The Strength of Model Columns Made with Alkali-Silica Reactive Concrete

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ABSTRACT

Longtitudinal cracks due to ASR in prestressed concrete support columns for the roof of a covered reservoir gave concern because tests indicated that, if the columns behaved as four independent sub-columns, the factor of safety under axial load was 1.4 and would be lower if there was eccentricity of loading.

Quarter scale model concrete columns were constructed to study this problem. Four of these columns were constructed using reactive aggregate from Cyprus (5%) and a KOH enhanced alkali content (10 Kg/m^3). Slices of this concrete were also stored in 100% RH at 15°C and monitored for dimensional change as were the model columns themselves. Expansions were monitored over a period of 78 days. The columns exhibited considerable and random variations in expansion at different points along their length and did not produce macroscopic cracks within this period. A series of concrete mix design experiments are now in progress with the objective of establishing a model mix that will reliably develop ASR cracking within a short time scale using readily obtainable reactive components.

Testing of model columns cracked longitudinally by other methods is currently in progress. Results so far indicate that, if the column is appropriately strapped, they will remain effective up to the design load.

INTRODUCTION

There are increasing numbers of examples of alkali-silica reactivity in concrete structures in the UK, some of which have been described by Allen (1981), Palmer (1978), and Gutt and Nixon (1979). The principal reactive aggregate components are flint and chert: however, reactions with quartzite, greywacke, and other rock types have also been recorded.

The development of alkali-silica reaction cracking at critical locations in a concrete structure is a cause for concern because of the consequent loss of structural continuity and strength. Information concerning the changes in strength of concrete members as the concrete develops ASR cracking is considered to be of value in making engineering judgements concerning the performance of affected concrete structures.

It is not often possible to test sections from prototype structures, and, because of the long time scales involved, it is not possible to test at intervals during the development of ASR in the structure. These difficulties have led engineers to consider using model structures in which ASR cracking can be reliably induced over shorter time scales than can normally be achieved using large test specimens such as those used by Putterill and Oberholster (1985).

Among ASR affected structures in England there is a covered water reservoir with ASR developed in the vertical concrete columns which support the roof. These columns are 7.3m high and have a square cross-section of approximately 0.3m side with twelve 6mm pre-stressing wires located close to their perimeter. A number of these columns exhibited longitudinal cracks due to ASR which in some cases extended almost to the full height of the column, effectively dividing it into two or four 'sub-columns'. Acoustic strain gauge monitoring of cracks over a 20 month period of these columns showed some cracks to have widened by 0.1mm (Figure 1). One of these columns had been removed from the reservoir in sections and was available for structural testing.

GAUGE No.	COLUMN No.	FACE TO WHICH GAUGE IS FITTED	SIZE OF CRACK AS AT APR.'84 (VISUALLY ASSESSED, NOT MEASURED)	NOTES
1	15A	NORTH	NOT CRACKED	ALIGNED VERTICALLY TO NEGATE ANY EFFECT OF FUTURE VERTICAL CRACKING
2	18C	WEST	1mm FULL HEIGHT CRACK	
3	18G	WEST	2mm FULL HEIGHT CRACK	
4	19B	WEST	2mm FULL HEIGHT CRACK	
5	20G	WEST	2mm FULL HEIGHT CRACK	
6	28C	WEST	2mm FULL HEIGHT CRACK	
7	20H	WEST	2mm FULL HEIGHT CRACK	
8	21F	WEST	2mm FULL HEIGHT CRACK	
9	23C	NORTH	SEPERATE 2mm CRACKS TOP & BOTTOM	GAUGE FITTED TO UPPER OF TWO CRACKS
10	28E	WEST	5mm FULL HEIGHT CRACK	STAINLESS STEEL CLAMPS FITTED AT MID-HEIGHT TO RESTRAIN CRACKING

