EFFECTS IN PRACTICE OF ALKALIS IN CONCRETE

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Concrete structures can suffer from internal reactions between the aggregates and the cement matrix. These expansive reactions disrupts the hardened concrete when unreinforced and are able to initiate severe cracking in reinforced concrete structures, and even in prestressed concrete structures.

With some susceptible aggregates, the alkalinity of the solution filling the pore structure of concrete, when above a specific level, leads to a slow expansion which cracks, unrestrained or partially restrained structures.

In practice, such distressed structures are to be "used-as-is" if a sufficient factor of safety still remains, as to stop the expansive reaction it would be necessary to dry out the whole structure.

However, strengthening the damaged structures by post-tensioning remains a costly yet possible alternative to mere replacement.

Nowadays, as the possible occurence of alkali aggregate reaction is widely publicized, specifiers and designers are exposed to over-estimate the danger when assessing new sources of aggregates.

As the reliability of the present accelerated tests is poor. Taking into account the corresponding uncertainty on the potential reactivity of the so-tested aggregates in concrete, the safest approach is to use a cement able to cope with reactive aggregates. The use of a low alkali Portland cement, or better of a pozzolan or slag cement seems presently the most effective précaution.

KEYWORDS : Detrimental expansion, service ability, safety.

1 - The present conference is divided in six session, 58 contributions are presented. 14 are dealing only or mainly on the pratical effects of alkalis in concrete. 7 case studies, necessary substratum of all work on the subject, 7 contributions dealing in a general way on the effects of the ASR on exposed structures, on the possible remedial actions. Without an even partial understanding of the causes, of the mechanism and environmental conditions of the reaction, the evaluation as to safety and service-ability of distressed structures and the more or less costly remedial actions to be eventually taken, would be ineffective. Against these 14 downstream contributions, 44 upstream contributions are dealing with alkalis in cement, on the mechanism of their reaction in concrete, or the examination and testing methods.

From the 5 conferences on ASR in most cases mainly qualitative prevision can be formulated for each type of aggregate. As stated by MATHER "all aggregates are reactives, but all are not be dealt with in the same way" (1). It is to be hoped that more quantitative previsions for each type of reactive mineral, the fruit of developed science, would be possible tomorrow.

However, as one of the founder of modern chemistry, Jean-Baptiste DUMAS taught in 1836, "it is possible that the sole practice, followed with constancy by an intelligent mind should lead to perfect industrial methods, which theory would have been unable to imagine" (2).

An instance of such practical success against a not well understood reaction, is the remedial measure adopted in Kansas for concrete roads using as aggregate, a combination of about 70 percent of deleterious sand-gravel with about 30 percent of coarse crushed limestone (3).

2 - AAR EXPANSION, FROM MORTAR TO CONCRETE

2.1. Testing of aggregates on mortar prisms (40 x 40 x 160 mm) or mortar bars useful as it may be to understand the nature of the reaction, and its development in time, can be misleading concerning the possibility and rate of development of the reaction in practice, that is in concrete structures. Further, the environment plays a major part, inhibiting a possible reaction (dry climate, protected structure) or exalting it (structure submitted to alternate wetting and drying). As the content and the dimensions of the reactive aggregate, the cement content of the mix is also very different from the 1/2,25 mix with the 0/4,75 mm aggregates of the standard mortar (4). For instance, mortars bars prepared with a pessimum content of Beltane Opal, can expand up to 2% at 200 days (5). On the other hand, if in the laboratory concrete prims expansion reaches 0,3 percent at 400 days (Hornfels with a cement of 1,30 percent of acid soluble alkalis (6)), exposed in the field, concrete prisms may expand no more than 0,8 percent in six years (andesite with a cement of 1,20 percent of acid soluble alkalis) (7).

2.2. Detrimental expansion

Most concrete structures are designed taking into account drying shrinkage and some reversible expansion following the daily, or yearly changes of ambient temperature. The extensibility of concrete has been defined as the tensile strain capacity to failure. The mortar bar test is not a measure of this extensiblity. The mere imbibition of water or the effect of a temperature rise, produces a reversible expansion ; such dimensional changes are not accompanied by internal distress. However when there is a wide difference between the coefficient of thermal expansion of coarse aggregate and the coefficient of thermal expansion of the components of concrete (aggregate and hardened cement paste), such a thermal incompatibility of the componenets may lead to permanent distress of the concrete (9).

