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Diagnosis of Pathological Manifestations and Service Life Estimation of Reinforced Concrete Structures of Water Reservoirs with Different Ages: Case Study

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ABSTRACT

The lack of preventive maintenance is one of the major factors contributing to the deterioration of concrete structures in the metropolitan area of Recife (RMR). It was not different from what happened to the three reservoirs of the Pernambuco Sanitation Company (Compesa), located on Rua da Mata, Dois Unidos, Recife (PE), Brazil. The lack of preventive maintenance and the high content of chloride ions added to drinking water treatment that acts as a catalyst for the deterioration of these structures contribute to the emergence of different pathologies. It was proposed by the authors based on the pathological manifestations to compare the diagnoses of each of these reservoirs of different ages estimating the service life using the Factor Method [ISO 15681:1] and an alternative equation, as well as indicate the best way to repair these structures.

KEYWORDS

Reservoirs, Concrete, Pathologies, Diagnoses, Service life.

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1 INTRODUCTION

Climates changes are critical for the good performance of structures. It is understood that compatible materials and specialized personnel together with the climatic conditions of exposure of these structures lead to the planned durability and service life design. However, pathologies in reinforced concrete structures still remain a topic of relevant discussions. Sitter [1983] shows the importance of paying attention to quality in the stages of design, construction and preventive maintenance during the corrosion initiation period in relation to corrective maintenance taken during the propagation period.

In this context, several studies have been developed in order to improve the durability and service life of concrete structures. Saffarini and Samra [2001] used the calcium nitrite as an inhibitor and retarder of corrosion rate after initiation, as well as the hydrophobic pore blocker in the repair of concrete structures in marine environment in Jordan. Castro et al [2007] contributed to the improvement of the estimation of service life of concrete structures from C_s values (concentration of chloride ions on the surface) in the marine environment. In Brazil, studies of Medeiros [2008], Hoppe and Son [2008] refer to the control of the stages of planning/execution of structures, with investigative methods for identification and maintenance of pathology. Cascudo [2001] focuses on the materials and their interaction in concrete and environment of exposure. In the city of Recife some relevant studies involving pathologies theme in concrete structures were developed, particularly:
1. Andrade [1997] in his dissertation, researched the most common manifestations encountered in reinforced concrete structures, as well as practiced forms of repairs. This study found that the columns, followed by beams and slabs were the most affected due to reinforcement corrosion, associated with the effects of structural applications. The occurrences of the manifestations were interrelated with inadequate procedures during the phases of the constructive process: planning/design and implementation;
2. Carneiro [2004] has contributed to a further intervention and restoration of bridges presenting a map of deterioration and improvements necessary to compensate degradation effects);
3. Oliveira et al [2008] presented a methodology to quantify damages, check-list and the use of tests to verify the state of deterioration of reinforced concrete and estimate service life of three residential building;
4. Mota et al [2009] performed an investigation on reinforced concrete elements on the seafront using the analysis of the deterioration level established by the CEB Bulletin 162 [1983], suggesting the need for immediate intervention. A feature of the mentioned studies was the disposal of the structures in environments near the sea with aggressive agents, specifically chloride ions, interfering on durability and service life.

Unlike conventional structures that tend to deteriorate due to environmental exposure, and the action of agents from external to internal area. The water reservoirs were designed to be continuously in contact with aggressive materials, because its stored water has a significant concentration of chloride used for water treatment. In this case, the aggressive action tends to occur in the opposite direction.
Thus, this paper presents a diagnosis pertaining to the manifestations and analysis of service life in water reservoirs located in a distribution unit of the Pernambuco Sanitation Company (Compesa), in Recife (Brazil).

2 EXPERIMENTAL PROCEDURES

For the diagnosis of pathologies in the reservoirs some procedures were established, namely: 1. survey in the outer area (mainly in direct contact with the sun, rain and wind) and internal structures (mostly protected from the sun, rain and wind); 2. physical characterization of the elements from visual inspection by means of photographic records and follow-up form indicating the level of concrete deterioration, the latter based on the CEB Bulletin 162 [1983]; 3. characterization of mechanical and chemical properties from the following tests: sclerometric examination, depth of carbonation, crack mapping, location of the reinforcement and testing of electrochemical potential; 4. estimated service life calculated by the Factor Method [ISO 15686-1] and an alternative equation, taking as parameters design life according to BS 7543 [1992]. At this stage, the effects of aggressive agents begin to manifest, as cracking of concrete, by chemical attack or stains due to corrosion of reinforcement.

