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Evaluation of Reinforced Concrete Structures with Views for Rehabilitation

Jackline de Assis Lopes S. Oliveira[1], Romildo Alves Berenguer[1], Lydia Barreto[1], Eliana Cristina Barreto Monteiro[1, 2] and Romilde Almeida de Oliveira[1]

1. Department of Civil Engineering, Catholic University of Pernambuco, Recife 51110-200, Brazil

2. Department of Civil Engineering, University of Pernambuco, Recife 51110-200, Brazil

Abstract: The increasing number of pathological occurrences is found in reinforced concrete structures, so does the demand for inspection and maintenance services in residential communities in the state of Pernambuco, which aim to detect damage to the structure in a timely manner to minimize repair costs, thus applying preventive maintenance in order to guarantee the estimated useful life of the project for the building. However, it is observed that the practice of periodic inspections is not yet part of the culture of a certain segment of the population that does not have economic means and knowledge of the importance of maintenance to ensure the integrity of the structure. It was used in this work an inspection script with use of tests and methodology to quantify damage and to check the state of degradation of two residential buildings with more than 20 years and built near the seafront where environmental aggression is strong. The deterioration found in each of the buildings has been differentiated due to different corrective maintenance performed at every building. The last maintenance, performed in Building A, was performed by corrective hand of unskilled labour guided by the community itself, which has no expertise in the field of civil engineering. In Building B, the situation is similar, compounded by the opinion of some tenants that there is no need for this routine, even the structure being in critical condition, as was confirmed with the application of the methodology employ. There should be a legislation that governs the execution of inspections and maintenance programs in addition to the existing technical standards. The methodologies presented suitable for checking the degree of degradation of the structures and performed tests confirmed the diagnosis obtained by visual inspection and quantification of damage.

Key words: Pathology, inspection, maintenance, lifespan, concrete.

1. Introduction

In the MRR (metropolitan region of Recife), several cases of disease and accidents with works of various types have occurred. These facts led to a serious social problem, by virtue of having created one of insecurity and apprehension framework for users of these buildings.

The reinforced concrete structures, even well designed, well executed and with the use of specified materials correctly, require preventive maintenance to achieve the expected lifetime, guaranteed by a durability with performance above the minimum acceptable limit. The current situation requires greater preparation for professionals and public awareness that the concrete structures are not designed for eternity.

In an attempt to increase the life of such structures, research institutions deepened studies on chemical reactions occurring during the hydration of cement, in view of the durability which is also directly connected to the constituents of the mixture (aggregates, cement and steel), the dosage (water/cement ratio, use of additives) and use of this material (density and healing). A maintenance program suited to the structure will increase the life and structural problems detected in its infancy and will have effects, and cost of repairs will lessen buildings.

2. Methodology

The methodology of the concrete deterioration

Corresponding author: Romildo Alves Berenguer, professor, research fields: concrete, corrosion and materials.

study developed by Swedish researcher Tuuti [1] classifies the evolution of corrosion process in two steps of initiation, where aggressive agents penetrate slowly through the concrete microstructure starting the damage and the step propagation, and the structures degradation rate is accelerated by the action of aggressive agents into the concrete, causing the appearance of cracks and loss of cover to the reinforcement and may compromise the stability of the building.

According to research carried out by Klein et al. [2], to works of art, Castro [3] found unfeasible in the proposal when applied to conventional structures. Thus, the methodology proposed by Castro [3] was based on principles contained in Klein's research [2], with adaptations and modifications necessary to quantify the evolution of damage over the life of the structure. There were still changes proposed by Lopes [4] and Boldo [5] and used by Lemos [6] in his dissertation, in order to better represent the damage to the structure. It is noteworthy that there was a concern not to distort the original configuration of the methodology proposed by Castro [3].

The methodology of the identification of pathological manifestations is found in reinforced concrete structures for residential buildings. Searches establish inspection and evaluation procedures of structure by determining the degree of deterioration of the structure and of their individual elements, in order to support maintenance plans of the structures over time.

