FIGURE 11. Comparison of measured and predicted tensile strains in reinforcing at J.

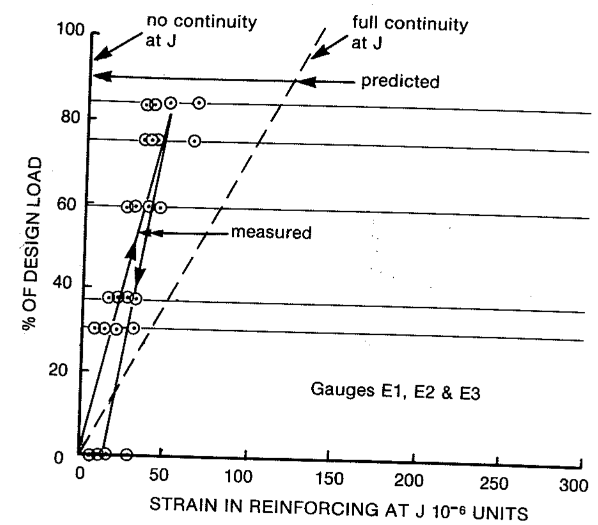
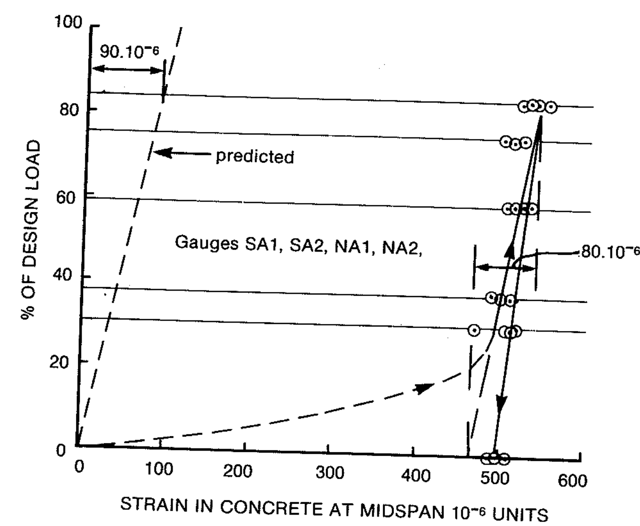


FIGURE 12. Comparison of measured compressive surface strains and predicted compressive strains in concrete.



ACKNOWLEDGEMENT

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SERVICE LIFE PREDICTION AND ALKALI-SILICA REACTIONS

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ABSTRACTS

Based on Danish experience the hypothesis is set forward that damage due to alkali-silica reactions only occur in structural members in which cracks previously are created during the production. The water penetrates along the cracks in an initiation period. The cracks open in a propagation period. At last a resting period enters, where nothing more happens. - Two cases are treated, one including a moisture analysis.

Keywords: Moisture analysis, service life, bridges, prestressed beams.

1. INTRODUCTION

Experience from Denmark shows that many structures of concrete made with alkali-silica reactive aggregate are sound, although the according to the textbooks ought to have cracks. Often it is seen that one part of a structure is whole the other cracked, or that only some of several obviously identical structural members in a building are cracked.

Further to this it is seen that cracked structural elements may stand for years in the cracked condition without any change of the crack pattern.

In the following I shall connect these observations to the possibility of moisture movements in the structures.

2. THEORY

To declare the above mentioned obviously contradictory observations I will put forward the following hypotheses. Cracking due to alkali-silica reactions (ASR) mainly occurs in structural elements, which have initial cracks from e.g. insufficient mixing, bad vibration, casting joints, bleeding, plastic shrinkage and thermal stresses from wrong curing. These initial cracks have two effects. Firstly the water moves much faster through cracks than through sound concrete. Secondly the cracks have less tensile strength than the solid concrete, and therefore the particles near the crack get the possibility of taking up water and hereby expanding the already existing cracks. This last effect should be seen as an example of the stress dependence of the water absorption capacity of the gel /1/.

From the above mentioned theory the following may be deduced concerning the crack development in an initially cracked structure.

*) From 1983-09-01: Building Materials Laboratory, Technical University, Lyngby, Denmark.

