STABILIZATION OF SÃO PEDRO DE ALCANTARA'S VIEWPOINT WITH MINIMIZATION OF EARTHWORKS

From the project to the execution

Pedro Pereira

Department of Civil Engineering, Instituto Superior Técnico, Universidade de Lisboa – PORTUGAL

April 2018

Abstract: The monitoring of the geotechnical work of stabilization of São Pedro de Alcantara's viewpoint slope with minimization of earthworks, served as the basis for the development of this Master's dissertation.

Over a period of 10 years, following a stabilization of the support wall of the upper platform of the garden, a set of campaigns of monitoring were developed in order to evaluate the slope overall stability.

From the evaluation of the monitorization and ground investigation processes, it was clear the existence of structural problems, mainly at the level of the support structure of the lower platform, as well as the possible existence of a sliding surface at depths of around 30 meters.

In order to solve the detected problems, the entity responsible for the equipment, instructed in order to develop projects to re-establish the safety conditions, taking into account the site constraints.

The proposal implemented in the field consisted in the construction of a stabilizing structure at the level of the lower platform, in the form of two secant piles walls, linked by counterfort. To solve the problems of displacements detected in the lower wall, a beam, was nailed to the counterfort and connected to the stabilizing structure through a series of tie rods.

At the end of the document, an economic evaluation of the work was carried out, as well as a perspective of the works to be performed in the future.

Keywords: Geotechnical engineering; Construction; Secant piles walls; Slope stabilization.

1 Introduction

In order to guarantee the safety of the slopes in urban areas, it is the responsibility of the public entities or private actors to correctly monitor - and, if necessary - to carry out corrective interventions. The type of accidents that can occur in these types of elements, can carry out high economic and human losses. However, it should be noted that in most cases these problems are difficult to detect because they occur in structures that are not visible. Slope instability can be manifested in the form of landslide mechanisms and/or rupture/collapse of structural elements inserted in the hillside areas, as well as the case of the support structures, questioning global or partial stability. It is in this context the areas of knowledge, such as geotechnical engineering or geology, are fundamental to support the corrective or stabilizing measures. These should be applied in the event of real or potential risks, a scenario that falls within the stabilization intervention of the S. Pedro de Alcantara's viewpoint slope with minimization of earthworks – which will be the main matter covered in this dissertation.

2 Location and characterization of São Pedro de Alcantara's viewpoint

The implementation of engineering solutions requires a prior knowledge of the constraints and characteristics of the intervention object. Whatever the type of intervention is - rehabilitation or new construction – in the pre-design phase it is important to know the materials used, as well as the physical characteristics of the intervened elements. These can be structural elements or the ground itself.

Figure 1 - View of São Pedro de Alcantara’s viewpoint.

António Nobre garden, better known as São Pedro de Alcântara’s viewpoint, features one of the most breath-taking views of the city of Lisbon’s downtown. The equipment is located in the hillslope of the hill of S. Roque that connects the Bairro Alto and Restauradores’ areas. The Figure 1 shows de viewpoint inserted in the hillside.

