ALKALIS IN CONCRETE

6th INTERNATIONAL CONFERENCE

COPENHAGEN - JUNE 1983

Session 5. Effects in Practice of Alkalis in Concrete

STRUCTURAL EFFECTS OF AAR ON REINFORCED CONCRETE AND CONSIDERATION OF REMEDIAL ACTION

Jonathan G.M.Wood and Peter J.Wickens
Mott, Hay & Anderson
CROYDON CR9 2UL U.K.
TEL.01-686-5041 TELEX 917241

----

1. ABSTRACT

The actual behaviour of reinforced concrete structures with AAR is contrasted with laboratory mortar bar tests. Study of fundamental behaviour of concrete indicates that expansion, micro-cracking and tensile strength loss from AAR will reduce structural strength most rapidly in details subject to shear stress and those with high bond stresses.

The need for research to be related to the practical problems of strength assessment of structures suffering from AAR and to determining the environmental conditions for slowing AAR is stressed.

Methods of strengthening and rendering structures less sensitive to deterioration are discussed.

Keywords: STRUCTURAL BEHAVIOUR, ALKALI-AGGREGATE REACTION, REMEDIAL WORK.

2. INTRODUCTION

Mott, Hay & Anderson have been appointed as Consulting Engineers to advise the owners of a number of structures suffering from AAR on the management of the structures. This work has covered inspection and diagnosis, supervision of coring and analysis of samples, load testing, structural appraisal, recommending action to delay deterioration, structural reinforcement and where appropriate structural replacement. One such structure is the Car Park at Charles Cross in Plymouth for which we are Consultants to Plymouth City Council. Other structures on which we are carrying out detailed studies include a range of highway bridges.

In this work we have had considerable assistance from research workers in the U.K. in particular those from Queen Mary College, the Building Research Station and the Cement and Concrete Association.

In this paper we will discuss some of our observations of structural behaviour when AAR develops, some examples of action we have recommended to reduce the vulnerability of structures and most importantly a shopping list of questions on the effect of AAR on concrete structures for the research workers.

3. STRUCTURES ARE NOT MORTAR BARS

All reinforced concrete structures are subjected to substantial strains, with resulting stresses and cracking, even when no AAR develops. These are due to differential thermal and drying movements in the cement mortar relative to the steel and aggregate particles and due to applied dead and live loads. Typically there is a net contraction of concrete relative to steel of between 0.05% and 0.07% compared with expansions of 0.1% to 2.0% noted for AAR in mortar bars at constant humidity. Sound hardened concrete has a maximum ultimate tensile strain capacity before cracking of the order of 0.2%, but this is very variable, and AAR is likely to significantly reduce this strain capacity.

In a concrete structure the triaxial expansion from AAR is resisted by the steel. Where the steel forms a substantial three dimensional cage the indications are that the steel contains the expansion and that ultimate strength loss does not become serious until secondary deterioration from spalling concrete and corroding steel develops. The development of cracking is strain related and results from a combination of concrete shrinkage, structural action and AAR expansion which is partially restrained in certain directions by the reinforcement. The initial cracking will tend to follow the orientation of structural tensile strains. Map cracking only develops in the later stages of deterioration of a stressed R.C. structure. This can easily result in faulty diagnosis.

Where the steel does not form a substantial three dimensional cage the ultimate strength of concrete structures may be substantially reduced during the early stages of AAR. Figure 1 shows an R.C. wall with steel in both faces but no through thickness steel. AAR expansion of this type of wall is restrained by the steel in both faces and this tends to split it in two, forming a crack through which moisture can percolate to feed the AAR.

The standard mortar bar test shows negligible adverse indication until cracking and substantial expansion starts. However work by Dr.Nixon of BRE and tests on cores indicate that there is a substantial loss of tensile strength in mortar and concrete before significant expansion and cracking develop. Although tensile strength is not used explicitly in R.C. design it is relied on for the development of bond strength and for carrying shear in concrete where full shear steel is not provided. The bond sensitivity makes halving joints (Figure 2) and corbel details particularily sensitive to deterioration.

