EVOLUTION UNDER STRESS OF A CONCRETE AFFECTED BY A.A.R. - APPLICATION TO THE FEASIBILITY OF STRENGTHENING A BRIDGE BY PRESTRESSING

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The bridge affected by A.A.R. is located near Paris. It is an open frame, the piers of which are severely damaged by A.A.R. In an attempt to stop the evolution of the horizontal deformation of the pier, 0.4mm/m/year, transverse prestressing of the piers is being considered.After a brief presentation of the bridge, its construction, and its disorders, the paper presents the experimental plan conceived to study the feasibility of strengthening by prestressing.The first stage of our study consisted of sampling cores, suitably oriented in the structure, and measuring their expansion under different compressive stresses (1, 3, and 5 MPa). At the same time, the free expansion was also measured.
Our expansion tests were intended to be as representative as possible of the conditions of exposure of the bridge. Accordingly, they were performed at 20°C in tap water. This was chosen after testing of free expansion in solutions regarded as more aggressive, such as NaCl or KOH and NaOH. The results obtained after a year of monitoring are presented, then interpreted, in the context of a strengthening of the bridge.

DESCRIPTION OF THE STRUCTURE

The structure studied is a frame bridge the design of which is original in that the piers are made of reinforced concrete and the deck of prestressed concrete. It is located at the entrance of Meaux, Northeast of Paris.

The piers are 8.50 m wide, approximately 7 metres high, and 1 m thick. The tier of reinforcements on the pavement side consists of HA 14 vertical reinforcements (12.5 cm spacing) and HA 14 horizontal reinforcements (40 cm spacing). On the earth side, the tier of reinforcements consists of 2 HA 32 vertical reinforcements (25 cm spacing) and HA 20 horizontal reinforcements (15 cm spacing). The component materials of the concrete are: a CPA 400 cement (420 kg/m3), a 0/5 mm Marne sand, a 6.3/20 mm calcareous gravel. The Water/Cement ratio was 0.47.

The primary-era limestone is partially dolomitic. The carbonate content is close to 90 %. The remaining 10 % consists mainly of silica, found both in the form of quartz and also in the form of a three-dimensional lattice forming a mesh of approximately 10 µm in which stacks of hexagonal platelets of tridymite can be made out. (see photo1 : amorphous silica in dolomitic limestone)

The presence of clays, primarily illitic, and of pentagonal-dodecahedral sulphides, the individual elements of which do not exceed the micrometre, may also be noted. The mean sulphide content is nearly 0.7 %, but locally it can exceed 1%. (see photo 2 : secondary minerals in dolomitic limestone)

The primarily siliceous sand is of alluvial origin. The grains of quartz often have a pitted surface appearance, with visible traces of dissolution and sometimes deposits of amorphous silica (photo 3).

The compressive strenghs measured at 28 days at the time of construction in 1976 reached 40 MPa for the West pier and 36 MPa for the East pier.

The deck, 8.50 metres wide, is 28.17 m long and 0.90 m thick. It is longitudinally prestressed by 32 CCL 12 T 13 tendons. The component concrete has a formula totally different from that of the piers and shows no sign of internal reaction.

DESCRIPTION OF DAMAGE

A detailed inspection, performed about ten years after construction, revealed the existence of multidirectional cracking occurring in the same way in both piers.

The vertical cracks have an opening width ranging from 0.3 to 3 mm. They are substantially more open than the horizontal cracks, the maximum opening of which does not exceed 0.6 mm. Denser and more open at the bottom, the cracks sometimes have offshoots that can reach 2 mm and that reveal differential swelling of the pier in the transverse direction.

The underside of the prestressed slab, for its part, shows no sign of alkali-aggregate reaction ; but , due to its fixed ends following the movement of the piers, longitudinal cracks form in the fixed ends and grow to lengths of 2 to 7 metres.

Given the occurrence of this damage, it became essential to perform methodical monitoring of the structure. Since 1988, the West pier has been instrumented and swelling has been monitored by invar wire distancemeters. Figure 1 gives the results of this monitoring, which shows that the pier swells more in the horizontal direction (0.4 mm/m/year) than in the vertical direction.