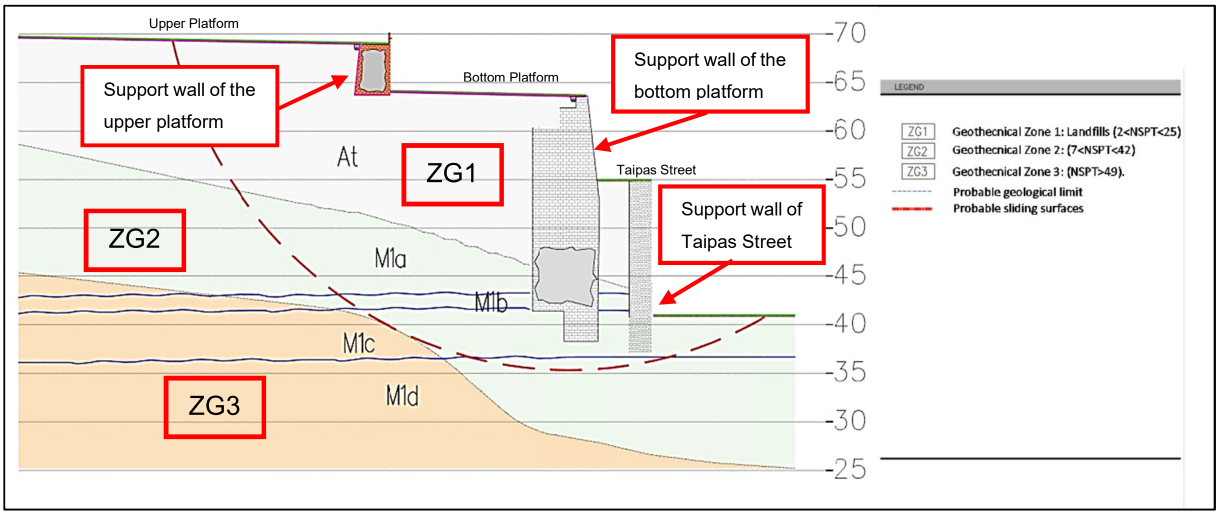

Figure 2: Cross section of the viewpoint and geotechnical zones.

The garden of the MSPA is divided in two levels (see figure 2), one superior, contiguous to the street of São Pedro de Alcântara, and a second platform that is located at a lower level and which is delimited by the lower wall that follows the Taipas street. Already outside the garden but still important to the complex of the viewpoint there is a third wall, which serves as support to the Taipas street. The detailed knowledge of the elements that compose the viewpoint complex, especially regarding the organization and architectural layout, are an essential component for the understanding of the processes and actions inherent to the slope stabilization.

3 Characterization of the existing situation

The year 2006 marks the beginning of a new phase in the life of the viewpoint, which culminated in the intervention of stabilization of the equipment. It was at this time, and as a result of the rehabilitation of the garden, that pathologies were evidenced at the level of the support wall of the upper platform and made clear the need for corrective measures to solve the problem. During a period of approximately ten years, starting in 2006 as mentioned before, monitoring and ground investigation works have been carried out to evaluate the safety of the equipment.

The set of works developed consisted of:

- Geological and geotechnical investigation;
- Monitoring of piezometric levels and inclinometers;
- Topographic monitoring.

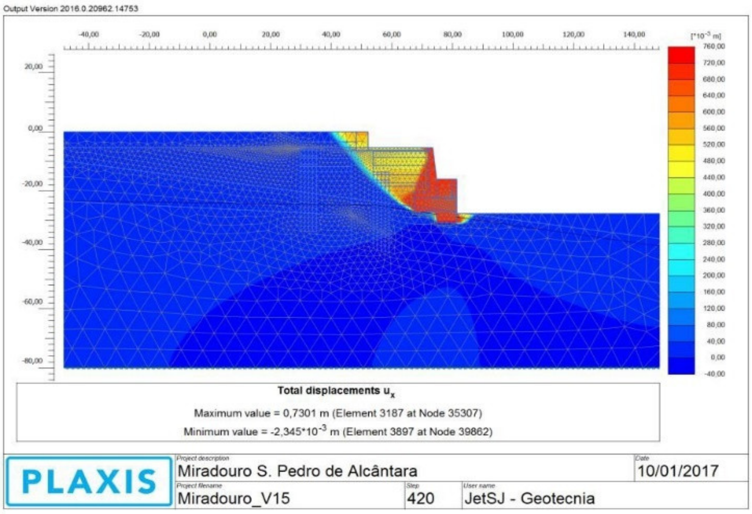

Figure 3: Horizontal displacements

Following the evaluation of the developed works performed by several entities, the main conclusions were presented:

- Characterization of the ground that supports the equipment and its framing in three different geotechnical zones (see fig. 2);
- Displacement of the lower support wall (see fig. 3);
- Possible sliding surface at depths of around 30 meters (see fig. 3).

The analysis of the gathered data during the various monitoring and ground investigation campaigns carried out in the equipment, throughout the years point to a set of problems, which could put the structure of the viewpoint, as well as the whole slope where it is inserted in risk. The assessment carried out by the technical managers who dealt with the problem is clear and unequivocal, indicating a high degree of risk associated with the viewpoint, especially regarding the dynamic actions - such as earthquakes. After the evaluation of the existing elements, especially the extreme sensitivity of the area in question, an urgent intervention decision was taken on the viewpoint, based in the need of restoring the safety levels of the surrounding area of the equipment, for both static and dynamics actions.

