Diagnosis and structural recuperation of foundation blocks under attack by AAR in a Brazilian building

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Abstract

The alkali-aggregate reaction has become increasingly common and harmful to structures in Brazil, especially in the northeast region of the country, due to the high temperatures that can accelerate its progress. This research is a case study that addressed this phenomenon in a residential building on the coast of the state of Pernambuco, describing the diagnosis of pathology through laboratory tests and the structural recuperation process performed on its foundation blocks, including the expansion process caused by the alkali-aggregate reaction, the step-by-step recuperation of foundation blocks affected by this pathology with the use of epoxy resin, as well as the need to lower the water table and waterproof the blocks, as they were partially submerged in brackish water. Finally, the phenomenon was monitored using an inspection window to verify any potential future expansion of the foundation blocks and the extent to which it might occur. The conclusions obtained demonstrate that the structural reinforcement procedure is satisfactory in terms of guaranteeing the integrity of the blocks and the maintenance of their support capacity, contributing to an increase in the useful life of the structures. However, since it is a pathology having only palliative treatment that can be very destructive, in some cases, it is possible to conclude that prevention is the best alternative.

Keywords: AAR, blocks, concrete, foundations, pathology.

1. ALKALI-AGGREGATE REACTION IN BRAZIL

The first studies that mention AAR in Brazil date from the 1960s, with the construction of the Jupiá dam on the Paraná River, whose gravel contained reactive chalcedony. In the Northeast, at least four dams of the São Francisco River hydroelectric system showed similar behavior (Paulo Afonso I, II, III, IV), in addition to two dams of the metropolitan water supply systems of Recife (Tapacurá) and Salvador (Joanes II), as covered by Gomes [1]. In Recife, extensive research was carried out when it was suspected that the Paulo Guerra Bridge was experiencing AAR, due to cracks in its foundation blocks, exposed by the variation of the tides. Studies carried out in 2000 shed light on the diagnosis that there were many cases of AAR in the city of Recife and its vicinity, especially in the foundations of bridges and buildings. The existence of reactive aggregates, the high concentration of alkali in the cement, and the high level of the water table are some factors that help to clarify the high frequency of this phenomenon, as confirmed by Figuerôa and Andrade [2].

2. CHARACTERIZATION OF THE BUILDING

The building described in this article was built in 2006. In 2018, it was diagnosed with AAR and the foundation blocks were recuperated. It is a class A residential building, with one apartment per floor and a total of 12 floors. It is located on the coast in the city of Recife, Pernambuco in a aggressive environment (class III), according to NBR 6118/2014 [3]. The building has 15 foundation blocks that are shown in Figure 2.1.

