ALKALI - AGGREGATE REACTION 1981 ALKALI - AGGREGAATREAKSIE S252

ALKALI-AGGREGATE REACTION IN SOUTH AFRICA - A REVIEW

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SYNOPSIS

The events leading to the diagnosis of alkali-aggregate reaction in concrete are briefly summarised and a global review of the research carried out to date by the NBRI in connection with the problem is given.

SAMEVATTING

Die gebeure wat gelei het tot die herkenning van alkali-aggregaatreaksie in beton word vlugtig genoem en 'n globale oorsig van die navorsing wat tot op hede by die NBNI gedoen is met betrekking tot die probleem word gegee.

S252/8

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

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

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1. INTRODUCTION

The history of the recognition of alkali-aggregate reaction in South Africa is fairly short and centres mainly around the efforts to explain the cracking of some concrete structures in the South Western Cape Province.

The information in the following paragraphs was personally communicated to the author by the late Dr Fulton.

In the second half of 1960 the Portland Cement Institute (PCI) received reports of the deterioration of the Steenbras Dam. These were followed during the period 1971-1972 by reports of several other concrete structures in the Cape Peninsula showing similar signs of deterioration.

During the period 1971-1974 the problem was investigated by the Cape Town branch of the PCI in conjunction with members of the Cape Portland Cement Company. It was immediately recognised that the problem was one of expanding concrete and efforts revolved around finding the cause of the expansion. Although the possibility of alkali-aggregate reaction was mentioned in connection with an outcrop of silcrete at Parow, several other reasons were put forward for the cracking of concrete structures that were built with Malmesbury coarse aggregate, for example, seasonal contamination of Eerste River sand that was used in the Steenbras Dam, by either sewage or winery effluent. At a very early stage in the investigation of the Oswald Pirow Street bridge it was maintained that the cause of cracking was some deleterious material in the aggregate but only two weeks later it was stated that it seemed more a matter of environment than aggregate because four different concretes manufactured at different times by different people all showed signs of distress.

Although the possibility of sulphate expansion was given prominence in the early stages of the investigation, the question was very soon asked whether this view had not put the investigators on a false scent.

Next, particular attention was paid to pollution being a cause of the problem. Possible sources such as power stations where the burners had been converted from coal to heavy fuel, gas works, sewage ejector stations, corrosive industrial wastes discharged into sewers, burning of plastic insulation around electric cables by scrap metal merchants and chlorine from bleaching industries were all given prominence.

Consequently, by the beginning of 1972 alkali-aggregate reaction had been ruled out 'because the alkali content of the concrete samples analysed was far too low' and the following probable causes were put forward:

> Oswald Pirow Street bridge, gas from sewage ejector stack; Landsdowne Road Bridge, bleaching agents; Eastern Boulevard and Woodstock subways, gases from smoking chimneys.

It was observed very early in the investigation that, where the concrete was moist for long periods, there was serious expansion but where it was dry there was no trouble.

By the end of 1974 results were inconclusive. Chemical tests carried out for reactive aggregate by PCI and the South African Railways were negative. Length change studies and microscopic examination had yielded no positive results.

In 1974 the South African Railways asked the NBRI to express an opinion on concrete cores extracted from a transom beam of the Oswald Pirow Street bridge. It was found that there was apparently reaction between the coarse aggregate and the cement. A white reaction product consisting of platelets, thin needles and gel-like material occurred on fracture surfaces of the aggregate and in voids in the concrete[1]. In March 1976, several concrete structures were examined in the Cape by the NBRI and the opinion was ventured that the deterioration could be attributed to expansive cement-aggregate reaction because the information was that a low alkali cement had been used for the construction of the bridge. The opinion was expressed that alkali was released by exchange of Ca^{++} from the cement with K^{+} of the potassium vermiculite in the coarse aggregate.

In 1976, it was established by chemical analyses that high alkali cement was being produced by two factories in the South Western Cape and the mortar prism test ASTM C227-71[2] was commenced with these cements and Malmesbury aggregate. The rates of expansion given by ASTM C227 as indicating potentially reactive combinations, could not be obtained and through ignorance and inexperience, the tests were terminated. Concrete prisms stored under ASTM C227 conditions, however, expanded more and it was therefore concluded by the end of 1976 that concrete containing a combination of Malmesbury aggregate and a high alkali cement, was potentially expansive.

As a result of these findings, the Electricity Supply Commission (ESCOM) requested the NBRI at a meeting in December 1976 to examine the materials to be used in the construction of the Koeberg Nuclear Power Station and to conduct a survey of a limited number of structures selected at random to obtain an indication of the seriousness of the problem. Because the first concrete was to be poured within about six months after the NBRI had commenced the survey and laboratory investigation, a decision had to be taken with the minimum of data available. The recommendation that only a low alkali cement be used in combination with either of the two types of aggregate that were available at that stage, namely Malmesbury aggregate or a granite from a particular source, was regarded as very conservative by the cement and aggregate industry. However, the data obtained in the long-term support the original decision.

It appears that up to this particular point in time neither the cement producers nor the aggregate producers grasped the full implications of the effect that the problem would have on their industries. Only when some public authorities and consultants started specifying low alkali cement or alternative aggregate was it realised that thorough attention should be given to alkali-aggregate reaction and its related problems.

