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History of Recent AAR Cases in Building Foundations in the Recife Metropolitan Area

Histórico de Casos de RAA Ocorridos Recentemente em Fundações de Edifícios na Região Metropolitana do Recife

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Abstract

In several countries, many cases of expansion and cracking in reinforced concrete structures - including those in bridges, flyovers and concrete walls - have been diagnosed as having in the alkali-aggregate reaction the main factor behind cracking scenarios of varying degrees. In Brazil, classic cases have until now occurred chiefly in large-scale hydraulic constructions (concrete dams) with few cases having appeared in other kinds of concrete structures, which were subsequently isolated and spaced out. This behavior has hampered the perception in technical circles that the phenomenon may be more common than was once believed. Before 2005, in the Recife Metropolitan Area (RMA), three cases of concrete structures affected by the AAR had been diagnosed: one dam and two pile caps of different building foundations. Yet, several other cases of cracking in foundation elements had already being observed but were attributed solely to mechanical causes. However, since 2005, through the petrographic analyses of cracked concrete cores, eight confirmed cases of reinforced concrete foundations affected by the AAR with varying degrees of cracking have already been identified. This paper provides a brief description of the reasons leading to the foundation inspections and the diagnosis of the eight cases studied.

Keywords: alkali-aggregate reaction, cracking, foundation.

Resumo

Em diversos países, muitos casos de expansão e fissuração de estruturas de concreto armado em pontes; viadutos; muros de concreto; entre outras, têm sido diagnosticada a reação álcali-agregado como um fator determinante para o aparecimento de quadros fissuratórios de intensidades variadas. No Brasil, os casos clássicos concentravam-se, até o momento, em obras hidráulicas de grande porte (barragens de concreto), tendo surgido poucos casos comprovados em outros tipos de estruturas, os quais foram isolados e espaçados. Essa tendência dificultou a percepção do meio técnico de que o fenômeno pode ser mais comum do que se imagina. Na Região Metropolitana do Recife, antes de 2005, foram diagnosticados 03 casos de estruturas de concreto afetadas por RAA: uma barragem e duas fundações em blocos. Por outro lado, diversos outros casos de fissuração em blocos de fundação já tinham sido observados, sendo creditadas, essas manifestações, unicamente, a causas mecânicas. Entretanto, a partir de 2005, através de análise petrográfica do concreto extraído dos elementos fissurados, já foram diagnosticados 08 casos confirmados de fundações em concreto armado que estão sendo afetadas pela RAA, as quais apresentaram níveis variados de fissuração. Esse trabalho descreve, resumidamente, as motivações que levaram as inspeções das fundações e o processo do diagnóstico dos 08 casos estudados.

Palavras-chave: reação álcali-agregado, fissuração, fundação.

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1 Introduction

This paper is of great interest to the technical community of the city of Recife, Brazil, due to the recent occurrence of several cases of cracking in base plates and blocks in the foundations of residential and commercial buildings in the Recife Metropolitan Area (RMA).
So far, in all the cases investigated, specific petrographic tests, Scanning Electron Microscopy (SEM) and dispersive x-ray spectrometry (EDS) diagnosed the occurrence of deleterious reactions like the AAR, which could be one of the major causes of the existing cracking situations.
Prior to 2005, although occurrences of the AAR in foundation elements and dams had been recorded in the RMA and environs, such cases were isolated and spaced out, which prevented the local engineering community from becoming aware of the problem and from taking action, so as to improve the knowledge of the phenomenon in the region. Such knowledge is essential for preventive action to be taken with a view to minimizing future occurrences of the phenomenon in future engineering works.
This paper focuses on the history and analysis of the main cases from January 2005 to date, in which the development of the AAR was diagnosed in reinforced concrete elements of building foundations. This information shall be included in the doctoral thesis of the author, whose theme aims to explore scientific investigation of real cases, thus making a much-needed contribution to the technical community.

2 History of the problem

At the end of 2004, prompted by the collapse of the 12-storey Areia Branca Building, located in the RMA, an inspection was carried out in a 21 year-old building close to the site of the accident. That inspection was performed on account of the concern shown by the building's residents regarding the integrity of the its reinforced concrete structure, which was subject to intense vibration when impacted by the collapse of the Areia Branca.