For this study two types of tests were conducted, namely:

a) destructive tests: carbonation [RILEM CPC 18] and corrosion potential [ASTM C87/87];

b) non-destructive testing: checking the position and density of the rebars with pacometer [NBR 6124/80], [ACI 228 2R-98]; sclerometry [NBR 7584/95], [ASTM C 805], [ACI 228.1R- 98] and measurement of CO_2.

2.1 Characterization of environmental exposure of the researched structures

The region where the three reservoirs of this study is found has a rugged topography, altitude of 69 m, of difficult access, with narrow streets and closed vegetation in their surroundings. According to NBR 6118 [2003] the aggressive environment is Class IV due to the purpose of the building. The structures of the reinforced concrete reservoir are located in the community of Alto do Céu, located at Rua da Mata, in the neighborhood of Dois Unidos, Recife (PE), see 'Figs. 1 and 2 '. The location coordinates of the area are 7,9958^{0}S e 34,9156^{0}O.

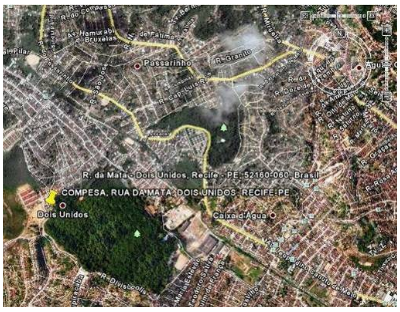


Figure 1. Location of the reservoirs. Source: Google Earth [2010].

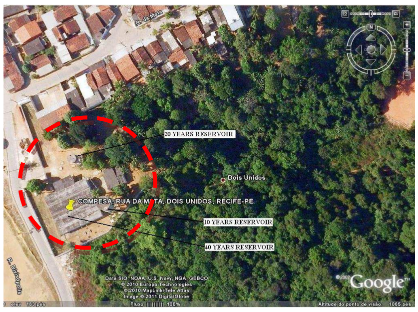


Figure 2. Location of the reservoirs (dashed area). Source: Google Earth [2010].

2.2 Description of the inspected reservoirs

Three reinforced concrete reservoirs were analyzed, aged 10, 20 and 40 years. The purpose of the reservoirs 10 and 20 years is the accumulation of water with subsequent distribution to the community around, while the 40 years reservoir is responsible for chlorination and supplying the other two. The 10 years old reservoir is composed by a reinforced concrete tank supported by six columns and both having a protective paint applied on them. The 20 years old reservoir is composed by reinforced concrete and has its tank also supported by six columns, however, visually more deteriorated than the previous one. Its surface has cement rendering layer and a much worn painting. The 40 years old buried water reservoir is composed by a reinforced concrete tank, presents painted mortar coating facades. Both inside and outside the reservoir the covering and lime paint are similar. There is no record of repair or any kind of intervention in the concrete structures inspected. Also, there was nor neither information regarding the construction process adopted at the time that it was built nor information of its structural design.

3 INSPECTIONS AND REPORT

3.1 Ten year old reservoir

3.1.1 Visual Inspection

The pathological manifestations present in this reservoir were minimal, some points of stains, mud and water infiltration were identified. Columns were in perfect conditions of exposure

3.1.2 Sclerometric test

The compressive strength test was estimated at three columns of this reservoir, respectively: 39.7 MPa, 35.1 MPa and 38.2 MPa, with a mean value of 37.7 MPa.

3.1.3 Concentration of CO_2.

Two concentration measurements of carbon dioxide (CO_2) were performed near the reservoirs, with the following results: 287 ppm and 237 ppm.

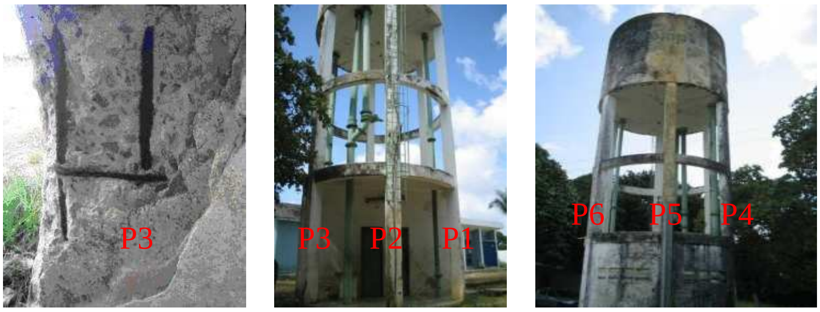
3.1.4 Level of concrete deterioration

During the investigation of the columns, it was observed that the level of deterioration in the scale of the CEB [1983] was "A".

