25 YEAR MANAGEMENT OF 253 BRIDGES POTENTIALLY AFFECTED BY AAR

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Abstract

The aim of this paper is to present the asset management methodology developed, adapted and followed by SANEF (French conceded highway operator) after discovering the first signs of AAR disorders on highway bridges in 1990. During the first period (1990-1992) a general overview of the 253 bridges from A26 highway was realized: that allowed to classify the bridges into 5 groups (not concerned: 29 bridges, highly deteriorated: 24 bridges, deteriorated: 63 bridges, slightly deteriorated: 116 bridges, less affected: 21 bridges). In the second period (1992-1993), a simplified monitoring was installed and a material diagnosis was performed on the most deteriorated bridges. These studies were also conducted, over the years, on the bridges showing new disorders. During the third period (1993-2006) the simplified monitoring was continued on all the bridges, and the most deteriorated bridges were protected (implementation of a sealing coating on the walls and piers and waterproofing of the deck). Sensors were installed to detect any abnormal dimension variations. During this period, some verifications were conducted to validate the repair methodology (verification of the absence of disorders on the walls in contact with the soil, loading test to confirm the structural capacity of the most deteriorated deck, coating product testing).

In 2006, a first assessment was conducted by the French authorities controlling the activities of the highway operators. It was decided to continue the simplified monitoring of the bridges. It was also decided to focus the monitoring of the coated bridges only with the sensors installed on metallic bars. The visual inspections were also maintained, especially to check the coatings degradation. In the last period (2007-2015) some specific investigations were realized (verification of rebar along major cracks, loading test). A new assessment was performed in 2014 by the French authorities allowing to reduce the rate of the simplified monitoring to one measure per year. It was also decided to realize specific investigations and to replace the oldest coatings to avoid any water penetration into the concrete.

Keywords: alkali-reaction, delayed ettringite, asset management, repair works, coatings

1 INTRODUCTION

As part of its monitoring process, SANEF (Abertis group) highlighted in 1990, on the Reims - Calais section of the A26 highway (figure 1), the presence of concrete structures affected by internal swelling reactions (alkali aggregate reaction and/or delayed ettringite formation). The first signs were observed on some structures nearby Bethune and led SANEF to launch a recognition campaign to determine the extent of disorders affecting all the bridges of the A26 highway. SANEF had already been faced with disorders related to the alkali aggregate reaction on the A4 highway (District of Coutevroult) where two bridges (PS 24 and PS 32) had to be blown up, and another bridge (PS25) was protected with a waterproofing coating. With this experience and on the basis of 1990's knowledge, a global management of the A26 highway structures potentially affected by internal swelling reactions was gradually deployed. This paper describes the process that was implemented, the main results achieved and the decisions taken during the past 25 years. It shows how the asset management of this patrimony was developed and adapted taking into account the disorders evolution and the increasing knowledge of the AAR by the scientific community.

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2 INITIAL INVESTIGATION

The first step was to do, between 1990 and 1992, an audit of all the A26 highway bridges [1]. This first study, willingly rapid and simple, provides observations at the macroscopic level (quick visual inspection of the structure), at the microscopic level (sampling and observation on thin sections of the cement paste – aggregate contact, and nature of the aggregate), and at the mineralogical level (X-Ray diffraction analysis of a sample fraction to search for potentially deleterious minerals such as ettringite and thaumasite).

The initial visual inspections of the bridges have shown that the most degraded areas of the overpass bridges were, first, the top of the piers with vertical cracks with a width less than 1 mm and centimeter size map-cracking, second, the mid-height of the piers with centimeter or decimeter size map-cracking, and third, the cap beam extremity with vertical cracks of 1 to 2 mm and centimeter size map-cracking. The most degraded areas of the underpass bridges are the abutment (vertical cracks, and map-cracking in the central part of the bridge), and the wing walls (centimeter size map-cracking).

The bridges were then ranked into 4 groups on the basis of these visual observations:

- Group 1: bridges with very many degradations,
- Group 2: bridges with numerous degradations,
- Group 3: bridges with some damage,
- Group 4: bridges showing no degradation.

Based on the mineralogical observations, the presence of cracks and the quality of the contact between the cement paste and the aggregates, bridges were classified as follows:

- Group 1: concrete with many voids at the cement paste – aggregate interface and/or many cracks,
- Group 2: Concrete with abundant cracks and some voids at the cement paste – aggregate interface,
- Group 3: concrete presenting some delamination and/or cracks,
- Group 4: concrete with no cracks and no voids at the cement paste – aggregate interface.

