Excavation with old facades preservation

Critical analysis of the Jasmin Noir building

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June 2018

Abstract

The increasing occupation of the urban underground space has consequences for existing buildings, which often are not properly assessed when projects involving excavations and peripheral walls are carried out. Thus, it is necessary to make studies and analysis addressing this issue, in order to provide a scientific basis for the essentially empirical construction methods, which depend heavily on the geological and geotechnical conditions. In this context, the thesis is focused on a construction work called the 'Jasmin Noir' building in Lisbon, located at the Príncipe Real square - emphasizing retention of facades to preserve and their underpinning as well as excavations and peripheral contention. An underground car parking was performed using Munich type walls. An analysis of the displacements was made through the finite element program PLAXIS 2D. Finally, two alternative solutions have been studied to examine if the solution performed was possible to become optimized. In order to compare their viability a technical and economic study was made.

KEYWORDS: Underpinning; Peripheral contention; Munich type walls; PLAXIS 2D; Alternative solutions.

1. Introduction

As a Belgian Erasmus student, the opportunity arose to study an excavation work in Lisbon city, where the techniques used fit the content of the dissertation and ranged from king post walls, concrete slab bands, micropiles to retaining and underpinning facades. In the thesis, the detailed execution of some of these techniques is described in greater detail. A general historical overview of Lisbon and its rebuilding actions after the Great Lisbon earthquake was made to understand the seismic, geological and geotechnical conditions situation in the capital of Portugal. The case-study was analysed using a Finite Element model, PLAXIS 2D, which gave an overview of the expected deformation of the soils and could be compared with the alert and alarm criteria. Several companies who design and develop geotechnical engineering solutions are asked to propose other possible solutions for the Jasmin Noir project. Belgian and Portuguese companies have different experience gathered through numerous geotechnical projects, so they give different solutions. These solutions are examined technically, practically and economically for this case study.

2. Lisbon’s great earthquake

Through its history, Portugal mainland has experienced the effects of various moderate to strong earthquakes, thus presenting a moderate seismic risk [1]. In 1755, a great earthquake devastated Lisbon, destroying or rendering uninhabitable most of the wealthy city's buildings. This earthquake occurred in the Kingdom of Portugal on Saturday, 1 November 1755, the Catholic holiday of All Saints’ Day, at around 9:40 a.m. On this day the deeply religious Portuguese packed Lisbon's churches and cathedrals to celebrate the important feast day. As part of the religious celebrations every possible candle was lit and the churches were decorated with flowers and flammable decorations. There were three distinct quake shocks over a ten minute period, which made the candles tumble and ignited the flowers. These fires ravaged Lisbon for five further days after the earthquake. Approximately 40 minutes after the earthquake, a tsunami engulfed the harbour and downtown area, rushing up the Tagus river. This first tsunami wave was followed by two more waves which hit the shore. [1] Eighty-five percent of Lisbon's buildings were destroyed, including famous palaces and libraries, as well as most examples of Portugal's distinctive 16th-century Manueline architecture. Several buildings that had suffered little earthquake damage were destroyed by the subsequent fire. Because most of the effects of the offshore quake were caused by the massive tsunami and widespread fires that followed, rather than by ground shaking, it was believed that were a similar event to occur today, modern tsunami warning systems and disaster response practices, as well as superior building construction, would moderate the scale of damage and casualty. The geotechnical soil characterization is of the utmost importance for seismic risk assessment, being used, in particular, for site effect assessment. They depend mainly on the geological, geotechnical and topographic site characteristics. The large number of old masonry buildings present the most significant potential for large loss earthquakes in Lisbon. [2]