Symbol meanings can be found as following:

CO_2: carbon dioxide;

SO_2: sulfur dioxide;

H_2S: gas hydrogen sulfide;

$Ca(OH)_2$: calcium hydroxide;

F_p: damage weighting factor;

F_i: damage intensity factor;

D: degree of damage;

M: amount of damage found on the element;

Gde: degree of deterioration of the element;

Gdf: degree of deterioration of the family of an element;

N: number of component elements family;

R_f: factor family relevant structural elements;

Gd: degree of deterioration of the structure;

K: number of families of elements present in the building;

VUE: estimated useful life;

VUR: life reference component.

3. Results (Case Studies)

3.1 Characterization of Respondents Environments

Inspected buildings are residential, aged between 20 and 30 years of built and located in the neighborhood Candeias, Jaboatão dos Guararapes, PE, in marine area of regions whose environmental aggressiveness is Class III, according to Ref. [7].

3.2 Description of the Analyzed Constructions

The first building, known as Building A, which has 20 years of built and a distance of 300 m from the seafront of Candeias, has three floors, type of apartments and the ground. Its facade is originally coated with gum and ground columns covered with tile, which is already part of the community intervention.

At a distance of 100 m from the seafront, the second studied building is located and has 25 years of built. It also consists of three floors and type of ground, used as a garage. This building, named Building B, has the facade coated with ceramic on three of its faces and the last one is only covered with plaster and paint.

3.3 Experiment Planning and Results

3.3.1 Environment Location

The inspected buildings contain three and seven floors, located in environmental aggression Class III, according to the rank [7]. Slabs, beams and reservoirs were inspected building. There were no authorizations for inspection of foundations in the two buildings. Scratch tests, carbonation depth and speed of the ultrasonic pulse on the ground floor (stilts) were performed, where there are the garages of the three buildings. It was difficult for the tests because it is not yet common practice in inspections, using difficulties of some equipment or availability.

3.3.2 Edification A (Visual Inspection)

In Building A, on visual inspection (Fig. 1), we observed detachment of the tablets on the facade, some cracks in the pavement edge beams at the level of infiltration stilts and the ceiling slab from the sanitary system facilities. Condo information was found that there were attempts to fix the leaks, but they did not succeed. Buildings regarding maintenance and condominium realize that information is held whenever it is necessary and possible financially to the tenants.

3.3.3 Carried-Out Tests (Edification A)

3.3.3.1 Test Speed of the Ultrasonic Pulse

In Table 1, the studied columns and their randomly-chosen results are listed, according to Ref. [8].

Despite the observed variation in the results obtained in this test (Fig. 2), the concrete quality is considered good according to the classification of Ref. [9].

3.3.3.2 Sclerometry Tests

Table 2 lists the columns and the results of sclerometry tests to Building A.

3.3.3.3 Carbonation Depth Test

The carbonation depth found in the tested columns of the building (Fig. 3) was small, compared with the result of the two buildings. Table 3 gives the depth of carbonation columns of Building A.

3.3.4 Deterioration Degree of Structure Elements

3.3.4.1 Columns

The building structure consists of 10 columns, in which damage was found in only three of them. With the identified damage, degree of deterioration of the element (the expression Gde_1 being developed by Castro [3] and Gde_2 by Lopes [4]) was calculated. Table 4 shows the conditions found during the inspection.

For this situation, it is observed that the degrees of deterioration of the elements are equal, both in use of

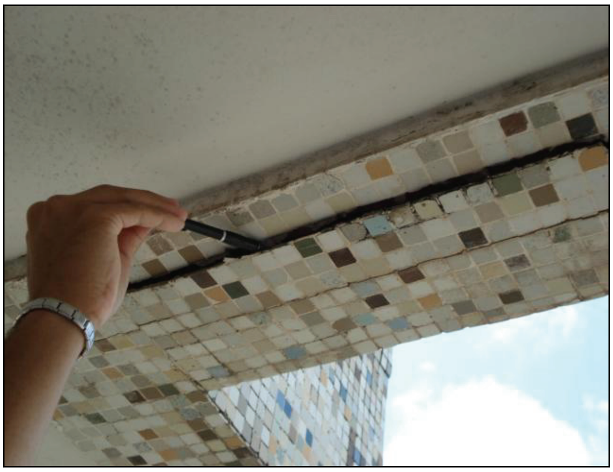

Fig. 1 Fissure in the edge beam of Building A.