Then, two samples per bridge were analysed by X-ray diffraction. The main detected minerals are quartz, calcite, portlandite, ettringite and dolomite. These minerals reflect the composition of the cement paste and aggregates used to make the concrete. Some minerals present in too small quantities are not detected. Other minerals have been more or less partly destroyed by the grinding and are no longer identifiable. It should be recalled that the alkali aggregate reaction gels are amorphous phases, not crystallized and unidentified by X-ray diffraction analysis. Ettringite (sometimes associated with thaumasite [2]) is the mineral on which the ranking was based, understanding that this analysis does not distinguish between primary and secondary (or delayed) ettringite:

- Group 1: bridges with > 4.5% of ettringite,
- Group 2: bridges with 3.5% <ettringite <4.5%,
- Group 3: bridges with 2.5% <ettringite <3.5%,
- Group 4: bridges with 2.5% <ettringite.

Taking into account that the level of observation and analysis is not the same for each of these rankings, some weighing coefficients were applied to allocate the final note given to the bridges (coefficient 1.5 for degradation on site ranking, coefficient 1 for optical Microscopy classification and coefficient 0.5 for X-ray diffraction classification). Among the 253 structures of this section of the A26 highway, 224 bridges were the subject of this study, while the other 29 bridges were not affected by these internal swelling pathologies (newly built structures, steel bridges and reinforced earth walls). This rating system resulted in a ranking of 224 concrete structures of the A26 highway into 4 groups:

- Group 1, the most deteriorated: 24 items (10%).
- Group 2: 63 deteriorated bridges (28%).
- Group 3: 116 rather deteriorated bridges (52%). (Groups 1 + 2 + 3 = 203 structures).
- Group 4: the less deteriorated bridges: 21 items (10%).

It should also be noted that at this stage of the study, 46 bridges were considered potentially reactive with respect to AAR or DEF, according to their chemical and mineralogical composition (cement with high alkali content, presence of potentially reactive aggregates and/or high concentrations of ettringite crystals). Bridges of group 1 are essentially underpasses, and four bridges of group 1 are particularly deteriorated: PI328, PI 329, PI 330 and PI 338. These four bridges were built between April and December 1974, probably during the summer months and were part of the deviation of Bethune. This deviation was the first section of the A26 highway.

3 ANALYSIS OF OWNER'S FILES

Given the length of the highway (over 200 km) and the duration of the works (over 10 years), concrete constituents (sand, gravel and cement) vary from one section to another. Thus the following formulations are found:

- Saint-Omer/Lillers section: Cement: Lumbres, non reactive sand and gravel: Boulonnais marble,
- Lillers/A1: Cement section: Barlin, sand: Rue or Seine, reactive gravel: Gaurain (Tournaisis limestone),
- A1/Cambrai-Masnières section: Cement: Cantin, sand: Rue or Seine, reactive gravel: Gaurain (Tournaisie limestone),
- Cambrai-Masnières/Gauchy section: Cement: Origny Ste Benoite, sand: Seine or Oise, gravel: Viry Noureuil, sligthly reactive aggregate,
- Gauchy/Laon section: Cement: Origny Ste Benoite, sand: Seine or Oise, gravel: Oise or Viry Noureuil, sligthly reactive aggregate,
- Laon/Valley of Aisne section: Cement: Origny Ste Benoite, sand and gravel: Oise. sligthly reactive aggregate.

Based on today knowledge, it appears that the Tournaisis limestone (Gaurain quarry in southern Belgium) is particularly reactive and that the Barlin cement factory (Bethune region) now closed, provided a particularly alkaline rich cement [1, 3]. The equivalent alkali content of Barlin cement was approximately 1.12% Na_2Oeq (0.4% Na_2O and 1.1% K_2O) or 4.4 kg per m^3 of alkalis for a concrete made with 400 kg of cement. It is therefore "normal" that the most deteriorated bridges are located in the Lillers - A1 section (Bethune bridges). It should also be emphasized that coal residues materials, potentially rich in sulfates, were used to backfill the structures of the Bethune area.

