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STUDY ON THE INFLUENCE OF ALKALI-SILICA REACTION ON MECHANICAL PROPERTIES OF REINFORCED CONCRETE MEMBERS

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ABSTRACT

Expansion produced by alkali-silica reaction (ASR) has been observed in the turbine generator foundation of the unit 1, Ikata nuclear power station, Japan. The foundation is a reinforced concrete frame structure. This paper, as a part of the series of investigation and experiments, discusses tests on mechanical properties of concrete members affected by ASR. The purpose of the study is to investigate the influence of expansion rate by ASR, reinforcing ratio, specimen dimension on elastic modulus, and compressive strength of concrete; to get appropriate input data for analysis model which is to be carried out to simulate actual behavior of the turbine foundation.

Compressive tests were carried out on concrete cylinder test pieces, core samples, and reinforced concrete member specimens.

From the results of the test on the member specimens, the specimens with more reinforcement ratio showed less expansion and larger elastic modulus. It is considered that restraint by rebars made the expansion small and restrained the drop of the elastic modulus by ASR. Restraint by rebars on ASR specimens did not affect much compressive strength. The data helped to fix input material properties for the analyses representing the actual foundation conditions.

Keywords: Alkali-silica reaction, Compressive strength, Elastic modulus

1. INTRODUCTION

Expansion produced by alkali-silica reaction (ASR) has been observed in the turbine generator foundation of the unit 1, Ikata nuclear power station, Japan. It is a PWR plant whose commencement of commercial operation was in 1977. The foundation is a reinforced concrete frame structure supporting turbines and a generator. A series of investigations and experiments has been carried out on structural integrity of the foundation, which has a length of 50 m, a width of 15 m, and a height of 18.7 m. This paper, as a part of the series, discusses tests on mechanical properties of concrete members affected by ASR. The purpose of the study is to investigate the influence of expansion rate by ASR, reinforcing ratio, specimen dimension on elastic modulus and compressive strength of concrete; to get appropriate input data for analysis model which is to be carried out to simulate actual behavior of the turbine foundation.

It has been recognized by some studies on relationships among expansion, strength, and elastic modulus that the restraint by rebars affects the characteristics of concrete.

2. TEST PLAN

2.1 TEST PARAMETER

ASR specimens, which were made with ASR concrete generating expansion, and normal ones, which were made with concrete without expansion, were tested under axial compressive load.

Test parameters were

Concrete (with or without ASR),
Curing conditions (the accelerated curing or normal curing condition),
Material age (3 ages according to expansion amount), and
Reinforcement ratio of main rebar (0%, 0.63%, or 1.27%).

The reinforcement ratio, 0.63%, targeted the ratio in the actual foundation. A material age was controlled to get an expansion amount similar to that in the actual foundation.

Table 1 shows the specimens, and Table 2 summarizes the test parameters.

Compressive tests were carried out on cylinder test pieces, core samples, and member specimens. The cylinder test piece had a diameter of 100 mm and a height of 200 mm.

The member specimens had nearly equal amount of rebars with actual turbine foundation. Figure 1 shows the dimension and rebar arrangement of the specimens.The member specimens,in some of which axial and shear reinforcing was arrnged,had the rectangular dimension with side-lengths of 300mm and a height of 600mm.

Figure 2 shows cored position for the core sample specimens in the beam model. The core samples,which had the same dimensions with the cylindder test pieces,were cored from reinforced concrete specimens with ASR to study the effect of release from rebar restraint. They were cored at each material age.

Table 1 list of specimen

specimen			number of specimen		
			age-1	age-2	age-3
normal concrete	cylinder		3	3	3
	core sample		—	3	—
	member	non-reinforced	—	3	—
		reinforced	—	3	—
ASR concrete	cylinder		3	3	3
	core sample		3	3	3
	member	non-reinforced	—	3	—
		reinforced-1	3	3	3
		reinforced-2	3	3	3

Each of the specimens consisted of concrete without ASR or concrete in which alkali was added to induce ASR. The ASR concrete specimens were, for over two months intermittently, cured in accelerated condition whose targets were 40 degrees centigrade and 100% of relative humidity. Eighteen cylinder test pieces, 12 core samples, and 27 member specimens were tested.

