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CONCRETE STRUCTURES DAMAGED BY ALKALI-SILICA REACTION

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1. INTRODUCTION

Alkali-aggregate reaction (AAR) had been believed not to occur in Japan. Since 1982 when AAR was recognized in a pier of a bridge, vigorous efforts have been made to detect damaged structures by AAR. As the results, remarkable number of damaged structures by AAR have been detected mainly in the area of southwest of Japan. This paper introduces the examples of the damaged structures and the results of investigations made for these structures.

2. METHOD OF INVESTIGATION

Damaged concrete structures were detected by inspection. Investigations were carried out mainly on core drilled from these structures. These investigations included measurement of core expansion at 40℃ and 100% RH, rock identification by mineralogical inspection, measurement of alkali and chlorine content, measurement of crack width and depth, checking of corrosion of reinforcing bars, compressive strength and Young's modulus of concrete.

3. RESULTS OF INVESTIGATION

3. 1 Damaged concrete structures

Figure 1 shows location of damaged structures investigated.
The investigations were carried out at 47 locations mainly in the southwest of Japan. Table 1 shows types of structures at these locations and Table 2 shows the construction time of these structures.

Figure 2 shows the production and usage of aggregate in Japan.
The appearance of AAR in Japan at late 1960 seems to be in accordance with rapidly increased usage of crushed stone due to the lack of river gravel and due to increased demand of aggregate for concrete, in addition to the increase of alkali content in concrete due to the increase of cement content by adoption of pump placing, due to the use of sea dredged sand and due to the increase of alkali content in cement itself. Most of the alkali aggregate reaction occurring in Japan was found to be alkali-silica reaction (ASR).

Figure 3 to Figure 11 show the examples of damaged structures. Figure 3 is a typical example of ASR cracks in a reinforced concrete beam. Main cracks are developing in the horizontal direction. This beam was repaired 4 years ago by an ordinary coating. These cracks include cracking of the coating itself. Figure 4 shows cracking in a bridge column where vertical cracks are developing. Figure 5 shows cracking in an abutment where map like cracks are developing. Figure 6 shows cracking in a retaining wall where horizontal cracking is dominant. Figure 7 is an example of irregular cracking in a sea defence without reinforcement. Figure 8 is an example of cracking in a building. Figure 9 shows cracking in steps where the axial cracking is dominant. Figure 10 shows an bridge pier. More cracks are developing at the unsheltered part since this part is exposed to direct sunshine and rain drop. Figure 11 is deformed parapet and cracks are also developing.

