The reinforcement of foundation in a building with 7 floors after 20 years

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ABSTRACT: During the design life of buildings, events can cause the structure to move, the occurrence of differential settlements of the foundation can lead to pathological manifestations that affect structural stability; thus, the monitoring of settlements makes up an important quality control activity throughout the lifetime of the structure. Therefore, the actual work presents the case study of a 7-floor building that showed pathologies after 20 years of its construction, the pathologies were analyzed, and the reinforcement and the monitoring of settlements were presented. From the study, it was verified that the pathologies occurred due to an external post-construction event, this fact demonstrates the importance of carrying out periodic inspections of the structure and the elements close to it.

KEY WORDS: Foundation, Settlements, Pathology, Monitoring, Reinforcement.

1 Introduction

In the building construction context, we need to acknowledge that they are subject to pathologies, having more repercussions when they occur in large proportions, causing visible consequences in the buildings. According to Milititsky et al. (2015), the incidence of anomalies is frequent in small and medium-sized works, because of poor planning and the absence or inefficiency of construction quality control.

According to Ioshimoto (1988), pathological manifestations can originate at any stage of the construction or use of the building, being closely related to the level of quality control required at each stage. In this matter, an effect that often leads to pathologies in buildings is the occurrence of vertical movements in the foundations, especially when they lead to great distortions between the supports, the self-described differential settlements.

Therefore, measuring settlements on building supports is a quality control action, as it allows identifying the actual behavior of the soil, subjected to loads from the superstructure, verifying the performance of foundations, and the safety of buildings. Thus, it is evident the importance of accomplishing efficient monitoring and quality control of the building at all stages of construction, from design to its finish.

In this context, the present work aimed to investigate pathologies that occurred in a 7-floor building in the city of João Pessoa/PB, which occurred 20 years after its construction, as well as to expose the proposed reinforcement elaborated for the foundation. In this study, the monitoring of settlement that was carried out before and after the reinforcement was also presented, to verify the stability of the foundations.

2 Study of the causes of pathologies

Pathologies in constructions can occur immediately or can manifest themselves after many years of use of the building (Deutsch 2011),originating from failures committed during the activities of the construction process and after the use of the building. According to Helene (1992, apud Giacomelli, 2016), the construction and use process can be divided into five stages: planning, design, manufacturing of materials and components outside the construction field, execution, and use. In this way, the source of pathologies can be caused by failures that occurred in any of these steps.

The occurrence of pathologies can be associated with many factors, such as design aspects regarding the understanding of the proper behavior of the soil, and techniques related to the construction process. Pathologies can also arise as a consequence of events after the completion of construction, following completion of work, buildings can be subjected to events that can lead to destabilization of buildings, such as changes in the loading acting on the structure, performing a movement of soil mass in the vicinity, the occurrence of vibrations or shocks, as well as the degradation of the foundation elements (Milititsky et al. 2015).

Plus, there is also the beginning of leakage in the soil, close to the foundation as a post-construction event that can lead to serious damage to the structure. The occurrence of water or sewage leakage, or changes in the water table can lead to an overload of the soil that causes its movement, which directly affects the performance of the foundation, harming the entire structure, therewith, this effect is aggravated when the soil is collapsible, because of increased moisture content to a critical value, the soil is susceptible to loss of its macro-void structure by the structural collapse which leads to additional settlement caused by soil saturation. (Milititsky et al. 2015; Rebello 2008).

3 Importance of Settlements Control

Settlement is described by NBR 6122 (2019) as “the absolute or relative descending vertical displacement of points on the structure”. The specific differential settlement (angular distortion) is the relationship between the difference in settlement of two supports ($\Delta\rho$) and the distance between them (L), this is the most damaging settlement to the structure when compared to the total settlement that is uniformly suffered by the structure.