The culmination of these events was a meeting in July 1977 of an ad-hoc committee to consider the problem of the deterioration of concrete in the South Western Cape Province, where it was decided that a Technical Steering Committee on Research into the problem of the deterioration of concrete in the South Western Cape Province consisting of representatives of the cement industry, the aggregate industry,the concrete industry, various public authorities, the NITRR and the NBRI, would be formed to guide the research by the NBRI. For this research effort, which commenced by November 1977, generous sponsorship was obtained for a period of three years from the bodies mentioned at the end of this paper.

In August 1980 a special meeting of the Technical Steering Committee recommended that the research effort be extended for another three years, that continued sponsorship be obtained and that, because of the national impact of the problem, the name of the committee be changed to The Technical Steering Committee on Research into the Problem of the Deterioration of Concrete due to Alkali-Aggregate Reaction in South Africa.

The rest of this paper reviews the current status of the subject in South Africa.

2. SURVEYS

The results of the surveys carried out in the Western Cape by the research team are to be presented in detail by another speaker at this Conference[3] and will not be dealt with in this paper.

The type of concrete structures affected are fairly numerous and include bridges, earth retaining walls, a water storage dam, reservoirs, a concrete pavement, dolosse, bollards, culverts and conductor mast foundations.

The survey showed the important role played by exposure conditions. Damp earth on one side of retaining walls, water flowing through joints over beams of bridges, east, west and north exposure, all aggravate the deterioration. However, concrete completely immersed in either fresh or sea water does not deteriorate because of the alkali-aggregate reaction; this observation has been verified in laboratory experiments with concrete prisms.

Careful evaluation of the cause of the cracking of structures is important. Cracking of concrete and staining around cracks should not be taken as an indication of the alkali-aggregate reaction unless definite signs of expansion such as closure of expansion joints, spalling, off-setting and warping of structural members and pavements and misalignment of machinery based on concrete are evident. Once it has been established that expansion has taken place the cause, such as alkali-aggregate reaction, or sulphate expansion, must be determined. The cracking of concrete structures due to shrinkage can appear to the inexperienced observer to be due to alkali-aggregate reaction. Therefore, whenever it is practical, cores should be extracted from the affected structures for examination in the laboratory.

In the Eastern Cape Province the cracking of some structures as a result of shrinkage may be ascribed by the inexperienced observer to alkali-aggregate reaction. The similarity in the cracking pattern of the transom beam of a bridge which was affected by alkali-aggregate reaction shown in Figure 1 is obvious if compared with that in Figure 2 which shows cracking of a balustrade of a dam due to shrinking aggregate. Other cracked structures in this area show no clear signs of either shrinkage or expansion and a decision can only be made after a thorough study of concrete from the structures.

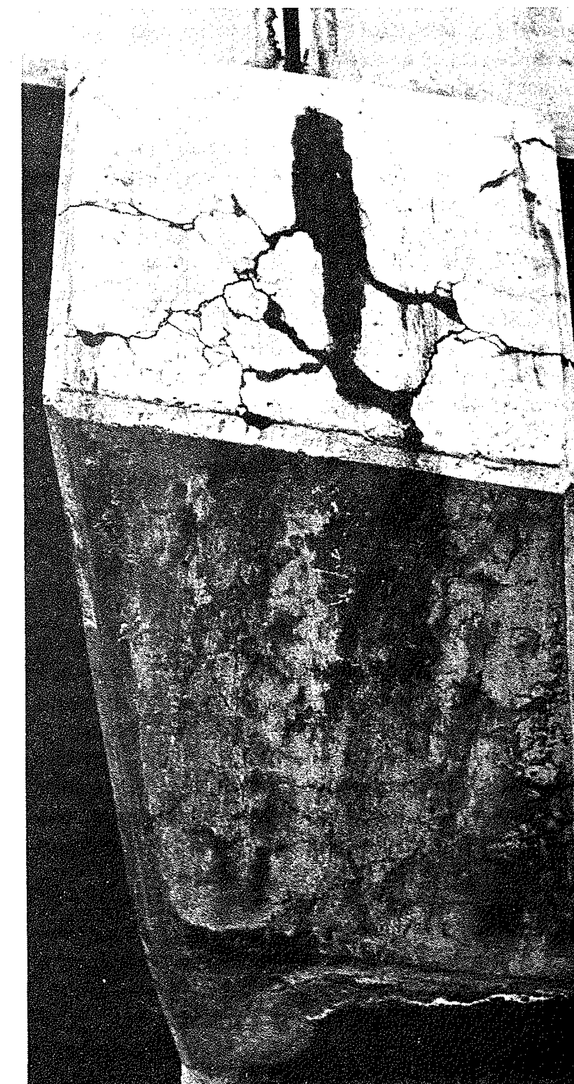

FIGURE 1: Cracked transom beam of Stellenbosch-Klapmuts road bridge (R44) over N1.

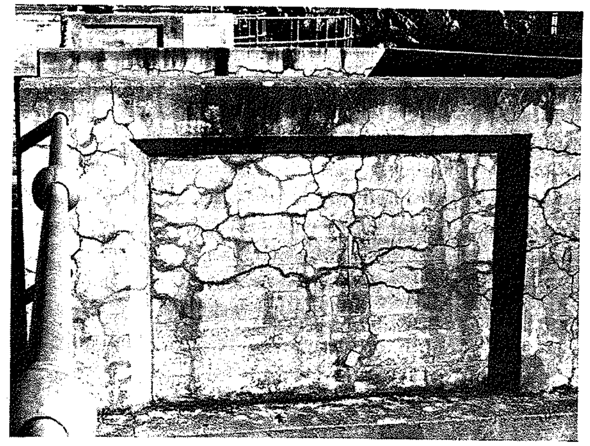

FIGURE 2: Cracking due to shrinking aggregate, Churchill dam, Eastern Cape Province[4]

In general, it is our experience that information such as the aggregate source, the cement source and the alkali content of the cement, which could make a valuable contribution to the interpretation of laboratory results, is difficult to obtain for completed structures.

