Inspection and rehabilitation of the marquee of the Ibirapuera Park in Brazil

Marcelo Henrique Farias de Medeiros[1] · Paulo Helene[2]

Abstract

Reinforced concrete is the structural material that distinguished the architecture related to the world modernist movement. In Brazil, the main representative of this movement was the architect Oscar Niemeyer, known for exploring the potential of producing curved structures with reinforced concrete. Ibirapuera Park was built in the 1950s and features a historic marquee of 29,000 m^2 made of reinforced concrete. After more than 50 years, this construction has presented pathological manifestations that motivated the need for an inspection, diagnosis and rehabilitation project for this structure. This article presents a technical-scientific discussion applied to a real case, carried out in the period of 2005 and 2006. The work, which is a record and important example of detailed inspection of a construction with historical significance, showed the main problems encountered and the solutions implemented. Various inspection methods were applied to support the diagnosis of the main problems encountered. It was found that there is a need to remove excess loading of the slab due to the overlap of waterproofing systems. In addition, there is a need for repairs and rehabilitation of corroded reinforcements in pillars, beams and slabs. Finally, it is evident that the entire concrete structure of the marquee, now over 65 years old, needs to be protected with the use of high-efficiency paints to drastically restrict the entry of water and oxygen into the concrete, stagnating the process of corrosion deterioration of the reinforcements already installed.

Keywords Inspection · Diagnosis · Reinforced concrete · Reinforcement corrosion · Heritage structures

1 Introduction

Carrying out an inspection, diagnosis, prognosis and recovery project for reinforced concrete structures is fascinating for professionals who like to combine research with practice. Professionals in this area need to reconcile the elaboration of theories with the investigation and confirmation of them. This is carried out based on on-site and laboratory tests, the interpretation of results and the application of innovative or well-established recovery techniques and materials [1].

In this context, the inspection of reinforced concrete structures is an important activity in the field of construction pathology, and must be performed by trained personnel with a strong knowledge of field tests and the degradation mechanisms that can occur in each exposure condition. The dissemination of case studies of real constructions being inspected is also an essential practice to generate an exchange of important experiences among professionals working in the area. Regarding inspection work records, relevant examples include the publications of Shash [2], Tiago and Júlio [3], Medeiros et al. [1], Medeiros et al. [4, 5], Medeiros Junior et al. [6, 7], Hoppe Filho et al. [8], Balestra et al. [9], Esteves et al. [10] and Balestra et al. [11].

It is worth mentioning that the historical context is part of the inspection and diagnosis of structures, which consists of highlighting architectural aspects of the inspected object as well as the importance of the structural designer and the architect of the project, particularly if this is a renowned professional, in addition to the architectural genre to which the work belongs. Another important part of inspection work is the characterization of the construction and the exposure

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conditions at the time of inspection. These steps precede the carrying out of a campaign of field tests that focus on identifying the causes and effects of the deterioration mechanisms at work in each case.

This article aims to detail the inspection work of a construction considered an icon of the modernist movement in Brazil, discussing the results and measurements made.

2 Background and history of projec

Inspection and diagnostic activities were carried out which allowed the understanding and evaluation of the problems existing in the "José Ermírio de Moraes" Marquee, an integral part of the Ibirapuera Park. The focus of the work was to obtain indispensable subsidies to elaborate the project and technical specifications for the necessary corrective intervention in this important construction of the Brazilian modernist movement.

This work begins by demonstrating the significance of Ibirapuera Park and the "José Ermírio de Moraes" Marquee, both for São Paulo citizens and for Brazil in general. Also presented in this article is the process of inspection, diagnosis and proposed solution to the problems encountered in this construction, which at the time of inspection had 52 years of service life. Today the marquee has been in operation for 66 years.
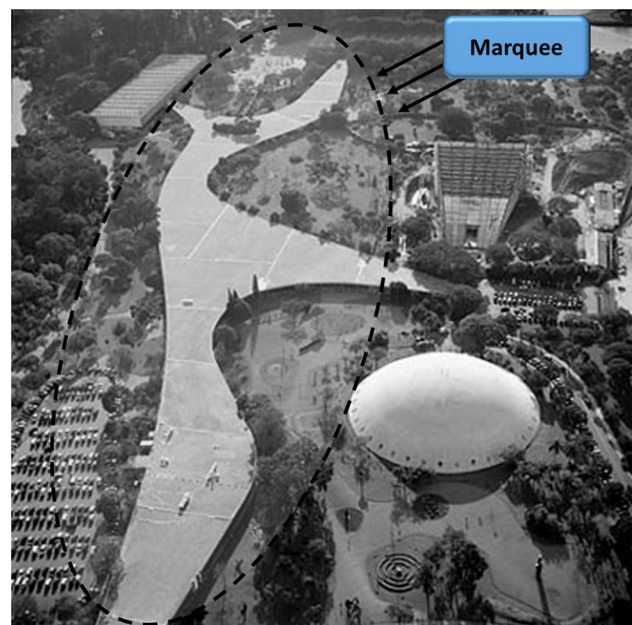
2.1 The Ibirapuera Park

Ibirapuera Park, inaugurated on August 21, 1954, is a milestone in the history of São Paulo, Brazil. In 1951, 3 years before the city's fourth centenary, architect Oscar Niemeyer was invited to design the park. Lakes, streets, lawns and gardens would be designed by landscape architect Roberto Burle Marx.

The hiring of Niemeyer and Burle Marx would mainly give continuity to the modern style that guided thought for the development of the city of São Paulo, Brazil. The central idea that guided this work would be to unite urban modernity through bold architecture with a landscape design no less advanced.