To limit transverse expansion and avoid longitudinal cracking of the deck, the idea of prestressing reinforcement of the piers was put forward. The feasibility study of this solution would require determining the origin of the damage and investigating the influence of stresses on the expansion of the concrete.

ORIGIN OF DAMAGE

On cores taken from the zone where the most extensive cracking was visible, we carried out a characterization of the origin of the damage and an evaluation of the residual potential reactivity. This approach required the preparation of five cores 40 mm in diameter and 100 mm high. After finishing of the ends using a diamond-coated grinding wheel, the cores were saturated with water, then each immersed in a different reaction medium and monitored for free swelling.

The solutions used as reaction media were:

- tap water, for 2 specimens
- 1 N sodium hydroxide)
- 1 N potassium hydroxide (for 1 specimen
- 1 N sodium chloride)

Each specimen, immersed in its solution, was covered by a ground stainless steel helmet on which a micron comparator was applied as shown by figure 2.

The comparator was supported by an invar rod. The measurements were made at very short time intervals at first, then daily for 1 week, and finally weekly until the end of the test (100 days). Three of the specimens tested had swollen 0.7%, and water was one of the swelling media in which this value was reached.

Our previous experience had led us to test the influence of depth also, and in our initial sampling we set up two batches :

* the first batch, consisting of two specimens, was sampled in the first 10 centimetres, i.e. in the "skin".
* the second batch, consisting of three specimens, was sampled at a depth comparable to the core of the mass of concrete.

We found that the two batches follow different courses. The deep batch exhibits a faster evolution, and in the case of the specimen immersed in water a final value roughly twice as large as that obtained with the surface specimen. It was also found that the batch from the deep part is very homogeneous; the swelling values reached are very similar whatever the medium, KOH, NaCl, or H_2O.

This first series of experiments showed us that :

- The swelling potential of the concrete is still very important and it can spread up to failure of the structure.

- The swelling media are of rather little importance, so for the rest of our experiment it would be possible to use tap water, a fact that makes the apparatus much easier.

- The surface zone consisting of the first ten centimetres should if possible be avoided. Much more microcracked and doubtless rather substantially leached, it does not give the largest expansion values.

- Finally, microstructural observations confirm that the origin of the damage is in fact the development of an alkali-aggregate reaction, locally associated with a sulphate reaction (see photo 4).

SWELLING WITH CONFINEMENT

This first stage was followed by a second intended to yield information about the influence of stresses opposing the swelling. For practical reasons having to do with the existence of uniaxial loading frames, and given the complexity of making transverse strain measurements in a liquid, only the longitudinal strain of the specimens was monitored. However, it should be borne in mind that the absence of longitudinal strain is not synonymous with the absence of transverse strain.

The second phase required a core 150 mm in diameter. This sample was so oriented that we could take our test specimens in the direction of the largest swelling values observed on the structure.

Preparation of specimens and conduct of test

Preparation of specimens : the initial 150-mm-diameter core was finished with a diamond-coated grinding wheel along two opposed chords as shown by figure 3. This produced two parallel plane surfaces allowing the taking of four test specimens 69 mm in diameter and 120 mm high in the horizontal direction. The first ten centimetres of the initial core were eliminated to avoid taking into account a zone that is both lower in reactivity and also more heterogeneous.

Conduct of test

The experiment proceeded as follows: one specimen was left to swell freely in tap water in the same device as shown in figure 2. The remaining three specimens were subjected to uniaxial stresses of 1, 3, and 5 MPa, with tap water as the swelling medium. The arrangement is shown schematically in figure 4.

For the duration of the test, 378 days, the temperature was recorded. It varied by ± 2°C about 20°C. The measurements were then corrected.

Results

It can be seen that the free swelling is close to 0.7 % as early as 200 days and that it changes very slowly thereafter. Under 1 MPa, the expansion is nearly 0.3 % by 220 days, and thereafter evolves very slowly. Under 3 MPa, the expansion is not more than 0.1 % after 378 days. Finally, under 5 MPa, it is found that the expansion is cancelled for 200 days and does not exceed 0.01 % after 1 year of measurement.

