Analysis of the behavior of excavations for circular section shafts

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1. Introduction

This extended abstract has the purpose of resuming the thesis: *Analysis of the behavior of excavations for circular section shafts*, highlighting its essential aspects.

The thesis refers to the construction of three shafts in the Alcântara sewage tunnel, that are part of the project for repair and maintenance of the sewage tunnel.

For the peripheral earth retaining structure, a flexible support structure is used: a curtain of bored piles, braced at the top by a continuous beam and at the bottom by a foundation slab.

Taking the referred construction project as case study, it is the purpose of the thesis to analyze the chosen solutions for the design of the shafts, comparing them with alternative solutions.

This analysis is performed through the numerical modeling of the solutions, both the original and the alternatives, using for that effect the finite element software *Plaxis 2D*. The interpretation of the results is mostly based on a displacements analysis.

The main objective of the thesis is to understand if the chosen solutions were the most suitable ones, as well as the main advantages and disadvantages related with the adoption of different solutions.

1.1. Brief history of the shafts

A shaft is a geotechnical construction element characterized by a vertical soil excavation.

This excavation activity begun about 14000 years ago, being its main purpose the search for potable ground water. Nowadays, besides the shafts destined to the search for potable water, there are oil shafts, visit shafts, ventilation shafts, etc.

The visit shaft, which is the type of shaft that this thesis refers to, has the purpose of connecting an element of interest, located underground, to people or equipment, located at the surface. The said element of interest can be a tunnel in need of repair, a structure that was unintentionally buried, etc. This shaft can have a circular section, which is a very effective section, because due to the mobilization of the arching effect, it provides a more economical design than, for example, a rectangular shaped shaft. The peripheral earth retaining structure can be executed using a curtain of bored piles, which was the solution that was studied in this thesis.

2. Curtain of bored piles

A curtain of bored piles is a flexible support structure that can be defined as a wall of piles, whose main purposes are: structure foundation, peripheral earth retaining structure, and control of the incoming water as shown on Figure 1. (Sandra Lopes – IST)

Figure 1 – Visit shaft executed with a curtain of bored piles

The utilization of concrete bored piles begun in the beginning of the 20th century, and it has today many different applications. The curtain of bored piles can be built with three main types: spaced, tangent, or secant, and it is a widely spread solution due to its versatility.

Structurally, the curtain of bored piles is a flexible support structure, and its design usually respects the following sequence: definition of the soil's earth pressures, analysis of the deformations, and consideration of the resulting efforts.

Alternatively, and as a solution to the same kind of problems, other solutions can be considered, like the diaphragm walls, the jet-grouting, and the CSM (Cutter Soil Mixing).

3. Case study

The project that served as base to this thesis consists in the execution of three visit shafts (A, B, C), with the name “3ª fase da Reparação do Caneiro de Alcântara a montante da ETAR da Av. De Ceuta”, executed by the company Alves Ribeiro, between 2013 and 2014.

The purpose of the shafts was to create an access to the Alcântara sewage tunnel, through a connection tunnel located at the shaft base. The three shafts have a circular section, with an interior radius of 4,00m, an interior concrete staircase, and the following depths: A-24m ; B-14m ; C-18m. As shown at the Figures 2 and 3, the peripheral earth retaining structure solution for the shafts is a curtain of bored piles, with 0,80m diameter, 0,91m apart from each centerline.

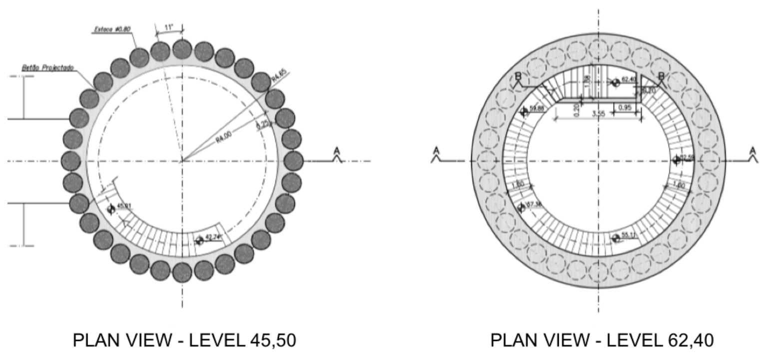

Figure 2 – Plan view of the Shaft A (SimTejo – Projecto de Execução)

