Management Strategies for Buildings and Bridges Subject to Degradation from Alkali-Aggregate Reaction

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ABSTRACT

The basis of assessment and categorisation developed in advising clients on the management of about 100 structures with Alkali Aggregate Reaction (AAR) is described. The procedures for diagnostic testing, recording and interpretation of cracking and crack growth, assessment of structural details, evaluation of environmental conditions including the benefit of cladding and tests on coatings is set out.

1. INTRODUCTION

The effects of AAR on structures vary from insignificant to those so serious that the structure must be strengthened or replaced, (1) and (2). The information required to make such assessments and recommendations is obtained from the careful combination of the following field, laboratory and desk top procedures.

(1) Visual examination of the structure including monitoring rates of crack development and growth.

(2) Detailed examination and testing of concrete samples extracted from the structure to determine the current and potential severity of reaction.

(3) Analysing the structure, in particular its reinforcement details for possible structural consequences of developing reaction and evaluating the potential for strengthening.

(4) Evaluating the environmental conditions to which the structure is subjected and determining ways in which the more severe of these environments can be ameliorated.

(5) Examining the consequences of the developing deterioration on the serviceability, strength and fitness for purpose of the structure and the effectiveness of each option for long term management.

2. CRACKING IN THE STRUCTURE

Cracking in a structure develops wherever the tensile strain from the combined effects of AAR, structural loads and reinforcement restraint exceeds the tensile capacity of the concrete. The pattern of cracking therefore provides a good indication of the surface stress state on the structure. This provides guidance for analytical procedures and the prediction of internal cracking. The logging of crack patterns and relating them to the structural behaviour therefore has a high priority in assessing a structure.

At MHA we have developed a standard 'Crack and Defect Summary Sheet' which provides a semi-quantative overall record of the condition of the concrete structures. The detailed mapping of all the cracks and crack widths is only carried out at locations selected for coring and Demec measurements. The format of the sheet facilitates input into a computer program which stores and analyses the information during long term monitoring when changes in crack extent need to be analysed after each survey. Classification of the severity of cracking is made possible by a 0 - 9 'Crack Severity Index' where 0 represents no cracking and 9 represents a number of cracks with widths in excess of 5mm. To differentiate between static cracks and active cracks which are diagnostic for AAR and to determine the rate of deterioration, Demec readings are taken on representative areas of structures which are processed by computer and plotted automatically. From our records we have found that the crack growth rates below ground generally show a steadily increasing trend, while cracking in the superstructure tends to follow a pronounced seasonal pattern of opening and partial closing. We have yet to find a structure where damage from the reaction has stopped even after 20 years, possibly because the reactive particles are in the 2-10mm range. The pattern of internal cracking is being studied using pulse-echo, epoxy injection with coring and the dissection of parts of structures.

3. TESTING OF CONCRETE

Expansion tests, USPV measurements and petrographic examination of representative cores extracted from individual structures provides the basis for judging the severity of reaction in concrete. The MHA expansion test procedure is outlined in a separate paper (Wood et al 1986). Where expansive strains exceed about 1mm/m they are likely to swamp normal structural effects and can cause serious damage. Below 0.4mm/m the effects on the structure are likely to be minor. In order to obtain some idea of the extent of the reaction that has already taken place USPV's using Pundit are measured throughout the expansion test. Limited petrography is used to identify the reacting particles and state of reaction.

We are presently evaluating field techniques which relate the expansive behaviour of previously graded reactive pours to other similar concretes without the need for coring. Representative discs are cut from cores in the different expansion classes and catalogued so that visual comparisons can be made with locally abraded structure surfaces. Although the method may not be suitable on a national scale it may be applicable on a regional basis to identify suspect structures before severe visual deterioration occurs.

4. SENSITIVITY OF STRUCTURAL DETAILS TO DEVELOPING REACTION

The effects of any given level of expansiveness on the structure depends on the stress levels within it and the configuration and detailing of the reinforcement. It has been shown from restrained expansion tests (Wood et al 1986a) that with low levels of reactivity the expansion can be controlled by suitably detailed reinforcement, but with the most expansive concretes, forces are generated which are sufficient to yield steel at normal levels of reinforcing. In the field we have observed that the magnitude of the anchorage forces generated by the reaction and its weakening effect can delaminate the ends of slabs and beams. Shear failure caused by the cracking developed from differential expansions in combination with normal structural loads can potentially cause serious sudden failures.

In assessing the effects of AAR expansion on structural details we have adopted a 0 - 9 grading system where 0 represents a well anchored 3 dimensional cage of reinforcement in which the detrimental effects of AAR are mitigated and 9 represents a detail with a high risk of sudden failure. In grading typical structural details it is not merely a case of checking the detail against current codes of practice and applying a reduction factor to the strength. The embrittlement of the structure due to the reaction and the resulting complex internal redistribution of stresses arising from micro cracking must also be considered, (Wood 1985), (Wood 1986b).

