Study on Cracking Damage of a Concrete Structure Due to Alkali-Silica Reaction

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ABSTRACT

In 1982, a new type of cracking was found on the surface of concrete piers in Osaka, Japan. Various investigations have been carried out and the cause of cracking was determined to be alkali silica reaction. This paper introduces a part of the investigations and the characteristics of the reaction.

1. INTRODUCTION

Since 1982, many cracks with 1 to 5 mm in width have been observed on the concrete surface of several T shape piers of Hanshin Expressway in Osaka, Japan. Cracks in the pillars are mainly in the vertical direction and those in beam are mainly in the horizontal direction. Various investigations have been carried out to determine the cause of cracking. As a result, the cause of cracking was considered to be expansion of concrete due to so the called alkali aggregate reaction. This paper deals with the investigations performed on concrete cores obtained from the cracked piers. Since then, various concrete structures damaged by cracking due to alkali silica reaction have been recognized all over Japan. Figure 1 to 3 show some typical examples.

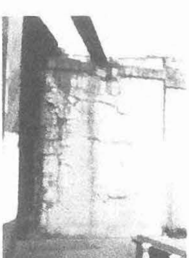

Figure 1

Figure 2

Figure 3

2. METHOD OF INVESTIGATION

The following investigations were made on concrete cores of 10cm in diameter and 25cm in length obtained from the beams of 9 piers.

(1) Measurement of expansion of concrete cores and observation of exuded gel.

Drilled cores were stored in a wet room at 20°C and the strains due to expansion were measured periodically until they converged. Then, these cores were placed in a room 40°C and 100% R.H. to obtain the residual expansion. At the same time, observation of gel exuded from the concrete surface was made.

(2) Test of aggregate

Mineralogication inspection identification of the rock types and ASTM C227 tests were performed on aggregates taken out from the cores by disintegrating them in HCl.

(3) Measurement of alkali and chlorine content in concrete

Alkali and chlorine contents of the concrete were measured by the hot water extraction method using samples prepared by pulverizing the cores.

(4) Observation and analysis of exuded gel

Observation of reaction rims around the reacted aggregates and of exuded gel were perfomed by optical microscope. Observation of the gel by SEM, analysis by EPMA and chemical analysis were made.

3. TEST RESULTS

3.1 Outlook and expansion of core

Figure 4 is a typical example of a reaction rim around a reacted aggregate particle in the core. While the core was stored in room at 20°C and 100%R.H., gel exuded gradually on the surface of the reactive aggregate. Figure 5 shows the typical example in which the gel is transparent and gelatinous. Figure 6 shows the expansion of the cores obtained from pier No.45 of which the beam is badly damaged. The maximum strain reached about 0.2%.

The relationships obtained between the maximum expansion at 20°C and 100%R.H. and at 40°C and 100%R.H. are shown in Figure 7. The result given in Figure 7 shows that residual expansion after storage at 40°C is generally low if a large expansion occurred during storage at 20°C. This is probably due to less unreacted material remaining in samples stored at 20°C and 100%R.H. which showed large expansions.

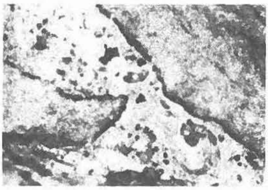

Figure 4 Reaction rim on surface of core

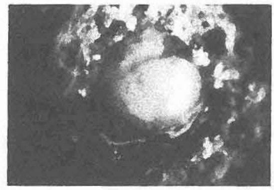

Figure 5 Exudation of Gel on reactive aggregate

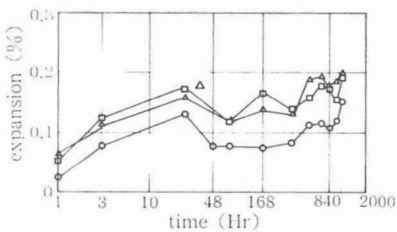

Figure 6 Typical core expansion

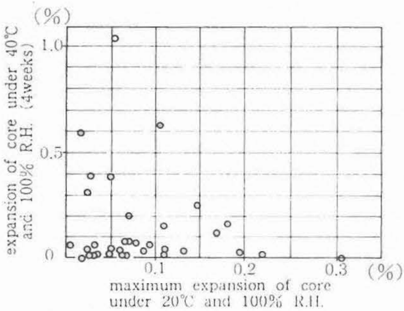

Figure 7 Comparison of maximum expansion of core

3.2 Mineralogical properties of the aggregate

The composition and grain size of the aggregates used in the concrete piers is shown in Figure 8. The rock types were labeled A,B,C and D.

Table 1 shows the results of mineralogical tests of Rock A,B,C an D by polarizing microscope and EDX. From these tests, cristobalite, and volcanic glass were detected in Rock A, C and D and these rocks were indentified as Bronzite andesite.

Rock B was Rhyolitic welded tuff. The existence of cristobalite was also confirmed by X ray diffraction analysis of Rock C. (Figure 9)

Motar bars tested according to ASTM C227 expanded by 0.05% with a cement with an alkali content of 0.95% Na_2O equivalent and by 0.18% with a cement with an alkali content of 1.95% Na_2O equivalent.