3. Lisbon rebuilding actions and plans

Three typologies of masonry buildings are usually recognized in the Lisbon County: Pombalino buildings built after the 1755 earthquake and systematically imposed during the whole reconstruction program, Gaioleiro buildings built with inferior constructive quality between 1870 and 1930 and Placa buildings, a short-term structural solution which precedes the reinforced concrete buildings [3]. The Pombalino construction represents the first time in history that a city was entirely built making use of solutions designed to withstand future earthquakes. The new downtown design placed the buildings in rectangular quarters with similar dimension following an orthogonal grid of streets. According to Mascarenhas (2005), the structural regularity of the buildings provided a similar performance of the construction within the compound, which besides reinforcing the group effect also gave them superior structural stability. Vertical and horizontal timber elements were added to the facade walls, stiffening the masonry structure around the window openings. The interior structure was composed by timber-masonry walls, timber floors and roof, linked to the exterior walls by timber connecters partially embedded on the masonry and reinforced by metal straps. The wood structure results on the buildings strength and energy dissipation capacity, essential to support the seismic actions in any direction [4]. The existence of the three-dimensional timber structure is named 'gaiola pombalina'. The principal structural material is not only masonry but also wood elements that exist wrapped up in it like a cage made of vertical and horizontal elements braced with diagonals, enclosed on the walls above the first storey. These diagonal elements form Saint Andrew's Crosses, which allow forces redistribution from horizontal actions. The wooden cage is the main earthquake resisting system, eventually leaving masonry to a secondary role. It is known that the mass of a building plays an important role regarding the seismic effects, thus, a timber structure would drastically reduce the weight of the building which combined with the cross timber members conferred an increased resistance that could not possibly be achieved with a simple masonry wall [5]. The Gaioleiro buildings were aggregated in quarters with interior yards and surrounded by a grid of secondary streets, wider than the streets of the Pombalino downtown. There were no standards for buildings height or depth, neither for the architectural design of the facade walls. The construction was carried out by private entities, and therefore the quality of the buildings is very variable. During the nineteenth century, the cage structure characteristic of the Pombalino buildings was progressively simplified. The diagonal elements started to be removed, conditioning the bracing of the timber structure and the rubble infill was then replaced by brick masonry, solid on the lower floors and hollow on the upper. In 1938, a new urbanization plan was commissioned by engineer Duarte Pacheco. The first buildings were built with exterior masonry walls and timber floors strengthened by peripheral concrete beams. The concrete slabs were extended to the whole floor, supporting the name '*Placa*' (meaning concrete slab) given to this typology of buildings [6].

4. Munich type walls

When King Post walls are structures which consist of metal profiles with between them, profiles of wood or precast concrete panels [7], these types of retaining walls are temporary and they are called Berliner walls. Although, when the execution of the walls is a permanent solution that uses reinforced concrete poured in site, supported by micropiles staled at the ground vertically, this technique is called Munich walls. These walls can be used as the final wall of an underground floor. The name of these techniques has already led to some controversy, because they are similar but definitely not the same. The use of Munich-type walls is a solution widely used nowadays in buildings where is expected to maintain its facade, since it presents several advantages over other solutions [8]. For the execution of Munich-type walls, first a general excavation has to be executed, just up to the bottom of the crown beam. This should be as low as possible, dependent on the conditions of the project. Then, the micropiles can be installed vertically and the crown beam can be made. The crown beam makes sure that the remaining loads of the building can be transferred to the micropiles. Therefore, the crown beam connects the micropiles to the remaining structure of the building. Just like the execution of the Berliner wall, the execution of the Munich-type wall is done in vertical stages. But here the use of horizontal staging is also important, because of the 'Soil-arching effect'. Horizontal stages usually have a width of 1m to 1,5m. In this alternate panel method, primary panels shall be cast first, leaving suitable gaps in between. These gaps are excavations made in a slope for an optimal soil-arching effect. Secondary panels shall then be cast, resulting in a continuous Munich wall. Each stage consists of the placement of the reinforcement and formwork, followed by pouring the concrete. The crown beam has the objective of joining all the profiles so they can work together.

