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Air-conditioning supports for buildings: Challenges for a sustainable city

Wildson Wellington Silva
Master's student, UPE, Brasil.
wildsonws@gmail.com

Willames de Albuquerque Soares
Professor PhD, UPE, Brasil.
was@poli.br

Eliana Cristina Barreto Monteiro
Professor PhD, UPE, Brasil.
eliana@poli.br

SUMMARY
With the advancement of technology and the increase in global temperatures, there has been a demand for individual and collective cooling systems in residential and commercial buildings, leaving air conditioning equipment and their respective supports exposed on their facades. The objective of this study is to evaluate the degradation of reinforced concrete supports in a case study. It was found that 49.5% of the buildings have supports for air conditioners in the external area of their facades and of these 69% are reinforced concrete. From the aerial images it was possible to observe cracks in 90% of the supports and 21% presented partial collapse of the structure. It is concluded that the failure in the design of the reinforced concrete support without giving importance to the minimum requirements of coverage and quality control in the manufacture of concrete, are decisive in the increase of porosity and the entry of aggressive agents. The low useful life of these supports is associated with the risk of serious or fatal accidents with the fall of parts of these structures and leads to frequent replacement, demanding more cement consumption and more construction waste.

KEYWORDS: Corrosion of reinforcement. Durability of concrete. Service life. Construction waste.

1 INTRODUCTION

Buildings require cooling equipment, and it's common to install supports for air conditioning units on their facades. Among the types of materials used, reinforced concrete, metal, plastic, and fiberglass can be highlighted. These materials are subjected to various weather conditions such as sunlight, rain, wind, pollution, and animal waste.

Concrete has degradation mechanisms that prevent a longer service life, such as leaching, sulfate expansion, alkali-aggregate reaction, as well as reinforcement corrosion processes due to carbonation and chloride ion action, exacerbated by the environmental aggressiveness class. According to Bertolini (2010) and Almeida and Sales (2018), three aspects related to the region and its microclimates are decisive in this degradation: relative humidity, marine atmosphere, and population centers, which are influenced by rainfall and winds.

This study addresses the pathological manifestations of reinforced concrete supports in a case study of a building located in a coastal region, characterized by higher levels of environmental aggressiveness.

High concentrations of relative humidity facilitate the transmission of chlorides within the concrete. An analysis was conducted varying the humidity from 20% to 100%, and it was identified that higher relative humidity leads to higher chloride concentrations and a subsequent increase in chloride ion diffusion depth, expanding by up to 4.3 times (JIN et al., 2022). Humidity levels above 70% enable chlorides to be present as a saline solution rather than in crystalline form (CASTAÑEDA et al., 2018).

With the increase in temperature, the transmission and depth of chloride diffusion are accelerated within the concrete, with a temperature rise from 5°C to 65°C, the chloride diffusion depth expands by 3.3 times (JIN et al., 2022).

Rain has a cleansing characteristic, as the intensity of rainfall increases, there is a reduction in chloride ions on the concrete surface. With longer durations of rain, the depth of access into the interior of the concrete is greater, leading to a more profound reduction of chloride ions. Higher rainfall intensity amplifies the potential damage to the porous structure. In drier concrete, rainfall permeability is greater, resulting in a reduced concentration of chloride ions (JIN et al., 2021).

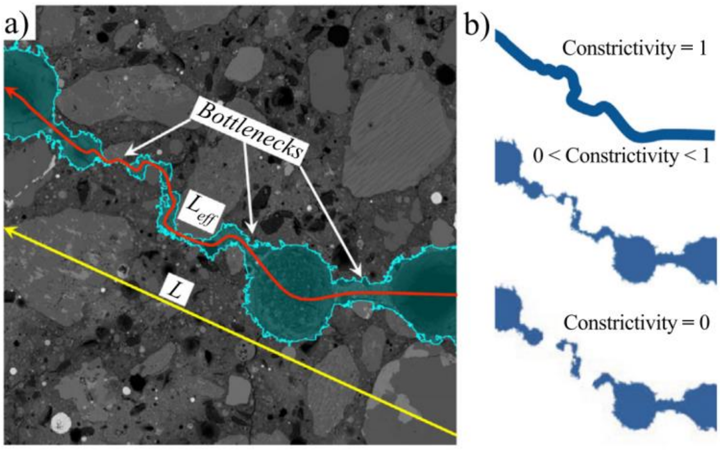
Corrosion rates are higher in areas where wind direction impacts buildings. Facades that are exposed to these winds during rainy periods and experience high relative humidity are more prone to degradation. An even more significant increase in degradation occurs in coastal regions (PAKKALA et al., 2019).