Thus, the architectural project was prepared by architect Oscar Niemeyer's team, which was composed of: Zenon Lotufo, Eduardo Kneese de Mello and Helio Cavalvanti, with the collaboration of Gauss Estelita and Carlos Lemos. The first study in the area by the Niemeyer Team was presented in 1952 (Fig. 1), with a proposal made up of an architectural ensemble of large buildings joined by a large marquee, surrounded by a lake and entertainment areas. The final project underwent modifications, as represented in Fig. 2.
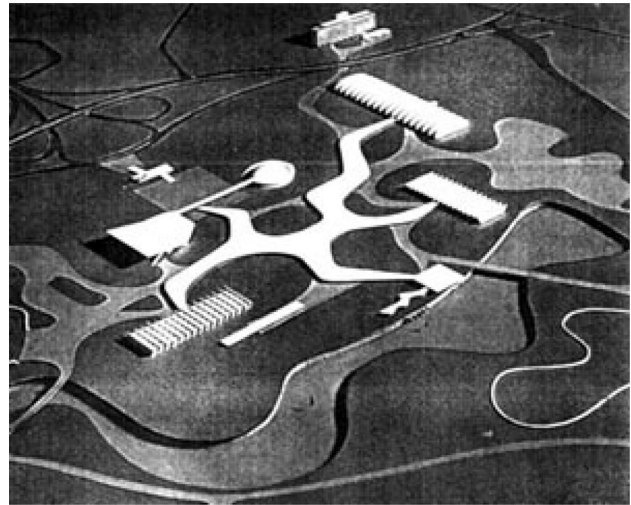
Fig. 1 First Project for Ibirapuera Park by the group of architects led by Oscar Niemeyer, 1952 (Preliminary Project for the Exhibition of the IV Centenary of São Paulo. 1952) [12]

Fig. 2 Aerial view of the Marquee in 2004. Photo kindly provided by Nelson Kon (Preliminary Project for the Exhibition of the IV Centenary of São Paulo. 1952) [12]

Now in operation, Ibirapuera Park receives an estimated population of between 60,000 and 100,000 people on weekends, when concerts are held outdoors. This population gives the place a festive atmosphere rarely found in other parks. This virtue can only be attributed to the great Marquee, which was intended to fulfill this mission from the beginning.

2.2 The "José Ermirio de Moraes" Marquee

According to Valle [13]: "In the Ibirapuera project, Niemeyer proposes for the first time a spatial concept that will be recurrent in his work, a derivative of the concept "shape on platform and pilotis. The Ibirapuera marquee, which is a covered path between buildings, is one of the best examples of this typology and made Ibirapuera Park a unique phenomenon among the largest known urban parks in the Western world…".

Figure 2 shows an aerial view of the marquee, photographed in 2004, which has an area of 29,000 m² and a perimeter of 1700 m. It has a variable height of 3 m at the ends and 4.25 m in the center part, all curved and sloped. The structure is one of a kind, both in size and type.

Designed by architect Oscar Niemeyer, constructed by the Construction and Engineering Office "ECEL," and using reinforced concrete calculations by Engineer Fernando Paes da Silva, the structure of the marquee is formed by 18 blocks, with their respective expansion joints, slabs of ribbed concrete, beams and pillars. The marquee is supported by 121 pillars, 113 of which have a circular section and 8 of which are V-shaped pillars located at the four ends of the marquee (Fig. 3a). The pillars of circular section and the pair of V-shaped pillars at each end are receded in relation to the facade, so that there are sections supported between beams and sections that are cantilevered. The pillars are interconnected by a lattice of beams and the slab is composed of an upper table about 7 cm thick and a lower Table 4 cm thick, constructed with reinforced concrete, as indicated in the sketch of Fig. 3b.
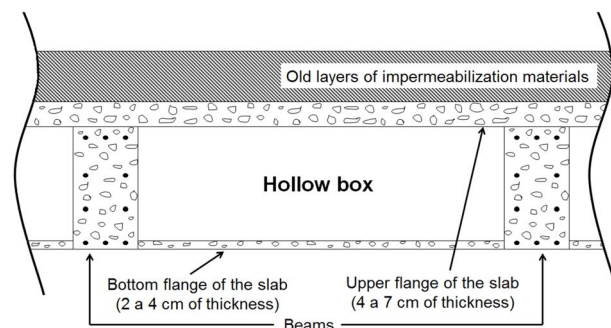
3 Inspection methodology

The inspection was conducted according to nationally and internationally established methodology for inspecting reinforced concrete structures. The work steps, the tests performed, the data collected and the criteria used followed the precautions and procedures of national and international publications [14–19], using the most relevant recommendations of each one.

Figure 4 shows the basic work steps in an inspection, diagnosis and rehabilitation process for a building interacting with the environment over the years. The work process comprises understanding the problem using verbal and documentary information, as well as tests carried out in the field and in the laboratory. This is important to determine the cause, origin and mechanisms of the problem that the inspected building presents. A well-founded diagnosis is very important as a support for the correct elaboration of an adequate rehabilitation design. In the work process the following main steps can be identified:

- **Preliminary inspection:** visual examination (inspection), background check, initial quick tests, pre-diagnosis, selection of the necessary information to be surveyed by tests, work planning, selection of study areas, photographic record of anomalies;
- **Detailed inspection:** carrying out on-site tests, taking samples, carrying out laboratory tests;
- **Diagnosis:** analysis of test results and joint assessment of the available information;
- **Rehabilitation:** description of the means to make the building able to perform its functions correctly with durability. This part of the process is the rehabilitation design and must indicate the places of intervention. Each material specification and execution procedure must also be documented in the rehabilitation design.

Fig. 3 **a** View of one end of the marquee with the V-shaped pillars; **b** Sketch of the marquee slab configured by an upper and lower reinforced concrete table

