HISTORICAL BACKGROUND AND SEDIMENTARY EVOLUTION OF BUGIO FORTRESS

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Keywords: *Bugio Fortress, Sandbank, Morphological Analysis, Erosion, Accretion, ArcGIS, Tagus River "Golada"*

Abstract. *Once known as "Torre da Cabeça Seca", the Bugio Fortress was strongly linked to the maritime defense of Lisbon. The construction started at the end of the XVI century. With its imposing circular structure on which stands a tower about 16 meters high, the Bugio Fortress presents itself as one of the most interesting military architecture projects.*

Strategically located at the entrance of the Tagus estuary, in the direction of Cova do Vapor, it is quite credible that at the time of the construction, the place where it stood would be above the mean sea level (MSL), so making the analogy to the present day we can see that the area in question has a strong sedimentary dynamic.

The present work consists of historically frame the entire construction process of Bugio Fortress over the years and also make a more recent analysis by specifying the various interventions of redevelopment and protection that were carried out due to the constant threats that put into question the stability of the Fortress structure.

In another phase, the intention is to carry out an analysis of the morphological evolution of Bugio's Sandbar, using ArcGIS software. At this stage of work, the purpose is to follow up and compare the results obtained with a study developed by the Prof. Mota Oliveira in 1994, analyzing the processes of erosion or sediment accretion that may have occurred, using a bottom profile in that has the same location in both studies.

After this morphodynamic analysis on the closure of Tagus River "Golada", as a future intervention, highlighting the implications of the evolution of Bugio's sandbank may have on the coast line and the very stability of Bugio Fortress.

1 Introduction

The Bugio Fortress, built in mid-sixteenth century, symbolized at the time a very important landmark with regard to strengthening the coastal defense adjacent to Lisbon. In 1580, when the Spanish invasion took place, the structures suffered considerable damages, which in turn proved the fragility of the defensive structure, which had as its main function the defense of the Tagus bar. So, it has been decided that it would be obvious and unavoidable the need to reinforce the defense of the coastline near to Lisbon.

One of the purposes of the paper is to undertake a historical overview about the constructive evolution of the Bugio Fortress over the years, since its construction in the mid-sixteenth century to the present time. Finally, it will be assessed more thoroughly the rehabilitation and protection works carried out.

This study proposes a morphological analysis of the Bugio's sandbar evolution and the sedimentary evolution in the surrounding perimeter of the Fortress. For this analysis series of surveys on the bathymetric lines over this area have been provided by the Hydrographic Institute (HI) and proceeded to their analysis using the system models Geographic Information System (GIS), in particular the *ArcGIS* software. The aim is also to highlight the implications that the Bugio's bank evolution may have on the coast line and check the stability of the Bugio's Fortress structures. This work may prove to be important to understand how future interventions should be carried out.

2 Historical Background

After the time under the rule of the Spanish in particular King Philip I, who had entrusted in 1580 to Vicencio Casale the constructions of the Bugio Fortress. There is no knowledge of any letter or document that proves the beginning of the Bugio's Fortress constructions in "Cabeça Seca", however according (Boiça & Barros, 2004) is estimated to have begun in 1590. Three years after the elaboration of the project, in 1593, the Fortress's foundations were far from being completed. A few months before Casale's death, he addresses a letter to the King, which was a short history of how, until then, were the development of the constructions and the phase that they were in. In the explanations to the monarch the architect mentions the various construction phases until then elaborated and begins by explaining that initially delimited the construction area by wooden piles, forming a circle of large diameter, Figure 1.

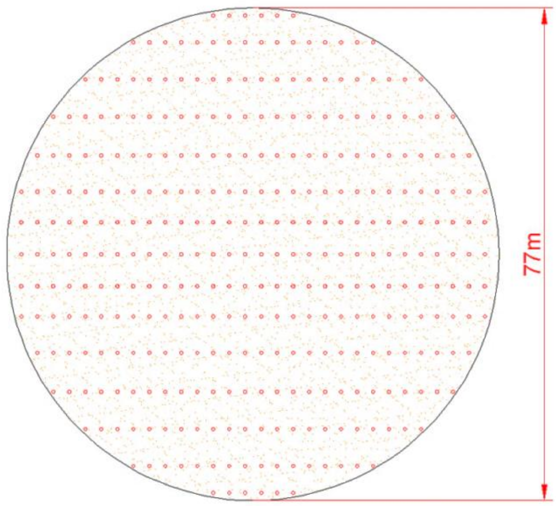

Figure 1: Delimitation space, using wooden stakes.

By this time, it had already been accumulated in the pre-defined ring two overlapping layers of rockfill. However, the level was still immersed but it was expected that with the third stone layer the foundation exceeds the water level, getting the foundation completed, Figure 2.

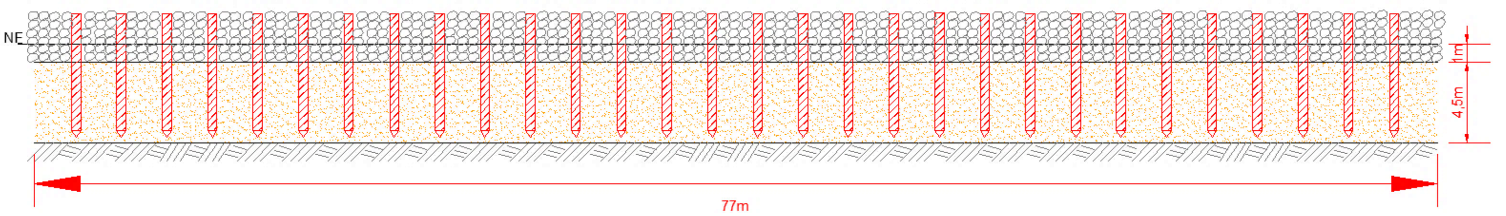

Figure 2: Project elevation of Fortress's foundations using wooden stakes and rockfill layers.

