Solutions of Excavation and Peripheral Earth Containing Walls with Preservation of Historical Façades

Paulo Alexandre Van Den Broeke Costa

Instituto Superior Técnico, University of Lisbon, Lisbon, Portugal

paulovdbcosta@gmail.com

Abstract: In Portugal, the economic crisis has strongly affected the construction sector. It originated a surplus of dwellings in the cities outskirts, unbalancing the supply and demand ratio. In this context, rehabilitation is becoming more relevant in the sector, originating constructions with particular challenges. It is becoming common to see rehabilitation in historical and/or symbolical buildings in the urban centers, since there are some entities (such as banks, hotel chains, companies) that are willing to invest in order to have a prestigious place to offer their services.

Rehabilitation has various degrees of intervention, but the main focus of this paper is about *Fachadism*. This type of rehabilitation preserves the original façades, demolishing everything else on the interior. In order to keep the façades, temporary steel structures are installed, thus complying with the urban planning and preservation of symbolic buildings regulations, and guaranteeing a new building ready to work with the latest infrastructures as well as the modern safety demands. In order to add value to the real estate, these constructions often include deep excavation for the creation of parking lots, since these are scarce in the city centers and highly profitable. This adds the extra difficulty of excavation in city centers with the execution of a peripheral earth retaining wall.

In this thesis, a construction of this type was accompanied, in Lisbon – *Hotel Rua Rosa Araújo 16* – from the beginning of the works until the end of the excavation. Particular importance was given to the instrumentation and observation plan, enabling the managing of the construction behavior and certifying that the security of the works were always checked. In the end, a numerical analysis was made, in order to compare results obtained in the model with results registered in the monitoring devices.

Keywords: *Fachadism*, façades retention, excavation, peripheral earth retaining walls, instrumentation and observation, numerical analysis.

1. Introduction

The main goal of this thesis was to observe and analyse the performed works at the site – *Hotel Rua Rosa Araújo 16.* This way, it could be witnessed firsthand the difficulties in a construction of this type – excavation in urban centres with preservation of the façades. It also enabled a parallel analysis between the project and the execution, analysing the main conditionings at the conception stage, and the difficulties to implement the solution on site.

The results of the instrumentation and observation plan were accompanied and analysed, being noticed that the results of the peripheral earth retaining walls was registered with some delay, although the movements were altogether very limited.

At the end, a numerical analysis was made, varying the main geotechnical parameters in order to calibrate the model response. An attempt to compare the model results with the results registered at the instrumentation devices was also made, but this comparison was limited due to the fact that it was difficult to contextualize the instrumentation results with the model results.

2. Study Case - *Hotel Rua Rosa Araújo 16*

2.1. General Framework

The construction site that related with the considered case is located near Avenida da Liberdade, one of the main avenues in Lisbon, and the construction started in March 2014. This area has been the target of several investments and promotions to requalify it, promoting business and tourism around the area. The construction will originate a 4 star hotel, with 6 floors above the ground (2 more than the original building), and 3 underground floors, in a total of 10 floors.

In order to achieve a solution for the excavation and peripheral earth retaining walls project, the owner provided the following elements [1]:

- Geological and geotechnical study of the area, developed by the company *CêGê*, in May 2011.
- Architecture project, developed by the company *ARP*, in November 2012.
- Structures and foundation project, developed by the company *Pecnon*, in November 2012.

2.2. Conditions

Constructive Issues

This construction is inserted within the limits of *Plano de Urbanização da Avenida da Liberdade e Zona Envolvente (PUAZLE)*. This urbanization plan sets rules and guides in order to promote and preserve the built heritage. Therefore, since the building to be rehabilitated was classified as heritage, it was imposed that the façades were kept intact, constituting the main condition of constructive nature [2]. It was chosen to make a complete new interior, forcing the constructor to execute a temporary steel structure in order to maintain the preserved façades stabilized. Although this makes the construction significantly more expensive, both in terms of direct and indirect costs, it brings some advantages that are worth mentioning [3]:

- Some companies, entities or groups are willing to pay more in order to establish their services in a building with historical/symbolic value. The original façades gives this prestigious value, while a new interior gives the required conditions for the operation. In this study case, a hotel with a symbolic façade (along with its favored localization) adds value to the touristic market.
- The buildings have to follow the regulations in force in the year of their construction, being that the actual regulations are usually more restrictive in terms of areas and safety requirements. Maintaining the façades, it is possible to keep the original depth and height of the original building.
- These historical buildings are usually outdated and unable to receive the modern infrastructures needed to run a certain service. Also, the architectural layout may be incompatible in terms of space distribution. A new interior will solve these issues.

This construction, located in an urban center, has some limitations in terms of storage space, demanding a good organization of the available space and a good coordination between different works. The fact that the implementation area is relatively small (578m^2) and that a temporary steel structure has to be executed to stabilize the façades, aggravates this condition.

Being in an urban center, the works adopted have to take in account the neighborhood conditions. The surrounding buildings should maintain their daily activities uninterrupted, so intrusive solutions should be avoided. It is also important to validate the initial assumptions made in terms of the geometry and conservation state of neighboring buildings foundations, as well as their respective exact location.

Geological/Geotechnical Issues

In 2011, the company *CêGê* made a geological study, in order to evaluate the soil mechanical behavior. The study included:

- 3 base holes with SPT tests (S1, S2 and S3) with continuous recovery of samples.
- Lab tests on the recovered samples, including permeability Lefranc test.
- Installation of 3 piezometers inside the base holes.

With the results obtained, and from the knowledge of the geological scenario in the area, it was possible to separate the following stratigraphic layers:

- **Fills:** On the surface layer, constituted by clay-sands with an abundance of masonry fragments, with a variable depth between 9 and 10,5 metres.
- **"Prazeres Clay" (M^1_I):** Underlying the fills, constituted by sandstones with sandy intercalations, sandy marl and sandstones carbonated concretions.