Figure 3A shows a typical piled or pad foundation with heavy bottom steel, light top steel and vertical steel only below the column and at the edges. The superposition of shear and tensile stresses from the AAR expansion, on top of those from structural actions, can cause serious cracking and weakening of this type of base in which the tensile strength of concrete is relied on to carry shear.

4. MODELLING THE EFFECTS OF AAR

Finite element techniques for modelling ordinary concrete behaviour including differential strains and the development of cracking are available. We are making use of these programs in assessing the expected behaviour of concrete with AAR by feeding in the expansion and reduced tensile strength properties of the concrete.

A typical output of principle stresses from 0.1% AAR expansion is shown on Figure 3B.

The results of this type of analysis must be regarded with caution as the data we have on the change in concrete tensile strain capacity and AAR expansion with time is sketchy. There is also uncertainty on the variation in rate of development of AAR in the surface zone compared with the centre of the concrete mass.

The determination of these data for finite element analysis is the first item on our shopping list for research.

5. REMEDIAL WORK AT CHARLES CROSS CAR PARK

After detailed studies and load testing at Charles Cross it was concluded that it was not possible to predict how much longer certain critical details would retain an adequate factor of safety. These critical details included the badly cracked corbels to columns and halving joints. These details, unlike the beams, were not ductile enough to show warning signs before collapse could occur.

The strengthening work had to be carried out with the minimum disruption to the use of the car park and also remain aesthetically unobtrusive because of its prominent position in the centre of Plymouth. Because the precast tee beam floors are clear of AAR it has been possible to provide a duplicate column and edge beam system which will ensure that the overall stability of the car park structure is assured. The work was carried out, with a major part of the car park always remaining in use, during a 6 month period.

The Charles Cross remedial work necessitated the opening up of the foundations. They were found to be severely cracked. The vulnerability of buried foundations to attack because of their damp environment has also been noted on other structures.

6. VARIATION IN RATE OF DEVELOPMENT OF AAR

Because the extensive nature of the structures we have examined it has been possible to obtain some insight on the way in which site mix variation and exposure to moisture influences the rate at which deterioration first becomes apparent and the rate at which it develops. It is too early to state how much further the deterioration can be expected to develop in these structures.

For a series of columns of nominally identical mix built in 1970, all known from coring to be potentially reactive and all with similar exposure there is a wide range in the current state of cracks from no visible cracking to parallel vertical cracks typically 0.5 - 1.0mm wide at 200mm centres. However the worst column showed negligable cracking 3 years ago. Crack growth rates are now being monitored with DEMEC gauges.

Although there is a slight tendency for cracks to develop first on the face most exposed to rain and sun there is no consistent change in the degree of cracking in the same pour of concrete between that below ground in saturated soil, that above ground but exposed to rain and that tight up below the deck where it is sheltered from rain and sun but subject to condensation.

Concretes exhibiting AAR in the field generally have been found to have above average cement contents and high alkali cement. The reactive aggregates have been found to be cherts forming a small proportion in river gravel or sea dredged aggregate.

However there is clear acceleration of deterioration in local areas where water contaminated with road salt has

accumulated on horizontal surfaces below bearings or has seeped over the edge of the road deck.

We conclude that variation in the concrete mix from pour to pour is a significant factor in variation in the rate of development of AAR. Variation in the relative exposure to rain or condensation has a limited effect on the rate of development of AAR in outdoor structures. Continual dampness with road salt is the most adverse condition.

We have carried out some trials at Charles Cross on protective coatings to limit the supply of moisture to the concrete. Their main potential value seems to be on deck or floor surfaces where saline damp might otherwise soak into the concrete.

7. RESEARCH PRIORITIES

When appraising a structure diagnosed as having AAR the fundamental questions are:-

Is it still structurally safe?
How long will it remain safe?
What repairs are necessary to keep it safe?
How soon are the repairs required?
Can we slow down deterioration?

We do not yet have the information we need to answer these questions fully.

There is an urgent need for a series of test programmes on the fundamental strength properties of concrete with AAR (e.g. tensile strength, bond strength, compressive strength, tensile strain limit, expansive strain etc.).

