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RESEARCH ARTICLE

Analysis of structural integrity of a non-completed 28 year-old building in the city of Patos de Minas (MG)

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Abstract Factors such as durability and performance must be the guideline in the design of any building, since most of the pathological manifestations that affect the buildings are associated with construction stages, from project design to use of the structure, severely influencing the useful life of structure. This work aims to diagnose the pathological manifestations of the current reinforced concrete structures in the urban environment, through a case study. The inspections were carried out in an anonymous non-completed building in Patos de Minas (MG), with an estimated age of 28 years. It was carried out the diagnosis of the main pathological manifestations and prognosis of the analyzed system. It used to inspections in the field—visual and detailed—and laboratory tests, such as measurement of propagation velocity of ultrasonic waves, reinforcement locate (scan), rebound hammer test, compressive strength test, Brazilian disk test, capillary water absorption test and carbonation depth measurement test. The pathological manifestations found in the concrete structure analyzed were cracking, peeling, carbonation and reinforcement corrosion. The value of rebound and ultrasonic pulse velocity obtained were relatively high (around 58 rebound and velocity of 4000 m/s), due to advanced carbonation (average across 30 mm). Already water absorption by capillary found in the laboratory was high too (in the range from 6105.17 to 30181.64 g/m^2). Due to the high degree of deterioration, corrective or recovery measures are not applicable.

Keywords Pathological manifestations · Nondestructive method · Concrete structures

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1 Introduction

One of the main concerns when planning structures made of reinforced concrete is durability, and, consequently, the useful life they will have [1]. It is intended that the structures meet throughout its service life his duties as usability, capacity and stability. It is usually expected that the structures meet the demands to which they were built, without neglecting the safety and economy, besides the performance of the system to its users. However, many factors may specially influence the safety and performance that this structure will provide to those who will use it [2].

The durability should be initially secured by a suitable structural design as well as a suitable selection of the materials and the execution quality. However, some defects arising out of the enforcement proceedings can pass unnoticed [2]. Conception and project errors, technological control of materials, improper execution of said structure, added to the misuse and lack of preventive maintenance, originate the pathological manifestations. Apart from natural catastrophes, that demand from the structure much more than it was built to stand, the pathological manifestations originate summarily from human error [3–5].

It is necessary that the designer understand the factors that initiate the deterioration mechanisms of structures. It is assumed that there are two different sources of deterioration: one has substantially continuous effects and is tied in general to environmental and operating conditions (ageing); the other is already arising from short-term phenomena (shocks), which may occur due to external actions, and also to sudden changes in the deterioration mechanisms [3].

Only seldom is concrete degradation due to a single origin. The degradation mechanisms can be of physical, chemical or mechanical, besides the physical–chemical phenomena can act synergistically [6]. A major cause of deterioration of reinforced concrete structures is corrosion of the reinforcement, which is relatively difficult to intervene or repair [3, 7, 8].

Two main agents initiate reinforcement corrosion by destroying its passive coating: carbonation and chloride ingress. Carbonation is more common in urban and industrial areas, is characterized by a physical–chemical process involving pH reduction of the concrete with the diffusion of CO_2, gradually advancing over time until reaching the passive coating, allowing its corrosive process occurs [3, 9].

Knowing the mechanisms of deterioration of reinforced concrete structures, it is necessary understanding of ways to diagnose them. Therefore, there are research techniques to the concrete, which are classified into two macrocategories: destructive and non-destructive tests. The nondestructive tests are used to diagnose causes and origins of pathological manifestations and investigate the quality of the material they are made of, or even the necessity of maintenance of the system [1, 10].

It is possible, through nondestructive tests, to obtain valuable information to evaluate the structural integrity and maintenance of an existing structure, since the evaluation of performance and durability of a given structure demands, most of the times, which we go beyond the subjectivity of visual inspection. Visual inspections are summarily of qualitative character, whereas, in the majority of times, measurable data is necessary for a complete diagnosis and a possible prognostic. When measuring a pathological manifestation, it is possible to come to the conclusion of which alternative is the most suitable: reinforcement, recovery, limitation of use, or even demolishing the structure [2].

The main objective of this research is to understand the pathological manifestations of structures of reinforced concrete through a case study. To do so, an anonymous building in the city of Patos de Minas (MG) was used as the object of study to verify the structural integrity of the system, making both the diagnosis and prognostic possible.

Specifically, the guidelines are: the analysis of the structure's state in face of the environmental and use conditions; the visual evaluation of the structure as well as the use of such method to estimate its structural integrity; identifying the major pathological manifestations present in the structure; searching for evidence that can prove the raised hypothesis, leading to a diagnosis, and, besides, providing a technical opinion in relation to the structure's degree of deterioration and the possible evolution of pathological manifestations, if there is no intervention. For the study to be possible, mainly nondestructive tests were applied, which were determined beforehand through an initial analysis of the system.

