A CASE STUDY OF THE INVESTIGATION OF AAR IN HONG KONG

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ABSTRACT

Until very recently AAR was not considered to be a problem in Hong Kong. A case study, carried out over a three-year period, involving detailed field and laboratory investigations, has confirmed the presence of AAR in the concrete structures of a sewage treatment plant constructed using imported volcanic aggregates.

The study demonstrated the need to review international test methods and investigation procedures for the confirmation of AAR and classification of AAR potential, and to adopt them to suit local conditions.

In order to minimise AAR risk from the use of both locally produced and imported aggregates, specification clauses have been introduced to control the alkali content of concrete to be used in engineering and building works contracts in Hong Kong.

Keywords: chemical analysis, in situ monitoring, petrography, physical testing, specification

INTRODUCTION

With the huge demand for aggregates associated with the rapid growth in construction and infrastructure development, Hong Kong has had to supplement local production of aggregates, predominantly of granitic origin, with steadily increasing imports from the neighbouring parts of China.

The imported material included aggregates of volcanic origin. The use of imported volcanic aggregates together with the planned redevelopment of Hong Kong's largest quarry, which will produce significant quantities of volcanic tuff for possible use as concrete aggregate, is giving concern that significant AAR problems may develop in Hong Kong as some minerals in certain types of volcanic rocks are widely recognised as being potentially reactive.

The appearance of cracks in structures and buildings within the Territory has until recently been assigned to causes other than AAR. This view has been supported by the satisfactory performance of concrete made with local granite aggregates, which are considered to be non-reactive.

In mid-1991, the Public Works Central Laboratory (PWCL) in Hong Kong commenced an investigation into the cause of extensive cracking of the concrete in a sewage treatment plant in the New Territories of Hong Kong. The investigation involved field inspection and monitoring of cracks, core expansion tests, petrographic examination, and chemical analysis and testing of core samples taken from the site.

DESCRIPTION OF THE SEWAGE TREATMENT PLANT

The sewage treatment plant is located in the north-western New Territories of Hong Kong. It was constructed between 1980 and 1983. The plant consists of a number of lightly-reinforced concrete aeration and sedimentation tanks, surrounded by concrete parapet ring walls, and a number of small pump-house structures. The inner faces of the tanks are regularly submerged under sewage. Extensive map cracking has been developed over the internal and external surfaces of the tanks (see Figure 1). In addition, longitudinal cracking is present along the top of a number of the parapet walls. The cracking was first inspected by the PWCL in late 1991. However, it was not possible to determine when the cracking first developed.

Concrete used in the construction of the structures at the site was produced from a dedicated on-site batching plant. The concrete used in the construction of base slabs for the tanks and foundations for associated structures below ground contained granite aggregates supplied from a quarry in Hong Kong. The concrete used in the construction of the walls of the tanks and other above ground structures contained volcanic aggregates supplied from a quarry in Southern China.

Figure 1 Map cracking on parapet wall

FIELD INVESTIGATION

Sampling

In early 1992 thirty core samples, 100 mm in diameter and 300 mm long, were taken at different locations from the walls of the sedimentation and aeration tanks of the sewage treatment plant. The cores were taken both through and adjacent to cracks present in the walls of the tanks. Immediately after coring the cores were immersed in water and then subsequently removed and wrapped in wet cotton towels and placed in UPVC tubes for transport to the laboratory. Upon arrival in the laboratory, the cores were stored individually in a cylindrical container filled with clean tap water.

After about one to two weeks in this condition, considerable growth of a 'white fibrous substance' was observed on the outsides of the core samples.

Crack Survey & Monitoring

In late 1992, a field monitoring programme was commenced to examine the development of cracking in the concrete of the sewage treatment plant. The following field monitoring was carried out over a period of one and a half years:

Stereo-photography and Crack Plotting

High definition stereo photographs were taken over one selected area of the tanks which had developed intensive cracks on the concrete surface. Precision plotting of the crack patterns to an accuracy of 1 mm was also produced. The data were stored in digital form in order that the development of any further cracking at that area could be monitored in future, if required.