4 COMPLEMENTARY MATERIAL DIAGNOSIS

In order to conclude on the origin of disorders and consider the establishment of a maintenance policy, a thorough diagnosis of the four most damaged structures (Group) 1 was made. This diagnosis included:

- A simplified monitoring following the LCPC recommendation [4].
- Core sampling to perform mechanical, physical and chemical testing,
- Optical microscope observation to characterize the nature of the aggregates and observe the micro-cracking of the cement paste,
- Scanning electron microscope observation to identify the nature of deleterious phases (alkali-silica gel and/or ettringite and/or thaumasite),
- Aging tests specific to AAR: highly accelerated test in autoclave at 120°C in a 100% humid environment during 24 hours. This test, originally developed to characterize the reactivity of aggregates in a given concrete formulation (aggregate characterization test in an autoclave [5]), was diverted to evaluate the residual swelling potential of concrete affected by AAR. This test, judged too severe, is no longer applied in France nowadays and is replaced by tests developed by LCPC [6].
- Aging test specific to sulfate attack [7]. This test, also now considered too severe (3 week duration), is no longer practiced today in France and is replaced by tests developed by LCPC [8].

The results obtained are summarized in Table 1. They formed the basis for discussions to establish the bridges monitoring, knowing that in 1993, knowledge about these pathologies were much less developed than today. PI 328 and 338 were the subject of an expertise by LCPC in 1995, three years after the initial expertise. If sulfate attack has been highlighted by LCPC in concretes of these two bridges, it should be emphasized that no alkali reaction was observed in concretes of PI 328. This difference indicates likely that three years later alkali reaction was not or was no longer the dominant pathology in these concretes. These observations accredit the fact that the two pathologies often occur concomitantly.

5 MONITORING AND TESTING

A team composed by SANEF, CONCRETE, LCPC and Ministry of Transport (IGOA) was established in January 1993 to review the situation. It was decided to set up a crack monitoring and to realize preliminary tests before achieving the waterproofing coating of the most deteriorated bridges.

5.1 Bridge monitoring

The cracks monitoring of the bridges was carried out by the LCPC method n°47 [9]: measurement of the number and opening of cracks on the vertical, horizontal and diagonal axes (1square meter surfaces on 3 to 6 different areas of the bridges). This monitoring has been set up by CONCRETE for bridges in groups 1 and 2 and was extended to the bridges of the groups 3 and 4 by the teams of SANEF. A total of 224 bridges was monitored using this technique.

The cracking index thus measured (average of the sum of crack width) allowed to classify the bridges into 6 categories: category A<0.15 mm/m, category B<0.30 mm/m, category C<0.60 mm/m, category D<1.20 mm/m, category E<2.40 mm/m and category F>2.40 mm/m. The measurements were performed twice a year, in spring and fall. CONCRETE has performed measurements on structures with cracking index higher than 0.6 mm/m (categories D, E and F). The SANEF staff undertook the measurements on all the other bridges. CONCRETE has provided training for the SANEF teams conducting the surveys. Wherever possible, the same person was responsible, over the years, to carry out these surveys. All data was collected by SANEF in a specific database.

Annual assessment of the cracks evolution was made jointly between SANEF and CONCRETE. Structures with a change in their cracking index toward a D, E or F categories were the subject of a pre-visit to validate the evolution of the cracking index and avoid possible measurement artefacts. It was possible to show that some bridges, sometimes highly deteriorated, showed no changes of their cracking index. This is the case of the PI 328 which served to conduct repair work test including testing of waterproofing coatings.

Bridges of category D, E or F (cracking index greater than 0.6 mm/m) were then subjected:

- ✓ First, to a specific study to determine the nature of the pathology causing the observed disorders (diagnostic material identical to that described in Chapter IV).
- ✓ Then, in a second phase, to repair works, if the pathology was proven and if the residual swelling potential was important,
- ✓ And/or to a cracks monitoring.

5.2 Testing conducted before the completion of the repair works

Among the most degraded bridges, the PI 328 was selected for testing and further investigations.

5.2.1 Embankment removal behind one pier

The portal type structures affected by internal swelling reactions exhibit significant cracking of the surfaces exposed to air and weathering. No information was available on the disorders affecting the opposite side. It was therefore decided to proceed with the removal of the backfill behind the abutments of the PI 328 (Calais side pier, direction Reims - Calais). To do this, in 1993, sheet piling was beaten 3 meters behind the structure and the fill consisting of black shale and red shale was removed using a mechanical shovel. After high pressure water cleaning, it was possible to inspect the surface of the wall. It appeared some localized disorders (powdered concrete), especially at the interface black shales - red shale, but no map cracking characteristic of the AAR or delayed ettringite formation was observed. This important information validated the proposed treatment: applying the coating only on the faces exposed to air and water.

