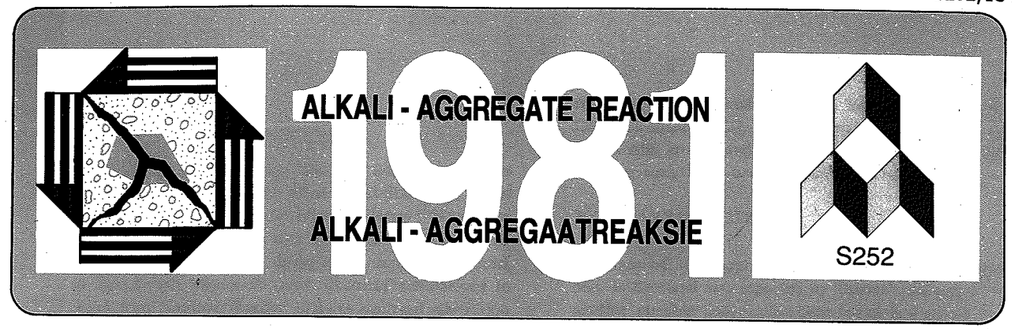

ALKALI-SILICA REACTION IN GREAT BRITAIN - A REVIEW

by R T L Allen*

SYNOPSIS

Since 1971 when the first case of alkali-aggregate reaction was reported in the British Isles a number of other cases have been identified. The history of some of these is examined and proposed future research work outlined.

SAMEVATTING

Sedert 1971 toe die eerste geval van alkali-aggregaatreaksie in die Britse Eilande aangemeld is, is 'n aantal ander gevalle ook geïndentifiseer. Die geskiedenis van enkele hiervan word ondersoek en voorgestelde toekomstige navorsingswerk word aangedui.

S252/18

Conference on alkali-aggregate reaction in concrete
Cape Town - South Africa
March 30 - April 3, 1981

Secretariat: NBRI of the CSIR
P O Box 395, Pretoria 0001, South Africa
Telephone (012) 86-9211 Telegrams Navorsbou
Telex SA 3-630

Konferensie oor alkali-aggregaatreaksie in beton
Kaapstad - Suid-Afrika
30 Maart - 3 April, 1981

Sekretariaat: NBNI van die WNNR
Posbus 395, Pretoria 0001, Suid-Afrika
Telefoon (012) 86-9211 Telegramme Navorsbou
Teleks SA 3-630

* *Cement and Concrete Association, London, UK.*

world. Many British engineers were operating in the Middle East where this was usually not possible. The supply of cement in the Middle East was unpredictable and one could not specify the use of a low alkali cement; at times it was not even possible to specify the use of an ordinary Portland cement. One got cement in all sorts of bags and from all sorts of places and this could vary day by day. The second reason was that one of the biggest problems in the Middle East was that the aggregates often contained quite a high proportion of sodium chloride, and even if the proportion of sodium chloride present was reckoned to be tolerable from a reinforced concrete point of view, this could still add sufficient sodium to the system to negate the benefit of using a low alkali cement. So although this was often a possible preventive measure, in some areas of important construction activity it could not always be implemented.

Prof U Ludwig (RWTH, Aachen, West Germany) referred to the situation in Germany, where it had been found that when using ready mixed concrete difficulties could be encountered with placing the concrete, because there were great variations in the workability of the concrete with the same cement, and sometimes one had to break off concreting when building bridges, to change the mix-design. The variation in the workability of the same cement occasionally led to the fear that the cover over steel reinforcement would be unsatisfactory. They had therefore started discussions on changes in workability with the same cement. He therefore asked, what, when changing the water/cement ratio and reducing the cement content, was being referred to, was the role of the cement itself.

Mr Flanagan said that he personally had not come across this phenomenon, although he had read about it in the literature. Here in the Cape there were 3 different cements, and in the normal work they did they had not been able to pick up any difference even in cement from different factories. There were, of course, many other factors, for example temperature and the method of measuring workability, which exerted such a big influence that he thought they would probably mask any effects that occurred unless they were really dramatic. Depending on whether the concrete was made early in the morning or in the heat of the day, there would be differences, and he thought these were far larger than those produced by a change in the cement.

