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ALKALI–AGGREGATE REACTION IN NEW ZEALAND —A CONTINUING PROBLEM

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ABSTRACT

Condition surveys of highway bridges are revealing that up to 20% of the bridges inspected may be suffering from AAR in those areas where reactive aggregates are present. This situation has largely occurred because, for the decade 1958-1968, a high-alkali cement available in the areas of concern was used with reactive aggregates. A review of the alkali-aggregate problem in New Zealand clearly shows that a serious problem will exist unless control is exercised. This paper describes the known extent of AAR in New Zealand, the recent and current investigations and discusses the actions considered necessary to bring the problem under control.

1. INTRODUCTION

About 30% of aggregates used in concrete in New Zealand are potentially reactive [1]. Until 1980, this use appeared to have caused only one known case of expansive reaction in a structure. However, recent work now shows that in areas where reactive aggregates are in use, up to 20% of structures may be affected. Since the problem of AAR in New Zealand has been extensively investigated for over fifty years, the increasing number of bridges and other structures found to be undergoing the reaction is unexpected and disappointing. This paper describes the known extent of AAR in New Zealand, the recent and current investigations and discusses the actions considered necessary to bring the problem under control.

2. THE CURRENT SITUATION

2.1 Causes of the Current Problem

The current problems encountered with AAR in New Zealand structures are due to two causes. These are the use of a cement containing in excess of 1.0% Na2O equiv. during the period 1958-68 and a reluctance by engineers to accept that the potential problem of AAR reported by investigators would become a reality unless effective preventative measures were maintained. The overall situation has been reviewed [1,2].

2.2 The Alkali Content of New Zealand Cements

The alkali content of the cement believed to have caused many of the problems is shown in Fig.1. Over the decade 1958-68 much of the production can be seen to exceed ~1.0% Na_2O equiv and it was in this decade that many of the now damaged structures were built. Other cements, with the exception of two small works whose productions were not used in public works, generally contained less than 0.7% Na2O equiv. As both high-alkali and low-alkali cements were available in the areas of concern where both reactive and innocuous aggregates are used, theoretically up to 25% of structures could have been affected. Thus the 20% found to be affected to date is not unduly high under the circumstances.

2.3 The Engineers' Attitude

The reluctance of New Zealand engineers to grasp the reality of AAR appears to have been related to the size of the project. In large projects where reactive aggregates were used, strict use of low-alkali cement has prevented any known cases of AAR in these structures. In smaller structures such as bridges, reservoirs and pavements the need to use low-alkali cement with reactive aggregates does not appear to have been as well understood. For instance, old records show that in one area the problem of AAR was correctly identified for local materials used as coarse aggregate. However, failure to identify a major sand source as being reactive has led to substantial damage in some structures in this area.

2.3.1 Reinforcement of Attitudes. Until 1980, only one structure (3) was known to be undergoing AAR. Considering that most damaged structures were taking up to 20 years to identify it is easy to see why only the most informed engineers recognised the need for action when dealing with AAR. With the lack of obviously damaged structures it is not surprising that a situation has arisen where there is little mention or guidance on AAR in NZ standards and codes.

2.4 The Use of Low-Alkali Cement

In 1968, the largest public construction agency, the Ministry of Works, wrote its own specification effectively ensuring that only low-alkali cement was available in the country. Since then there has been no cement importation and the use of low-alkali cement appears to have been relatively effective in preventing AAR. This allowed the construction to industry to become complacent. Recently the New Zealand cement industry has been de-regulated and the possibility of high-alkali cement being available to the construction industry will have to once again be faced by engineers.

3. THE EXTENT OF DAMAGE

Some sixty-one structures, known or suspected of AAR, have now been identified. Analysis of the construction dates shows that 28% were built between 1928 and 1940, 17% during 1949-58, 48% during 1958-68 and 8% are subsequent to 1968. These figures indicate nearly half the structures were built in the decade when the one high-alkali cement was used but also suggest that some high-alkali cement was available before this period. The structures built after 1968 should contain only low-alkali cement. The occurrence of AAR after 1968 is of some concern as the use of low-alkali cement has been and will continue to be New Zealand's principal preventative measure against AAR. The physical damage to most of the bridges is limited and to date has generally involved no more than minor maintenance. However, the deck beams of a motorway bridge were replaced in 1988 at a cost of NZ$850,000 and an air base pavement may need replacement within the near future at an estimated cost of NZ$M3-5.