2.2 MATERIAL USED AND PROCUDURE FOLLOWED TO MAKE SPECIMENS

Table 3 shows concrete proportioning. Crushed sand and stone of andesite with reactivity were used as fine and coarse aggregate for both concrete with ASR and without ASR. Water-cement ratio was 60% equal to the ratio in the actual turbine foundation. Alkali was added only in concrete with ASR, which was to generate expansion by ASR. Table 4 shows material properties of the rebars used for the specimens.

Table 2 Test parameter and specimen

items	parameter	specimen
curing condition	1. standard curing 2. accerelated curing (temp.40℃、humidity100%)	cylinder specimen
material age	controlled by expansion by ASR 1. age 1(expansion 1000µin RC-1) 2. age 2(expansion 1500µin RC-1) 3. age 3(expansion 1500µin RC-2)	cylinder specimen core sample member specimen
reinforcement ratio	1. without reinforcement 2. 0.63%(RC-1) 3. 1.27%(RC-2)	member specimen

The forms were removed after two weeks from concrete placing and the specimens were cured, during six weeks after the placing, under “normal condition" meaning that they were covered with sheet to make them wet. After the six weeks, ASR specimens were cured under "accelerated condition", 40 degrees centigrade and 100% of relative humidity approximately in a curing room. The normal specimens, ones of concrete without ASR expansion, were cured continuously under the normal condition. Some of the ASR concrete cylinder test pieces were cured under the normal condition; some of the normal specimens were cured under the accelerated condition.

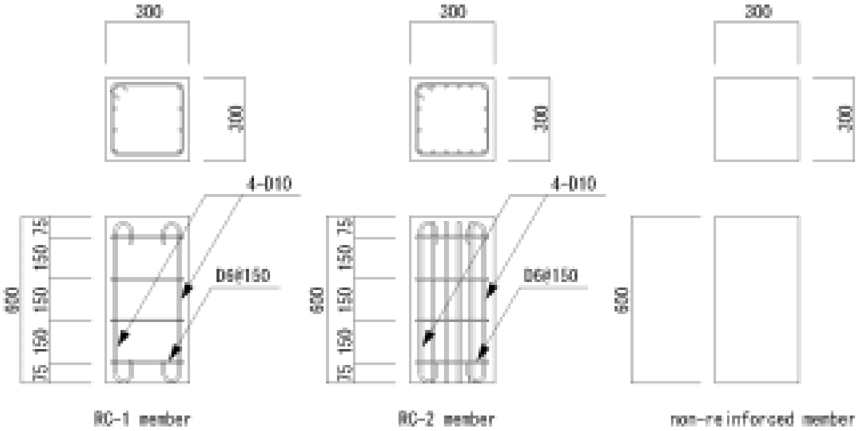

Fig. 1 dimension and rebar arrangement of member specimens

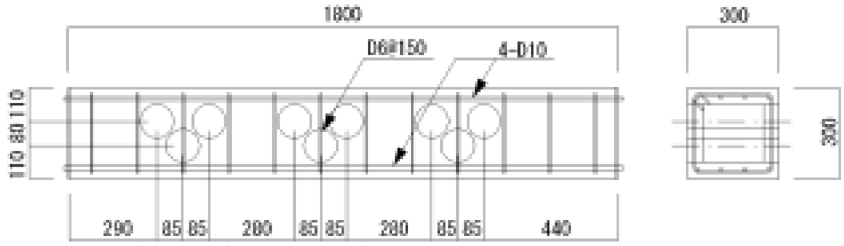

Fig.2 Cored position for core sample specimen

Table 3 Concrete proportioning

concrete type	unit weight of water (kg/m2)	volume(1/m^3)			surface dried weight(kg/m^3)			admixture		added alkali
			aggrigate			aggrigate				
		cement	fine	coarse	cement	fine	coarse	P70	SP-8S	NaOH
normal	176	93	319	372	293	845	990	C×0.26%		
ASR	176	93	319	372	293	845	990		C×2.2%	C×3%

