

# Control of Reinforcement Concrete in Pile Caps over Steel Piles – Case Study

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**Abstract:** This paper presents a case study about the challenges and good building practices involved in the execution of structural reinforced concrete pile caps over steel piles. The structural reinforcements were carried out in a project with 3 residential towers of approximately 30 floors each, located on the seafront. As a result, it was observed that mix design to define the type and characteristics of concrete, prototype event, particularities of the construction site, executive procedures employed, as well as the systematic monitoring and control of concreting events and other constructive stages were determining factors to promote the safety and quality of reinforcement services in accordance with the assumptions and design requirements.

**Key words:** structural reinforcement; pile caps; concrete

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## 1. Introduction

It is located on more than 7000 square meters of land about 250 meters off the coast of Victoria City in eastern Brazil. The project consists of 3 residential buildings, totaling 166 entrances. Building 1 has 33 floors, building 2 and building 3 have 31 floors respectively.

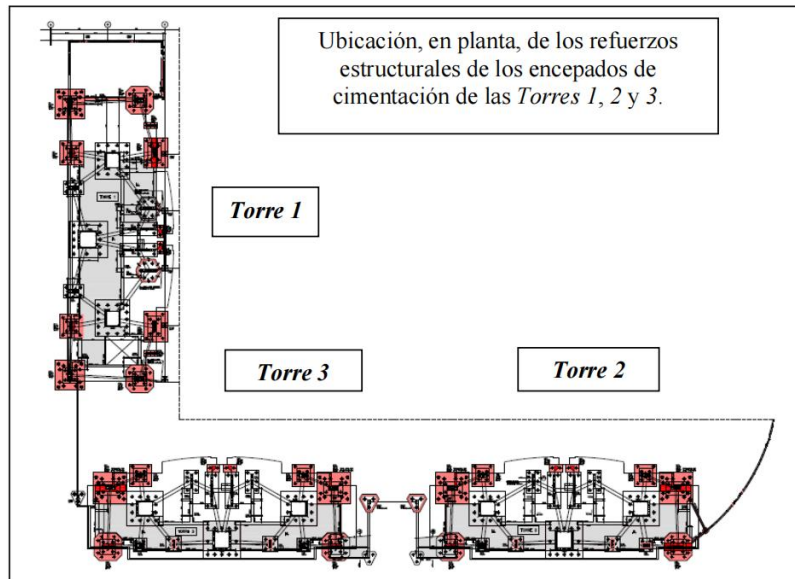
The construction of the residential area was completed at the end of 2010 and there are still two levels of parking under the projection of the tower and the public use area, both above the water level, i.e. the use of auxiliary pressure tanks is not required. The structural reinforcement of the foundation pile caps of the residential towers of the project was carried out during the first half of 2018, between January and May, due to the observation of structural non-compliance and the verification of a partial collapse of the recreational area of the project.

This paper introduces the research, test, originality, good building practice, procedures and activities for implementing these reinforcing bars, with emphasis on the quality control of concrete.

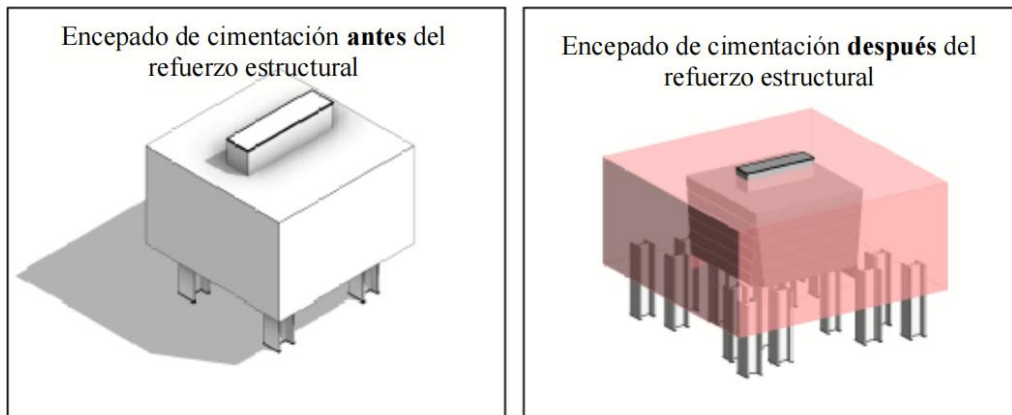
## 2. Basic Data of Reinforcement Works and Concrete Traces

The structural reinforcement project for the foundation pile caps of residential towers has been developed in accordance with the recommendations of ABNT NBR 6118:2014 standard. This project considers the reinforcement of 20 structural elements as highlighted in Figures 1 and 2, which show the plane figure and perspective drawing of the structural

reinforcement (highlighted in red), respectively.