The supports of all constructions are subjected to the occurrence of settlements, therefore, there are permissible limits of settlements, which can cause problems in the performance and safety of the structure. In Figure 1, the allowable total settlements are presented as a function of surface soil and type of shallow foundation according to Skempton et al. (1955) and Figure 2 presents angular distortion limits recommended by some authors.

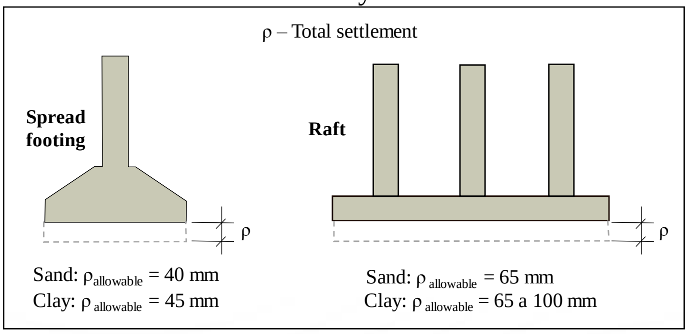
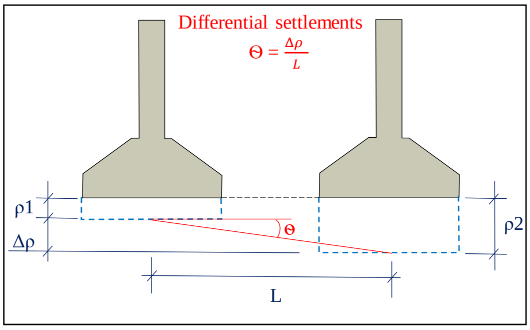


Figure 1- Allowable total settlements according to Skempton and MacDonald (1956)



Damage / Author	Cracking in walls and partitions	Strutural damage
Skempton e MacDonald (1956)	$\frac{1}{300} < \theta \le \frac{1}{150}$	$\theta > \frac{1}{150}$
Meyerhof (1956)	$\frac{1}{500} < \theta \le \frac{1}{250}$	$\theta > \frac{1}{250}$
Polshin e Tokar (1957)	$\frac{1}{500} < \theta \le \frac{1}{200}$	$\theta > \frac{1}{200}$
Bjerrum (1963)	$\frac{1}{500} < \theta \le \frac{1}{150}$	$\theta > \frac{1}{150}$

Figure 2- Threshold values of angular distortions Δρ/L for structured buildings and armed bearing walls. Adapted from I.S.E. (1989) apud Velloso & Lopes (2011)

In this context, monitoring settlements is an important practice in the quality control of constructions, as it allows identifying the behavior of the soil when subjected to loads coming from the superstructure, making it possible to verify the performance of foundations. According to NBR 6122 (2019), performing foundations is verified through at least the monitoring of the structure's settlements, the standard makes it mandatory to carry out this monitoring in the following cases:

a) Structures in which the variable load is significant, concerning the total load, such as silos and reservoirs;

b) Structures with over 55.0 m in height from the ground floor to the roof slab on the habitable top floor;

c) Ratio of height over width (smallest dimension) greater than four;

d) Unconventional foundations or structures

However, the importance of monitoring settlements in all types of works is highlighted, as due to the dynamics of the soil and the variety of its geotechnical parameters, likewise, foundations may behave differently than expected in the project, besides the possibility of post-construction events that could lead to the destabilization of the structure.

4 Characterization of the site

The building analyzed in the present work is a condominium in the Jardim Cidade Universitária district, in João Pessoa/PB, as shown in Figure 3. The building is composed of seven floors on pilotis, with a reinforced concrete structure composed of 17 columns whose loads are transmitted to the ground using a footer enlarged, as illustrated in Figure 4.c).