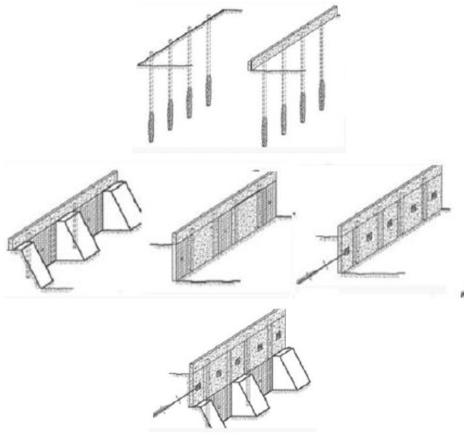

Figure 1: Munich type walls

5. Case study – Jasmin Noir building

This case study is about an excavation site with the preservation of the old facades. The 'Jasmin Noir' building was built more than hundred years ago and is not liveable anymore. The facades must be preserved as a request of the Lisbon Municipality and there will be an excavation because the basement will become a place for two parking lots.

Figure 2: Jasmin Noir building front facade

Figure 3: Jasmin Noir building rear façade

Figure 4: Shoring upper floors

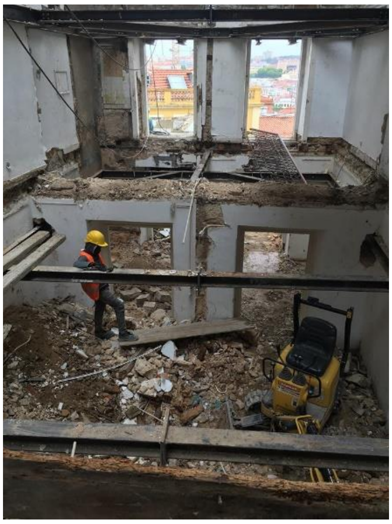

Figure 5: Shoring basement floor

Figure 6: Micropiles

5.1 Geotechnical and geological information

ATTITUDE, S.A. requested Tecnasol FGE to do geotechnical tests of the building's area to recognize its characteristics. They did this using two drill holes that allowed to identify the soils that occurred, followed by dynamic SPT penetration tests (Standard Penetration Test). For the identification of the base and geometry of the lateral wall foundations in the backyard of the building, two inspection wells P1 and P2 were made. From the interpretation of the described tests, it was possible to establish the existence of four geological units (ZG1, ZG2, ZG3 and ZG4). These geological units are described by the parameters presented in Table 1.

Table 1: Geotechnical parameters

Zone	Description	γ (kN/m³)	Ø (°)	C (kPa)	E (MPa)
ZG4	Landfills	10-14	15-20	0	2,5* 3,5**
ZG3	Clays with silt	19-21	30-33	22-50	16,5-18,7* 23-26**
ZG2	Clays with silt, sometimes with marls	20-21	34-36	50-110	24-34* 33-48**
ZG1	Clays with silt and silt with clay	21-22	35-40	100-150	45* 60**

* Assymetric loading
** Flat deformation

5.2 Modelling in PLAXIS 2D

Geotechnical applications require advanced constitutive models for the simulation of the non-linear, time-dependent and anisotropic behaviour of soils and/or rock. PLAXIS 2D is a finite element program, developed for the analysis of deformation, stability and groundwater flow in geotechnical engineering. With Staged Construction the software can accurately model the construction process, by activating and deactivating soil clusters and structural elements in each calculation phase. With plastic, consolidation and safety analysis calculation type, a broad range of geotechnical problems can be analysed. The soil model that is recommended to describe the layers of the ground in excavations of this type is the Hardening-Soil. This model simulates a realistic way the soils behave, using three stiffness' to characterize the soil, E_{50}, E_{ur}, and E_{oed}, Only the behaviour of one section was modelled and analysed, the one where the excavation is the deepest, which is at the section closest to the front façade. After defining the geometry of the model, the input set has the appearance shown in Figure 7.

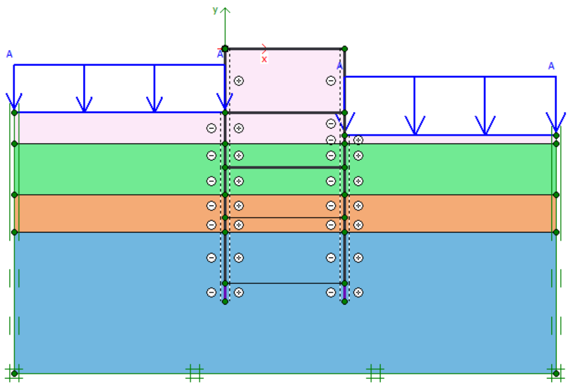

Figure 7: input PLAXIS

Using the data contained in mechanical boreholes, geological and geotechnical reports, technical notes and some correlations between parameters, the four distinct layers of soil were defined. In table 2 are the parameters used to characterize the soils.