Figure 1 - Cracked side of the core

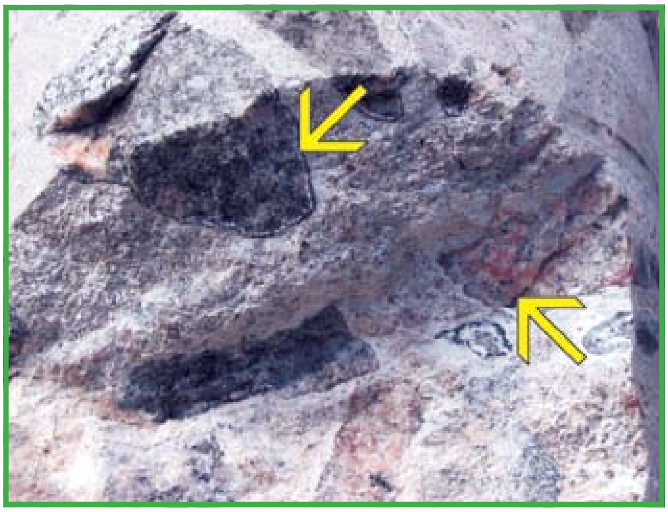

Figure 2 - Reaction rims seen surrounding the coarse aggregate

That inspection, which also included the visual observation of the building's foundation elements, base plates and beams), detected the existence of cracking, of varying intensity, on the upper surface of the base plates.
Initially, the engineers responsible for the inspection attributed the cracking to the accident in the neighboring building, since the review of the structural project revealed that the base plates had been executed in compliance with standard sizing criteria.
The point was also raised that the cracking may have been induced by mechanical efforts, which had not been foreseen when sizing those base plates. Another professional speculated that the type of cracking indicated a process of expansion in the foundation's elements.
Cores were extracted for tests of the concrete's compressive strength and to measure the depth of the existing cracks. After the removal of the cores, visual observation of the cracked side of the specimens (top) indicated the existence of reaction rims between the coarse aggregates and the cement paste and that the concrete macropores were filled with a whitish gel, as can be seen in figures 1 and 2.
That observation led to the suspicion that the concrete may have been developing an alkali-aggregate reaction, due to the resemblance of the features found in the cores with those found in cores extracted from the blocks of the Paulo Guerra Bridge, inspected five years earlier.
Built in 1977 and connecting Recife's inner city neighborhoods to the Boa Viagem neighborhood, that bridge had for several years featured intense cracking in the 16 foundation blocks, which remain partially submerged due to tide variations (fig. 03). In 2001, the Municipality of the City of Recife hired a company specialized in concrete technology to diagnose the causes behind the deterioration of the blocks.
Through investigations that included several tests on the cores extracted from the blocks – petrographic tests among them – an intense situation of alkali-aggregate reaction was verified.

Figure 3 – Fissures and crackings that are typical of expansion induced by the alkali-aggregate reaction in one of the blocks of the Paulo Guerra Bridge

Figure 5 – Foundation block with top surface seriously cracked, featuring openings of up to 25 mm in some areas

At the time, the possibility of there being other cases in underground concrete structures in the RMA was raised, as it was unlikely that those aggregates had only been used in the aforementioned bridge. Yet, back then, that suspicion was not enough to bring about further investigations.

In the first case (the building close to the Areia Branca), seen in figure 1, a sample of the concrete was sent to the laboratory of the Brazilian Association of Portland Cement (ABCP) in São Paulo. Through the ASTM C 856 [01] and the NBR 7389 [2] test methods, the existence of the reaction between the aggregate and the cement past was verified.

In that analysis, the coarse aggregate was characterized as cataclystic gneiss, featuring strained quartz grains, with undulatory extinction and recrystalized microcrystalline quartz, which are features that may confer a reactive character on the aggregate.

Under both the stereoscopic magnifying glass and the optical microscope, it was possible to see the reaction rims, with gel typical of the alkali-aggregate reaction. Under the scanning electron microscope (SEM), crystals resulting from the reaction were also seen.

Immediately after the first case, two new cases under suspicion emerged in a short time span. The second case occurred in a nine-year old, 24-storey building in the Boa Viagem neighborhood. Excavations down to the foundation blocks were prompted by the appearance of vertical cracking in one of the pillars in the garage level, and in cracking on masonry works located above the foundation blocks (figures 05 and 06).