3. MONITORING OF STRUCTURES

To confirm the expansion of concrete in structures, it is necessary to target certain elements of such structures and to take length and temperature measurements at regular intervals. Such measurements are time-consuming, and trends can only be established in the long term because of superimposed short-term fluctuations in temperature, and the slow rate of expansions under natural conditions. Target points have to be placed in fairly inaccessible positions to prevent damage by vandalism. However, the information obtained is very valuable and complements laboratory results. Figure 3 shows the data obtained in this way for a bridge element.

4. CEMENTS

Alkali content of cements. Detailed information on the alkali content of cements produced in the South Western Cape Province during the period 1960 - 1978 will be presented at this Conference in the paper by Semmelink[3]. As regards the position in South Africa as a whole, the range of the alkali content of cements produced during the latter half of 1977 is summarised in Table 1.

The localities of the cement factories are given in the paper by Davis[5].

One plant in the Western Cape and another in the Transvaal have subsequently ceased production. Currently, portland cement with an Na_2O equivalent of between 0,5 and 0,6 per cent is produced in both the Eastern and Western Province. Some of the implications for the production of a low alkali opc in the South Western Cape have been discussed at this Conference by Damp[6].

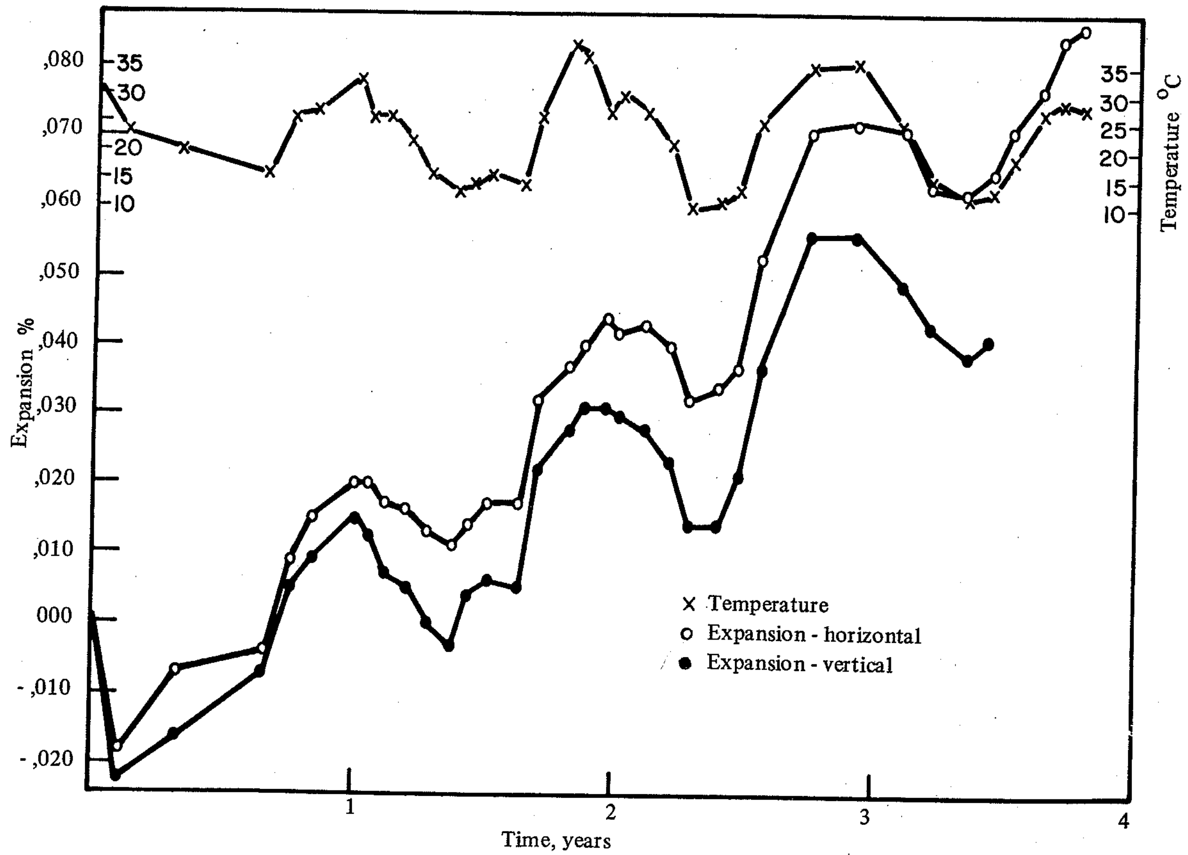

FIGURE 3 : Results of length measurements taken on a bridge element by the Cape Regional Office

TABLE 1 : Range of alkali contents of cements produced in South Africa during the latter half of 1977

Region	Number of plants producing cement with the following Na_2O equivalent (per cent) <0,55	0,55 - 0,64	0,65 - 0,84	>0,85
Western Cape	0	0	2	1
Eastern Cape	0	0	0	1
Northern Cape	1	0	0	0
Transvaal	5	2	0	1*
Orange Free State	1	0	0	0

