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STRUCTURAL EFFECTS OF ASR IN FRANCE ON REAL AND LABORATORY STRUCTURES

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ABSTRACT

This paper gives the latest information on the affected structures in France as far as bridges and dams are concerned. It summarises the main results reached by the Laboratoire Central des Ponts et Chaussées (LCPC) and Electricité de France (EDF) in the research field on Alkali-Aggregate Reaction (AAR), presents a new experimental survey launched to gather data for mechanical models validation and describes available devices specially designed for the measurement of weight and deformations of concrete specimens (cylinders and beams) affected by internal swelling reactions (AAR or sulphate attack).

Keywords: Alkali-silica reaction, bridges, dams, models, experiments, measurement methods, deformation, weight.

INTRODUCTION

While many years have been devoted to the characterisation of aggregates reactivity or to the study of the chemical mechanisms, modelling the behaviour of ASR-affected structures is still a recent subject of interest.

The stake of models to predict the long-term behaviour of AAR-affected structures has been emphasised at the last Melbourne Conference on AAR in Concrete (Moranville 1996, Capra et al. 1996, Larive and Coussy 1996, May 1996, Sellier et al. 1996, Wen and Balendran 1996). Two types of models can be distinguished: microscopic and macroscopic ones. This paper deals with the second type.

Mechanical models can be considered as helpful for the maintenance of degraded structures only if they can give reliable results by using reachable input parameters. Models must give information on how an affected structure will evolve, in terms of final state and degradation rate.

Before being considered as reliable, models first have to be validated on both:

- laboratory-made structures for which all the main parameters can be monitored much more easily than on field structures,
- long-term monitored affected structures.

This paper gives some recent information on the French affected structures. Then it describes experiments and specific tools designed to gather data on lab-made structures for the validation of structural models.

CONSEQUENCES OF AAR ON AFFECTED STRUCTURES IN FRANCE

First identified in 1976 on the Chambon dam, there has been no other reported cases of AAR until 1986 when it has been discovered inside an increasing number of deteriorated bridges. A committee gathering all the involved specialists has thus been officially created by the Direction des Routes in 1989. Its first work has been to elaborate Recommendations for the prevention of damage caused by Alkali-Aggregate Reaction, first Provisional (in 1991) then updated (in 1994).

Bridges

On the French National Roads network, about four hundred and fifty bridges are highly suspected of being affected by Internal Swelling Reactions (ISR). ISR is a global term gathering:

- Alkali-Aggregate Reaction
- Sulphate attack either due to:
  - delayed ettringite formation,
  - external sulphates (water, soil, de-icing salts...),
  - internal sulphates (pyrites, cement...).

Distinction between those reactions all leading to quite similar concrete swelling can only be obtained by thorough microstructural analysis.

About two hundreds of the French affected bridges are located in Brittany. Two other hundreds are located in the Nord-Pas de Calais region. The remaining ones are disseminated everywhere in France. No region can claim to be AAR-free.

The most worrying consequences of AAR for bridges, from a structural viewpoint, are:

- cracking or map-cracking when the cracks openings exceed 0.2 mm (because of the risk of reinforcement corrosion and of steel plastic yielding),
- softening (movements under heavy traffic, unrecoverable and plastic deformations).

Hydraulic Dams

Among about 130 monitored concrete dams operated by Electricité de France (EDF), 30 % are showing signs of irreversible displacements in upstream and upward directions but 80% of these are affected by rates lower than 10 µm/m/year. Only three of them need remedial measurements.

On the Chambon gravity dam, heavy remedial works have been performed including the construction of a new spillway, the installation of an impervious membrane on the upstream face, and 8 slot cuttings. A delay of about 7-8 years is expected before the planning of new sawings.

For the Temple-sur-Lot river dam, swelling of concrete causes the flexion of the extreme piles and reductions of the gates clearance. Mitigation work on the embedded parts has been performed and need to be repeated. Other works like drilling of passive anchors and watertightning of the pile faces are proving to be efficient in slowing the cracking of the pile. Their effects on irreversible displacements are less evident to assess.

