8th ICAAR 1989 KYOTO

8th Internationl Conference
on Alkali–Aggregate Reaction

APPRAISAL OF THE STRUCTURAL EFFECTS OF ALKALI–SILICA REACTION

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1. INTRODUCTION

There is a wide range of structures in the UK potentially affected by AAR, including bridges, buildings, hydraulic structures, car parks, grandstands and foundations of various types. Although the number is not very great there is the potential involvement of a significant number of engineers in their appraisal and management. In order to augment the rather general guidance available on structural appraisal [1] the Institution of Structural Engineers has just published interim technical guidance on the structural effects of Alkali Silica Reaction [2]. This draws on UK case histories which are being compiled into a database by the Building Research Establishment (BRE).The sparsity of information on these effects means that the document will need to be developed and extended in the light of further data, research and experience, probably in a year or so. The purpose of this paper is to outline the approach adopted in reference 2 and to identify the areas of greatest uncertainty.

2. EFFECTS OF ASR

After summarising the development of ASR damage in UK structures, the report [2] outlines the chemical process of alkali-silica reaction but relies on other references, such as [3], for a fuller discussion. The physical effects are summarised in terms of the local swelling pressures of pore gels, the variability of expansion which may be observed at the scale, typically, of cores, the general nature of cracking in larger volumes of concrete and the changes in physical properties and the timescale at which they may occur. The relevance of various types of measurement is the subject of continuing debate and study [4].

ASR is generally very variable, even within a single structural element, and therefore leads to differential expansion with physical effects of the following forms: fine microcracking through and around individual expansive particles; map-type macrocracking arising from the variability of expansion between adjacent small volumes of concrete within a pour; differential movements between separate pours of concrete, expanding at different rates; modifications to crack patterns and/or curvatures because of restraint of expansion by reinforcement and/or applied or developed stresses; increased tensile strains in reinforcement, and increased bond stresses beween steel and concrete.

There is mounting evidence that restraint and reinforcement influence crack patterns and bond but the observed effects on structural elements in service are not sufficiently numerous and consistent to allow confident conclusions to be drawn. Differences in design and detailing practice need to be assessed particularly carefully when comparing data from different countries. Bond and bearing strength also need to be related to appropriate measures of basic concrete strength.

3. EXPANSION AND CRACKING

ASR will generally be suspected either on the basis of unexplained cracking in the structure or because construction records show that the specification for the concrete used is the same or close to one that has proved to be damaging in other structures. In the case of cracking the engineer must review the range of other possible structural [1] and nonstructural [5] reasons for cracking. Where cracking cannot be clearly attributed to other causes the procedures for ASR diagnosis [6] can be used. However, such procedures must be integrated into the overall structural assessment in terms of the selection of samples and tests.

A flow chart and accompanying notes have been developed to assist in providing a logical appreciation of the factors involved in the appraisal of a structure in which ASR is believed to be a relevant factor.

In order to estimate the total expansion it is necessary to estimate the two components of expansion separately: first, the expansion that has occurred up to the time of the investigation (current expansion); and secondly, the potential for future additional expansion that will have occurred when the alkali-silica reaction is exhausted (potential additional expansion: additional from cores + estimated long-term additional). The relationship between current and potential additional expansion is illustrated on Figure 1, where the various components have been referenced. Approaches to assessing these components are suggested [2], although more research is needed to develop reliable practical guidance. The estimated maximum potential free expansion and the estimated current free expansion can be combined as shown in Figure 2 to define an expansion index.

4. APPRAISAL OF STRUCTURAL STRENGTH

4.1 Two structural appraisals are usually required: one based on the current condition of the structure; and one based on the estimated condition of the structure at some specified time in the future. Guidance is given on structural appraisal in terms of five levels (figure 2) of severity of the total ASR expansion that is estimated to have occurred (or is predicted to occur) at the time of interest (ie either now or at some specified time in the future).

The five levels of expansion are related to three classes of reinforcement detailing: **Class 1:** a 3-dimensional cage of very well anchored reinforcement; **Class 2:** a 3-dimensional cage of conventionally anchored reinforcement, and **Class 3:** a 1- or 2-dimensional cage of reinforcement, or a 3-dimensional one that is inadequately anchored. Examples of these Classes for a wall are shown in Figure 3. If turned through 90°, the three diagrams also illustrate the Classes for the reinforcement at the edge of a slab, or end of a beam.