3.2 Twenty years old reservoir

3.2.1 Visual Inspection

It was observed in the columns, cross-section reduction of the reinforcement bars, stains and sludge on the surrounding of the reservoir, see 'Figs. 3 a, b and c'.



(a) (b) (c)

Figure 3.Visualization of pathologies from the 20 years old reservoir structure.

3.2.2 Sclerometric test

The rebound hammer had an index below 20, presenting a separated concrete layer near the surface with fissures.

3.2.3 Concentration of CO_2

Four concentration measurements of carbon dioxide (CO_2) were performed near the reservoirs, with the following results: 355 ppm, 361 ppm, 337 ppm and 322 ppm, with an average of 343.75 ppm.

3.2.4 Carbonation test

The tests were performed with phenolphthalein in columns P1, P2 and P3 showing carbonation depth, 4.46 cm, 4.74 cm and 2.20 cm, respectively. All bars have started the process of corrosion due to carbonation.

3.2.5 Electrochemical Potential

The test was carried out at the columns P1 (- 236 mV), P2 (- 275 mV) and P3 (- 271 mV), and according to standard [ASTM C 876 / 87] the probability of corrosion was uncertain. It is important to note that the visual analysis showed that the corrosion process had already started.

3.2.6 Level of concrete deterioration

The classification levels of the concrete deterioration of the columns P1, P2 and P3 were D, C and D, respectively, requiring immediate intervention [CEB 1983].

3.3 Forty years old reservoir

3.3.1 Visual Inspection

It was observed small cracks in the coating, stains, sludge and mould on painting outside the reservoir. In the inner area mould stains, detachment of the plaster coating, exposing the masonry covering, and the arch beam with loss of section of the ties, and probably of the main reinforcement bars were visible, 'Figs. 4 a and b '.

(a) (b)

Figure 4. deteriorated components.

3.3.2 Sclerometric test

The columns P1 and P2 on the outer surfaces showed average compressive strength 45.5 MPa and 36 MPa, respectively.

3.3.3 Carbonation test

Column 1 showed an almost imperceptible level of carbonation. However, the P2 had average carbonation depth of 8.5 mm, average cover thickness of 1.9 cm and average reinforcement cover of 3.2 cm 'Fig 5 '.

3.3.4 Electrochemical Potential

The average electrochemical potential of the external columns P1 and P2 were -271 mV and -332 mV, respectively. Again, the visual analysis showed that the corrosion process had already started, as shown in 'Figure 6 '.

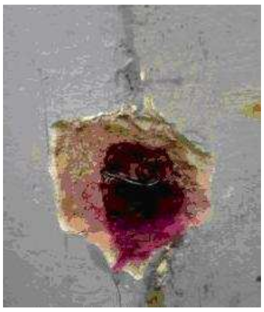


Figure 5. The color shows the carbonation of concrete in column P2.

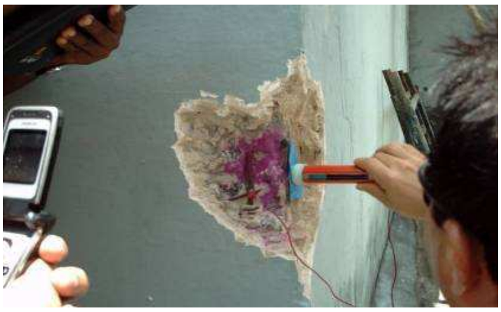


Figure 6. Application of the positive electrode on the face of wet concrete and connected to negative reinforcement in the column P1.

3.3.5 Level of concrete deterioration

According to the CEB [1983], the levels of deterioration of the concrete columns P1 and P2 were evaluated as A. The interior of the reservoir has also been investigated and classified as D.

4. SERVICE LIFE ESTIMATES OF THE RESERVOIRS

The service life estimations (VUE) of the respective reservoirs were calculated using the Factor Method equation [ISO 15.686-1:2000] and the alternative service life equation developed by Zarzar [2007] using multiple linear regression, taking as parameters a reference service life (VUR) = 60 years according to BS 7543 [1992], and using values of minimum and maximum factors of 0.8 to 1.2 a range of [ISO 15.686-1:2000].