Fig. 4 General methodology for inspection, diagnosis and prognosis of pathological manifestations in civil construction works [18]
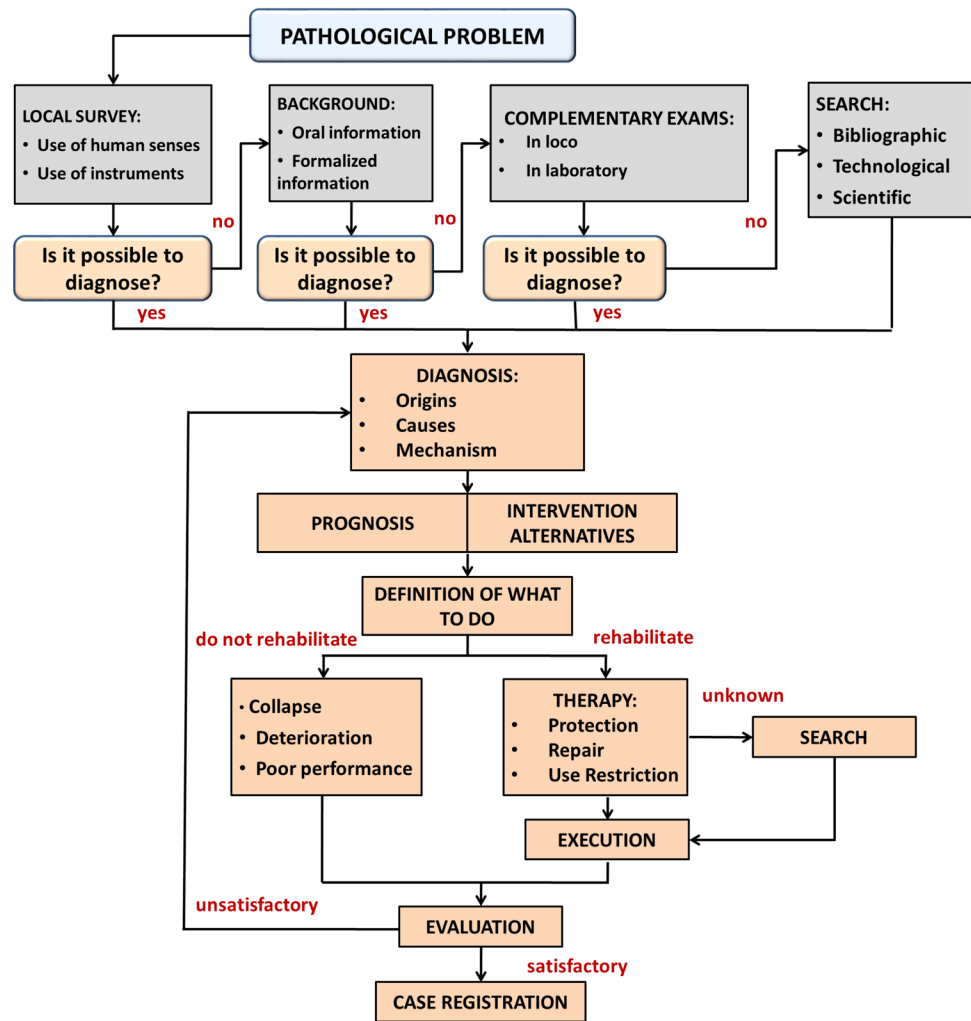
3.1 Compressive strength, water absorption and void ratio

To check the compressive strength, the core extraction technique was used with a diameter of 75 mm, as shown in Fig. 5. After extraction, the cores were identified and the ends were cut in the laboratory in order to have the length of 150 mm. After cutting, the cores were dried in an oven at a temperature of 60 °C until reaching mass constancy (until mass variation was less than 0.10 g). Then, the cores had their mass recorded (M_{Dried}). Following this, the cores were immersed in water for 72 h and then weighed in their saturated condition with a dry surface (M_{Sat}). Finally, the mass in the submerged condition (M_{Sub}) was determined. This process was adopted to determine the water absorption (Eq. 1) and the void rate (Eq. 2) of the cores before their rupture in compression.

Fig. 5 Core extraction of one of the pillars of the Ibirapuera Park marquee

$$Absorption = \frac{M_{Sat} - M_{Dried}}{M_{Dried}} \times 100 \qquad (1)$$

$$p = \frac{M_{Sat} - M_{Sub}}{M_{Sat} - M_{Dried}} \times 100 \qquad (2)$$

Subsequently, these cores were then capped and subjected to the axial compression test in the saturated state with a dry surface. The compressive strength test was performed in 75×150 mm cylindrical specimens as described in the Brazilian standard NBR 5739 [20]. In this context, samples were placed on a hydraulic machine, where they were compressive loaded until failure. During this experiment, equipment with a loading capacity of 1000 kN and a loading rate of 0.45 ± 0.15 MPa/s was used.

3.2 Electrical resistivity

In this inspection work, the Wenner four-electrode method was used, which was standardized by ASTM G-57 [21] and originally used to measure soil resistivity. However, this method has been used classically to assess the resistivity of concrete to the point that it is currently regulated by the European code UNE 83,988-2 [22].

Table 1 Criterion for evaluating the electrical resistivity of concrete—CEB 192 [24]

Electrical resistivity of concrete	Corrosion risk
> 20 kohm $\times$ cm	Negligible
10 to 20 kohm $\times$ cm	Low
5 to 10 kohm $\times$ cm	High
< 5 kohm $\times$ cm	Very high

The electrical resistivity of concrete is an important parameter for the corrosion kinetics of reinforcements, since electrical resistivity is the main regulator of the corrosion rate [23]; that is, it controls the kinetics of the process. Thus, since reinforced concrete is already in the corrosion propagation period, electrical resistivity has an important relationship with the regulation of the corrosion process, having a direct influence on the construction's residual service life.

For analysis and judgment of the results obtained, the resistivity ranges prescribed by the Comité Euro-international Du Beton (CEB) were used as criteria, as shown in Table 1.

The test was carried out on site in wet areas in a standardized manner in which 20 sprays of water were applied with an interval of 10 min between them. This was the way to proceed with the measurement in a condition of equal contact with water for the different assessment areas, simulating the measurements in more critical conditions such as in the case of rain on the reinforced concrete. Figure 6 shows the procedure being used in the fieldwork.

3.3 Corrosion potential (E$_{corr}$)

The determination of the corrosion potential consists of obtaining information regarding the thermodynamic state of the corrosion, that is, the indication of the passive or active corrosion state of the reinforcements embedded in the inspected structural elements.

This type of measurement was carried out by applying a non-destructive electrochemical method that follows the procedure of ASTM C 876 [25]. The equipment used consists of a Cu/CuSO$_4$ reference electrode connected to a high input impedance voltmeter, as shown in Fig. 7. Table 2 shows the criteria frequently used for the thermodynamic evaluation of corrosion by measuring the corrosion potential, as stated in ASTM C 876 [25].

Fig. 6 Electrical resistivity test using the Wenner four-electrode method: **a** Preliminary wetting; **b** Apparatus being used on the slab's box void

Fig. 7 Corrosion potential test using Cu/CuSO$_4$ electrode—ASTM C 876 [25]

A Laboratory   **B** On site

Table 2 Criterion for the corrosion assessment through corrosion potential—ASTM C 876 [25]

Corrosion potential (Cu/CuSO$_4$ electrode) (mV)	Corrosion probability (ASTM C 876) (%)
< −350	95
Between −350 and −200	50
> −200	5

Table 3 Corrosion assessment criteria according to the corrosion rate measurement [27]

Corrosion rate (μm/year)	Corrosion current (μA/cm^2)	Corrosion level
< 1	< 0.1	Negligible corrosion
1–5	0.1–0.5	Low corrosion
5–10	0.5–1.0	Moderate corrosion
> 10	> 1.0	High corrosion

3.4 Corrosion rate (I$_{corr}$)

The corrosion rate is the parameter that characterizes the kinetics of the corrosion process, defining the rate of deterioration of the reinforcements and, therefore, of the structure itself. One of the most used methods for measuring the corrosion rate is the "polarization resistance" (Rp). This is a test that has been applied regularly since the 1990s by Andrade and González [26], who adapted and developed the techniques originally used in the late 50 s by Kaesche and Baumel and Engell for reinforcements embedded in mortar and concrete.

