Present Situation of Alkali-Aggregate Reaction in Japan

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ABSTRACT

Recently the number of cases of damage caused by alkali silica reaction (ASR) is rapidly increasing in Japan. This paper reports the practical aspects on ASR problems including the reasons for increasing ASR damage.

The abstract of guidelines for maintenance inspection and prevention of ASR in new construction recommended tentatively by the Ministry of Construction is also briefly explained.

HISTORICAL ASPECTS

In Japan, alkali aggregate reaction (AAR) was first identified as a decisive cause of extensive cracking in concrete structures in 1950s. At that time, the alkali reactivity was evaluated in approximately 100 kinds of river aggregates by means of the Chemical Method and Mortar Bar Method, but only two kinds chert and shale were found to be potentially deleterious. In 1965, another paper reported the deterioration of a part of parapet of a reinforced concrete building that was built approximately 35 years before. The cause of deterioration was also confirmed to be due to AAR between alkalies and andesite aggregate containing much tridymite. For many years, no information concerning AAR was available in Japan except for the above examples.

Since 1982, however, the number of cases of damage caused by expansive cracking, that can be not explained by the common causes of cracking, have been increasing. Comprehensive studies based on the ASTM Tests, X-ray diffraction

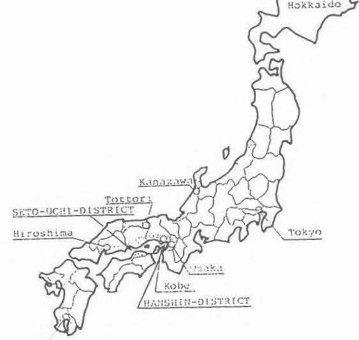

Fig. 1
The observed areas of cracking damage to concrete structures due to alkali aggregate reaction in Japan

analysis, microscopic examination and expansion measurements on drilled concrete cores, etc. indicated that the damage was due to alkali silica reaction (ASR), the most common form of reaction.

Typical regions where ASR attack was found in Japan are shown schematically in **Fig. 1.**

REASONS FOR INCREASING ASR DAMAGE

The possible reasons for increasing damage due to ASR in Japan can be explained as follows:

i) Many kinds of crushed rocks without a service record are being widely used, mainly, as the coarse aggregate, because of a lack of commonly used river aggregates due to the vast of demand for concrete. However, the types of reactive rocks in Japan are limited, at present, to andesites, cherts and slates.

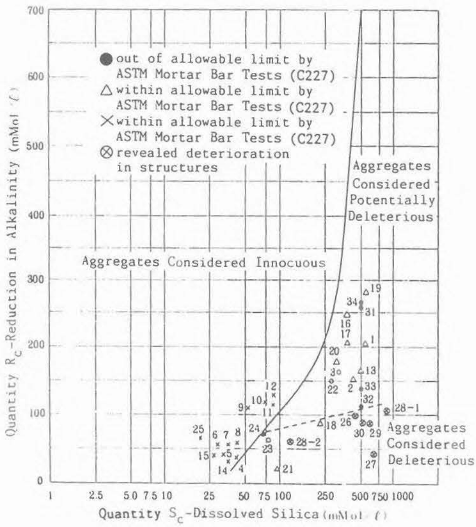

Fig. 2 Results of ASTM C289 on some aggregates in Japan

In **Fig. 2** are shown some types of rocks for concrete aggregates together with the results of ASTM Tests (C227 and C289).

ii) The use of sea sand is increasing significantly as a replacement for commonly used river sand, resulting in increase of alkali level in concrete.

iii) Cement content tends to be increasing, partially, in response to the Japan Industrial Standards (JIS) for ready mixed concrete.

CHARACTERISTICS OF DETERIORATION

Characteristics of deterioration due to ASR attack in concrete made with bronzite andesite aggregates, the typical reactive rock in Japan, are as follows.