Table 2: Used parameters for the hardening-soil model

Parameters	Geotechnical zones			
Hardening-soil model	ZG4	ZG3	ZG2	ZG1
γ_{unsat} [KN/m³]	10	19	20	21
γ_{sat} [KN/m³]	14	21	21	22
e_{init}	0,5	0,5	0,5	0,5
E^{ref}_{50} [KN/m²]	3500	24500	40500	60000
E^{ref}_{ur} [KN/m²]	10500	73500	121500	180000
E^{ref}_{oed}[KN/m²]	3500	24500	40500	60000
c_{ref} [KN/m²]	0	36	80	125
ν^{nu}_{ur}	0,2	0,2	0,2	0,2
Φ [°]	17,5	31,5	35	37,5
Ψ [°]	0	0	0	0
R_{inter}	1	1	1	1
R_f	0,9	0,9	0,9	0,9
p_{ref} [KN/m²]	100	100	100	100
m	0,7	0,7	0,7	0,7
K_0	0,5	0,5	0,5	0,5

In the subroutine 'Calculate' it is necessary to characterize the various stages of the construction of the earth retaining wall, trying to reproduce as closely as possible what happens in reality.

The calculation stages are briefly presented below:

- Phase 0: initial phase;
- Phase 1: external load;
- Phase 2: micropiles;
- Phase 3: first slab;
- Phase 4: first level excavation (2,86m);
- Phase 5: first level Munich walls (ΣMstage = 0.7) (2,86m);
- Phase 6: first level Munich walls (ΣMstage = 0.3) (2,86m);
- Phase 7: second slab;
- Phase 8: second level excavation (2,74m);
- Phase 9: second level Munich walls (ΣMstage = 0.7) (2,74m);
- Phase 10: second level Munich walls (ΣMstage = 0.3) (2,74m);
  Phase 11: third slab;
- Phase 12: third level excavation (2,35m);
- Phase 13: third level Munich walls (ΣMstage = 0.7) (2,35m);
- Phase 14: third level Munich walls (ΣMstage = 0.3) (2,35m);
- Phase 15: fourth level excavation (2,60m);
- Phase 16: fourth level Munich walls (ΣMstage = 0.7) (2,60m);
- Phase 17: fourth level Munich walls (ΣMstage = 0,3) (2,60m).

After the characterization of each phase, the model was run, yielding efforts and final displacements, which serve as reference for the design of the solution and prediction of actual results in terms of displacements.