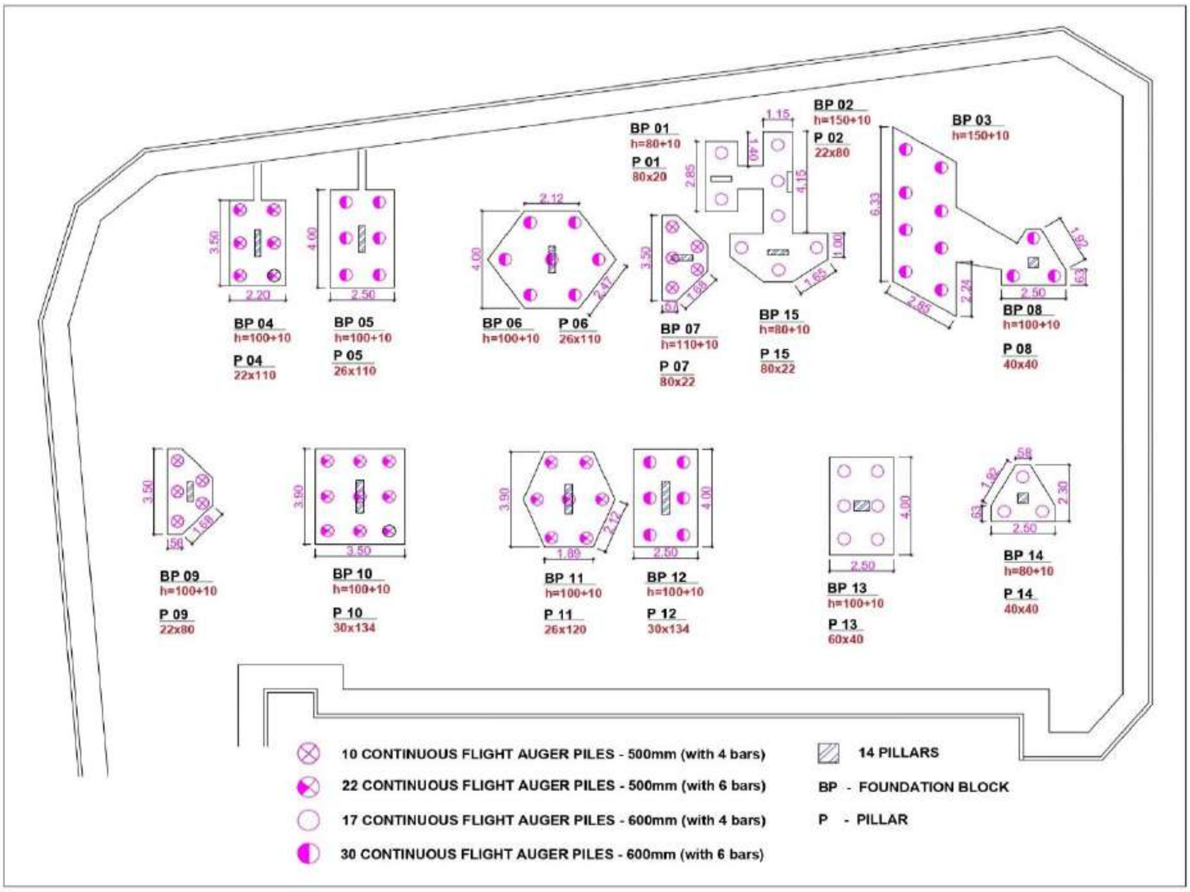

Figure 2.1: Outline of the building's 15 foundation blocks

3. DIAGNOSIS OF THE PATHOLOGY

When structural problems are suspected, an investigation should ideally be carried out, inspecting the structure. However, more careful investigation is often necessary through the collection of samples for laboratory studies, in addition to the collection of data on materials, structure and environment, in order to assist in the correct diagnosis of the problem [4].
The pathology was discovered during a routine inspection contracted by the outsourced company that manages the building. The inspector became suspicious of cracks, as shown in Figure 3.1, found on the garage floor of the building's basement and requested an inspection to see what, in fact, was causing them.

Figure 3.1: Cracks on the floor

Figure 3.2: Partially exposed block

During this inspection, two foundation blocks were excavated in order to diagnose the pathology, as shown in Figure 3.2. Four samples were extracted (shown in Figures 3.3 and 3.4) and later sent off for laboratory tests to the ABCP - Brazilian Association of Portland Cement [5], in São Paulo, for diagnosis and verification of the reactive potential of the aggregates.

Figure 3.3: Sample extraction

Figure 3.4: Samples

4. PETROGRAPHIC ANALYSIS AND RESULTS

Petrographic analyses using stereoscopic and optical microscopy and scanning electron microscopy were performed by ABCP using the following methods: ASTM C856 - 04 [6] and ABNT NBR 15577 - 3/08 [7]. According to the results obtained, the coarse aggregates are principally feldspar quartz with smaller amounts of biotite, amphibole, titanite, epidote, and opaques. The rock is of the metamorphic type, the petrographic classification is cataclysmic gneiss, and the potential reactivity is potentially reactive [5].

The results also indicate that the coarse aggregate has textural features that allow it to be characterized as potentially reactive to concrete alkalis. Also, according to the report, the concrete exhibits features typical of an alkali-aggregate reaction of the alkali-silica type. The aggregates exhibit well-defined reaction edges and it is possible to identify the reaction gel filling pores and voids in the mortar. The products of the reaction were characterized under an electron microscope, appearing mainly as leaf or lancet crystals deposited at the aggregate paste interface, and by the presence of expansive gel filling pores and voids [5].

5. MEASURING CRACKS AND DETERMINING THE STRUCTURAL RECOVERY TYPE

Following the diagnosis, an alkali-aggregate reaction of an alkali-silica type was proven. The engineer responsible for inspecting the building therefore asked the condominium to hire a calculation engineer to determine the necessary procedures for the immediate recovery of the blocks and to contract a company to carry out the structural reinforcement.