4 Design Solutions

The implementation of a project presupposes always a motive, in this case, to solve the detected problems of stability. However, the solutions to be presented must incorporate a set of requirements defined by the owner of the work, as well as the limitations associated with the site and with impact on the design options.

Project constraints and requirements are:

- Preserve the historical value of the equipment;
- Preserve the landscape design of the garden;
- Geomorphological and hydrological constrains;
- Site location;
- Climatic conditioning and execution time;
- Restoration of the safety conditions of the viewpoint.

Based on the conditions previously mentioned, the company *Jetsj - Geotecnia Lda* presented four design solutions [1] with the objective of:

- “Reduction/stabilization of deformations observed on existing earth supporting walls”;
- “Control of the slope deformations, taking precautions regarding instability movements of the geological device in depth (...)";
- "Reinforcement of the geological device in order to maintain, or even increase, the factor of safety of the global stability of platforms (...)”;
- "Control of internal erosion phenomena caused by the infiltration of rainwater and/or productive water lines".

The four solutions presented are characterized by:

- Project 1: Implementation of a structure for a car park on the upper platform supported by piles, and as a support system for the excavation is proposed the use of piles walls;
- Project 2: Implementation of a structure for a car park on the top and bottom platforms supported by piles, and as a support system for the excavation it is proposed the use of piles walls;
- Project 3: Stabilization with the use of landfills of compensation in lightweight aggregates at the level of the two platforms;
- Project 4: Stabilization with the use of secant pile walls and landfills of compensation in lightweight aggregates at the lower platform level.

Project 4, which aims an intervention, essentially at the level of the lower platform, is in line with what was stated in the technical report issued by the LNEC [2], which indicates some possible ways to solve the stability problems.

Taking into account the constraints and requirements presented and the technical evaluation of the actors, the solution chosen by the city council was the one presented in the project 4.

5 Case Study: Stabilization of São Pedro de Alcântara's viewpoint with minimization of earthworks

➢ The Project

The project designed for the stabilization of S. Pedro de Alcântara's viewpoint consisted in the implantation of two secant bored pile walls in the lower platform, locked and connected by a set of buttresses secant bored pile walls (see figure 4). Adding to the above-mentioned "superstructure" of concrete, a set of drainage and waterproofing devices for the ground were also planned, such as the use of a landfills of lightweight aggregate, geotextiles and geomembranes to be placed over the ground and the beams.

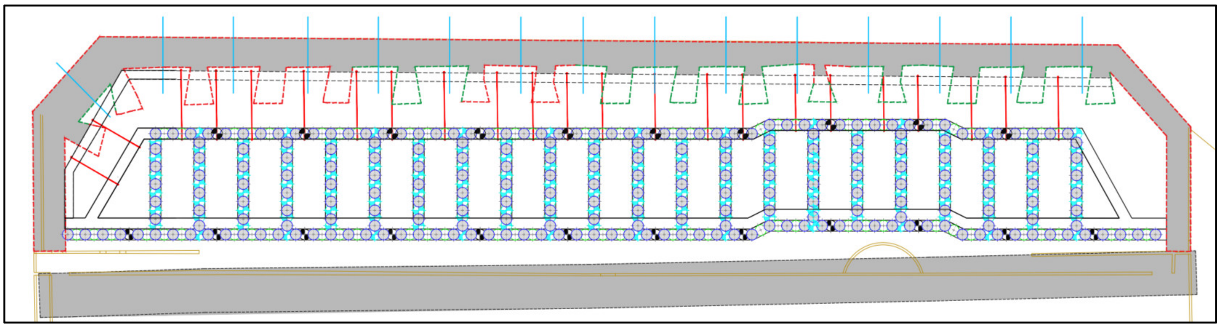

Figure 4: Stabilizing structure to be performed on the lower platform

The piles used in the stabilizing structure were bored piles with different lengths. These piles intersect alternately between reinforced concrete piles (secondary piles) and non-reinforced elements (primary piles) to form the secant pile walls. In the right image of figure 5 it is possible to see the way these elements were inserted in plan in the ground.