The desire to put as soon as possible the artillery in place, already drafted by Casale, made the construction of the Fort slow down their execution and focus efforts on the installation of a provisional wooden Fortress. Filipe Tercio, chief engineer of Portugal, was the person in charge for the execution of this project. In 1594, and after several tests to determine the behavior of the structure in terms of resistance to natural forces and the action of their own artillery, it was being established that the Fortress responded well to the requirements imposed, been approved the temporary Fortress.

Figure 3: 3D reconstitution of the wooden Fortress of 1594. Overview. Adapted from (Boiça & Barros, 2004).

However, the weak offensive power that the temporary Fortress provided was considered inadequate for the defense of the bar's entrance, this was the main reason why it was being considered to continue with the construction of the initial project, the stone Fortress designed by Vicencio Casale.

In 1594, the issue of silting was probably related, for the first time, with the Fortress construction in "Cabeça Seca". According to (Boiça & Barros, 2004) the submerged base that was built on the sand, would result in a greater accumulation of sand next to north and south "Cachopos", reducing the width of the navigation channel. Even though this issue came several times to debate, it was not sufficient to stop the construction works in the Fortress.

In 1643, after the restoration of independence, King John IV nominate to the position of engineer in charge of the construction in "Cabeça Seca" the Friar João Turriano and the construction acquires a remarkable boost, although its rhythm had been conditioned by the lack of resources that the kingdom had to support the war effort against Spain. However, it was clear concern to prevent that the Fortress construction would be jeopardized. In 1646, João Turriano puts into consideration of the King two fortification projects different from each other, one of the projects consisted in an oval construction and the other project would be a simpler construction that could respond to the urgent need to put in place artillery. This last project was approved by the King.

Although the project has been approved it also came to significant changes, they were due to the absence of a cistern for water storage, the existence of a central courtyard and the volumetry of the building that prevent the construction of a high battery and take advantage of the privileged position of the site to monitor and control the navigation in Tagus bar. In Figure 4 there is shown a schematic example of the final project.

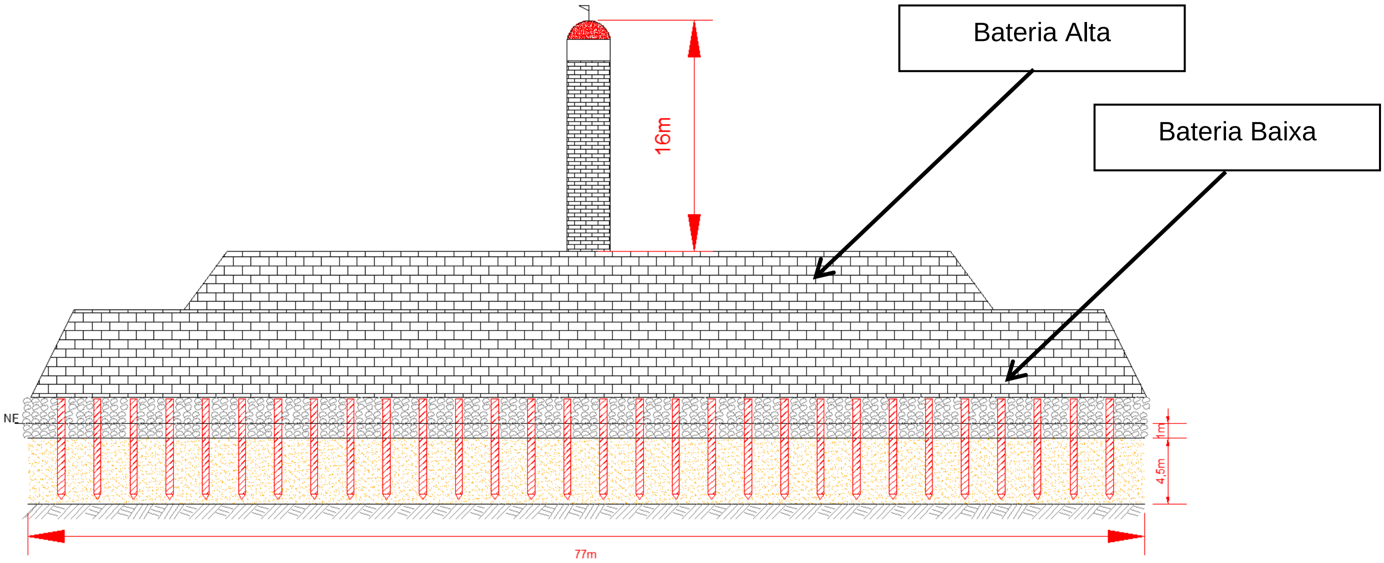

Figure 4: Final draft, which notes the presence of a central tower.

After the 1755 earthquake, where the Fortress was seriously damage, they have emerged over the years some major projects for its reconstruction, although those projects never escaped much of that shown in Figure 4, because they were designed mostly to punctual reconstruction due to damages provoked by the sea action or due to new military requirements.

3 Bugio Fortress Protection Works

Since 1981, with the automation process and the consequent dismissal of the continued presence of lighthouse keepers, the reality in the Fortress has become another. By not being inhabited their homes and work spaces, quickly became degraded and lost all sense of existence. The complete absence of life in Bugio Fortress brought problems to the maintenance of the Fortress, however, the effects of total abandonment were to acquire even greater proportion. The Fortress was protected by a defensive barrier around all the perimeter of its walls, which in turn, was intended to ensure the protection against sea agitation. Along with this set of circumstances, another returned: the collapse of a part of the Fortress's lower platform, due to the sea action in the winter of 1993, Figure 5 and 6.