* This plant utilises waste gypsum for clinker production

Chemical analysis. It was apparent from provisional data obtained by local laboratories as well as from the results of the International Cement Analysis Study conducted by the DSIRO, New Zealand[7] that before the inclusion of a limit for the Na_2O equivalent of a low alkali cement in a South African standard specification, attention would have to be given to drawing up a procedure for the determination of the alkalis in cement using flame emission and atomic absorption methods and also to the within-laboratory and between-laboratory variation in results obtained when using this procedure and to the accuracy to which the limit for alkali content can be specified. The outcome of this exercise, co-ordinated by the South African Bureau of Standards, and in which 13 South African and 3 foreign laboratories participated, was the acceptance of a method for the determination of alkalis in cement and of the principle that the limit should be specified to the first decimal only.

Limit on alkali content of cement. The Technical Committee on SABS 471[8] has accepted a maximum value of 0,6 per cent Na_2O equivalent, i.e. per cent Na_2O plus 0,658 x per cent K_2O, as defining a low alkali cement.

Active alkali content and reactivity of cements. Results obtained with a large number of South African and some overseas cements in mortar prism tests confirmed that the total alkali content of a cement does not necessarily characterise it with respect to its potential to cause expansion with an alkali-reactive aggregate. Consequently attention was and is still being given to physical and chemical methods in an attempt to establish an indicator for the reactivity of cements that would be universally applicable to the various alkali-reactive aggregates. To date these have encompassed research into the mortar prism tests ASTM C227-71[2] and ASTM 441-69[9] using different reactive aggregates such as Pyrex glass, Beltane opal and Malmesbury aggregate and the determination of water soluble and available alkalis. The results of the provisional investigations are reported at this Conference in the paper by Brandt et al[10].

5. AGGREGATES

Aggregate production in the South Western Cape Province. The localities of the aggregate quarries included in the investigation are given in Figure 4. In 1976 when construction activity was at a peak an estimated 6 million tonnes of aggregate were produced in the Cape Peninsula and its environs, of which about 43 per cent was used for road construction. Through the years more than 90 per cent of the aggregate supplied was greywacke and hornfels from the Malmesbury Group, only a small proportion being supplied from quarries on Cape granite and Table Mountain quartzite, which have subsequently closed down.

As a result of the problem of alkali-aggregate reaction in the South Western Cape Province, and the fact that all the concrete structures affected by it contain Malmesbury aggregate and that to date alkali-aggregate reaction has not been identified in any of the comparatively small number of concrete structures containing granite and quartzite aggregate in that region, there has been considerable activity in prospecting for alternative aggregate sources close to the major area of demand, namely the Cape Peninsula. Further afield where single major concrete constructions are in the offing and the various preventative measures against alkali-aggregate reaction must be considered, for their economic implications, much attention must also be given to the potential alkali reactivity of the available aggregate sources. It is, therefore, logical that the demand for quick and reliable evaluation of such aggregates is at a premium.

Petrographic examination. Provisional screening of aggregates for potential alkali reactivity by petrographic methods will obviate a large amount of unnecessary long-term testing if it can be applied successfully.

The recognition of potentially alkali-reactive aggregates containing reactive forms of silica such as tridymite, cristobalite, chalcedony and opal, chert, flint and intermediate-to-acid volcanic glass such as is likely to occur in rhyolite, andesite or dacite, should in general not present problems. Furthermore, based on their service record in the South Western Cape Province, the mere identification of a rock as a phyllite, hornfels or greywacke should immediately classify it as a potentially alkali reactive aggregate without further qualification of the type and amount of reactive constituent it contains.

Serious difficulty is, however, experienced with the petrographic screening of rocks containing quartz such as granite, granite gneiss, quartzite and quartzarenite containing quartz with crystal lattice irregularities, for potential alkali reactivity. Gogte[11] has found a correlation between the expansion of mortar prisms stored over water in sealed containers at 50 °C and the amount of quartz in a rock showing strong undulatory extinction and other strain effects observed under the microscope.

At the NBRI the evaluation of such rock types is still to a great extent subjective and is based on the amount of

