THE FRENCH PREVENTIVE APPROACH TO AAR COMPARED TO EXPERIENCE

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ABSTRACT

The approach described in the "Recommendations for the prevention of damage by the alkali-aggregate reaction" and in the "Guide to the Preparation of Quarry Documentation" takes into account a set of data that are:

- related to the environment of a structure;
- specific to concrete;
- and specific to aggregates.

When the use of aggregates rated as non-reactive is recommended for the building of a structure (case of exceptional structures) or when, for a routine structure, knowledge of the materials used is requested, does the qualification procedure developed, which includes a petrographic determination followed by a battery of tests, yield a reliable diagnosis?

We answer this question by comparing the diagnosis and the behaviour of an existing structure for which both a sufficiently long period of observation and adequate documentation are available. It is also essential, for this comparison, to be able to procure exactly the same aggregates, and this was possible here. Each of the standardized tests has already been separately "calibrated" in this way, but it was also judged useful to compare the methodology as a whole to experience.

Our study shows:

- that the qualifying approach is relevant and accurately identifies risks;
- that the preventive approach is effective and suggests realistic solutions.

FOREWORD

One of the motive factors in the alkali-aggregate reaction, which may be defined schematically as the result of reactions reflecting cement-aggregate incompatibility, is the presence of alkalis in quantities exceeding some threshold. The recommendations published by the French Ministry of Equipment and Transportation indicates a threshold value of about 3 kg per cubic metre of concrete.

- In addition, observations both in France and abroad have shown that the reactions are more or less marked according to the type of aggregates, the type of cement, and also the ambient conditions, i.e. the environment of the concrete.

- Our choice, when the aim is to reduce the risk or make it acceptable, will therefore depend on these parameters. It will also depend on the level of risk one is prepared to accept. This will be determined by economic criteria, but also be influenced by psychological and social factors.

- The approach described in the "Recommendations for the prevention of damage by the alkali-aggregate reaction" (1) and in the "Guide to the Preparation of Quarry Documentation" takes this set of criteria into account.

- If, through ignorance, carelessness, or penny-pinching, the method were to be abridged, there would no longer be any assurance of prevention of the risks. For this reason, it is necessary to guard against pseudo-solutions, such as declaring a supply non-reactive on the basis of a test not chosen on grounds of petrographic knowledge as required by the approach recommended by AFNOR standard P 18-542 (2).

- On the other hand, performing the whole battery of tests would not enhance the level of protection against damage. It is, at most, the best way of making a bad decision. Similarly, the petrographic approach must not be taken too far. It must be adapted to the materials to be used and to such knowledge as is available (or as one is entitled to demand) of the other constituents of the concrete.

BRIEF REVIEW OF THE PREVENTIVE APPROACH

a) Choice of level of prevention

This choice is based on an approach using objective criteria, such as the environment of the planned structure and its characterization, which includes its location, its strategic and economic importance, its size, its purpose, the constraints imposed by maintenance work, etc. This said, the Employer is responsible for the decision as to which category the structure belongs to.

Table 1. Level of prevention versus category of structure and exposure

Environmental class **Category of structure**	1 dry or not very damp	2 damp to wet	3 damp with frost and de-icing salts	4 maritime environment
I Slight risk acceptable	A	A	A	A
II Risk not very acceptable	A	B	B	B
III Risk unacceptable	C	C	C	C

- According to this decision, the document proposes one of three possible levels of prevention, A, B, or C. There are precautions specific to each level. All of this constitutes the preventive approach, described in more detail elsewhere

b) Associated precautions

Level A: No special precautions with respect to the alkali-aggregate reaction are necessary. The only requirements are the usual rules of construction.
Level B: In this case, which is the commonest (it applies to most civil engineering works), there are theoretically six possibilities allowing the use of potentially reactive aggregates. They allow the use of aggregates of all types, and satisfying the conditions of any one of the possibilities eliminates the risk.
Level C: In this case, non-reactive aggregates (NR), or else aggregates characterized as potentially reactive with pessimum effect (PRP), may be used in the concrete.

When there is no other possibility, the "Recommendations" document allows the use of potentially reactive aggregates in this category of structure, provided that the planned formulation is thoroughly studied on an experimental basis specified by contract.

The philosophy underlying this approach can be summed up in three points:

giving responsibility to the participants in construction;
making the best possible use of natural resources; and
building to last at the lowest possible cost.

The question now is, Is this approach reliable?

THE APPROACH COMPARED TO EXPERIENCE

Does the qualification procedure developed, which includes a petrographic determination followed by a battery of tests (flowchart 1), yield a reliable diagnosis?

