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STUDY OF ALKALI–SILICA REACTION BY REINFORCED CONCRETE MODELS

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1. INTRODUCTION

Cylindorical reinforced concrete models with 2.0m, 1.0m, 0.5m and 0.3m in diameter and 2.0m, 1.4m, 1.0m and 0.5m in height, respectively, were made by ASR concrete and stored in 40℃ and 100%RH for 270 days, in 60℃ and 100%RH for 185 days then in the atmosphere for 1345 days. Most of models were made of normal portland cement and some were made of fly ash cement and blast furnace cement. Some models were stored in the atmosphere and one of them was sheltered. Strain measurement and crack observation have been made periodically.

This paper gives the informations on ASR observed from these concrete models.

2. MODELS

Table 1 shows the concrete models and their storing conditions. Table 2 shows the mix proportion of ASR concrete which is same as a bridge pier. The reactive aggregate used is Bronzite andesite and the fine aggregate used is not reactive. The alkali content of the ASR concrete was adjusted to be 6.14 kg/m³ by adding NaCl. The size and steel ratio of model A are same as the actual pier. The difference between the actual pier and the model A is the restraint at the top and the bottom. The top of the model A is free and the bottom is restrained only by the friction of the base concrete. The model C-1 was made of fly ash cement and the model C-2 was made of blast furnace cement. After stripped at the age of 5 days and cured in wet condition and 20℃ for 11 days, these models were stored in the specified conditions as shown in Table 1. Expansion of these models was measured periodically by strain gauge. Cores of 70mm in diameter and 150mm in length were drilled 3 times from the model A and the expansion of the cores was measured. The cores were stored in 20℃ and 100%RH until the expansion converged then moved into the room of 40℃ and 100%RH for measurement of the residual expansion.
The ultrasonic velocity of the models was also measured.

Table 1 Concrete models

<table>
<tr><th rowspan="3" colspan="2">Model NO.
(size)</th><th colspan="2">Longitudinal bar</th><th colspan="2">Hoop bar</th><th rowspan="3">Type of cement</th><th rowspan="3">Equivalent Na_2O
(kg/m³)</th><th colspan="3">Storing Condition</th></tr>
<tr><th rowspan="2">size</th><th rowspan="2">steel ratio (%)</th><th rowspan="2">size</th><th rowspan="2">steel ratio (%)</th><th>Stage 1</th><th>Stage 2</th><th>Stage 3</th></tr>
<tr><th>270days</th><th>185days</th><th>1345days</th></tr>
<tr><td colspan="2">A
(Diameter; φ 2.0m
Height ; h2.0m)</td><td>D32</td><td>0.92</td><td>D25</td><td>0.23</td><td>Normal portland cement</td><td>6.14</td><td>40℃ 100%RH</td><td>60℃ 100%RH</td><td>Atmosphere</td></tr>
<tr><td colspan="2">B
(φ :1.0m
h:1.4m)</td><td>D22</td><td>0.90</td><td>D16</td><td>0.20</td><td>Normal portland cement</td><td>6.14</td><td>40℃ 100%RH</td><td>60℃ 100%RH</td><td>Atmosphere</td></tr>
<tr><td rowspan="5">C
(φ :0.5m
h:1.0m)</td><td>C-1</td><td rowspan="5">D16</td><td rowspan="5">0.92</td><td rowspan="5">D16</td><td rowspan="5">0.24</td><td>Fly ash cement (30% replacement)</td><td>4.80</td><td rowspan="3">40℃ 100%RH</td><td rowspan="3">60℃ 100%RH</td><td rowspan="4">Atmosphere</td></tr>
<tr><td>C-2</td><td>Blast furnace cement (50% replacement)</td><td>4.24</td></tr>
<tr><td>C-3</td><td rowspan="3">Normal portland cement</td><td rowspan="3">6.14</td></tr>
<tr><td>C-4</td><td colspan="2">Atmosphere (sheltered)</td></tr>
<tr><td>C-5</td><td colspan="3">Atmosphere</td></tr>
<tr><td colspan="2">D
(φ :0.3m
h:0.5m)</td><td>D29</td><td>0.92</td><td>—</td><td>—</td><td>Normal portland cement</td><td>6.14</td><td>40℃ 100%RH</td><td>60℃ 100%RH</td><td>Atmosphere</td></tr>
</table>

Table 2 Mix proportion of concrete

Gmax (mm)	Slump (cm)	Air (%)	W/C (%)	S/a (%)	W (kg)	C (kg)	S (kg)	GR (kg)
20	8	4	55	41	191	345	745	1070 (GR/G=100%)

GR ; Reactive Aggregate

3. RESULTS

3.1 Cracking pattern and distribution of ultrasonic velocity

Figure 1 shows cracking pattern of model A and Figure 2 shows the distribution of ultrasonic velocity of each model. The cracks started from the top of the model and increased gradually. The cracks continuously developed also in the atmosphere. The ultrasonic velocity dropped also from the top of the model. These results indicate that deterioration by ASR starts from a free end, where restraint by reinforcement is relatively small.