Table 1 Speed test of the ultrasonic pulse in Building A.

Column	Speed V (m/s)	Concrete quality
P1	4,050	Durable
P2	3,850	High
P20	4,000	High

Fig. 2 Test speed of the ultrasonic pulse on Column P1 of Building A.

Table 2 Sclerometry test.

Column	Sclerometric index
P1	46
P2	36
P4	30

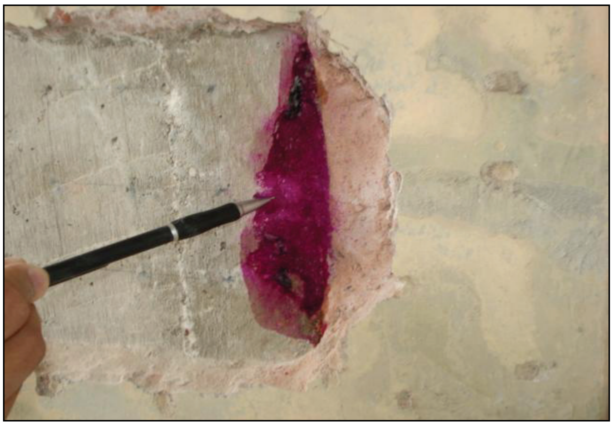

Fig. 3 Carbonation depth test of Column P20 of Building A.

Table 3 Carbonation depth test.

Column	Carbonation depth (cm)	Covering (cm)
P1	0	2
P5	0.1	1.8
P20	0	2

Table 4 Damage assessment and degree of deterioration of the column element.

Column	Damages	F_i	F_p	D	M	Gde_1	Gde_2
P3	Geometric deviation	2	8	6.4	1	6.4	6.4
P5	Segregation	1	6	2.4	1	2.4	2.4
P8	Exfoliation	1	8	3.2	1	3.2	3.2

Fig. 4 Detachment of reinforced concrete beam of Building A.

the formulation proposed by Castro [3] as the proposal by Lopes [4] and as analyzed columns which had only damage. And for the *Gdf*, zero was considered because in none of the columns damage was evidenced with $Gde \geq 15$, which would indicate spread of damage.

3.3.4.2 Beams

Despite showing damage in just two beams, it can be seen in Fig. 4 that intensity damages were considerably high, since equipment corrosion was observed (Table 5).

3.3.4.3 Slabs

As shown in Table 6, the damages found in slabs (Figs. 5 and 6) were punctual but in an advanced state.

3.3.4.4 Reservoir

In the visual inspection and by questioning the residents, there have been no damages to the reservoirs.

3.3.5 Degree of Deterioration of the Structure

Table 7 presents the degree of deterioration of the structure considering the deterioration of each element and the factor of structural importance.

Table 5 Damage assessment and degree of deterioration of the beam element.

Beams	Damages	F_i	F_p	D	M	Gde_1	Gde_2
Right side	Exfoliation	2	8	6.4	1	6.4	6.4
Staircase	Exfoliation	3	8	32	2	32	46.93
	Corrosion	3	7	8			

Table 6 Damage assessment and degree of deterioration of the slab element.

Damages	F_i	F_p	D	M	Gde_1	Gde_2
Disabled coverings	2	6	4.8	4	28.8	33.03
Corrosion	2	7	5.6			
Infiltration	3	6	24			
Efflorescence	2	5	4			

Fig. 5 Efflorescence on slab of Building A.

Fig. 6 Corrosion of slab reinforcement of Building A.

Table 7 Degree of deterioration of the structure of Building A.