In this building, all the foundation blocks were uncovered for the purposes of intervention (encapsulation). Of the 17 existing blocks, seven did not feature any cracking, and it was subsequently confirmed by the

Figure 4 – Concentric cracking in one of the base plates in the building close to the Areia Branca Building, where the holes bored for epoxy injecting can be seen

Figure 6 – Foundation block where cracking was first detected due to the appearance of vertical cracks that led to the excavation down to the foundation block

Figure 7 – Intense cracking on one of the foundation blocks in the downtown commercial building

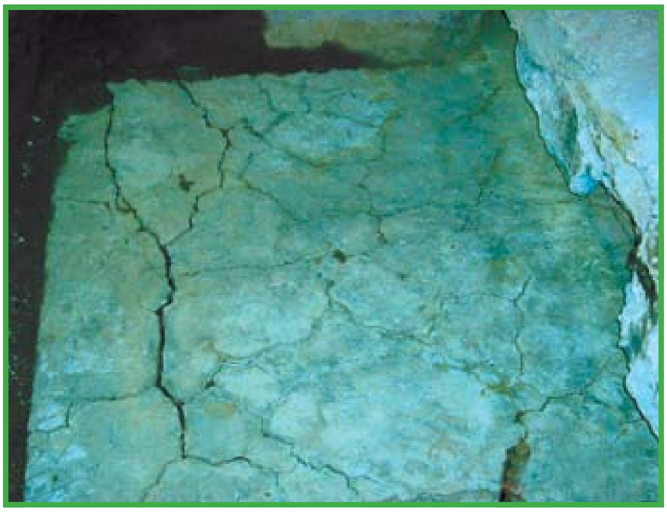

Figure 8 – Detail of crack on the left side of another block, with an opening of more than 30mm

builder that two concrete mixing plants had provided the foundation concrete.

A sample was taken from one of the cracked blocks in order to perform a petrographic test that was also sent to the ABCP, in which the occurrence of the alkali-aggregate reaction was again confirmed. The test classified the reactive coarse aggregate as milonite, with a milonite/cataclastic texture, featuring as potentially reactive minerals both strained quartz, with undulatory extinction, and recrystalized microcrystalline quartz.

The third case occurred immediately after the second, in a 21-year old commercial building in the downtown area. Given the intensity of the cracking, this case was classified as the most serious of all cases investigated thus far in the RMA, and the only one in which rather serious symptoms were observed in the superstructure, which may have been due to damage encountered in the foundation (figures 7 and 8). All the blocks were significantly deteriorated and are currently under intervention. The reaction was confirmed, but the proprietor of the building did not make the test results available for publication.

The fourth case of cracking was also detected in the Boa Viagem neighborhood, in a building that was only three years old. In the petrography test, the coarse aggregate was classified as a cataclasite, with milonitic/cataclastic texture, containing strained quartz with undulatory extinction and recrystalized microcrystalline quartz in mortar.

In this specific case, in addition to the AAR products, an amount of ettringite above normal was seen, suggesting that the expansion may have also been induced by a sulphate attack. This hypothesis was confirmed by the high percentage of sulphates found in the foundation's water table.

The fifth case occurred in the Piedade neighborhood, in the RMA, in two 11-year old buildings of the same constructors. Inspection of these buildings was not stringent, and some blocks appeared severely cracked (photos 09 and 10), but it was not possible to detect if cracking was widespread. At first, some blocks appeared not to have been

Figure 9 – Cracks on the top side of the blocks, descending to the sides

Figure 10 – Detail of the cracks on the side of the block

Figure 11 – Detail of a block in which the tie restricted the expansion towards it, thus inducing wedge-shaped cracking

Figure 12 – Random cracking on the top side of the block

damaged. The samples were sent to the ABCP, which classified the coarse aggregate as strained horblende gneiss, with granoblastic texture and featuring strained quartz with undulatory extinction and recrystalized quartz.
The sixth case, a rather serious one, was detected in a 21-year old building in the Boa Viagem neighborhood. All the blocks featured cracking, with some appearing visually very critical (Figures 11, 12, 13 and 14).
The coarse aggregate was classified as cataclystic gneiss, with a guided structure and granoblastic/cataclastic texture, containing strained quartz with undulatory extinction, recrystalized quartz and fine quartz.
The seventh case was detected in a 12-year old public building, with a serious cracking condition, especially considering the age of the building. The coarse aggregate was classified as milonite, with flowage and guided structure and milonitic texture, featuring strained quartz with undulatory extinction, fine quartz and recrystalized quartz.
The eighth case is considered the most interesting of all, and relates to a residential building whose construction had been suspended 10 years before. In order to resume construction, the new building company hired a specialized firm to inspect the foundation and superstructure.
During inspection, after the demolition of the floor slab of the garage level (partly underground), a situation of varied cracking intensity was observed on the foundation blocks (figure 19). It must be noted that during the 10 years in which construction was paralyzed, the floor that was partly under ground was covered by a sheet of water a great deal of the time, due to poor drainage of the rain water and the high level of the local water table in the rainy season.
After inspecting the blocks, it was possible to track down the foundation concrete, since the engineer responsible for the structure had filed the placing information at the time of construction.
According to the data found in those documents, the placing of the foundation blocks and ties were performed in four stages, as shown in Table 01.