From the structural design, it was possible to identify the dimensions of each of the 15 foundation blocks to be recuperated. The foundation block chosen for this article was identified in the design as BP11. It is worth mentioning that the structural recuperation process was carried out in full on all of the blocks, with BP11 being chosen for study because two of the four samples taken to perform the test were extracted from it, and also because it has the widest cracks. Because of this, the block was also chosen to have an inspection window in order to monitor its pathology.

After excavating the block (Figure 5.1), it was cleaned with a high-pressure washer in order to remove all types of residue from its surface, as shown in Figure 5.2, and to open its pores for better penetration of the structural adhesive and afterwards, better adhesion of the waterproofing.

Figure 5.1: Exposed foundation block

Figure 5.2: Block surface after cleaning

The width of the block's cracks was measured with the aid of a fissurometer and was on the order of 1.8 mm, as shown in Figure 5.3.

Figure 5.3: Crack measurements performed by fissurometer

Even when concrete appears to be severely cracked and visibly deteriorated, the structural effects, may be negligible [8] thus a calculation engineer should be consulted. The type of repair to be performed was determined by the calculation engineer responsible for the structure. The solution recommended was to inject epoxy resin to seal the cracks, as this method would best suit the width of the cracks found in the block. The possibility of encapsulating the block was considered, as there was a possibility that the reinforcement had been exposed and lost part of its load capacity. The concrete could also have lost some strength due to the tensile forces it suffered when the block expanded.

Citing a methodology suggested by Istructe (Institution of Structural Engineers) [9] to practically assess the expansions that already occurred in the concrete based on the crack width measurements, Figuerôa and Andrade [2] proposed that at least five straight lines (25 cm apart with a minimum length of 1 m) be drawn on the surface of the element in both directions, cutting across the existing cracks. For each line, the sum of the crack widths was determined (using a method precise to less than 0.2 mm) and this sum was divided by the length of the line, giving an approximate expansion value (mm/m). This methodology gives only an approximation of the real expansion value, as other factors may also influence cracking, such as shrinkage and temperature [2].

The engineer measured the widths of the cracks on the face of each block and then divided the total width by the size of the block face. This calculation led to the conclusion that it would not be necessary to encapsulate any of the blocks because the cracks were quite narrow. It was recommended, however, that all blocks be waterproofed with a product having a greater ability to support expansion in order to ensure that any future cracks would not compromise the waterproofing of the block.

6. ATTACHING THE ADHESION NOZZLES AND SEALING THE CRACKS

The width of the cracks was increased with the use of a sander to allow for greater adherence between the block and the materials used in the recuperation. Subsequently, nails were placed on the surface of the block to mark the cracks, as shown in Figure 6.1, and to allow the attachment of the adhesion nozzles shown in Figure 6.2.

Figure 6.1: Open cracks

Figure 6.2: Adhesion nozzles

Structural adhesive was used to fix the nozzles to the block, as shown in Figures 6.3 and 6.4. This procedure was performed on the top and sides of each block recuperated. The external cracks in the block were sealed with structural adhesive immediately after attaching the nozzles.

Figure 6.3: Nozzles with structural adhesive

Figure 6.4: Attaching the adhesion nozzles

This adhesive (the same used to attach the adhesion nozzles) seals the cracks, preventing the escape of the filling material. The product is an epoxy-based adhesive with medium viscosity, has a compressive strength of 70 MPa after 7 days and an adhesion resistance to concrete ≥ 2.2 MPa. It is contained in two packages that were manually mixed and then applied to the block to seal the cracks using a spatula, as shown in Figure 6.5.

Figure 6.5: Application of structural adhesive to cracks

Figure 6.6: Block following crack sealing

7. INJECTION WITH EPOXY RESIN

After sealing all external cracks on the top and sides of the block with structural adhesive, as shown in Figure 6.6, epoxy resin was injected.

This resin is a bicomponent material (a base and a hardener) that was mechanically mixed until a homogeneous material was obtained. This material is a low viscosity epoxy resin for sealing and structural repair of cracks through injection, in order to reinforce the structure and ensure high resistance in the block. The resin has 70 MPa of compressive strength, 30 MPa of tensile strength, an elastic modulus of 2,600 MPa, and is able to achieve good penetration into cracks and cavities ≥ 0.3 mm.

The epoxy resin was injected into the block with an injection pump. The resin penetrated the blocks through the nozzles, filling all internal cracks in the block, as shown in figures 7.1 and 7.2. Figure 7.3 shows the block with all cracks sealed.