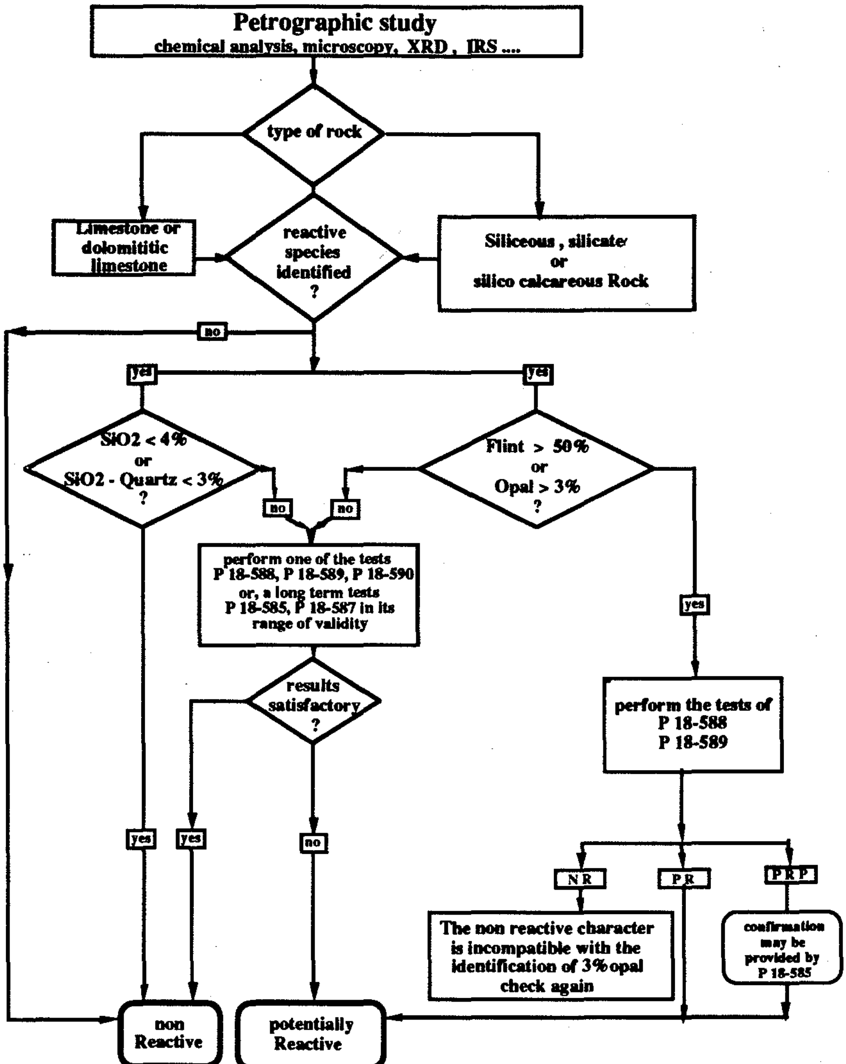

Fig 1 Flowchart of tests This flowchart clearly shows the order to follow to qualify a material with respect to the alkali-aggregate reaction ; first a petrographic study, then possibly a test chosen according to the petrographic diagnosis.

This question can be answered by comparing the diagnosis with performance on existing structures for which both a sufficiently long period of observation and adequate documentation are available. Each of the qualification tests of aggregates has already been "calibrated" in this way. The methodology as a whole, as described in the "Recommendations" document, also had to be compared to experience.

In all cases in which we were able to make the check, we found good agreement between the after-the-fact characterization and the diagnosis that could be established for the structure.

But it may happen that the conclusions are not so simple and obvious and that interpreting the combination of petrographic information and test results calls for reflection and experience, as the example that follows shows.

In a recent study, we had an opportunity to test the approach on a structure built just before 1940. This work had suffered damage sufficient to prompt the operating authority to request a study to find out why. The damage included but was not limited to progressive multidirectional cracking.

A series of cores taken from various parts of the structure in accordance with the methodology developed for this purpose led to a diagnosis of alkali-aggregate reaction, with no room for doubt.

The petrographic slices taken from the cores revealed the mineralogical composition of the aggregate, a rock made up of:

. - quartz, in crystals of various sizes exhibiting more or less corrosion and very often microcracks;

. - sparse alkaline feldspars, badly crazed (Sanidine);

. - plagioclases (oligoclase, andesine);

. - a vitreous phase, more or less abundant depending on the aggregates;

. - ferromagnesians (the commonest being biotite and chlorite).

Depending on the aggregate observed, the structure of the rock ranges from microlithic to microgranular. The phenocrysts (large and well crystalised minerals measuring several millimetres or centimetres) are represented by quartzes and plagioclases.