Monitoring of Crack Movement

Pairs of Demec points were installed at 90 degrees to selected cracks at six locations. A Demec gauge of 100 mm gauge length was used to monitor crack widening.

Ten hexagonal rosettes of Demec points were installed to enable strains to be derived from the measurements in three directions. A Demec gauge of 200 mm gauge length was used for the monitoring.

The ambient temperature and relative humidity were also recorded at the time of monitoring for reference purposes.

Typical results of the insitu crack monitoring are given in Figures 2 & 3.

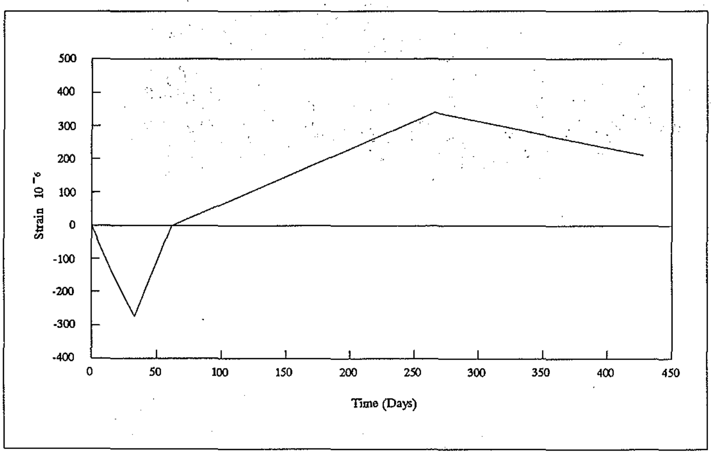

Figure 2 Typical results of insitu measurement of cracks using demec points

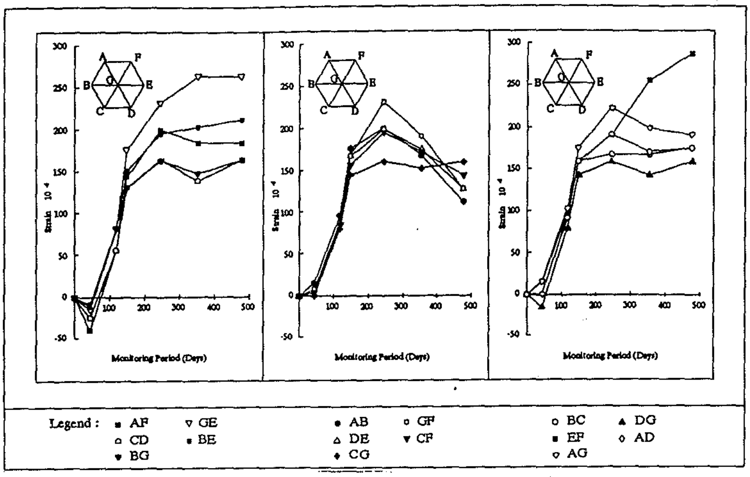

Figure 3 Typical results of insitu measurement of cracks using hexagonal rosettes of demec points

LABORATORY INVESTIGATION

Core Expansion Tests

Seventeen bars with approximate dimensions of 25 mm x 25 mm x 295 mm were prepared from nine 100 mm diameter cores taken at selected locations in the walls of the sedimentation and aeration tanks of the sewage treatment plant.

The test procedure adopted was based on ASTM C227-87 (ASTM, 1987). The bars were individually wrapped in wet towels and placed inside a sealed plastic container. They were then stored in an environmental chamber with the temperature maintained at 38°C and relative humidity above 95%. The expansions of the bars were measured at regular intervals over a period of 365 days.

A typical set of test results is shown in Figure 4. The results indicated that after fourteen days all the specimens showed an expansion of about 200 to 300 microstrains (equivalent to about 0.02 to 0.03% strain) but the subsequent expansion was negligible.