Figure 7.1: Use of Injection pump to apply epoxy resin

Figure 7.2: Injection of epoxy resin into the foundation block

Figure 7.3: Foundation block with cracks filled with epoxy resin

8. WATERPROOFING THE BLOCK AND LOWERING THE WATER TABLE

Waterproofing is an attempt to prevent water from entering the block. Its purpose is to make it difficult for any further reaction to occur. The product used was a flexible, bicomponent, waterproof coating based on acrylic polymers (thermoplastic resin) with cement and reinforced with fibers, especially suitable for structures that are subject to movement. Fibers give it greater resistance to cracking, and it has an adhesion of 1.5 MPa and a density equal to 1.60 kg/L. This waterproofing agent has flexible memory, which means that in practice, it has the ability to expand along with the block and prevent cracks from being opened.

Before applying the indicated waterproofing product, it was necessary to completely remove the adhesion nozzles (Figure 8.1), clean and regularize the surface of the block to ensure that there were no points that would perforate the waterproofing layer. The side surfaces were sanded (Figure 8.2) and then cleaned with a compressor to remove particles of dust and cement laitance from the block.

Figure 8.1: Removing the adhesion nozzles

Figure 8.2: Regularization of block surfaces and corners using a sander

The level of the water table beneath the structure was high. Through the opening in the block, it could be seen that about 30 centimeters of the block were immersed in water and that it would therefore be necessary to lower the water table. A pump was used to ensure that the block remained dry until the end of the reinforcement process (see the drainage device in Figure 8.3). It is also possible to observe in this figure the clean and regularized surfaces, ready for waterproofing.

The waterproofing product must be applied to a clean surface with the aid of a compressor and spread with a brush. The waterproofing product (made of a liquid and a powder), must be mixed with a low-speed mechanical mixer until a homogeneous mortar is obtained. One layer of this product was applied evenly to ensure full coverage of the surface, as shown in Figure 8.4.

Figure 8.3: Groundwater lowering system

Figure 8.4: Application of waterproofing product

To maximize the efficiency of the waterproofing, a PVC-coated polyester canvas was also used. This screen was measured and cut to cover the required surface, especially the corners, and applied immediately after the first coat of the waterproofing product was applied (Figures 8.5 and 8.6).

Figure 8.5: Screen being applied to the block

Figure 8.6: Screen being applied to the block corners

Subsequently, three more coats of the waterproofing product were applied, making a total of four. In Figure 8.7, the block was completed. The curing of the product was monitored for seven days and then the block was reburied (Figure 8.8).

Figure 8.7: Block after waterproofing

Figure 8.8: Block finished and reburied

9. FLOOR RECONSTRUCTION AND PATHOLOGY MONITORING

The last step was the reconstruction of the floor and creation of the inspection window. This window is necessary because AAR is a pathology still lacking a definitive solution. Repair is palliative and it is still possible for the block to expand again. The size of the window was chosen (50 cm x 50 cm) and a wooden form was constructed so that the block would be completely exposed (the detail at the bottom of the form can be seen in Figure 9.1).

The inspection window was positioned to expose the largest crack in the block, shown in Figure 5.2. To do this, the bottom part of the formwork was sanded until the mortar was removed, making the crack visible (see details of the crack exposed in Figure 9.3). After removing the formwork and finishing the floor, a thin plate of glass was placed over the crack and waterproofed using epoxy resin (shown in Figure 9.2). If the block begins to expand again, the glass will crack, revealing this expansion.

Figure 9.1: Construction of the floor and inspection window

Figure 9.2: Inspection window

Figure 9.3: Detail of the sealed crack

10. CONCLUSIONS

There are various possible measures that can be taken to avoid the alkali-aggregate reaction. One of the most effective is to act during the construction planning phase. In cities like Recife, with high rates of AAR, a foundation design may already suggest the use of additives in the concrete to avoid expansion, such as Metakaolin and Silica Fume. An appropriate type of Portland cement should also be used to inhibit the reaction and aggregates can be replaced when their reactive potential is identified or when it is impossible to attenuate the reaction with the use of inhibitors.

In cases of buildings for which this care was not taken, as with the building in this case study, the solution is merely palliative. Even with structural recuperation done with full attention and care, there is no guarantee that the pathology will not come back over time. In these blocks, the probability is even greater because the foundation blocks are in direct contact with the water table.

Therefore, an inspection window must be left so that any signs of further cracking in the block can be quickly identified and new possible measures be evaluated.

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