By its composition and structure, this material is classified in the family of rhyodacites (volcanic rocks intermediate between rhyolites strictly speaking, the igneous counterpart of granites, and dacites, the counterpart of quartzitic diorites). A few aggregates exhibit little or no quartz. They correspond to parts in which the excess silica is found in the vitreous mesostasis.

The documentation on the structure made it possible to identify with certainty the quarry that had provided the aggregates. This was a quarry opened specially for the job and unused since. The samples taken in the rock in place showed the same composition as already described. We completed our knowledge with a chemical analysis and proceeded to crush about a hundred kilograms of rock to perform the qualification tests, a performance test on the actual formula in conformity with the procedure described in the "Recommendations" document, and tests designed to ascertain the limit beyond which the formulation becomes reactive.

Chemical composition of the rhyodacite

SiO2	Al2O3	Fe2O3	CaO	MgO	SO3	Na2O	K2O	TiO2	MnO	P2O5	Pf	Total
69.67	13.80	2.47	2.9	0.73	0.06	2.15	4.65	0.11	0.12	0.11	3.47	99.93

The silica content of 70% is between a control rhyolite at 73-75% and a dacite at 63-68%. To go from a rhyolite to a rhyodacite, one must also find a smaller proportion of potassium feldspar, and so a smaller proportion of potassium (control rhyolite 5.30%; material of our study, 4.65%).

In short, the chemical analysis clearly shows that the material is rich in silica, and also that the alkali content is average for this type of rock and that there is roughly twice as much potassium as sodium.The sodium content as Na2O equivalent is:

$$0.658(K_2O) + Na_2O, = 5.20\%.$$

The test of release of active alkalis (4), performed on rocks having an identical structure and composition, showed that the quantity of active alkalis likely to go into solution in the concrete could be estimated at 300 grams per tonne of aggregates, or 600 g/m3 of concrete.

Petrography classifies the material in the rocks as probably reactive, with the reactivity resulting primarily from the more or less abundant vitreous phase and the corroded and microcracked quartzes. It would be tempting to say that the rock possesses a slow reactivity.

Given this diagnosis, the possible qualification tests, among the rapid tests, are:

- test P 18-588, the Microbar test;
- test P 18-589, the kinetic test;
- test P 18-590, the autoclaving test.

The Microbar test rated the material as potentially reactive, with a value of 0.12%, just above the critical threshold of 0.11%.

In an actual case, given the good agreement between the petrography and the test, we would have stopped there and qualified the materials as

- Potentially reactive.

Since our aim was to validate the methodology, we attempted to confirm this diagnosis. Test P 18-590 also placed the material in the category of aggregates that are

- Potentially reactive.

Test P 18-589, for its part, placed the aggregates in the zone of materials that are

- Non-reactive.

This contrast between the kinetic test and the other two tests is not surprising. We have already seen that the material is heterogeneous in terms of the constituents qualified by petrography as reactive. And the values given by the tests based on dimensional variations are just above the critical thresholds. Finally, the kinetic test, otherwise often good, is not ideal for materials having a slow kinetics.

Summary table of results of characterization of the aggregates

Test	Results
Petrographic examination	rock: rhyodacite reactive species: yes - glass more or less in stage of devitrification ....>PR -corroded quartzes, with or without undulatory extinctions
Chemical analysis	SiO2 approx 70%
Test P 18 589 (chemical kinetics)	Result NR; disagrees with petrographic examination
Test P 18 588 (rapid test of dimensional variation)	Result PR; agrees with petrographic examination; test on which decision is based
Test P 18 590 (autoclaving - rapid test of dimensional variation)	Result PR; confirms test above and petrographic examination
Examination of concrete of structure	multidirectional cracking and alkali-aggregate reaction products

In any case, if there is disagreement between the petrography and the diagnostic test chosen, the approach calls for performing a second test belonging to a different group. We see that in this case the diagnosis would have been: - Potentially reactive -
Given the character of the structure (it would be classified in category C), the approach would lead to rejection of the aggregates or, if no other source could be found, to the requirement of a mix design study providing guarantees regarded as adequate and accepted by contract. The procedure currently considered most dependable consists of a series of dimensional variation tests at increasing alkali contents, for example

2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, ... kg/m3

The duration and threshold might be 8 months, as in test P 18 587, at a temperature of 38°C, or 5 months, as in the performance test, at a temperature of 60°C, or even some longer period.
This approach may determine the alkali content above which the mix design becomes sensitive. Using a mix design in which the level is lower, with an adequate but realistic margin, should forestall the risk. This way of proceeding is long and constraining, but for exceptional works, for which in principle the necessary time can be taken, it can be applied profitably.