Expansion resulting from reactive aggregate on the other hand is not reversible, as the chemical reactions causing it are not, and as cracks in the cement past, in the interface and in the aggregates, remain open even when the reacting products are totally consumed. This is manifested by the halving of the compressive strength of such expanded concrete, the tensile strength being practically reduced to zero, at least on laboratory mortar specimens. Cores exhibit a lesser weakening of the mechanical chacteristics of concrete. However LENZNER maintains that when reaction stops, the reaction product becomes

with time solid and hard (8). Such healing is manifested by an increase in resonance frequency after expansion has stopped. The swelled structure is healed, but the detrimental effects of the expansion on the adjacent structures remain.

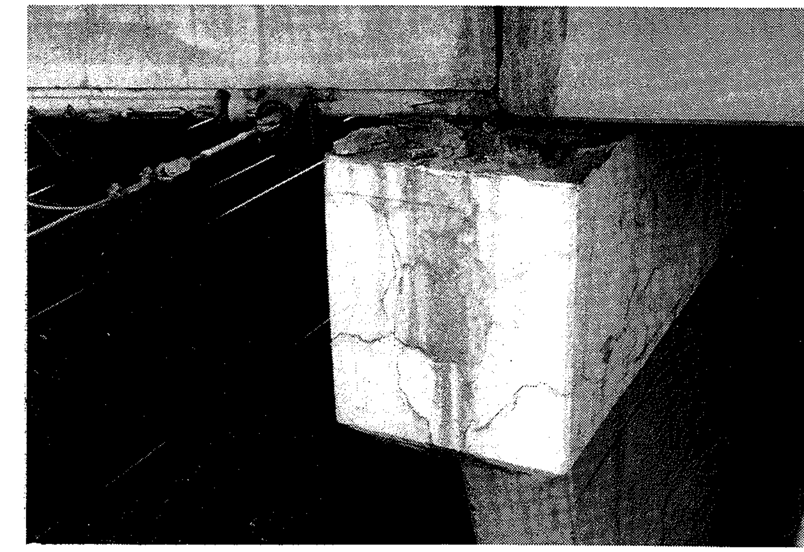


Fig. 1 - ASR distressed road bridge (South Africa)

a. reinforced concrete pier caps severely cracked in its exposed ends

b. the prestressed concrete beams of the simply supported spans have sufficiently expanded to close the joint so that the lower end of the beams is crushed (pieces from the corner can be seen on the top of the cap)

3 - EXPANSION AND CRACKING OF UNREINFORCED CONCRETE

Easier would be apparently the correlation between the results of laboratory tests on mortar or even concrete specimen and the behaviour of unreinforced concrete structures. Highway slabs, dolosse, gravity or arch dams have paid an heavy tribute to the ASR and their distress has been thoroughly anlysed. An extensive pattern cracking must be highly detrimental for a slab or a road, but only uglyfying for a massive retaining wall . For large massive structures like dams, the general expansion is more detrimental that the surface crackings even of several mm width, as usually these cracks disappear in the region of moisture equilibrium some 300 to 500 m deep (fig. 4).

4 - EXPANSION AND CRACKING OF REINFORCED CONCRETE

The ASR cracking of concrete above the deck of bridges or building (acrothers), is most conspicuous and as these relatively thin structures are generally seldom stressed in service and their reinforcement is in accordance not very important : some 20 to 40 kg/m³ of reinforcing bars. The random expansion produces, in these conditions, a pattern cracking.