From the beginning the cracks are invisible with the naked eye. The water starts to penetrate from the outside driven by capillary forces and diffusion. During the first period the particles in the outermost parts will expand and produce compression here and tension in the inner parts of the element. The cracks are still invisible. After this initiating period the water reaches the inner parts of the elements. Then the stress situation will change, compression is produced in the inner parts and the cracks will open up to the outside. The crack propagation period lasts as long as reactive particles near the cracks are available for the creation of solid state gel. (It is the solid state gel which causes the expansions). When the last aggregate particle near the crack has contributed to the expansions the cracking comes to rest, and nothing more happens due to the ASR. If the structure is exposed to one-sided water pressure, de-icing salt or freezing in saturated condition, the damage may continue for these reasons.

To illustrate the validity of the theory stated above, I will present analysis of a waterworks roof (case I) and of some selected motor road bridges (case II). Further the crack propagation scheme is illustrated from mortar bar experiments and from concrete dam expansions.

3. CASE I. WATERWORKS ROOF

The load bearing structure of the filter hall of the Hornsherreds waterworks consists of 11 double-T-beams (TT-beams) placed side by side. They are 20,5 m long, the height of the ribs is 550 mm and the smallest breadth of the ribs is 150 mm. They are prestressed with 14 cables. Hooks are only used in the anchorage zones.

The beams were cast during the winter 1971-72, and put in place during 1972. In 1978 cracking was seen on some of the ribs. The cracks occurred as longitudinal cracks on the underside of the ribs and on the sides about 150 mm above the underedge. The cracks were limited to 8 of the 11 beams, but on these beams both of the ribs were cracked. The lengths of the cracks varied from 5% to 90% of the beam length. The deformations perpendicular to the cracks were followed by strain measurements. In 1979 most of the deformations had occurred and from 1980 no further cracks or deformations were seen; some of the cracks even started to contract. The beams were inspected latest June 1983.

As mentioned the beams were cast in winter. The cement content was 445 kg/m^3. During the curing the temperature reached 60^{o}C. With this temperature the beams were taken from the production hall to the outside stock, where the temperature was around 0^{o}C. The geometrical and climatic conditions were so, that if no wind was blowing, the cooling of the beams was so slow that the thermal differences between the center and the rim of the beams were harmless. But if the wind velocity was about 5 m/s thermal differences above 20^{o}C were produced causing cracking of the beams. So literaly the cracking has occurred as the wind blew /2/. The cracks were formed parallel to the prestress direction. Thermal cracks normally are invisible with the naked eye when thermal equilibrium is reached.

So, the reason for this special crack pattern shall be found in the production conditions. During the first 7 years of the life time the water penetrates to the center causing stresses as principally shown on fig. 1. In the next 2 years the cracks develops, and hereafter nothing more happens.

In this case I the argument about the water penetration was tentative. No moisture analysis was made. However this was done in an examination of motor road bridges, case II.

Fig. 1. Crack development at the Hornsherreds waterworks. Top: Cross section of one rib of the TT-beam. The placing of the cracks is shown. Bottom: Principal sketch of the development of the stresses as the water penetrates the body. When compression occurs in the central parts of the beam the cracks will open.

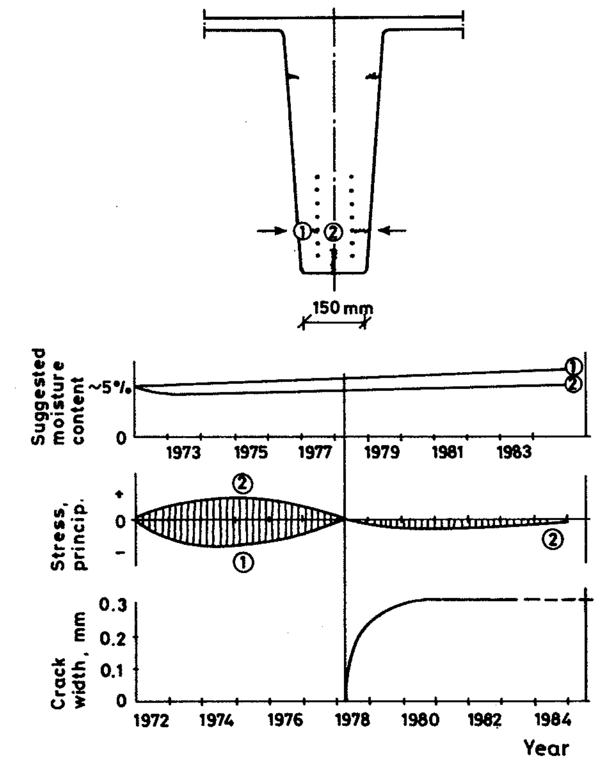
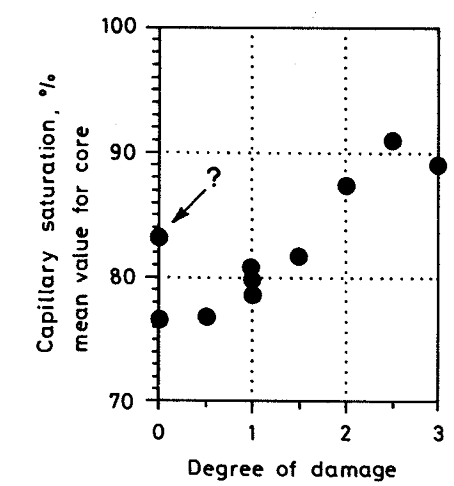


