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FIELD AAR INSPECTION FOR THE FOUR HARBORS IN TAIWAN

Chau Lee
Department of Civil Engineering, National Central University,
Chung Li, Taiwan 32054

Shu-Wang Sheu
Office of Sci. & Tech. Advisors
Ministry of Transportation & Communications
Taipei, Taiwan

Kuei-Ching Chen, Jeng-Long Ko, and Cliff C. Rau
Harbor Engineering Material Division
Institute of Harbor and Marine Technology, Ministry of Transportation
Wu-Chi, Taichung, Taiwan

ABSTRACT

Structures in the four harbors in Taiwan were inspected for alkali-aggregate reaction (AAR). Visual investigation, non-destructive tests and drilling cores were performed in the field. Petrographic examination, accelerated expansion tests, and SEM analysis of the concrete cores were conducted in the laboratory. The reactivity of the aggregates currently used in concrete construction and the alkali content of local cements were investigated for evaluating the potential of AAR in the future. Results showed that the embankments and blocks in Hwa-Lian Harbor as well as the blocks in Keelung Harbor appeared to be affected by AAR. No evidence of AAR was found in Taichung and Su-Au Harbors. The reactivity of the aggregates from several sources showed deleterious or potentially deleterious for AAR. Most of the local cements contain high alkali content.

Keywords: Alkali-aggregate reaction, concrete structures in harbor, cracking, expansion.

INTRODUCTION

Since good aggregate is limited in Taiwan, marginal aggregate has to be used in future construction of concrete structures. Deleterious and potentially deleterious reactive aggregates have been found in this island (Wang and Yang 1991, and Yen et al. 1996). The alkali content in most commercial cements exceeds 0.6% eq. Na_2O as required by ASTM C150 for low alkali cement. Thus, the occurrence of alkali-aggregate reaction (AAR) is possible if the environment is suitable for promoting the expansion.

The harbor concrete structures are in the environment containing saline water and high humidity, which are aggressive for AAR. Therefore, the purpose of this study was to investigate the potential for AAR in the concrete structures in Keelung, Su-Au, Hwa-Lian, and Taichung Harbors, which are four of the five harbors in Taiwan. The locations of the five harbors are shown in Fig. 1. This paper reports results of field inspection including visual examination of AAR, and non-destructive tests. Results of petrographic examination, scanning electron microscopy, and accelerated expansion tests of the cores taken from the field are reported. The reactivity of the aggregates from the possible sources used in the four harbors and the alkali content in local cements have also been studied.

Fig. 1: Locations of the five harbors in Taiwan

EXPERIMENTAL PROCEDURES

Field Investigation

Field investigation included visual inspection, non-destructive tests and drilling concrete cores. Visual inspection emphasized on the major symptoms of AAR, map cracking and the reaction products exuded on the concrete surface. Non-destructive tests were for evaluation of general quality of the concrete, which included rebound hammer test, carbonation depth measurement, and concrete resistance test. Concrete cores with 10cm in diameter and about 30cm in length were drilled for further studies of AAR in the laboratory. The cores were drilled on the concrete surface showed AAR symptoms, or drilled every 300 meters on the surface of embankments and blocks if no AAR symptom was found. Four to six cores were taken at each selected position.

Laboratory Analysis

Petrographic examination, compressive strength measurements, scanning electron microscopy (SEM), and accelerated expansion tests were conducted in the laboratory for the cores taken from the four harbors. The concrete cores were first cut for the required tests. Sliced cores were used for petrographic examination. Cores 20cm in length were for compressive strength measurements, and the broken pieces were used for SEM analysis. The paired cores left were for accelerated expansion tests.

Accelerated expansion tests (Shayan and Morris 1997) were used to evaluate the potential of future expansion for the concrete in aggressive environments. The cores obtained from the same drilling position were made pairs. The cores were trimmed to the length depending on the result of drilling, and were fitted with four sets of two demec discs, in opposite positions, at 20 or 15cm gauge length depending on the core length. All the cores were soaked in 1N NaOH solution at room temperature for 1 day, to allow the core to absorb water and increase the alkali concentration in the pore solution of the concrete. After 1 day of soaking in the NaOH solution, the initial lengths of the cores were measured. One of the paired cores was placed in a sealed container over water at 38°C. The other core was kept in the 1N NaOH solution in sealed conditions and also stored at 38°C. The length changes of the cores were monitored regularly, and the average of the four readings on each core recorded.

Reactivity of Aggregates

To evaluate the potential of AAR for future construction of concrete structures, the reactivity of the aggregates obtained from the potential sources for the four harbors was studied according to ASTM C289.