2 Methodology procedures

This case study was developed in two distinct environments: field and the Laboratory of Technologic Analysis of Materials of Centro Universitário de Patos de Minas (UNIPAM). In the structure itself, the visual analysis of ground floor and underground was done, besides the nondestructive tests in the underground (columns e diaphragm wall). In the laboratory, nondestructive tests with the structure's specimens were done to correct possible mistakes in the data from the field. Figure 1 summarizes the methodology process adopted for the analysis of structural integrity of the object.

2.1 Elements of the study

For the field analysis, mainly underground elements were used, since they were not as deteriorated as the ones from ground floor. Figure 2 illustrates part of the analyzed structural arrangement.

The test areas were distributed according to the dimension of the analyzed structural element, this way, the bigger the element, the more areas were necessary to represent the material in the study. The bigger quantity of areas also permits to verify the homogeneity of the material. Eight columns were analyzed, with dimensions ranging from 25 to 60 cm of thickness and 80 to 102.5 cm in width, and other three diaphragm walls of varied widths. The Fig. 3 shows the schematic representation of the building in plan layout and in section.

In the laboratory, specimens molded from the structure were used; dated in the interval from 01/12/1987 to 12/03/1988, found in the construction. It is a very delicate situation to affirm that these specimens are actually part of the structure.

The builder and owner were contacted to investigate information about the specimens, confirming that they belong to the analyzed work. However, it was not possible to obtain access to projects and the extraction of testimonies. Therefore, it has been necessary to accept that the specimens would be sufficient for analysis of the structure to thereby obtain a much closer study of the identified pathological manifestations; since they were exposed to the

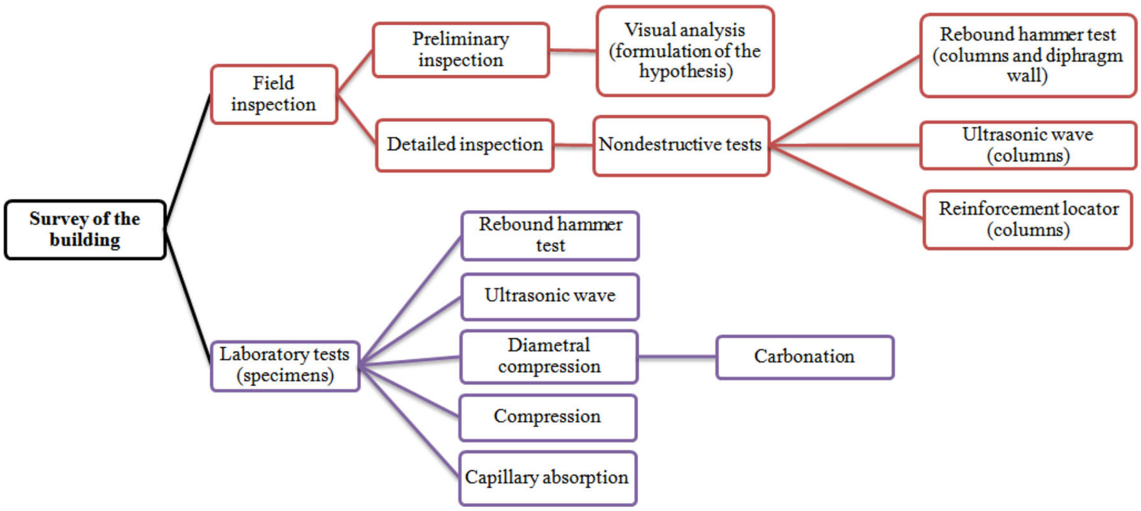

Fig. 1 Methodology process adopted for structural analysis

Fig. 2 Structural elements used for analysis

same environment as the structure. This and the fact they were exposed to the same humidity, aggressive agents, and micro weather as the building, since they were left in the place back then. 17 elements with 15 cm of diameter and 30 cm of length were used.

The specimens were randomly divided into four groups. The first and the fourth groups contemplated the tests of rebound hammer test, ultrasonic waves, and uniaxial compression. For the elements of the second test group, capillary water absorption tests and, as in the auxiliary tests, Brazilian disk test. Since the third treatment was mainly intended to evaluate carbonation in a qualitative way.

2.2 Used methods

2.2.1 *Visual analysis*

The visual analysis was done to formulate hypothesis regarding the possible causes for the appearance of pathological manifestations. To begin the analysis of the structural arrangement, a search for visual pathological manifestations was done. Despite being subjective and qualitative, this stage enabled the choice of more representative elements of the system. First, the slabs and beams were analyzed for the visual characterization; then, we proceeded to the analysis of the columns, both the underground and the ground floor ones. Besides the visual analysis, we also resorted to measuring the fissures and cracks through the use of a comparative crack gauge. With the preliminary analysis completed, it was determined which elements would be the targets of the nondestructive tests.