Fig. 2. Cores from 10 structural members of 4 motor road bridges. Mean value of S_{cap} for each core versus degree of damage.



4. CASE II. MOTOR ROAD BRIDGES

10 motor road bridges were built in 1975 between Århus and Skanderborg in Denmark. In 1976 cracks occurred on some structural elements. The cracking developed further in the next years. Inspections with descriptions and photographs were made in 1976, 1977, 1978, 1980 and 1983. From the photos it has been possible to draw a curve of the quantitative impression of the crack development, fig. 5.

Microscopical investigations showed that the fine gravel contained alkali-silica reactive particles.

In 1982 it was decided to paint the bridges to prevent further damage. A preparatory investigation started, which among other things included a description of the state of the bridges and a moisture analysis.

The state of the structural elements were described through a visual determined "degree of damage" (more correct "degree of cracking"). A four step scale from 0 to 3 was used, where 3 is the most severe cracking seen on these bridges. (No 3-cracking, however, was not so severe that it should call for immediate repair). The scale corresponds to the scale used in /4/. The facade and the corresponding core were judged individually and the mean value taken.

The moisture analysis was carried out on dry drilled cores from 10 structural elements with various "degree of damage". The cores were cut in layers in the laboratory. For each layer the moisture content was determined by weight, the degree of capillary saturation, S_{cap}, and the relative humidity in the pores /5/. In this presentation I will treat only the S_{cap}-values.

Fig. 2 shows the mean value of S_{cap} for each core versus the degree of damage. A reasonable correlation is seen for 9 values. One value (shown by a question mark) falls outside the common pattern having no damage and a relative high S_{cap}. This case is explained below.

The sliced-core method makes it possible to obtain moisture profiles of the examined structural members. Fig. 3 and 4 gives same examples.

Fig. 3 shows profiles from two nominally equal retaining walls. One is uncracked and in a drying-out state, the other one is cracked and has a high degree of saturation the hole way through. It must be suggested that the last specimen has got initial cracks, so that this is the point, where the two walls differ.

Fig. 4 shows profiles from two nominally equal edge beams. One is cracked and has a high degree of saturation the whole way through. The other one is identical with the question mark point in fig. 2. It is uncracked, but it is seen that the S_{cap}-profile is U-shaped pointing to the fact that water is penetrating the beam from both sides. It must be expected that in some years the high moisture level will reach the center and cause cracking. Then the question mark point on fig. 2 will move to a position on the correlation line.

These moisture profile results do not contradict the theory set up in ch. 2 on the importance of the water penetration.

5. CRACK DEVELOPMENT

The development of the cracks on the bridges is shown qualitatively on fig. 5. This is the same type of crack development as we have seen on the roof structure treated above (fig. 1). In fact we see the same time of crack development on our mortar bar experiments (fig. 6).

Fig. 3. Retaining walls from bridge 02.
Top: Sound wall in drying-out state. $S_{cap} \sim 80\%$ can be calculated as what may be expected from the selfdesiccation /1/.
Bottom: Cracked wall.

