REVISION OF THE INSTITUTION OF STRUCTURAL ENGINEERS REPORT - STRUCTURAL EFFECTS OF ALKALI SILICA REACTION

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The Institution of Structural Engineers report on the 'Structural Effects of Alkali Silica Reaction' has now been substantially revised from the 1988 'Interim Guidance' to the 1992 'Technical Guidance on the appraisal of existing structures'. The main developments include quantitative guidance on strength changes, greater emphasis on structural and reinforcement configuration in appraisal and improvements to the basis for estimating current and future expansion.

INTRODUCTION

In 1986 The Institution of Structural Engineers set up an ad hoc committee to provide guidance on the identification, engineering appraisal and management of structures affected by Alkali Silica Reaction. The Interim Guidance (1) was published in 1988 and was reported on at the Kyoto conference (2), and now has been revised as the 'Technical Guidance' (3).

It was appreciated then that the research work which had been initiated by SERC, BRE and TRRL in the UK on the structural effects of ASR and the practical experience of using the Interim Guidance and of testing structures in the field would justify a revision before long. The task group has also benefited enormously from research published at the Kyoto 8th International Conference on AAR (4) and other recent specialist publications (5). The 9th AAR Conference in London provided a target date for the revision.

The broad framework and principles of the interim report published in 1988 have been retained. Considerable progress has been made in improving the quantification of the current and the potential future degree of damage from the reaction in structures. Far more importance is now given to the reinforcement detailing of the structure, and the stress levels, in making recommendations for monitoring, maintenance and management of the structure. Research has indicated that the strength of well reinforced concrete is remarkably tolerant of moderate levels of ASR, but serviceability may suffer.

The procedures in the Interim Report have been used on a wide range of structures and practical results from these (6) have contributed to the revision, with laboratory research providing the quantitative back up. The role of the Building Research Establishment in providing a confidential route for some of this information and of the Department of Transport in making information on their structures available has been of major value.

There remain important areas for research and for the development of techniques for monitoring and testing samples from structures. Two priority items are the relationship between the physical behaviour in short term laboratory studies and long term field performance and the effects on expansion of compressive and tensile stress and of restraint.

IDENTIFICATION

The appraisal of ASR effects is considered in the context of the overall assessment (7) of a structure in which a number of other deterioration phenomenon may be present. Consideration has also been given to the occurrence of ASR in structures which were not designed to up-to-date standards and so are poorly detailed and overstressed, even without ASR effects. Many of the structures with ASR damage which have required remedial works fall into this category.

For the diagnosis of alkali silica reaction the task group has relied on close cooperation with the BCA based Palmer Committee on diagnosis which has been updating its 1988 report (8) concurrently with our work and is due to publish this year. The need to consider the range of structural and non structural causes of cracking (9) in concrete, which can interact with or be confused with ASR damage, has been reinforced in both documents.

The distinction between the rapid 38°C expansion testing, favoured for diagnosis, and the longer term lower temperature tests (at 20°C, 13°C, 5°C, with freeze thaw cycles or on site exposure) which are helpful in long term prognosis and monitoring of structural behaviour have been discussed, so that a balanced test programme can be developed to cover the needs of both diagnosis and appraisal.

The procedures for estimating both the expansion to date and the potential for future expansion have been refined. Expansion to date can be estimated from the crack intensity and improved calibration for this from experimental work by Chana (10) and by Ng (11) have given more confidence in this approach. The relationship between drop of stiffness in cores and the expansion to date provides (12) a complementary method of estimating expansion to date, which merits further development.

ENGINEERING APPRAISAL.

The introduction of the data in Table 1 of lower bound residual strengths, relative to 28 day values, related to expansion levels is based on Clark's review (13) of the literature on testing. This enables an initial assessment of the maximum loss of strength to be made. Where this initial check shows problems, and for severely damaged structures, advice on core testing to establish actual strengths is given. In many structures ASR is associated with high cement contents so actual concrete strengths are well above that required, providing an additional margin for deterioration.

Each part of the structure is classified to establish the Structural Element Severity Rating using Table 2. This determines the Severity Rating, on a scale from 'n' normal concrete to 'A' very severe, from the degree of current or future expansion [I <0.6mm/m to V 2.5 - 5.0 mm/m], the environment ranging from dry to wet, and the structural detailing [Class 1 for a well anchored three dimensional cage, Class 2 for normal UK reinforcement detailing and Class 3 for concrete lacking a three dimensional reinforcement cage to restrain the effects of expansion]. Procedures for more detailed testing, appraisal and management of the structure are then related to the Severity Rating. The consequences of failure and stress levels are used to adjust the rating.

If Table 2 is compared with the corresponding table in the 1988 Interim Guidance, it will be seen that the emphasis for the management approach has shifted from a primary concern with the magnitude of expansion to a main emphasis on the three dimensional restraint of expansion damage provided a well anchored reinforcement cage. Conversely mass concrete or lightly reinforced concrete, lacking three dimensional reinforcement restraint, requires more careful investigation. It follows that people who detail their reinforcement for earthquake loading can be less concerned with ASR that those who live on a more stable geology.