For columns or wing walls, a longitudinal crack is often met depending on the importance of the transversal reinforcement. In column from 2 to 1% of longitudinal reinforcement is provided against 0,25 to 0,50% of transversal reinforcement, it explains the opening of longitudinal cracks. (fig. 4)

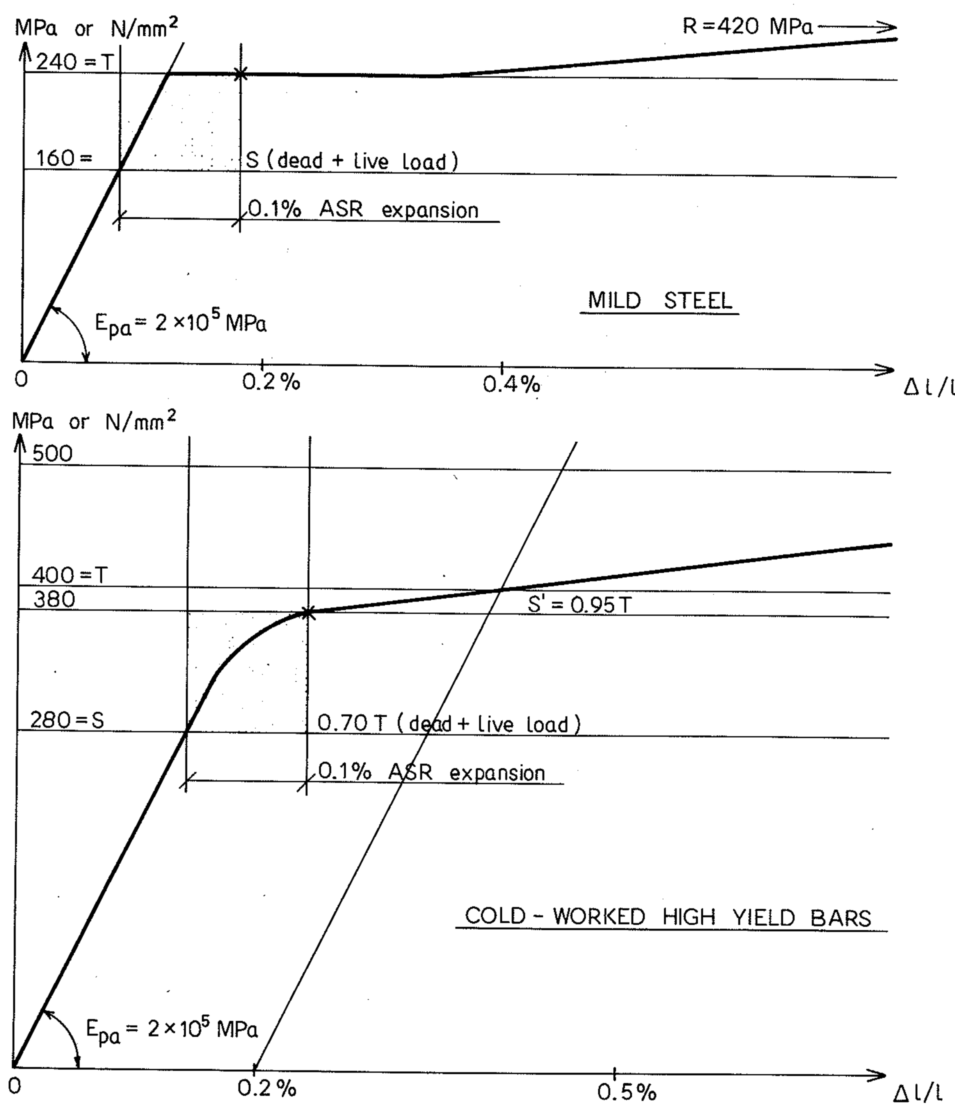


Fig. 2 - ASR affected R.C. beam

Suspended slabs or beams are rather heavily reinforced, both longitudinally and transversally, the reinforcing steel content averaging from 40 to 80 kg/m³ for slabs, and from 80 to 160 kg/m³ (beams). Such structures are rarely distressed by ASR, as they are generally protected against humidification by an impervious riding surface or a waterproofing membrane.

When they are distressed but free to expand (in bridge decks on elastomeric bearings), the expansive force of the reaction produces a hogging rather than cracking as in restrained members. Longitudinal reinforcement is consequently overstressed and the factor of safety lowered (fig. 1 and 2)

However, when restrained their expansion is able to destroy the restraining connections as has been the case for the reinforced concrete floor of a steel girder bridge on the Republican River in St Francis (Kansas) (10 (fig. 1).