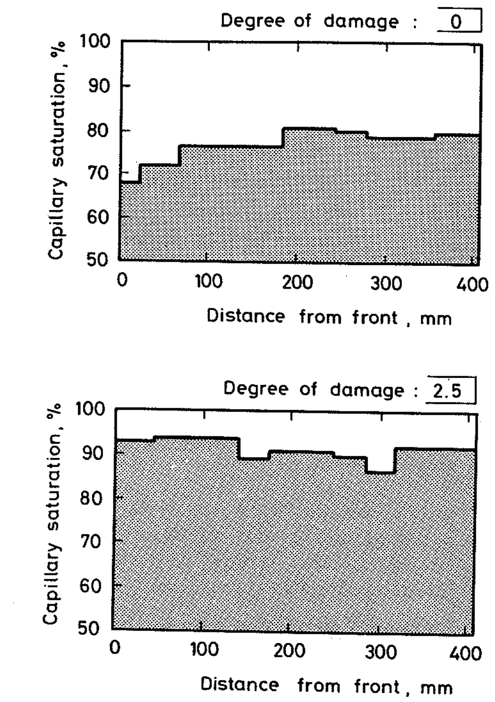
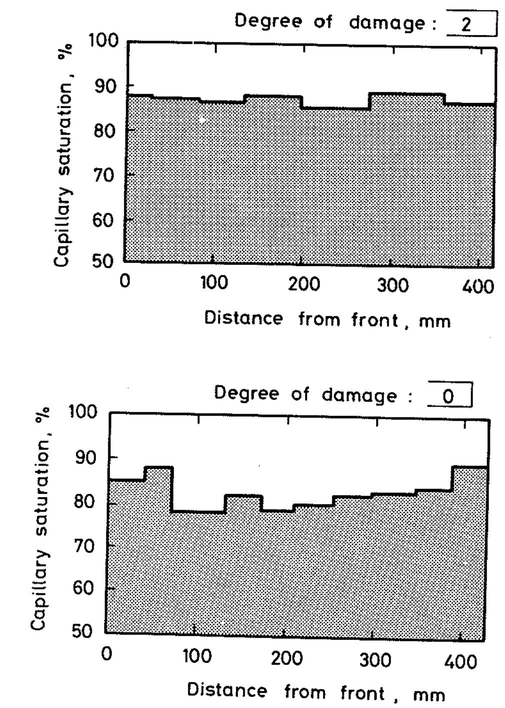


Fig. 4. Edge beams from bridge 88.
Top: Cracked beam.
Bottom: Until now uncracked beam. It is seen that the water is penetrating from both sides. Cracking must be expected when the water reaches the central parts. The mean value of S_{cap} is shown on fig. 2 with a question mark.



Recently measurements from USA on the deformations of concrete dams suffering from ASR have been published /6/ (fig. 7). Again we have the same type of time curves with a period of initiation, of propagation and of rest.

The length of the different periods depends upon

* the severeness of the initial cracking (the more severe, the faster the water will penetrate)
* the magnitude of the members (things happen faster in a mortar bar than in a dam) and
* the climate in question.

Fig. 8 shows a principal diagram of the development in time of deformations due to pure ASR.

6. LOAD BEARING CAPACITY

Danish experience until now tells that no structure has collapsed due to pure ASR.

Extra deflections - due to pure ASR are not either seen. The cases I and II treated above are examples. /7/ reports a test load experiment on a motor road bridge frame, where the change of the stiffness was not alarming and could be predicted reasonably well on the basis of laboratory measurements.

In my opinion the minor influence of the ASR to the strength and deflections may be explained by thinking of the cracked structure as a three dimensional interlocking puzzle. The cracked concrete is able to take shear and tensile forces across the cracks. This is also shown experimentally in /8/.

7. CONCLUSIONS

From the investigations described above and from further experience from Danish structures made of concrete with alkali-silica reactive aggregates and standing in moist surroundings the following conclusions may be drawn concerning the crack development at pure alkali-silica reactions.

Structures without initial cracks from vibration, bleeding, thermal stresses etc. will not show cracks caused by alkali-silica reactions. It is impossible to predict a shorter service life time, than that proposed at the design.

For structures with initial cracks there will be an initiation period, in which the water penetrates the concrete. After this period the cracks propagate to a certain degree. Hereafter the cracks come to rest and nothing more happens.

The load bearing capacity and the stiffness of the structures are obviously not influenced from the cracking.

As mentioned the conclusions above are valid only for pure alkali-silica reactions. If the structure is exposed to one-sided water pressure, to de-icing salts or to freezing in saturated condition, then the deterioration may continue for these reasons.

Fig. 5. Development of cracks in motor road bridges. Overall impression from photos (Olsen /3/).