RESULTS AND DISCUSSION

Visual Inspection

Table 1 shows the results of AAR symptoms in the visual inspection of the four harbors. There are no significant AAR symptoms found in Taichung Harbor and Su-Au Harbor, built since 1972 and 1974, respectively. However, map cracking and gel like reaction products were found on the surface of embankments and blocks in Keelung Harbor and in Hwa-Lian Harbor, as shown in Fig. 2 and Fig. 3, respectively. The cracked blocks in Keelung Harbor were constructed since 1987, and the cracked embankments and blocks in Hwa-Lian Harbor were built in the periods of 1980 to 1988. The damaged concrete seemed to depend on the construction projects by different contractors because reactive aggregates and high alkali cement might be used in the concrete. The cracked concrete structures were in the zone with high humidity or in the tidal zone. No significant AAR symptoms were found on the concrete surface of buildings and pavements in the four harbors.

TABLE 1: Results of Visual Inspection for Symptoms of AAR in the Four Harbors

Harbor / Structure	Taicuung	Keelung	Su-Au	Hwa-Lian
Building	none	none	none	none
pavement	none	none	none	none
Embankment	none	none	none	map-cracking and gels
Block	none	map-cracking and gels	none	map-cracking and gels

Non Destructive Tests and Core Strength Measurements

Evaluations of concrete qualities for the blocks and the embankments in the four harbors were conducted through field non-destructive tests and core strength measurements. The results are presented in Table 2. The concrete qualities varied with the positions where tests were conducted. In general, most of the concrete structures are still in good condition, except the strength of some concrete is below the design strength.

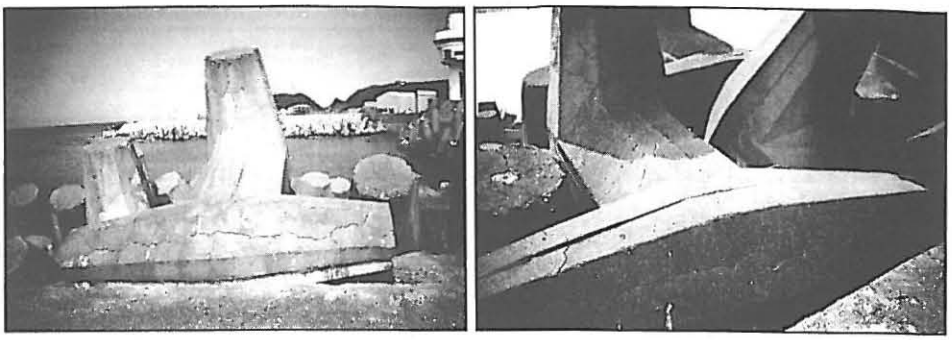

Fig. 2: Map cracking on the concrete blocks in Keelung Harbor

Fig. 3: Map cracking on the concrete blocks and on the embankment in Hwa-Lian Harbor

TABLE 2: Results of Field Non-destructive Tests and Core Strength Measurements

Test items \ Harbor		Taichung	Keelung	Su-Au	Hwa-Lian
Test hammer	Reading	28~40	27~37	22~37	26~44
	Strength (kg/cm^2)	180~351	167~306	108~306	154~416
Concrete resistance (kΩ-cm)		4~18	5~22	4~15	4~20
Carbonation depth (mm)		1~5	1~5	1~5	1~8
Core strength (kg/cm^2)		212~348	167~418	289~305	240~407

Petrographic Examination

Results of petrographic examination of the aggregates in the concrete cores obtained from the four harbors are listed in table 3.

TABLE 3: Results of Petrographic Examination for the Aggregates in Cored Samples

Harbors	Aggregates
Taichung	Sandstone, Quartzite, Metamorphic Sandstone, Slate, Vein-quartz.
Keelung	Sandstone, Quartzite, Metamorphic Sandstone, Vein-quartz, Siliceous Sandstone, Silt Stone
Su-Au	Sandstone, Quartzite, Metamorphic sandstone, Vein-quartz, Slate.
Hwa-Lian	Quartzite, Sandstone, Quartz-schist, Marble, Schist, Vein-quartz, Serpentine, Andesite, Gneiss, Limestone, Slate.

SEM Analysis

Scanning electron micrographs of cores drilled from the blocks showing cracks in Keelung Harbor are presented in Fig. 4. SEM revealed gel like AAR products at the cement paste/aggregate boundary. EDX showed these products to be rich in sodium.