Table 4 Mechanical properties of rebars

dia.	type	yield stress (N/mm^2)	ultimate strength (N/mm^2)	elongation (%)	elastic modulus (×10^{5}N/mm^2)
6mm(D6)	SD345	392	502	28.4	1.88
10mm(D10)	SD345	403	547	25.2	1.87
16mm(D16)	SD345	396	587	25.3	1.91

2.3 LOADING METHOD

Compressive tests were done on the core samples and the cylinder test pieces, whose strain was measured with compressometer.

Figure 3 shows the equipment for the compressive test of the member specimens. The compressive tests were carried out by a 10 MN universal testing machine. Strain of the specimens were measured with WSGs put on the center of the each of the four side faces of the specimen during the test.

3. TEST RESULTS
3.1 STRAIN AFTER QURING

Expansion during curing was measured continuously with wire strain gages (WSG) put on the rebars and periodically with contact strain gages(CSG) measuring the distance between gage points put on the surface of the specimens. Table 5 shows strain after curing.

Figure 4 and Figure 5 show relation between the reinforcement ratio and the main rebar strain and the axial strain of concrete respectively. The figures show that expansion is restrained more when rebar is arranged more. Plots of the axial strain versus the reinforcement ratio are located between the broken line and chain line in the Figure 4 and Figure 5. The lines, containing the plots, correspond to the following equation respectively with the gradients, a, of -400 and –600.

Expansion (μ) = a (reinforcement ratio %) + expansion of member specimen without rebar.

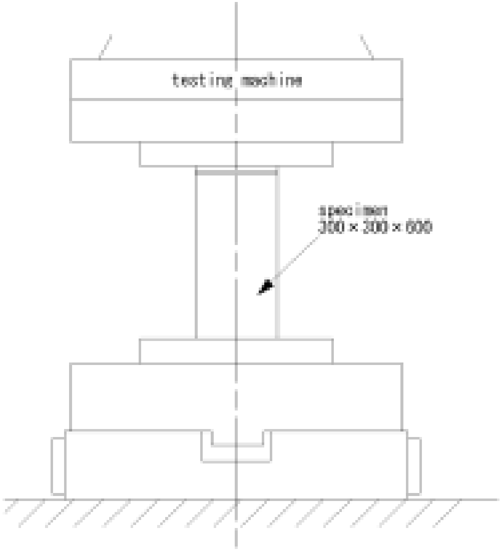

Fig.3 Loading equipment

Table 5 observed rebar and concrete strain caused by ASR

		strain after curing(μ)					
		age1		age2		age3	
		main rebar WSG	axial direc. CSG	main rebar WSG	axial direc. CSG	main rebar WSG	axial direc. CSG
cylinder		—	2041	—	3186	—	3203
core sample		704	623	1331	1270	1345	—
	non-reinforced	—	1255	—	2316	—	—
member	RC-1	961	1007	1437	1439	1506	1513
specimen	RC-2	633	787	965	1072	1091	1225