Service life equation of Factors Method: **VUE= VUR×A×B×C×D×E×F×G**

Alternative service life equation:
$$\hat{Y}(VUG) = VUR\times(-5{,}72 + 0{,}358\times A + 0{,}797\times B + 1{,}40\times C + 1{,}23\times D + 0{,}976\times E + 0{,}777\times F + 1{,}59\times G)$$

Substituting the factors values in both equations the desired estimate is obtained [Table 1, Table 2].

Table 1. Factor values to estimate the service life of the 10, 20 and 40 years old reservoirs.

	Reservoir of tem years	
Factor Classes	*Factors features*	*Factor values*
A	Quality of the component: reinforced concrete, fck estimated at 37.7 MPa.	1,1
B	Design level: good.	1,1
C	Work execution level.	1,0
D	Indoor environment: very moist, subjected to the action of chlorides.	0,8
E	Outdoor environment: wet, subjected to the action of chlorides and carbonation. No protection against wind, sun and rain.	0,9
F	In-use conditions: normal (for the reservoir).	1,0
G	Maintenance leve: bad.	0,8
	Reservoir of 20 years	
Factor Classes	*Factors features*	*Factor values*
A	Quality of the component: reinforced concrete, fck estimated at 15 MPa; (This was the average value thirty years ago according to NB-1[1978]).	0,8
B	Design level: inadequate reinforcement cover.	0,8
C	Work execution level.	0,9
D	Indoor environment: very moist, subjected to the action of chlorides.	0,8
E	Outdoor environment: wet, subjected to the action of chlorides and carbonation. No protection against wind, sun and rain.	0,9
F	In-use conditions: normal (for the reservoir).	1,0
G	Maintenance leve: bad.	0,8
	Reservoir of 40 years	
Factor Classes	*Factors features*	*Factor values*
A	The columns P1 and P2 have average compressive strength of 45.5 MPa and 36 MPa in the external sides, respectively.	1,1
B	Design level: inadequate reinforcement cover.	0,8
C	Work execution level.	0,9
D	Ambiente interno: muito úmido, sujeito a ação dos cloretos.	0,8
E	Outdoor environment: wet, subjected to the action of chlorides and carbonation. No protection against wind, sun and rain.	0,9
F	In-use conditions: normal (for the reservoir).	1,0
G	Maintenance leve: bad.	0,8

Table 2. Results of the service lives analyses, using both equations.

	10 years reservoir	20 years reservoir	40 years reservoir
Service life (FM)	41.8	19.9	27.4
Service life (**Ŷ(VUG)**)	51	21.8	28.3

5. REPAIR RECOMMENDATIONS

From the structural components analyzed and considering the data studied herein, the following major restoration work for each structure is suggested:

5.1 Reservoir of 10 years

The structure shows no significant damage, visually detecting stains. It is worth mentioning the need for developing and implementing a regular maintenance plan, since the reinforcement cover does not meet the specifications of ISO 6118. For the slab, the implementation of sealing is recommended.

5.2 Reservoir of 20 years

The deteriorated structured presented rust stains, loss of cross-sections bars around 25% and longitudinal cracks in beams and columns. According to Ripper [1998] strengthening of the reinforcement bars is recommended when loss of steel reinforcing bars is greater than 15%. However, this value is arguable for more serious cases. The recommendation is to structurally reinforce the steel bars that showed loss of cross-section in the columns and beams and follow the procedures in the literature, in particular Ripper [1998] and Helene [1992]. For the slab, which is less deteriorated, it is recommended an application of sealing and an appropriate maintenance plan, see 'Figs. 3b and c'.

5.3 Reservoir of 40 years

The external investigated columns showed no need for intervention. However, visual inspection of the inner area showed the need for further investigation, and likely, prompt intervention followed by structural strengthening. Because of the chlorination of water, the reservoir has high levels of chloride which leads to reinforcement corrosion. For the arched beams in the inner side, structural strengthening of the deteriorated structured with materials resistant to chloride ions is recommended. The implementation of sealing and an appropriate maintenance plan are also necessary.