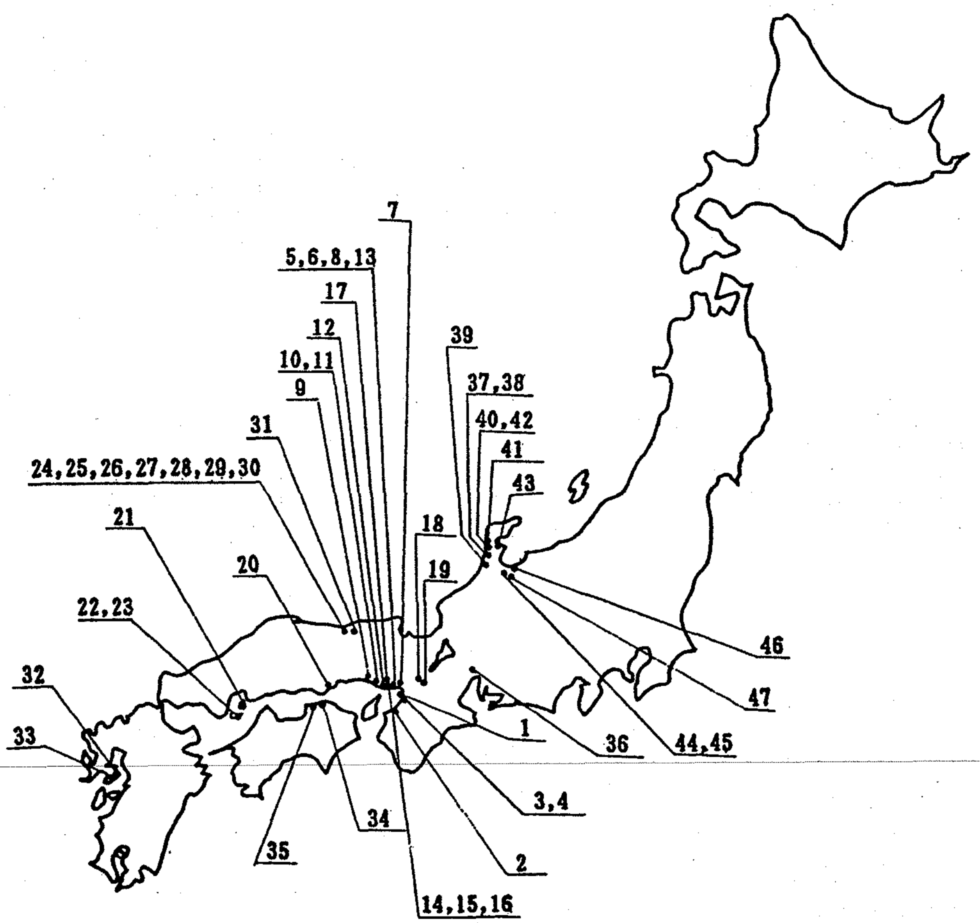

Figure 1 Locations of damaged structures

Table 1. Type of the damaged structures

Type of structure	Number of locations
Abutment Pier	28
Concrete defence Retaining wall	4
Tunnel Box culvert	5
Building	4
Others	6

Table 2. Construction time of the damaged structure

Construction	Number of locations
1966～1968	2
1969～1973	25
1974～1978	11
1979～1983	4
unknown	5

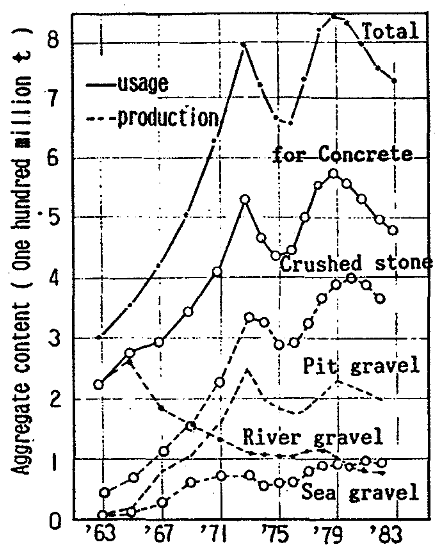

Figure 2 Production and usage of aggregate in Japan [1]