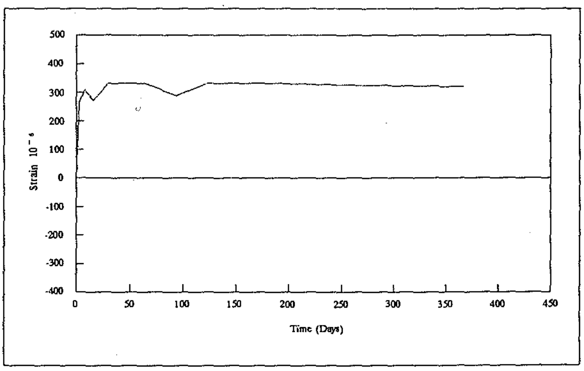

Figure 4 Typical expansion test results

Petrographic Examination

Petrographic examination of thin sections and polished plates was undertaken by the PWCL on five concrete core samples containing significant cracking. The petrographic examination of concrete core samples was carried out generally in accordance with the requirements of ASTM C856-88 (ASTM, 1988). Reference was also made to the guidelines given in BCA (1992), French (1991) and West & Sibbick (1988) for the identification and assessment of AAR in concrete.

The cores examined generally exhibited similar composition consisting of volcanic tuff coarse aggregate, fine aggregate of predominantly granite and volcanic tuff, and Ordinary Portland Cement with no additives.

The coarse and fine volcanic tuff aggregate contains abundant microcrystalline quartz in the rock matrix and strained quartz in the coarse crystal component which are widely recognised as potentially reactive materials (RILEM, 1993).

Evidence of AAR was observed in all of the core samples examined except SW115. The evidence included the presence of reaction sites and residual gel deposits in voids and microcracks. The extent of the reaction was generally quite limited in most of the core samples except SW102 and SW206, which contained numerous reaction sites and abundant gel deposits. The reaction sites where observed were mainly associated with coarse aggregate particles of volcanic tuff. A summary of the results of the petrographic examination is given below in Table 1.

Table 1 Summary of petrographic examination results on concrete cores

Cement	Coarse Aggregate + Fine Aggregate	Cracking	Presence of Reactive Minerals	Presence of Gel
Surface carbonation to 5 mm (10-25 mm in cracks). Residual clinker finely divided and generally <50 μm, occasionally up to 200-300 μm in size. Portlandite crystals where developed are around 50 μm, occasionally 100 μm in size. Small number of voids generally <2 mm in size. Ettringite crystals frequently present in voids.	20 mm nominal size crushed rock. Predominantly fine grained volcanic tuff with occasional free quartz particles. Some flaky and elongate particles. 5 mm nominal size crushed rock. Mixed sources of granite, tuff and some free quartz.	Surface macrocracks penetrate to several cm depth. Some fine cracks and micro-cracks passing through cement and aggregate particles. Ettringite present in some cracks.	Micro-crystalline and strained quartz present in coarse and fine aggregate. Some reaction centres present mainly in coarse aggregate with occasional reaction rims.	Traces of residual and layered gel in some micro-cracks and within reaction rims around aggregate particles and occasionally in small voids.

Chemical Analyses

Chemical analyses were carried out on the 'white fibrous substance' which was observed on the outside of core samples.

The substance was initially oven-dried at 105°C for 4 hours. The dried powder, when examined under an Scanning Electron Microscope (SEM), exhibited a flaky form and occasionally a flower-like pattern. Such crystal forms have been reported by others and are considered to be one of the characteristics of AAR gel products (Shayan, 1989).

Elemental analysis of the dried powder was carried out by Energy Dispersive X-ray (EDX) analyses which indicated that the substance contains mainly calcium, silicon and potassium in proportions similar to those reported by Shayan (1988) as being typical of AAR gel products (see Figure 5).

