

An Investigation into Alkali-Silica Reaction in Concrete Bases at an Electricity Substation at Drakelow Power Station, England

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ABSTRACT

Cracks in the concrete bases to substation installations at Drakelow Power Station near Burton-on-Trent in the Midlands area of England were identified in 1982. The bases had been constructed in three phases; 1953/4, 1962/3 and 1969/70. It was suspected that the cause of cracking might be alkali silica reaction (ASR). The aggregates were of a type which had been identified as suffering alkali attack in other cases of ASR.

It was thought that the cement content of these mass concrete bases was relatively low. Consequently the alkali concentration was also expected to be low and less than that generally believed to be necessary for damaging ASR to occur.

Because of the important implications of this for the specification of concrete materials to avoid damage caused by ASR a detailed investigation of the concrete at Drakelow substation has been carried out. The objectives were to establish the cause of the cracking, the extent of the deterioration, the nature of the component materials and, most specifically, the cement contents and alkali contents of the concrete. The possibility of loss or migration of the alkalies since construction has been studied by taking cores for analysis and other studies from sheltered and weathered concrete and from different levels.

The investigation revealed some general problems in analysing set concrete and in particular the precise assessment of the alkali content. The Paper discusses the overall results and implications of the investigation.

EARLY CASES OF ASR IN SUBSTATIONS IN SOUTH WEST ENGLAND

When, in 1976/7, ASR was first identified in the United Kingdom, a number of electricity substations in the south west were found to be affected.

At these the most seriously cracked concrete was in mass or lightly reinforced bases about 1 metre deep with their top surfaces either exposed or covered by a 75 mm layer of loose chippings. This form of construction seems to be particularly vulnerable to damaging ASR. Pending detailed investigations into alternative means of minimising the risk of damage, the use of cement having a maximum Na_2O equivalent alkali content of 0.6% was specified by the CEBG for use at substations.

Analysis work at the time indicated that the alkali content of the affected concretes was around

3 kg/m³ which was being proposed as a "safe" level. The working party report (Hawkins 1983) recommended that for particularly vulnerable forms of constructions the 3 kg/m³ maximum alkali level may not be adequate to minimise the risk of ASR damage.

A.S.R. IN SUBSTATION BASES AT DRAKELOW POWER STATION

Introduction

In 1982 ASR was suspected in bases at the above substation in the Severn Trent valley near Burton on Trent. The concrete was cast in three phases in the early 1950's, early 1960's and late 1960's. Cores were taken from cracked and uncracked bases from each phase and were physically tested and chemically analysed. The results showed that there was confirming evidence of ASR and that the alkali content of the cracked bases was generally higher than in the uncracked bases. As in the cases in the south west there was an indication that ASR was damaging concrete with around 3 kg/m³ or less of alkali.

In view of the importance of these results to the establishment of "safe" levels of alkalis in concrete, a further detailed study has been made of concrete from this site. Special attention has been given to the following.

- * Concrete selected where "wash out" of alkalis since casting is unlikely to have occurred
- * Sample preparation to assess "wash out" of alkalis during core cutting
- * Accuracy of analysis for alkali content
- * Alkali migration within the concrete

The opportunity has also been taken to carry out the following

- * Chemical analysis for selected chemicals and for cement content
- * Detailed petrographic examination of concrete
- * Detailed petrographic examination of coarse and fine aggregates taken from a nearby pit and believed to be similar to that used in the works
- * Physical tests, density, USPV, crushing and cylinder splitting strength determinations
- * Microscopic examination
- * Expansion tests at 20°C and 38°C and 100% R.H.

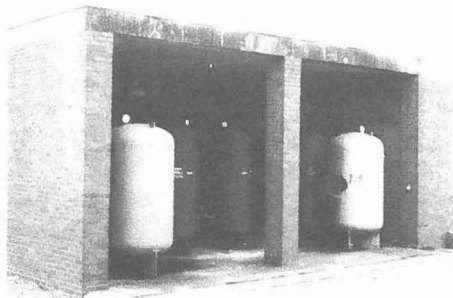


Plate 1 - Air receiver store
from which the
cores were taken

Coring

The concrete cores examined have been cut from the 900 mm thick unreinforced ground floor slab of an air receiver store approximately $8\frac{1}{2}\text{m} \times 5\frac{1}{2}\text{m}$ with a concrete roof and open to the weather on the long front side but protected from the sides and rear. It was constructed in 1962. The surface has typical ASR cracks which are more evident near the open side. Sets of $2 \times 75\text{ mm}$ and $1 \times 150\text{ mm}$ dia. cores were taken using normal wet core cutting technique from the open front and sheltered back of the slab. An air/water mixture was used for cooling these cores which reduced substantially the amount of water used in the flushing. It was also hoped to take 100 mm dia. cores by a dry coring technique but this proved impractical.

There is very little chance that the concrete at the back has lost alkalis due to the downward penetration of rain water. The front of the slab will have been wetted by rain but its upper surface has been dry for the majority of its life. Surface evaporation is likely to have exceeded surface absorption and moisture movement in the concrete would tend to be generally upwards.

To obtain dry concrete samples the 150 mm dia. cores were cut in the laboratory using a dry cutting technique as shown on Figure 1. Cutting was carried out successfully using a blade specially designed for dry cutting and cooling was by compressed air. Pieces A have a similar outside (water cooled) surface to area ratio as 100 mm dia. cores cut by the normal wet method. Pieces C have been taken from the inside of the core and have not been subjected to "wash out" of soluble salts. USPV and concrete crushing strengths of pieces C were determined prior to chemical analysis.