This test is also known as the "linear polarization resistance" test. The corrosion assessment criteria, according to Andrade and Alonso [27], are shown in Table 3. For the corrosion current intensity readings and their conversion into corrosion rate, a piece of equipment commercially known as Gecor 8 was used, as illustrated in Fig. 8.

3.5 Carbonation depth

Carbonation is a natural phenomenon that occurs in concrete and its rate depends on numerous factors, from aspects related to concrete such as porosity and alkaline reserve, to aspects related to the climate such as relative humidity, temperature, environmental CO_2 content and cycles of wetting and drying.

The fact is that when the carbonation front reaches the reinforcements, they leave their original state of protection and start to present thermodynamic conditions for the development of reinforcement corrosion that results in the appearance of numerous pathological manifestations in the structure. Thus, concerning reinforcement corrosion, the

Fig. 8 Corrosion rate measurement with GECOR 8

phenolphthalein method is a good indication of the initiation of corrosion by carbonation [28].

In this work, a semi-destructive method of determining the carbonation depth was used, for which the chemical indicator called phenolphthalein (pH turning range between 8.3 and 9.3) is normally used. The determinations were made according to the RILEM CPC-18 method [29]—"Measurement of Hardened Concrete Carbonation Depth" and the carbonation depth measurement was performed on a recently fractured concrete surface. Figure 9 illustrates the performance of this test.

4 Inspection and diagnosis results

In the case of the construction in question, it is located within a large urban center (the municipality of São Paulo); that is, immersed in an urban atmosphere, with atmospheric pollutants such as CO_2 (carbon dioxide), CO (carbon monoxide), and other acid gases such as SO_2, which give rise to the so-called acid rain that is highly deteriorating to concrete structures. In addition to this aggressiveness, there is the presence of acid soot resulting from the burning of fuels and the presence of

Fig. 9 Carbonation depth test in reinforced concrete inspection work at the Marquee of the Ibirapuera Park

fungi typical of hot, humid, urban and industrial environments such as the great São Paulo (Metropolitan Area).

According to the classification criteria for environmental aggressiveness recommended by the ABNT NBR 6118 y[30] standard for the Concrete Structures Project, the context in question can be considered to have, from the macroclimate point of view, a level of strong aggressiveness—level III.

In order to allow the implementation of an adequate intervention project that reflects the needs of conservation, durability and safety of this historic marquee that has more than 50 years of service life, a detailed inspection of the construction was carried out.

To this end, tests, information processing and a diagnosis of the situation were carried out. These activities are summarized as follows.

4.1 Pillars

In the pillars, the compressive strength, water absorption and void rate of the concrete were initially determined. This was done with the extraction of cores, the results of which are shown in Table 4. There is a high variation in the results, indicating a standard deviation of 8.5 MPa and a coefficient of variation of 30%. This reflects the variation in technological control of a construction carried out in the 1950s. In addition, the concrete had an average water absorption of 5.3% and a void rate of 14%. These values reflect good quality concrete for that time.

Figure 10 shows the measurements of carbonation depth and concrete cover thickness of the sampled pillars, which makes it evident that the carbonation of the concrete reached the bars in all the sampled cases. This fact supports the diagnosis that conditions favorable to the development of reinforcement corrosion are present in these structural elements. This fact corroborates the data in Figs. 11, 12 and 13, which show the results of electrical resistivity, corrosion potential and corrosion current. In the first two graphs, it is shown that the pillars are, in general, classified as high probability of corrosion. Figure 13 shows that the corrosion current obtained with Gecor 8 indicated that the pillars are in a corrosion process at a level classified from moderate to high.

This set of information collected on site supports the argument that the structure has reached the end of its service life and that it needs rehabilitation and protection measures to prevent it from going into advanced degradation, compromising an important building for Brazil's modernist architecture.

Table 4 Compressive strength, water absorption by immersion and void rate of the sampled pillars

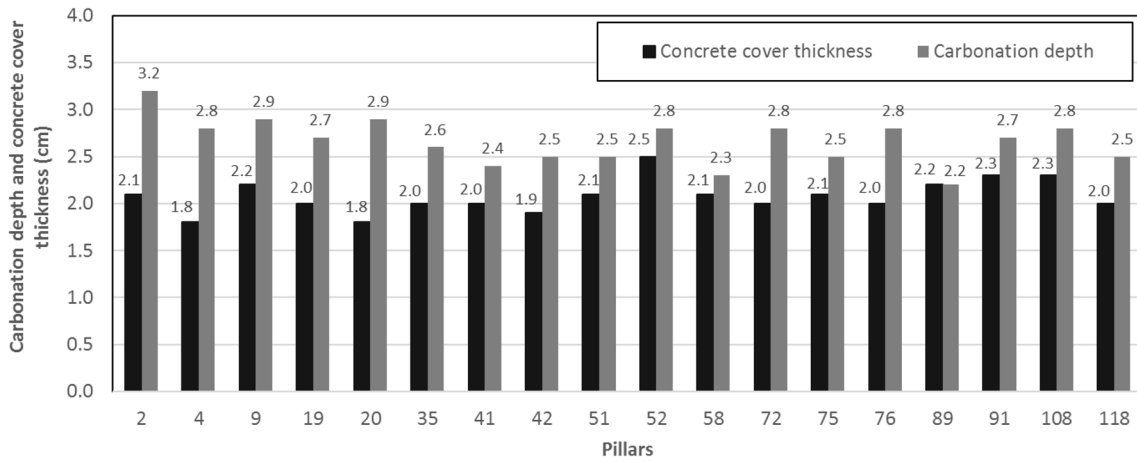| Pillar	2	9	20	35	42	58	75	89	108	118
Compressive strength (MPa)	15.4	19.3	25.1	26.1	29.6	40.1	30.3	45.8	25.9	29.8
Water absorption (%)	5.7	5.9	5.5	5.3	4.9	4.2	5.6	4.4	5.9	5.6
Void rate (%)	14.6	15.0	14.3	13.9	13.0	10.9	14.7	11.7	15.3	14.6