5.2.2 Tests on waterproofing products

Waterproofing product tests have been realized on a PI 328 wall (wall on the Reims side, in the direction Calais - Reims). The purpose of these tests was to retain a product or a family of products to achieve waterproofing of external surfaces of the bridges. Before selecting a specific product for the treatment of structures affected by internal swelling reactions, we should ideally be able to answer two questions. First, is internal water able to supply and maintain the reaction? If the answer to this question is positive, it is likely that waterproofing the concrete will only slow down the expansion. The question will be whether we can slow down the reaction sufficiently to avoid cracking of concrete and waterproofing coating. Second, should the coating make a simple impermeability to rain water, or a more complete impermeability to water vapor? Usually the hydraulic binder coatings have a certain permeability to water vapor to allow water contained in the concrete to evaporate.

The selected products are impermeable to water and have some flexibility to withstand any residual cracking. They also have a good durability (resistance to blistering and peeling, maintaining the elastic properties and resistance to cracking and good resistance to freeze-thaw) and have sufficient adhesion to the support (at least 1 MPa). A product based on styrene - butadiene (Decadex Pentagon), waterproof and vapor-proof and 5 products based on modified hydraulic binders (Sika, MBT, Kristo, and Lanko Betorec), waterproof but not vapor-proof have been implemented by providers on surfaces of 2m x 2m. The support has been previously sandblasted and adhesion tests were performed to verify the thickness and the bonding of the products. In parallel, accelerated aging tests were performed on cores coated with the same products. These tests confirmed that the modified hydraulic binders were perfectly suited to slow residual swelling phenomena related to the AAR and/or delayed ettringite formation. They also confirmed that the styrene - butadiene product could, thanks to its very high elasticity and its impermeability, meet the criteria imposed by the pathologies affecting the structures of SANEF. To date, products implemented for over 20 years are the Masterseal from BASF and the Decadex from Pentagon.

5.2.3 Loading test of a strongly cracked deck

The PI 361 (Saint Omer) had a strongly cracked deck (horizontal cracking and map-cracking). The diagnosis confirmed the AAR reaction, with however a limited residual expansion. It was therefore decided, as with all highly deteriorated structures, to implement a coating on the walls in contact with the environment and renewed the waterproofing membrane of the deck. However, given the abnormally high level of cracking, it was also decided to perform a loading test on both decks of the bridge.

A first loading test was conducted in 1995. Four additional points of measurement have been installed in addition to the mandatory point in the center of the bridge. The objective was to verify the effects of disorders related to AAR in the most damaged part of the deck. This loading test showed a normal elastic behavior of both decks, a slightly larger deformation compared to the initial loading test of 1975, leading to a very small decrease of the safety factor in the most deteriorated part (12%), and no change in the non-deteriorated deck compared to the initial loading test of 1975. These results confirmed that the bridge could be simply treated by a waterproofing coating and that the evolution of its mechanical behavior should be controlled within 10 years. The methodology followed by SANEF during these first 10 years was presented at the 11th International Conference on alkali reaction in 2000 in Quebec [10].

6 TREATMENT WORKS AND MONITORING

6.1 Repair works

Depending on the observation results and on the aging tests, and depending on the cracking index, it was decided whether works had to be performed on the bridges. Thus, the most deteriorated bridges and/or the bridges with a strong residual potential expansion were selected. A total of 10 bridges (PI 322, 328, 329, 330, 354, 355, 361, 363, 365 and PS 357) have undergone rehabilitation works:

- With application, in 9 cases out of 10, of a flexible hydraulic coating or, in the case of PI 328, of a flexible polymer coating based on styrene butadiene on all visible facings (abutments, wing walls and deck soffit).
- With replacement of the waterproofing membrane of the deck.

For the bridges which are not the subject of repair works because of the lack of disorders or the absence of significant residual expansion, the monitoring of the cracking index was continued. The waterproofing works were spread over more than 7 years (between 1996 and 2006) following the evolution of the cracking index and the diagnosis results. The repair works were carried out according to the following phasing:

- 1997: PI 322, PI 329, PI 330 and PI 361,
- 1999: PI 354,
- 2000: PI 355 and PS 357,
- 2003: PI 363 and PI 365,
- 2006: PI 328 (on one abutment due to the absence of cracking evolution).

6.2 Monitoring of coated bridges

To verify that the coating slowed down satisfactorily the internal swelling reactions, the treated bridges have been monitored using displacement sensors, either by measuring the opening of a crack, or by measuring the overall deformation of the pier via metallic bars (Figure 2). For each bridge, a sensor was installed per abutment and deck and on 2 metallic bars (6m and 12 m long).