**Figure 1.** Plan details of the structural reinforcement location of the foundation pile cap of the residential tower.



**Figure 2.** Generic detail in perspective drawings (before and after) of the structural reinforcement of the foundation pile caps.

In Figure 2, it can be seen that additional metal posts are nailed to the periphery of the existing pile caps. A total of 152 W200×86 and W250×115 profile piles were driven, with working loads of 194tf and 258tf respectively. The execution length varies from 20 meters to 22 meters. The foundation reinforcement project was developed according to the requirements of ABNT NBR 6122:2010.

The compressive strength of the concrete specified for the reinforcement of the elements was  $f_{ck} \geq 40\text{MPa}$ , modulus of elasticity  $E_c \geq 32\text{GPa}$ , for a stress corresponding to 14MPa (0.35 of  $f_{ck}$ ), with a maximum w/c ratio of 0.50. According to ABNT NBR 6118:2014, sub item 6.4 "*Environmental Corrosivity*" and sub item 7.4 "*Quality of Coated Concrete*", the specification meets the strong environmental corrosivity level (CAA III) required by the project.

Therefore, according to the project premise, the availability and demand of investment in this area and the particularity of the project, a dose study was conducted. ABNT NBR 12655:2015 and ABNT NBR 15823:2017 standards on self compacting concrete part 1 to 6 were used in the study. In addition to these standards, it also served as a reference to the IBRACON method guidelines (Tutikian, B.; Helene, P., 2011) for development of a self-compacting concrete, with

dispersion type SFII, which is presented in Table 1.

**Table 1.** The amount of self compacting concrete in dry materials: for 1m<sup>3</sup> concrete,  $f_{ck}$  at 28 days is  $\geq 40$ MPa.

Dose of Self Compacting Concrete, Dispersion Grade SFII	Designed for $f_{ck}$ 40MPa
Cement consumption per cubic meter (CP III-40-RS)	425kg
Water/(Cement+Addition) Ratio	0.43
Water	183kg
Fine Sand	329kg
Medium sand	494kg
Stone 0	960kg
Multifunctional additive	2.5kg
Additive superplasticizer <sup>1</sup>	1.5kg

(1) Completely added at the concrete plant. Only in the case of eventual dispersion corrections, the additional use of this admixture was allowed on site, in small quantities, depending on the need.

The visual appearance of concrete can be observed in Figures 3, 4 and 5, which demonstrate the dispersion, J-ring passing ability and L-box passing ability tests conducted according to ABNT NBR 15823-2:2017, ABNT NBR 15823-3:2017 and ABNT NBR 15823-4:2017 respectively. In addition, in Figure 3, it is also possible to observe the visual stability index (VSI) of the concrete that was developed especially for the structural reinforcement of the foundation pile caps of this development project.



**Figure 3.** Details of the dispersion test performed in the laboratory during the dosing study.



**Figure 4.** Details of the ability test to pass the L-box conducted in the laboratory during the dosing study.



**Figure 5.** Details of the ability test to pass the J-ring conducted in the laboratory during the dosing study.

In order to minimize the possible inconsistency related to the compressive strength and elastic modulus of concrete, the relevant personnel agreed in advance that in the event of structural reinforcement pouring, after leaving the premixing company (where the mixing water is properly controlled by the hydrometer), no water will be added to the concrete truck.

Thus, on site, after performing the acceptance tests (dispersion measured by slump flow test), if there is a need to correct the dispersion of the concrete, it will be necessary to do slump flow test, and this would be done only by means of the admixture, through the technical support of the consultant.