1. External appearance

i) Pattern of cracks: Relatively wide cracks tend to run parallel to the main reinforcing bars when the expansive force due to ASR is restrained, for example, by a large amount of reinforcement, while random pattern cracking is typically observed in unrestrained or extremely low reinforced concrete. The relative dislocation can be often observed between two adjacent planes bounded by the ASR crack.

ii) Location of cracks: Parts of structures in which cracking is most prevalent are those exposed to falling rain or leaking drainage.

iii) Deformation: Shifting of members with respect to others frequently occurs because of expansion joints closed due to ASR; the concrete at the joints is sometimes broken by excessive expansive forces.

2. Ultrasonic pulse velocity

i) Structures: The pulse velocity (V) measured directly on the deteriorated structures is, in general, less than 3.5km/s, although can be as low as 1∿2km/s in the most severely damaged cases.

ii) Drilled cores: The value of V measured in drilled concrete cores tends to be somewhat higher than in structures, because the former usually contain no large defects. It is suggested from the field examinations that there may be some possibility of deterioration when $V \leqq 4.0$km/s, while the probability is high when $3.0\text{km/s} < V < 3.7\text{km/s}$.

3. Usual signs of distress observed on drilled cores

i) Gel deposits: Gelatinous gels are extruded within several days on cores which are stored after drilling at 20℃ and 100%RH.

ii) Reaction rims: Reaction rims are formed around the reactive aggregate grains.

iii) Length change: Cores from affected concrete structures show an expansive strain exceeding, in most cases, more than 500×10^{-6} when stored at 20℃ and 100%RH for about 5 weeks or so.

iv) Elastic modulus: Elastic modulus of deteriorated cores may be 30∿50% of that of sound ones. The reduction in elastic modulus caused by ASR is more marked than the reduction in compressive strength.

v) Detailed examinations

(a) Gel is found to be an alkali-silicate compound by the chemical analysis or X-ray diffraction analysis.

(b) Aggregate is confirmed to be reactive by the ASTM C289 and C227 Tests, and also is found to contain reactive silica by X-ray diffraction and microscopic examination.

(c) Affected concrete contains much of Na_2O and K_2O.

MAINTENANCE INSPECTION AND EVALUATION OF AFFECTED CONCRETE STRUCTURES

Effective maintenance inspection and evaluation of structures affected by ASR are being extensively carried out by the public organizations in Japan. An example of guidelines, tentatively recommended by Hanshin Expressway Public Corporation is shown in **Fig. 3.**

1. Structures to be inspected with care are:

i) Reinforced concrete with total length of cracks (width≧0.3mm) exceeding 30m and prestressed concrete with that (width≧0.2mm) exceeding 20m, and

ii) Those structures with wider expansive cracks in local portions.

2. Inspections of ASR are made by:

i) Measuring expansion ($\varepsilon_1+\varepsilon_2$) of drilled core of dia. 75mm : ε_1 is the expansion under the condition of (20°C, 100%RH) for about 5 weeks after drilling, and ε_2 is that under the accelerated conditions of (40°C, 100%RH) for about 10 weeks.

ii) Observing exudation of gel on the external surfaces of drilled core.

iii) Identifying aggregate minerals by the X-ray diffraction analysis or polarization microscope.

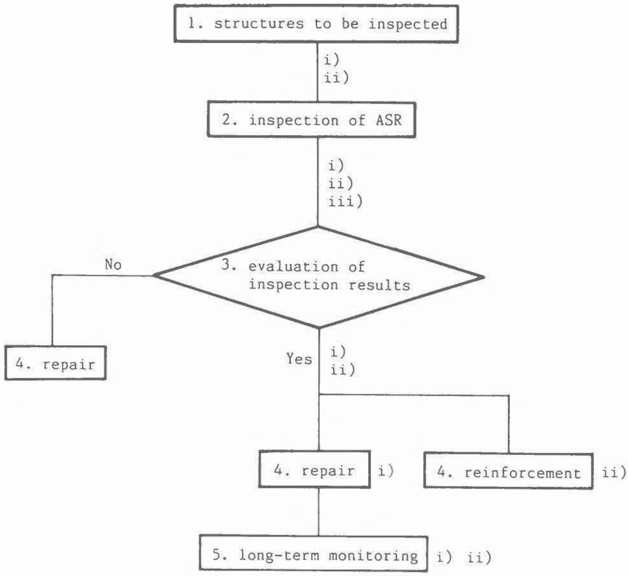

Fig. 3 Maintenance inspection and evaluation methods of affected structures

3. Evaluation of Inspection Results is performed as follows:

In each of following two cases, the structures should be considered for repairing or strengthening ("Yes" in Fig. 3).

i) Total expansion ($\varepsilon_1+\varepsilon_2$) of the core (dia.:75mm, length:150mm) reaches 1000×10^{-6} or more together with exudation gel,

ii) Total crack length as defined in 1.-i) reaches 100m or more together with exudation of gel.