1. INTRODUCTION

No cases of alkali-aggregate reaction were identified in the British Isles until 1971 when it was discovered in the Val de la Mare Dam on the island of Jersey[1]. It was not until late 1976 that cases were identified on the mainland in Great Britain when alkali-aggregate reaction was found in foundation blocks in three electrical sub-stations in south west England. Further cases in electrical sub-station foundations were identified during the subsequent year, and late in 1977 or early in 1978 the reaction was identified in some war time anti-tank obstacles near the coast in Suffolk and in three reservoirs, two of them in the Midlands and one in South Wales. It was also identified in a multi-storey car park in south west England. These cases were all reported by Palmer at a Conference at Purdue University, USA[2] and will not be discussed in detail here. As was to be expected, however, some further instances have been identified subsequently.

2. ELECTRICAL SUB-STATIONS

The reaction has been positively identified in foundations in some further electrical sub-stations in south west England and in the Midlands. In addition there are some sub-stations, particularly in south west England, where the foundations show crack patterns resembling those caused by alkali-aggregate reaction but it has not been considered necessary to drill cores for examination at this stage.

For the first twelve months after alkali-aggregate reaction was first identified on the mainland of Great Britain, all cases were in electrical sub-stations. Consequently, it was suspected that electric currents might be involved in some way, although all the sub-stations contained extensive copper earthing systems so it was unlikely that there would be appreciable leakage currents passing through the concrete. Induced currents resulting from strong alternating electro-magnetic fields remained a possibility, however, and laboratory tests were carried out in order to determine the possible effects of electric currents on specimens containing reactive aggregates when they were exposed to sodium hydroxide solutions. These tests showed that direct currents produced migration of alkalis within the specimens, accompanied by accelerated expansion and cracking. Alternating currents also produced increased expansion compared with control specimens in which no electric current flowed, even after allowing for the temperature rise caused by the current, but the expansion was considerably less than that caused by direct current and it was slower to develop. This work was reported by Moore at the Conference at Purdue University, USA[3]. When alkali aggregate reaction was detected in structures in which electricity could not have been involved it was concluded that the presence of electrical installations on the affected foundations was coincidental, and that conditions of exposure were a more likely mechanism for setting off the reaction. A feature common to all the affected bases was that their upper surfaces were approximately level with the surrounding ground and were fully exposed to the weather. In many cases the ground water table was high.

3. DAMS IN SCOTLAND

One case of alkali-aggregate reaction in a small concrete dam in Scotland was reported by Palmer[2]. Subsequently, another possible instance has been found in a second dam in Scotland, in this case built in 1956 with precast concrete block facing. It has not been considered necessary at this stage to obtain concrete samples large enough for a full laboratory investigation.

The aggregate in the first dam consisted of greywacke and in the second dam a mixture of greywacke and felsite. In both cases the aggregates were obtained from local excavations and not from commercial sources.

4. BRIDGES IN SOUTH WEST ENGLAND

Alkali-aggregate reaction has been identified in free-standing concrete piers supporting a footbridge over a main road. This structure was built in 1967. Concrete in the piers contained crushed limestone coarse aggregate and marine sand. The deck of the bridge is carried on precast pre-stressed concrete beams using different aggregates and the reaction is not suspected in these at the present time.

Another footbridge over a river was built in 1970 alongside a rather narrow roadbridge in order to separate pedestrians from vehicular traffic. Mass concrete abutments were built into the river bank and faced with precast concrete blocks which were tied into the mass concrete with wall-ties. In 1980 it was noticed that some of the blocks had been displaced and so the facing was removed for investigation. This revealed the typical crack-pattern in the mass concrete behind and tests on core samples drilled from the concrete have confirmed alkali-aggregate reaction. The concrete mix appears to be similar to that used in the piers of the first footbridge.

Crack patterns suggestive of alkali-aggregate reaction have appeared in abutment wing walls in two bridges over a main road. Both were built in 1974 as part of the same contract. No concrete samples have been examined yet but it is highly probable that the concrete mixes used in them were similar to those that have caused trouble elsewhere in south west England.

5. OFFICE BUILDING IN SOUTH WEST ENGLAND

The elevation of this building consists of infill panels contained in a framework of precast concrete beams and concrete-encased structural steel columns, the latter having been encased in concrete at the precasting works. The building was completed in 1972 and cracks were first noticed about four years later. Alkali-aggregate reaction

was diagnosed at the end of 1978. Coarse aggregate was crushed limestone, with siliceous pit sand containing chert particles.