Figures 5 and 6 show the shapes of the free swelling and the expansions with confinement, respectively.

From this experiment, we can draw the following conclusions:

- The largest values measured at the end of the first phase are reached by the specimen left to swell freely, but the kinetics is slower. This finding shows that the internal reaction that is the origin of the damage has no reason to stop before all of the mineral capable of reacting has participated in the reaction.

- The application of a stress substantially reduces the expansion in the direction of the stress. But it should be noted that a stress of 5 MPa must be applied to reduce expansion to negligible values. This result is opposed to the values sometimes proposed in the literature to reduce expansions. But it is in very good agreement with the values mentioned by many authors, who situate the swelling pressure between 3 and 10 MPa.

- Our experiment suggests proposing to apply a "prestress" of 5 MPa to reduce significantly the transverse swelling of the piers of the Nanteuil bridge. However, before a strengthening operation that will in any case be experimental is undertaken, there are still a number of problems to be examined, such as:

- the current compressive strength of the concrete,
- the adherence of the existing passive reinforcements to an expanding concrete.

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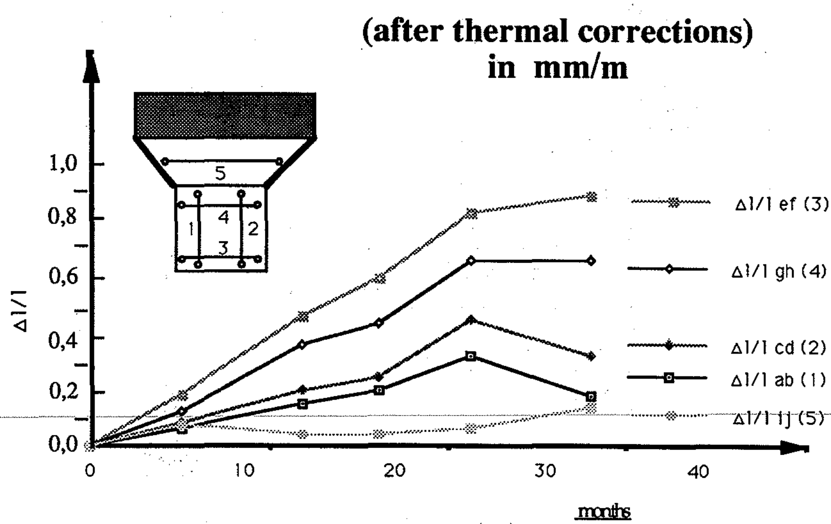