5 - EXPANSION AND CRAKING OF PRESTRESSED CONCRETE

It has been observed that in the parts of distressed concrete structures where compressive strength is high, the alkali silica reaction has not arisen, has been inhibited (11).

On a serie of bridges where the same concrete materials were used for the prestressed bridge decks and for the piers and abutments, these structures only were distressed and the prestressed box girders were not. (fig. 6, 7)

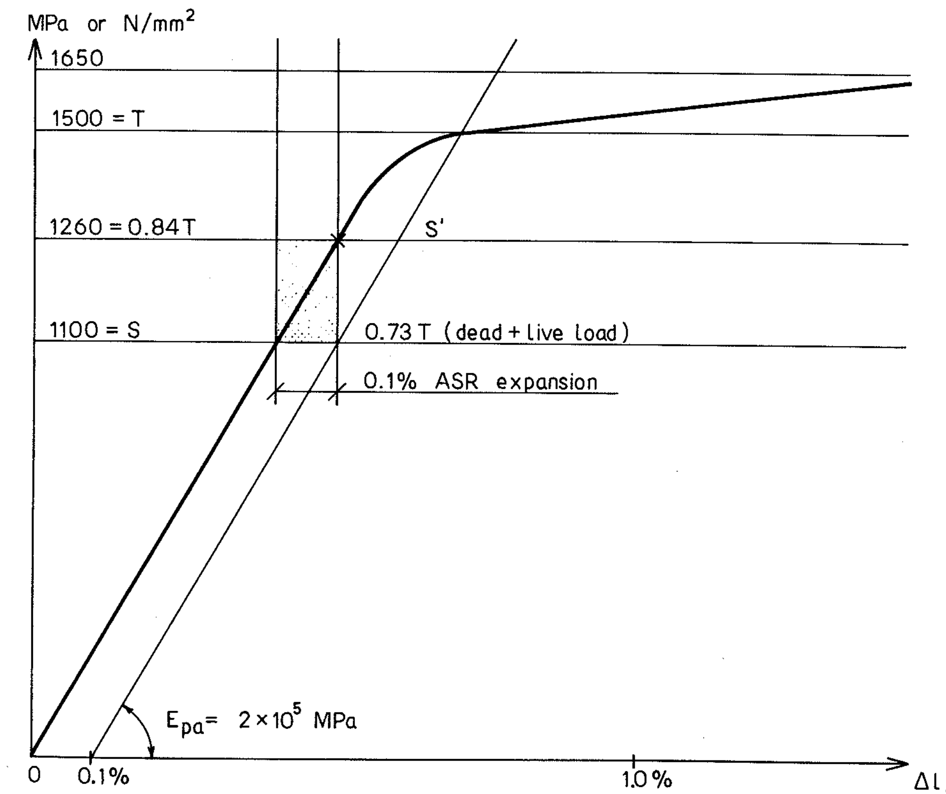


Fig. 3 - ASR affected prestressed concrete beam

Fig. 4 - ASR distressed Abutment of a railway bridge (Equatorial Africa) :

Reinforced wingwall is longitudinally cracked

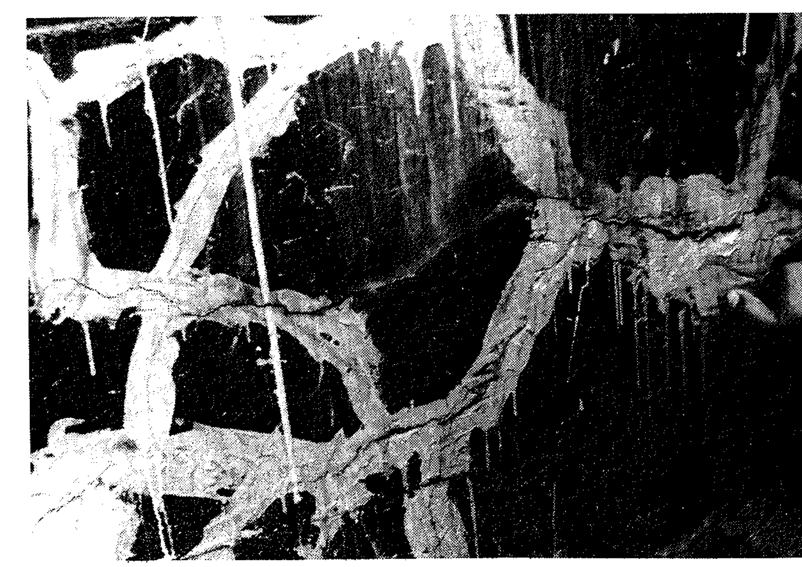
Are we to conclude that a permanent compressive strength of the order of 2 to 8 MPa is sufficient to inhibit the reaction ? The principle of LE CHATELIER (12) lead some to presume it , and that consequently for prestressed concrete, potentially reactive aggregate can be safely used with high alkali Portland cement ? It seems that no laboratory experiment has been attempted to clarify this issue and that some post-tensioned beams have responded to ASR by longitudinal cracks...