Family	Gdf_1	Gdf_2	Gdf_3	F_r	K	Gd_1	Gd_2	Gd_3
Columns	-	-	-	5	2	31	40	40
Beams	32	47	47	4				
Slabs	29	33	33	4				
Lower Reservoir	-	-	-	3				

Gdf_1: calculation by the term used by Castro[3];
Gdf_2: calculation by the term used by Lopes [4];
Gdf_3: calculation by the term used by Boldo [5];
Gd_1: *Gd* calculation by the term used by Castro [3];
Gd_2: *Gd* calculation by the term used by Lopes [4];
Gd_3: *Gd* calculation by the term used by Boldo [5].

Fig. 7 Beam reinforcement corrosion with section loss in Building B.

3.3.6 Edification B (Visual Inspection)

Through visual inspection (Fig. 7), some conditions were observed in Building B that require immediate interventions, in order to minimize damage to the stability of the building. Infiltrations on stilts ceiling slab come from sanitary system facilities, corrosion of reinforcement comes in slabs, columns and beams in some cases at an advanced stage. There is also detachment of ceramic plates on the facade among other pathologies. It was also observed that the maintenance services and repairs are carried out improperly. It was found that part of the shareholders do not agree with the need for periodic maintenance.

3.3.7 Carried-Out Tests (Edification B)

3.3.7.1 Speed Test of the Ultrasonic Pulse

Table 8 shows that the inspected columns were randomly selected and their results are related to ultrasound testing.

Despite the observed variation in the results of this test, the quality of the concrete is considered good according to Ref. [9].

3.3.7.2 Sclerometry Test

Table 9 lists the columns and the results for the sclerometry test.

3.3.7.3 Carbonation Depth Test

Columns P4, P9, P13, P18 were tested, although the ultrasonic testings have characterized these concrete columns and durable high quality carbonated surface was found, as shown in Table 10.

Despite the variation found in coatings, we can see that work performance according to Ref. [10] in force

Table 8 Speed test of the ultrasonic pulse.

Column	Speed V (m/s)	Quality of concrete
P9	4,045	Durable
P13	3,600	High
P18	4,060	Durable
P20	3,950	High
P23	4,060	Durable
P22	3,670	High

Table 9 Sclerometry test.

Column	Sclerometric index
P4	45
P9	41
P13	23
P18	33
P20	36
P23	40
P22	15

Table 10 Carbonation depth test.

Column	Carbonation depth (cm)	Coverings (cm)
P4	2	2
P9	1.5	1.5
P13	> 2	2
P18	1.5	1.5

Fig. 8 Detachment column due to reinforcement corrosion.

at the time recommends coatings (least 1.5 cm) for reinforced concrete subjected to aggressive environments in Class III. And even with the recommended coatings, it can be seen that the carbonated thickness reaches the reinforcement (Fig. 8).

3.3.8 Quantification of Damage

3.3.8.1 Deterioration Degree of Structure Elements

(1) Columns

Table 11 presents the damage found in 22 of the 24 columns of Edification B. Analyzing the found data, it observes 41 kinds of damage to the columns.

(2) Beams

Table 12 shows the damages found in the beams of Building B (Fig. 9), where Gde_1 and Gde_2 are expressions used by Castro [3], Lopes [4] and Boldo [5], respectively.

(3) Slabs

During the inspection, infiltration of the slab from the sanitary system facilities was observed, where they are presented in Table 13.

(4) Lower Reservoir

To the found lower reservoir, the damages are listed in Table 14.

Table 11 Damage assessment and degree of deterioration of the column element.