Fig. 10 Carbonation depth and cover thickness

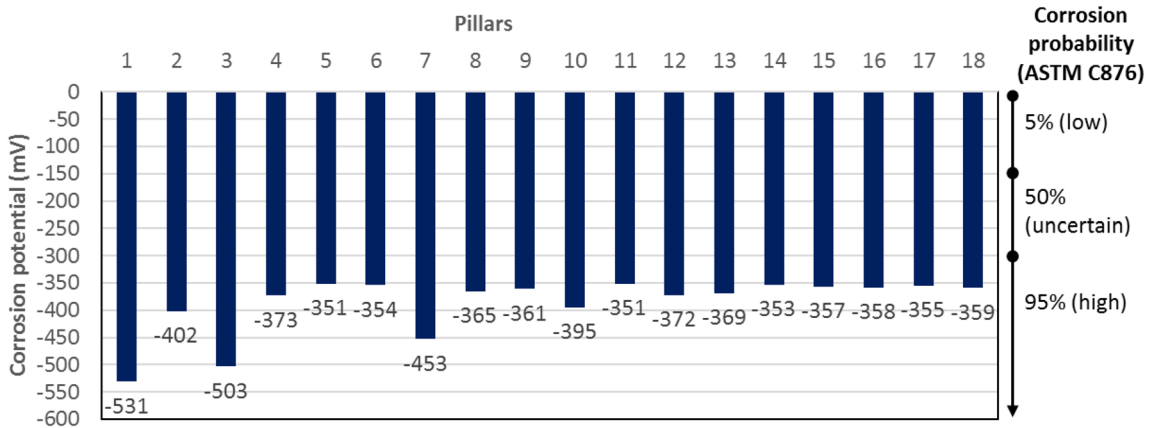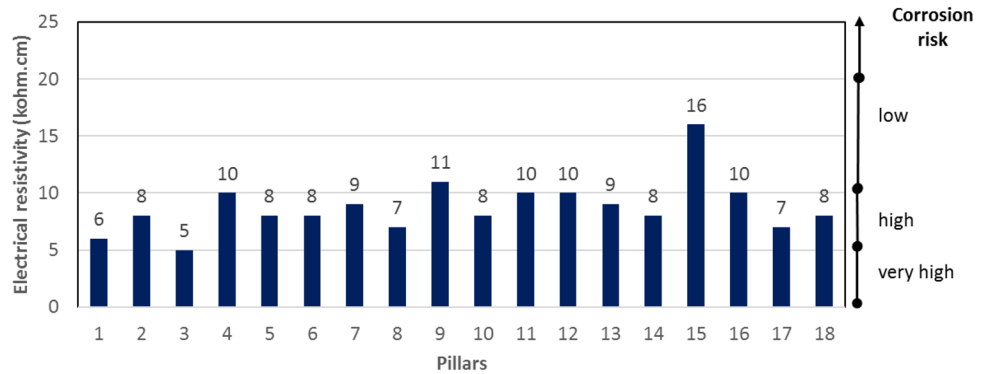**Fig. 11** Electrical resistivity of the pillars sampled in the inspection

Fig. 12 Corrosion potential of the pillars sampled in the inspection

The on-site visual survey showed that 10% of the total of 121 pillars have visible reinforcement corrosion problems. The diagnosis showed that the cause of the corrosion was the depassivation of the steel by carbonation, aggravated by the presence of constant humidity by infiltration of rainwater. Figure 14 shows an illustration of this type of problem.

Each of the four ends of the marquee is supported by a pair of V-shaped pillars, as shown in Fig. 15a. Figure 15b shows that the head of one of these pillars is cracked and

partially broken by shearing due to the thermal movements of the roof slab. This occurred in the pillars at two of the four ends of the marquee and indicated the need for reinforcement and rapid intervention.

4.2 Slabs

As shown in Fig. 16a, the Ibirapuera marquee can be divided into two parts: 1—Sections of slabs and beams between pillars; 2—Cantilevered sections (with pillars at only one end). After analyzing the structural projects,

it was found that these cantilevered sections have a predisposition to intense cracking.

With the removal of waterproofing layers up to the structural slab, flexural cracks were found parallel to the beams between pillars that support the cantilevered section (usually 80 cm in height and width ranging from 80 to 100 cm) in practically all open inspection windows. Figure 16b shows an example of this crack in one of the open inspection windows.

Figures 17 and 18 show, in sketch and photo, the occurrence of rainwater infiltration in the marquee slab.
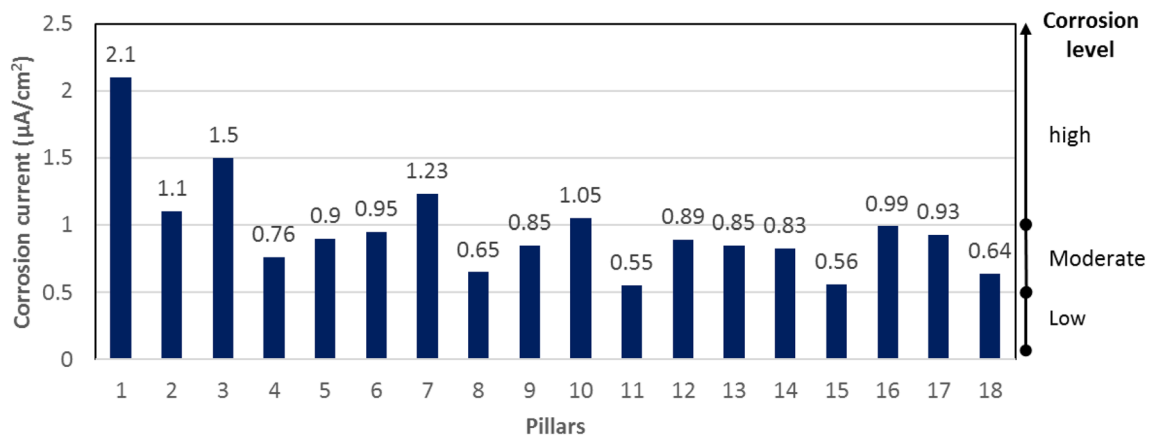
Fig. 13 Corrosion current of the pillars sampled in the inspection