Accelerate Expansion Tests

Results of the accelerated expansion tests for the cores drilled from the four harbors are shown in Fig. 5. It is expected that the greater the difference in expansion between the NaOH soaked cores and the humid cured cores, the greater the potential for the occurrence of AAR. For the cores obtained from Taichung and Su-Au Harbors, the concretes showed no significant AAR symptoms, the differences in expansion between the NaOH soaked and the humid cured cores were limited. For the cores drilled from Keelung and Hwa-Lian Harbors, where the embankments and the blocks showed map cracking, curing the cored

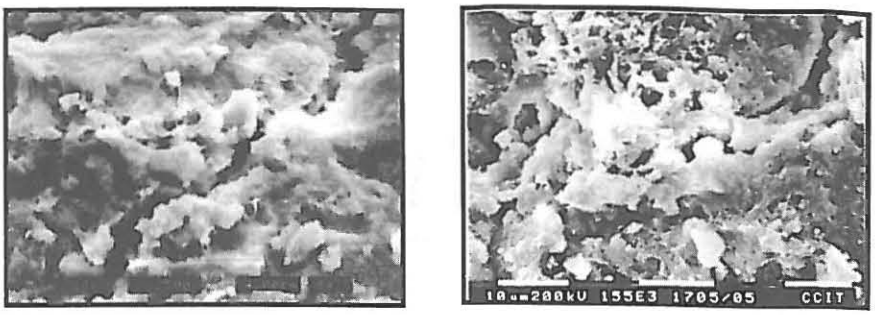

Fig. 4: SEM micrographs of cores from the concrete blocks in Keelung Harbor

samples in the two conditions showed significant difference in expansion. However, the cores need to be monitored for longer periods.

Reactivity of the Aggregates

Since the records of the materials used to mix the concrete in the four harbors are unavailable, the reactivity of the possible aggregates used to make concrete currently was studied by ASTM C289. The results are listed in Table 4, and the possible sources of aggregates for the four harbors are shown in Table 5. The reactivity of the fine aggregates probably used in the concrete for harbor constructions are deleterious or potentially deleterious to induce AAR.

TABLE 4: Reactivity of the Aggregates for the Four Harbors by ASTM C289

Source of Aggregate	Sc	Rc	Reactivity
Coarse aggregate from Ta-Chia Creek	76.1	116.5	Innocuous
Fine aggregate from Jwo-Shoei Creek	127.2	108.5	Potentially deleterious
Coarse aggregate from Wu Creek	44.5	97.5	Innocuous
Fine aggregate from Wu Creek	85.4	81.5	Potentially deleterious
Coarse aggregate from Lan-Yang Creek	138.5	158.5	Innocuous
Fine aggregate from Lan-Yang Creek	139.3	105.0	Potentially deleterious
Coarse aggregate from Ho-Ping Creek	96.8	173.5	Innocuous
Fine aggregate from Ho-Ping Creek	137.7	50.5	Deleterious
Aggregate from Mu-Gua Creek	90.6	26.1	Deleterious
Aggregate from Yueh-Mei Creek	46.9	59.2	Innocuous