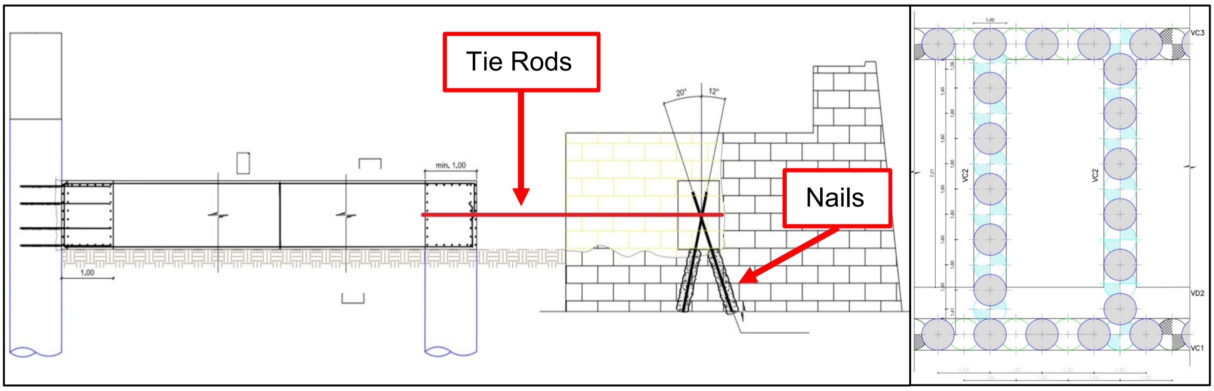

Figure 5: Buttresses cross sections and plan of the piles alignments.

The piles are the main structural elements of retaining structures, however, other complementary elements, such as capping beams and ground anchors (temporary or permanent), play a key role in this type of structure, mainly in the process of forces transmission along all the elements. To solve the problems of displacements detected in the lower wall, a beam, was nailed to the counterforts of this structure and connected to the stabilizing structure through a series of tie rods. In the left image of figure 5 can be seen the set of beams proposed for this project. In the same image it is possible to see the implementation of the Gewi tie rods, used to connect the structures. In addition to the already mentioned above, there is still the need to rehabilitate the lower support wall.

- **Project execution**

After the project has been defined, and taking into account the solutions presented, it was necessary to define the work plan to be executed. This was a contractor's competency.

The set of works required to carry out the project, based on the planning defined by the contractor can be grouped as follows:

- Preparatory work;
- Work related to the construction of the stabilisation structure;
- Drainage devices;
- Final works;
- Monitoring procedures;
- Rehabilitation of the lower wall.

The tasks developed in each of the groups are exposed hereunder:

- **Preparatory work**: a) Assembly of the construction site; b) Construction of the access ramp; c) Lower platform preparation.

Figure 6: Installation of the crane tower and view from the access ramp to the lower platform

Among the installed equipment in the constructions site, the installation of the crane tower (see figure 6) and the execution of an access ramp are the two elements with higher visibility.

- **Works related to the implementation of the stabilization structure**: a) Construction of the guide wall; b) Execution of the piles; c) Execution of beams (capping and structural beams); e) Execution of prestressed tie rods.

The first work to be carried out regarding the construction of stabilizing structure was the insertion of the guide walls in the ground (see figure 7 first image). The next process was the execution of the piles, and this can be split into the following steps: First the drilling, and then the insertion of the steel reinforcement bars into borehole finalized by concrete pouring through the tremie pipe. The construction process of piles can be seen in figure 7.

Figure 7: Execution of the piles

The execution of the beams was divided into three parts: 1) Production and placement of the steel reinforcement cages according to the design; 2) Preparation and placement of formwork with lateral shoring; 3) Concrete pouring. The three images of figure 8 represent each one of those steps.

Figure 8: Execution of the capping beams.

To control the displacements of the support wall of the lower platform a beam was installed over the nailed buttresses and connected to the stabilizing structure with pre-strengthened tie rods. Figure 9 shows the application of these two elements in the construction site.

- **Installation of drainage devices and executions of compensation landfills**.

At the level of the drainage elements it was important to highlight the application of horizontal drains on the lower support wall. In addition to these elements a geomembrane and a geotextile were also applied

Figure 9: Application of gewi rods and geotextile fixation

to separate the area of ground from the landfills zone with lightweight aggregates. The application of these elements can be seen in the central image of the figures 9 and in the first image of the figure 10.

- **Final Works**: a) Reconstruction of the wall in the south side; b) Rehabilitation of the lower support wall.