Fig. 14 Corrosion of reinforcements in pillars supporting the marquee

Fig. 15 End pillar of the marquee: **a** V-shaped geometry; **b** Cracking and partial rupture of the pillar head by thermal expansion of the slab
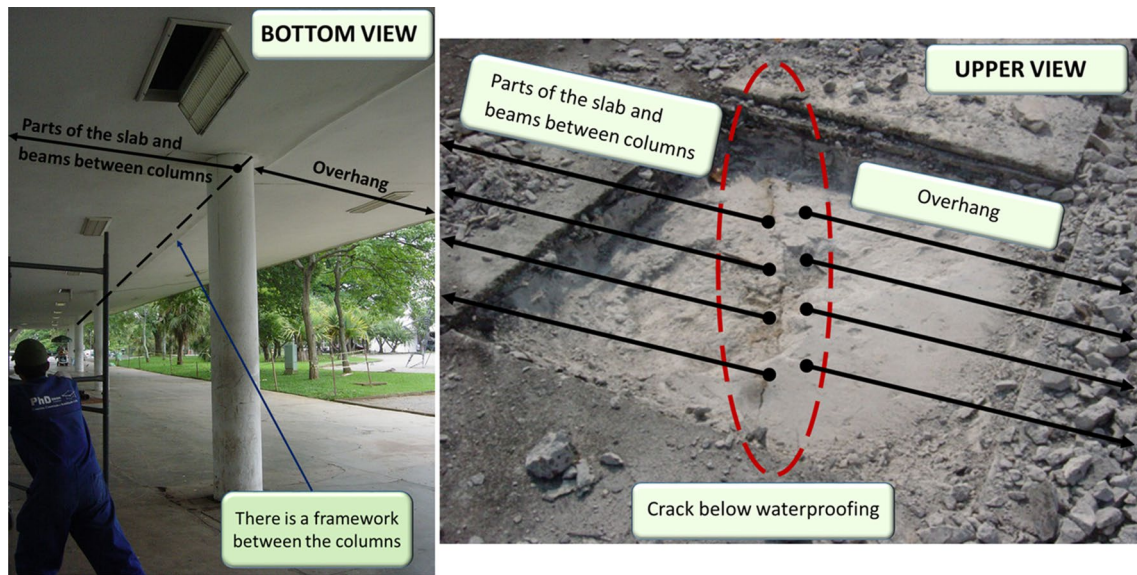
Fig. 16 Location of the cantilevered area and example of cantilevered slab crack (upper surface of the roof)

Figure 17 shows that the slab is formed by an upper and lower table, with a box void between the two. Figure 18 shows a view from below the marquee (bottom table) with clear rainwater infiltration. This is caused by the failure of the waterproofing of the upper table of the slab, allowing the water to penetrate through the concrete and accumulate in the internal part of the box void, more specifically in the upper part of the lower table of the slab (Fig. 17). This deterioration process causes the calcium hydroxide in the concrete to dissolve and be carried away, causing an increase in porosity and a reduction in the alkalinity of the aqueous extract. The consequence of this process on reinforced concrete is the corrosion of the reinforcement, in which the leaching of natural alkaline products of the concrete reduces the pH and causes the depassivation of the steel. In the inspection, an estimate was made of the 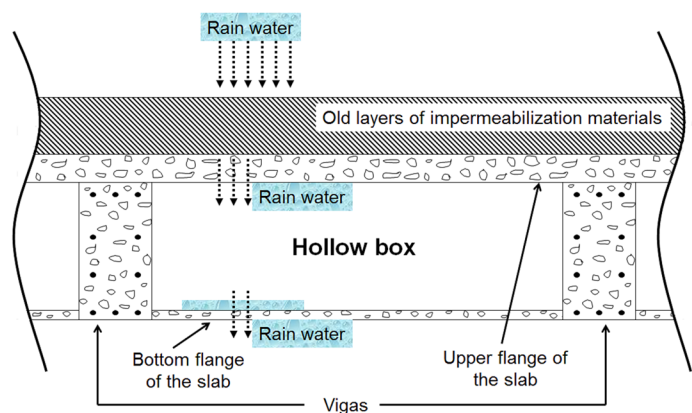reinforcement corrosion of the lower table of the covering slab by visual evaluation. The result was that the incidence is of the order of 20% of the total surface of the marquee.

In the inspection, excessive overload was identified in the order of 300 kg/m^2 of the covering slab of the marquee due to the improper overlap of several layers of water-proofing systems, as shown in Fig. 19, corresponding to one of the cores extracted from the upper table of the slab.

## 4.3 Lateral wall of the marquee slab

The tiles on the outer edge wall of the marquee are in the process of being detached and in several regions there is a risk of these falling and hitting park visitors. Figure 20 shows this pathological manifestation occurring in the construction.

Fig. 17 Sketch of the rainwater infiltration process

Fig. 18 Slab leakage deficiency, with rainwater infiltration and reinforcement corrosion
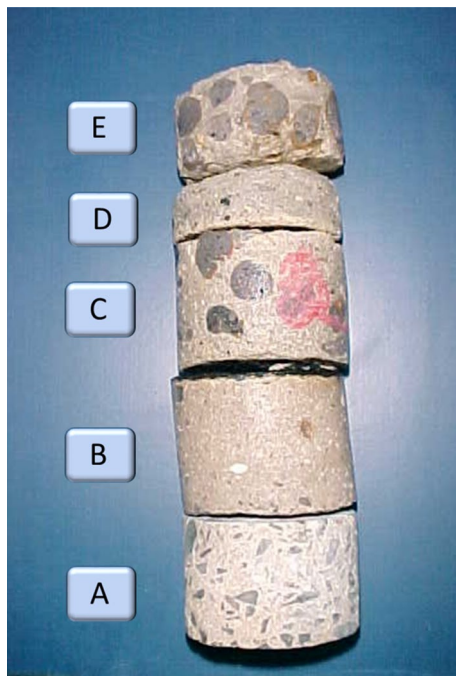
Fig. 19 Overlapping layers in the upper table of the covering slab due to overlapping layers of waterproofing systems: **a** upper structural table of the slab (4–7 cm); **b** mortar for smoothing and draining the first waterproofing system (3–10 cm); **c** mechanical protection mortar for the first waterproofing system (5–7 cm); **d** mortar for smoothing and draining the second waterproofing system (2–3 cm); **e** mechanical protection mortar for the second waterproofing system (3–6 cm)

5 Solution to the main problems

The following are some of the rehabilitation processes specified in the recovery project. However, it should be noted that the work was broader and needed to be summarized in this article.