6. CLADDING PANELS IN LONDON AREA

Some cladding panels containing white Portland cement and decorative glass aggregate were erected in 1967 or 1968 and alkali-aggregate reaction was diagnosed at the end of 1978 by two laboratories, although the diagnosis was questioned by a third. This case is unusual because of the materials involved, and it is described in more detail by Figg in another paper at this Conference[4].

7. BASEMENT IN EAST OF ENGLAND

The basement forms part of an extension to an older building and was built in 1974. An isolated exudation of gel-like material has occurred and alkali-aggregate reaction was tentatively diagnosed in 1979. Some pressure grouting was carried out immediately after construction because of leakage of ground water into the basement, and it is possible that silicate grouts may have been used. Analysis of the gel suggests that the cement is the most likely source of alkalis.

8. RESERVOIR IN MIDLANDS

In addition to the cases reported by Palmer[2], alkali-aggregate reaction has been diagnosed in a third reservoir in the Midlands. It is about 30 years old and, like the earlier cases, it is a covered reservoir with the roof supported on precast concrete columns, a number of which show discontinuous vertical cracks. No remedial action has been considered necessary at the present stage but the cracks will be re-examined next time the reservoir is emptied for cleaning.

9. COLLIERY SHAFT IN MIDLANDS

Alkali-aggregate reaction has been detected in the concrete lining of a colliery shaft which is probably about 50 years old. Pieces of concrete have spalled from the shaft surface and reinforcement has corroded but a concrete core shows extensive fine cracks with fine-grained chert particles reacting. It is probable that saline ground water has made some sodium ions available for the reaction.

10. MATERIALS

Typically the reaction has taken 6 years or more to become evident in the cases reported here, so it has often been difficult to obtain information about the materials that were used during construction. This has applied particularly where concrete was supplied by local ready-mixed concrete firms that have subsequently been taken over by larger organizations. In south west England a factor common to most of the cases reported has been the use of a sea-dredged sand in which the coarser particles have contained a large proportion of reactive chert. Also, in many cases the cement was obtained from a particular works and had an alkali content of the order of 1 per cent equivalent sodium oxide which is high in comparison with most British sources. The coarse aggregate has usually been crushed limestone, basalt or granite, which has not taken part in the reaction. These factors have not all applied in every case in south west England: in some cases cements having lower alkali contents have been used, and in some cases aggregates were obtained from inland gravel pits.

One of the first three electrical sub-stations concerned was built in several stages. In the first stage, sea-dredged coarse and fine aggregates were used and no cracking has been detected. In the second stage sea-dredged fine aggregate and crushed limestone coarse aggregate were used, and it is in this work that alkali-aggregate reaction has become evident. It is almost certain that cement for both stages came from the same source and cement contents of the concrete were probably similar. Although no corroborative experiments have been carried out, it is possible that the reactive silica content of the aggregates that were used in the first stage of construction may have been greater than the pessimum range.

Elsewhere in the British Isles other cements have been used with various alkali contents. Coarse aggregates have usually been either crushed limestone or gravel, the latter being obtained either by dredging from the Bristol Channel or from gravel pits in the Midlands. Sands have usually been obtained either from the Bristol Channel or from pits, and the reactive material has usually consisted of chert particles in the coarser fraction of the sand but, in some instances, chert and quartzite gravel coarse aggregate has also shown signs of reaction. The Scottish dams have been different in that the aggregates have consisted largely of greywacke and have not been obtained from commercial sources.

11. FOOTBRIDGE IN MIDLANDS

A footbridge of cantilever and suspended span construction was built over a road in the Midlands in 1960 or 1961 and, early in 1980, a cantilever suffered some damage and the precast pre-stressed concrete beams forming the suspended span were removed. This revealed some longitudinal cracks in the beams which clearly had not been caused by the damage to the cantilever, and further investigation showed the presence of alkali-aggregate reaction. The Highway Authority decided to replace the beams with new ones and some of the old beams are to be utilised for research purposes. A total of 1 edge beam and 5 inner beams have been made available, with dimensions approximately 375 mm wide x 600 mm deep x 10 m long.

It is believed that the aggregates for the precast concrete beams were obtained from a gravel pit in the Midlands. The reacting material consists of chert and quartzite particles in both coarse and fine aggregates. Analysis of samples shows a cement content of about 480 kg/m³ with a chloride ion content equivalent to about 0,6 per cent calcium chloride by weight of cement in the interior of the beams. There are higher and very variable concentrations at the outsides of the beams, which probably

originated from de-icing salts. Compressive strength tests indicate equivalent cube strengths between 73 and 91,5 MPa[2].