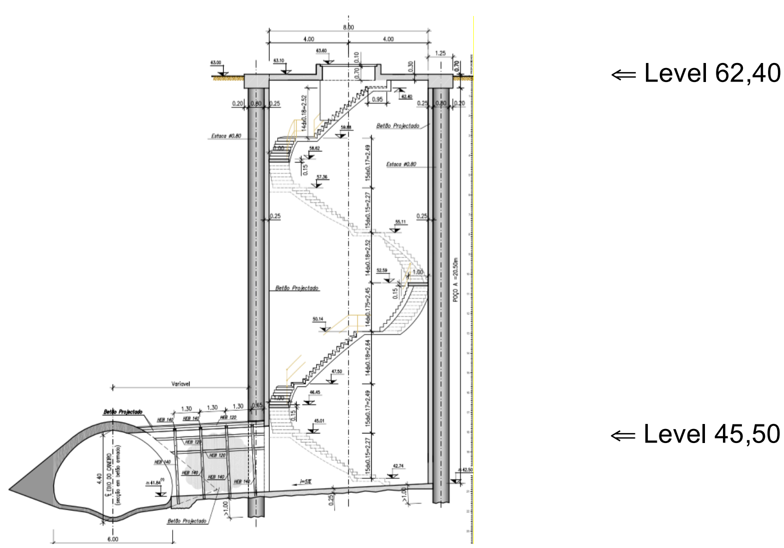

Figure 3 – Section of the Shaft A (SimTejo – Projecto de Execução)

3.1. Onsite report

One of the focuses of the thesis was to witness, to record, and to study the key points of this construction project.

The following phases were observed and documented: execution of the bored piles for the shaft A (from the drilling until the concrete pouring) - (Figure 4) ; excavation works for the shaft A (Figure 5) ; execution of the concrete interior lining walls.

Figure 4 – Execution of bored piles - drilling

Figure 5 – Excavation of the shaft

4. Solutions modeling

This chapter refers to the modeling of the executed and the alternative solutions regarding the peripheral earth retaining structure of the shafts. The software used for the modeling was *Plaxis 2D*, a finite elements software, using an axisymmetric model.

4.1. Executed solution

With the objective of knowing the efforts and the displacements of the curtain of bored piles, the first solution that was modeled was the executed one. The first step of the modeling was the model definition: the loads, the parameters regarding water and earth pressures, the geotechnical parameters, and the parameters regarding the geometry and the materials used at the piles curtain (Figure 6).

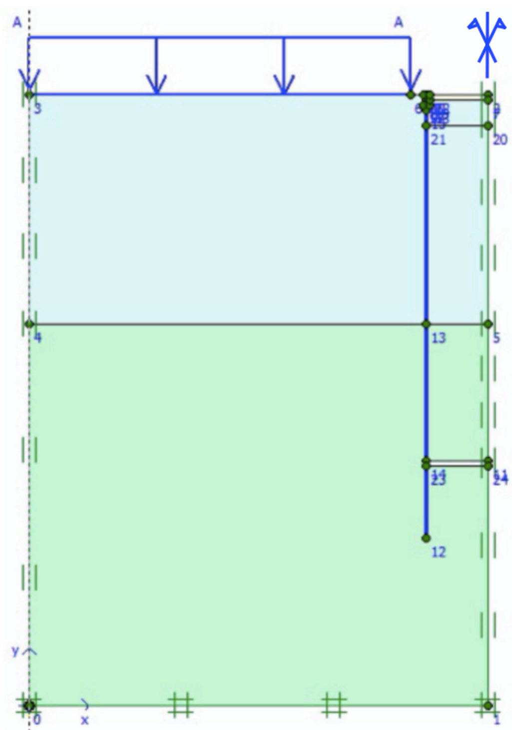

Figure 6 – Geometry of the model

After the definition of the constructive sequence, the obtained results were analyzed from two points of view: displacements and efforts.

Displacements

The maximum horizontal displacement is $\gamma_{Hmáx}$ = 6,78mm, and it happens approximately at the mid excavation depth of the curtain. This value is very reduced due to some factors, amongst which the high level of confinement of the structure, the non-existence of ground water table, and the good geotechnical characteristics (Figure 7 and Figure 8).

