Building Project using Post-Tensioning

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Resume

Nowadays building flexibility is an aspect to be taken into account at the idealization and project stages. The number of buildings that throughout their lifetime have more than one type of use is increasing and for this, an adaptation of structural project is necessary for that different uses. One way to increase buildings flexibility is by increasing free spans inside it throughout the use of a Post-Tensioning System.

This work represents a structural project of a reinforced concrete building, using post-tensioning technique in building slabs to withdraw the interior columns that was part of original architecture project. For this, a special attention was given to the analysis of building slabs, using a multi-way process where cables design, type of cables and the different characteristics of different kinds of slab used, were variables of the process. The objective of this process is determining the most economical solution of slab that meets the usage and technical requirements.

This work was based on the implementation of the new structural regulation, as Eurocode 0 – Bases for Structural Design, Eurocode 1 — Actions on Structures, Eurocode 2 – Design of Concrete Structures and Eurocode 8 — Design of Structures for Earthquake Resistance. Dimensioning and detailing was performed on main structural elements.

Keywords:

Project; Structure; Reinforced Concrete; Post-Tensioning; Eurocodes; Dimensioning.

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1. Introduction

This document presents a structural building project using reinforced post-tensioned concrete slabs, located in Sintra.

In order to increase the building flexibility, the initial arquitectural project was changed, removing the interior columns and creating large spaces inside it. The building is constituted, in terms of vertical elements, for walls in the middle of the building and columns in the outer contour. For the new spans created, between 10 m and 15 m, a post-tensioning system was used in slabs.

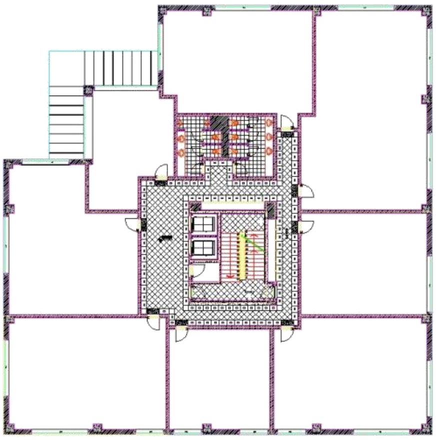

Fig.1 – Building layout without interior pillars.

Repeating a structural solution of a slab in building height, as it was in this project of 6 floors above ground and 1 floor below, needs an optimization from the standpoint of material and weight minimization, to make it more efficient from a structural and economic point of view.

2. Materials and Actions

2.1 Actions

The building structure is made with reinforced concrete and its use is as an office building. The corresponding dead loads and live load used were listed in Eurocode 1.

For the vertical elements sizing, the horizontal action considered was the earthquake type 1, defined by Eurocode 8 response spectrum.

2.2 Materials

The resistance class of concrete used in this project, for the main elements of the structure, was a C35/45. The adopted class corresponds to the lower class that satisfies the requirements of the project and ensures a better relationship between behavior and economy. For foundations, retaining walls and slabs, concrete used have different characteristics, shown in the table 1.

Elements	**Concrete Specifications**
General	NP EN 206-1 C35/45 XC1 Cl 0,40 D_{max} 25mm S3
Post-Tensioned Slabs	NP EN 206-1 C35/45 XC1 Cl 0,20 D_{max} 25mm S3
Foundations	NP EN 206-1 C25/30 XC2 Cl 0,40 D_{max} 25mm S2
Retaining Walls	NP EN 206-1 C25/30 XC2 Cl 0,40 D_{max} 25mm S2

Table 1 – Specifications of concrete used in this project. (1)

The steel used for ordinary reinforcement is of A500NR type, due to the good relationship between its yield tension and its cost compounding with the A400NR. For pre-stressing steel, type Y1860 S7 15.2 was used.

3. Structural Slabs Solution

To determine the best solution of slab that satisfies the requirements of economy and functionality, 4 types of solution slabs were analyzed, flat slab, bands slab, ribbed slab and voided slab. To be able to compare the different solutions obtained it was necessary to limit the maximum elastic deformation to a value set to 0,5 mm. This was necessary to establish one criterion for all solutions.

Flat slab solution, only with one thickness value, has its optimum application field limited to 10 m spans, but nevertheless this type of solution meet the criterion of maximum elastic deformation tax. For it was used a slab with a thickness of 0,45 m and a displacement of post-tensioning cables in plant shown on Figure 2. (2)

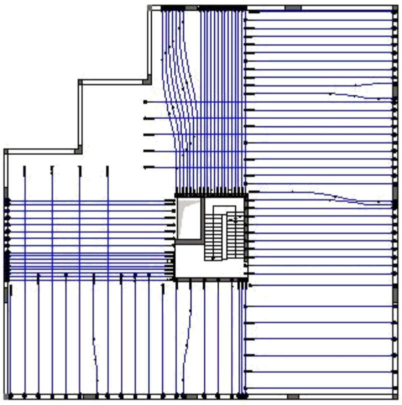

Fig.2 – Post-Tensioning layout in flat slab solution.