12. PROPOSED RESEARCH

Some of the research that has been carried out at the Cement and Concrete Association and at the Building Research Establishment is reported separately at this Conference by Hobbs[5] and by Nixon and Gaze[6] respectively, but it is proposed to carry out further work as follows:

(a) A block of concrete has been cast in damp ground at the Building Research Establishment. Cores will be drilled from it at intervals and migration of alkalis within the concrete will be investigated. This follows on from earlier work reported by Nixon et al[7].

(b) One of the edge beams from the Midlands footbridge will be used for materials investigation at the Building Research Establishment:

(i) Ultrasonic pulse velocity, pull-out and core strength tests.
(ii) Aggregate sampling.
(iii) Determination of alkali migration.
(iv) Study of water and gel distribution and crack propagation.

(c) The 3 inner beams will be kept at the Cement and Concrete Association's Research Station and will be monitored for further crack development while stored under the following conditions:

(i) Dry
(ii) Submerged in water
(iii) Exposed to weathering

(d) Load/deflection tests will be carried out on some of the beams at intervals.

(e) At the Building Research Establishment, the effects of various surface coatings and of resin impregnation will be studied in order to determine their effectiveness in concealing cracks and in arresting further deterioration.

(f) DEMEC demountable mechanical strain-gauge points will be fixed to concrete cores that will be stored under warm, moist conditions at the Building Research Establishment, and movements will be monitored in order to investigate the possibility of predicting future expansion.

(g) When suitable opportunities arise, concrete samples taken from actual structures will be tested in order to study any migration of alkalis within the concrete.

13. GENERAL

The majority of cases reported have occurred in south west England, and the reactive aggregate involved in most of them was sea-dredged sand that was widely used there when the structures were built. Use of that particular sand ceased several years ago for commercial reasons before any cases of alkali-aggregate reaction had been detected, so it is possible that trouble may be less frequent in the future. Also, now that the industry is aware of the problem, precautions can be taken when appropriate in order to reduce the risk.

A problem remains, however, for owners of structures that are already deteriorating because of alkali-aggregate reaction. While it is generally recognised that the structural consequences of cracking may be less serious than they sometimes appear at first sight, a method of arresting further deterioration would undoubtedly be most valuable. It is to be hoped that some of the proposed research work mentioned above will lead to a better understanding of the phenomenon and to the development of remedial or palliative measures.

REFERENCES

1. COOMBES L H COLE R G and CLARKE R M *Remedial measures to Val-de-la-Mare Dam, Jersey, Channel Islands.* Paper presented at BNCOLD/ University Symposium, University of Newcastle-upon-Tyne, England. September 1975.

2. PALMER D *Alkali-aggregate reaction: recent occurrences in the British Isles.* Paper presented at 4th International Conference on the Effects of Alkalies in Cement and Concrete, Purdue University, West Lafayette, USA, June 1978.

3. MOORE A E *Effect of electric current on alkali-silica reaction.* Paper presented at 4th International Conference on the Effects of Alkalies in Cement and Concrete, Purdue University, West Lafayette, USA, June 1978.

4. FIGG J W *Reaction between cement and artificial glass in concrete.* Proceedings Alkali-aggregate Conference, Cape Town, 1981.

5. HOBBS D W *Expansion due to alkali-silica reaction and the influence of pulverised fuel ash.* Proceedings Alkali-aggregate Conference, Cape Town, 1981.

6. NIXON P J and GAZE M E *The use of flyash and granulated blast furnace slag to reduce expansion due to alkali-aggregate reaction.* Proceedings Alkali-aggregate Conference, Cape Town, 1981.

7. NIXON P J COLLINS R J and RAYMENT P L *The concentration of alkalies by moisture migration in concrete - factor influencing alkali-aggregate reaction.* London, Cement and Concrete Research, vol 9, No 4, July 1979.

Addendum

The following information was included in the verbal presentation but not in the printed paper:

Sewage treatment works in the midlands.

A circular sludge digestion tank, about 15 m dia. and 10 m deep, was built in 1966-7. Its walls projected about 1 m above ground level. Alkali-silica reaction had been confirmed in the tank wall, with map-cracking. The aggregates were natural gravel and sand containing chert and quartzite. Coarse and fine aggregate particles were reacting. The source of the cement was not known.

Some flights of steps in the sewage works showed the typical crack pattern, but some other tanks that were built in the same contract had not cracked.