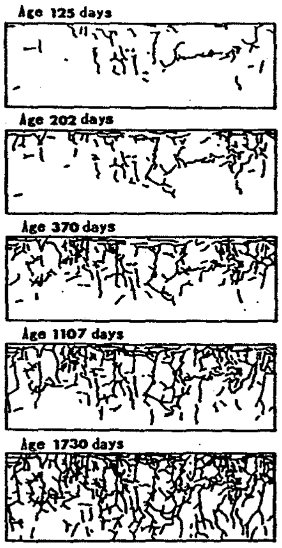


Figure 1 Cracking pattern of model A

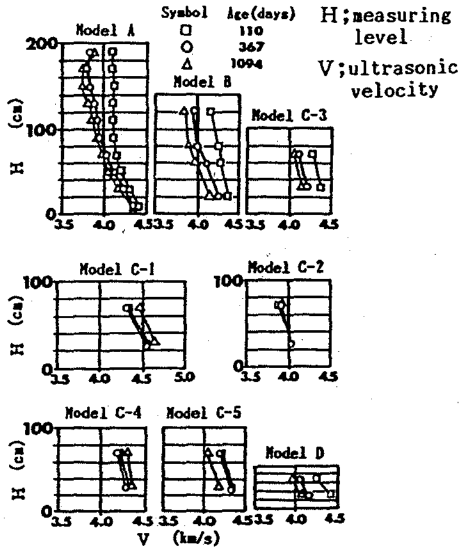


Figure 2 Ultrasonic velocity

3.2 Expansion of models

Figure 3 shows the expansion of model A, B, C-3 and D measured at the center. The expansion of model A, B and C-3 reached 500 to 600×10^{-6} under 40℃ and 100%RH then rather contraction occurred under 60℃ and 100%RH and successive atmospheric condition. Model D expanded only 200×10^{-6}. Figure 4 shows the expansion of model C-4 and C-5. The expansion of model C-3 was plotted again in the figure for comparison. Figure 5 shows the distribution of expansion in each model.

According to these results, following points are inferred.

(1) Expansion due to ASR depends upon the size of the structures.
(2) 40℃ and 100%RH is more severe condition than 60℃ and 100%RH for the reaction of Bronzite andesite.
(3) Atmospheric condition without initial accelerated condition might yield more ASR expansion as a whole.
(4) Cut of water supply delayed the reaction of Bronzite andesite.
(5) Expansion due to ASR occurs not only near the surface but also inside of the structure although cracking remains within the concrete cover.