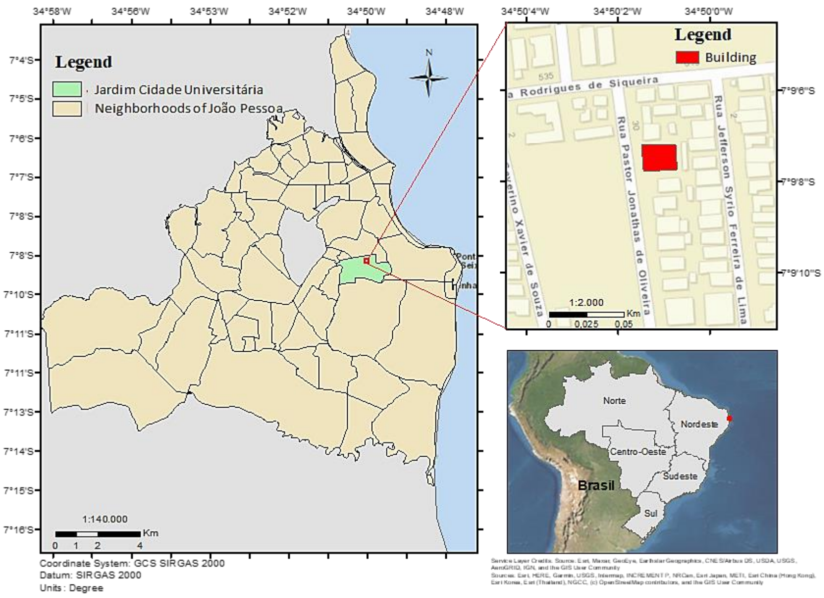


Figure 3 - Building Location

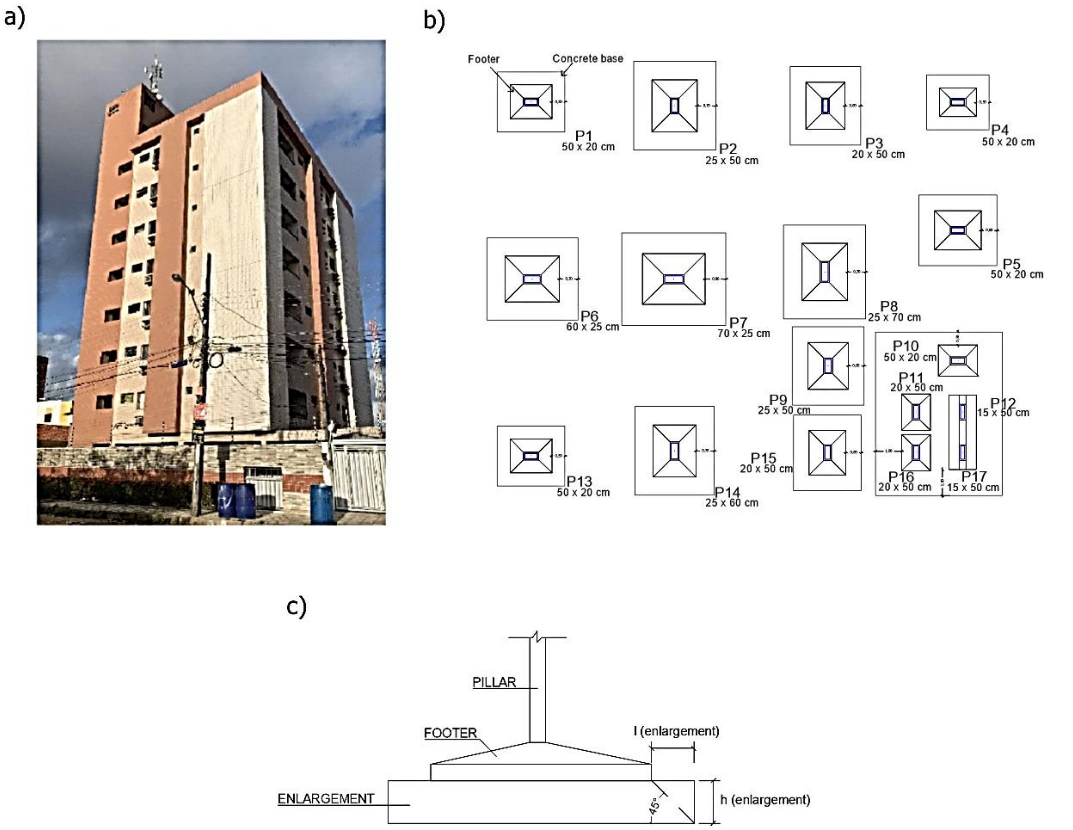


Figure 4 – a) Image of the Building b) Location of pillars and footings c) Detail of the footing enlargement

5 Geotechnical and geological characterization of the área

5.1 Soil stratigraphy

SPT tests were carried out in the study area, from these probing tests, it was possible to identify the soil stratigraphy. As shown in Figure 5, the soil is formed by the following layer arrangements: sandy embankment with shrapnel, soft, of variegated color (0.00 to 1.80 m); sandy clay silt, soft, light brown color (1.80 to 3.90); clayey sandy silt, soft, of variegated color (3.90 to 5.20 m); clayey sandy silt, stiff, orange (5.20 to 8.30 m); clayey sandy silt, hard, variegated in color (8.30 to 11.00 m); and clayey