2.2.2 *Rebound hammer test*

The rebound hammer test allows gauging the superficial hardness of the material, based on the principle of reflection. The rebound hammer test has qualitative and quantitative character, since it allows investigating, respectively, the quality and the potential homogeneity of

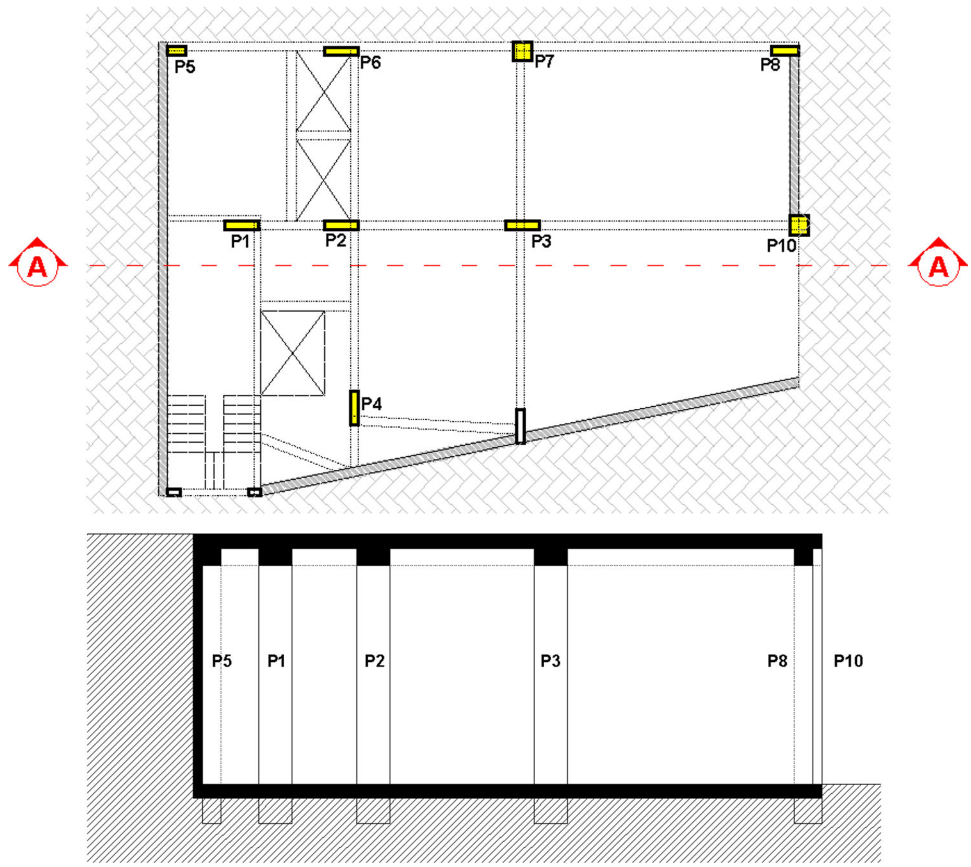

Fig. 3 Schematic representation of the building in plan layout and in section

the concrete, and, through the correlation curve, the compressive strength. However, many factors interfere in the relation rebound and compressive strength, among them, the age of the concrete, due to carbonation, and the presence of aggregators near the impact surface [11].

Due to the advanced age of the studied object, we chose to build a characteristic curve of the analyzed material, using the structure's specimens. The digital rebound hammer test type RN was used in every stage of the study. Tests were done both on the field elements and the specimens in the laboratory to compose the new calibration curve of the rebound hammer.

2.2.3 Ultrasonic test

The ultrasonic test consists of the evaluation of the propagation velocity of the ultrasonic wave pulses through two predetermined points. Some factors influence the collected data, such as the presence of rebars, the density of the concrete, possible voids and failure in concreting, relative humidity, age of the concrete, and others [12].

The test allows three types of readings according to the adopted disposition of the transducers: direct transmission (opposed faces), semi direct (perpendicular faces) and indirect (same face) [12]. In all the stages, readings of the direct type were done, since the elements were of average thickness and reasonable dimensions; besides the fact that it was the most precise type of reading for the collection of data. To do the readings, an ultrasonic wave device in the frequency of 220 kHz and silicone grease couplant to increase the contact area between the transducers and the analyzed surface were used. It is emphasized that the surface was normalized with silicon carbide prism and cleaned of all powdery residues.

Direct readings were done both on the field structural elements and the specimens to verify their properties in order to reinforce the representativeness of the batch. The propagation of ultrasonic wave pulses test in the structure's specimens was performed in their transversal part [13]. To do that, three direct measurements were done in each specimen to get the value of the propagation time. We opted for the lowest time value [14], despite it being used for mortar settlement and jackets; however, it offers a script with the necessary amount of readings to reach the correct representativeness of the data.