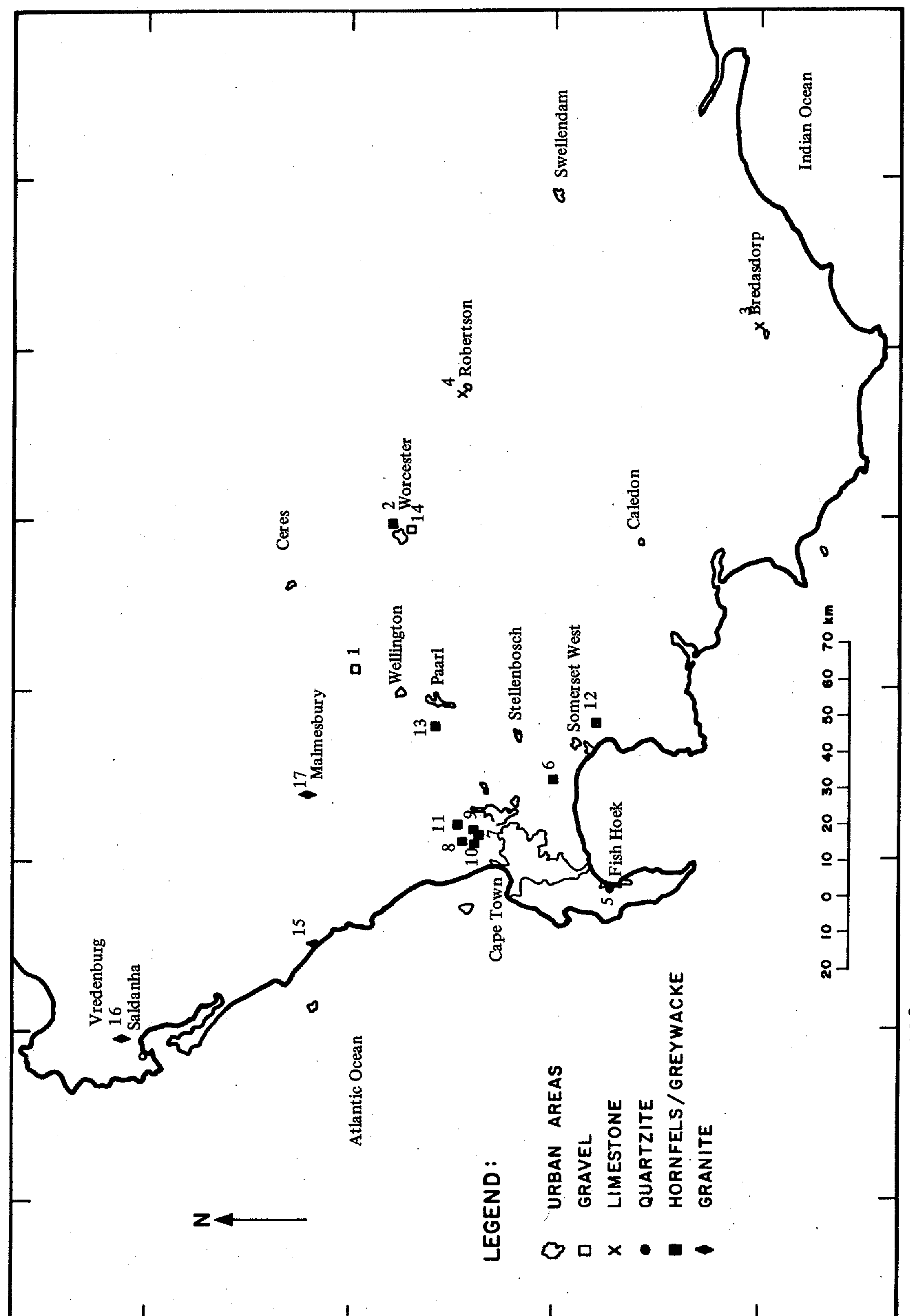

FIGURE 4 : Localities of aggregate quarries

quartz present in a rock showing the following strain effects as described by Young[12]: 'sutured or crenulated crystal-crystal contacts, deformation bands, undulose or segmented extinction, bimodal distribution of and elongation of grains.' Undulatory extinction alone, without other deformation effects is not regarded as indicative of expansive alkali reactivity.

Figure 5 shows a photomicrograph of a thin section of a gneissic granite which expanded slowly in combination with a high alkali cement in the mortar prism test ASTM C227-71[2]. Figure 6 is a photomicrograph of a quartzite which expanded as much as the most reactive Malmesbury aggregate examined to date.

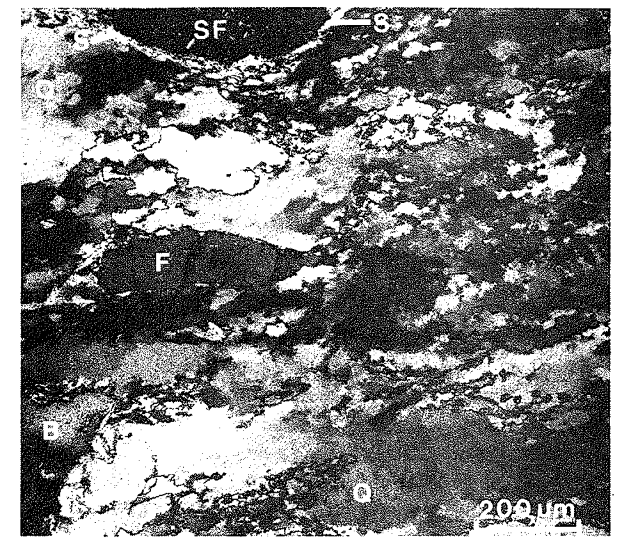

FIGURE 5: Thin section of a gneissic granite showing extremely strained nature of quartz. Crossed nicols. Q = quartz, F = feldspar, B = biotite, S = sericite, SF = sericitised feldspar

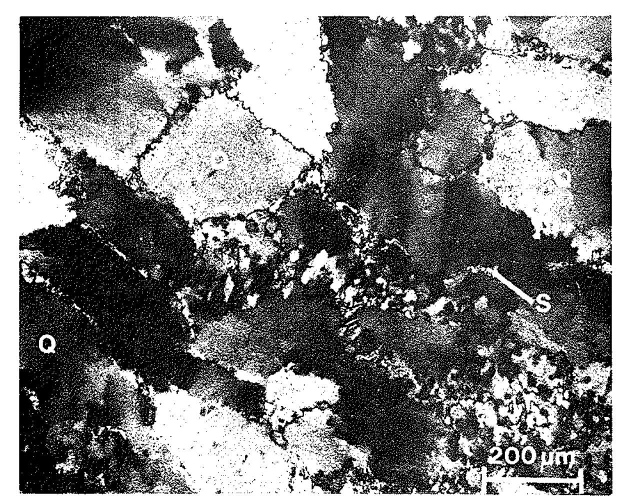

FIGURE 6: Thin section of quartzite aggregate displaying undulose extinction, sutured boundaries and mortar structure of quartz. Crossed nicols. Q = quartz, S = sericite