sandy silt, with gravel and laterite, hard, variegated in color (11.00 to 13.45 m). It should be noted that the water level for the depth probed was not found.

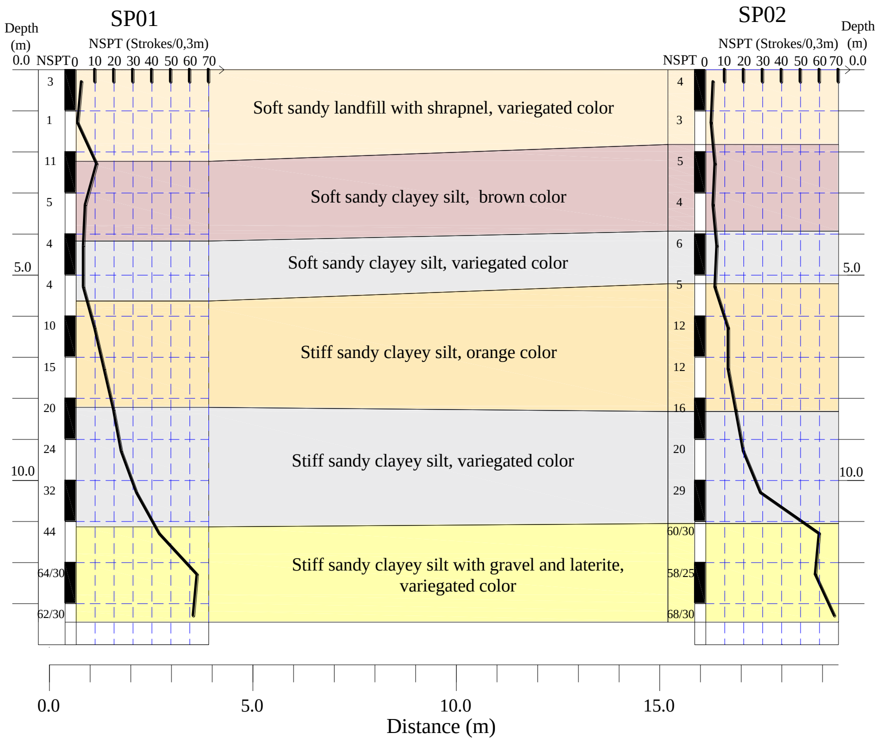


Figure 5 – Geotechnical Profile

6 Pathologies presented in the building

The building under study is a 7-story residential edifice that began to appear visible pathologies after 20 years of use. Pathological manifestations were observed in the internal and external environments of the building, as well as in some structural elements. In Figure 6 some pathologies identified in the building are presented, one can verify the occurrence of cracks in the floor, cracks in the walls, falling plaster lining, and shattered window glass. Cracks were also confirmed in the structural elements (pillars and beams) as shown in Figure 7.