However, before pouring the reinforcement of the foundation pile caps, a prototype event (simulation in a concrete mixer) was carried out to evaluate the behavior of the concrete studied in the laboratory under field conditions. It was observed that the transport time of the concrete from the ready-mixer to the construction site was approximately 25 minutes, a distance of 9.6 km, and the concrete pouring time was a maximum of 30 minutes per truck.

During the prototype casting event, cylindrical specimens were also cast for compressive strength tests at 3, 7, 14, 28 and 45 days of age and modulus of elasticity at 28 days, as shown in Figure 6.



**Figure 6.** Detail of the cylindrical specimen molds in the prototype casting for compressive strength tests and modulus of elasticity tests.

Based on the laboratory dosing study and the favorable results of compressive strength and modulus of elasticity obtained from the above prototype, the structural reinforcement of the pile caps was pouring according to the steps detailed in the execution procedure later.

### 3. Executive Procedures

The executive procedures used in this case study are based on current Brazilian standards, mainly ABNT NBR 14931:2004 and good building practice.

This work starts with placing metal piles in the areas around the foundation piling, which will be reinforced as shown in figure 2. These piles vary in depth from 20 m to 22 m and are secured by a suitable pile driver located between the plates, as shown in Figure 7.



**Figure 7.** Details of a suitable pile driver positioned between the plates to perform piling services for structural reinforcement piles.

Due to the difficulty of access, the dimensions of the driving equipment and the existing interference at the site, some additional services were necessary for the execution of this reinforcement step, including:

- ✓ Pre support the road panel on the first floor, where the driving equipment is supported;
- ✓ Adjust all piling equipment so that the tower height of the pile driver is greater than the distance between the plates (right foot);

- ✓ Execute localized demolitions and holes in the first floor slab to allow the driving of metal piles;
- ✓ Pre segmentation of metal piles (variable length of 2 to 4m) to locate the profile of the drive site by drilling;
- ✓ Use a supplement (on the pilot's head helmet) to aid in contour articulation.

In this way, the metal segments of the piles are driven and immediately welded to the rear segments as the work progresses. Figure 8 illustrates the execution of the work and the piles driven in the perimeter of one of the foundation pile caps. In the latter case, to improve the visualization, the recording of the image was made after the excavation of the surrounding area of the block.



**Figure 8.** Detail of the execution of the piping works (on the left) and of the metal piles driven around the foundation block to be reinforced (on the right).

After driving all the piles of a given foundation pile cap, the excavation was carried out. For this purpose, a system with water level dewatering pumps was installed in the region around the block or pile cap (this system would be deactivated only after emptying and filling). The excavation is carried out with small equipment. In most cases, it is carried out manually under interference and difficult access conditions.

Subsequently, 5cm thick concrete was ballasted, the dimensions of the existing pile driver were measured, and the possible eccentricity of the existing pile (under load) was verified by the terrain, as shown in Figure 9.



**Figure 9.** Details of dimensioning of existing pile drivers and metal piles after concrete excavation and construction.

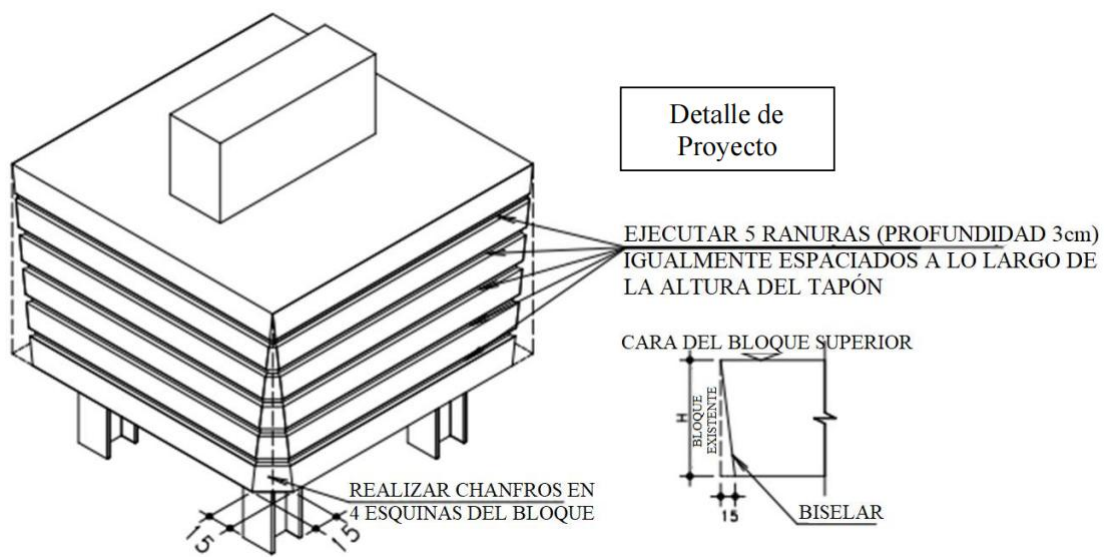
At the end of this stage, it is need to cut the pile. The pile top should be 35cm higher than the bottom elevation of the reinforcement block, and prepare the side of the foundation pile, as shown in Figure 10. At this stage, according to the requirements of the structural design, the edges and sides of the block were chamfered and grooved, and all surfaces except the bottom could not be identified.