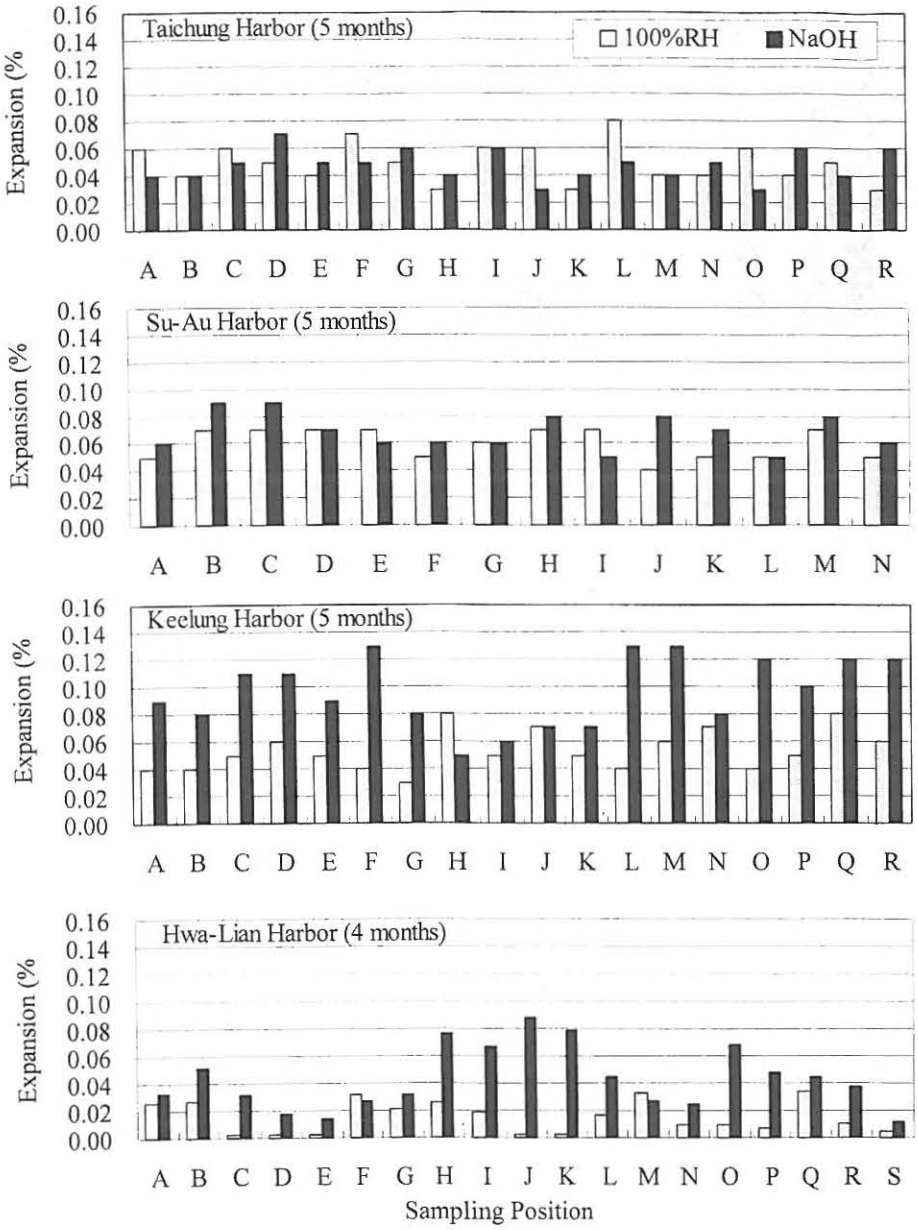

Fig. 5: Accelerated expansion test for the cored samples from the four harbors

TABLE 5: Possible Aggregate Sources for the Four Harbors

Harbor	Aggregate Sources
Taichung	Ta-Chia Creek, Jwo-Shoei Creek, and Wu Creek
Su-Au	Lan-Yang Creek, and Ho-Ping Creek
Keelung	Hwa-Lian Creek, Jwo-Shoei Creek, and Ho-Ping Creek
Hwa-Lian	Mu-Gua Creek, and Yueh-Mei Creek

Alkali Contents in Local Cements

To evaluate the potential of AAR in concrete structures, the alkali contents in the cements produced by major cement plants in Taiwan were investigated, and the results are shown in Fig. 6. In 18 cement plants, the alkali contents in only two cements were less than 0.6% eq. Na2O, the maximum alkali content required by ASTM C150 for inhibition of AAR. The alkali content in 30% of cements exceeded 1.0% eq. Na2O.

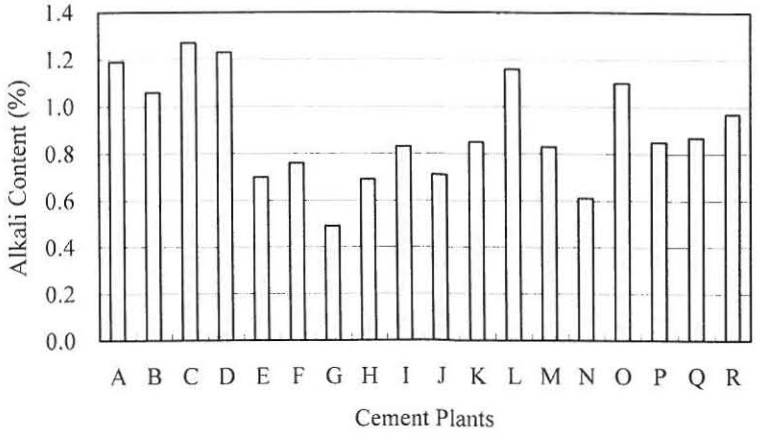

Fig. 6: Alkali content in local cements

Consequently, since some of the aggregates show reactivity for AAR and the cements contain relatively high alkali content, the occurrence of AAR in concrete structures is possible when the environmental conditions are suitable for the reaction.

CONCLUSIONS

This study has shown that the concrete blocks in Keelung Harbor as well as the embankment and the blocks in Hwa-Lian Harbor have developed AAR associated with

cracking. The reaction products were observed in the cored samples. Significant difference in expansion of cored samples stored in conditions of 1N NaOH solution and 100% RH environment at 38℃ have been measured.

No evidence of AAR was found in the concrete structures in Taichung and Su-Au Harbors. However, the concretes are susceptible to expansion in storage of 1N NaOH and humid conditions at 38℃, and the reactivity of part of the aggregates is considered to be potentially deleterious for AAR. A long term monitoring of the concrete structures is needed.

Some of the aggregates show deleterious or potentially deleterious reactivity in Taiwan, and high alkali cements are commonly used in concrete construction. Mitigation of AAR is needed in future construction.

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