New data on bond strength developed from Chana's work (10) is of particular importance as the additional bond stresses generated by the expansion combine with a drop in bond strength where laps are not contained by stirrups. This can be a critical feature in cantilever retaining walls and in longer span bridge decks.

The UK experimental programme which has assisted these developments also included the work by Clayton(14) at BRE, Swamy (15) at Sheffield, and work to be reported in other papers at the 9th AAR conference by Cope at Plymouth and Wang at British Rail Research. The input from overseas work has been assisted by corresponding members of the Task Group from Denmark, Japan, South Africa and the USA, as well as the increasing flow of published data on the structural behaviour of concrete with ASR.

MANAGEMENT

The recommended management actions for testing, monitoring and reducing water ingress are related to the Severity Rating in Table 3. The majority of structures have been found to come in the 'Mild' or 'Moderate' categories, for which attention to waterproofing and drainage and regular inspection with a little detailed monitoring of core expansions and cracks are appropriate. Comprehensive testing and complex analysis are inappropriate for these structures.

For the few 'Severe' or 'Very Severe' parts of a structure, which have high expansions or potential for substantial future expansion or are highly stressed and/or poorly detailed, outline guidance is given on specialist procedures appropriate to quantify the risks. In many structures the sensitive details subject to serious damage are very localised and appropriate local strengthening can maintain the structure in service for many years. This can be cheaper than complex analysis, testing and inspection programmes for some structures.

The most difficult elements remain large foundations and pile caps and retaining walls, which because of their size, their reinforcement configuration and their inaccessibility have necessitated major works for inspections and remedial work.

The value of improving drainage and waterproofing of ponding surfaces and at expansion joints and the value of ventilated cladding of rain-wetted surfaces in reducing the rate of deterioration from AAR, and secondary deterioration from corrosion and frost, is stressed. It is as important to encourage the drying of the structure as it is to keep water out.

Attention is drawn to problems which can occur from overall expansion from ASR distorting, jamming or fracturing steel or non-expansive concrete structures or equipment fixed to it, even at low expansions. Sims (16) has highlighted the particular problems that can arise with dams.

Examples of structures with a range of ASR damage, with and without remedial works, will be included in the tour after the 9th International Conference.

CONCLUSIONS

The new Technical Guidance provides a framework for a balanced evaluation of ASR damage to structures. This short paper has only touched on some of the more important changes so that reference can be made to the Report both for the initial evaluation of suspected ASR, with the Diagnosis Report, and when major problems are identified in structures as a guide to specialist appraisal related directly to the research and case studies covered in the references.

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	Percentage Relative to 28 day Unaffected Concrete.				
at Free Expansion mm/m	**0.5**	**1.0**	**2.5**	**5.0**	**10.0**
Mechanical Property					
Cube Compression	100	85	80	75	70
Uniaxial Compression	95	80	60	60	
Tension	85	75	55	40	
Elastic Modulus	100	70	50	35	30

Table 1 Lower Bound Residual Mechanical Properties.

Site Environment	Reinforcement Detailing Class	Expansion Index I > 0.6 mm/m	II 0.6 - 1.0 mm/m	III 1.0 - 1.5 mm/m	IV 1.5 - 2.5 mm/m	V 2.5 - 5.0 mm/m
Dry	1	n	n	n	n	n
	2	n	n	n	n	D
	3	n	n	n	D	C
Intermediate	1	n	D	C	C	C
	2	n	C	C	C	B
	3	n	B	B	A	A
Wet	1	D	C	C	B	B
	2	D	B	B	B	A
	3	C	A	A	A	A

Structural Severity Ratings	A = Very Severe.	B = Severe.	C = Moderate.
	D = Mild.	n = Normal.	

Table 2. Structural Element Severity Rating:
for significant consequences of further deterioration

	Structural Severity Rating	A V. Severe	B Severe	C Moderate	D Mild
1	Improve drainage and protect surfaces from water run off and ponding.	**	**	**	**
2	Overall crack surveys including estimate of expansion to date.	**	**	**	**
	Frequency, Years	1	1	3	6
3	Coring for stiffness and expansion tests for current and future expansion estimates.	**	**	**	*
4	Coring for stiffness and strength tests to evaluate specific failure mode.	**	**	*	-
5	Evaluate benefits of load reduction, strengthening to improve detail class or replacement of critical elements	**	**	*	-
6	Detailed inspections and monitoring of cracks and, where important, overall movement (1) one set at a sample location only	**	**	**	** (1)
	Frequency , 1st six readings , Months	0.5	1	2	6
	Frequency , Long term, Months	1	2	4	12
7	Inspection for spalling risk from secondary corrosion and frost damage	**	**	**	**
	Frequency, Months	3	6	12	12
	Desirable	**			
	May be required	*			
	Seldom required	-			

Table 3. Management Actions Related to Structural Element Severity Rating.