In the Maury arch dam, problems are mainly located in the right abutment, strengthened with an 1200 T active anchor. Laboratories and numerical analysis are leading to the conclusion that reinforcement measures are necessary in order to keep the same global structural integrity.

In the above dams, combination of alkali-aggregate-reactions and sulphate attack is often observed but from a mechanical point of view their effects are very similar.

Structural and mechanical analysis performed for the analysis of the mechanical behaviour and the design of remedial works are faced with the common following problems: the influence of water and stresses on the swelling rates and the prediction of the growing potential.

1989-1998 ACTIVITIES ON AAR AT LCPC & EDF

LCPC (Laboratoire Central des Ponts et Chaussées) Research Activities

Since 1989, one of the LCPC major goals has been to provide numerical tools to predict the long-term performance of AAR-affected structures (on a megascopic scale). The first step has been to study a large number of concrete specimens in order to identify the main causes of swelling (on a microscopic scale) and to determine the order of magnitude of the main parameters governing the material behaviour (on a macroscopic scale).

The results of this long-term study are gathered in a research report (Larive 1998). Their major consequence is that input parameters for a mechanical modelling have been identified (Fig. 1):

- the asymptotic (maximum) expansion,
- the "latency" time corresponding to the initiation/acceleration period,
- the "characteristic" time corresponding to the decreasing reaction rate period,
- the anisotropy coefficient.

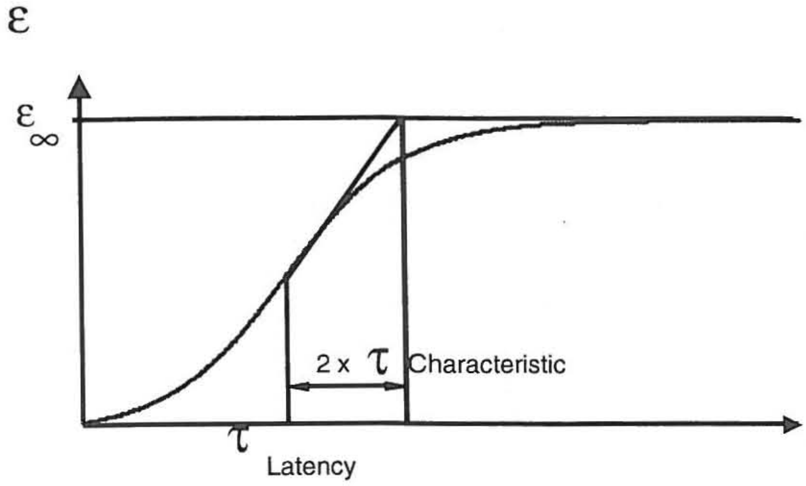

Fig. 1 : Visualization of some parameters of a mechanical model

The effects of water and temperature on these parameters have also been established on lab-made specimens. Methods to determine these data for real concrete are now investigated in the case of an affected bridge in Terenez (Brittany).

EDF (Electricité de France) Research Activities

On his part, EDF is first interested in developing finite element modelling in order to facilitate the understanding of the mechanical effects observed on AAR-affected dams. For such works, one of the main problems is to take into account the effects of the multi-axis stresses on swelling. A first model, using four easily reachable parameters, was thus developed by Capra et al. (1995). These parameters are the relative humidity, the potential of reactivity, the temperature and the stress. This model enables the calculation of anisotropic swelling and was validated with an uniaxial compression test (Larive 1998). Up to now, no experimental data on multi-axial stresses is available.

The second EDF's research aim is to provide assistance tools for management of structures. The development of a microscopic model is under way to estimate the AAR progress and the potential further swelling. This model based on the initial cement composition and the reactivity of aggregates is validated on laboratory samples.

LCPC & EDF Common Needs

LCPC and EDF both needing more experimental data have decided to undertake an important experimental survey leading to a database gathering results on laboratory structures. Two different ways of structural modelling will be kept, one mainly devoted to dams (EDF), the other more appropriate for bridges, taking into account the effects of reinforcement (LCPC).