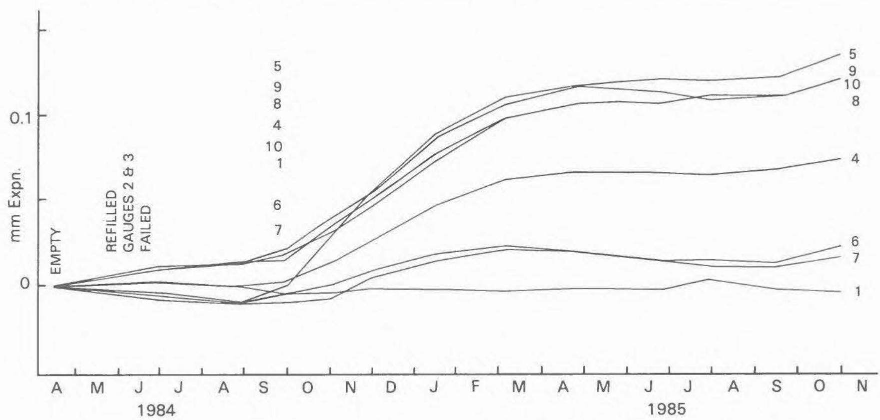


Figure 1. Increase in crack width calculated from acoustic strain gauge readings. (Data by courtesy of Severn Trent Water)

FULL SCALE STRENGTH TESTING

The column had been removed in sections approximately 1.8m in length and exhibited varying degrees of cracking. Two sections were tested to destruction in a 600 tonnes Mohr & Federhoff testing machine and subjected to an axial load increasing in 0.446 tonne increments. Column section 1 failed on a plane passing through existing cracks but the oblique failure surface affected less than half the area of the base of the column and did not propogate through its length, indicating premature failure due to eccentric loading or the irregularly shaped base of the specimen. The second section failed, explosively splitting the column from end to end. Results for both tests are given in Table 1.

Table 1 Results of Column Tests at Failure, 1-8m Sections

Column Section	Axial Load (Tonnes)	Comprehensive Stress Full cross-sectional area	Uncracked Concrete Young's Modulus	Uncracked Concrete Poisson's Ratio
1	403	42.5 N/mm^2	39.4 KN/mm^2	
2	341	36.0 N/mm^2	32.3 KN/mm^2	

These values may be compared with the estimated working axial load of 43.9 tonnes. The Euler buckling effects for the full length columns can be estimated using Table 18 of CP 114 (1964). Assuming the column acts as an integral section, a factor of safety of 7 is obtained for axial design loading. However, if the column behaves as four long independent sub-columns due to the longitudinal cracking, the factor of safety would drop to 1.4. The Euler load is a theoretical occurrence and any eccentricity in loading or geometry would produce a worse case.

MODEL COLUMNS

In order to investigate column strengths further, a series of sixteen quarter scale model columns were prepared. Four of these contain alkali reactive silicious limestone aggregate from Cyprus. The mix design used is given below.

6.25 Kg	OPC (Alkali equivalent 0.5)
11.90 Kg	6mm nominal, flint coarse aggregate
0.92 Kg	6mm nominal, silicious limestone coarse aggregate
5.60 Kg	Quartz sand fine aggregate
2.20 Kg	Water

The alkali content of the cement was enhanced by the addition of potassium hydroxide in the mix water bringing the total alkali equivalent of the concrete to 10 Kg/m^3. The columns cast were 1.8m in length with a square cross section of 0.075m side. Four 1.25mm prestressed wires were located close to each corner of the column and prestressed to 4500 N each. The target 28 day cube strength was 60 N/mm^2.

An array of 50mm spaced pairs of demec points were attached to two surfaces of these columns and also a triangular arrangement of points was attached to both cut surfaces of slices taken from cubes of the same model concrete simulating the monitoring arrangement for concrete cores and now widely used in the U.K.