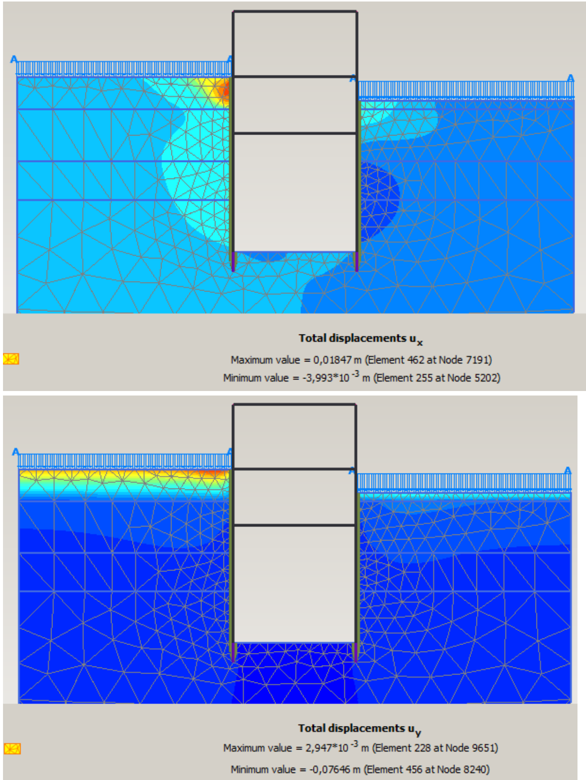

Figure 8: Results PLAXIS

According to Figure 8, it can be seen that the maximum horizontal displacement occurs behind the pile curtain, under the adjacent building. This horizontal displacement is in the direction of the interior of the excavation and has a maximum value of approximately 18 mm. This is 3mm more than the admissible value, but is not an alarm criteria. However, experience has shown that this deformation value is considerably higher than those that happen in reality. The maximum vertical displacements occur under the neighbouring building, corresponding to settlements of 76 mm. This is because of the load of the building, not because of the excavation. The upper layer of the soil will settle under the load because the foundations of the adjacent buildings are not modelled. At the base of the excavation and next to the curtain wall, there is a displacement of about 8 mm. This is lower than 10mm, the admissible value.

6. Alternative solutions

6.1 Underpinning in a contained slot

Munich type walls are an easy, cheap containment method which can be executed against the soil. This is a very common used technique in Portugal, but isn't used like this is other countries. In Belgium there's a very common used method with almost the same advantages, but there are some differences. As far as the stability of the upper structure allows it, a pre-excavation is realized with a minimum of 0,50m above the existing foundation that should be kept. The excavation of the slot will happen in horizontal phases, like the Munich type walls, to avoid the soil-arching effect to damage the structure of adjacent buildings. The width of these horizontal strips is usually 1m, while the sloth has a length of 1,5 to 2m, which makes it possible to carry out the excavation work with sufficient room for manoeuvre. The soil is excavated in vertical stages of 0,4m while systematically applying formwork over the entire perimeter of the pit. The wall that is under the existing foundation is covered with lost prefabricated concrete elements. The other three sides are temporarily covered (for example with wood). The evacuation of the excavated soil is usually done with the help of a bucket lift. This process is repeated until the predetermined depth is reached. After the completion of the excavation process, a reinforcement is placed first and then the formwork of the front side of the wall is put in place. Eventually the concrete can be poured. These first phase strips have to harden for a couple of days, before the second phase can start. This second phase follows the same steps, but the prefabricated concrete formwork has to be placed behind the ones of the first phase, so a continuous wall is created.

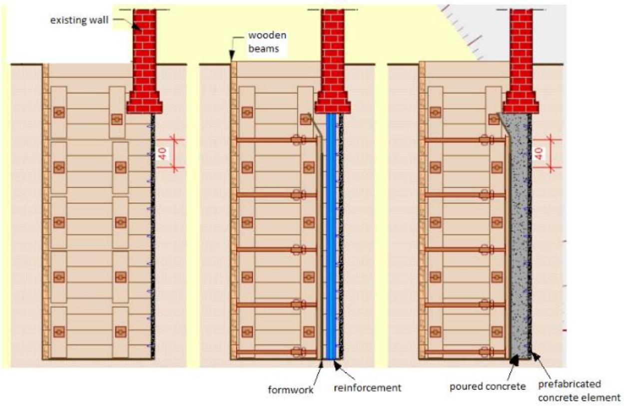

Figure 9: Underpinning in a contained slot

Considering the construction pit reaches a depth of more than 10m in certain locations of the Jasmin Noir site, the safety aspect is very important in this case. In Belgium they still use this technique, usually for underpinning cases of 3-6m, although depths of more than 15m are also possible. Sufficient attention must be paid to dimensioning and implementation, since careless realization can entail major risks. For this reason, the technique hasn't been used in Portugal for a lot of years and especially in this case, the safety of the employees must be guaranteed. On top of that, the execution of this technique would take a long time because it's a manual excavation which exists out of a lot of stages.

6.2 Mini CFA piles

Mini CFA piles can be made out of micro concrete with HEA-profiles and have a smaller diameter as usual. CFA piles are typically installed with diameters ranging from 0,3 to 0,9 m, while the mini CFA piles have a diameter of 250mm and are constructed with the same machine as micropiles. CFA piles are a type of drilled foundation in which the pile is drilled to the final depth in one continuous process using a continuous flight auger. While the auger is drilled into the ground, the flights of the auger are filled with soil, providing lateral support and maintaining the stability of the hole. At the same time the auger is withdrawn from the hole, concrete or a sand/cement grout is placed by pumping the concrete/grout mix through the hollow center of the auger pipe to the base of the auger. Simultaneous pumping of the grout or concrete and withdrawing of the auger provides continuous support of the hole. To create a continuous earth retaining wall with enough stiffness, HEA 160-profiles are placed every two columns.