4. INVESTIGATIONS

4.1 Condition Surveys of Bridges

Between 1983 and 1986, Ministry of Works surveyed four hundred and twenty three bridges in the North Island of which some two hundred and twenty one were located in areas where reactive aggregates are present [4,5]. Cracking due to AAR was only one of a number of faults surveyed. Some fifty bridges were found with cracking which is thought to be due to AAR expansions. The surveying is not complete and two important areas where reactive aggregates used are yet to be surveyed. These are the Auckland metropolitan and Bay of Plenty-Coromandel areas.

4.2 Petrographic Examinations of Concrete Cores

Petrographic examination of concrete cores from ten bridges in Taranaki [1], identified as possible cases of AAR by the MWD surveys, showed that all the suspect bridges were undergoing AAR. Identification of the aggregates used in the concretes turned out to be of considerable interest as two of the bridges did not contain the local Egmont andesite but a 'high grade' greywacke aggregate trucked in from the Rangitikei River, well to the south of the area. This aggregate proved to be contaminated with volcanics that have been sufficient to cause moderate cracking.

Recently, a bridge on the Auckland Southern Motorway was found to have two or three longitudinal cracks in the bottom surfaces of each of the precast, prestressed, hollow-core, deck beams. No transverse or pattern cracks were visible on these bottom surfaces although vague, weathered, pattern cracking was visible on top surfaces. The cap beams to the abutments contained vertical cracks that approximately lined up with the beams. Petrographic examination of cores showed the concrete in the deck beams to be undergoing a severe and advanced AAR due to reaction of the rhyolite in the Waikato river sand used. The concrete was so badly pattern cracked that only the interlocking of aggregate and restraint of reinforcement appeared to be holding it together. In addition there was some evidence that delamination of the beams was occurring in reinforcement planes. In contrast the cap beams, which also contained reactive rhyolite but were cast in-situ, were not undergoing AAR. The cracks were solely due to expansion of the deck beams causing strain on these support cap beams. As mentioned earlier, the damage due to AAR was considered serious and these deck beams have now been replaced at a cost of NZ$850,000.

4.3 Investigation of the Field Geology of Two River Aggregates

From the data derived from the surveys and petrographic examinations it was evident that both the Waikato and Rangitikei River aggregates required investigation. Results of investigation [6] showed that the sands in the lower Waikato River are reasonably uniform in composition and contain approximately 32% of reactive grains consisting of 7-9% rhyolite, 10-13% pumiceous material, 7-9% of volcanic glass and minor amounts of andesite, dacite and tridymite. A further 13% of innocuous grains were partially rimmed with volcanic glass. In the case of the Rangitikei River the situation is complex. The main source of the reactive material is redeposited pumice and tuff beds in the central portions of this river valley which contribute to the aggregates a maximum of 2-3% volcanic glass, 2% rhyolite, 1% andesite, 1-2% chert and minor amounts of tridymite and pumice.

4.4 Mortar Bar Tests on Waikato and Rangitikei River Aggregates

The only ASTM C227 mortar bar test data on Waikato River sands is from the upper river area [7] and no data at all is available on the Rangitikei aggregates.

Ministry of Works has commenced an extensive test programme on these aggregates with data becoming available within the next one to two years. This test programme is important as the lower Waikato River is a major sand source for Auckland City while the Rangitikei River is an important aggregate source in the lower North Island.

4.5 Chemical Investigations of Aggregates and Concretes

4.5.1 The Use of the Chemical Test ASTM C289. New Zealand experience indicates that ASTM C289 works well with the local volcanic aggregates. Because recent problems with AAR have been highlighted in the New Zealand news media, many aggregate producers are now checking their potentially reactive materials using ASTM C289. In addition, Chemistry Division is attempting to broaden the scope of test data to include a range of basalts and aggregates from areas of the country where previous testing has been fragmentary.

4.5.2 Relationship of Rock Texture to Bulk Analyses & Reactivity. A co-operative project to compare the textures of Japanese and New Zealand volcanic rocks used as concrete aggregates has been carried out and is reported at this conference [8]. The results indicate that more attention needs to be paid in New Zealand to the possible presence of cristobalite, and to a lesser extent tridymite, when petrographically assessing the potential reactivity of volcanic rocks. It also appears that as the volcanic aggregates used in New Zealand are all fresh, total silica of the bulk rock and whether the rock norm is over saturated with silica may be a useful additional indicator of potential reactivity. These factors are important when assessing the potential reactivity of basalts. Thus basalts which contain more than 50% total silica would require testing by ASTM C289 before being considered innocuous.