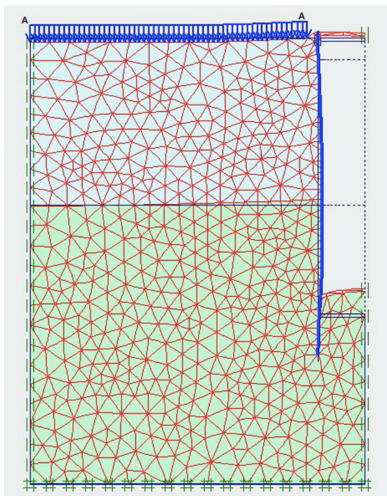

Figure 7 – Deformed form

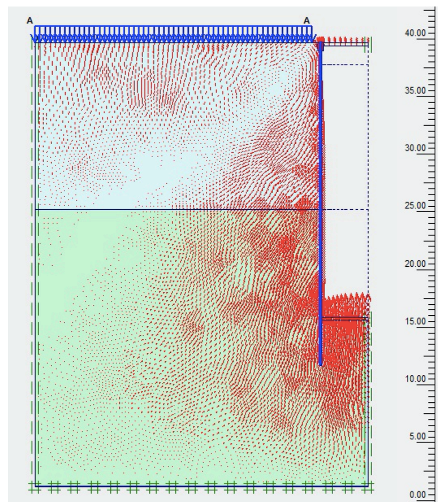

Figure 8 – Total displacements (scale in cm)

Efforts

The maximum Axial Effort has a value of 579,26kN/m, which is due mainly to the weight of the piles (476,40kN/m). Both the Shear and the Bending Moment have very reduced maximum values (180,74kN/m and 132,74 kNm/m, respectively), located at the slab, as this is the element that has the higher shear resistance (Figure 9).

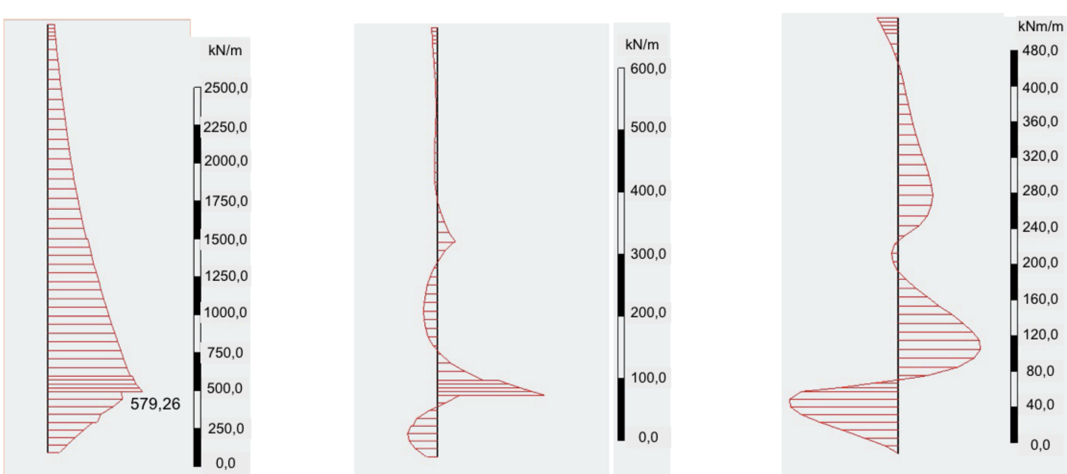

Figure 9 – Graphics for Axial, Shear, and Bending Moment

4.2. Alternative solutions

Some alternative solutions were considered, like a curtain of bored piles with reduced diameter of the piles, a curtain of bored piles with the piles further away from each other, and amongst them, the one that was modelled and that served as main comparison to the executed solution, was the execution of a curtain of micro piles.

For the micro piles there were considered HEB 160 laminated steel sections, and the micro piles 0,91m apart from each centerline. The modeling process was similar to the one used on the executed solution (Figure 10).

