than the other concrete columns at the same compressive strength, although the ultimate load capacity of ASR concrete column is decreased because of reduction in compressive strength for the same water-cement ratio as Normal concrete.

(3) Ductility of ASR concrete column at the final stage is higher than that of Normal concrete or Expansive concrete column.