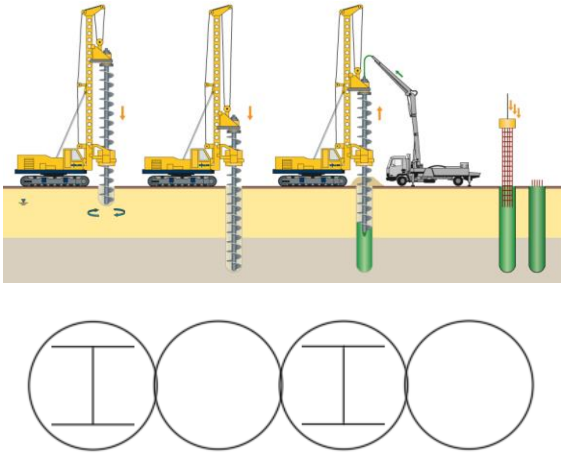

Figure 10: Mini CFA piles

7. Comparison analysis

To compare the different solutions of the Munich walls, underpinning in a contained slot and mini CFA piles, we have to look at all the properties. An economical comparison is made, the results obtained by PLAXIS have to be compared and also other aspects like the need of specialized employees and technology, safety, the time factor and the ability to save space have to be investigated.

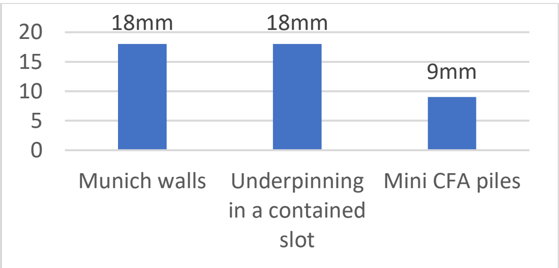

Figure 11: Maximum horizontal displacement of the soil [mm]

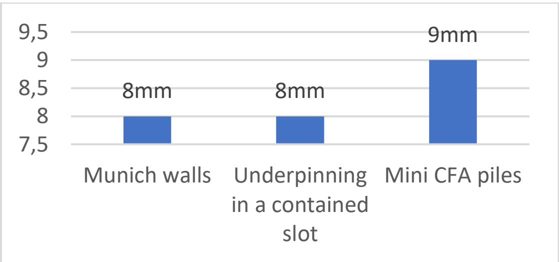

Figure 12: Maximum vertical displacement of the soil [mm]

Figure 11 and 12 show the horizontal and vertical maximum displacements caused by the excavation. All the techniques give a safe solution for the excavation and earth retaining of the basement floors, all values are lower than the alarm criteria.

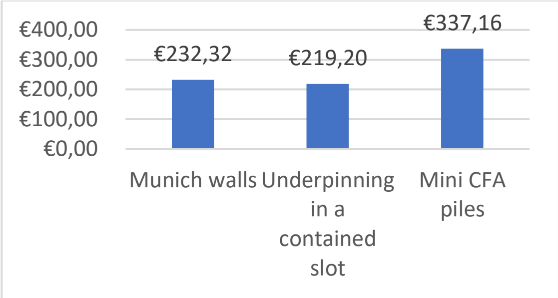

Figure 13: Estimated cost per m² of the retaining wall plan view [€]

The cost per m² of the retaining wall plan view of underpinning in a contained slot is similar to the Munich wall technique, the main difference is the lack of the core beam. The use of mini CFA piles is the most expensive option, because of the use of HEA-profiles. The cost of the employee's salary is not included in this estimation, but can't be forgotten. The execution of Munich walls or underpinning in a contained slot is a manual excavation and will take a long time, approximately they can make six panels/week. The mini CFA piles is a faster solution, which can be executed in three weeks per level of 3m depth.