5. ENVIRONMENTAL CONDITIONS

The expansion associated with AAR deterioration requires sufficient moisture to be present to produce gel swelling pressures. If the relative humidity in the concrete can be maintained below 75% the expansion can be stopped or retarded. Consequently, the level of humidity in the concrete can give a guide to its rate of deterioration. We have developed a reliable method for measuring the insitu equilibrium relative humidity of the concrete (Wood et al 1987). This enables us to correlate crack movement with the measured insitu environments in all the structures we are monitoring. The conditions in which expansion is prevented are currently being determined using temperature and relative humidity ranges measured at Demec locations and laboratory and site exposure core tests.

Change in the superstructure environment may be achieved by the use of ventilated cladding to reduce the severity of expansion in the short term. Coatings and surface treatments are at best disappointing, at worst damaging. There are no reliable treatments which can control the reaction below ground. The elimination of salt ingress and ponded water on horizontal surfaces is given a high priority in all structures with AAR. It must however be borne in mind that the breakdown of protective treatments may exacerbate the situation in the long term. Whilst maintaining the RH below 75% halts the expansion, the early stages of the reaction seem to continue. If the concrete is rewetted, gel forms rapidly and cracking occurs with much less warning than would have occurred in a more uniform environment and the signs of damage are hidden.

6. POTENTIAL CONSEQUENCES OF FURTHER DETERIORATION

In the preceding sections we have concentrated on the factors which combine to produce some indication of the likelihood of failure in a structure because of AAR. The investigation would not be complete unless the consequences of this deterioration to the public at large are assessed. Initially the consequences can be classified serious or non-serious. Deterioration which might possibly lead to failure of an element precipitating collapse of the structure with little warning, with a risk of direct or indirect loss of life, has been categorised as serious. Cases in which inspection should provide adequate warning of slowly developing damage, of little consequence to public safety are classified as non-serious. These considerations often dictate the choice of structure management.

7. SUMMARISING THE RESULTS

'Overall Structure Rating' Classification System

In presenting the results of our investigations we adopt a tabular form which subdivides the structure into discrete structural elements (Table 1). Each element is reviewed and assigned a 'Severity Rating' code which is based upon consideration of the previous sections. An 'Overall Structure Rating' is then produced on the basis of the severity rating of the most severely affected part or parts of the structure. It is the Overall Structure Rating on an A to E scale which broadly classifies the extent, severity and implications of the reaction. The preliminary rating zones and a general statement on the action required within each zone is presented in (Table 1).

	GENERAL SEVERITY DESCRIPTION	INSPECTION FREQUENCY	CRACKING (0-9)	CORE RESULTS (A*-E) [BASED ON UPPER QUARTILE OF SIMILAR MIXES]	SENSITIVITY OF DETAIL (0-9)	SITE ENVIRONMENT (1-5)	POTENTIAL CONSEQUENCES OF FURTHER DETERIORATION IN THE NEXT 2 YEARS	SEVERITY RATING (TOTAL)
REDUCE AAR AGGRAVATION BY LIMITING SALT AND WATER INGRESS	ACTION REQUIRED WITHIN 6 MONTHS TO STRENGTHEN OR REDUCE LOADING	6 WEEKS	>2 AND/OR >5 AND/OR	B OR A A	>7 >5 <7	3,4,5 3,4,5	SERIOUS SERIOUS	A
	FULL INVESTIGATION AND SOME REMEDIAL WORK NEEDED WITHIN 1 TO 2 YEARS	3 MONTHS	<2 AND/OR <3 AND/OR	D OR C B OR A	>7 >5 <7	3,4,5 3,4,5	SERIOUS NON-SERIOUS	B
	SPECIAL MONITORING AND MORE FREQUENT INSPECTION REQUIRED	YEARLY	>3	C, B	<5	3,4,5	NON-SERIOUS	C
	LIMITED ADDITIONAL INSPECTION & MONITORING IS ADVISABLE	3 YEARLY	<5	D/E OR D	<5	ALL	NON-SERIOUS	D
	NORMAL CONCRETE	NORMAL INSPECTION PERIOD	>2 >3 OR KNOWN OTHER CAUSE	D/E E	<7 <7 } IF >7 NOTIFY CLIENT	NOT RELEVANT	NOT RELEVANT	E

TABLE 1
OVERALL STRUCTURE RATING

These rating zones are then adjusted on the basis of engineering assessment of the vulnerability to failure and the full details of each structural member.

8. CONCLUSIONS

For many of the structures we investigate, the robustness of the reinforcement and the mildness of the reaction enable them to be managed on the basis of routine inspections and some action to reduce the moisture and salt supplied to the structure. A small number of highly stressed structures possessing sensitive details have required either local strengthening or replacement of major structural elements.

Below is shown the distribution of a range of buildings and structures, in our care, in the A - E rating zones.

LOCATIONS IN THE UK		NUMBER OF STRUCTURES	OVERALL STRUCTURE RATING A	B	C	D	E
SOUTH WEST REGION		36	6	6	16	7	1
OTHER UK		27		6	14	7	
TOTALS	No	63	6	12	30	14	1
	(%)	100	10	19	47	22	2

Once a serious problem (Overall Structure Rating A or B) is encountered the management strategy adopted needs to be tailored to ensure the continuity of function of the structure for the owner. This sometimes necessitates early decisive action. In other cases (Overall Structure Rating C or D), a low key, long term monitoring and maintenance programme is sufficient to enable them to serve their function for many years to come despite the presence of the reaction in their structure.

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