The transport of chloride ions is influenced by coastal water depth, tidal amplitude, wave breaking, and particularly by the direction of winds from the coast to the mainland. Reductions in salinity occur within distances of 100 meters to 150 meters from the shore, and this reduction happens abruptly (LEE; MOON, 2006). These distances are influenced by obstacles, rainfall, and the gravitational effect. In a northeastern region of Brazil, significant reductions were observed in the first 100 to 200 meters (MEIRA et al., 2020).

The model developed by Cole et al. (2013) identified chloride deposition patterns based on wind factors. Two premises were adopted: chloride produced by wave breaking (< 1 km), where chloride deposition rates exponentially decrease within the first kilometer, and those formed by sea waves (>1 km), which are lighter and smaller, gradually decreasing further inland. As a result, a map was generated indicating chloride deposition range. Areas with high concentrations within the first kilometer are marked in red, while lower concentrations were found to extend nearly 100 km from the coastline (PONGSAKSAWAD et al., 2021).

Many factors are associated with ionic transport such as geometry, pore distribution and connectivity, chemical reactions due to ion bonds the walls of the pores, chemically active and the effect of electrical potential, because the wallscharged negatively, enabling the effect of membrane potential, affecting ion diffusion. The aging of concrete and the result of chemical reactions over time, reflects in the decrease of porosity and the consequent tortuosity. For more the increase of the temperature interferes in all the mentioned processes, conceiving more binding capacities (ZHANG; LUZIO; ALNAGGAR, 2021), as Figure 1.

Figura 1 – Porous microstructure of concrete showing a) tortuous trajectory of pores and b) different conditions of constrictivity



Source: Adapted from (ZHANG; LUZIO; ALNAGGAR, 2021)

Carbon dioxide or carbon dioxide gas (CO2) is an abundant element in the atmosphere. Upon contact with concrete, it infiltrates the pores through diffusion and adsorption, and when in the presence of moisture, it forms carbonic acid (H2CO3). This newly formed material reacts with the hydrated cement paste, such as calcium hydroxide (Ca (OH)2), producing calcium carbonate (CaCO3) and water (H2O). This process is known as carbonation and is associated with concrete leaching (POSSAN, 2010); (XU et al., 2022).

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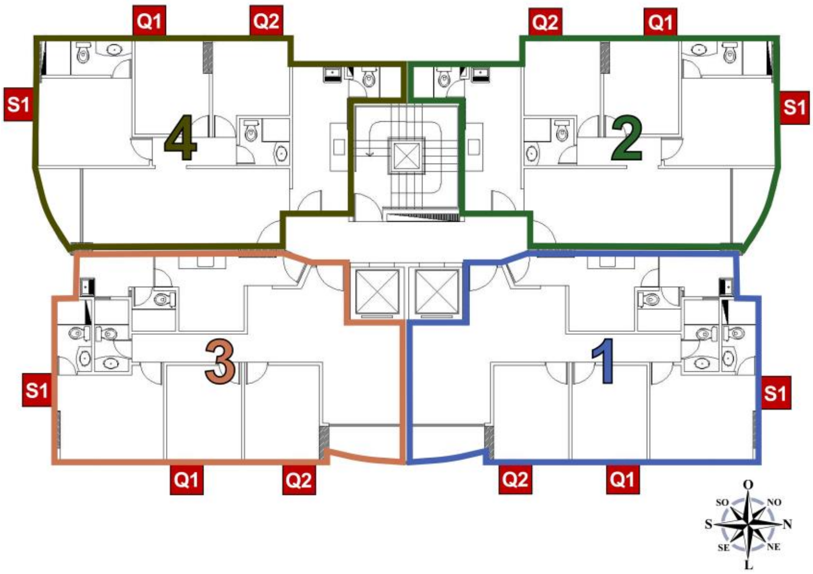
2 METHODOLOGY

A residential building was selected, consisting of two towers named A and B, with 14 floors of apartments and an additional 3 floors for parking, including one underground level. It has four housing units per floor, totaling the two blocks in 112 housing units. Located in the Casa Amarela neighborhood, in the northern zone of Recife, at 3574 Estrada do Arraial, state of Pernambuco, ZIP code: 52.070-230, and under the Universal Transverse Mercator (UTM) geographical coordinates, zone 25 L, with longitude 289041.00 m E and latitude 9112227.00 m S.

The separation of the two blocks was carried out according to the condominium's plans, with the designation of blocks A and B, and the separation by Residential Unit with the endings 1 to 4. Furthermore, the three-bedroom units were classified as S1, Q1, and Q2, based on the reinforced concrete supports for air conditioning for each of them, as depicted in Figure 2.

Figure 2 - Classification of Air Conditioning Units.