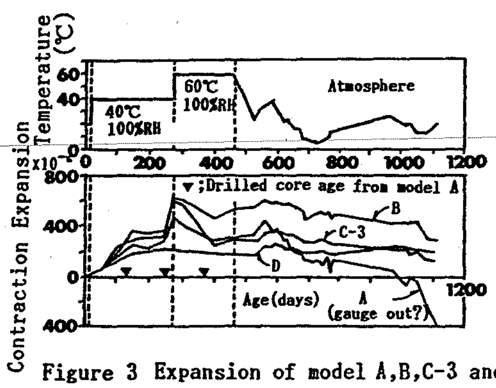


Figure 3 Expansion of model A,B,C-3 and D

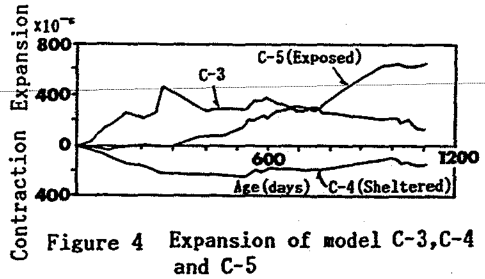


Figure 4 Expansion of model C-3,C-4 and C-5

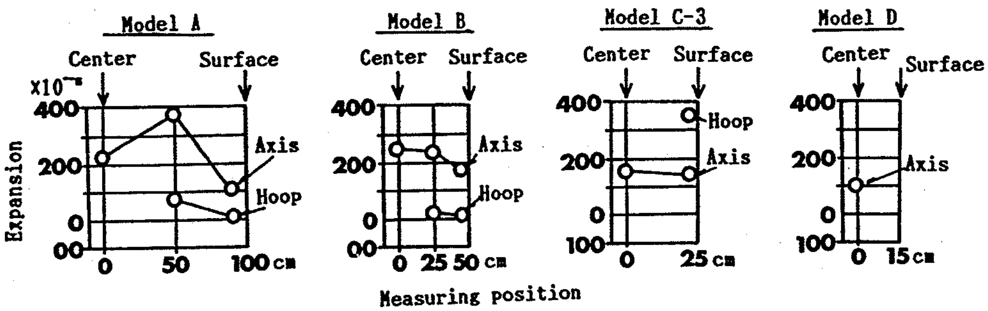


Figure 5 Distribution of the expansion in each model at the age of 3 months

3.3 Expansion of cores from model A

Figure 6 shows the expansion of cores drilled from the model A at 3 different age. Figure 7 shows the released expansion of the cores which is defined as the expansion occurred under 20℃ and 100%RH. In this figure, the expansion of the model A is also plotted. Figure 8 shows the residual expansion of the cores which is defined as the expansion occurred under 40℃ and 100%RH. In this figure, residual expansion of the model A is also plotted. This residual expansion was obtained by subtracting the expansion already occurred at the particular age from the total expansion converged at the age of 400 days.
Expansion in Figure 7 and 8 is the average expansion of cores from lower and upper part of the model A. Expansion measured near the surface of the model A was adopted as the expansion in Figure 7 and 8.

According to these results, expansion

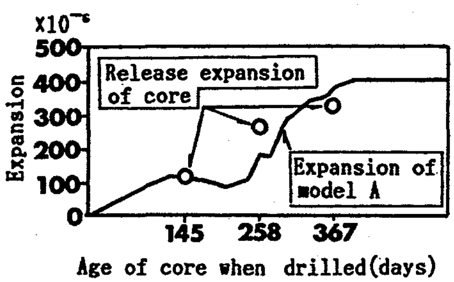


Figure 7 Released expansion

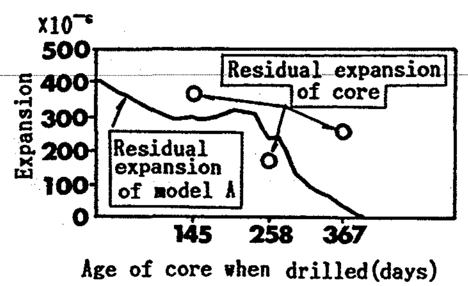


Figure 8 Residual expansion

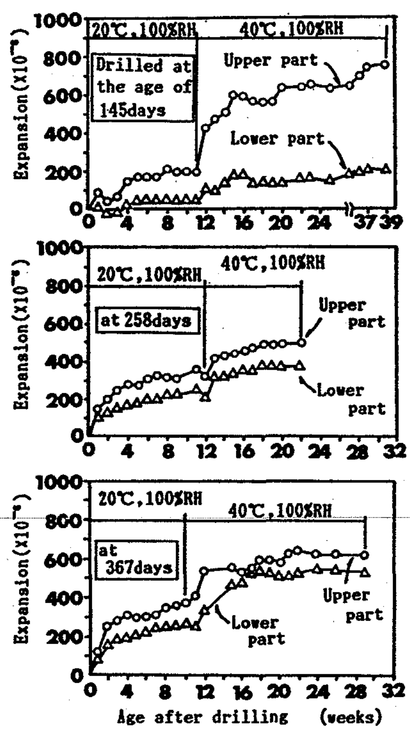


Figure 6 Expansion of cores from model A

of core drilled from a damaged structure due to ASR would provide good measure of the expansion of the structure and residual potential of the expansion.

3.4 Effect of fly ash and blast furnace cement

Figure 9 shows the expansion of the model C-1, C-2 and C-3. Figure 10 and 11 show these models at the age of 1000 days.

According to these results, the models made of fly ash cement and blast furnace cement expanded less than the model made of normal portland cement and no cracking appeared in these models. This test result indicates that the use of fly ash or blast furnace cement may protect ASR.