Generally, the efficiency of reinforcement in maintaining the integrity of a structure depends on the degree of containment it provides to the differential expansion. Parts of the structure with reinforcement of Class 1 or 2 that are moderately stressed by dead and imposed loading will be little affected even by fairly severe ASR expansions, whereas a similar degree of expansion in parts of a structure with Class 3 reinforcement may produce severe structural effects, even when the stresses from dead and imposed loading are light.

4.2 Expansions of the order of 0.4 mm/m occur in normal concrete, and are of no concern even if ASR has been identified petrographically. Provided that the structure has been properly designed and has reinforcement corresponding with Class 1 or Class 2, ASR expansions up to 0.6 mm/m will only marginally affect the strength.

4.3 Expansions in the range 0.6 to 0.9 mm/m do not affect the compressive strength of the concrete significantly. The reductions in concrete tensile strength may adversely affect behaviour in shear and bond, although, provided that the structure is detailed as Class 1, any shortfall may, again, be assumed to be covered by the normal safety factors. However, Class 2 or Class 3 detailing must be assessed with care.

4.4 For structures with expansion in the range 0.9 to 1.5 mm/m, mild-steel reinforcement may yield, and a detailed appraisal will be necessary, with full consideration of potential reductions in bending and compression capacities as well as of shear and bond. Danish and Japanese tests have indicated increases in shear strength of ASR-affected beams but the majority of the Japanese beams that failed in shear had good end anchorage to the main reinforcement and the percentage of steel was often greater than in the UK because of seismic loading.

On bond, a pro rata reduction in strength should be taken in proportion to the reduction in concrete tensile strength. In this expansion range the Brazilian cylinder splitting and the internal gas pressure [7] tests give different answers, and it will be a matter of judgement as to the reduction in tensile strength that will be appropriate in a given case. Specific guidance on the contribution from links still has to be derived.

4.5 For expansion of 1.5 to 2.5 mm/m, high-yield steel may yield, and a detailed appraisal is required. The comments above are applicable.

4.6 At expansions greater than 2.5 mm/m each structure will have to be the subject of special study, testing, appraisal and monitoring, which might include load testing.

5. APPRAISAL OF STRUCTURAL SERVICEABILITY

Without minimising the importance of serviceability it is sufficient here give the main considerations: appearance, cracking and corrosion in reinforced or prestressed concrete, deformations of structural members, deformations in mass concrete, frost resistance and fire resistance.

6. MANAGEMENT AND MONITORING OF ASR-AFFECTED STRUCTURES

Experience so far indicates that significant remedial measures are seldom needed urgently. Rather, a period of observation, monitoring and considered evaluation will be repaid by a more reliable prognosis of long term performance and more cost-effective actions. A procedure is suggested which enables a severity rating to be given to each member of a structure with guidelines for inspection frequency, water and chemical exclusions, strengthening or load restrictions. A logic diagram and accompanying notes [2] explain the guidelines recommended for the management of structures.

6.1 Structural severity rating

Table 1 summarizes the way in which the structural severity rating is assessed. The first parameter introduced is the expansion index and the second parameter is the site environment, classified as 'dry', 'intermediate' or 'wet'.

The third parameter is the quality of detailing found in the structure (Figure 3) and the fourth parameter leading to the structural severity rating is the seriousness of the consequence of failure: 'slight' means that the consequences of structural failure are either not serious or are localized to the extent that a serious situation is not anticipated, and 'significant' that there is a risk to life and limb or a significant risk of serious damage to property.

The logical approach inherent in Table 1 should facilitate decisions on managing a structure suffering from ASR, with suitable management procedures summarised in Table 2.

6.2 Monitoring

This should be designed to afford systematic information on crack geometry and behaviour, and should also review the effectiveness of measures to exclude water from the structure. It should also include the recording of deformations, movements and clearances at joints. The suggested frequency of monitoring depends on the structural severity rating as discussed above and summarised in Table 2.