Source: Author, 2022

To determine the state of deterioration of each box, flights were performed with Unmanned Aerial Vehicle (UAV), model MAVIC 2 Pro of the DJI manufacturer, aiming to capture images for the upper faces, front and side and with a digital camera model COOLPIX P520 from Nikon for image capture on the lower face. With a total of 336 concrete boxes, 3 per apartment, totaling 1,344 images captured.

Figure 3 shows how the images were captured: S1 - upper face; S2 - front face; S3 - left face; S4 - right face and put an end to S5 - lower face.

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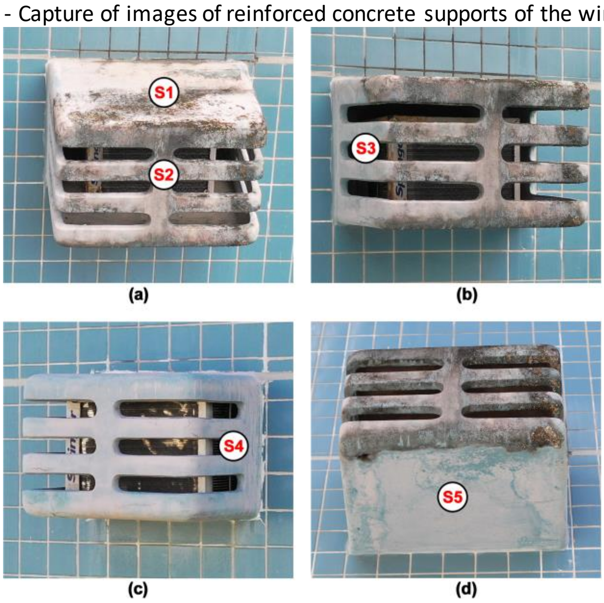
Figure 3 - Capture of images of reinforced concrete supports of the window type.



Source: Author, 2022

After collecting the images, the pathological manifestations could be classified according to the types of problems present. The photos of each part of the concrete supports were analyzed according to the following criteria in Chart 1.

Chart 1 – Classification of pathological manifestations

Code	Pathological manifestation	Description
1	Paint peeling	When the paint layer meets removed portions.
2	Stains	When it accompanies white, yellow, green, and dark stains.
3	Cracks and fissures	When there is the initiation of linear and superficial cracks in the concrete.
4	Fractures	When there are openings in the concrete with mass rupture.
5	Concrete spalling	When concrete detaches, removing its structural function.
6	Exposure of reinforcement	When the reinforcement is visibly exposed.
7	Partial collapse	When part of the structure is missing.

Source: Author, 2022

3 RESULTS

3.1 Geographical and climatic characteristics

Regarding the local topography, an elevation profile was obtained, identifying altitudes ranging from sea level to a maximum of 12 meters at the elevation of Parque Arraial do Bom Jesus, and 10 meters at the building site, as shown in Figure 4.

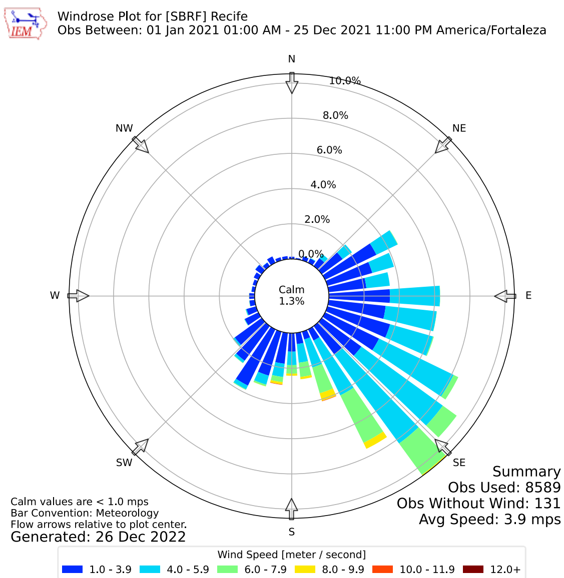
Figure 4 - Elevation profile from the building to the wave breaking point

Source: Adapted from (GOOGLE LLC, 2022)

The measurement of solar radiation, which interferes with the ambient temperature, can be seen on the solar chart of Recife, where it is possible to see temperatures throughout the year of no less than 20º C and mostly more than 25º C, according to the measurement scale of the Dry Bulb Thermometer (TBS), which measures the temperature of the environment where it is installed (ANALYSIS SOL-AR, 2022).

In order to gather information about wind direction, a Wind Rose map was generated for the city of Recife, covering the period from the completion of the building in 2010 to 2022. This map provides wind direction and speed data, indicating predominant directions and the speeds of the strongest winds. The highest wind speeds are from the SE direction, reaching speeds of over 12 m/s. Wind speeds are considered calm, with speeds less than 1 m/s, for only 2% of the year, as shown in Figure 5.