Except for the technical and economical comparison, other important aspects have to be taken into account. Values are estimated in % of positive effect in Figure 14, to visualise these properties. This way, the option of underpinning in a contained slot can immediately be neglected, because of safety reasons. Doing a manual excavation in a deep contained slot brings too much risks for the employees. The execution of mini CFA piles enables the safest solution because this is not a manual excavation technique and also allows the excavation to be executed faster. For this case study with a small width of approximately 5m, it's very important to execute the retaining wall against the soil with the least loss of space for the basement. This is the main advantage of the option of the Munich walls, but also for the mini CFA piles this problem can be solved by demolishing a small part of the piles on the inside of the basement.

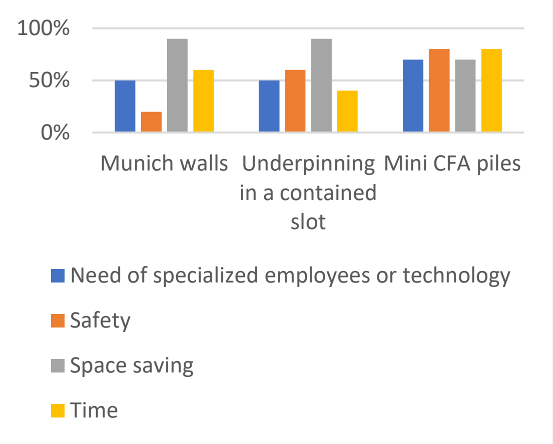

Figure 14: Other aspects [estimated %]

8. Conclusion

8.1 General remarks

To accomplish the objectives, a general historical overview of Lisbon and its rebuilding actions after the Great Lisbon earthquake are described. Through its history, Portugal mainland has experienced the effects of various moderate to strong earthquakes, thus presenting a moderate seismic risk. The geotechnical soil characterization is of the utmost importance for seismic risk assessment, being used, in particular, for site effect assessment. In old cities there is an increasing market of buildings rehabilitation and it is usually necessary to keep the main facades, which implies more difficulties to the earth retaining structures. Allied to this, facade retention solutions must be associated with excavations for basements execution. When King Post walls are structures which consist of metal profiles with between them, profiles of wood or precast concrete, these types of retaining walls are temporary and they are called Berliner walls. Although, when the execution of the walls is a permanent solution that uses reinforced concrete poured in site, supported by micropiles staled at the ground vertically, this technique is called Munich walls. This is a common used technique in Portugal with many advantages and based on the geological, geotechnical and topographic site characteristics one of the easiest techniques to excavate the Jasmin Noir site. Because of the small width of the construction site, the main advantage is the possibility to execute these walls in a small work area and against the soil to save space. An advanced constitutive model for the simulation of the non-linear, time-dependent and anisotropic behaviour of the soils of the site is made in PLAXIS 2D. This finite element program, developed for the analysis of deformation, stability and groundwater flow in geotechnical engineering gives a clear view of the expected displacements. However, experience has shown that these values are considerably higher than those that happen in reality. The results obtained show that the chosen Munich walls technique gives a safe solution for the execution of the basement floors at the Jasmin Noir site. Other solutions are investigated to optimize the work, such as underpinning in a contained slot and mini CFA piles. Both have at least one dominant disadvantage that justifies the choice of the Munich walls. Underpinning in a contained slot was suggested by Belgian companies, but because of safety reasons this method hasn't been applied for years in Portugal. The use of mini CFA piles is a faster solution but will dissolve in a higher cost. The frequency of use of any engineering technique depends mainly on the technical feasibility and economics of the system. In geotechnical engineering, the more problems a construction technique can solve, and the more soil types in which it is effective, the more applications will be available for the system's use.

8.2 Future developments

The process of the excavation using the top/down-method and the execution of the Munich walls couldn't be observed because of the short term of the Erasmus exchange. Further follow-up of the 'Jasmin Noir' site is advised and monitoring results can be found. A retro-analysis of the final solution could be executed, as an attempt to narrow both the displacement values provided by the instrumentation and the modelling values.

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