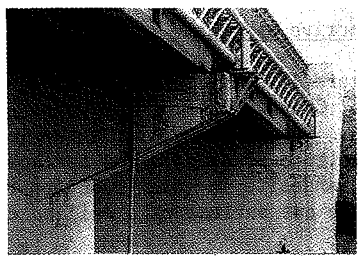

Figure 3 Pier

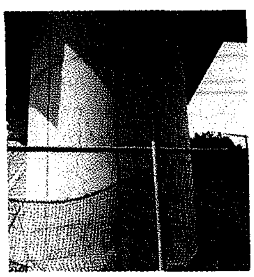

Figure 4 Column

Figure 5 Abutment

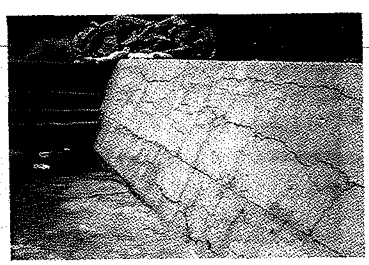

Figure 6 Retaining wall

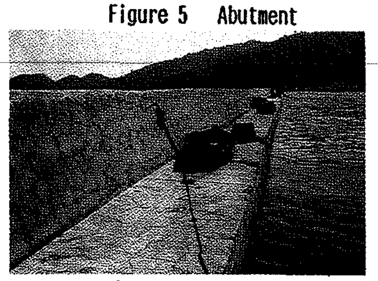

Figure 7 Sea defence

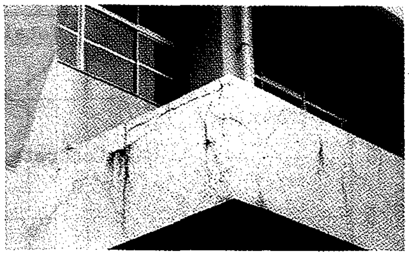

Figure 8 Building

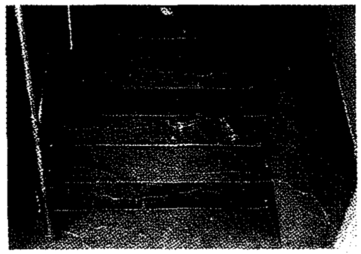

Figure 9 Steps

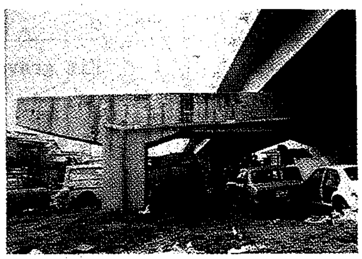

Figure 10 Pier

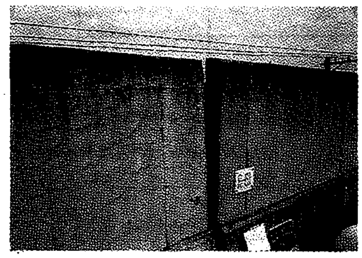

Figure 11 Parapet

3. 2 Reactive aggregate

Figure 12 shows reactive aggregate found in the investigations. Bronzite andesite, Chert, Slate, Tuff, Opal, etc. have been found in the damaged structures in Japan. Bronzite andesite seems to be the most popular reactive aggregate in Japan. Figure 13 shows a cut surface of core drilled from a damaged structure by Bronzite andesite in which reaction rims can be seem. Figure 14 shows the exuded gel at the cut surface of a drilled core.

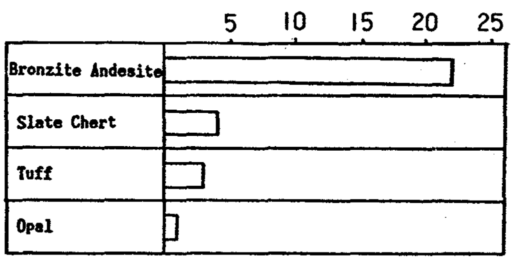

Figure 12 Reactive aggregate

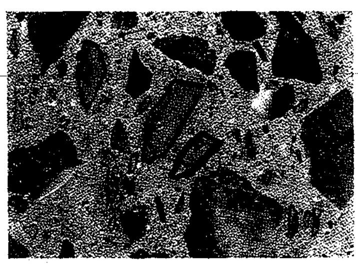

Figure 13 Reaction rim

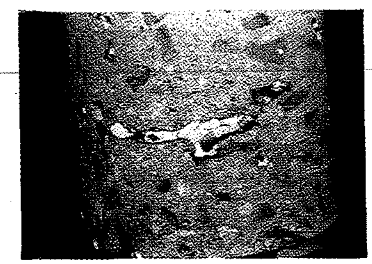

Figure 14 Exuded gel

3. 3 Expansion of core

Figure 15 shows the total and residual expansion of cores obtained at 21 locations among 47. The total expansion ranged from 160 to 2000X10^{-6} and the residual expansion ranges from 0 to 1400X10^{-6}. The average total expansion was 770X10^{-6} and the average residual expansion was 450X10^{-6}. It should be noted that some of the structures still have high potential of expansion even at the age of 15 years.

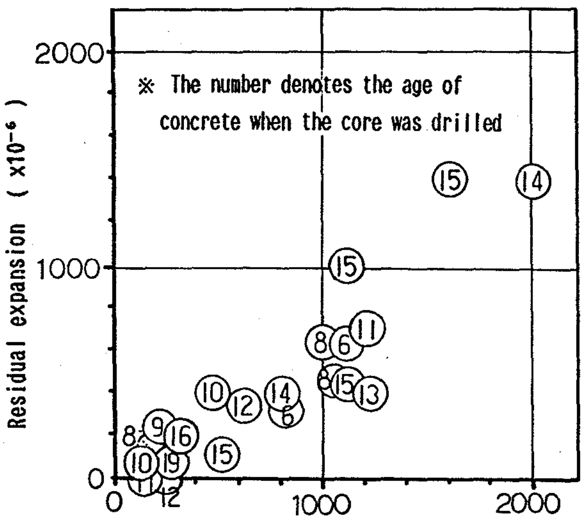

Figure 15 Expansion of cores

3. 4 Alkali and chlorine content in the concrete

Figure 16 shows the amount of water soluble Na_2Oeq obtained from cores. The alkali content ranged 3.5 to 8.6kg/m³ and the average value was 5.7kg/m³. According to the measurement of $C\ell^-$ in the concrete, about 1.2kg/m³ of alkali was estimated to be supplied by the sea dredged sand.