7. ACKNOWLEDGEMENTS

The authors are grateful to the Institution of Structural Engineers for th opportunity to draw freely on Reference 2, and particularly their colleagues in drafting it. This paper is published with the permission of the Director of the Building Research Establishment.

8. REFERENCES

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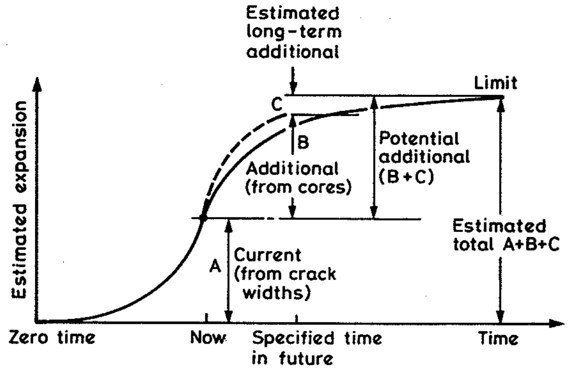
Table 1 Structural severity rating

site environment	reinforcement detailing Class	expansion index of ASR I: Sli	I: Sig	II: Sli	II: Sig	III: Sli	III: Sig	IV: Sli	IV: Sig	V: Sli	V: Sig
		consequence of further deterioration									
dry	1	VM	VM	VM	M	M	M	S	S	SV	VSV
	2	VM	VM	VM	M	M	M	S	SV	VSV	VSV
	3	VM	VM	VM	M	M	S	S	SV	VSV	VSV
intermediate	1	VM	VM	VM	M	M	S	S	SV	VSV	VSV
	2	VM	VM	M	M	S	S	SV	VSV	VSV	VSV
	3	VM	VM	M	M	S	SV	SV	VSV	VSV	VSV
wet	1	VM	VM	M	S	S	SV	SV	VSV	VSV	VSV
	2	VM	VM	S	S	SV	SV	VSV	VSV	VSV	VSV
	3	VM	M	S	S	SV	SV	VSV	VSV	VSV	VSV

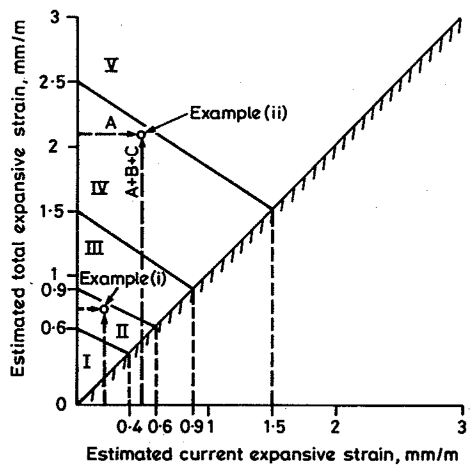
Legend
Sli: the consequence of structural failure is either not serious or is localized
Sig: there is risk to life and limb or a significant risk of serious damage to property
Structural severity ratings:
VM: very mild
M: mild
S: serious
SV: severe
VSV: very severe

Table 2 Summary of management procedures

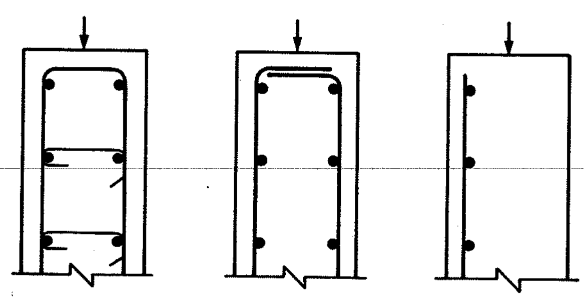
structural severity rating	*summarized management procedure*
very mild	routine inspections at the frequency that is generally accepted for the type of structure
mild	three yearly engineering inspections may be appropriate as may the monitoring of cracks and laboratory testing of cores
serious	annual engineering inspections may be appropriate. Crack monitoring will be required. The use of other instruments should be considered. Laboratory and field testing of cores probably required
severe	three-monthly inspections may be appropriate. Extensive instrumentation and laboratory testing will be required. Structural strengthening may be necessary. Load restriction may be necessary. Water exclusion is important
very severe	immediate action and specialised and detailed studies are required.



1. Definitions of various free expansions



2. Expansion index



3. Detailing classes