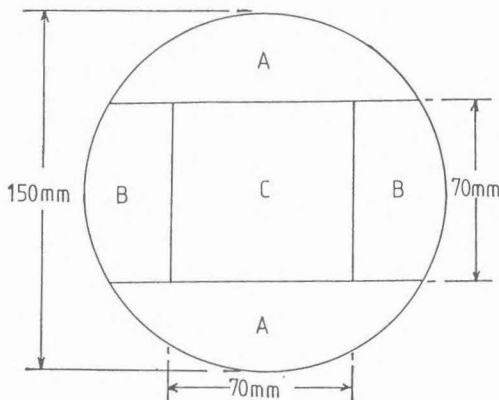


Figure 1 - Sectional diagram of prism and segments obtained by longitudinal dry cutting

Sample preparation and analysis

Samples for analysis were prepared from the top, middle and bottom of the pieces C and from the top and bottom of pieces A of the 150 mm dia. cores from both the front and back of the slab. 8 sets of powdered sub-samples 150 mm max. size each no less than 50g were produced by riffing and stored in numbered screw topped containers. Precautions were taken to avoid

pollution of material and loss of fine fractions during grinding.

Similar powdered samples were produced from the fine and coarse aggregates from the nearby pit which had been found by a petrographic examination to be similar to those used in the concrete.

Samples have been analysed by three selected laboratories which operate commercially and by three specialist laboratories. In calculating the alkali contents of the concrete the results of one laboratory have been disregarded because they were inconsistent.

Analysis Results

- * The dry densities of the concrete cores were determined before sample preparation - Table 1.
- * The analyses showed that the aggregates were less than 2% acid soluble. The aggregate content of the concrete has been arrived at by assuming that all the acid insolubles in the concrete came from the aggregates and that the ratio of coarse to fine aggregate was 2:1.
- * The cement content was taken to be the acid soluble fraction of the concrete less the loss on ignition and the acid solubles from the aggregates. This gave a typical cement analysis of:-

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	Sum
22.1%	6.0%	2.6%	62.4%	1.1%	2.8%	0.8%	0.3%	98.5%

- * The alkali contents of the outside (A pieces) and inside (C pieces) of the cores were not significantly different.
- * The acid soluble alkali levels of the powdered concrete include alkalis from the aggregates which are not included when calculating alkalis in a mix contributed by the cement. Values of the alkalis from the cement in Table 1 have been calculated by deducting the contribution from the aggregates, which were 0.046% of the coarse aggregate and 0.054% of the fine aggregate expressed as Na₂O equivalent. Thus, correction for alkalis in the concrete attributable to the aggregates is 0.81 [2/3 x 0.046 + 1/3 x 0.054] % = 0.040%. A mean correction of [2100 x 0.040 x 10⁻²] = 0.84 kg/m³ of concrete has been taken.
- * The results in Table 1 also show that whilst the cement contents in the bottom of the slabs are slightly lower than elsewhere, the alkali contents are significantly lower.

Core details				Aggregate Content	Cement Content	Alkali content as Na ₂ O equivalent		
Origin	Length	Dry density	kg/m ³			kg/m ³	Total	Corrected
	mm	kg/m ³		kg/m ³	kg/m ³			kg/m ³
Rear	Top	250	2055	1664	317) mean*	4.28) mean*	3.44) mean*	1.08) mean*
	Middle	320	2122	1701	345) 326	4.01) 3.74	3.17) 2.90	0.91) 0.89
	Bottom	260	2162	1783	311)	2.89)	2.04)	0.66)
Front	Top	280	2150	1755	320) mean*	3.55) mean*	2.71) mean*	0.85) mean*
	Middle	310	2045	1681	300) 304	3.72) 3.27	2.88) 2.43	0.96) 0.80
	Bottom	220	2083	1726	290)	2.29)	1.45)	0.50)

* Weighted mean allowing for core length

Table 1 - Calculated cement and alkali contents

Conclusions on Alkali Contents

- * Laboratory determination of alkali levels needs extreme care to produce accurate results. Increased standardisation of procedures would improve repeatability between laboratories and pre-calibrated test materials would be a check on the accuracy being achieved.
- * Wet coring of 100 mm dia. concrete samples makes little difference to the alkali content of the cores taken.
- * In back analysis of concretes a correction must be made for alkalis from the aggregates which are not normally considered in calculating the alkali contents of new concrete.
- * After correction for alkalis from the aggregates the alkali content in the rear core is 2.90 kg/m^3 which is less than the suggested safe level of 3.00 kg/m^3 . The level at the front of 2.43 kg/m^3 is even lower.
- * In both the front and back cores the alkali content in the bottom of the slab expressed as a percentage of cement content is only 60% of that in the top of the slabs. This is probably caused by alkali migration due to moisture movement. The mean alkali contents of the front and back cores, expressed as a percentage of the cement weights are similar. Chemical analysis and microscopic examination confirm that it is unlikely that two different cements were used for the top and bottom concrete.

Additional Work

Some of the additional studies scheduled in the introduction are not yet complete. The results will be fully reported when they are available.

Preliminary results of the microscopic examination indicate that the alkali-silica reaction in this concrete has principally affected the cherts, present as a minor constituent (approx. 3%) in a mainly sandstone and quartzite gravel aggregate.

There may also be evidence of attack on sandstones; one, containing very finely crystalline silica showed characteristic internal cracking and gel production and another, compressed sandstone containing highly strained quartz, showed surface degradation, perhaps by contact with gel.

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REFERENCE

Hawkins Working Party. 1983. Minimising the risk of Alkali-Silica Reaction - Guidance Notes.