2.2.4 Reinforcement locator (scan)

The reinforcement locator (scan) [15] allows the identification of rebars using as parameters their localization, quantity and diameter, besides the concrete coating. However, there are limiting factors, such as the measuring field not being inferior to 120 mm, knowing the diameter of the bars, and the space between them being bigger than 100 mm [16].

Despite not having accessible structural projects for the sake of comparison, this test had the main objective of measuring the coating of the elements' bars, in order to verify the compliance or not to the ruling norm at the time [17].

The reinforcement locator (scan) allowed gauging the diameter of the bars of the prospected elements, as well as the thickness of the coatings. Columns P1, P2, P3, P4 were analyzed, since they had all of their faces free, allowing to breakdown the element.

2.2.5 Other tests

Besides the rebound hammer test, ultrasonic waves, and reinforcement locator (scan), three complementary tests were also done on the specimens: uniaxial compressive strength, evaluation of carbonation, and capillary water absorption. The tests made it possible to verify the compressive strength the material has, besides the format of the break [18].

For the evaluation of carbonation, a diametral compression test of auxiliary character was used [19] to allow the longitudinal opening of the specimen. Evaluating the depth of the carbonation front allows us to verify if the depassivation of the rebars occurred or not. In case there was depassivation of the rebars, other deterioration processes may occur, such as corrosion, and eventually, the fissure and break of the element. To gauge the carbonated front, carbonation depth measurement test in a 1% solution was used, by means of immediate spray irrigation after the break of the elements [20].

The capillary water absorption is one of the properties that has great influence in the transportation of water and harmful agents to the interior of the concrete, because of the use of its pore network. The bigger the capillary diameter, the smaller the absorption depth and bigger the total quantity of water absorbed. Normally, concretes with reduced water/concrete ratio have smaller capillary diameter and, simultaneously, these capillaries have fewer intercommunications. This test allows us to determine the capillary water absorption. Despite not being initially destructive, the test requires that a diametral break of the body be done at the end of the process in order to longitudinally verify the pore network [1, 21].

The capillary water absorption test consisted of leaving three specimens in a kiln for 72 h and, afterwards, putting them on a 5 mm-deep water line to investigate the fluid transportation mechanisms through capillarity. After the 72 h of semi immersion, the specimens were broken due to diametral compression in order to investigate the capillarity height in the bodies [21].

3 Results

3.1 Visual analysis

3.1.1 Slabs

Initially, it was seen that the slabs of the structure, in their majority, presented a common problem in the execution of structures of reinforced concrete: lack of spacers to guarantee the minimum coating of the rebars. In this case, the distribution rebars had bare spots or insufficient coating in many parts. Another point that should be pointed out is the action of leaching and humidity in these elements. There is formation of spots in the material, as well as the formation of stalactites and efflorescence, resulting from the transportation of products for concrete hydration. Both cases can be verified in Fig. 4.

Due to insufficient cover, it can be seen that the corrosion of the rebar affected the material in a more aggressive way, promoting the peeling of the concrete surrounding the rebars. It can also be seen that the cement laitance, in various structural elements, flowed while the structure was

Fig. 4 Analyzed slabs

been concreted, indicating forms without water tightness and sealing.

3.1.2 Beams

The beams, in general, present fissure and peeling on the coating layer, as it can be seen in Fig. 5.

Despite the rebars being exposed in many points, yet, the beams haven't come to the point of deterioration to which the columns and diaphragm walls have. The corrosion of the rebars affected the beams, at first, not allowing the formation of corrosive products regarding the other elements, to the point of generating break of the concrete coating. It is possible to see that the layer of concrete protecting the rebars suffered the action of carbonation, losing its mechanical resistance, and due to the strain of the structure, over time, there was peeling of the material.

3.1.3 Columns

Initially, the ground floor columns were analyzed. As it can be seen in the pictures of Fig. 6, the concrete was porous and fragile. We can notice over the photographic record that there was formation of calcium composites on the surface of the columns (caused by leaching of the hydration products). There is also the biologic attack to the start rebars of the ground floor. Another pathological manifestation that spread over the construction elements was the corrosion of the rebars. The degree of deterioration of these elements is at an advanced stage, since the useful part of the bars was compromised.

Fig. 5 Rebar exposes on the beam

In other points, it is visible that the corrosion of the rebars reached the point where they got bent, due to the great formation of iron oxide at the base of the bars, generating an increase of volume. It is interesting to point out that the bars have 25 mm of diameter, showing strain due to the formation of corrosive products so that a bar of bigger gauge could suffer bending. When oxidation products were formed around the rebars, the concrete suffered exacerbated expansion, causing the break of coating by traction, leaving it even more exposed to weather and aggressive agents, as shown in Fig. 6.