The results of finite element analysis using these properties should be compared with actual test strengths of reinforced concrete with AAR. The test specimens may either be from structures with AAR or made specially for tests with the reactive aggregate. These tests must be concentrated on those types of detail most likely to be sensitive to loss of ultimate strength.

If we are to use moisture control to slow or halt deterioration it is essential that the relationship between temperature, moisture content, salt supply, concrete mix and rate of deterioration is established. If coatings are to effectively halt structural deterioration as well as hiding the evidence of it they must produce a sufficient and consistent reduction in moisture contents to halt the reaction.

Once the limiting moisture content is known it will enable coatings to be rapidly evaluated for their ability to control internal moisture levels.

The same data will also enable more reliable predictions of future deterioration to be made for those structures which cannot be dried out fully.

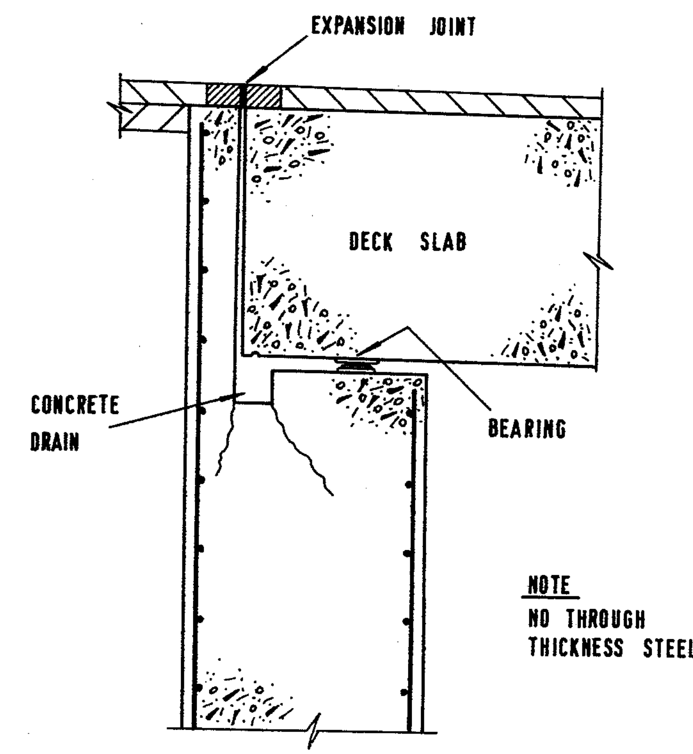

FIGURE 1.

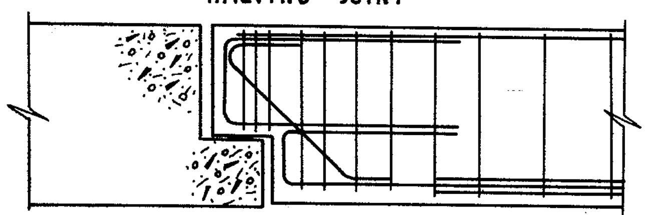

FIGURE 2.