Figure 6 – Pathologies presented in the external elements

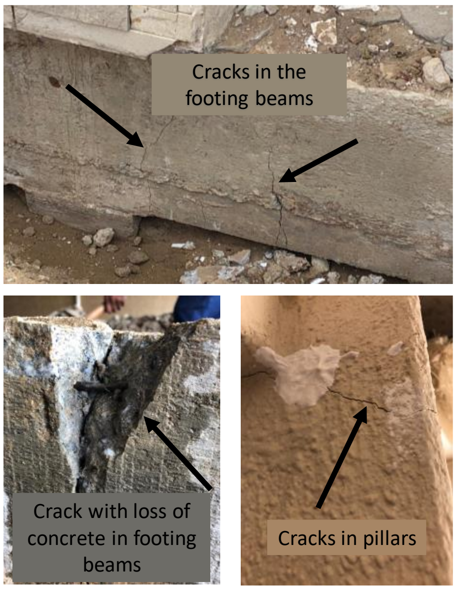


Figure 7 – Pathologies presented in the foundation elements

According to reports from residents of the condominium, the pathologies started in September 2020, in the same period that a leak was identified, from the cistern installed next to the building. Figure 8 shows the location of the cistern, the simulation of the leakage, and the places where pathologies were identified, it can be seen that the pathological manifestations were concentrated on the front facade of the building.

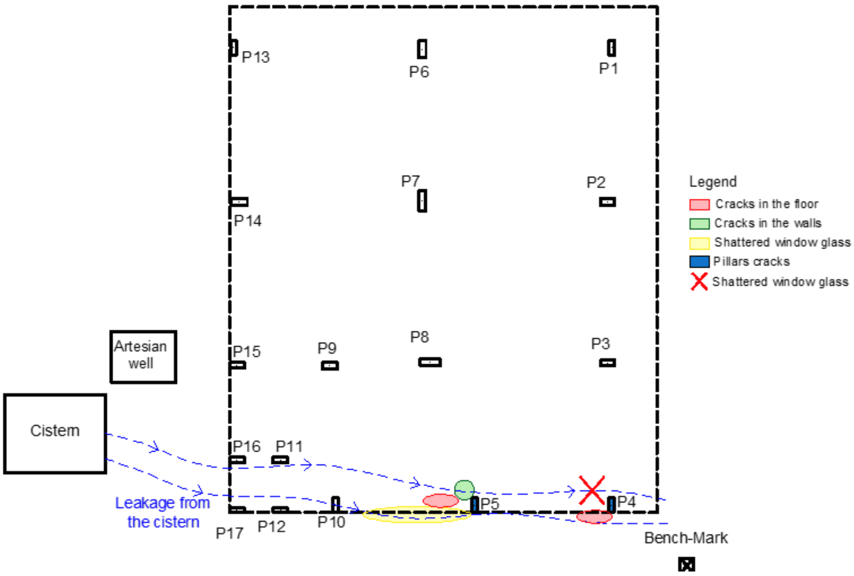


Figure 8 – Location of the cistern that had leaks, and location of pathologies

Thus, the occurrence of building pathologies can be attributed to this water leakage that happened in the building's vicinity, which caused the ground to flood and consequently reduced the bearing capacity, harming the building’s structure. The geotechnical profile verified the existence of an embankment layer of approximately 2 meters; this porous material in the surface layer of the land may have contributed to the percolation of water affecting the structural elements on the front facade of the building. Given these considerations, the occurrence of pathologies in the studied building can be attributed to the leaking of the cistern that occurred years after the construction.