**Figure 10.** Details of the execution of the chamfers and grooves on the edges and lateral surfaces of the foundation pile caps.

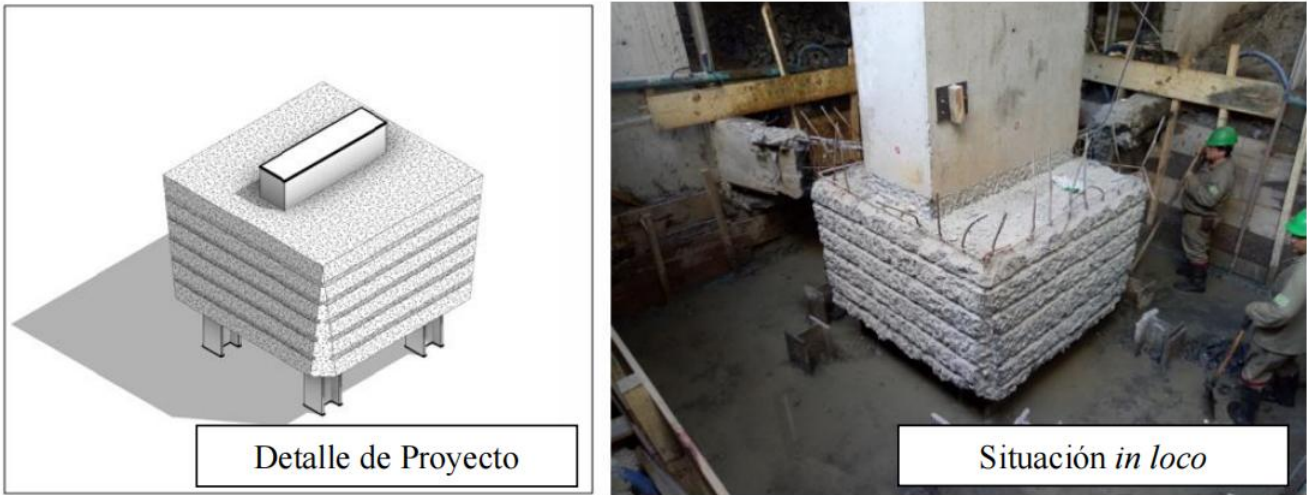
The execution of the chamfers and grooves on the sides of the existing pile caps were essential and very important, as they were intended to guarantee the quality of the pouring joint at the old concrete/new concrete interface (to be cast) and to collaborate in the transmission of forces. The execution of the chamfers on the lateral edges provided a cone-shaped geometry that dispensed with the verification of the bond between the existing block and the structural structural reinforcement.

It was recorded that the grooves were executed with a depth of 3cm along the entire lateral surface and the chamfers of the lateral edges with dimensions varying from 0cm (on the upper face) to 15cm (on the lower face of the block), as shown in Figure 11.



**Figure 11.** Project details showing the location of grooves and chamfers.

Figure 12 shows the foundation block after concrete surface treatment.



**Figure 12.** Details of the surface treatment of the foundation block. Project details (left) and on-site situation (right).

After the surface treatment, they started the reinforcement of the structure by a professional company and certified workers, and accompanied and thoroughly verified the project, involving the location, measurement, reinforcement quantity and other quality control stages, including the use of multi-support type spacers on the sides and bottom of the block, in order to ensure the overlap specified in the project (40mm).