Chemical method ASTM C289-71[13]. The chemical method for the determination of the potential reactivity of an aggregate, if it could be applied reliably to distinguish innocuous from potentially deleteriously reactive aggregates, would be very useful since results could be obtained within a short time. However, to date this method could not be applied with confidence at the NBRI. In general, the following trends have emerged from the relatively small amount of data obtained. Malmesbury Group greywacke and hornfels give Sc values (silica dissolved) of generally less than 60 millimoles per litre and Sc/Rc values greater than one, although at least one relatively very reactive hornfels had a value of less than one. The silica dissolved varies between about 0,2 and 0,4 per cent (ie about 32 and 65 millimoles/litre) and the amount of expansion measured with the mortar prism test[2] does not necessarily increase with an increase in the amount of silica dissolved.

For granites the Sc values are generally below 30 millimoles/litre; however, one sample which gave a high expansion in the concrete prism test had an Sc value of 33 millimoles/litre and an Sc/Rc = 0,89.

The quartzites generally give Sc and Sc/Rc values in the same range as the greywackes and hornfelses. One quartzite that was judged potentially alkali reactive by the mortar prism test[2] gave an Sc value of 55 millimoles/litre and Sc/Rc = 1,49.

More information about the results obtained with the chemical method on Malmesbury aggregates is given in the paper by Brandt et al[14].

Mortar prism method ASTM C227-71[2]. Method ASTM C227-71 is probably the most useful method for reproducing expansion due to alkali-aggregate reaction in the laboratory. The notes and subtle sentences accompanying it indicate a very well founded test method. However, because of the complex nature of the problem, there are certain difficulties and inconsistencies which confront the inexperienced investigator especially when examining aggregates such as hornfels, greywacke, granite, quartzite, quartzarenite, etc.

The method is firstly suitable for the investigation of the potential alkali reactivity of a particular cement-aggregate combination for use in a particular job, in which case the only requirement regarding the cement is that it should be representative of the cement to be used for the entire structure and that the alkali content should be higher than 0,6 per cent Na_2O equivalent.

Secondly, besides systematic evaluation, the method can be used for making comparisons between the potential alkali reactivity of aggregates, in which case the basic approach should be to use a standard reference cement with the highest possible alkali content defined in terms of active alkali content or of reactivity with an alkali reactive aggregate. There is, however, one proviso, namely that the aggregate does not show a pessimum effect. If it is an aggregate

that shows a pessimum effect, a series of prisms, containing different amounts of the aggregate, must be made.

Therefore, the feeling at the NBRI is that in the application of ASTM C227-71 to the assessment of aggregates one of the first steps should be to standardise the cement used for the tests.

The next step is to establish criteria for distinguishing innocuous aggregates from potentially deleteriously reactive aggregates. Although their service record has proved the Malmesbury aggregates to be deleteriously alkali reactive, about 90 per cent of the samples tested to date in combination with a selected high alkali cement (Na_2O equivalent 1,3 per cent) are classed as innocuous according to the criteria of ASTM C227-71.

Apart from the limits given in ASTM C227-71 several other criteria have been proposed for the assessment of the potential alkali reactivity of aggregates when using the basic procedure of ASTM C227-71; some criteria are summarised in Table 2. From the table it is seen that for some of the criteria a fixed Na_2O equivalent is specified. However, there are still some uncertainties, such as:

(a) The total alkali content is not necessarily a measure of the active alkali content as mentioned earlier.

(b) It is not stated whether the criteria still apply if a cement with a higher alkali content is used and whether a higher expansion rate applies if the alkali content is higher.

(c) Likewise, it is not stated how the criteria should be adjusted if a cement with a lower alkali content is used.

Therefore, the current consensus of opinion at the NBRI is that limits cannot yet be set for the rate of expansion that would distinguish innocuous from deleteriously expansive aggregates. It is also not clear whether the same rates of expansion can be applied to different types of aggregate. For example, should quick expanders such as opal-containing rocks and slow expanders such as greywackes, hornfelses and granites, be assessed in the same way?

Data obtained on the alkali reactivity of Malmesbury Group aggregates are discussed in the paper by Brandt et al[14].

Concrete prism method. This method has the advantage that the materials can be used in the proportions and grad-

TABLE 2 : Summary of some criteria that have been proposed to judge aggregates for potential deleterious alkali reactivity by the mortar prism and concrete prism tests. Storage conditions: over water in sealed containers at 38 °C.