7 Reinforcement solution for foundations with visible damage

Based on the analysis of the problems observed, it was verified that the P4 pillar presented damage to its structure in a more critical way, with a greater amount of cracks and greater damage to the footing beams connected to it. Thus, it was proposed to carry out the reinforcement of the foundation of the P4 pillar, with the execution of micropiles joined by employing capping blocks connected by beams.

Given the load presented for the aforementioned pillar presented in Table 1, the reinforcement project included the execution of 8 micropiles of 200 mm in diameter (2 blocks with 4 piles each), spaced 60 cm axis by axis, designed with an average length of 9 m, for a working load of 98,066 kN (10 tf). Together with the piles, the execution of the capping blocks was planned, whose connection with the pillar took place through a beam as shown in Figure 9 and Figure 10.

Table 1 – Acting loads and dimensions of the P4 pillar foundations

Loads	631,55 KN
Footing	1,40 x 1,10 m
Enlargement	2,40 x 2,10 m
Tension on the soil	137,29 KPa

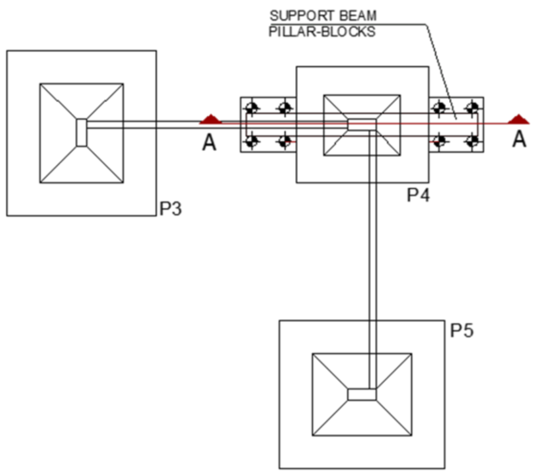


Figure 9 - Reinforcement Project

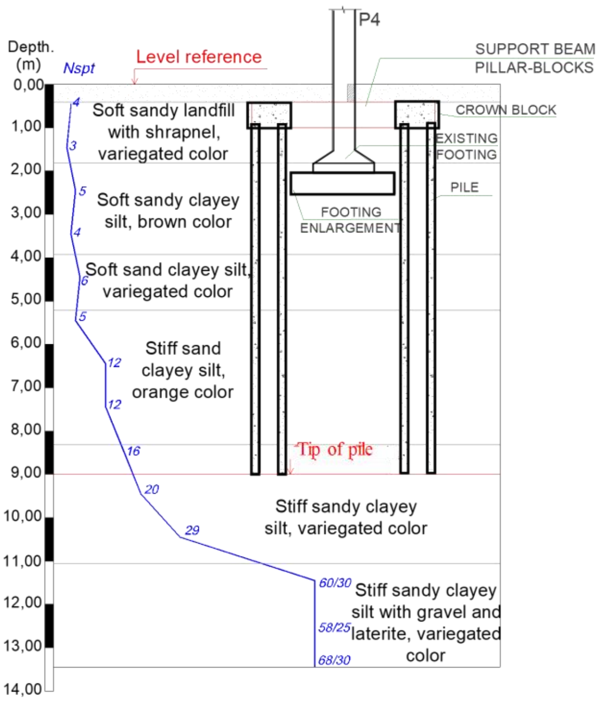


Figure 10 - AA Section - Geotechnical Profile

7.1 Monitoring of settlement

In monitoring settlements, the measurement was performed using the geometric leveling method, in which the difference in the level of two points from horizontal sights is measured, by reading vertical staff gauge positioned at each point as illustrated in Figure 11. For the monitoring of the settlement, a level reference called Bench-Mark was initially executed. The Bench-Mark is a reference point that must be immovable, not being able to be influenced by the movement of the structure, therefore, it is executed with the installation of a steel bar in deep layers of the ground, being protected by a tube to avoid contact with ground movements.