Infra-red Photospectrometry was also carried out on the dried powder. The results showed that silicon was present which reinforced the findings from the EDX (see Figure 5).

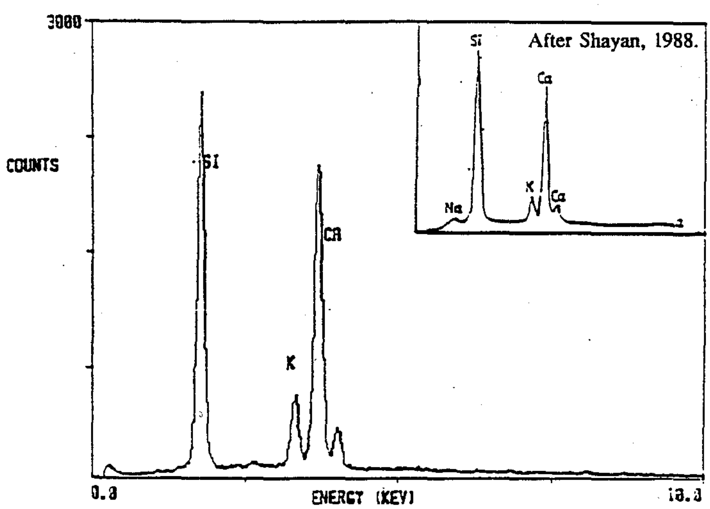

Figure 5 Typical EDX results of white gel from concrete core

DISCUSSION OF RESULTS

The results of the field monitoring indicated that the concrete structures at the treatment plant had no signs of continued expansion. The concrete core expansion test was used to assess the potential for continued expansion. BCA (1992) has suggested that if the total observed expansion is about 700 microstrains or less in the expansion tests, it is unlikely that there will be further expansion of the member from which the cores have been taken. The PWCL expansion test results show that the total expansion was about 200 to 300 microstrains for all of the 17 test specimens. The expansion in the early stage of the test may be attributed to the additional water absorption by the existing AAR gel. It may also be due to thermal expansion associated with raising the temperatures of the cores to 38°C. Negligible expansion was recorded in the later stage of the tests. This lends further support that AAR in the concrete structures has come to an end.

The presence of potentially reactive aggregate particles together with evidence of reaction sites and the occurrence of alkali silica gel identified in the core samples examined is considered to represent confirmation that AAR has occurred in the concrete (BCA, 1992; West & Sibbick, 1998). The gel deposits observed in voids and microcracks were frequently carbonated and recrystallised suggesting that much of the reaction may be historical.

The results of the chemical analyses appear to confirm that the 'white fibrous substance' is AAR gel product.

CONTRACT SPECIFICATIONS

In view of the possible risks of using potentially reactive imported and local aggregates in concrete production, the Hong Kong Government has introduced a $3kg/m^3$ limit on the reactive alkali content of concrete used in Government projects. The limit is based on experience in the UK and Canada. A set of specification clauses incorporating this limit have been used in all engineering and building works contracts since late 1994 for the control of AAR in concrete. The PWCL and local universities are presently carrying out research on AAR. It will be necessary to review the present approach towards minimising AAR risk in Hong Kong as local research results become available.

CONCLUSIONS

The investigation carried out confirmed that the cracking in the concrete of a sewage treatment plant in the New Territories of Hong Kong was due to AAR. The main findings of the investigations were as follows:

(a) The insitu monitoring of cracks in the concrete indicated negligible movement throughout the monitoring period and that further cracking of the structures is unlikely to occur.

(b) The core expansion tests indicated that there was unlikely to be any further expansion in the structures from where core samples were taken.

(c) The petrographic examination and chemical analyses confirmed the presence of reactive volcanic aggregates and AAR gel products in the cores examined.

This is the first documented case study on AAR performed by the PWCL in Hong Kong. Further work is being carried out to develop and establish appropriate test methods and procedures for determining the potential reactivity of concrete constituent materials used in Hong Kong.

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