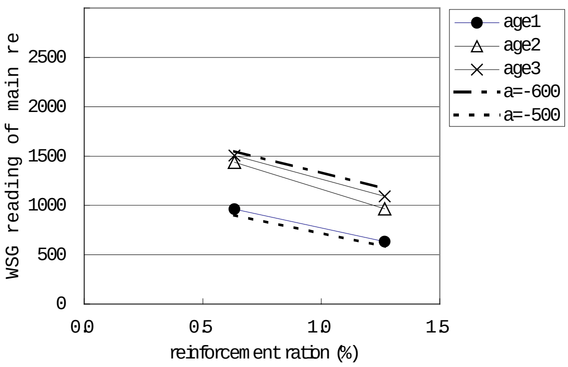

Fig.4 Relation between reinforcement ratio and rebar strain

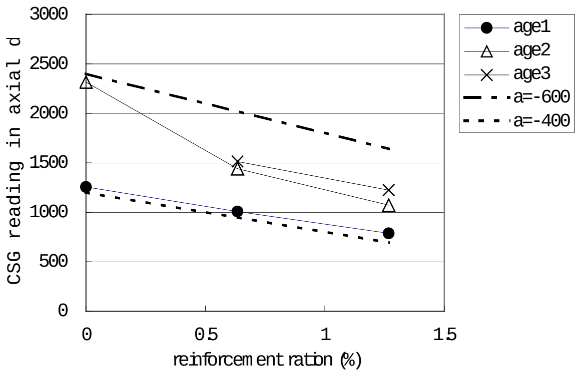

Fig.5 Relation between reinforcement ratio and axial strain of the members

3.2 Compressive strength and elastic modulus

Figure 6 and Figure 7 show relations between material age and compressive strength, elastic modulus respectively in the compression test of cylinder test pieces. It shows the results of the ASR concrete specimens cured under accelerated condition and normal condition and the ones of normal concrete specimens under the each of the condition.

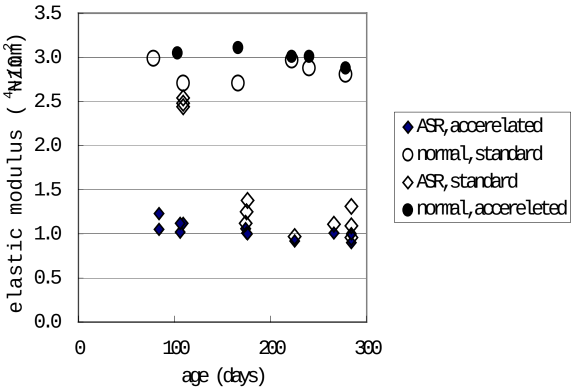

Fig.6 Relation between material age and compressive strength

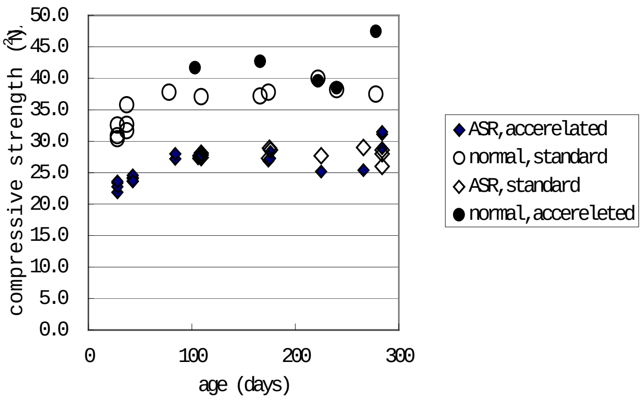

Fig.7 Relation between material age and elastic modulus

Compressive strength and elastic modulus of the ASR concrete specimens cured under the accelerated condition are smaller than that of normal concrete specimens cured under the normal condition. The difference of the elastic modulus is relatively large.

In case of the normal concrete specimens, the compressive strength of the specimens cured under the accelerated condition was as high as or higher than the strength under the normal condition. In case of the ASR concrete specimens, the difference of the compressive strength in the curing conditions was small. It resulted from that the increase of compressive strength due to the accelerated curing and the decrease due to ASR acted in the opposite directions with each other.

In case of the normal concrete specimens, the elastic modulus of the accelerated curing condition specimens was larger than that of the normal condition until the material age of 200 days. The difference got smaller after the age. In case of the ASR concrete specimens, the normal curing condition specimens showed slightly larger elastic modulus. It suggests that the effect on elastic modulus by ASR was larger than the effect by curing condition.