4. Repair or Reinforcement should be done in case of "Yes" in **Fig. 3**.

i) Repair: Injecting epoxy resin into cracks and coating with epoxy resin after stopping water leakage at the joints,

ii) Reinforcement: adding strengthening steel when a high possibility of damage to steel bars can be expected.

Satisfactory amelioration can be expected merely with epoxy resin coating when "No" in **Fig. 3**.

5. Long-term monitoring after repair or strengthening is to be carried out by:

i) Measuring change of crack width,

ii) Measuring change of pulse velocity.

PREVENTION OF ASR IN NEW CONSTRUCTION

It is confirmed that deterioration of concrete due to ASR will occur only when the following three conditions are met simultaneously:

- sufficient alkaline solution in the concrete pore solution,
- aggregate susceptible to attack by the above alkaline solution,
- sufficient supply of water.

Based on this standpoint, practical countermeasures for preventing or minimizing ASR attack caused by typical reactive aggregates used in Japan, as well as the testing methods for reactivity of aggregates, are being investigated by both of the engineering societies and public organizations.

One or more of the following measures should be taken for preventing ASR in new concrete structures, according to the tentative recommendations proposed by, for instance, Ministry of Construction.

i) Use of aggregates considered innocuous by means of either the Chemical Method or the Mortar Bar Method

Reactivity of deleterious aggregates based on the expansion measurement of mortar bars can be significantly affected by alkali content in the mortar, although the alkali content is not stipulated in the ASTM Mortar Bar Method. On the other hand, it is recommended in this tentative plan that the total alkali content (Na_2Oeq) shall be adjusted to be 1.2±0.05% by using NaOH aqueous, and that the expansion shall be measured on the 40×40×160mm mortar specimens using a dial gauge according to the JIS A 1129. Extensive tests done by the joint committee of Japan Society of Materials Science and Hanshin Expressway Public Corporation also indicated that the Mortar Bar Method modified with Na_2Oeq of 1.2% could predict conservatively the possibility of expansive cracking of concrete made with the bronzite andesite aggregate.

ii) Use of low-alkali (less than 0.6% equivalent Na_2O) portland cement

The use of portland cement with a low-alkali content of $Na_2Oeq \leq 0.6\%$ conforming to JIS R 6501 is accepted as the best means of minimizing the risk of damage due to ASR.

iii) Use of appropriate blended cement or admixtures

Use of blastfurnace slag cement of Type B or Type C with slag contents of 30∿60% and 60∿70% respectively or replacing part of the portland cement by appropriate admixtures is accepted as one of practical means of reducing ASR.

iv) Control of total alkali content in concrete

It is suggested in West Germany and United Kingdom that the ASR attack can be effectively prevented by limiting total alkali content (Na_2Oeq) to $3kg/m^3$ or less in concrete. Extensive tests in Japan also confirmed that expansion due to ASR would not occur in concrete when total alkali was less than $4∿5kg/m^3$. Based on these considerations, the tentative plan recommends that the total alkali content of the concrete mix shall not exceed 3kg of Na_2Oeq per cubic meter when portland cement is used.

CONCLUDING REMARKS

Recently the number of reinforced and prestressed concrete structures damaged by alkali aggregate reaction, in particular, alkali silica reaction (ASR), is rapidly increasing, although for many years few cases of ASR attack were found in Japan.

Practical aspects on the ASR problems in Japan were briefly described in this paper. Prompt and practical testing methods for identifying reactivity of aggregates in actual concrete, evaluating methods for structural soundness and successful repair methods for damaged concrete structures due to ASR attack can be expected to be established in the near future through systematic laboratory-investigation and field-tests.