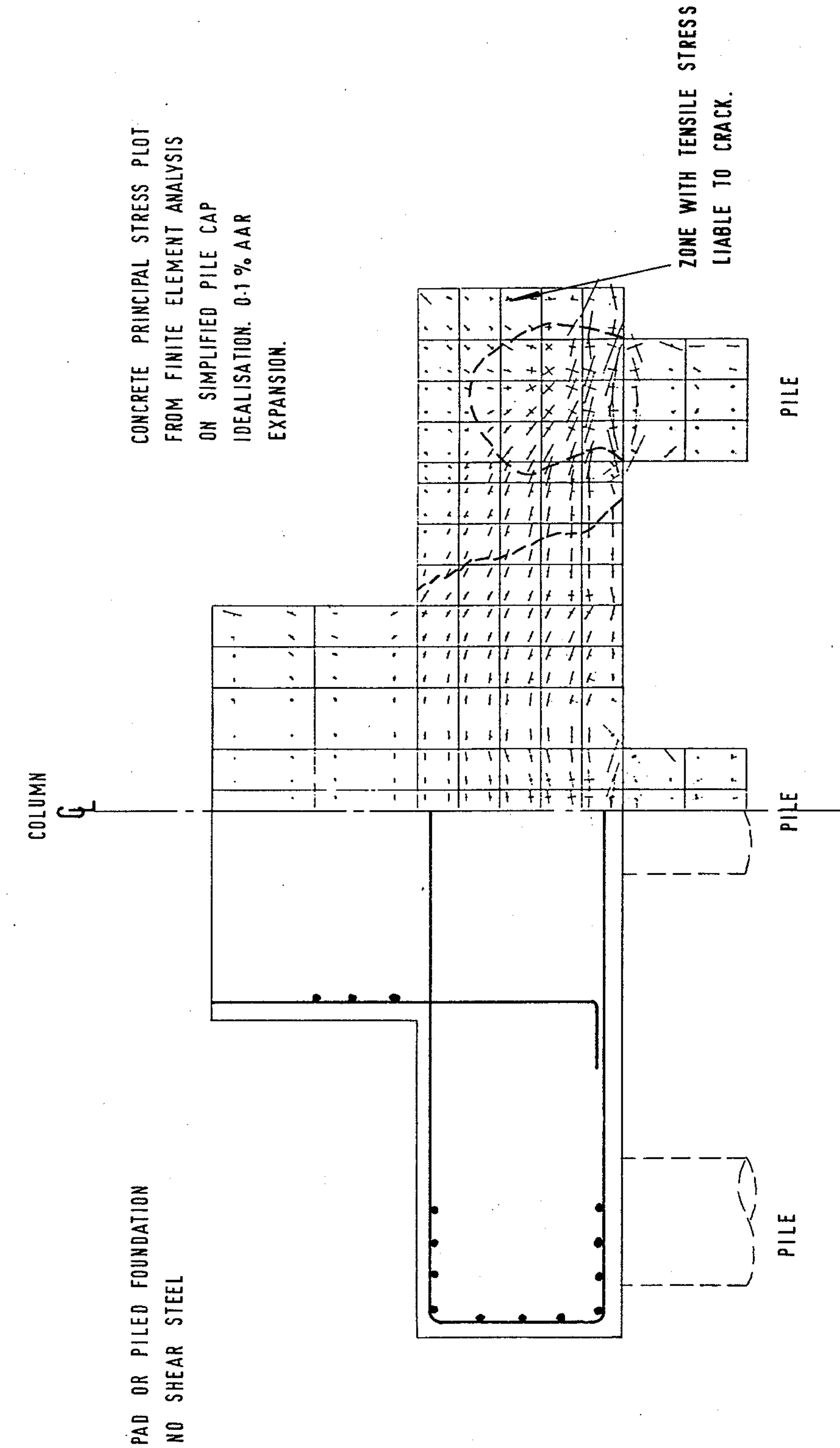

FIGURE 3a

FIGURE 3b

ALKALI-AGGREGATE REACTION IN LIGHTWEIGHT CONCRETE

Branka Zatler,M.Sc.; Edvard Mali,B.Sc.

Institute for Research and Testing in
Materials and Structures, Ljubljana, Yugoslavia

1. ABSTRACT

The properties of lightweight concretes made of expanded clay, and expanded clay with perlite as aggregate was studied. As the expanded clay and perlite contain silicium dioxide components in amorphous form, the potential silica aggregate reaction was tested with the modified methods by ASTM C-227 and ASTM C-289.

2. KEY WORDS

Expanded clay, expanded perlite, alkali silica reaction

3. INTRODUCTION

Laboratory concretes were prepared from expanded clay and expanded perlite. They were watertight and stable against freezing and thawing. In accordance with the ACI classification /1/ their compressive strength alligned them in the group of "moderate strength concrete". Their composition and basic properties are presented in Table 1. If they were used as facade walls (monolithic or prefabricated) they would be exposed to the action of water and moisture ,alkali silica reaction could take place, and concrete stability would be uncertain.

4. EXPERIMENTAL

4.1 Chemical analysis of concrete constituents

Yugoslav expanded clays contain from 65 to 70 per cent of silicium dioxide and expanded perlites from 70 to 75 per cent. Free alkalies content expressed as Na_2O, in Yugoslav portland cements varies from 0,8 to 1,4 per cent.