4.5.3 Determination of Alkali Contents of Concretes. In the petrographic examination of concrete cores, the ability to determine the cement and alkali content of the hardened concrete is essential. Records of concrete mix designs for structures are often missing and not always reliable when available. Recent work at Chemistry Division to develop a satisfactory analytical method has shown that the classical method of concrete analysis using dilute HCl digestion can give up to 700% error in determing alkalies. The errors are greatest when basalt is present in the aggregate and become progressively less as the acidity of the volcanic aggregates increases. It has been reported [9] that hot water extraction could be used for assessing changes in alkali content of mortar bars. Soxhlet extraction with water, of concrete reduced to 300um in size, extracted 85-90% of the alkalies. However, the efficiency of the extraction method appears to vary according to the cement. Extraction with picric acid in methanol/water mixtures appears to be a promising method. Results to date show the method still extracts some alkalies from basalt.

4.6 Quarries and Minerals Survey

The Quarries and Minerals Survey has been completed and the statistics of production show that some 30% of concrete aggregates used are potentially reactive [1]. The Survey contains over 4500 records of mineral and aggregate sources with data of location, production and geology. A users manual has been published [10].

5. REFORMULATION OF STANDARDS AND CODES

It was concluded at a Workshop on AAR held in Auckland, New Zealand, on the 29th September, 1988, that the most important and immediate work required in tackling the problem of AAR was education of engineers, principally through reformulation of the appropriate standards and codes. It was felt that the use of low-alkali cement with reactive aggregates was an effective measure for preventing damaging expansion in concrete provided that high cement contents were not used. In these cases the additional safeguard of specifying the maximum alkali content of the concrete would be considered and reference to the recent U.K. recommendation [11] of $3kg/m^3$ was discussed. It is the author's opinion that this $3kg/m^3$ level would be adequate for andesite and basalt aggregates but its adequacy for the highly reactive New Zealand rhyolites and dacites which show marked pessimum proportions is in need of investigation. Work has already been started on rewriting portions of codes and standards and this should contribute significantly to preventing a repetition of the unsatisfactory situation which occurred in the decade 1958-68.

6. CONCLUDING DISCUSSION

By limiting the alkali content of cements, New Zealand has attempted to avoid AAR resulting from the extensive use of reactive aggregates in its concretes. Because this limit was not applied for an important decade when extensive roading work was carried out, and because the problems of AAR were not fully appreciated by all engineers, damage to structures resulting from the use of high-alkali cement and reactive aggregates has occurred. Even when the low-alkali cement policy was fully applied after 1968, some damage to structures has occurred. As these are yet to be investigated, the alkali content of their concretes is not yet known .

In a country such as New Zealand, with many reactive volcanic aggregates, control of AAR requires identification of all sources of potentially reactive aggregates, their volume usage and more importantly full investigation of affected structures. It has always been agreed that field evidence of aggregate reactivity takes precedence over laboratory data. It logically follows that the unwitting experiment which occurs when a structure is damaged by expansive reaction provides vital data and the structure should be fully investigated.

It is now evident from the experience in many countries that assumptions made about the reactivity of aggregates without investigational data to support them can be costly. The complexity of the alkali-aggregate problem requires all facets of the problem to be investigated if adequate engineering control is to be acheived. Over the last decade in New Zealand these broad investigations have been attempted and it is hoped that the results will lead to better control of AAR in the future.

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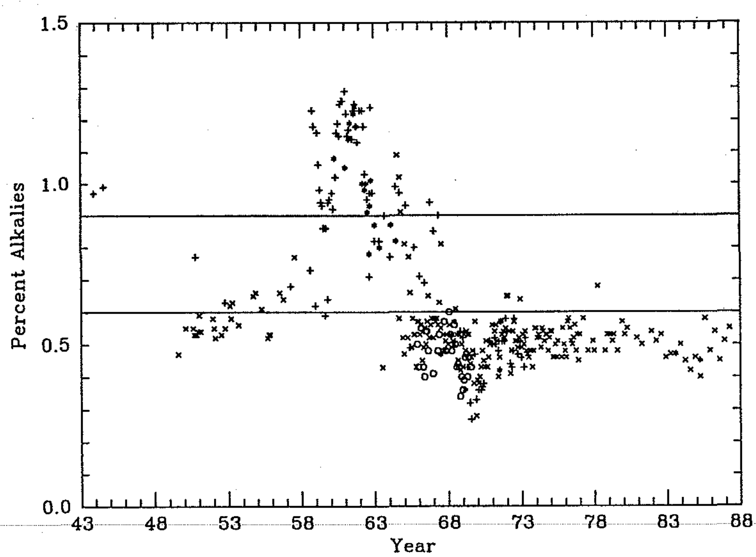

Fig. 1 The alkali content of the cement believed to have significantly contributed to the AAR problem in New Zealand. Note the high levels for the decade 1958-1968.