When prestressed concrete members are to be exposed to wetting and drying, as electric lines poles, it would be unsafe to admit such an immunity. If the longitudinal expansive force resulting from the non inhibited reaction is balanced by the prestressing tendons, it is at the cost of an overstressing of the steel and a concomitant lessening of the safety of the structure. An overall longitudinal expansion of 0,1 percent which would destroy a reinforced beam, can be however accepted by a prestressed beam (fig. 2 and 3).

Fig. 6 - ASR distressed abutments of a railway bridge. (Equatorial Africa)

The attempt to stop the expansion by sealing the cracks and filling them with an epoxy injected under pressure has failed Six month after, injected cracks have reopened and new cracks have appeared (fig. 6)

Fig. 7



6 - CONCLUSIONS

Even in dams no major structural failures, that is collapse, can be attributed to alkali aggregate reactions, its most damaging effects are economical, as met in concrete pavements.

Thanks to Stanton and to the Us Bureau of Reclamation, the classical alkali-silica reaction can be efficiently avoided in major projects : the Hongrin-Leman dam in Switzeland built in 1968, is an excellent instance of this achievement (12). But as shown by Idorn, modern concrete, is not sufficiently protected against excessive temperature rise and stress-developing temperature differences. Early internal micro-cracking makes it often permanently invalidated against further aggressivity (13). The inconsiderate use of high strength cements for relatively massive structures in hot environment exalts these deficiencies. However, the progress of the cement industry offering now, at least in Europe, diversified products and their intelligent use with the design of less energy consumpting mixes, should enable us to build durable concrete structures with a wide range of natural aggregates, including, at least partially, potentially reactive aggregates.

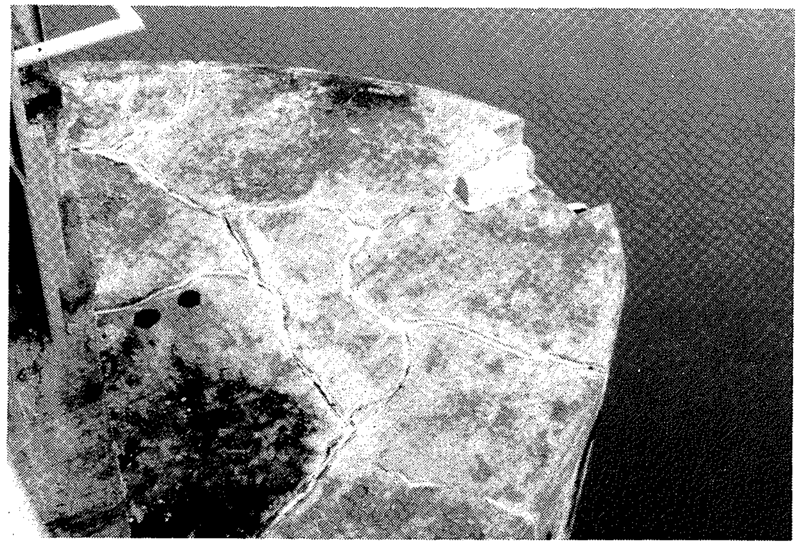


Fig. 5 - Old soldiers nerver die ... upstream end of one the cracked piers of a 33 year old river dam in Southern France. Sealing of the cracks has been ineffective to stop the expansion, the pier has been cored to evaluate the internal distress.

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