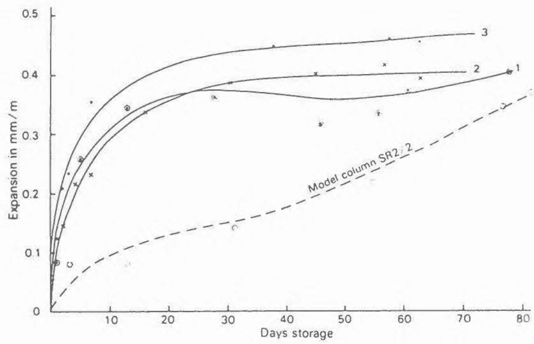
Both columns and slices were stored in a humid environment above water, the former at 23° wrapped in water absorbant material, the latter at 15°C in a closed container containing a small fan. Monitoring of dimensional change was continued for 78 days.

DIMENSIONAL CHANGES

After an initial adjustment period lasting 15 to 20 days, columns with non-reactive aggregates showed no overall dimensional change but random local fluctuations of expansion and contraction were measured from time to time. The reactive columns exhibited a slow overall expansion to approximately 0.3mm/m at 78 days. However, considerable local variations in expansion (and in a few cases shrinkage) were monitored along the length of these columns. Expansion of the slices of concrete cube followed an expansion curve similar to those observed for concrete cores from ASR affected structures with a rapid initial expansion followed by more gradual expansion after the first month. The gain in weight of these slices is also consistent with those observed for discs from ASR affected concrete.

Figure 2 illustrates the type of expansion of these columns and cube slices, and compares them against two adjacent slices taken from a core of ASR affected concrete.

Figure 2
Expansion against time. 1 concrete cube slice 2 and 3 adjacent slices from a concrete core stored at 30°C and 15°C respectively



The limited expansions noted have not led to macroscopic cracking of the concrete and it has become clear that insufficient reactive aggregate was incorporated in the concrete and that flint may be an unsuitable choice of coarse aggregate because of its porosity.

Further work on producing ASR cracking in model columns was suspended and a series of experiments commenced with the objective of producing a model concrete mix containing readily obtainable reactive components which will reliably produce ASR cracking within a few months of manufacture. The basic mix design for these experiments is given below and the experimental scheme tabulated in Table 2.

	Scheme 1,2 & 3	Series 4
OPC	7.15 Kg	7.15 Kg
Coarse aggregate	10.12 Kg	8.82 Kg
Fine aggregate	8.70 Kg	7.43 Kg
Reactive aggregate	2.56 Kg	5.13 Kg
Water	2.57 Kg	2.57 Kg
W/c ratio	0.36 Kg	0.36
Alkali equivalent	12.00 Kg/m^3	12.00 Kg/m^3

Twenty two prisms, each with three 100mm cubes for strength tests have been prepared and are currently being monitored for dimensional change. Hair-line cracks developed in some of the series 4 prisms after 14 days and all prisms are expanding rapidly. The series 1 prisms are included with the objective of producing early cracking similar to ASR cracking by a different mechanism.

MODEL STRENGTH TESTS

A number of the 1.8m scale columns have been cracked longitudinally by other methods and the effectiveness of strapping the segments together are being investigated. Results to date suggest that, if the columns are appropriately strapped at 100mm centres on the models, relative movement does not take place along the crack interface and that the columns may be considered fully effective up to their design load.

Table 2 Experimental scheme for 380 x 100 x 100mm test prisms

Series	Aggregate Type	Reactive Component	Storage 20°C	Storage 40°C
1	10mm Flint	2-8mm Gypsum (12%)	*	*
	20mm Flint	2-8mm Gypsum (12%)	*	*
2	10mm Flint	3mm Fused Silica (12%)	*	*
	20mm Flint	3mm Fused Silica (12%)	*	*
	6mm Dev.Lst.	0.5-1mm Fused Silica (12%)	*	*
3	10mm Flint	2-8mm S.H.Sst. (12%)	*	*
	20mm Flint	2-8mm S.H.Sst. (12%)	*	*
	6mm Dev.Lst.	0.5-1mm S.H.Sst. (12%)	*	*
4	10mm Flint	2.8mm Siliceious Lst.(24%)	*	*
	20mm Flint	2.8mm Siliceious Lst.(24%)	*	*
	6mm Dev.Lst.	0.5-1mm Siliceious Lst.(24%)	*	*

S.H.Sst. : Reactive Schleswig Holstein Sandstone

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