Table 7 summarizes the compressive strength and the elastic modulus of the normal concrete specimens, and their ratio to the value of core samples. Table 8 shows similar values of the ASR concrete specimens.

According to the test results of member specimens, larger reinforcement amount showed a tendency to get larger elastic modulus. The specimens with larger amount of reinforcement showed smaller expansion under curing.

Restraint by rebar probably made expansion small and prevented elastic modulus lowering due to ASR.

Comparison between the results of core samples and RC-1 member specimens, which has generally equal amount of reinforcement with the actual turbine foundation, showed the same tendency.

The compressive strength and elastic modulus of cylinder test pieces, member specimens, and core samples hardly decreased as the material age progressed.

In case of both compressive strength and elastic modulus, the ratio of each of normal concrete specimens to core samples was between 90% and 110%. In case of compressive strength of ASR concrete specimens, the ratio was similarly ranged near 100%, meaning that ASR did not have much effect. Elastic moduli of member specimens, which were affected by restrain due to rebar, were larger than the moduli of core samples, in which no rebar was arranged. Elastic modulus ratios of RC-1 member specimens to core samples ranged from 1.36 to 1.71; the same ratios of RC-2 member specimens ranged from 1.50 to 2.01. Elastic moduli lowering of core samples due to ASR was larger than one of member specimens, which were reinforced. Release from restraint by reinforcement probably made the lowering of elastic modulus large.

4. CONCLUSION

The results of the tests on a series of specimens lead us to the following conclusions.

The results obtained included data showing the effect of rebar amount on expansion by ASR, strength, and elastic modulus of the concrete. From the results of the member specimens, the specimens with more reinforcement ratio showed less expansion and larger elastic modulus. It is considered that restraint by rebars made the expansion small and restrained the drop of the elastic modulus by ASR. Rebar constraint showed the same tendency in the results of core samples compared with member specimens. The elastic moduli of core samples with ASR were smaller than the moduli of ASR member specimens that had the same reinforcement ratio with the specimen from which the core samples cored. From the results of the ASR concrete specimens, the compressive strength of the cylinder test pieces and the member specimens were not different from the strength of core samples by more than 10%. Restraint by rebars on ASR specimens did not affect much the compressive strength. The data helped to fix input material properties for the analyses representing actual foundation conditions.

Table 7 Test result (normal concrete)

age	specimen	compressive strength		elastic modulus	
		(N/mm^2)	ratio to core sample	($\times 10^4 N/mm^2$)	ratio to core sample
1	cylinder	37.1	-	2.71	-
2	cylinder	37.2	0.89	2.71	0.92
	non-reinforced member	39.7	0.95	2.84	0.96
	RC-1 member	35.7	0.85	3.20	1.08
	RC-2 member	—	—	—	—
	core sample	42.0	1.00	2.96	1.00
3	cylinder	37.5	-	2.81	-

Table 8 Test result (ASR concrete)

age	specimen	compressive strngth		elastic modulus	
		(N/mm^2)	ratio to core sample	($\times 10^4 N/mm^2$)	ratio to core sample
1	cylinder	27.4	0.98	1.12	1.05
	non-reinforced member	—	—	—	—
	RC-1 member	30.1	1.07	1.48	1.38
	RC-2 member	28.2	1.00	1.79	1.67
	core sample	28.1	1.00	1.07	1.00
2	cylinder	26.9	0.96	1.06	0.95
	non-reinforced member	24.9	0.89	1.35	1.22
	RC-1 member	28.8	1.03	1.51	1.36
	RC-2 member	30.8	1.10	1.67	1.50
	core sample	27.9	1.00	1.11	1.00
3	cylinder	28.9	1.09	1.00	1.01
	non-reinforced member	—	—	—	—
	RC-1 member	28.9	1.09	1.69	1.71
	RC-2 member	30.9	1.16	1.99	2.01
	core sample	26.6	1.00	0.99	1.00