7 FIRST ASSESSMENT AFTER 16 YEARS

A first assessment of the monitoring was established in 2006, 16 years after the start of the operation, by the team created in January 1993 to examine the situation (SANEF, CONCRETE, LCPC and the Ministry of Transport - IGOA). The first assessment was intended in particular to consider the follow-up actions and the observed evolutions. Its aim was also to take medium and long term decisions. The objective was also to be consistent with the maintenance recommendations defined in France for structures affected by internal swelling reactions [11].

7.1 Patrimony covered by the investigations

It appears that 243 bridges were finally monitored among the 253 bridges of this highway. The last ten bridges that are not monitored, are identified and may be integrated in this monitoring in case of developments which would be detected during the regular inspections.

7.2 Cracking index monitoring

The monitoring of the cracking index was performed on the 243 bridges. After 16 years, the classification of the bridges was the following:

- Category A, B and C: cracks less than 0.6 mm/m: 230 bridges followed by SANEF (Béthune: 46 bridges, St Omer: 47 bridges, Cambrai: 26 bridges and St Quentin: 84 bridges).
- Category D, E and F: greater than 0.6 mm/m cracking: 13 bridges followed by CONCRETE (Béthune: 8 bridges, Saint Omer: 3 bridges, Arras: 1 bridge and Saint Quentin: 1 bridge).

The cracking index is measured twice a year by the SANEF districts or by CONCRETE. The data are still centralized in a specific database, and any changes are jointly validated by SANEF and CONCRETE. This methodology seems well adapted and maintained at the same rate, that is to say twice a year, except for bridges that seem to be stabilized and for which an annual rate may be admitted.

7.3 Material diagnosis

If any changes in the cracking index is observed, the method involves:

- Core sampling in the most deteriorated parts,
- Optical microscope observation to characterize the nature of the aggregates and observe the micro-cracking of the cement paste,
- Scanning electron microscope observation to identify the nature of deleterious phases (alkali-silica gel and/or ettringite and/or thaumasite),
- Aging tests using LCPC methods [6, 8].

7.4 Monitoring using displacement sensors

The nine structures fully protected by a modified hydraulic binder-based coating are monitored with displacement sensors, either directly on cracks or to the end of metallic bars of different lengths (3, 5, 6 or 12 m depending on the geometry of the bridge. The principle of this instrumentation is to detect swelling that would be masked by the coating which is sufficiently flexible not to crack under a moderate deformation [12].

The results obtained between 1997 (for the first monitored structures) and 2006 (the first assessment) highlighted a number of problems with the use of the sensors and their maintenance (power problems with solar panels or battery, abnormal aging, probe corrosion). Furthermore, measures on cracks have not given interesting results. It was therefore decided to pursue the monitoring only on the bars. The equipment was replaced or refurbished and sensors have been reprogrammed to take a measurement every 4 hours instead of every hour earlier.

The monitoring highlighted in most cases only seasonal variations. No significant increase was demonstrated, confirming the effectiveness of the used coatings. After this update, the following equipment was in place:

- PI 322 (VIPP post-tensioned beams not affected by any pathology): 1 vertical 5 m bar on abutment and 1 horizontal 12 m bar on abutment,
- PI 329 (VIPP post-tensioned beams not affected by any pathology): 1 horizontal 12 m bar on abutment,
- PI 330 (VIPP post-tensioned beams not affected by any pathology): 1 horizontal 12 m bar on abutment,
- PI 354: one 5 m bar on deck and a 12 m bar on abutment,
- PI 355: one 5 m bar on deck and a 12 m bar on abutment,
- PS 357: two 3m horizontal bars on pier,
- PI 361: one 6 m bar on deck and a one 12 m bar on abutment,
- PI 363: one 6 m bar on deck and a one 12 m bar on abutment,
- PI 365: one 6 m bar on deck and a one 12 m bar on abutment.

The processing and analysis of results also changed as shown in Figure 3 where a low expansion was measured between 2009 and 2014 on the PI 354.

7.5 Inspection and monitoring results

The results carried out during these 16 years have led to make the following decisions, in addition to the continuation of cracking index measurements and the pursuit of sensors monitoring on bars after repackaging of the material:

- Loading test on the PI 361, 10 years after the previous test,
- Checking the condition of the rebars of PI 329 in the most open cracks,
- Repair of the deteriorated coatings on a few bridges,
- The coatings are globally in a good shape. However a complete renovation of the coatings has to be programmed every 20 years.