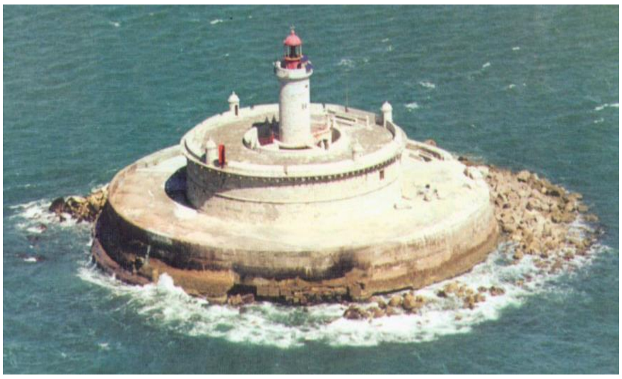

Figure 5: Bugio Lighthouse in 1993, before the reconstruction work. Photo courtesy, Eng.º Lopes de Castro.

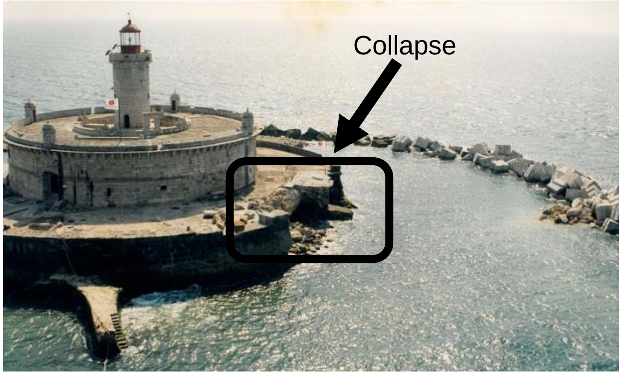

Figure 6: Representation of the collapse that occurred in the Fortress wall and the beginning of the deposition of Antifer cubes, in 1998. Photo courtesy, Eng.º Lopes de Castro.

Between 1997 and 2001 it took place the restoration of existing ruins and wall. As for Fortress surrounding, was built a robust semi-circular breakwater consisting of two layers, of 60 and 80 kN rockfill and 15.1 m3 of Antifer cubes which began to absorb the impacts of the sea waves. Underneath the antifer cubes and rockfill layers there is a general layer of ToT, (WW - Consultores de hidráulica e Obras Marítimas, 2014). In figures 7 and 8 it is possible to observe the execution of the works.

Figure 7: Transportation and laying of the rockfill layer and Antifer cubes in the surrounding of the Fortress. Photo courtesy, Eng.º Lopes de Castro.

Figure 8: Bugio Lighthouse in 1998. Placement of Antifer cubes. Photo courtesy, Eng.º Lopes de Castro.

4 Tagus's Bar

Tagus's bar and practically all the Portuguese coastal area is characterized by being very sensitive to morphodynamic effects. Since the late nineteenth century, this area has suffered a narrowing of the shoreline, especially the sandbar that stretches between Bugio Fortress and Cova do Vapor. In this study is intended to show the morphological evolution that has been occurred in this sandbar, comparing the results provided by Hydrographic Institute (HI) that contains the data of bathymetric lines survey held between September and October in the years of 1990, 1992, 1994, 1996, 1998, 2000, 2002, 2006, 2008, 2010, 2012 and 2015 with the study data conducted by Professor Mota Oliveira: "*Melhoria das condições de acesso pela Barra Sul",* in 1994, which cover the years between 1929 and 1985. For the present study, the area of HI survey is the same carried out in 1994, shown in Figure 9.

