J.W. Figg:

PRELIMINARY APPRAISAL OF PROBLEM AREAS AND REACTIVE AGGREGATES WITH APPROPRIATE PREVENTIVE MEASURE

THIS PAPER INTRODUCES THE DRAFT DEFINITIVE BIBLIOGRAPHY ON ALKALI-AGGREGATE (ALKALI-SILICA AND ALKALI-SILICATE) REACTIVITY AND RECORDS SOME OBSERVATIONS ON THE FAILURE MODE OF CONCRETES AFFECTED BY ALKALI REACTIONS AND PRECAUTIONS AGAINST DELETERIOUS REACTIVITY.

The Cement & Concrete Association, on behalf of CEMBUREAU is undertaking a study on alkali-aggregate (alkali-silica and alkali-silicate) reactivity, which is intended to provide information for the cement industry and its advisory service on the problem and will attempt to summarise current thinking on the most acceptable methods of combatting it.

The first step in the preparation of this Report has been the compilation of a comprehensive bibliography on the subject(1). This compilation has been prepared from the library resources of the Building Research Establishment, England; the Cement & Concrete Association, England; the Concrete Research Laboratory, Denmark; Engineering and Resource Consultants Ltd, England; the Transportation Research Board, USA; the Transport and Road Research Laboratory, England; and the Portland Cement Association, USA; with additional assistance from a number of individuals especially Prof S Diamond, Purdue University, USA; Bryant and Katherine Mather, Waterways Experiment Station, US Army Corp of Engineers, Prof A Poole, Queen Mary College, University of London; and Dr P Sereda and Dr V S Ramachandran, National Research Council, Division of Building Research, Canada. The bibliography, containing about 500 references is intended to cover all the work published on the subject of alkali-silica reactions in concrete up to the end of 1974. A search with the Science Citation Index using a ten per cent sample of the references revealed that the literature recovery includes at least 98 per cent of all published articles on the subject. Comments on the draft Bibliography regarding errors, omissions etc will be gratefully received.

To date the CEMBUREAU study has been an information-gathering exercise through literature searches, discussions with researchers and experienced concrete practitioners, and by inspections of structures known to be affected by alkali-silica reactivity. However some preliminary observations and tentative conclusions are presented here to stimulate discussion and comments which will be of value for the CEMBUREAU Report.

Concrete affected by alkali-aggregate reactivity often has a characteristic appearance. Early workers recorded the incidence of map-cracking, pop-outs, gel exudation and damp spots. Not all features are observed on any one particular structure but certain similarities do exist wherever in the world the concrete is situated. For example Figures 1 and 2 are of concrete in North America and Europe respectively, which bear a remarkable similarity to one another.

Another feature which seems to occur over and over again is that of three cracks originating from a single point and radiating at approximately 120^{o} with respect to one another. Often gel may have leached from the concrete to emphasise the crack near the "hub" by forming a smooth and possibly stained area each side of the crack. Such "Isle of Man" cracks - so called because of the similarity to the "Three legs" emblem of this Island (Figure 3) - are illustrated in Figures 4 and 5 which are of concretes photographed in North America and Europe respectively. Presumably the 3-point crack formation is an expression of the tensile stresses induced in the concrete by an expanding aggregate particle or particles not too far from the surface. The predominance of threefold over other multiple cracks is not yet explained.

However the corollary of the above observations, namely that a certain crack pattern is indicative of alkali-aggregate reactivity is certainly not valid. Thus figures 6 and 7 show rather similar cracks in concrete, both with brown staining adjacent to the cracks, both taken in the same Country, but whereas Figure 6 is of concrete affected by alkali-aggregate reactivity, Figure 7 is an example of extreme drying shrinkage. The formation of cracks is the response of the concrete to an applied force greater than the tensile strength of the material. In itself the cracking tells nothing of the underlying causes of the distress although other features associated with the cracking may well provide a clue.

Damage to concrete structures in the field is very rarely due to one single cause, almost invariably other factors will be concerned such as carbonation of cement paste, rusting of embedded steel reinforcement, sulphate attack, wetting and drying, and freezing and thawing. In Northern climates the eventual break-up of the concrete is almost always due to frost damage after the initial 'opening-up' of the concrete through alkali-silica reactivity.