5.1 Pillars

An intervention that is considered important is a surface protection treatment on the pillars, as they are in the process of carbonation corrosion. Thus, the reasoning was to drastically reduce the access of water into the reinforced concrete of the pillars. If the painting is periodically renewed, the building's service life tends to be extended by decades. In the case in question, the recommendation was to prepare the concrete base and apply an aliphatic polyurethane finish, which must be renewed every 5 years.

Another necessary intervention is the placement of a support device on the 8 V-shaped pillars at the ends of the marquee. This was specified because due to their geometric shape (see Fig. 14) and the fact that they are embedded, they are unable to absorb the deformations generated by the thermal movement of the structure, causing breaks as can be seen in Fig. 14. This service must be performed in the following steps:

Fig. 20 Detachment of the marquee edge wall tiles

Step 1: The first step is to shore up the slab with traditional metal shoring following the premises of support capacity used in conventional works. The weight of the slab was estimated and the metallic shoring was dimensioned.

Step 2: Demolition of the top of the pillars with a cutting disc and hammer—after shoring, the concrete of the pillar head must be demolished with an electromechanical hammer with a maximum weight of 10 kg and power of 1500 W, as indicated in Fig. 21a and b.

Step 3: Cut out the pillar reinforcements with a diamond disk to a level 12 cm below the slab, as shown in Fig. 21c. After cutting the reinforcements, sand the bottom surface of the beam with a diamond disc to smooth it, making it flat, and then install the support device. Apply a two-component epoxy primer to the reinforcements to avoid subsequent corrosion, and then sand them until they appear to be "almost white metal."

Step 4: Installation of impenetrable molds to recompose the pillar head. To guarantee the watertightness of the molds, ready-to-use self-expanding polyurethane foam must be used along the entire perimeter between the mold and the concrete substrate and between the plywood boards (see Fig. 21d). The surface must be moist, clean,

and free from oils, greases, release agents or any greasy elements. Remove dust or loose particles of any kind.

Step 5: Filling the pillar with high strength grout. This consists of filling the molds with the cement-based grout modified with polymers. The filling of the molds must be done completely in order to leave a space of exactly 9.5 cm for the placement of the neoprene base support (with dimensions $47 \times 32 \times 10$ cm, length x width x height). After 7 days of grouting, try to place the support in the 9.5 cm left between the pillar and the beam. Vaseline must be applied to the neoprene to facilitate entry. If not, use a diamond disc sander to reduce the grout layer. This procedure must be repeated until the neoprene base support can be fitted. This procedure ensures that it is placed on load because when the hydraulic jack is removed, there will be reduced deflection of the beam.

5.2 Slabs

The program of tests related to durability indicated several regions with a high risk of corrosion and, for this reason, it is concluded that surface protection is a factor of great importance for the service life of the structure. The waterproofing of the upper slab will prevent moisture from accessing the concrete of the structure and will considerably reduce the
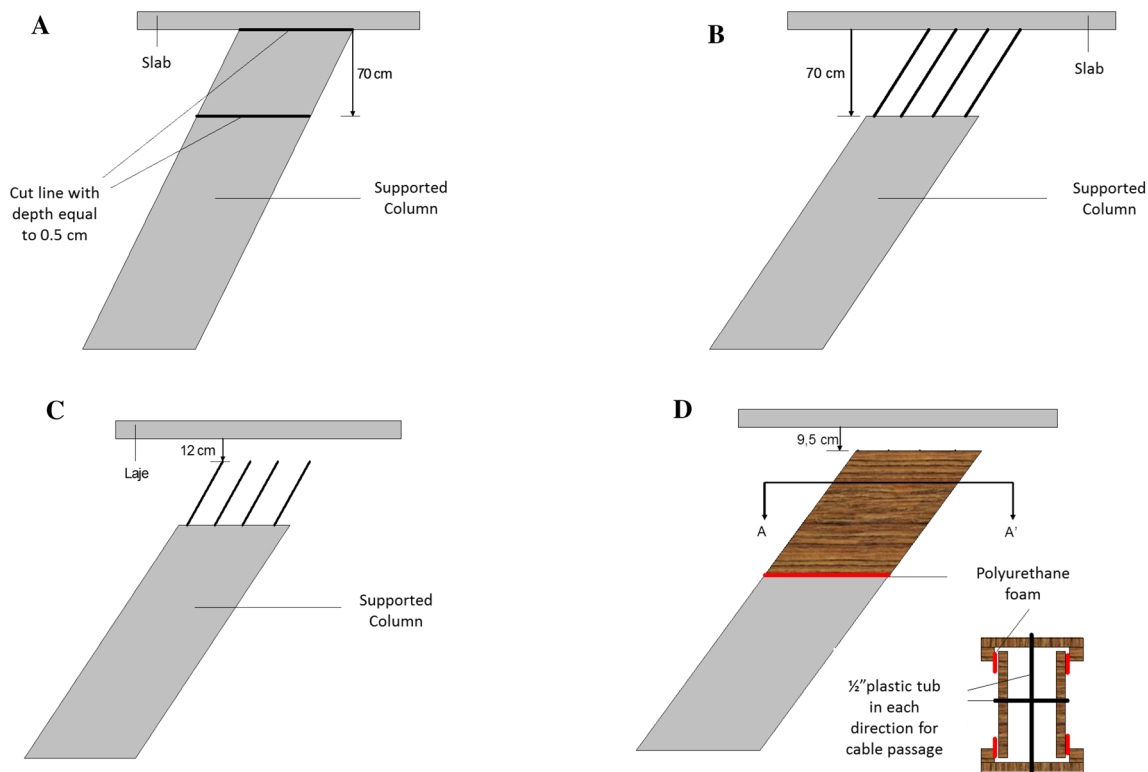
Fig. 21 **a** Illustrative drawing of the cut that precedes scarification; **b** Illustrative drawing of the pillar scarification; **c** Cutting the reinforcement; **d** Detail of the mold for grouting

kinetics of the corrosion process. In addition, it is necessary to apply paint for aesthetic purposes and to restrict the entry of aggressive agents in the concrete of the structure.

For the intervention of the slabs, the demolition and restoration of damaged sections was specified, which consists of carefully demolishing these previously marked areas with a hammer and chisel. The demolished regions must be delimited as rectangular geometric figures and special care must be taken not to damage the original reinforcements when performing this service. If this happens, replacement of the reinforcement is necessary. The demolished area needs to exceed the region with corroded reinforcement by at least 10 cm in all directions of the effectively damaged area to ensure that all deteriorated material is actually removed.