Figure 1 : Global deformations of the structure

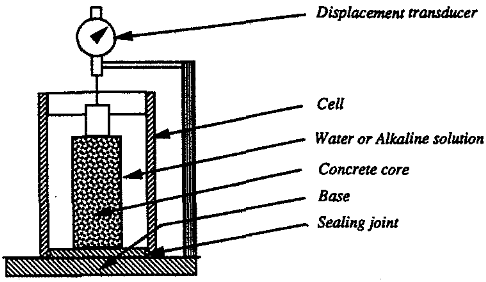

Figure 2 : Free expansion device

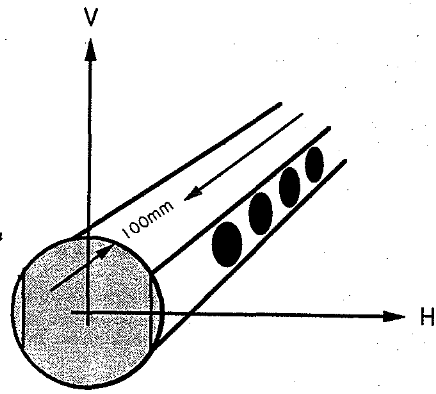

Figure 3 : Schematic positioning of core samples

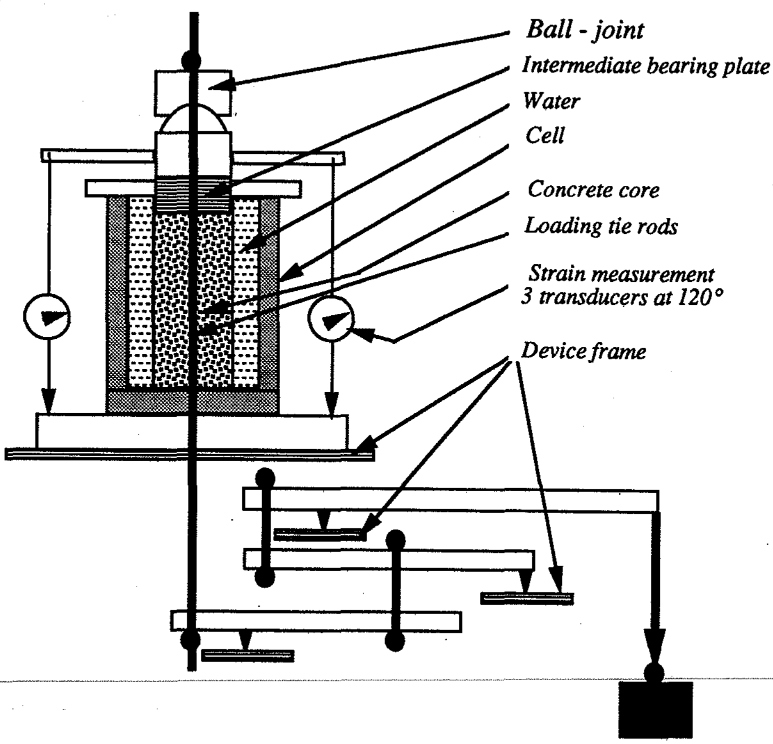

Figure 4 : Controlled stress expansion device

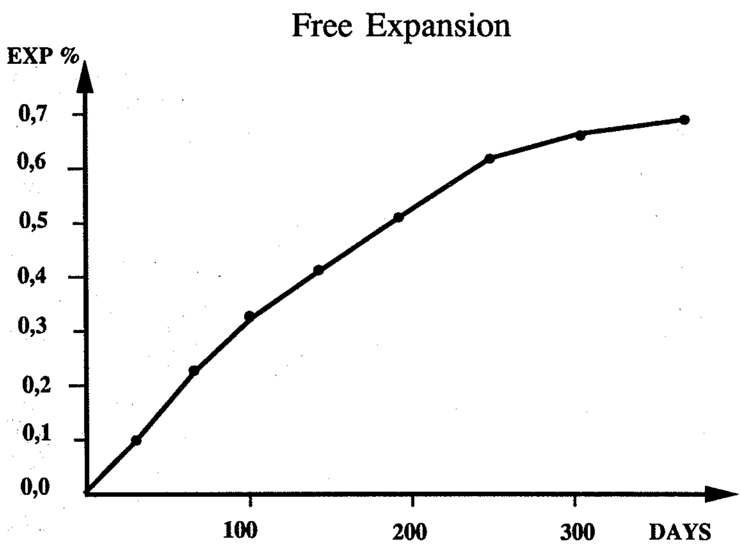

Figure 5 : Longitudinal expansion of the specimen subjected to free swelling.