7.6 Preventive treatment

The following preventive works were decided after this assessment:

- ✓ Partial application (parts exposed to rain and runoff) of a styrene- butadiene based coating (Decadex Pentagon) on two bridges (PI 525 and PI 631),
- ✓ In order to avoid the replacement of the backfill behind the abutment and the demolition and reconstruction of the bridges, the following work was programmed:
  - Replacement of the sidewalk waterproof membrane and installing a general waterproof on the entire surface of the deck.
  - Closure of the central part of the decks and drainage of the water,
  - Waterproofing of the backfills on 30 meters either side of the bridges.

7.7 Residual functionality of the retaining devices

Many bridges of this highway show materials degradation with structural consequences (eg the PI 329 and PI 361). However, few elements are available about the functionality of the safety devices. They are probably made with the same concrete and they made develop similar pathologies. Therefore, specific studies must be engaged on these elements.

8 CONTINUATION OF THE MONITORING AND BRIDGE TREATMENT: 2007-2015

8.1 Rebars

Reconnaissance surveys were conducted on the PI 329, the most cracked bridge, to check the condition of the reinforcements at the location of the open cracks. Investigations showed no deformed or sectioned armature.

8.2 Loading test

A second loading test was performed in 2007 on the PI 361, under the same conditions as in 1995. This test showed a normal elastic behavior of both decks, a good symmetry behavior of both decks, a lack of significant change in the deformation of the deteriorated deck and a slight increase of the deformation of the deteriorated deck.

The changes compared to 1995 are low compared to the measured values, but still show an increasing trend likely related to the AAR and/or delayed ettringite formation. The apparently good condition of the coating implemented in 1995 on the facings of the structure and especially on the decks, and the absence of traces of water circulation through the deck following the replacement of the waterproofing membrane suggest that the pathologies affecting the concrete were strongly slowed. They still remain active as suggested by the increasing deformation under loading test which will require lifelong maintenance of the waterproofing coating.

It also should be ensured through regular load tests (every 10 years), the maintaining of the elastic behavior of the decks.

9 SECOND ASSESSMENT IN 2014

A second follow-up report of the bridges was established in 2014, nearly 25 years after the start of the assessment operation. It is found after 25 years of follow-up that among the 253 bridges:

- 18 are not likely to be affected by an internal swelling reaction,
- 182 are in a fair condition (cracking less than 0.3 mm/m),
- 39 are in an "average" state (cracking between 0.3 and 0.6 mm/m)
- 4 are particularly deteriorated (cracking higher than 0.9 mm/m).

It was observed that the number of damaged bridges evolved slowly over the last 10 years and that the works carried out had limited the development of disorders.

9.1 Cracking monitoring of the least deteriorated bridges

The monitoring carried out for 25 years has shown its reliability. It was decided to reduce it (once a year or once every 2 years).

9.2 Cracking monitoring and condition of the most deteriorated bridges

Several bridges (PI 322, 329, 338, 354) showed no swelling since the implementation of the coatings, for over 15 years for some bridges. Some bridges show weak or negligible trends (PI 330, 355). Two structures show a swelling, AAR gel exudates and cracks on the wing walls (PI 363 and 365). A check of the monitoring equipment and annual monitoring of the coating and of the cracking is expected.

The PI 361, which showed a slight increase of the deck deformation during the 2007 loading test shall be subjected to a new load test in 2017. There is also an increasing deterioration of the waterproofing coating (Figure 4). A replacement of this coating is to be expected especially as it has nearly 20 years.

The PS 357 shows a significant evolution (2 m horizontal bars with sensor) and its coating is cracked in several locations (Figure 4). Further investigations are to be expected on this item:

- Coring on the crack to determine its depth and compare it to the rebar cover,
- Removal of the coating on a 10 cm wide horizontal strip to measure the crack opening,
- Aging test,
- Measurement of the concrete compressive strength and concrete modulus of elasticity.

10 OVERALL CONCLUSIONS

The methods used by the authors for the analysis, monitoring and treatment of the bridges are well adapted to the problem and allowed to perform repair works adapted to the pathology. They permit also to limit the repair works on the actually damaged bridges.

Although the demolition - reconstruction of certain structures is not to exclude in the future, this paper shows that good policy management and maintenance of structures affected by internal swelling reaction of concrete can afford to keep them in service and significantly extend their life while respecting the necessary security conditions. It should of course implement enhanced surveillance of these structures and to ensure the good condition of coatings and good evacuation of rainwater.

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TABLE 1: Diagnosis results of the 4 most deteriorated bridges.