As for the cleaning of the reinforcements, the corrosive agents formed on the surface of the corroded bars must be removed mechanically for better protection against corrosion, good mechanical functioning and correct loss assessment of the section of reinforcements. Therefore, any corrosive agents on the surface of the bar that are loose or powdery must be removed.

As for the preparation for repairing demolished sections, in areas with breaks in the lower slab table where more intense demolitions are necessary, provision should be made for the installation of the support mold with 10 mm thick pressed wood sheets, which serves as a support base of the repair mortar to be applied (Fig. 22).

The filling or repair mortar must be a cement-based mortar modified with polymers and reinforced with non-metallic fibers. The filling must be carried out in sequential layers of 2 cm maximum thickness. The repaired area must be finished with a metal trowel, leaving the surface with the same alignment and texture as the renovated part, without visible undulations.

A structural check showed that the tensile stresses in the cantilevered region are up to five times higher than the stresses admitted in the service limit state. Because of this, it was recommended to "sew" the cracks reported in Fig. 15 in the upper part of the cantilevered section with carbon fiber along the entire perimeter of the marquee, with the function of controlling the opening of these cracks. The aim was to minimize the incidence of increased deformations in the future, as has already occurred in a section of the cantilevered region of Block 11 of the marquee, where there was a shear rupture of a section of the slab.

Carbon fiber blanket must be applied over the entire perimeter composed of the beams between pillars that support the cantilevered marquee along the 18 modules. The ratio of carbon fiber to be placed is equivalent to a width of 60 cm per linear meter of the perimeter mentioned above. The carbon fiber fabric pieces, having a density of 600 g/m^2, a width of 30 cm and a length of 60 cm, were placed with 20 cm spacing between them. The carbon fiber reinforced composite was designed to arrest the cracks. Figure 23 illustrates the specified configuration.

6 Final considerations

The focus of this article was a case study of the inspection, diagnosis and rehabilitation project of the Ibirapuera marquee, located in São Paulo, Brazil. It is a structure designed by architect Oscar Niemayer in 1952 and is an important icon of the modernist movement in worldwide architecture.

This work showed the main problems encountered and the solutions implemented as a record and important example of detailed inspection of a construction with historical significance. Various inspection methods were applied to support the diagnosis of the main problems encountered.

As this construction has been in operation for more than 50 years, the need for intervention is expected, as was

Fig. 22 Diagram of positioning and securing the mold
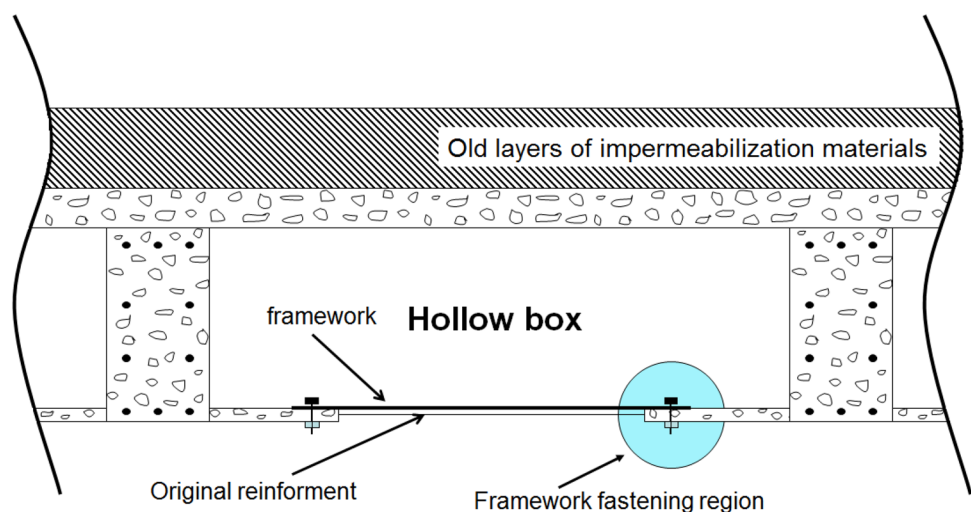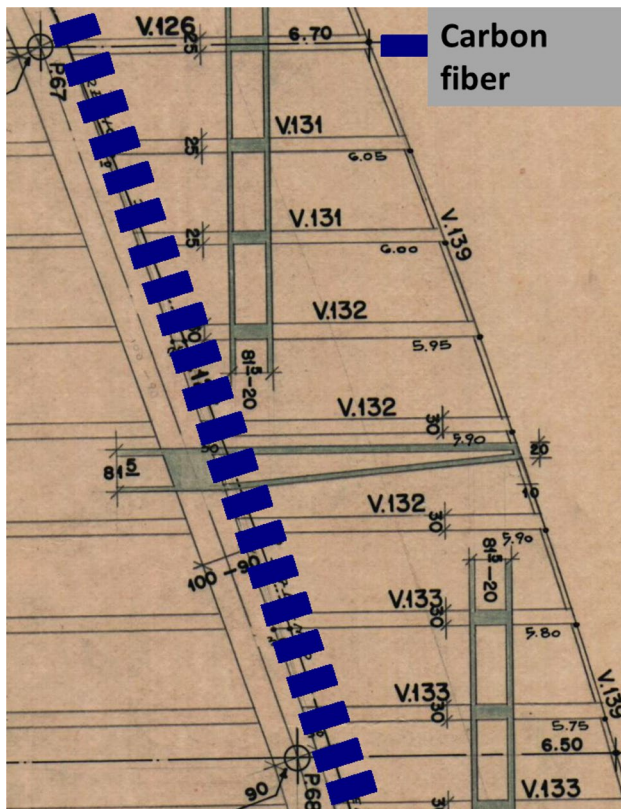
Fig. 23 Carbon fiber orientation in the proposed reinforcement for the entire marquee perimeter

described in the description throughout this work. The following conclusions should be highlighted:

- After 52 years in operation, the carbonation front has gone beyond the thickness of the cover at all measuring points on the pillars. This leads to the conclusion that carbonation is the degradation mechanism that caused corrosion in the reinforced concrete structure.
- There is a need to remove excess loading of the slab due to the overlap of waterproofing systems.
- There is a need for repairs and rehabilitation of corroded reinforcements in pillars, beams and slabs.
- The entire concrete structure of the marquee needs to be protected with the use of high-efficiency paints to drastically restrict the entry of water and oxygen into the concrete, stagnating the process of degradation by reinforcement corrosion.

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