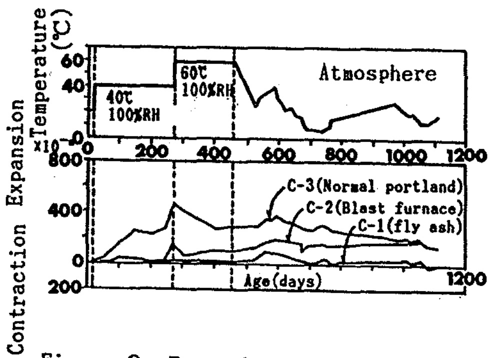


Figure 9 Expansion of the model C-1,C-2 and C-3

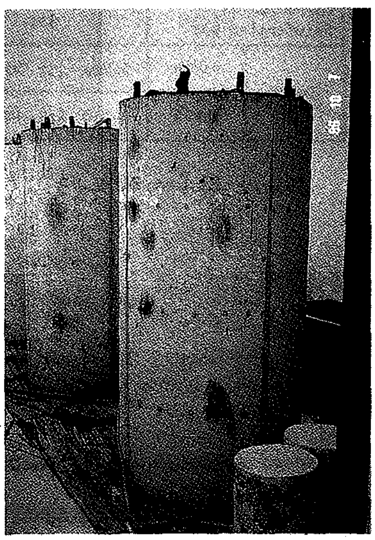


Figure 10 Model C-1 and C-2

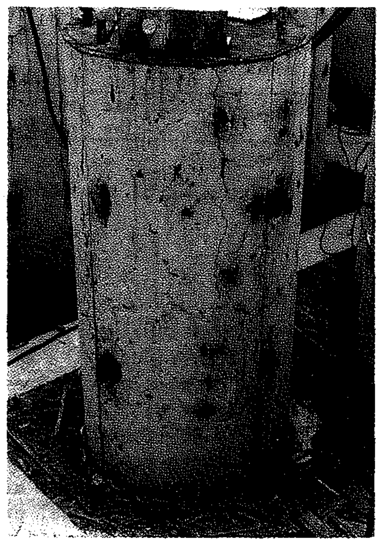
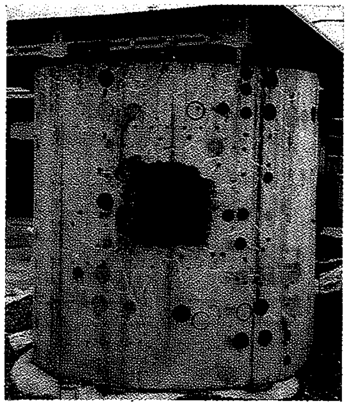


Figure 11 Model C-3

3.5 Comparison of the actual structure and model A

Figure 12 shows the cracking pattern of the model A and Figure 13 shows that of the damaged bridge pier. Cracking density of the pier was 7.1 m/m^2 and the maximum crack width and depth were 0.7mm and 9.1cm, respectively, at the age of 5 years. On the other hand, cracking density of the model was 6.6 m/m^2 and the maximum crack width was 1.6mm at the age of 5 years.

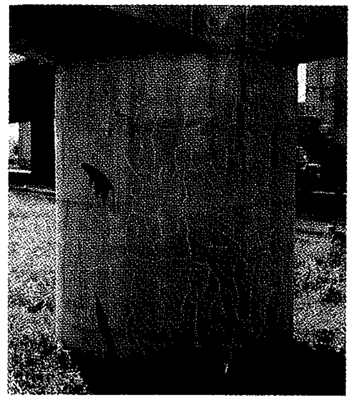
These results indicate that the model reproduced the ASR phenomena occurring in the actual pier ([1][2]).



Type of Structure		Columnar model (φ 2.0Xh2.0m)
Year of Construction		1984
Reactive Aggregate		Bronzite Andesite
Compressive Strength of core		322 kgf/cm² (at the age of 145days) 278 kgf/cm² (at 1year)
Corrosion of Reinforcing bar		Nil
Crack	width	0.3mm (at 1year) 1.6mm (at 5years)
	depth	3.7cm (at 1year) N.I. (at 5years)

N.I.;Not investigated

Figure 12 Cracking of the model A



Type of Structure		T-type pier (column φ 2.0Xh2.0m)
Year of Construction		1979
Reactive Aggregate		Bronzite Andesite
Compressive Strength of core		219 kgf/cm² (at the age of 5years)
Corrosion of Reinforcing bar		Nil
Crack	width	0.7mm (at 5years)
	depth	9.1cm (at 5years)

Figure 13 Cracking of bridge pier

4. CONCLUDING REMARKS

From the test, following results were obtained.

(1) The model reproduced the ASR phenomena of the actual bridge pier.
(2) Cracking started at the free end of each model, where restraint by reinforcement was relatively small.
(3) ASR of the sheltered model was delayed.
(4) Cracking depth was up to the concrete cover although expansion due to ASR was also occurring at the middle of the model.
(5) The released and residual expansion of core drilled from a damaged structure due to ASR would represent the expansion phenomena of the structure.
(6) ASR model made of fly ash cement or blast furnace cement did not expand so much and no cracking appeared in the model.

REFERENCES

[1] Okada, K., Ono, K., et al., Proceedings of Symposium on Alkali Aggregate Reaction, p.27-41, JSMS, 1985.

[2] Ono, K., Damages of Concrete Structures in Japan due to Alkali Aggregate Reaction, p50-56, Concrete Journal, 1986.