Figure 5 – Wind direction and speed (Wind rose) from 2010 to 2022



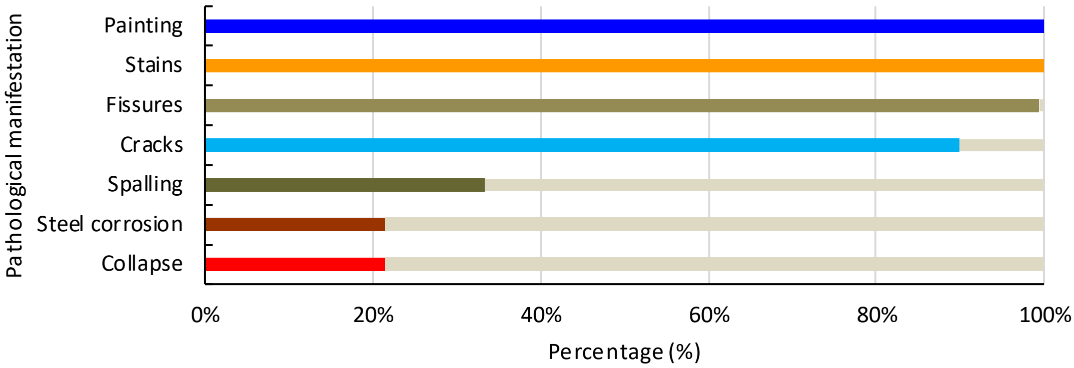
Source: (IOWA STATE UNIVERSITY, 2023)

Relative humidity is high when influenced by equatorial and tropical zones, as well as by effluents or oceans, allowing a larger amount of water vapor in the atmosphere. By observing the minimum and maximum values from (INMET, 2022) for the year 2020, it's evident that humidity varies throughout the day. The average relative humidity remains above 60%, with maximum values exceeding 90% and rainfall occurring in every month of the year.

3.2 Case study

After identifying the pathological manifestations of reinforced concrete supports, it was possible to detect paint deterioration and the presence of stains in 100% of the concrete supports. Surface cracks were found in almost all cases, at 99%, followed by fractures at 90%. Among the more severe manifestations of deterioration, concrete spalling was observed in 33% of cases, followed by corrosion of exposed reinforcement at 21%, and finally, partial collapse at 21%, where parts of the structure are missing, as shown in Figure 6.

Figure 6 - Pathological manifestations of reinforced concrete supports



Source: Author, 2022

Cracking is an indicator of the deterioration state of concrete structures, but simply indicating its presence doesn't reveal whether it's in an early or advanced state of degradation, or whether it's localized or widespread. To stratify the 90% of supports with cracks, they were classified into three levels of degradation, as described in Chart 2.

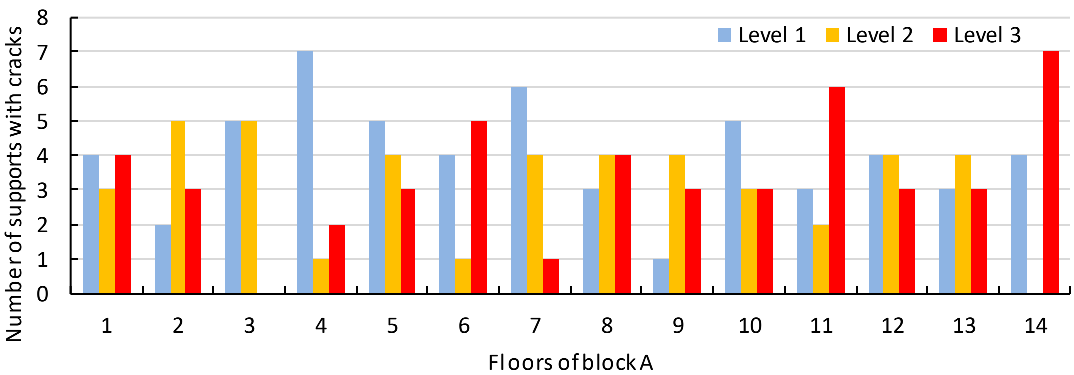
Chart 1 – Classification of cracks by level of degradation

Level of degradation	Criteria
Level 1	Cracks without continuity and localized in nature.
Level 2	When cracks are present in multiple areas.
Level 3	When larger cracks open up and appear in a widespread manner.

Source: Author, 2022

With this classification, it was possible to inspect the images of the air conditioning supports on the façade and categorize them by floor, with each floor having 12 reinforced concrete supports. Except for those classified as level 1, those at level 2 and level 3 are in a state of moderate to high deterioration. In Block A, the most advanced deterioration of supports was observed on the upper floors, such as the 11th and 14th floors, specifically concerning level 3 cracks, as shown in Figure 7.