As the inspection took place, we began the prospection to measure in which interval the fissure of the structure was exposed. To do so, a comparative crack gauge was used. The fissures that were measured present varied thickness. Fissures ranging from 0.3 to 0.55 mm were found.

On the underground, it is possible to notice that the biggest part of the pathological manifestations was located at the base of the columns, as it can be seen in Fig. 7; being quite rare the presence of exposed rebars at the mid-high portion of the columns.

3.1.4 Consideration regarding the visual analysis

The visual inspection allowed us to infer that the structure on the ground floor has a bigger degree of deterioration than the underground structure. This can be caused by many factors, such as:

- The ground floor structure is exposed, for approximately 28 years, to cyclic wetting and drying, thermal oscillations and, obviously, solar radiation;
- Inefficient concreting, with the coating of the start rebars smaller than necessary due to the lack of spacers (from this the necessity of using a layer of mortar to

Fig. 6 Exposed rebars on ground floor

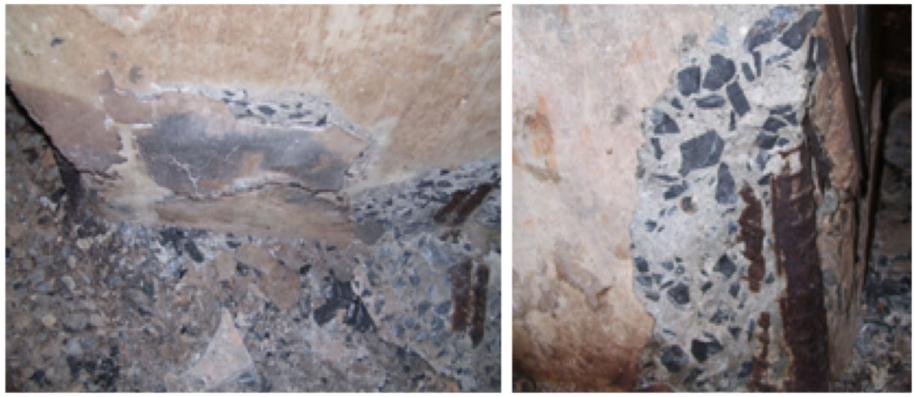

Fig. 7 Peeling of the basal cover of the columns and exposed rebar

increase the cover or a failed attempt to correct the first signs of corrosion in a lay manner);

- Concrete with a high water/concrete ratio, causing a higher porosity in the material.

Due to weather and solar radiation, the elements that compose the ground floor have become more porous, fragile, and, because of this, more prone to leaching and carbonation. Due to the degree of deterioration of the ground floor structure, we opted for not performing any nondestructive tests. Since the underground part was at an average degree of deterioration, it was decided that tests to verify how much the pathological manifestations affected the elements should be done.

On the field, the rebound hammer test on the columns and diaphragm walls was done, ultrasonic waves on the columns and reinforcement locator (scan). The analysis of the columns was emphasized, since they were shown to be more accessible and susceptible to pathological manifestations. The other elements—slabs and beams—could be visually analyzed.

3.2 Nondestructive tests on the field

3.2.1 Rebound hammer test

The values of the reflex index were determined according to criterion of calculus recommended by norm [11]. The values that distanced in 10% from the average were not considered in the final value of the rebound hammer index (RI). By discarding these values, the average was recalculated with the values considered valid. The summary of the data collected from the columns in on Table 1.

As for the diaphragm wall, it can be seen that the values of the impact areas didn't change due to distance, since, visually, the walls were less affected by pathological manifestations (in all their surface) than the columns, and had values of rebound hammer index around 54.20; a little below the average obtained from the columns.

The explanation for the values of the reflex index is a hypothesis, since they have low variation in relation to the obtained average, indicating certain homogeneity of the material's state on the surface. It causes suspicion, as it can be seen, that the rebound hammer indices are considerably high, since the steel for the calibration of the rebound hammer has hardness 80, showing the high rigidity of the material's surface, indicating that it is severely carbonated.

3.2.2 Ultrasonic test

The results of the UPV for the columns were verified in the limited areas by the longitudinal bars and stirrups, in order to avoid interference of the metal when measuring the velocity. The times relative to the propagation of the ultrasonic waves were obtained through the direct method on the columns. From the measurement of the diffusion time and the distance between transducers, the ultrasonic wave propagation velocity was obtained. From the average velocity obtained on the tests, the concrete could be characterized, according to Table 2.

Table 3 shows the transmission times that were obtained and their respective distances. Track M refers to the median region of the column (approximately 1.30 m) and track B, to the low region (approximately 0.90 m).

As it can be observed, the analyzed concrete is considered to have optimal quality. One of the raised hypotheses for that is due to the fact of carbonation filling the concrete pores with salts resulting from the neutralization reaction that characterizes it, leaving it denser.