The post-tensioning used was cohesive, integrally constituted by 7 strands cables with active anchorages at the outer side of the building and passive anchorages inside the slab. The cross-section of cables consists in straight segments, leveraging the maximum possible eccentricity on the element, in half of the span.

For slab bands solution, with thicker areas of slab (bands), the provision of these can be done in only one direction or in both directions of the principal horizontal directions of the building. In this way two solutions were obtained that meets the initial requirements of maximum elastic deformation, one with bands in one direction and the other with bands in both directions.

The solution with bands in just one direction (solution 1) has two bands adjacent to the central core of walls, in the vertical direction. They have 0,70 m of thickness and a width of 1,85 m. Due to high thickness of these elements, they are great for placing a higher density of pre-stressing steel in plant. The remaining slab thickness has 0,31 m.

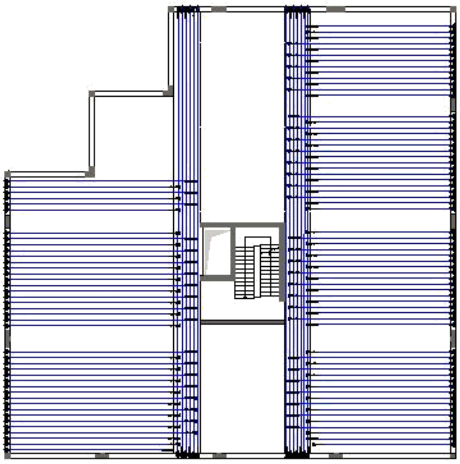

Fig. 3 – Post-Tensioning layout for bands slab solution 1.

In the slab bands, pre-stressing cables with 7 strands was used, whereas in current slab zone 4 strand cables with flat cover was used. The anchorages in the bands were alternating between active and passive, to distribute the tension application between the two ends of the band. In the rest of the slab and for the 4 strand cables, active anchorages stay in the building outline and the passive anchorages inside the slab. In cross-section of the cables, a parabolic path is used, composed of parabolic sections in the bands and straight sections in other slab areas. Parabolic sections were built so that the walls of the central core absorbs a portion of the post-tension down force, applying two inflection points in the layout, before and after core walls.

The solution with bands in both directions (solution 2) presents 2 bands in each of the two principal directions of the slab, with a thickness of 0,65 m. The width of the bands was conditioned by the architecture of the building and it is 1,85 m in vertical bands and 1,50 m in horizontal bands. The remaining slab panels have a thickness of 0,25 m.

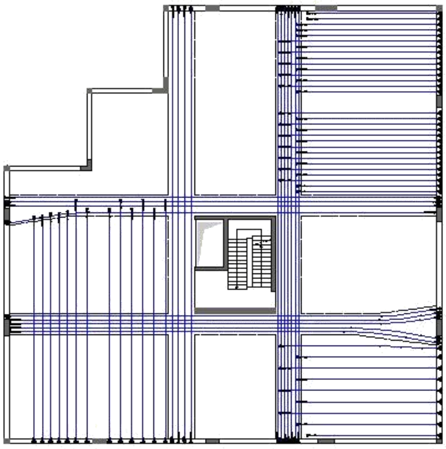

Fig.4 – Post-Tensioning layout for bands slab solution 2.

In the solution presented in figure 4 it was necessary to add post-tensioning cables in bands and in the other slab areas, in order to meet the maximum elastic deformation requirements. The post-tensioning cables used in bands and in the current zone are of the same type and have the same cross-section layout as those used in previous solution (bands slab solution 1).

The third type of slab analyzed is ribbed slab that was built using FG800 FERCA® molds with 40 cm thickness. Apart from the slab voids it is necessary to introduce massive slab areas for shear resistance and for placing a higher density of post-tensioning cables. These massive slab areas were placed on same place of the bands in bands slab solution 2, and on the periphery, along the side of the beam. The total height of both flat slab areas and ribbed areas is 0,50 m.

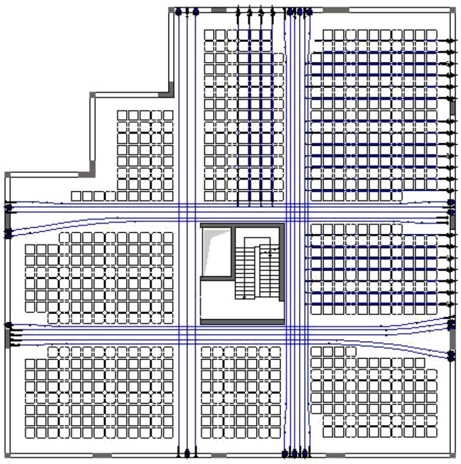

Fig.5 – Post-Tensioning layout for ribbed slab

The post-tensioning for this solution was placed both on flat slab areas and in the ribs. Due to the restrictions of this type of solution, cables adopted in areas adjacent to the central core of walls were 12 strands cables with a cross-section consisting of parabolic sections. Cables used in the ribbed zones of the slab were monostrands cables with straight sections in cross-section of the slab. In the anchorage areas of bands, and due to the restrictions imposed by the contour pillars, an extension of these zones was necessary to accommodate the active anchorages along the contour beam.