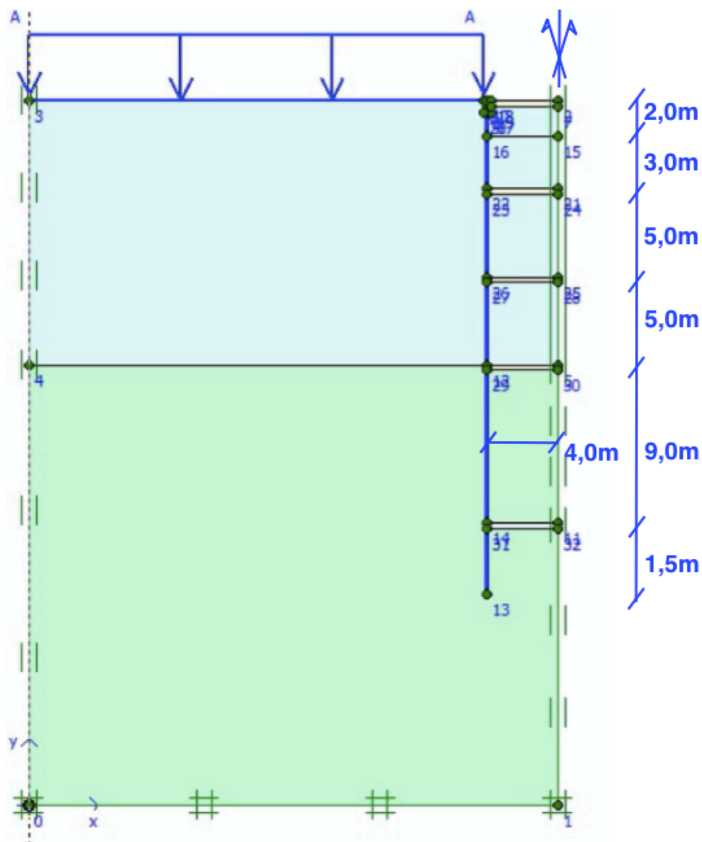

Figure 10 – Geometry of the model

As observed at the Figure 10, besides the bottom foundation slab and the top, three distribution beams were added, to help distribute the efforts through the micro piles. The obtained results were also analyzed from two points of view: displacements and efforts.

Displacements

The maximum horizontal displacement is $\gamma_{Hmáx}$ = 23,01mm, which is a value about four times higher than the one obtained at the original solution, (mobilized approximately at the same depth). This situation is expectable due to the lower stiffness of the solution of micro piles, being nevertheless a reduced value (Figure 11 and Figure 12).

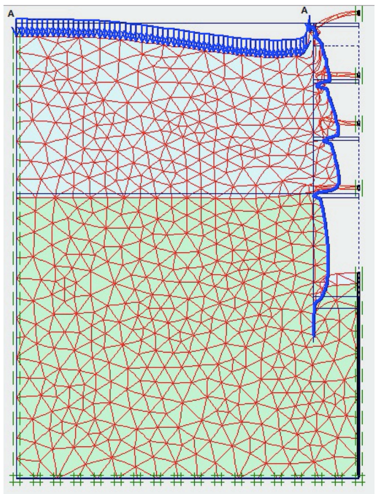

Figure 11 – Deformed form

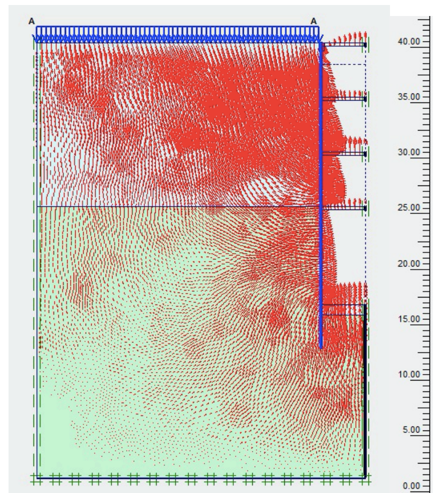

Figure 12 – Total displacements (scale in cm)

Efforts

The maximum Axial Effort has a value of 800,24kN/m, and both the Shear and the Bending Moment have non representative values. All of this happens because the stiffness of the micro piles is much lower, which causes the transversal resistance to be overwhelmed by the arching effect, which demands a bigger Axial Strength (Figure 13).