Bridge	Cracks starting	Deteriorated area	Pathology
PI 338	1983	Deck and abutments	Delayed ettringite and thaumasite No residual expansion
PI 328	<before 1983	Deck and abutments	AAR gel, ettringite and thaumasite High residual expansion for AAR and sulfate attack
PI 329	1977	Abutments	AAR gel, ettringite and thaumasite High residual expansion for AAR and sulfate attack
PI 330	before1983	Abutments	AAR gel and ettringite No residual expansion

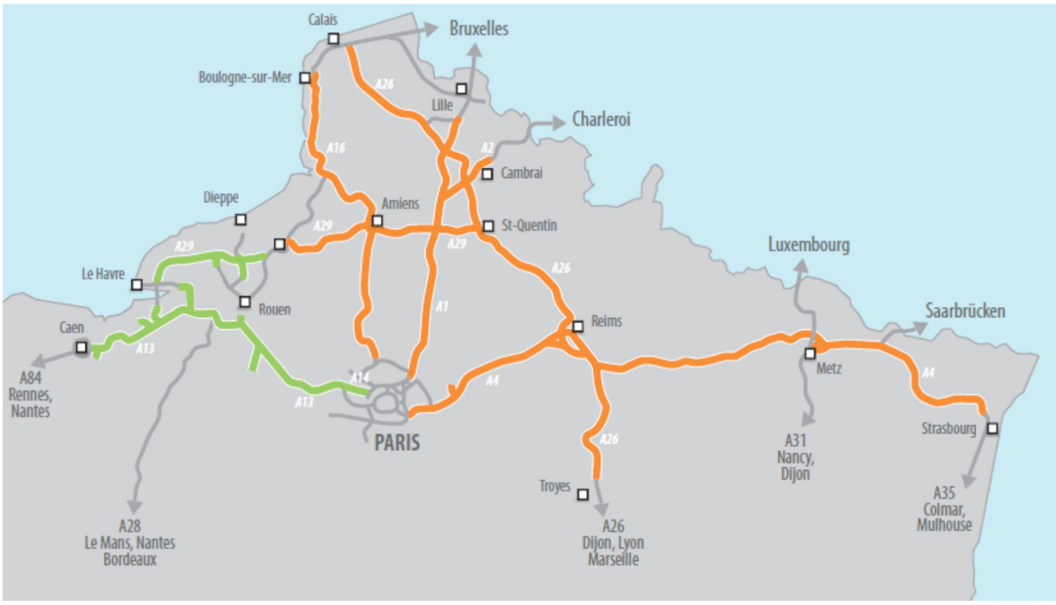

FIGURE 1: Map of the SANEF (Abertis group) highways.

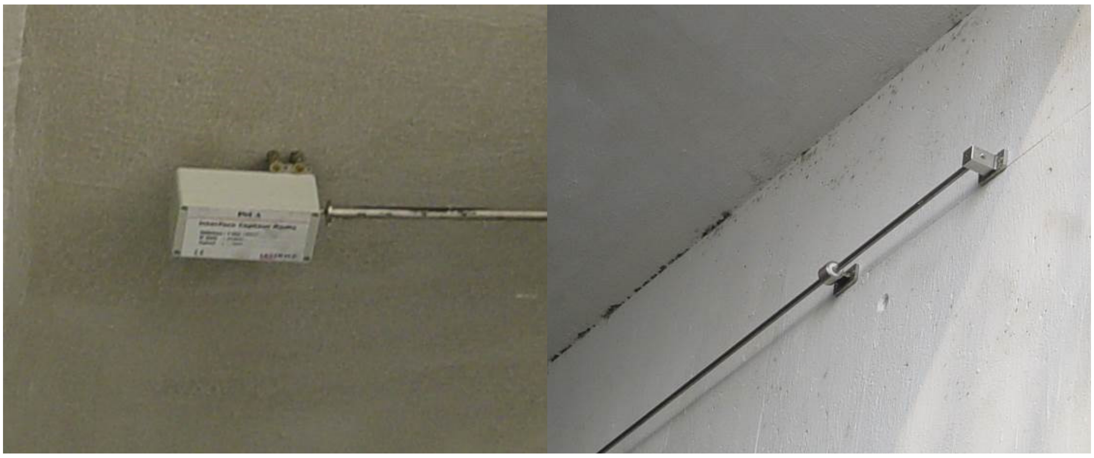

FIGURE 2: Expansion monitoring using displacement sensors at the end of metallic bars.