3.2.3 Reinforcement locator (scan)

The systematization of the details was done, as it is possible to observe below, listing the prospected bars and their respective coatings. The coatings of the prospected columns varied from 23 to 49 mm. Figure 8 illustrates the arrangement of column P1.

Table 1 Average rebound hammer index of the columns—Date: 11/08/2015

Element	$RI_{effective}$	C.V. (%)	Element	$RI_{effective}$	C.V. (%)
P1	58.9	6	P2	58.4	4
	60.8	4		56.8	4
	59.3	4		54.8	5
	56.8	4		58.4	5
P3	59.3	7	P4	65.9	5
	57.8	7		61.9	5
	61.8	4		59.9	5
	59.8	5		55.6	5
P5	55.2	3	P6	66.5	4
	56.0	5		68.1	3
P7	60.0	3	P8	57.4	5
	61.3	6		62.7	5
	60.1	4	Global average	59.7	
	58.0	5	Global C. V.	5.60%	

P1, *P2* columns analyzed, $RI_{effective}$ final rebound hammer index, *C.V.* coefficient of variation

Table 2 Correlation between propagation velocity and quality of the concrete [16]

Velocity of the ultrasonic wave (m/s)	Quality of the concrete
$V > 4500$	Excellent
$3500 < V < 4500$	Great
$3000 < V < 3500$	Good
$2000 < V < 3000$	Regular
$V < 2000$	Poor

3.3 Laboratory tests

3.3.1 Rebound hammer test

The collected values are representatives for the composition of the curve of compressive strength versus the reflex index, in order to correct the data in face of the action of carbonation, for a valid correlation between f_{ck} and the rebound hammer index, as shown on Table 4.

Figure 9 illustrates the graphic and mathematic relation between these two properties, according to data collected from the tests in the laboratory.

We opted to use this potential curve, because if the resistance is zero, the surface hardness will also be zero. It can also be inferred that the higher the mechanic resistance, the higher the ratio between resistance and surface hardness will be, indicating that: the bigger the f_{ck}, the lower the rebound hammer index will be, since the material under treatment is highly carbonated.

The compressive strength of the analyzed concrete, using the curve $f_{ck} \times SI$ built from the tests on specimens varied from 17 to 26.1 MPa for the columns, and from 14.3 to 20.7 MPa for the diaphragm walls, which, for the standards of the time when it was built, is a good result, despite the material being exposed to severe carbonation.

3.3.2 Ultrasonic waves test

The values collected in the test for propagation of ultrasonic waves in the specimens ranged from 4013 to 4684 m/s, then,

Table 3 Average transmission time on the columns—Date: 21/08/2015

Element	Track	Distance (m)	Time (μs)	Average velocity (m/s)	Quality	C. V. (%)
P1	M	25.50	61.58	4153.96	Great	6
P2	M	26.00	61.11	4262.84	Great	5
	B	26.00	59.63	4366.01	Great	5
P3	M	25.00	61.55	4080.88	Great	8
	B	25.00	61.80	4046.85	Great	2
P4	M	26.00	62.85	4139.20	Great	3
	B	26.00	70.83	3691.13	Great	9