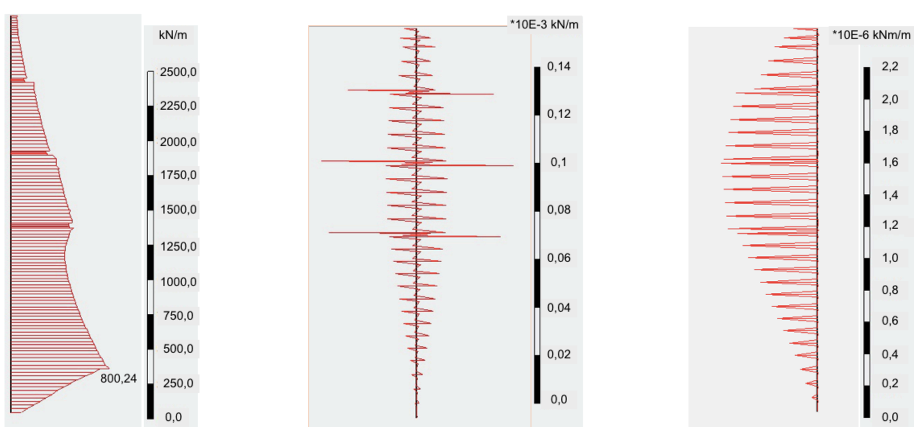

Figure 13 – Graphics for Axial, Shear and Bending Moment

4.3. Comparison of solutions

Taking into account the mobilized efforts and displacements, the obtained values for the alternative solution point to a possible and capable design, validating the solution theoretically in a structural level. Regarding the execution method, the alternative solution uses equipment that although it is very similar to the ones used in the original solution, has smaller dimensions, thus occupying less space and being easier to operate. Comparing the solutions, from the economical point of view there are two main differences that can be found, always with the advantage going to the solution of the micro piles: equipment flexibility, and regarding the materials, as it is shown in the two following tables:

Table 1 – Comparison of costs – Bored piles curtain

BORED PILES	
Drilling cost	50 €/ml
Concrete cost	80 €/m^3
Rebar cost	0,90 €/kg
Length of the piles	24 m
Volume of one pile	12,06 m^3
Mass of rebar per pile	113,76 kg
Number of piles	32
Total cost to execute the piles	**72 544 €**
TOTAL	**72 544 €**

Table 2 – Comparison of costs – Micro piles curtain

MICRO PILES	
Cost to execute micro piles with the HEB 160 steel section	60 €/ml
Length of the micro piles	24 m
Number of micro piles	32
Total cost to execute the micro piles	**46 080 €**
Concrete cost	80 €/m3
Volume of a distribution beam	3,9 m3
Number of distribution beams	3
Total cost for the distribution beams	**936 €**
TOTAL	**47 016 €**

In conclusion: The micro piles solution is quite appropriate as an alternative, as it is technically acceptable and very cost effective.

5. Final Remarks

The thesis that this extended abstract refers to, has as main objectives the design of the shafts, their modeling process, and their execution with a curtain of bored piles.

About the modeling using the software *Plaxis 2D*, it has proven to be an effective yet simple design tool for the design of geotechnical structures.

Regarding the execution of the shafts, the lack of instrumentation in the three shafts project really enhances its importance. If there was a monitoring and instrumentation program in place, the control of the behavior of the curtain of piles would have been possible, mostly by measuring the mobilized displacements.

In reference to this project specifically, an alternative to the the solution of the curtain of bored piles was found. Although very adequate to the problem, the curtain of bored piles can be less cost effective when compared with the solution of micro piles, for a similar technical performance.

Regarding future developments, it would be interesting to perform a 3D modeling of the problem, analyze its results, comparing them with the results obtained with the *Plaxis 2D* axisymmetric mode.

References

ALDEIAS, João ; Soluções de escavação e contenção periférica intersectando o nível freático ; 2011 ; IST

CARVALHO, Filipa ; Soluções de escavação e contenção periférica – Parque de estacionamento Alves Redol ; 2013 ; IST

LOPES, Sandra ; Elementos da disciplina de “Tecnologia da Construção de Edifícios” ; IST

FRANÇA, Pedro et al ; Estação Salgueiros do Metro do Porto: Aspectos Executivos e Estudo do Comportamento ; 2006

PRADO, Nuno ; Projecto da estrutura de suporte de uma escavação para um grande edifício no Porto ; 2008 ; FEUP

SIMTEJO ; Empreitada da3ª Fase de Reparação do Caneiro de Alcântara – Projecto de Execução ; 2011

TOMLINSON, M.J. ; PILE DESIGN and CONSTRUCTION PRACTICE ; E & FN Spon ; 1994