It was recorded that the steel bars used in the structural reinforcement of the pile caps (measurements 25mm, 20mm, 16mm and 12.5mm) were delivered to the site cut/bent and duly identified. Figure 13 shows the execution of the pile cap reinforcement work.



**Figure 13.** Details of the execution of the reinforcement work of the foundation block.

After reviewing and releasing the assembly by the engineering team, the assembly of the wooden and support formwork began, as shown in Figure 14. All these works were also supervised in terms of level, plumb, dimensions, closure and watertightness.





**Figure 14.** Details of the shapes of the structural reinforcement of the foundation pile caps.

After completing the structural reinforcement work, according to the detailed dose in item 2 of "*Basic Data of Reinforcement Project and Concrete Trace*" in this paper, the reinforcement of structural members was evacuated by self-compacting concrete pumping. Figure 15 shows the visual appearance of the concrete observed in the field.



**Figure 15.** Appearance of self compacting concrete used to reinforce structural formwork.

At this stage, the concrete must be projected at a low speed to prevent air from accumulating on the lower surface of the block, thus avoiding possible hidden emptying failures. In order to avoid the disqualification of this property, the concrete at the lower part of the block is slowly projected to one side of the block and moderately vibrated with an immersion vibrator with a diameter equal to 40mm.

It is important to record that the treated surface of the existing blocks in the new and old concrete interface area was previously cleaned with pressure water to remove all dust, powdery materials or any other contaminants. Self compacting concrete shall be projected onto a clean surface under dry saturated conditions.

Figure 16 shows a reinforcement emptying event of a foundation block, which was conducted with self compacting concrete, while respecting the premise mentioned in the previous paragraph.



**Figure 16.** The details of the foundation block reinforcement emptying are made of self compacting concrete.

After receiving the concrete at the site, according to the recommendations of ABNT NBR 15823-2:2017, a dispersion test (slump flow test) was carried out on all concrete mixers by a professional laboratory. In these cases, the dispersion grade or visual stability index obtained is observed and analyzed. As the acceptance standard of fresh concrete, or as the visual aspect of concrete, the concrete should have cohesion without obvious seepage or separation. As mentioned above, when dispersion needs to be corrected, additive superplasticizer is hardly used. In any case, dispersion will not be corrected by adding water at the construction site.

In addition to the above receiving tests, as far as possible, technical visits were made to the concrete metering station in order to accompany the concrete production process, including input control, testing for the determination of the moisture content of fine aggregate, batching, mixing and other stages.

In order to minimize the risk of cracks, the side wall shall be kept for 3 days after emptying to prevent the surface evaporation of water. In addition, by spraying drinking water, the upper surface of the block is always kept wet to ensure ideal curing conditions.

Subsequently, after the removal of the formwork, a thorough inspection of all surfaces of the reinforcement being executed and the area of the new/old concrete interface was carried out. According to records, no nonconformities related to emptying faults, cracks, etc., were found.

Figure 17 shows the appearance and surface finish of hardened concrete used to reinforce the foundation cushion.



**Figure 17.** Details of the appearance and surface finish of the reinforced blinding concrete.

Then, after inspection, the pile caps are released to cover. Mechanical compactors are used for this purpose.

As for the technical control of concrete, according to Article 6.2.3.1 "Control of Concrete Per Total Sample (100%)" of ABNT NBR 12655:2015 standard, using the total sample standard, 6 test pieces are poured for each concrete mixer truck to conduct the compressive strength test at 7 days, 28 days and 45 days (2 days per age).

The specimens were emptied, stored and transported in accordance with ABNT NBR 5738:2015. It is worth emphasizing that the specimens evacuated within 45 days can be tested only when the disqualification related to 28 day compressive strength is determined. The results obtained will be detailed later.

#### 4. Achievements

Taking into account the above implementation procedures and good building practices, the achievements in the integrity and quality of the concrete used are introduced.

After emptying and visual inspection of all reinforcements of the foundation cushion, it was found that these reinforcements did not crack due to shrinkage or any other relevant emptying failure that might damage their integrity, durability and service life of the structure.