Source	Type of prism	Na_2O eq of cement, per cent	Criteria : Expansion
ASTM C 227-71[2]	Mortar	> 0,60	1. More than 0,05 per cent at 3 months 2. More than 0,10 per cent at 6 months
ASTM C 289-71[13]	Mortar	1,38	More than 0,1 per cent in a year
DUNCAN et al[15]	Mortar	1,00	0,05 per cent at 72 weeks
MAJID and GRATTAN-BELLEW[16]	Mortar	1,08	Slope of regression line more than 18 x 10^{-5}, ie equal to 0,032 per cent at 180 days or 0,065 per cent at 365 days*
DUNCAN et al[15]	Concrete	0,90	0,05 per cent at 120 weeks
GRATTAN-BELLEW[17]	Concrete	1,08	Slope of regression line more than 20 x 10^{-5}, ie equal to 0,036 per cent at 180 days or 0,073 per cent at 365 days*

* Calculated from the equation y = mx for a straight line passing through the origin where y = % expansion, x = age in days

ings intended for the actual construction. Also, the objection that some coarse aggregates when crushed to sand size may give increased expansion in the mortar prism test owing to the increased surface exposed upon crushing is eliminated.

In general, at the NBRI, expansions of the same order have been obtained with concrete prisms and mortar prisms for Malmesbury Group aggregates. However, for granites higher expansions are obtained with concrete prisms than with mortar prisms and for quartzites higher expansions are obtained with mortar prisms than with concrete prisms.

Some of the criteria proposed for the evaluation of the potential alkali reactivity of aggregate with the concrete prism method, are also summarised in Table 2. At present the NBRI cannot propose rates of expansion for the concrete prism method to separate innocuous from deleteriously reactive aggregates.

Rock core method. The results obtained with the rock core method are discussed fully in the paper by Brandt et al[14]. Suffice it to say that if the expansion results from the alkali-silica reaction, it is difficult to envisage how the rock cores could expand in a medium where the alkali-silica reaction product would be in the sol state.

Service record. The NBRI agrees with the approach of Mather[18] that a fine or coarse aggregate will be classed potentially deleteriously reactive when service records show that deleterious reactions have occurred in a structure in which the aggregate has been used. However, some workers, by analogy to the above approach want to extend it to one which says that a fine or coarse aggregate will be evaluated as innocuous when existing service records show that deleterious reactions have not occured in structures in which the aggregate has been used (in combination with a high alkali cement). Great caution should be applied in the rigid application of an approach such as the latter.

Specification. The South African Specification for aggregates from natural sources, SABS 1083-1976[19] contains no procedure for the assessment of the potential alkali reactivity of aggregates. The reason for this is that at the present time and for the methods currently in use it is felt that no limits can be proposed that would separate innocuous from potentially deleteriously alkali reactive aggregates, and which could be universally and with confidence applied to the variety of aggregates found in South Africa. However, reference to the problem is made and a list of the rock types that may cause problems in combination with a high alkali-cement appear in an appendix to the specification.

Exposure of test specimens to natural environmental conditions. To establish the correlation between results obtained with mortar and concrete prisms under laboratory test conditions and concrete in practice, 300 - mm concrete cubes and concrete beams measuring 1000 x 450 x 300 mm are being exposed to natural environmental conditions at the NBRI test site in Cape Town. Hopefully, results obtained from these specimens will assist in establishing criteria for the evaluation of potentially alkali reactive aggregates with the mortar and concrete prism methods.

Alkali-aggregate reaction in other areas in South Africa. In their paper presented at this Conference Blight et al[20] report on alkali-aggregate reaction in concrete made with Witwatersrand quartzite. The NBRI has examined one sample of Witwatersrand quartzite aggregate and found it to be potentially deleteriously alkali reactive. In the Eastern Cape Province (Port Elizabeth and its environs) where only high alkali cement was produced in the past, a small number of concrete structures built with Table Mountain quartzite show cracking which resembles expansion due to alkali-aggregate reaction. From a provisional field survey it was concluded that some of this cracking is caused by the shrinkage of concrete (due either to the use of shrinking aggregate or to high water content) and some of it possibly by the alkali-aggregate reaction. However, this is subject to confirmation. The mortar prism test ASTM C227[2] has shown some of the quartzite aggregates from that area to be deleteriously expansive with a high alkali cement (Na_2O equivalent > 0,80 per cent).

Preventive measures. In NBRI information sheet X/BOU 2-47[21] precautions to mitigate alkali-aggregate reaction are given and in the paper by Flanagan[22] to be presented at this Conference, some practical preventive and remedial measures are also discussed.

However, preventive measures normally appear more straight-forward than they are in practice. Many consultants might tend to write the guidelines given in the NBRI information sheet into their specifications instead of evaluating all the factors involved for a particular construction and then taking a decision based on a certain risk factor which cannot be eliminated.

For example, based on the results obtained initially with concrete prisms on a very reactive Malmesbury aggregate and a cement with an Na_2O equivalent of not much higher than 0,6 per cent, the NBRI recommended that when using Malmesbury aggregate the total alkali content of the mix should not be more than 2,1 kg/m^3. Numerous subsequent results have shown that there is a wide range of reactivity in Malmesbury aggregates and that in more than 90 per cent of the cases deleterious expansion in the laboratory probably only takes place at a total alkali content of 2,8 kg/m^3 (ie 0,8 per cent Na_2O equivalent and 350 kg cement per m^3 of concrete). Therefore, the consultant could probably recommend that Malmesbury aggregate can be used for a structure provided that the total alkali content does not exceed 2,45 kg/m^3 (ie 0,7 per cent Na_2O equivalent for 350 kg cement/m^3 of concrete). However, this is a decision he must take for himself.