6 FINAL CONSIDERATIONS

Some considerations about the investigation:

1. The design of structures should foresee the aggressive environment, since the reservoirs are kept constantly in contact with water and chlorine;
2. Until now maintenance plans were not known or implemented, which shows the vulnerability of the structures along the lifetime;
3. The maintenance plan becomes necessary in all reservoirs in view of the aggressive agents to which the structures are exposed. A consistent plan would provide appropriate designs to the in-use characteristics of the structures;
4. The concrete structures were not suitable to the aggressive environment. Other materials with better compatibility to the deteriorative environment could provide greater durability and performance;
5. The diagnosis results were divergent in the reservoir of 20 years. While the test showed electrochemical potential uncertainty of the corrosion process, the table of the CEB [1983] identified the need for immediate intervention. However, it did not invalidate the study, since the worst case was adopted;
6. The real service lives were consistent with the calculated ones using both methods (Factor Method and the alternative equation). The elements of the reservoirs of 20 and 40 years should have been repaired in the estimated ages of 19.9 and 27.4 years respectively. The estimated service life calculated for the elements of the reservoir of 10 years presented a service life of 41.8 years due to the present conditions of exposure. In summary, it was shown that service life was less than the design service life, given the conditions of planning, quality of materials, performance and exposure to aggressive environment; In summary, it was shown that service life was less than the design service life, given the conditions of planning, quality of materials,

performance and exposure to aggressive environment. The study was considered relevant, proposing further analysis with other types of tests (considering the microstructure and macrostructure of materials) and larger number of samples including other structural elements. However, the actual recovery of these structures will depend on their costs in comparison with the cost of a new structure.

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REFERENCES

ACI 228-1R-03, *In-Place Methods to Estimate Concrete Strength*. Reported by ACI Committee 228.
ASTM C 805/C 805M – 08, Standard Test Method for Rebound Number of Hardened Concrete.
ASTM C 805. 2008, *Standard Test Method for Rebound Number of Hardened Concrete*. West Conshocken.

American Society for Testing and Materials. 1991, *Standard test method for half-cell potencials of uncoated reinforcing steel in concrete*. In: *Anual Book of ASTM Standards*. V.04.02, p. 429-4333.ASTM C 876-87. Philadelphia.

Andrade, J.J. 1997, *Durabilidade das estruturas de concreto armado: análises das manifestações patológicas nas estruturas no Estado de Pernambuco*. Porto Alegre: UFRGS. Dissertação (Mestrado em Engenharia Civil), 148p.

Carneiro, A. 2004, *Inspeção nas pontes da cidade do Recife. Relatório Técnico – Prefeitura da Cidade do Recife*. Recife- PE. 228p.

Helene, P. R. L. 1992, *Manual de Reparo, Reforço e Proteção de Estruturas de Concreto*. São Paulo: PINI.

Hoppe Filho, J. 2008, *Sistemas cimento, cinza volante e cal hidratada mecanismo de hidratação, microestrutura e carbonatação de concreto*. São Paulo: EPUSP.

International Standard 2000, *Building and constructed assets – Service life planning – Part 1: General Principles.* ISO 15686-1: 2000.

Mota, J. M. F. , Pontes, R. B., J. A. Candeias Neto, M. F. Oliveira, H. T. Almeida, A. M. P. Carneiro 2009, *Análise das patologias em estruturas de concreto na zona litorânea da cidade do Recife*-PE.

Medeiros, M. H. F., Helene, P. 2008, *Estimativa da elevação da vida útil do concreto armado através do coeficiente de difusão de cloretos*. São Paulo: EPUSP.

NBR 6118/2003 - *Projeto de Estruturas de Concreto*.

NBR 6124/1980 – *Determinação de Elasticidade, Carga de Ruptura, Absorção de Água e da Espessura do Cobrimento em Postes e Cruzetas de Concreto Armado – Método de Ensaio*.

NBR 7584/1995 - *Concreto endurecido - Avaliação da dureza superficial pelo esclerômetro de reflexão*.

Oliveira, J. A. L. S.; Zarzar, F. C. J.; Oliveira, R. A.; Monteiro, E. C. B. 2008, *Avaliação de estruturas de concreto armado com vistas à reabilitação*. Universidade de Aveiro, Portugal.

RILEM - CPC 18. 1988, *Measurement of hardened concrete carbonation depth*, 1988.

Ripper, T. & Souza, V. C. M. 1998, *Patologia, Recuperação e reforço de estruturas de concreto*. Ed. PINI, São Paulo.

Sitter, W. R. 1983, *Costs for Service Life Optmization the "Law of Fives"*. Comite Euro International du Beton – CEB. Boletim Técnico. Copenhagen, Denmark, n. 152, p. 131 - 134.

Standard Test Method for Half Cell. 1987, *Potential of Uncoated Reinforcing Steel in Concrete* ASTM Designation C 876.

Zarzar, Fuad C. J. 2007, *Metodologia para estimar a vida útil de elementos construtivos, baseada no método dos fatores*, Recife (PE): UFPE. Dissertação de Mestrado em Engenharia Civil.