Figure 13 – Random cracking on the top side of the block

Figure 14 – Random cracking on the top side of the block, descending along the vertical side

Table 1 – Summary of foundation block information

Placing	Date	Number of Blocks placed	Mixing plant	Situation
1st	11/03/95	6, 10, 11, 13, 17, 18	A	Little cracking
2nd	12/01/95	1, 2, 4/5, 9	A	Little cracking
3rd	01/22/96	3, 7, 12, 14	B	Intense cracking
4th	01/27/96	8, 15	A	No cracking

Several factors led to the conclusion that the existing cracking situation could not have originated from applied efforts, as explained below:

- The compressive strength results of the test specimens, retrieved from the technological control of the concrete blocks, are compatible with characteristic project compressive strength (25 MPa);
- Out of a total of 24 projected slabs, only 10 had been laid, and the peripheral masonry was only done up to the sixth floor. This load corresponds to approximately 20% of the total projected for the blocks;
- Pillar P8 and P12 blocks feature similar load, geometry and reinforcements, and pillar P12 block was severely cracked, while pillar P8 block had no cracking at all (figure 20);
- The intensity of cracking in the blocks is directly related to the placing stages, especially those of the third placing.

As expected, the petrographic classification of the coarse aggregate used in the three placing stages performed by mixing plant A was similar, proving that the same coarse aggregate had been used by the company. This aggregate originated from an igneous rock, and was classified as porphyritic granite. The analysis revealed strained quartz with undulatory extinction, which can be considered deleterious as regards the development of AAR. Due to the presence of this mineral, the aggregate was classified as potentially reactive.

As for the coarse aggregate used in the third stage of placing by mixing plant B, it originated from a metamorphic rock, and was classified as cataclastic/milonite gneiss. This rock originated from granite that underwent a dynamic metamorphism, thus straining, breaking and crushing the grains (minerals), generating milonitic and cataclastic textures. This process produced microcrystalline quartz, in addition to strained quartz with undulatory extinction. Given the texture of the deleterious minerals found, it was classified as a reactive aggregate.

This classification ties in with the cracking picture encountered in the blocks, where cracks were more intense in blocks of the third placing stage, in which an aggregate classified as having greater reactivity was employed.

On the other hand, the investigation performed on the concrete revealed the development of AAR in all the samples without exception, even in the fourth placing stage, in which the blocks did not yet show any type of cracking.

Figure 15 – Intense cracking on one of the blocks, with greater occurrence on the top and sides, down a certain length along the side, where the reinforcement is less intense

Figure 16 – Horizontal crack with a wide opening on the side of one of the blocks. In that area, there is a 35 cm zone without vertical reinforcement, which could restrict the expansion in that direction

However, the test revealed a greater quantity of reaction products in the blocks of the third placing and therefore corroborated the cracking picture observed.
In 2005, in addition to the eight cases above, in which the alkali-aggregate reaction was proved, there were another 14 cases of cracking – with varying intensity – on blocks and ties of building foundations. This number may even rise given the possibility that the technicians tackling the problem may not have identified some of the cases. Out of these 14 cases, the unfinished tests on four of them have already identified symptoms of the reaction. In the remaining 10 cases, the assessments are either being conducted by independent technicians or there was no interest on the part of the condominium to proceed with the investigations given the low level of cracking.
It is worth noting that, in all the cases, with the exception of the downtown residential building, the discovery of the pathological manifestation in the foundation blocks was not caused by symptoms in the superstructure that could point to a more serious problem of a structural nature.

Figure 17 – Detail of a crack on one of the corners of the block

Figure 18 – Side view of one of the cracked blocks

Figure 19 – View of a cracked triangular block

Figure 20 – View of two rectangular blocks, the first being intensely cracked, while the second (behind) has no cracking symptoms

3 Analisys of the problem

Table 2 sums up the petrographic analysis of the coarse aggregate in the eight cases that have already been tested. It can be noted that in these cases, the coarse aggregates always have in their composition strained quartz minerals with undulatory extinction, associated most of the time with microcrystalline and recrystalized quartz in a mortar structure.
In all but one of the analysis conducted, the aggregates of igneous origin underwent a process of greater or lower degree of dynamic metamorphism, becoming metamorphic rock. This type of metamorphism occurs in failure zones, which affect mainly the rock texture by warping, breaking and crushing the grains.
The cataclastic and milonitic texture originates from this type of metamorphism, which results in the appearance of strained, microcrystalline, recrystalized and fine quartz, hav-

ing lower or higher potential of reactivity with cement alkalis, due to the intensity of tectonic actions suffered by the rock of origin. Even the aggregate from porphyritic granite (eighth case) features strained quartz with undulatory extinction.