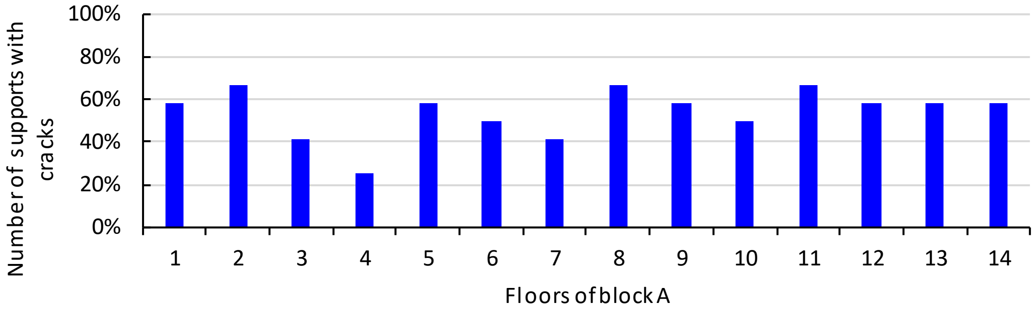
Figure 7 - Classification of cracks by level of deterioration in Block A



Source: Author, 2022

When the supports in level 2 and level 3 conditions are combined, an average of 54% of the supports are in this situation, reaching 67% on some floors. It's noticeable that although some supports are in a more damaged state on the lower and higher floors, the difference for the floors with median height is not significant, as shown in Figure 8.

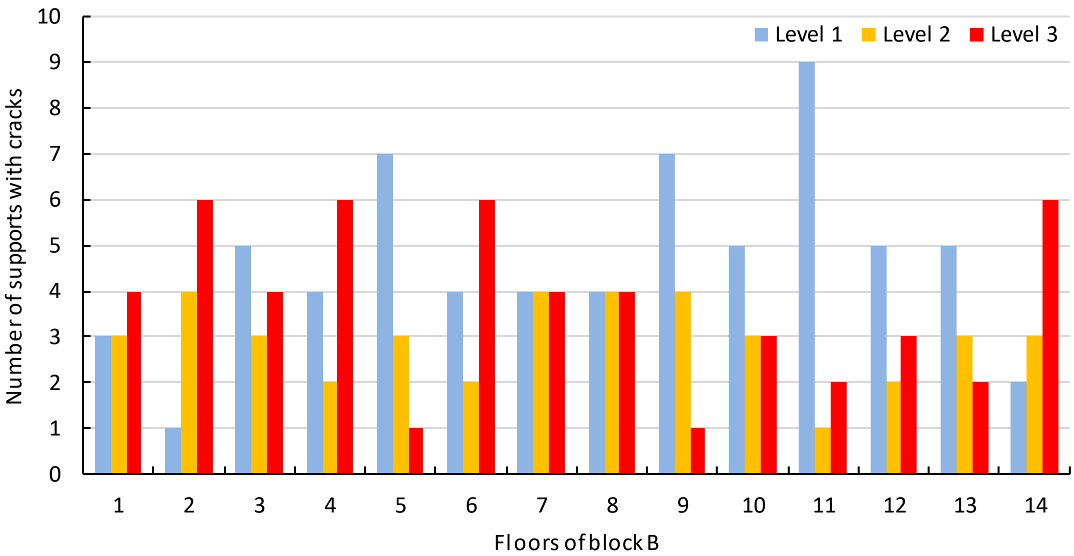
Figure 8 - Deteriorated supports in levels 2 and 3 per floor



Source: Author, 2022

For Block B, the supports with higher level 3 deterioration were observed on the lower floors, such as the 2nd, 4th, and 6th floors, as well as one higher floor on the 14th floor, as shown in Figure 9.

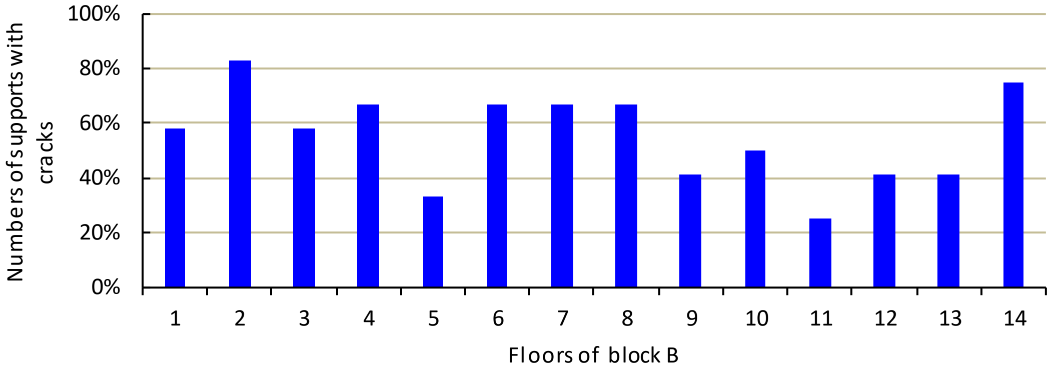
Figure 9 - Classification of cracks by level of deterioration in Block B