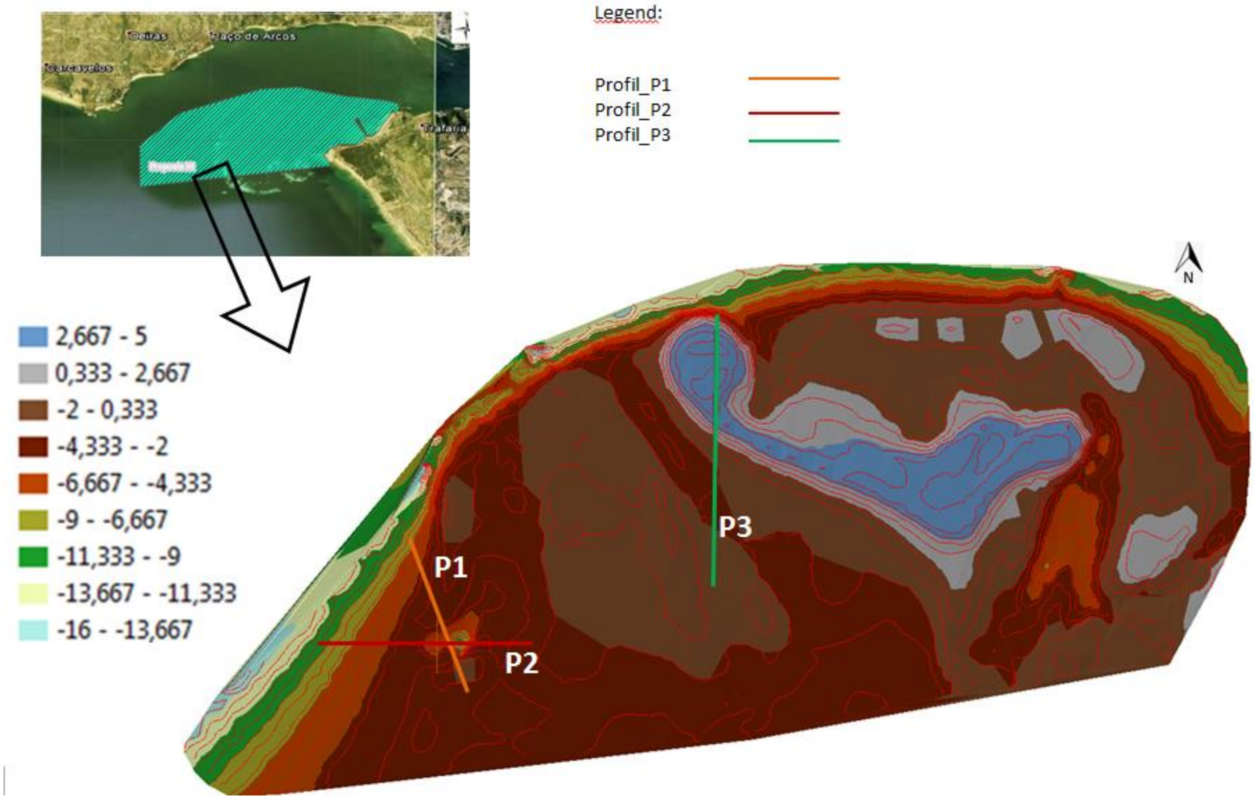

Figure 9: Geographic representation of the study area provided by HI and the profiles used to analyse the sedimentary evolution.

Most of the agitation system reaches the sector between Cova do Vapor and South area of Costa da Caparica due to diffraction and refraction phenomena, which in turn introduce a sedimentary displacement from south to north, combining the currents flood tide and wave action, which varies depending on the meteorological conditions on the sandbar. In Bugio's bank area the sediments displacement capacity increases in the same direction that in the end settle on the North face of the bank's slope, contributing to the spread of this one in the very same direction. During the ebb, the currents that have a constant rhythm and depend on astronomical factors related to tide variations, promote the sediments transport that will be deposited as the intensity of currents decrease, which reduces the depth verified in the Tagus River navigation channel. Then is the incident wave and the flood tide current that takes up the sediment transport process towards the coast, along with the slope facing South, completing the cycle shown in Figure 10.

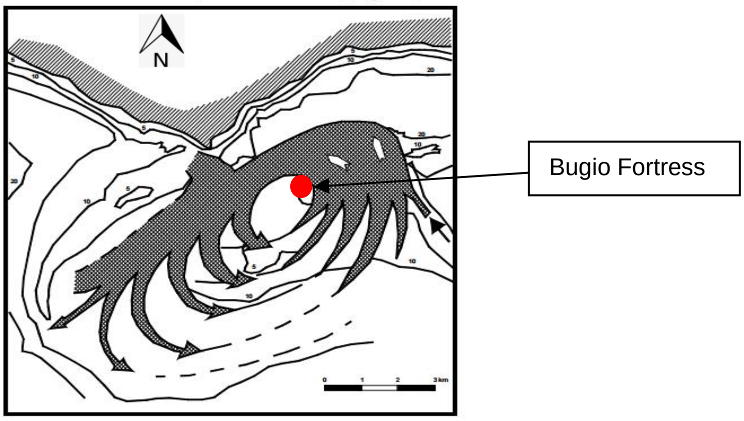

Figure 10: Representation of sediment movement, adapted from (Oliveira, 1994)

5 Evolution of Bugio’s sandbank

The analyses of Bugio’s sandbank morphological evolution, based on the analyses of Figure 11 and 12 for the years of 1929 and 1985 shows that, at least for a few years the “Golada” never had stabilized, quite the opposite, these analyses show the instability occurred in that area, with phases of expansion or opening followed by contrary actions phases. After the breakup of “Golada” in the 40’s, a volume around $36 * 10^6$ m3 of sand has been accumulated on the North side of Bugio’s sandbank, which resulted in an advance of about 700m northwards of this range, as represented in Figure 12.

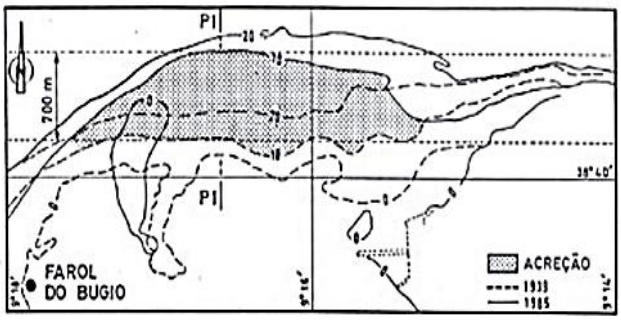

Figure 11: Bugio's sandbank evolution between 1939 and 1985, adapted from (Oliveira, 1994)

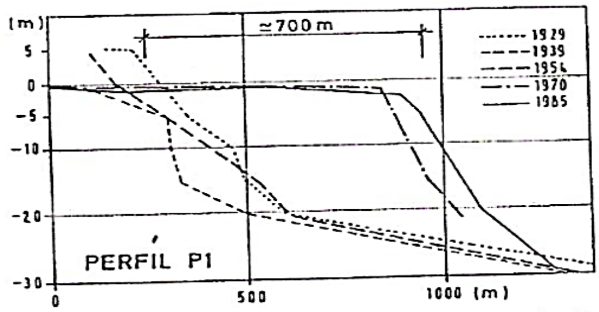

Figure 12: Longitudinal morphological evolution from 1929 until 1985, adapted from (Oliveira, 1994).