In the petrographic tests performed so far, the reactive aggregates are concentrated in the coarse aggregates; therefore, no emphasis was placed on the analyses of fine aggregates.

The alkali-aggregate reactivity of the rocks which have microcrystalline strained quartz is currently well known, as such reactivity is widely documented in the literature, such as in GRATTAN-BELLEW [03], SMITH et al. [04] and ANDERSEN; THAULOW [05].

In a CSA [06] classification, the rocks and mineral phases which are potentially reactive with cement alkalis are microgranular and macrogranular rocks of varied origins, containing microcrystalline and cryptocrystalline quartz and/or a significant amount of strained quartz with moderate or high undulatory extinction, as those found in the case studies.

An intriguing fact is that these rocks are characterized as having a slow reaction induction phase, generally featuring small expansions at young ages, although they may develop high expansions over longer periods of time. FOURNIER; BÉRUTÉ [07] reveal that this rock category is commonly found in eastern Canada and is characterized by a delay in the expansion and cracking of concrete, and can take between 10 and 25 years for the symptoms to appear. This characteristic does not match the cases found in the city of Recife, where intense cracking in the blocks are seen in 10-year old structures and even, in milder intensity, in three-year old ones. Although studies associate this characteristic with these types of rock, the possible development of higher expansion rates for the aggregates found in the region cannot be discarded due to the high complexity of the rocks, whose reactivity behavior can vary significantly.

The total absence of knowledge of the reactivity features of the region's aggregates increases the uncertainty as to the extent the alkali-aggregate reaction contributed to the cracking seen in the field. For a better understanding of the problem in the region, it is imperative to have an investigation program with laboratory tests, aiming to study the potential reactivity of the aggregates traded in the RMA. Such a laboratory program should not be restricted to the accelerated test of mortar bars and to the petrographic analysis of the aggregates, but should also perform accelerated tests of concrete prisms and analyses

Table 2 – Summary of the petrographic analysis of the aggregates in the eight cases described

Case N.	Type of rock	Petrographic classification	Texture	Reactive minerals
01	Metamorphic	Cataclastic gneiss	Cataclastic	Strained quartz with undulatory extinction, recrystalize microcrystalline quartz in a mortar structure
02	Metamorphic	Milonite	Milonitic/ cataclastic	Strained quartz with undulatory extinction, recrystalize microcrystalline quartz in a mortar structure
04	Metamorphic	Cataclastic	Milonitic/ cataclastic	Strained quartz with undulatory extinction, recrystalize microcrystalline quartz in a mortar structure
05	Metamorphic	Horblende gneiss	Granoblastic	Strained quartz with undulatory extinction and recrystalized quartz
06	Metamorphic	Cataclastic Gneiss	Granoblastic/ Cataclastic	Strained quartz with undulatory extinction and microcrystalline and recrystalized quartz
07	Metamorphic	Milonite	Milonitic	Strained quartz with undulatory extinction, microcrystalline and recrystalized quartz
08	Igneous	Porphyritic granite	Porphyritic	Strained quartz with undulatory extinction
	Metamorphic	Milonite/ cataclastic gneiss	Milonitic/ cataclastic	Strained quartz with undulatory extinction, recrystalized mircrocystalline quartz in a mortar structure

of the affected concretes by means of scanning electron microscopy, X-ray diffraction analysis, among others.
Moreover, research work to analyze the structural behavior of cracked pieces, employing the latest computer technology will be of great value in the understanding of the influence of stresses developed as a result of applied efforts, as well as in detailing the commonly used reinforcements in foundation blocks found in the existing cracking situations.
However, the development of alkali-aggregate reactions in the foundations of buildings in the city of Recife has been proved beyond question through petrographic analysis and must from now on be taken into account while diagnosing cracking situations observed in inspections performed in foundation elements of buildings and monuments in the region.

4 Conclusion

The alkali-aggregate reaction has become one of the likely causes of pathologic manifestations in reinforced concrete structures in Recife, especially those in permanent contact with water, such as the concrete elements of building foundations and concrete monuments.
In view of this, it is imperative that the technical community become aware of the need to acquaint itself with the phenomenon - particularly in the RMA - conduct preventive action to avoid it in future constructions and develop technical and cost-effective solutions to protect the elements that have already been by affected by the alkali-aggregate reaction.

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