The last developed works in this project were the reconstruction of the lower wall in the south zone and the rehabilitation and cleaning of the support wall of the lower platform. These actions can be seen in the last two images of the figure 10.

Figure 10: Execution of landfills with lightweight aggregates and reconstructions and rehabilitation of the lower support wall

➢ **Monitoring and observation plan**

The instrumentation plan applied in the execution phase of the work used some of the elements already installed in the previously monitoring phase and was characterized by the use of topographic targets and inclinometers.

The monitoring system procedures were divided into two parts:

- Installation of reading equipment: i) Topographical targets; ii) Installation of inclinometers in Taipas's street; iii) Installation of inclinometers inside the piles.
- Reading Campaigns.

Relevant Monitoring results:

• The analysis of the topographic targets of the crane tower in mid-August presented high values regarding the vertical component;

• Excluding the situation explained in the previous point, during the execution of the project no other occurrences with relevance were detected that could indicate some anomaly or problem in the viewpoint's structure.

5.1 Economic evaluation

The economic evaluation of the works was carried out based on bill quantities provided by the contractor. The overall cost of the work was approximately 5.3 million euros.

In summary, an economic evaluation of the work on the form of percentage of the overall value is presented:

- The cost associated with the pile execution represents 80% of the total costs, while the cost associated with the beams execution represents 3% of the total costs. (see figure 11)

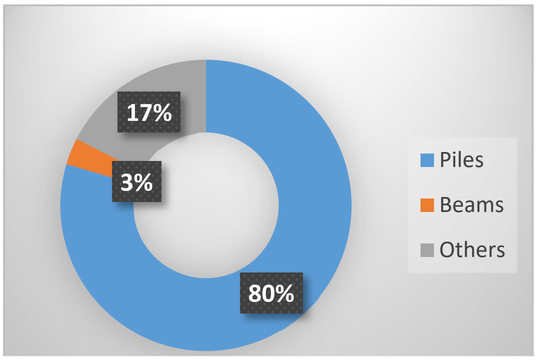

Figure 11: Main processes costs

- The distribution of costs among the elements that constitute the stabilizing structure is: 41.76% for the buttresses and 39.82% for the main pile curtains;
- The costs associated with the concreting processes (34.22%) are similar to costs of the drilling processes (30.99%).
- The "other" costs are associated with a series of works such as: preparatory works; installation of drainage devices and executions of compensation landfills; rehabilitation and cleaning of the lower support wall; monitoring plan.

6 Closing remarks

The execution of this work was based on the rehabilitation intervention carried out in the São Pedro de Alcantara's viewpoint, aiming to create a document that was comprehensive and to encompass the main phases of the process:

- Assessment of stability problems;
- Presentation of solutions to solve the problems detected;
- Implementation of the chosen solution.

The stabilization works fulfilled the intended objectives, among which it should be pointed out:

- Global stabilization of the hillside and of the lower retaining wall;
- No accidents occurred during the execution of the works;
- The execution time met the project time schedule (5 months);
- The costs were controlled and met the budgeted;

- The accomplishment of the work (see figure 12) allowed the preservation of the historical element and created conditions for the reestablishment of the landscape characteristics of the equipment.

Figure 12: View of the lower platform after the work has been completed.

6.1 Future developments

As future developments it is important to highlight these three points:

- The work has created the conditions for the implementation of surface green spaces design project – which is expected to be implemented soon - in order to re-establish the landscape characteristics of the element and to allow the equipment operational again;
- Follow-up monitoring campaigns developed after work, to evaluate the effectiveness of the stabilization works performed, and, if necessary, the development of a new back-analyses;
- Although the intervention has focused on the overall stability of the slope, it is important to evaluate the support wall of Taipas street, a structure that raises many doubts about its local stability. In this sense, it would be beneficial to implement an observation system on this structure and, if justifiable, to proceed to a reinforcement through a solution properly integrated with the one already executed in the lower platform.

References

[1] JETsj – Geotecnia S.A, "Avaliação e Reforço Estrutural e Geotécnico - Miradouro de S. Pedro de Alcantara - Memória Descritiva e Explicativa do Projeto de Execução," Lisboa, 2017. (in portuguese).

[2] LNEC, "Parecer sobre a estabilidade do miradouro de são pedro de alcantara em lisboa," 2017. (in portuguese).