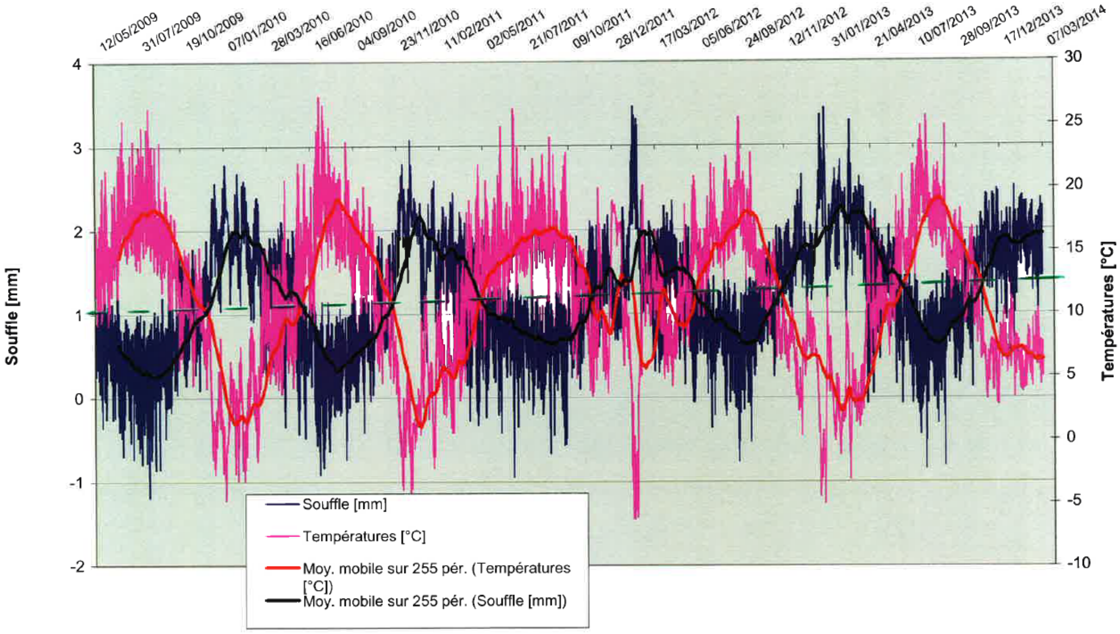

FIGURE 3: Moderate expansion measured on PI 354 between 2009 and 2014.

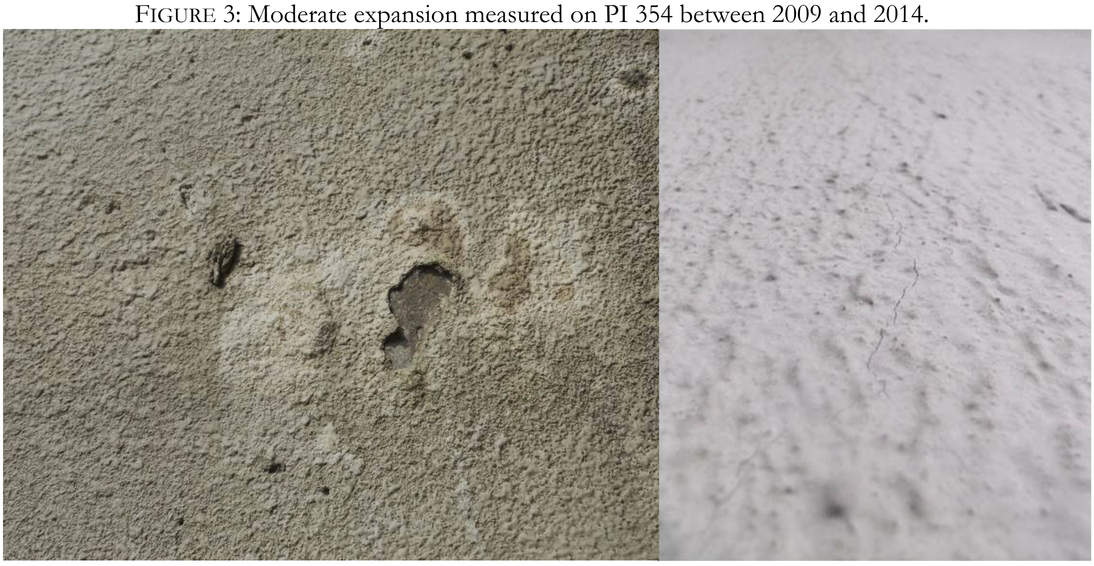

FIGURE 4: Coating deterioration after 15 years.