1999-2003 ACTIVITIES ON AAR-AFFECTED STRUCTURES AT LCPC & EDF

Experimental Program

The experimental program is composed of two major parts, one on beams, the second on cylinders.

Beams testing is useful for models validation. In this program, emphasis has mainly been put on water effects. Experiments on cylinders have two major goals:

- determine if parameters measured on small specimens can be used to predict the behaviour of structures (in particular potential residual expansion),
- study the effects of multi-axial stresses.

<u>Part 1: on beams</u> – Reactive and non-reactive, reinforced and plain concrete beams are compared in terms of <u>local</u> and <u>global</u>:

- deformations,
- water content,
- relative humidity (RH).

Six beams with watertightened lateral sides (two reactive without reinforcement, one reactive with low reinforcement, one reactive with high reinforcement, one non reactive without reinforcement and one non-reactive with low reinforcement) are submitted to a moisture gradient due to:

- immersion in water of the beams bottom face, ambient 30% RH imposed on their upper face during the first year,
- water immersion of both the top and the bottom faces during the second year.

Part 2: on cylinders cast with the same concrete mixture design – Material basic parameters (maximum expansion, latency & characteristic times, anisotropy coefficient) are to be measured and used to model the beams behavior.

Potential residual expansion tests will be regularly performed, then used to predict the future theoretical behavior of the beams and compared with their real behavior.

3 D-confinement tests will take place in creep devices and give useful information for dam modelling.

Specific Tools

The quality of experimental results highly depends on the measurements methods. As soon as a large number of measurements are required, automation becomes nearly mandatory and contributes to enhance the reproducibility of the results. New or improved specific tools have been designed to achieve the requested measurements on the beams and cylinders described above. As they can be useful for many other experiments on AAR, they are briefly described below.

Vibrating wire sensors (VWS) – AAR expansion is known to be highly affected by any type of reinforcement. Embedded sensors have thus to be stiffnessless. Among the available sensors, VWS are the most reliable for long term results in high humidity conditions. Low stiffness strainmeters had already been developed (Larive et al. 1995) but needed special equipment to be kept under sufficient tension during the concrete casting. New stiffnessless VWS have been designed (Fig. 2):

- They are as easy to use than traditional rigid VWS (same binding means).
- They can accept lateral deformations (which induce errors on the vibration frequency with traditional VWS).
- The inclusion is smaller (lower disturbance of the concrete real deformation).
- They are available in every dimension from 2 cm to 3 m.
- They can measure both swelling up to 0.6% and shrinkage up to - 0.18%.
- The precision of the measurement is 10 µm/m, taking into account all the uncertainties sources.

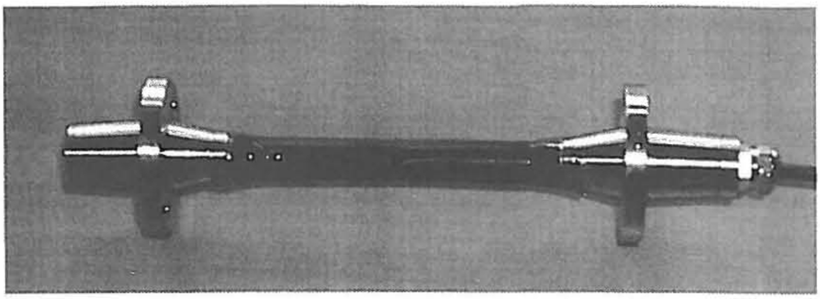

Fig. 2 : Stiffnessless vibrating wire sensor

Transverse and longitudinal swelling measurements – Because of heterogeneity and anisotropy, expansion should always be measured in both longitudinal and transverse directions and many measurements have to be performed to have a good assessment of the average value and of the corresponding standard deviation. A specific apparatus has been designed for that purpose (Larive and Coussy 2000). Dimensions can be adapted to various cylinder diameters.