Source: Author, 2022

When the supports in level 2 and level 3 conditions are combined, an average of 55% of the supports are in this situation, which is quite similar to Block A, reaching a peak of 83% on the 2nd floor. In the case of Block B, there is a disproportion among the floors, with some peaks and lower quantities among adjacent floors, as shown in Figure 10.

Figure 10 - Deteriorated supports in levels 2 and 3 per floor

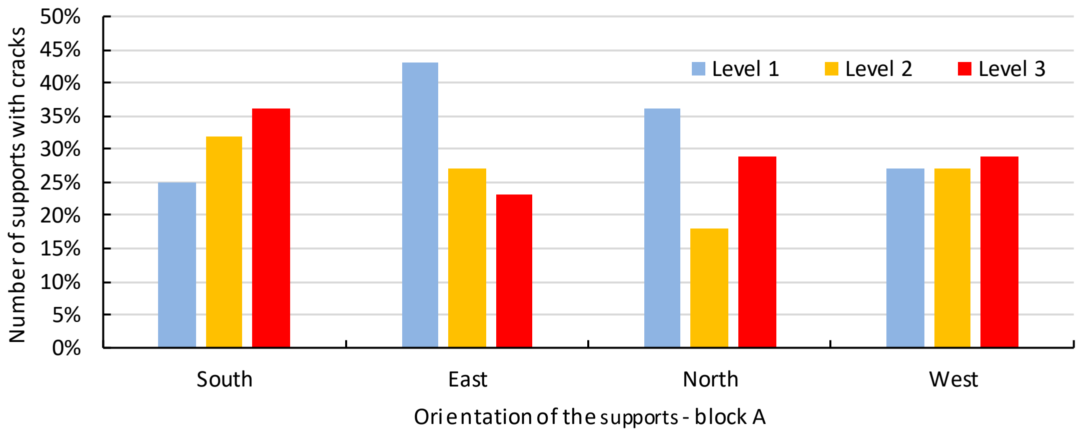


Source: Author, 2022

Another analysis correlated the deteriorations with the orientations of the cardinal points to identify correlations with wind direction, rainfall, and chloride ions. The supports with cracks were separated according to the level of deterioration and their respective directions: south, east, north, and west. In Block A, the results showed that 36% of the supports with level 3 deterioration are on the south side, followed by 29% on the north and west sides, and finally, 23% on the east side, as shown in Figure 11.

Considering that the prevailing wind is in the Southeast direction it is expected that the South and East facades have greater predominance of reinforced concrete supports in an advanced state of deterioration. In the South facade it is possible to verify this condition, but it is not seen in the East facade where it has more supports in the condition of cracks of level 1.

Figure 11 - Levels of crack deterioration in supports according to the cardinal directions in Block A

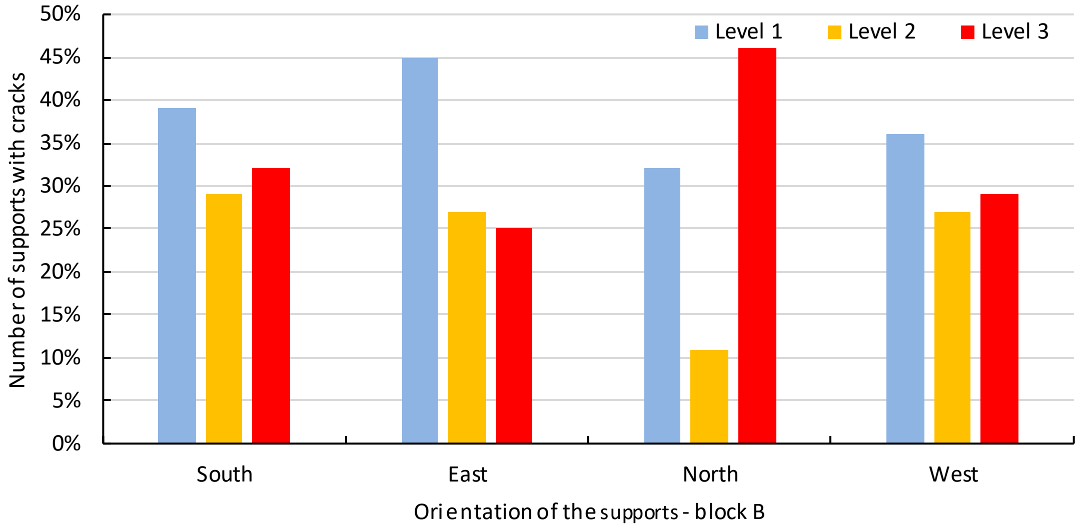


Source: Author, 2022

For Block B, there was a higher prevalence of supports deteriorated to level 3 in the north orientation at 46%, followed by 32% in the south, 29% in the west, and 25% in the east, as shown in Figure 12.