P1, P2 columns analyzed, *C.V.* coefficient of variation

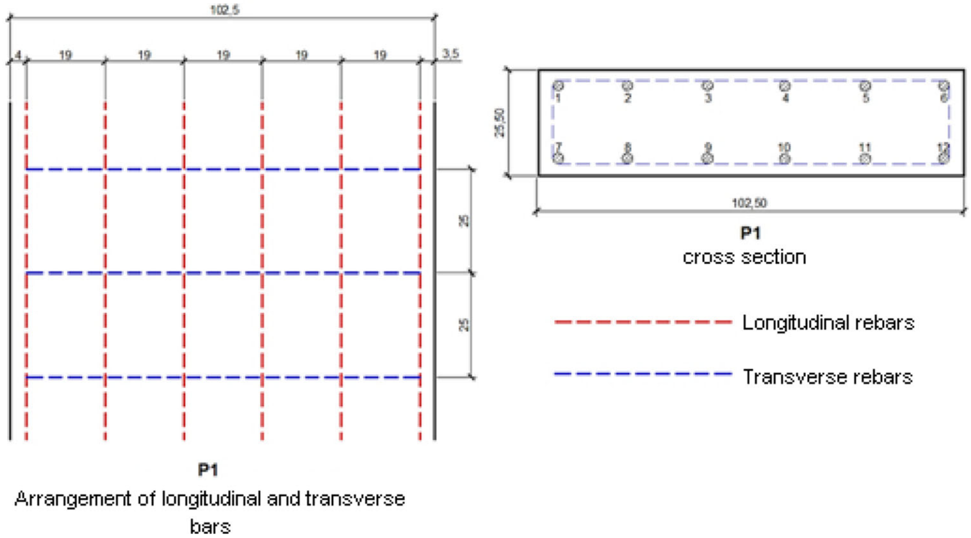

Fig. 8 Detailing of bars of column P1

Table 4 Relation between f_{ck} e $RI_{effective}$

Item	f_{ck} (MPa)	$RI_{effective}$	C. V. (%)	Item	f_{ck} (MPa)	$RI_{effective}$	C. V. (%)
CP 1	14.3	50.09	4	CP 6[a]	5.8	45.69	6
CP 2*	15.9	58.34	6	CP 7[a]	16.9	57.44	4
CP 3	22.2	58.23	4	CP 15	20.1	60.07	3
CP 4	13.6	46.41	5	CP 16	19.0	55.12	5
CP 5	18.9	51.91	4	CP 17	17.1	53.50	5

CP 1, CP 2 columns analyzed, *$RI_{effective}$* final rebound hammer index, *C.V.* coefficient of variation, *f_{ck}* characteristic strength of concrete

[a] Not part of the composition of the curve

being considered of optimal quality. It is also pointed out that the coefficient of variation of the test is considered low (5%), showing that the prospected material has similar characteristics.

3.3.3 *Evaluation of carbonation*

Figure 10 illustrates the specimens that were broken by diametral compression and sprayed with a 1% solution of phenolphthalein.

The observed carbonation front was quantified for correlation with the coating of the investigated rebars of the columns. Despite the variety of presentations, it can be inferred from all the collected data that the carbonation front affected the samples in an interval of 14.78 to 41.96 mm of depth.

3.3.4 *Capillary water absorption tests*

As it can be seen in Fig. 11, there is a great dissonance between CP 8 and the others, showing that it has higher capillary water absorption than the others investigated, besides having higher resistance. It can be noticed that,

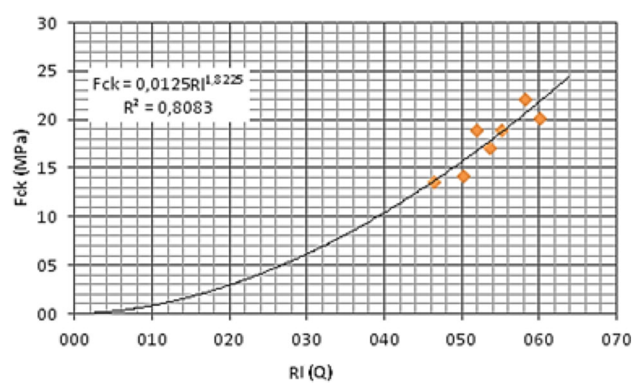

Fig. 9 Correlation curve between characteristic resistance (f_{ck}) and reflex index (RI)

despite the displacement of CP 8 from the others, its data has small variability.

Regarding the characteristics of the specimens, comparing them among themselves, some hypotheses can be formulated:

(a) The CP 8 has higher porosity than the others, since it has high capillary water absorption (3.01 g/cm^2) in comparison to CP 10 (0.62 g/cm^2). It also has