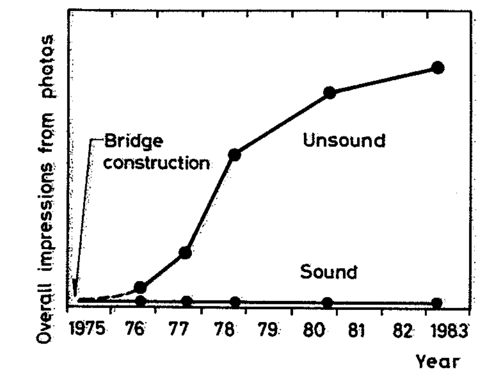


Fig. 6. Development of expansion in experiment with mortar bar 40 x 40 x 160 mm in saturated NaCl-solution according to the TI-method. Mogenstrup gravel.

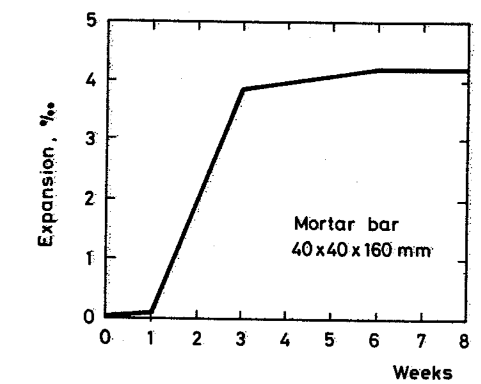


Fig. 7. Increase in elevation of midcrest of two concrete dams in USA /6/.

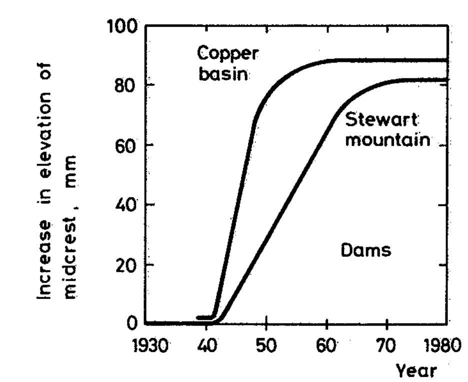
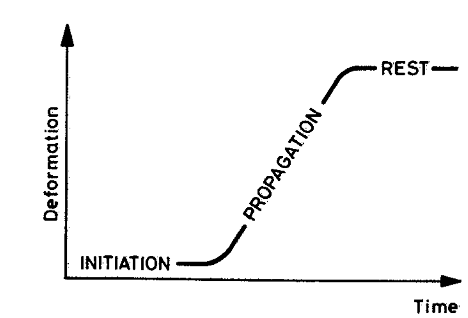


Fig. 8. Principal development of deformation and cracks in concrete suffering from damages caused by pure alkali-silica reactions.



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ALKALI REACTIVITY OF SILICEOUS ROCK AGGREGATES : DIAGNOSIS OF THE REACTION, TESTING OF CEMENT AND AGGREGATE AND PRESCRIPTION OF PREVENTIVE MEASURES

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1. ABSTRACT

In some badly cracked concrete structures containing orthoquartzite aggregate the cause of the deterioration is not immediately evident on site. Consequently concrete specimens have to be examined in an attempt to identify the reason for the deterioration.

Two possible methods for the determination of the active alkali content of cements are described.

Limits for the mortar and concrete prism methods performed under ASTM C227 conditions have been established for siliceous rock aggregates. An accelerated mortar prism test is described and limits proposed. Two variations of the quick chemical test to identify alkali-reactive aggregates, are discussed.

Limits for the active alkali content of concrete containing alkali-reactive siliceous aggregates have been established for a 0 per cent/100 per cent risk situation.

Keywords: reaction products, accelerated test methods.

2. INTRODUCTION

Although alkali-aggregate reaction was recognised in South Africa for the first time in 1974 a coordinated research effort into the problem was commenced only in the second half of 1977.

The aim of the research effort has been to obtain data with a view to advising laboratories on test methods, specification authorities on probable limits, consulting engineers and construction companies on precautionary measures, owners of structures on remedial measures and aggregate producers and cement manufacturers on the overall significance of the problem.

This paper is not intended as a review of the current status of research in South Africa but will present a brief account of some of the important or interesting developments since the last conference on this subject, held in 1981.

3. DIAGNOSIS

The visual appearance of concrete in the field that has been affected by alkali-aggregate expansion has previously been described /1/. However, situations arise where more definite evidence of alkali-aggregate reaction is required, for example where expansion is evident but sulphate attack is a possibility or where concrete is badly cracked but signs of expansion are not clearly observed. Under these circumstances examination of concrete taken from the structure and the characterisation of the reaction products in it are required.

The following data are for concrete from a number of structures in the Eastern