- To take the approach to its conclusion and arrive at a realistic evaluation, we carried out a concrete performance test. This test was performed using an alkali content of close to 1% in the cement. In conformity with the rules of the performance test, as laid down in the "Recommendations" document, given the nature of the aggregates (a material having a slow kinetics), five months was the duration fixed for the test. Under the experimental conditions, the theoretical total quantity of alkalis was the quantity contributed by the cement, 4 kg/m^3.

Under these conditions, the dimensional variation of the mix design was less than the 0.02% threshold at 5 months, as shown by figure 2.

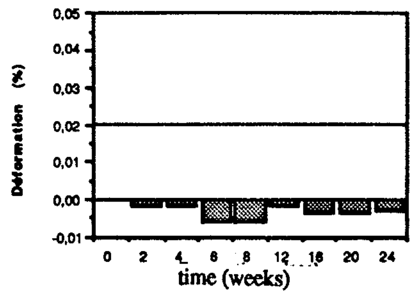

Fig 2. Dimensional variations at an alkali content of 4 kg/m3

The alkalis from the aggregates, with a theoretical quantity of not more than 0.6 kg/m3, are characterized by very slow release under the curing conditions of the test, which explains why they cannot contribute to the total content even though they in fact exist in the concrete of the structure.

- The level that must be reached to damage the concrete is 6 kg of alkalis per cubic meter of concrete, a level that may in fact be reached locally in the structure. In the case of a structure still to be built, prudence would call for limiting strictly the alkali content to the values proposed for category B structures in the "Recommendations on prevention of the risks arising from the alkali-aggregate reaction".

In the case of a cement content is 400 kg/m3, this limitation imposes a cement containing 0.6% alkali equivalent ((4 x 0.6) + 0.6) = 3 kg/m3.

- What trust can be placed in the preventive method?

We are already in a position to state that the proposed tests and methodology in fact qualify materials with respect to the alkali-aggregate reaction. Our approach still requires improvement when economic conditions make it necessary to use potentially reactive aggregates having a slow kinetics in works that are to be classified in category C.
Currently, one approach that is elegant, dependable, but slow, consists of performing tests at 38°C or 60°C with different alkali contents to be able to propose a limit above which the reaction will appear. These tests, used to judge the future of the structure, must be interpreted prudently, especially as regards the quantity of alkalis that may be released, and therefore the quantity of alkalis acceptable in the formulation.

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Diagnosis of Alkali-Aggregate Reaction in Concrete

DIAGNOSIS OF THE CAUSE OF CRACKING IN FOUR STRUCTURES IN WHICH ASR IS OCCURRING

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ABSTRACT

Four examples are considered of the diagnosis of the primary cause of visual cracking in concrete within which alkali-silica reaction has occurred: a dam, a reinforced beam, a prestressed beam and a wing wall. In the first, it is shown that frost attack is the likely primary cause of the visual cracking, in the second, alkali-silica reaction, in the third, thermal shock and in the fourth, 'delayed ettringite formation'.
Keywords: Alkali-silica reaction, delayed ettringite formation, frost attack, thermal shock.

INTRODUCTION

Often when alkali-silica reaction occurs, concrete has sufficient strength to resist the deleterious effects of the reaction, either because the available 'alkali' content is too low or because the reactive silica content is low or well above the pessimum. Gel-filled fine cracks, and aggregate particles which have cracked as a result of ASR can therefore be found in sound concretes, in concretes which exhibit visual cracking due to ASR, and in concretes which exhibit cracking due to other causes. As a consequence, the identification of ASR in a petrographic examination of a single representative thin section of a suspect concrete does not enable a judgement to be made that ASR is the primary cause of any visual cracking (Diagnosis Working party, 1992). To establish that ASR is likely to be the cause of the visual cracking it is necessary firstly, to rule out other causes of such cracking, secondly, to establish that expansion has occurred, thirdly, to establish by thin section examination that there is considerable evidence of alkali-silica reactivity within the concrete and fourthly, to establish that the internal crack distribution is characteristic of that induced by ASR (Diagnosis Working Party, 1992). Fig. 1 shows the characteristic internal crack pattern induced by the reaction. This crack pattern has been observed both in laboratory concretes and field concretes adversely affected by ASR. When abnormal expansion is induced by ASR, a network of fine cracks connecting cracked aggregate particles is formed in the heart of the concrete. The cracks are frequently filled or partially filled with gel, and in some cases, also partially filled with ettringite. In the exposed surface region of the concrete the reaction is of lower intensity and consequently, the exposed surface layers of the concrete restrain the expansion of the heart concrete resulting in a tensile stress in the surface layers and, if the intensity of the reaction is sufficient, macro-cracks are induced