The types of aggregate which may be or have been associated with occurrences of alkali-silica reactivity include sedimentary rocks which contain finely-divided or high surface area silica minerals, especially opaline silica and porous chert or flint; igneous rocks of acid composition, volcanic rocks of intermediate composition and certain rocks of basic type which contain acid glassy phases. Metamorphic rocks containing strained or complex-boundary quartz crystals may also be classified as reactive. Comprehensive lists of reactive concrete aggregates have been presented by J E Gillott [2] and H E Vivian[3] at this Symposium.

The most effective method of identifying a potentially reactive aggregate is examination of the material by a trained and experienced petrographer. It must be emphasised that such an examination can only identify POTENTIALLY deleterious materials, proof of reaction and damaging expansion requires supplementary tests. Most rapid test methods depend on immersion of the suspect aggregate in alkali solution for various periods, the combination is then examined for the development of an alkali-silica gel (as in the Gel-Pat test), the dimensional increase of the aggregate may be shown by Scanning Electron Microscopy (J E Gillott) or the alkali solution may be chemically analysed for dissolved silica and reduction in alkalinity (as in the Rapid Chemical Test). The Gel-Pat and Rapid Chemical Test prove only reaction between the aggregate and alkali, the SEM method permits expansion to be demonstrated. The expansion bar test is less useful in that it is a highly empirical and lengthy procedure, on the other hand it does provide a quantitative measure of the expansion of an aggregate which may then be compared with other aggregates tested under the same conditions. The "Large Cube" test[4] developed in Germany at the Verein Deutscher Zementwerke laboratory offers a simple and reliable method of testing aggregate and cement combinations. The cube dimensions (300 x 300 x 300mm) are large enough to permit the use of full size aggregate and for a moist internal environment to be maintained. Although tests at elevated temperatures from the more typical appearances at ambient temperature, (e.g. Figure 8).

The "pessimum" condition for any particular aggregate/cement/environment combination may include factors which in more normal circumstances would be considered good concreting practice. Thus the use of high cement content and low water/cement ratio is usually considered to result in a durable concrete. However, when reactive aggregates may be involved such a mix formulation may result in the introduction of large amounts of alkali into the concrete via the cement which together with concentration of the alkali in the pore fluid, can cause a deleterious alkali-silica reaction to occur. On the other hand the same concrete would have a high strength and therefore would be better able to withstand any internal expansive forces, it would also have a minimum permeability for the water which must be present for the expansive reaction to occur. The conflicting requirements between prevention of deleterious alkali reactions on the one hand and the manufacture of high quality concrete on the other may help to explain some of the different recommendations which have been made for the avoidance of alkali-silica reactivity.

Thus even cements of relatively low alkali content may in fact introduce a sufficient amount of alkali to give a damaging amount of expansion with an aggregate containing only a small proportion of reactive material when a high cement content mix is used. The other well-tried remedy of incorporating a pozzolan to react with the alkali derived from a Portland cement may, for a very high strength concrete demand the addition of so much pozzolan that the desired properties of the concrete cannot be attained. It is important that the properties of the cement and pozzolan should be matched in order to obtain optimum performance and the choice of a non-Portland type cement may be appropriate.

Modern accelerated curing techniques whilst taking maximum advantage of the strength gain which is possible may also induce alkali-silica reactions which would never develop with conventional low-temperature curing. The prestressing of concretes in which alkali-silica reaction has occurred can result in modification of the crack pattern in accordance with the Le Chatelier principle that the response of a system to an applied constraint is to move in such a way as to relieve the applied stress e.g. by cracking. In this case the major concern will then be the risk of corrosion of the prestressing steel.

Earlier recommendations have simply applied a blanket restriction on the alkali content of the cement when an alkali-susceptible aggregate has been identified. Such restrictions are over-cautious since they do not take account of environmental factors and are also expensive if cement must be specially obtained. The need for energy conservation also will effect the availability of cements of low alkali content. A more careful classification of the exposure condition of the concrete and considered use of aggregate selection and/or benefication are all practical remedies.

These and other factors will be considered in the CEMBUREAU Report.