With the analysis based on data provided by HI was performed, in *ArcGIS*, a morphological analysis of P3 profile, shown in Figure 9, in order to study the evolution of Bugio’s sandbank from 1990 until 2015, year of the last survey carried out. Note that the P3 profile matches with the P1 profile, shown in Figure 11, which provides the basis for the morphological study of Professor Mota Oliveira in 1994. The evolution from 1990 until 2015 can be analyzed based on Figure 13.

Compared to the analysis made by Professor Mota Oliveira in (Oliveira, 1994), it can be concluded that the evolution of Bugio’s sandbank North slope has found a balance, because its consecutive northward migration stagnated and is now in a state of slowing down regarding his evolution, which means that neither advances or setbacks in Figure 13 are very significant.

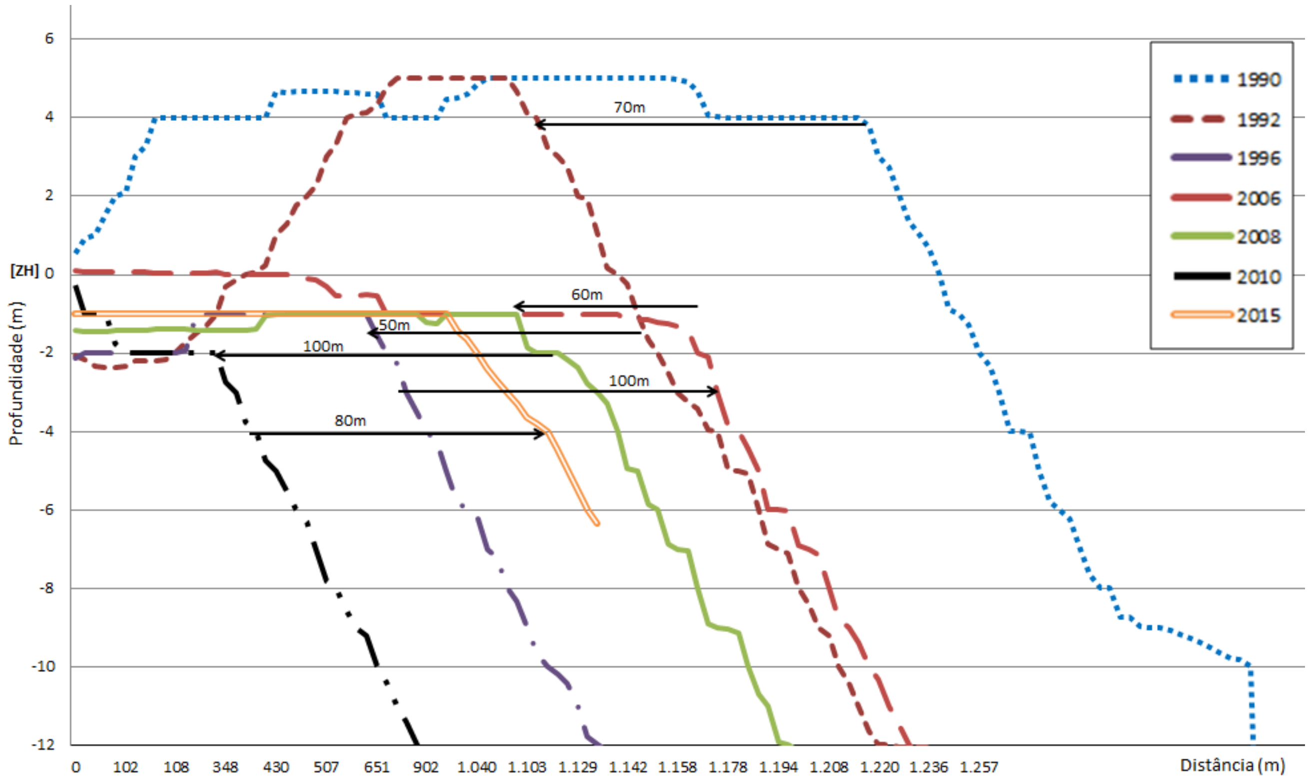

Figure 13: Sedimentray evolution of Bugio's sandbank, from 1990 until 2015.

6 Fortress sedimentary evolution in the surrounding perimeter

The morphological evolution in the surrounding perimeter of Bugio Fortress also becomes important to this analysis, to study the morphological stability of the immediately adjacent area of the Fortress's foundations all over the years. For this analysis, carried out once more by means of *ArcGIS,* the references of P1 and P2 profiles, represented in Figure 9, have been used. These profiles match the approximated location of Bugio Fortress, in order to provide a morphological analysis that represents the best sediment variation over the years at that same area. This analysis might be interesting to have an idea of how exposed to maritime actions the Fortress's foundation structures may be.