Column	Damages	F_i	F_p	D	M	Gde_1	Gde_2
P1	Gap	2	10	8	1	8	8
P2	Gap	2	10	8	1	8	8
P3	Gap Exfoliation	2 3	10 8	8 32	2	32	38
P4	Carbonation	2	7	5.6	1	5.6	5.6
P5	Exfoliation	2	8	6.4	1	6.4	6.4
P6	Segregation Corrosion Coatings insufficient	2 3 2	6 7 6	4.8 28 4.8	3	32.8	35
P7	Exfoliation Segregation	2 1	8 6	6.4 2.4	2	6.4	8
P9	Carbonation	3	7	28	1	28	28
P10	Exfoliation Corrosion	3 2	8 7	32 5.6	2	32	37
P13	Carbonation Gap	2 1	7 10	5.6 4	2	5.6	7.9
P14	Exfoliation	3	8	32	1	32	32
P16	Gap	4	10	100	1	100	100
P17	Exfoliation	2	8	6.4	1	6.4	6.4
P18	Carbonation	3	7	28	1	28	28
P19	Exfoliation Corrosion	3 3	8 7	32 28	2	32	47
P21	Exfoliation	3	8	32	1	32	32
P22	Gap	1	10	4	1	4	4
P23	Exfoliation	3	8	32	1	32	32
P24	Exfoliation Corrosion	3 4	8 7	32 70	2	70	70

Gde_1: *Gde* calculation by the term used by Castro [3];
Gde_2: *Gde* calculation by the term used by Lopes [4] and Boldo [5].

Table 12 Damage assessment and degree of deterioration of the beam element.

Beams	Damages	F_i	F_p	D	M	Gde_1	Gde_2
Bottom	Deficient coating Exfoliation Segregation Corrosion	2 3 1 4	6 8 4 7	4.8 32 1.6 70	4	82.8	94.79
Left side	Deficient coating Exfoliation Segregation Corrosion	2 3 1 4	6 8 4 7	4,8 32 1,6 70	4	82.8	94.79
Right side	Exfoliation Cracks Segregation	2 4 2	8 10 4	6.4 100 3.2	3	104.8	108.8
Front	Deficient coating Corrosion	3 2	6 7	24 5.6	2	24	28.54

Fig. 9 Stirrup of the exposed beam, with corrosion, in Building B.

Table 13 Damage assessment and degree of deterioration of the slab element

Damages	F_i	F_p	D	M	Gde_1	Gde_2
Coverings disabled	2	6	4.8	3	29.2	31.25
Corrosion	2	7	5.6			
Infiltration	3	6	24			

Table 14 Damage assessment and degree of deterioration of the reservoir element.

Damages	F_i	F_p	D	M	Gde_1	Gde_2
Waterproofing damage	2	8	6.4	2	8	11.55
Leak	2	10	8			

Table 15 Deterioration degree of structure of Building B.

Family	Gde_1	Gde_2	Gdf2	F_r	K	Gd_1	Gd_2	Gd_3
Columns	41	46	180	5	3	47	52	134
Beams	74	82	181	4				
Slabs	29	31	31	4				
Lower Reservoir	-	-	-	3				

3.3.9 Deterioration Degree of Structure Elements

In Table 15, the degree of deterioration of the structure of Building B is listed.

4. Results and Discussions

4.1 Visual Inspection

Although the recognition of the importance of maintaining the durability of reinforced concrete structures is growing, we observed the development of this research to give effect to the maintenance of buildings, and there is a need to create appropriate legislation.

By visual inspection, following the recommendations of the "checklist" developed by ABECE (Associação Brasileira de Engenharia e Consultoria Estrutural) [11], it was observed that the three structures are studied for wear at different points, the columns and the most deteriorated element of Building B, which has the columns coated with ceramic, thus providing greater physical protection to aggressive agents.

It was observed that damage, such as cracks, corrosion and leaks, performed more strongly in buildings, and the Building B was the most affected, with a critical situation. The Building A showed medium deterioration levels.

The last maintenance, performed on Building A, was corrective, performed by unskilled labor and driven by the condominium itself. In Building B, the situation is similar, compounded by the opinion of some tenants that there is no need for this routine, even the structure lying in critical condition, as was confirmed by the application of the methodology.

4.2 Tests

In an attempt to better characterize the structure, scratch tests, ultrasound and carbonation were used. In the sclerometry test, there was variability of the results, which were affected by phenomena, such as carbonation, roughness and moisture that existed in the tested parts.