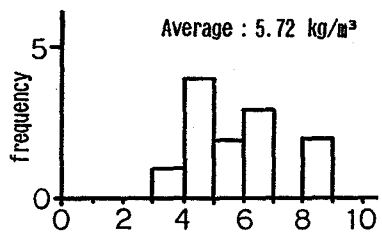

Figure 16 The amount of water soluble Na_2 O eq

3. 5 State of the damaged structures

Figure 17 shows the relation between the width and depth of crack due to ASR. According to these results, there is a tendency that wider cracks are deeper. Although some cracks reached beyond the reinforcing bar, the crack depth in most of the reinforced concrete structures remained within a range of the concrete cover.

Figure 18 shows the compressive strength and Young's modulus of cores. These results indicate that loss of the compressive strength occurs in ASR concrete. These results also indicate that Young's modulus of reacted concrete is very low. However, Young's modulus back-analized from the deflection of the beam was not so low [2]. The low Young's modulus measured by the core may be due to release of restriction existed in the structure. However, the gap has not been clearly understood.

According to the investigation of reinforcing bars by the half cell potential method and direct observation, reinforcing bars in damaged concrete structures in Japan due to ASR are still in good condition.

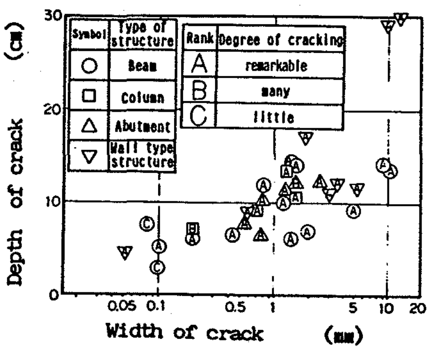

Figure 17 Relation between crack width and depth

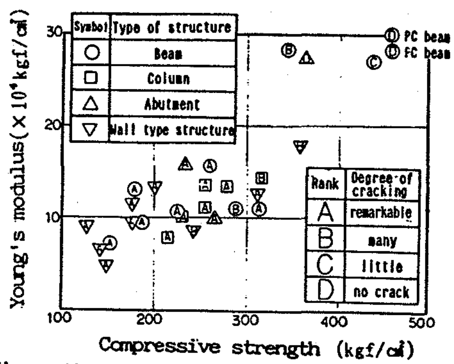

Figure 18 Compressive strength and Young's modulus of drilled cores

4 . CONCLUDING REMARKS

From the investigation, following points have been found;

(1) Most of alkali-aggregate reaction occurring in Japan is alkali silica reaction.
(2) ASR in Japan is generally caused by aggregate rather than sand.
(3) The main reactive aggregate found in the investigation is Bronzite andesite, Chert and Slate.
(4) Reactive aggregate found in damaged structures was generelly crushed stone rather than river gravel.
(5) Most of the damaged structures by ASR were constructed after the late 1960.
(6) There was a tendency that wider crack was deeper. However, most of the cracks in reinforced concrete structures remained within a range of the concrete cover.
(7) Corrosion of steel in ASR concrete have not advanced yet.
(8) Compressive strength measured by drilled core indicated that it could be lowered by ASR.
(9) Young's modulus measured by drilled core was very low. However the back analized value obtained by direct loading test to the structure was not so low. The low rated Young's modulus obtained from the core is probably due to release of restriction existed in the structure. The gap of Young's modulus depending on the evaluation method should be taken into account when assessment of a structure damaged by ASR is done by the loss of rigidity.

REFERENCES

[1] The production and usage of aggregate in Japan, The ministry of International Trade and Industry, 1983.

[2] A loading test on the beam of Hanshin Express Way, a report by Hanshin Kosoku Corporation and Ohtori Consultant, PP.1~58, August, 1981.