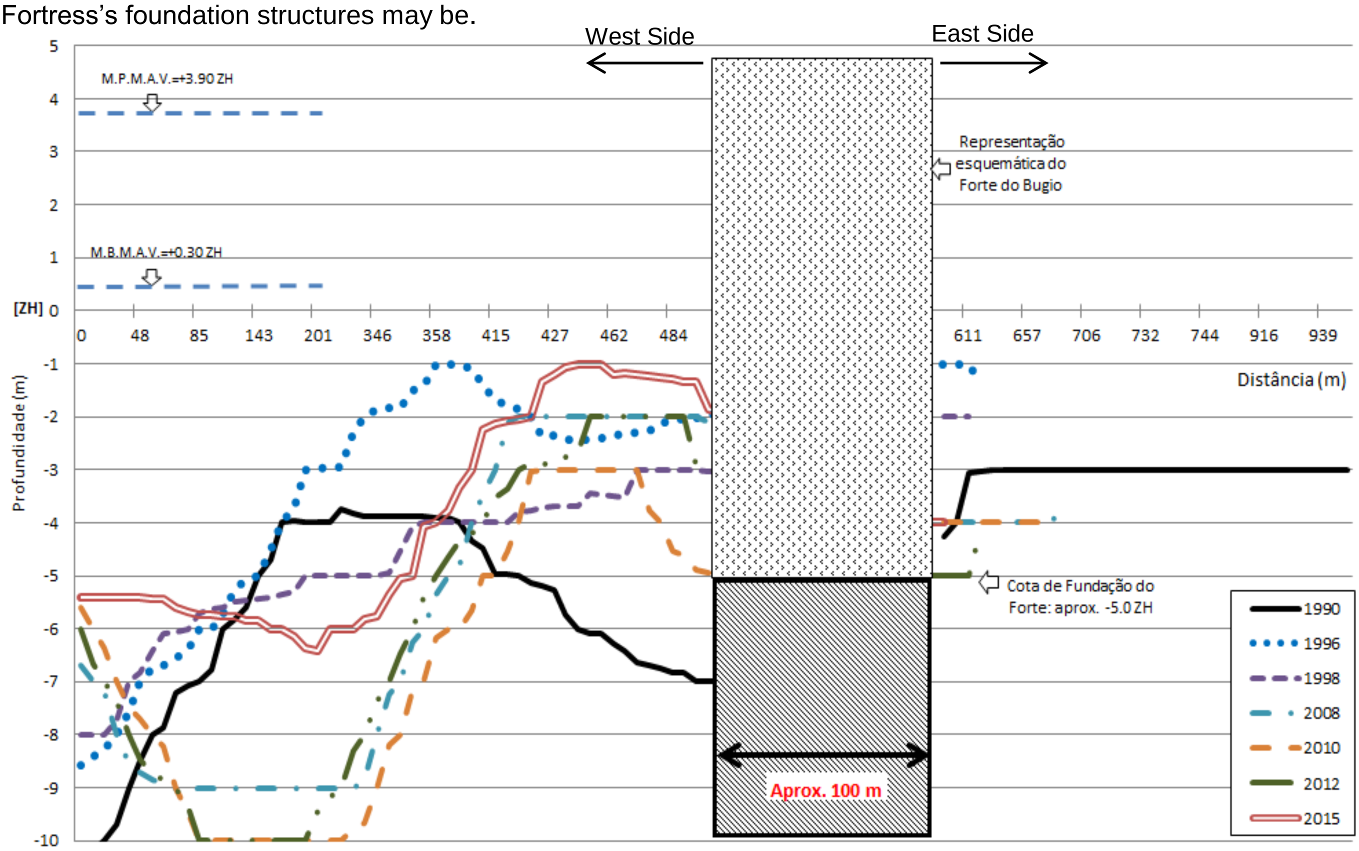

Figure 14: Sedimentary evolution near Bugio Fortress, according to Profile P1 from Figure 9.