For alternative aggregates such as granites and quartzites the situation must be assessed. The majority of granite aggregates examined to date are not deleteriously expansive, but a certain percentage is. Therefore, although granite aggregates can generally be used with a cement with

an Na_2O equivalent as high as 1,0 to 1,3 per cent (ie 3,50 to 4,55 kg Na_2O m^3) a certain risk is involved. With some Table Mountain quartzites yet another situation arises.

Concrete prisms made with these aggregates usually expand slower and less than Malmesbury aggregates, but mortar prisms have a higher rate of expansion. Therefore, although it appears that reactive quartzites can be used provided the alkali content of the concrete does not exceed say 2,8 kg/m^3, the mortar prism test seems to indicate that this figure must be reduced if crushed quartzite is used as sand.

It is, therefore, clear that there is a range of reactivities for aggregates and consequently that there is no clear cut-off point for the alkali content of a cement beyond which expansive alkali-aggregate reaction will not take place. At a rate of 500 kg cement per m^3 of concrete a cement with an alkali content of 0,6 per cent Na_2O equivalent (ie a low alkali cement per specification) can result in deleterious expansion in combination with a suitably reactive aggregate.

With regard to the use of mineral admixtures to prevent alkali-aggregate reaction, the paper by Oberholster and Westra[23] to be presented at this Conference discusses some of the work done to date on this subject in South Africa, while the paper by Johnson[24] will elaborate on practical experience with the use of pfa in ready-mixed concrete in Cape Town. The mechanisms for drawing up a standard SABS specification for pulverised fuel ash, natural pozzolans and calcined argillaceous materials have been set in motion and naturally the aspect of alkali-aggregate reaction will receive attention in the specification.

Prevention of expansive alkali-aggregate reaction in existing concrete which was built with potentially reactive combinations presents a difficult problem. Field experiments, to test a variety of coatings which could prevent the ingress of water are in progress. Some of these coatings are completely impervious and will also prevent water from moving out of the concrete while others are of the breathable type and will allow relatively free outward movement. It is, however, too soon to report definite results.

Remedial measures. To date remedial measures have been applied very much on a hit or miss basis. These amounted mainly to the grouting of wide cracks with epoxy mortar or polysulphide rubber and the application of impervious coatings to hide unsightly map cracking. It has been observed that the risk of cracks opening up through these coatings is high and that care should be exercised on walls that are continuously exposed to moisture on the back face. This could result in a moisture build-up behind the coating.

In October 1979 the Department of Roads of the Cape Provincial Administration commenced the evaluation of a range of surface treatments as a rehabilitation measure on approximately 2 km of the west-bound carriageway of the concrete road near the interchange leading to the D F Malan airport. At the same time the Division of National Roads of the Department of Transport and the Cape Provincial Administration jointly requested the NITRR to evaluate the synergistic effects of the alkali-aggregate reaction and traffic by means of accelerated trafficking tests of the N2 concrete pavement with a view to potential rehabilitation measures. Papers on this subject will be given by Freeme and Shackel[25] and van der Walt et al[26] at this conference.

6. SUMMARY

Alkali-aggregate reaction in concrete was first tentatively diagnosed in South Africa in 1974 and confirmed in 1976.

Initial research was aimed at establishing the extent of the problem, evaluating aggregates and cements with existing methods and against different criteria for their reactivity, developing suitable methods and criteria for assessing aggregates and cements in respect of alkali reactivity, evaluating mineral admixtures for use in the prevention of alkali-aggregate reaction and systematically collecting laboratory and field data to assist in advising the construction industry on practical preventive and remedial measures.

Where the first three years were devoted mainly to the collection of information that would partly satisfy the demand of the construction industry for help and advice on the problem, emphasis in the second phase will shift to more theoretical aspects to establish the reaction mechanism and kinetics of the alkali-aggregate reaction.

ACKNOWLEDGEMENTS

The contributions by Messrs M P Brandt, W B Westra and K C E Putterill of the NBRI and Mr C Semmelink of the NITRR to this project are gratefully acknowledged.

The research was carried out by the NBRI under the guidance of the Technical Steering Committee Investigating the Deterioration of Concrete in the South Western Cape Province, with financial support from the Cape Provincial Administration (Department of Roads), the Department of Transport, The Electricity Supply Commission (ESCOM), the National Institute for Transport and Road Research, the Portland Cement Institute, the Quarry Owner's Association of the Western Province, Ready Mixed Concrete (Cape) and the South African Railways and Harbours.

DISCUSSION

Mr E H J van Rensburg (Murray & Roberts, Cape Town) asked whether it was correct to assume that the total alkali per unit volume of the concrete was more important than the alkali content of the cement alone. If this supposition were correct, and the use of a reactive aggregate was unavoidable, he asked whether the degree of manifestation of the reaction would not be reduced by using both crushed fine and coarse reactive aggregate, as the concentration of alkalis per unit mass of reactive aggregate would then be decreased relative to the use of reactive coarse aggregate alone.

Dr Oberholster replied that in the first instance, it had been recognised that the alkali content per m³ of concrete was the significant factor, and not the alkali content of just the cement. Secondly, initially the possibility of the aggregate itself acting as, for example, a pozzolan had been examined but the Malmesbury aggregate had not been found to be useful at all. Although it could have certain effects, for instance with a quartzite aggregate, where higher expansion was found with mortar prisms than with concrete prisms the researchers were uncertain in which way the criteria should be adjusted. Could one expect a higher expansion for example if a crushed quartzite were used as fine aggregate together with the quartzite coarse aggregate or was the expansion going to be less?

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