The situation in Block B is similar to Block A, and the prevailing wind direction is Southeast. In this case, the southern and eastern facades would be more affected by adverse environmental conditions, favoring the prevalence of reinforced concrete supports in an advanced state of deterioration. It was observed that the northern facade had the highest rate of widespread cracks, while the southern, eastern, and western orientations had similar values.

Figure 12 - Levels of crack deterioration in supports according to the cardinal directions in Block B



Source: Author, 2022

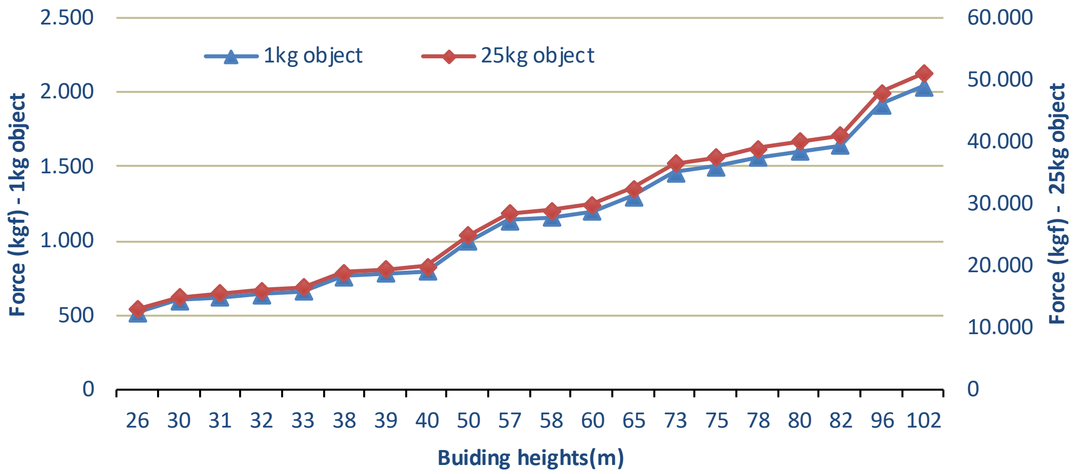
Inspections were carried out on reinforced concrete supports in the neighborhood of Boa Viagem, an area located just a few meters from the breaking waves of the sea and directly influenced by chloride ion attack. The deterioration of the supports is evident, as can be seen in Figure 13.

Figure 13 - Reinforced concrete supports for air conditioning in the Boa Viagem neighborhood in an advanced state of deterioration. (a) Advanced corrosion and presence of vegetation. (b) Almost complete collapse of the support. (c) Widespread corrosion with concrete spalling. (d) Advanced corrosion on the underside of the support.

Source: Author, 2022

In a study by Silva and Monteiro (2020) on air conditioning unit supports, they calculated the force (kgf) exerted by parts of a concrete support when they fall to the ground for objects weighing 1 kg and 25 kg, falling from heights ranging from 26 m to 102 m. This can be seen in Figure 14.

Figure 14 - Force applied by an object in contact with the ground



Source: (SILVA; MONTEIRO, 2020)

4 CONCLUSION

Based on the observation of environmental factors, it was possible to identify conditions conducive to the premature deterioration of concrete. These conditions are related to high relative humidity, elevated temperatures, the flatness of the region, proximity to the sea, and the occurrence of rainfall throughout the year. These factors are compounded by gusty winds.

A set of two residential buildings, located 6.64 km away from the sea and featuring reinforced concrete window supports, was used as a case study. The collection of high-definition aerial images of these supports was essential for gathering information about the pathological manifestations on all external faces.

The predominant issue observed in the case study of the building with reinforced concrete window supports was the presence of cracks resulting from reinforcement corrosion. This led to concrete spalling and the absence of parts of these structures.

In conclusion, the city's conditions, with high temperatures and relative humidity throughout the year, combined with the lack of quality control in the concrete supports and failure to meet the minimum cover requirements for the region, facilitate the rapid ingress of aggressive agents into the concrete, both in the form of CO_2 and chloride ions. All these factors contribute to the degradation of the reinforced concrete supports regardless of the direction or height of their installation.