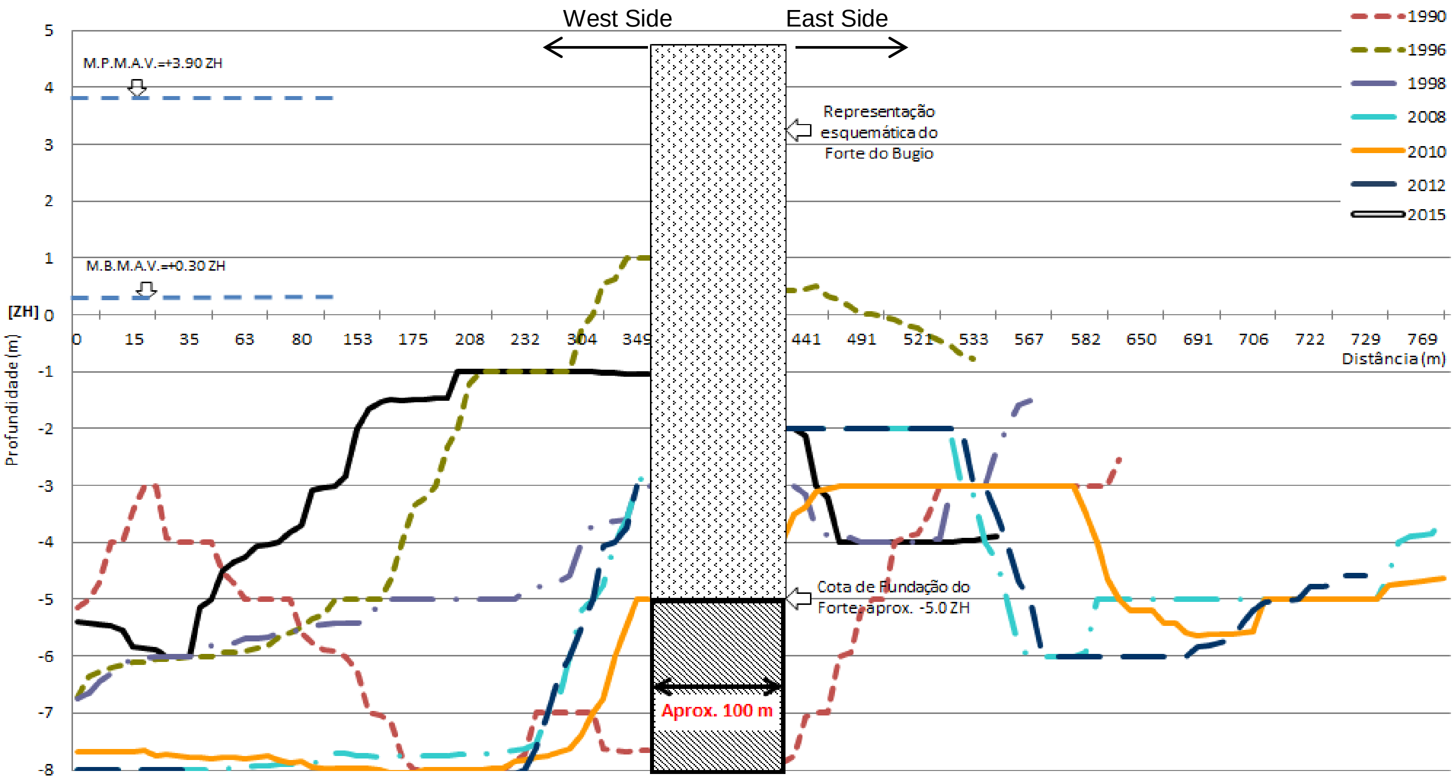

Figure 15: Sedimentary evolution near Bugio Fortress, according to Profile P2 from Figure 9.

As shown in Figure 14 and 15 relatives to immediately adjacent area of Bugio Fortress, the sedimentary cyclical flow may cause problems in the stability of the Fortress in any of the years presented, it is possible to verify that the sedimentary level in these years is below or very close to the foundation level, assumed to be approximately -5.0 relative to the hydrographic zero. Nowadays the West slope of Bugio Fortress is protected by the structures represented in Figure 16, consisting of antifer cubes, rokfill and TOT. Due to a constant sedimentary movement that occurs in this zone, this solution will not prevent in the long term that does not occur constant collapses in the protection structure around the Fortress. This problem may even influence the more peripheral piles under which the Fortress is founded, putting the stability in serious danger.

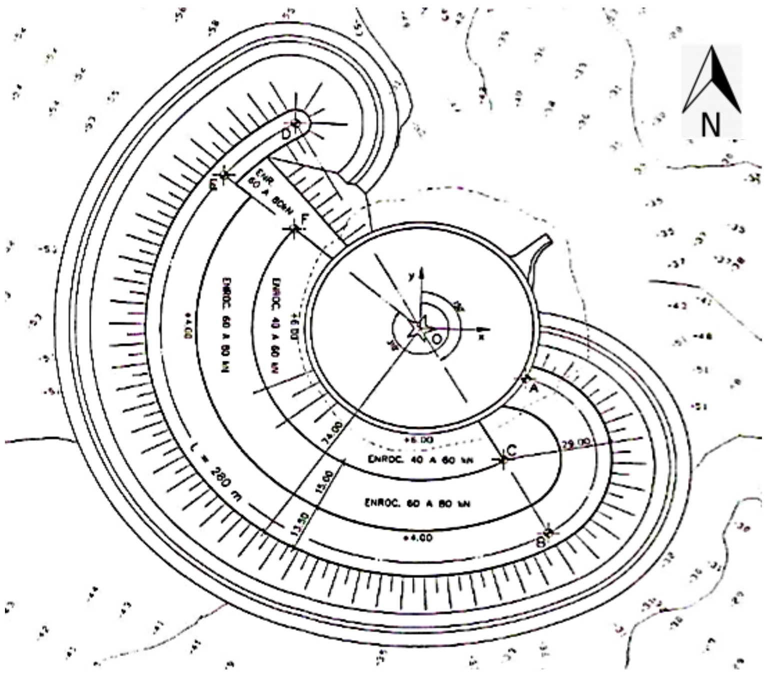

Figure 16: Representation of the protection structures around the West side of the Fortress, adapted by (LNEC, 1997).

7 Proposal Submission

Based on all the previous morphological analysis, the problem of the structural stability of the Fort, especially the foundations and the rest of the peripheral structure, is far from being solved.

One of the solutions that may be considered viable for this problem will be the introduction of sheet piles as a peripheral containment structure around the whole Fortress. Reducing the successive losses of sediments that are the supporting base of the foundations and of the very structure.

Next, a sequential scheme performed in *AutoCAD* is presented, which aims to demonstrate how the solution of sheet piles can help to contain the sediments in the peripheral areas of the Fortress. The profiles that will be shown below are intended to represent the P2 profile present in Figure 9.

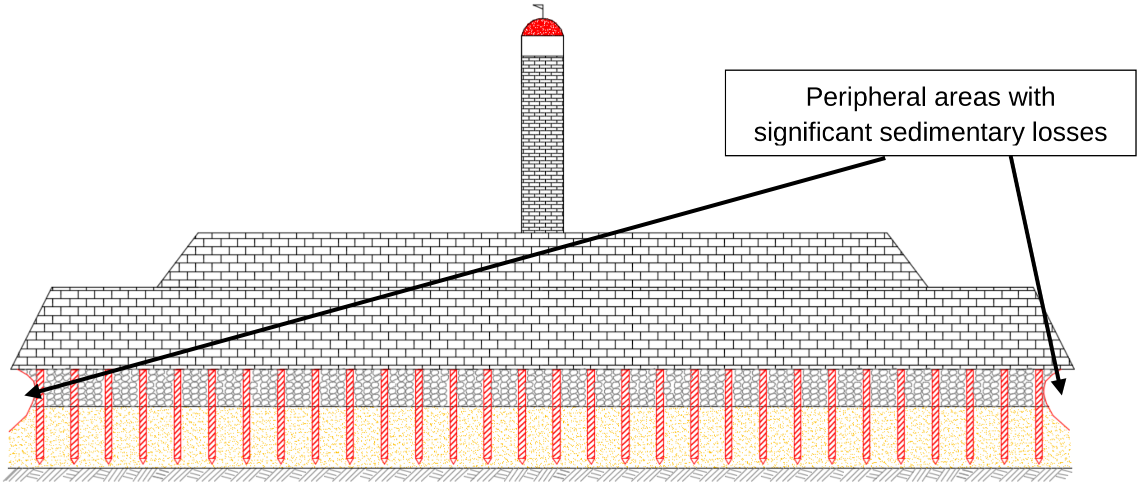

Figure 17: Scheme of the Forte, according to the profile P2, with the representation of the sedimentary losses in the peripheral zones.