REFERENCES

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3. H E Vivian
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FIGURE 1 Surface appearance of concrete affected by alkali-silica reactivity (N America)

FIGURE 2 Surface appearance of concrete affected by alkali-silica reactivity (Europe)

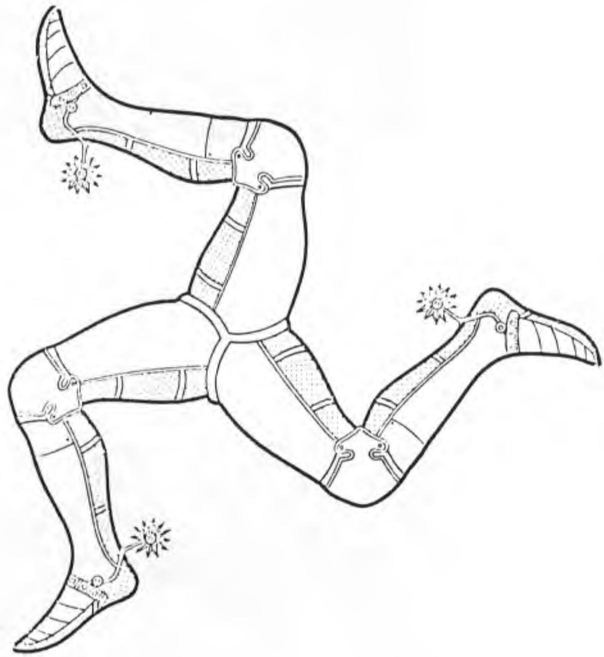


FIGURE 3   Isle of Man "three-legs" emblem

FIGURE 4 "Isle of Man" cracks on surface of concrete affected by alkali-silica reactivity (N America)

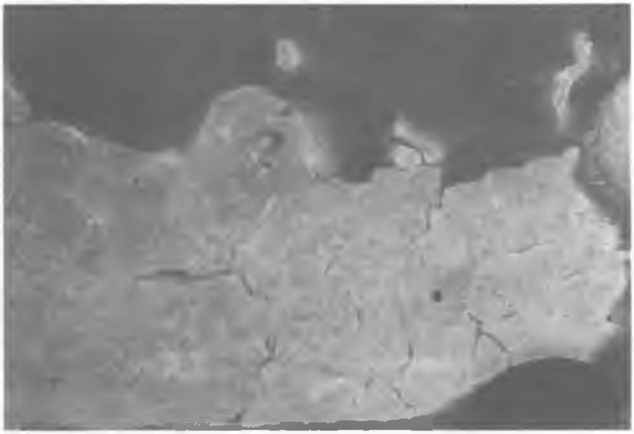


FIGURE 5 "Isle of Man" cracks on surface of concrete affected by alkali-silica reactivity (Europe)

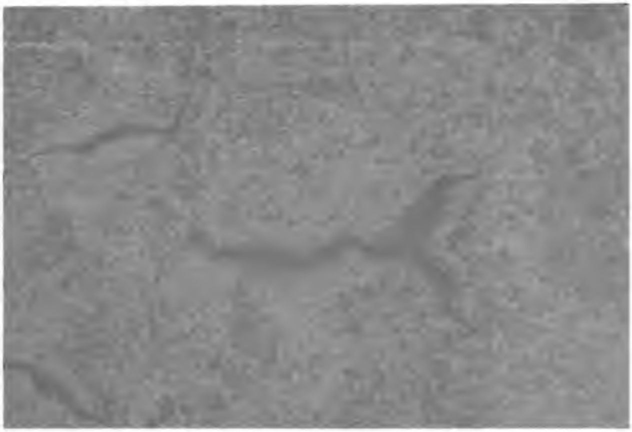
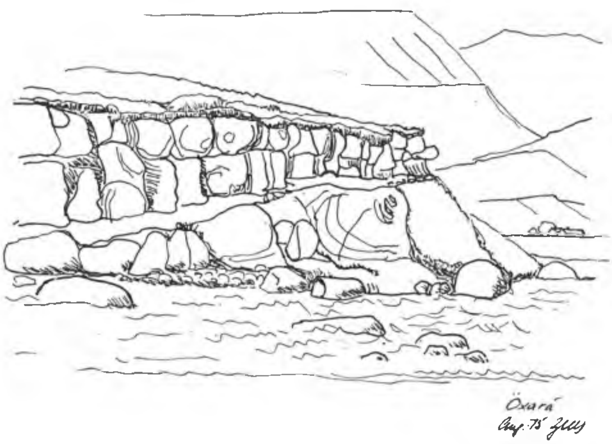


FIGURE 6 Cracking, gel exudation and staining of surface of concrete affected by alkali-silica reactivity

FIGURE 7 Cracking and staining of concrete due to extreme drying shrinkage

FIGURE 8 VDZ "Large cube" test for assessing reactivity of cement and aggregate combinations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