Confinement tests – Using the above swelling measurement apparatus, specimens can either be free or submitted to 1 or 3D-state of stress. A 1D-stress state can be applied via a creep device. A 3D-stress state can be reached simply by casting the concrete cylinders into steel moulds of controlled thickness, cut into slices to avoid restraining the longitudinal expansion.

Gammadensitometry – The classical gammadensitometry technique (Acker 1988) will be used directly on the beams to evaluate the water content profile during the drying and wetting periods (on three sections). The principle of this method is that the concrete beam is crossed by a gamma ray emitted by a radioactive source. The relative intensity of the transmitted flow is related to the mass of the crossed material. By successive measurements, the evolution of the mass loss is obtained. Assuming that the water loss is the only cause of the material weight variation, this measurement gives a direct access to the water content which controls the reaction process. It can be corroborated by measurements of relative humidity ("traditional" capacitive sensors placed in reservations kept tight except during the periods of measurement) and by the total weighing of the beams.

Ring-shaped load sensor – A particularly sensitive ring-shaped load sensor has been designed to weigh the beams. The main difference with a classical ring-shaped load sensor (dynamometric ring) is the use of a very précise vibrating wire sensor to measure the deformation of the ring under load. The device (Fig. 3) is first loaded by a reference weigh (metal beam of about 900 kg) then by the concrete beam. Assuming that the weigh of the reference beam is constant, one can follow the evolution with the time of a concrete beam's weight, correlated with its water loss. The precision of this method is better than 20 g out of 1000 kg, which allows to correlate the local measurements of water content and relative humidity with the global water content.