Through the quality of the ultrasonic test of the concrete, buildings were classified into durable and high, these results being justified by the fact that such test pieces did not show pathology.

For the carbonation test, it was observed that the two buildings showed contamination by carbon dioxide, but only in the last Building B reached the rebar, allowing the development of corrosion of the same process.

4.2.1 Degree of Deterioration of Structures

It is possible to see variation in results between the degrees of damage of the structures of buildings. In Table 16, we observe the marked differences, despite being in areas of environmental aggression classes similar construction and having the same patterns. Also the need to conduct a greater number of tests and samples to set the parameters is considered.

For Gd = 30, using the methodology [3] found in Building A, it is considered that the structure has a medium level of deterioration, necessitating periodic observation and short-term intervention. Using the expression of Ref. [5], Gde = 40 was found, which falls into the same situation with short-term intervention recommendations, at most one year. Through inspection and analysis in Building B, Gd = 39 has been found, according to Ref. [3] and Gd = 125 according to the recommendations of Ref. [5]. For Gd = 39, the measure to be taken is the periodic observation with intervention in the medium term. And when Gd = 125, immediate intervention is needed to restore the building functionality.

The factor method [12] allows us to estimate the useful life of a component or component family. The starting point of factor method is the life of reference (VUR), equivalent to the lifespan of the project, which is the period in years, in which it is expected that a component or group of components can last. The method uses a set of seven factors that weigh the quality parameters related to the construction and use of the building. Each of these factors has a value of 0.8 to 1.2.

The service life is estimated by the following VUE (estimated useful life) equation:

$$VUE = VUR \times A \times B \times C \times D \times E \times F \times G \quad (1)$$

where:

Factor A: component quality;

Factor B: project level;

Factor C: project execution level;

Factor D: internal setting;

Factor E: external setting;

Factor F: terms of use;

Factor G: maintenance level.

4.2.2 Estimated Useful Life for Buildings A and B

For the accessible structural component, VUR = 50 shall be considered, for being the presumed value in Ref. [7] with the adopted safety factors. Table 17, used in all three cases of this work, contains the values adopted for the factors.

Therefore, the estimates of service life for Buildings A and B are resulted lower than the design life.

There is:

- Building A:

$$VUE = VUR \times 0.8 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 0.8 = 0.64 VUR \text{ (years)}$$

Considering VUR = 50 years for three cases, it is VUE = 32 years;

- Building B:

Table 16 The damage degree of comparison between the surveyed buildings.

Surveyed building	Gd_1	Gd_2	Gd_3
Building A	31	40	40
Building B	47	52	134

Table 17 The factors used in Buildings A and B.

Class of factors	Factor characteristics	Value factors	
		Building A	Building B
A	Component quality of reinforced concrete: fck = 15 MPa	0.8	0.8
B	Design level: normal	1.0	1.0
C	Labor execution level: concrete taken from the place without control	1.0	0.8
D	Aggressive internal environment influence of wastewater, high humidity	1.0	1.0
E	External environment: marine environment	1.0	0.8
F	Conditions of use: normal	1.0	1.0
G	Maintenance level: nonexistent	0.8	0.8

VUE = *VUR* × 0.8 × 1.0 × 0.8 × 1.0 ×0.8 × 1.0 × 0.8
= 0.41VUR (years)
VUE = 21 years

5. Final Considerations

The obtained results show the following conclusions:

- It can seen that the "evaluation" developed by ABECE [11] is perfectly functional and effectively serves as inspection checklist;
- The methodologies presented suitable for the verification of the degree of degradation of structures and the performed tests confirmed the diagnosis obtained by visual inspection and quantification of damages;
- There was a need to create an enlightening information of importance and execution of the maintenance program with language directed to the end user, emphasizing their importance;
- It is noted that the Building A showed the lowest degree of deterioration in the structure and the Building B had the greatest degree of deterioration, presenting critical condition. This could also be seen through the factor method.

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