Regarding the technological control of the concrete applied in the structural reinforcement of the pile caps of the residential towers, Figure 18 presents graphically the results of the concrete compressive strength at 7 and 28 days of age of the 66 truck mixers (100% sample), in the form of a chart of individual values.

It can be seen that the average intensity obtained is 45.2MPa, the standard deviation is 2.9MPa, the coefficient of variation is 6.4%, and the extreme value is 40.7MPa (lowest) to 53.9MPa (highest). Considering the resistance specified in the project, all results are consistent.

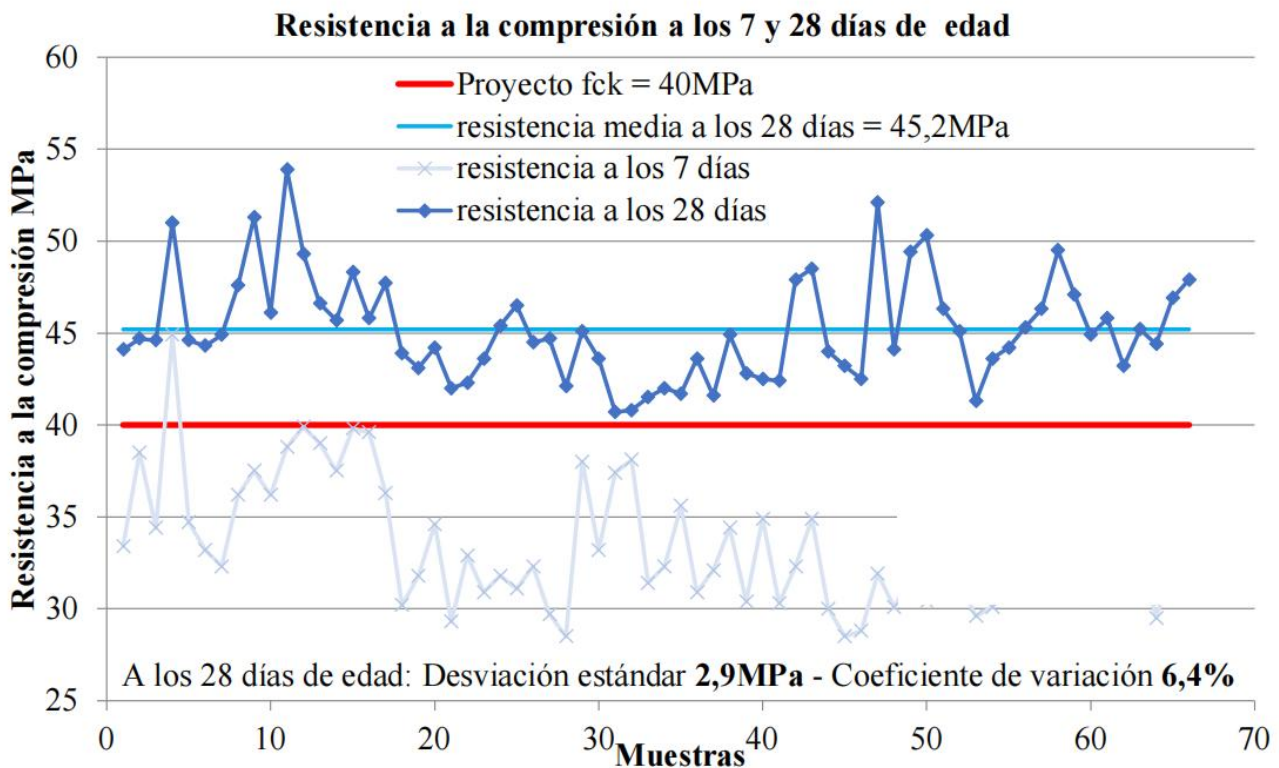


Figure 18. Chart of individual concrete values  $f_{ck} = 40\text{MPa}$ , self-compacting concrete used in the structural reinforcement of the foundation pile caps.

## 5. Final Consideration

The purpose of this paper is to emphasize that simple suggestions, previous studies, and systematic control and technical support for the activities before and during the pouring activities, which are in line with current standards and good building practices, are sufficient to promote complete structural elements and satisfactory final results according to the requirements of the project.

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### Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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