Understanding the issue and taking preventive action are essential to mitigate the dangers associated with the fall of support components. Depending on their size and height, these components can impact the ground with forces in the order of tons, potentially causing harm to people or objects. It emphasizes the need for using materials that are more resistant to environmental factors, such as aluminum, engineering plastics, and stainless steel. It's important to note that no material is entirely immune to deterioration over the years.

The consumption of cement has become one of the major dilemmas regarding greenhouse gas emissions, structures that do not have an adequate shelf life, provides greater consumption of this material, in addition to the consequences of the disposal of construction waste.

References

ALMEIDA, F. C. R.; SALES, A. **Ação do meio ambiente sobre as estruturas de concreto**. 2. ed. Rio de Janeiro: Elsevier Editora Ltda, 2018.

ANALYSIS SOL-AR. 2022. Disponível em: <https://labeee.ufsc.br/pt-br/downloads/softwares/analysis-sol-ar>. Acesso em: 11 ago. 2022.

BERTOLINI, L. **Materiais de construção: patologia, reabilitação, prevenção**. 1. ed. São Paulo: Oficina de Textos, 2010.

CASTAÑEDA, A. et al. Penetration of marine aerosol in a tropical coastal city: Havana. **Atmosfera**, v. 31, n. 1, p. 87–104, 2018.

COLE, I. S. et al. Holistic model for atmospheric corrosion: Part 2 - Experimental measurement of deposition of marine salts in a number of long range studies. **http://dx.doi.org/10.1179/147842203225008886**, v. 38, n. 4, p. 259–266, dez. 2013.

GOOGLE LLC. **Google Earth Pro**. 2022. Disponível em: <kh.google.com>. Acesso em: 5 set. 2022.

INMET. **Normais climatológicos do Brasil (1991-2020)**. 2022. Disponível em: <https://portal.inmet.gov.br/normais>. Acesso em: 22 dez. 2022.

IOWA STATE UNIVERSITY. **IEM - Custom Wind Roses**. 2022. Disponível em: <https://mesonet.agron.iastate.edu/sites/dyn_windrose.phtml?station=SBRF&network=BR__ASOS&bin0=2&bin1=5&bin2=7&bin3=10&bin4=15&bin5=20&conv=from&units=mps&nsector=36&fmt=svg&dpi=300&year1=2010&month1=1&day1=1&hour1=0&minute1=0&year2=2022&month2=12&day2=31&>. Acesso em: 24 fev. 2023.

JIN, H. et al. Influence of the rainfall intensity on the chloride ion distribution in concrete with different levels of initial water saturation. **Construction and Building Materials**, v. 281, p. 122561, 26 abr. 2021.

JIN, L. et al. Developing a model for chloride transport through concrete considering the key factors. **Case Studies in Construction Materials**, v. 17, p. e01168, 1 dez. 2022.

LEE, J. S.; MOON, H. Y. Salinity distribution of seashore concrete structures in Korea. **Building and Environment**, v. 41, n. 10, p. 1447–1453, 1 out. 2006.

MEIRA, G. R. et al. Behaviour of Surface Chloride Concentration in Concretes Subjected to Field Exposure in Marine Atmosphere Zone. **XV International Conference on Durability of Building Materials and Components (DBMC 2020)**, p. 921–928, 25 set. 2020.

PAKKALA, T. A. et al. Predicted corrosion rate on outdoor exposed concrete structures. **International Journal of Building Pathology and Adaptation**, v. 37, n. 5, p. 679–698, 5 set. 2019.

PONGSAKSAWAD, W. et al. Chloride distribution model and corrosion map of structural steels for tropical climate in Thailand. **Science of The Total Environment**, v. 787, p. 147465, 15 set. 2021.

POSSAN, E. **Modelagem da carbonatação e previsão de vida útil de estruturas de concreto em ambiente urbano**. Porto Alegre: Universidade Federal do Rio Grande do Sul, 2010.

SILVA, W. W.; MONTEIRO, E. C. B. As manifestações patológicas e os riscos dos protetores de aparelhos de ar condicionado em edificações. **Revista ALCONPAT**, v. 10, n. 3, p. 377–393, 2020.

XU, Z. et al. Effects of temperature, humidity and CO2 concentration on carbonation of cement-based materials: A review. **Construction and Building Materials**, v. 346, p. 128399, 5 set. 2022.

ZHANG, Y.; LUZIO, G. DI; ALNAGGAR, M. Coupled multi-physics simulation of chloride diffusion in saturated and unsaturated concrete. **Construction and Building Materials**, v. 292, p. 123394, 19 jul. 2021.