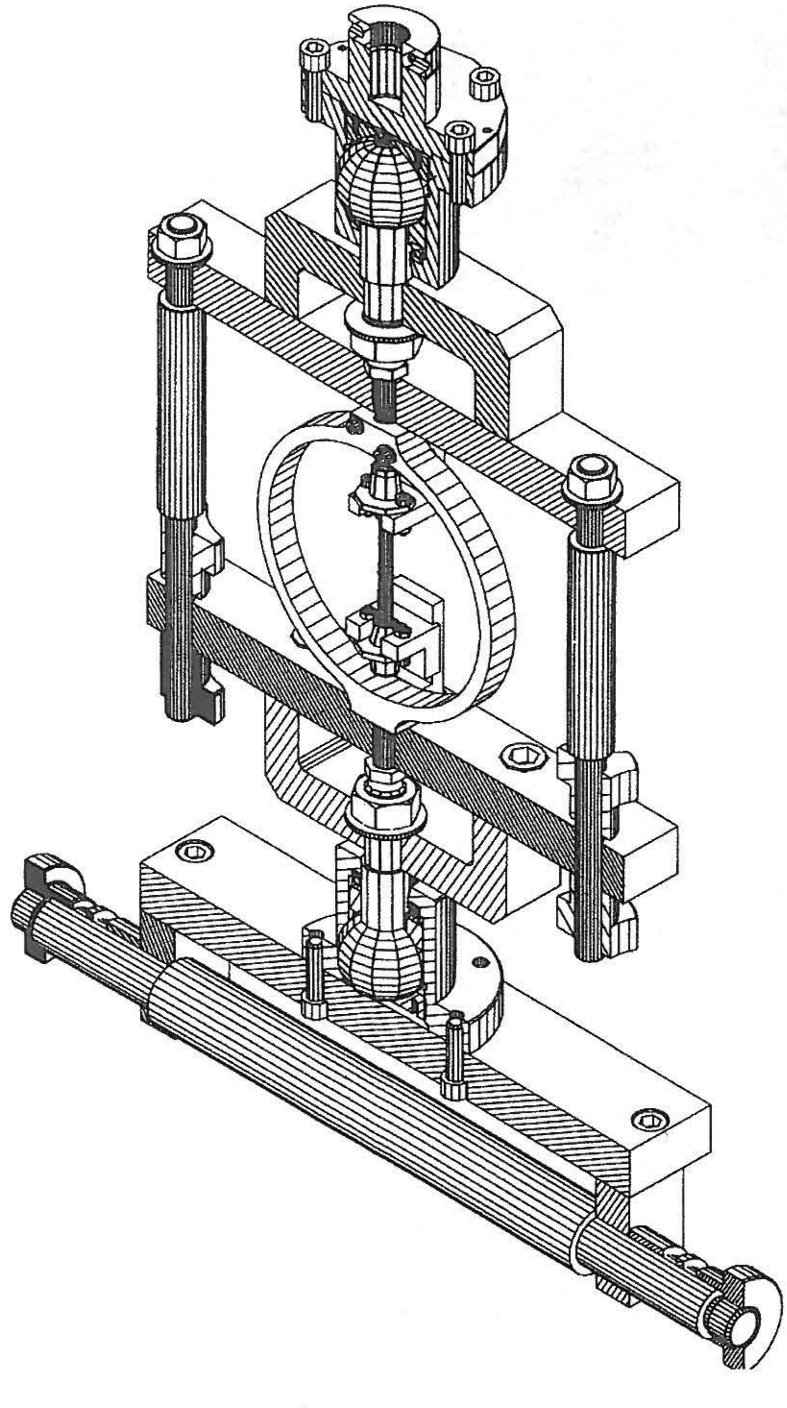

Fig. 3: Ring-shaped load sensor - The upper part is hanging on a gantry; the bar located at the bottom carries slings to which the beam to be weighed is suspended (see Fig. 4).

CONCLUSION AND PERSPECTIVES

Preventive methods to avoid AAR are now effective, in France as well as in other countries where the discovery of the AAR existence is old enough.

The appraisal of the French AAR-affected bridges and dams enlightens the need of improving the calculation tools. Predicting the evolution of the already affected structures becomes necessary for their management and to ensure proper long-term structural performance. Mechanical models must of course be adapted to the type of concrete : plain or reinforced, but in every case they must give reliable information on the final state and the degradation rate of the affected structures.

Validation of the proposed models is a first necessary step. Two types of validation are necessary : on long-term monitored structures and on well instrumented laboratory structures.

A laboratory experimental survey is starting to collect results and construct a data base useful for models validation. Specific tools which could be useful for others experiments have been designed. Such program joining experimental and numerical studies can also offer fruitful opportunities of cooperation between the different teams involved in this field.

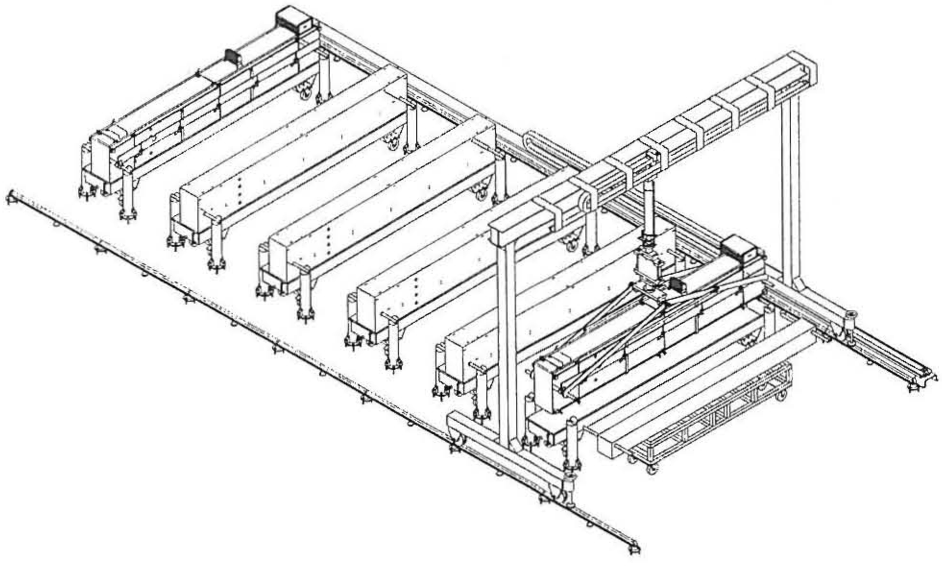

Fig. 4 : General view of the experiments on beams

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