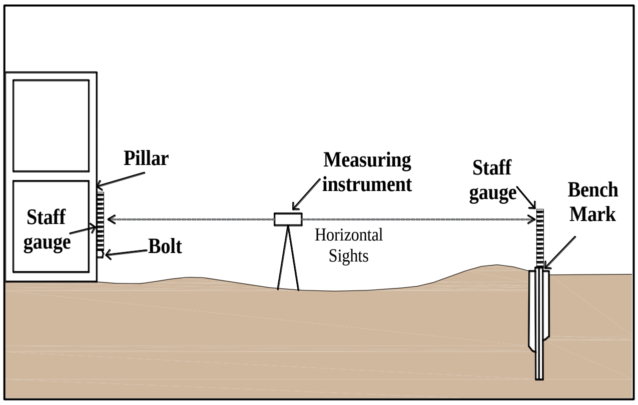


Figure 11 – Illustration of the geometric leveling method

7.1 Settlement Measurements

The monitoring of settlements was carried out on pillar P4, which needed reinforcement. In addition to that, five measurements were taken, the first on 11/06/2020 and the last on 09/24/2021. In Figure 12 the settlements suffered by the P4 pillar are presented.

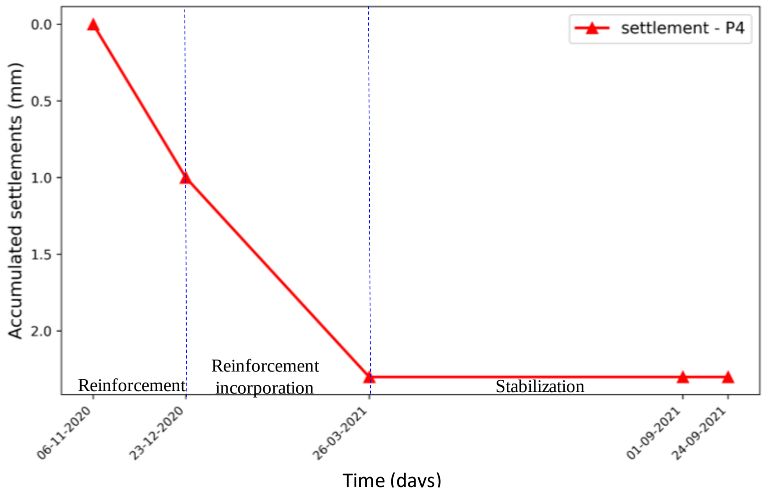


Figure 12 – Settlement suffered by the P4 pillar

The reinforcement of the P4 pillar was started on 12/14/2020 and ended on 12/22/2020, thus, the first measurement was performed before the reinforcement, on November 6th, and the second measurement was performed on the day after the completion of the booster, on December 23, in the interval that includes the booster performance, a settlement speed of 21.28 µ/day was verified.

From the subsequent measurement (26/03/2021), there is a decrease in the settlement speed, with a value of 13.98 µ/day, this stretch comprises the period of incorporation of the reinforcement, in which there is the redistribution of loads on the pillars. Finally, two measurements were performed in September 2021, one year after the occurrence of the leak and more than 5 months after the reinforcement was performed, considering the results, it was found that the settlement of the P4 columns has stabilized.

8 Final considerations

Given the arguing presented in the case studied, it is important to carry out frequent inspections of the lower reservoirs, to avoid the occurrence of leaks that may flood the soil and reduce the load capacity of the foundations, as seen in the building analyzed, the development of leakage can destabilize the structure of the building and bringing economic losses, furthermore, causing discomfort and affliction to the residents. Thus, it is essential to carry out periodic supervision, checking the physical conditions of the structure, in order to avoid future problems and ensure a longer lifecycle and safety of the construction.

Moreover, monitoring the settlement of foundation elements is an important measure, especially when there is some activity close to the building that may affect its structure, as settlement monitoring is an action to control the performance of foundations that allows for verifying the behavior of the infrastructure in the face of loads coming from the superstructure and checking the effects caused by events that occur around it.

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