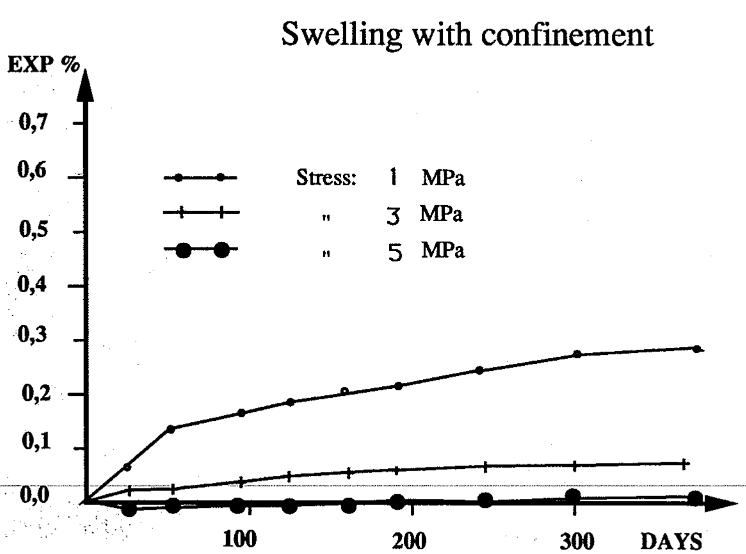

Figure 6 : Longitudinal expansions of specimen subjected to uniaxial stresses

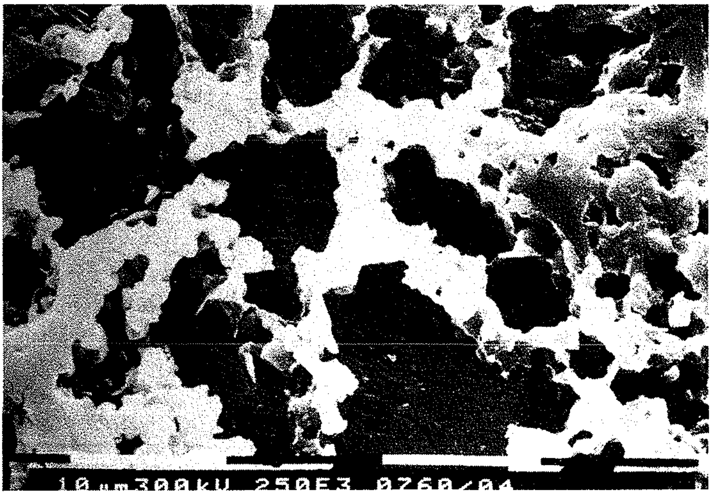

Photo 1 : Amorphous silica in dolomitic limestone.

Photo 2 : Secondary minerals in dolomitic limestone
(clays, sulphides and micro-quartz dispersed in calcitic matrix)

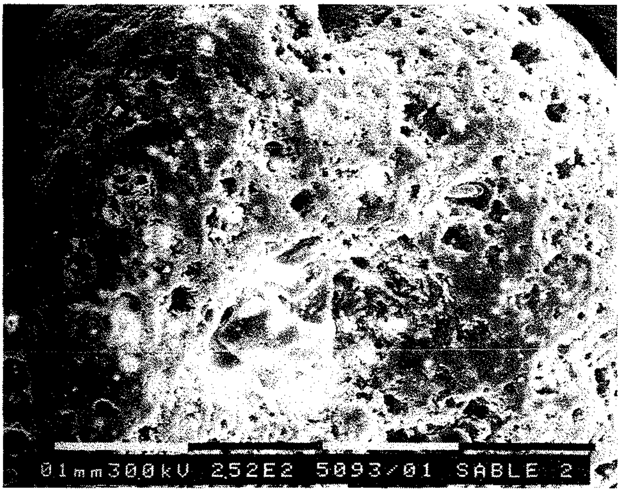

Photo 3 : External surface of alluvial quartz.

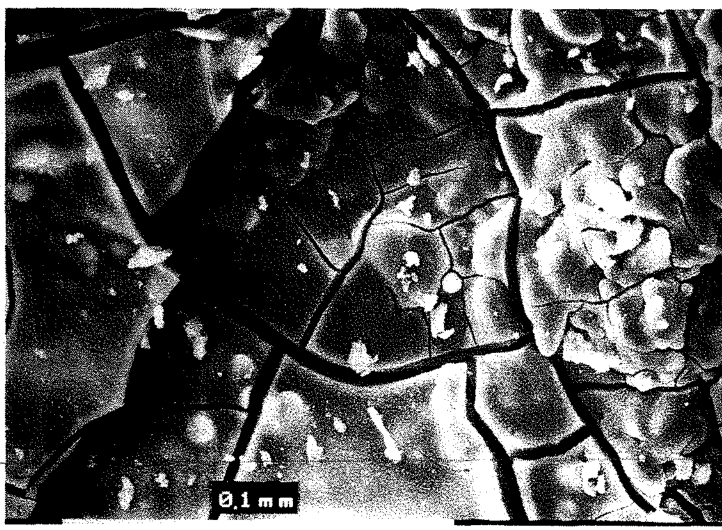

Photo 4 : Typical product of alkali-silica reaction.