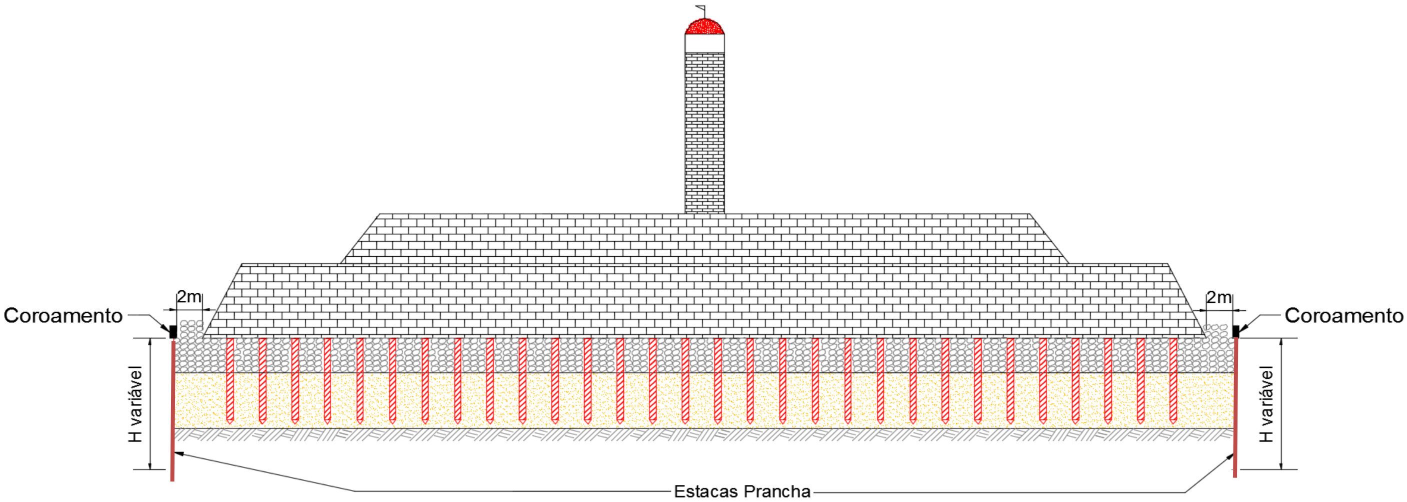

Figure 18: Representative scheme with the proposal of sheet piles as containment.

8 Tagus River "Golada"

The designation of Tagus River "Golada" comprises the passage between Cova do Vapor and Bugio Fortress, which have remained open for centuries, closing naturally between the 19th and 20th centuries. According to "*Abreu 2010*", the "Golada" have been reopened due to human action, when were removed several millions of sediments cubic meters to landfills on the banks of the Tagus river. It is argued that if "Golada" had kept closed the sedimentary accumulation in this zone would have continued, reinforcing the connection between the Fortress and Cova do Vapor.

The study carried out by HIDROTECNICA PORTUGUESA concluded that the closure of “Golada” would be the best solution for the maintenance of the South bar, by decreasing the length of the section through which a certain volume of water enters and leaves in each tide cycle, it will forcibly increase the section and the South bar depth and consequently the navigation channel itself.

According to “*Abreu, 2010*”, the Port of Lisbon is located at the intersection of the highest intensity of the world maritime traffic, representing 20% of all processed cargo in national ports and 44% of containerized cargo. However, the Port is slimming down and when this happens, it is reflected throughout the surrounding metropolitan area.

Taking this information into account, it will be necessary to stop this process, not only because of the importance of the Port, but also because of the impact that this phenomenon may have on the national economy. So, the Port of Lisbon needs to be prepared to receive the future container ships, with no other alternative than the sheltered location that will result from Golada’s closing work construction.

9 Final considerations

9.1 Conclusions

The sedimentary cyclical flow shown in Figure 10 may present problems in the structural stability of the Fortress, by the analysis of Figures 12 and 13, it can be verified that the sedimentary level in the presented years is below or very close to the foundation level of the Fortress.

The protection solution installed on the West side of the Fortress will not, in the long term, prevent that due to the constant sedimentary movements, will not occur collapses in the semi-circular protection structure and later in the Fortress very structure. Such situation may even be propagated to the piles which are in the peripheral zone, in which the Fortress is founded, placing at risk the structural stability.

Concerning the question about Golada’s closure, one of the problems that this may represent is the interruption of the cyclic movement shown in Figure 10, it will occur a sedimentary accumulation in the sandbank that will constitute the “Golada”, by the wave’s action, flood tide and sedimentary migration to the South due to ebb tide action, which will cause an aggravation of the sediment erosion problem in the Fortress West side, because it will be a flow that occurs at a constant rate without sedimentary replacement, due to the cycle interruption.

10 Bibliography

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