The last solution studied is the voided slab. It has the same geometry of flat slab areas and voided zones presented in the ribbed slab solution. This solution is voided with FERCA ® blocks, with a height of 0,34 m, causing the upper and lower blade of concrete to have a thickness of 0,08 m. For each 0,90 m of slab in the lighter area, there is a massive area with 0,15 m width, forming "beams". The total height of massive slab areas and voided areas is 0,50 m.

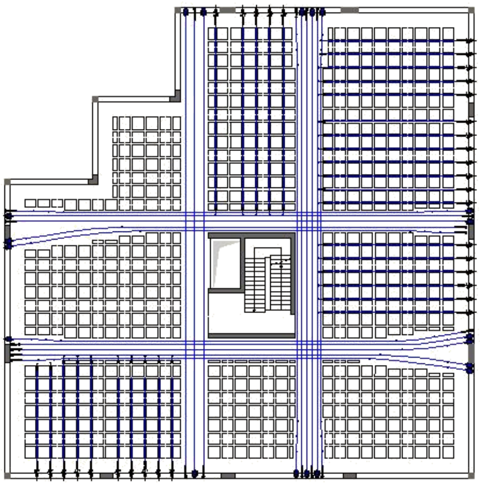

Fig.6 – Post-Tensioning layout for the voided slab.

The post-tensioning adopted to solve voided slab uses the same type of cables for the different zones of slab and the same cross-section layout adopted in ribbed slab solution. This solution only increases the amount of cables in some voided areas, as can be seen in Figure 6.

All solutions presents the same value of maximum deformation, 0,5 cm, and the deformation in the remaining spans is close among themselves. In this role a comparison of the different solutions in terms of quantity of material used was performed, taking into account the ultimate limit state verification performed for each one. The solution that has a smaller amount of material used is the bands slab solution 2 and the worse solution in this regard was the flat slab solution. On the basis of the quantities determined, costs were calculated for each one of the solutions.

	Costs (€)
Flat Slab	110570,80
Bands Slab Solution 1	107940,05
Bands Slab Solution 2	98390,69
Ribbed Slab	101095,68
Voided Slab	106003,29

Tabela.2 – Cost determined for each solution.[2]

The more cost-effectively solution is the bands slab solution 2 and so this was the solution adopted in this project.

4. Vertical Elements – Structural Solution

As vertical elements, it was applied columns in outer building, and interior shear walls. For the columns of the building it was necessary to limit its width to the width of the beam that intersects it so they stay completely within the wall, not visible to building users.

The building was modeled using the automatic calculation program SAP2000®.

5. Seismic Analysis

The seismic building analysis was made according to recommendations given in EC8. In seismic analysis, this building was classified regular in height and irregular in plant, leading to the adoption of a coefficient of behavior in two perpendicular directions of 2. The building is classified as a "torsional flexible building" and as a consequence it presents a first vibration mode with a frequency of 1, 95Hz and rotating move on its vertical axis, a second vibration

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[2] Unitary prices were obtained with the program Cype Gerador de Preços®, except in post-tensioning where it was given by VSL Portugal®.

mode with a frequency of 2.52Hz and a movement of translation in Y axis direction and a third mode with a frequency of 2.73Hz and a movement of translation in X axis direction. (3)

6. Dimensioning

In dimensioning it was performed an analysis for service limit states, ultimate limit state and checking fire behavior.

For those states, the building complies with the provisions of Eurocode 8 for the offset between floors. In this case the values are well below the maximum prescribed, which shows a high rigidity of building core walls.

For the ultimate limit states were determined the necessary steel for the various elements of the building, having regard to the provisions of Eurocode 2 and Eurocode 8. In this case it was necessary to take a special attention regarding the critical areas of building vertical elements.

Verification of fire resistance was held a prescriptive analysis determining the coating and minimum dimensions necessary for structural elements, in order to meet the requirements for each element during a fire of 60 minutes by Eurocode 2. (4)

7. Conclusions

The main conclusions from this paper are as follows:

- Post-Tensioning solutions allow the designer to get greater flexibility on the choices made during the design process;
- An optimized solution, from the standpoint of minimization of material, when it is repeated several times in the building, can lead to reductions in overall structure cost in the order of 5%, as was the case in this project;
- Not always the solution of slab that presents itself as the most suitable for building and for the spans in question is the most economical solution to be used;
- The structural Eurocodes that was used as regulation in this project define new criteria for seismic analysis that makes a quality improvement of seismic projects in a country as Portugal.

8. Bibliography

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