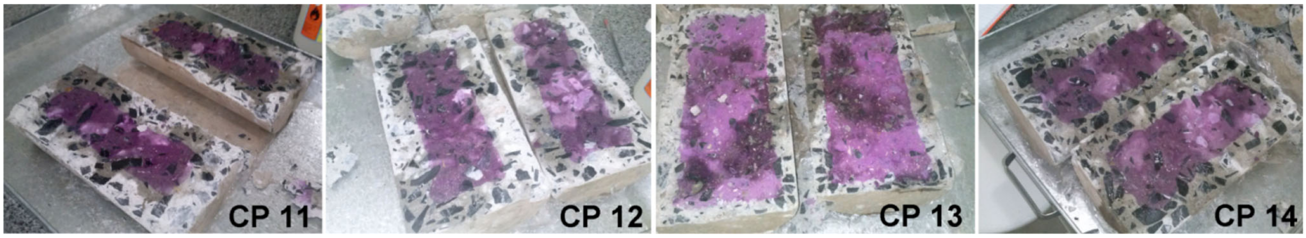

Fig. 10 Specimens exposed to phenolphthalein

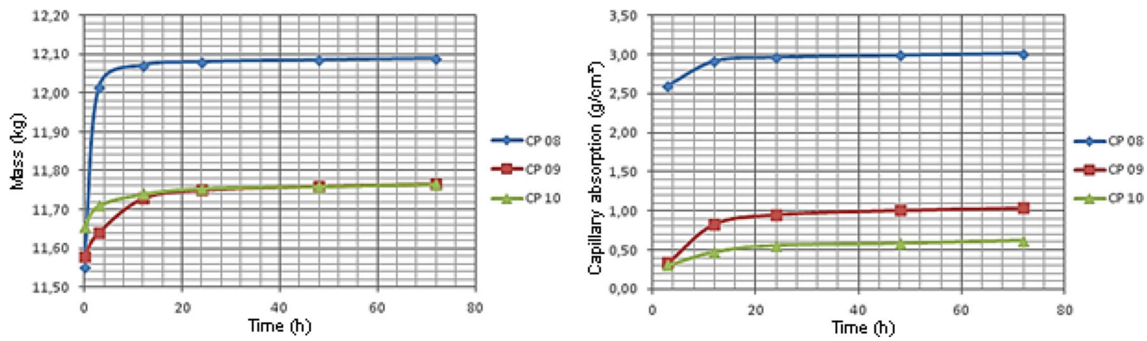

Fig. 11 Evolution of mass × time and capillary water absorption × time

Table 5 Capillary water absorption of the specimens

Element	Time (h)	Capillary water absorption (g/m^2)	Average height (mm)
CP 08	72	30,181.64	32.80
CP 09	72	10,637.78	45.51
CP 10	72	6105.17	8.12

considerable capillary height (32.8 mm), making it possible to infer that it has thin and interconnected pores, being more susceptible to the process of carbonation. It also has the highest resistance to traction (1.9 MPa) among the specimens analyzed in this test;

(b) CP 9, despite having the biggest capillary height (45.51 mm), has the lowest resistance (1.0 MPa). This makes it possible to infer that its pores are smaller, well interconnected; however, some factor influenced its lower resistance to traction, such as the ratio water/cement a bit higher than the others, formation of cement laitance, carbonation in a degree higher than the others, etc.;

(c) CP 10 has considerable resistance to traction (1.7 MPa), nonetheless, lower capillary water absorption and capillary height (8.12 mm). This makes it possible to infer that its pores have bigger diameter a/or little interconnection.

Table 5 shows the results of capillary water absorption:

The literature [22, 23] shows that concretes of 63 days of age have capillary water absorption around 1200 g/m^2 (for concretes with resistances 30 and 60 MPa); pointing out that the higher capillary water absorption can be found at 24 h (5000 g/m^2). With this data, it can be noticed that the capillary water absorption in the specimens and, consequently, the structure, is yet very high, taking into consideration the variability of the data.

4 Conclusion

In the visual inspection, according to Fig. 7, it was verified that the start rebars on ground floor had already deteriorated completely. As for the underground, it was noticed that it is at a lower degree of deterioration than the ground floor, since it is not daily exposed to weather and solar radiation. It was also observed that the corrosion of the rebars destroyed the base of the columns, a very critical region for repairs or therapeutic actions in a visible and severe degree of deterioration.

As for detailed inspection, it can be said about the underground:

(a) Even if the ruling norm at the time of the construction [17], not approaching the concepts of classes of environmental aggressiveness and considering the coating to be way below the recommended by current laws [24], all coatings would fulfill the criteria this time since the coating ranged from 3 to 49 mm, according to what was assessed in the reinforcement locate test;
(b) The depth of the carbonation front measured in the laboratory corroborated the corrosion of the rebars observed on the field, since in accordance to the interval measured in the laboratory, the front affected the rebars, causing depassivation, allowing the corrosion process to begin, as it could be observed during the visual inspection.
(c) These fact can also reinforce the hypothesis that the concrete that was used, respecting the ruling norm at the time or not, wasn't sufficiently resistant to the carbonation front. In some points, the norm permits (if the coating is smaller than the diameter) the use of coatings of the order of 15 mm (internal columns) to 25 mm (for open air apparent concrete—a more aggressive condition if compared to the context of the columns);
(d) The carbonation front measured in the laboratory shows that it wouldn't be affordable to remove the carbonated layer on the field, since it would leave the rebars completely unprotected, as the rebars already have their useful parts compromised by the intense corrosive process;
(e) It is inferred that the analyzed material has high capillary water absorption. From this, it is observed why the base of the columns had suffered a higher action of corrosion than the rebars, because it received corrosive agents through capillary absorption, since these elements were in contact with humidity.

However, to go further with this analysis and make it definitive, it would be necessary to resort to the collection of testimonies, analysis of the project, budget sheets from the time and foundation studies, which would be very informative.

It can be seen through the analysis of information on field inspection and the results of detailed inspection that the reinforced concrete structure did not support the action of the weather and time. The factors that caused the structure came to that decadence are several, such as negligent execution (as seen on the ground floor columns and lack of basement floor of concrete, allowing the elements stay in contact with soil moisture), materials with low technological control, lack of maintenance over time to protect the exposed elements, etc. This work is an example of how much can be harmful ignore concepts like durability and useful life; that errors in the various stages of the work can initiate serious pathological manifestations such as reinforcement corrosion. The pathological manifestations that arise in a given structure are rarely caused by only one factor in isolation. It is a synergistic process, so it is complex, but it is necessary to understand it so durable structures are designed.

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