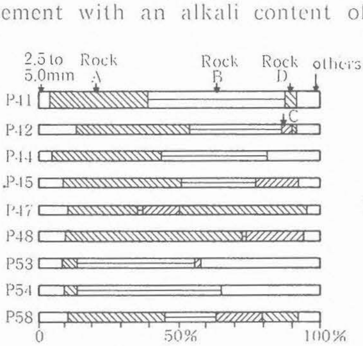

Figure 8 Rock constitution in the pier concrete

Table 1 Mineral constitution of aggregate rock

Mineral \ Rock	A Bronzite	B Rhyolitic welded tuff	C&D Bronzite andesite
Orthopyroxene	<10%	----	< 5%
Magnetite	< 1%	----	< 1%
Plagioclase	47%	small	37%
Alkalifeldspar	----	large	----
Silica minerals	----	Quartz	Cristobalite
Glass	53% H_2O rich	----	60% H_2O rich

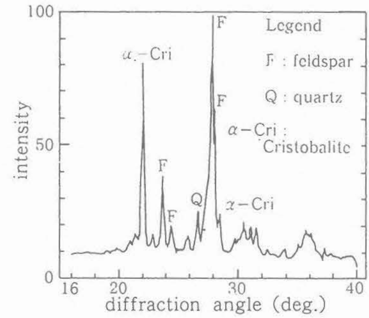

Figure 9
X ray diffraction
Analysis of Rock C

From these test results, Rock A, C and D were confirmed as reactive.

3.3 Alkali and chlorine in the concrete

Table 2 shows the content of water soluble alkali and chlorine in the concrete measured by the hotwater extraction method. From this test result, it is inferred that a considerable amount of alkali was introduced into the concrete by sea dredged sand since relatively large amount of chlorine was found in the concrete.

Table 2 Watersoluble alkali and chlorine in concrete by hot-water extraction method

Pier No	Na_2O(%)	K_2O(%)	$Na_2O+0.658K_2O$(%)	Cl(%)
P-41	0.16	0.16	0.27	0.048
P-42	0.18	0.16	0.29	0.072
P-44	0.16	0.13	0.25	0.060
P-45	0.19	0.16	0.30	0.086
P-47	0.18	0.15	0.28	0.058
P-48	0.20	0.14	0.29	0.080
P-53	0.12	0.12	0.20	0.045
P-54	0.11	0.12	0.19	0.046
P-58	0.22	0.17	0.33	0.095

3.4 Observation and analysis of exuded gel

Figure 10 shows SEM and the result of EPMA of the gel. Table 3 shows the chemical composition of the gel. The gel exuded on the surface of Bronzite andesite included fairly large amount of SiO_2 and relatively small amounts of Na_2O and K_2O.

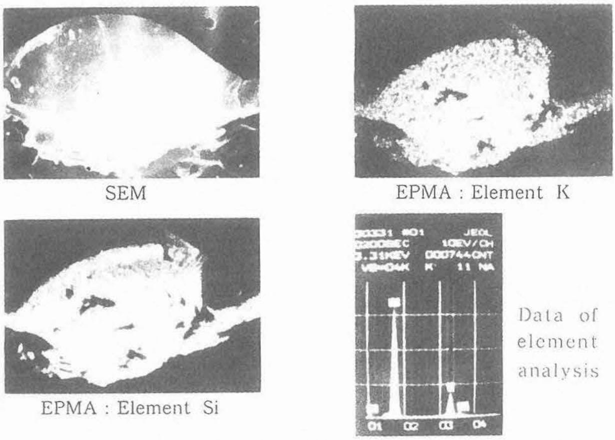

Figure 10 Figure of SEM and EPMA and data of element analysis

SiO_2	78.64
CaO	0.61
Na_2O	1.53
K_2O	2.24
Total	83.02

Table 3
Chemical composition of gel (%)

3.5 Factors affecting expansion of the core

Figure 11 shows the relationship between maximum expansion of of the core and the content of Rock A (plus 2.5 to 5 mm particle size). Figure 12 shcws the relationship between maximum expansion of the core and the water soluble alkali content. From these results, it was found that there existed pessimum with respect to expansion of concrete made of this reactive aggregate and that the pessimum for a mixture of Rock A plus 2.5 to 5mm size was about 55% and the pessimum for the content of water soluble alkali was about 0.29%.

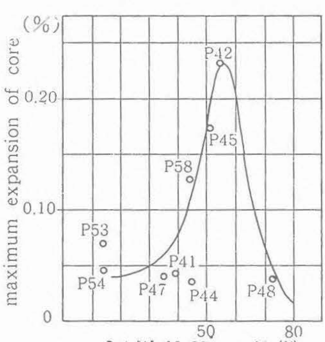

Figure 11 Relation between content of Rock "A"+2.5~5.0mm particle and core expansion

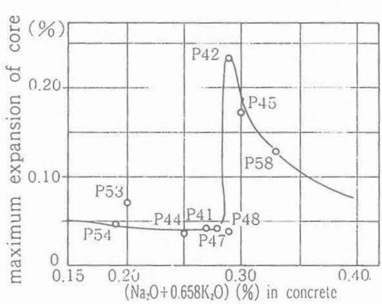

Figure 12 Relation between alkali content and core expansion

4. CONCLUDING REMARKS

The following results were obtained from the investigations on cores from cracked piers.

(1). The main cause of cracking was inferred to be alkali-aggregate reactivity.

(2). A significant amount of alkali was provided to the concrete by the cristobalite and volcanic glass in the aggregate.

(3). There existed a pessimum for Rock A of 2.5 to 5mm grain size and for water soluble alkali with respect to the expansion of concrete made with reactive aggregate.