A geotechnical zoning was made based on the described stratigraphy, with the following geotechnical parameters:

Table 1 – Geotechnical parameters (most frequent values) adopted in the different geotechnical zones (according to [1])

Zone -	N_{SPT} -	Depth m	ϕ' º	c' kPa	ϒ kN/m^3	E' MPa
ZG3 (fills)	1-7	0-9~10,5	28	-	18	7
ZG2 (Prazeres Clay	41-43	9-10,5	30	80	19	50
ZG1 (Prazeres Clay)	>60	>10,5	35	150	22	100

With these results, the initial solution of the excavation and peripheral earth containing walls was proposed.

2.3. Initial Solution

Knowing the conditions just referred, the initial proposed solution included a temporary steel structure to retain the façades (Figure 1).

Figure 1 – Temporary steel structure

This steel structure had pinned joints, making its setup relatively fast. It was supported on a concrete shallow footing founded in micropiles. In order to vertically stabilize the façade, two beams were executed (one on the exterior side and one on the interior), compressed against the façades by a pre-stressed bar of the *Gewy-Dywidag* type (Figure 2).

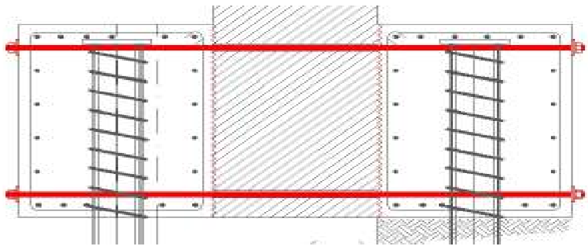

Figure 2 – Beams stabilizing the façade with the pre-stressed bar guaranteeing a better mobilization of the vertical loads (red) (adapted from [4])

The excavation and peripheral earth retaining walls were executed through the King Post walls technology. This kind of technology has competitive advantages towards other retaining walls in solutions with relatively small implantation areas, with limitations in term of storage space and where the ground water level is below the excavation. [5]. In order to support the walls vertically, micropiles were installed beforehand in the ground. Due to physical incompatibility, these micropiles were not embedded on the concrete that formed the containing walls, but executed in its outside. The forces were then transferred through steel cantilevers melded to the micropiles (Figure 3).

Figure 3 – Steel section guarantying the vertical forces mobilization between the retaining wall and the micropile.

There was a pre-treatment at the fills shallow soils (ZG3) with cement slurry, in order to make them stiffer, gaining better mechanical characteristics. This minimizes the decompression that occurs once the King Post walls panels open, enabling a better control of the deformations during the execution of this work.

In order to support the wall horizontally, it was foreseen the use of temporary ground anchors and, due to physical incompatibility in the views FGA and DE (underground parking lots in the neighboring buildings) to execute ground anchors, it was foreseen the use of concrete slab bands. The proposed project blueprint can be seen in Figure 4.

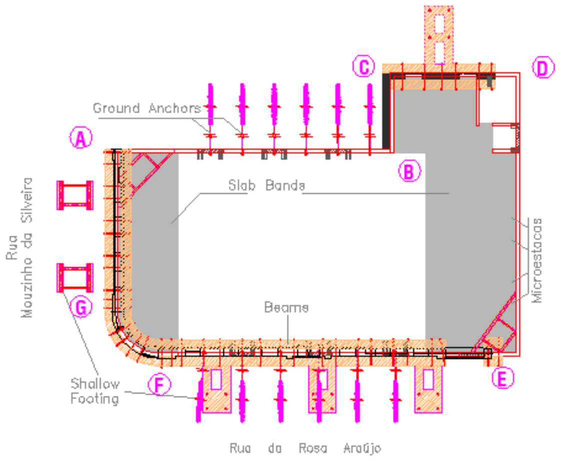

Figure 4 – Building plant of the proposed solution (adapted from [4])

2.4. Alternative Solution

An alternative solution was adopted by the constructor, before the beginning of the excavations works, with the approval of the owner and the office responsible for the excavations project (Figure 5). This alternative solution predicted corner shoring in the views where concrete slab bands were foreseen.

Although it's a more expensive solution, in terms of direct costs (the option is based on a temporary support structure instead of one that is incorporated in the definitive structure), this solution was adopted by the constructor in order to save time on this part of the construction. The slab bands consume more time to be executed, and makes the digging harder directly below its shoring.

Also, since the excavations started in July 2014 and had its deadline for November 2014, it also enabled the constructor to "escape" the autumn rains, avoiding potential delays caused by these unfavourable conditions.

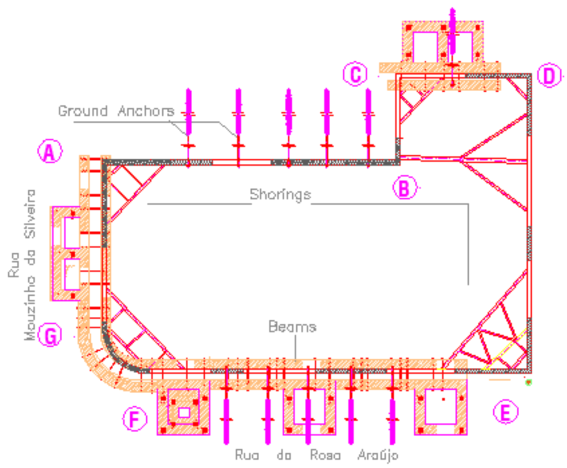

Figure 5 – Building plant of the alternative solution, executed in the construction (adapted from [4])

2.5. Instrumentation and Observation Plan

Due to the uncertainty associated in the definition of the geological and geotechnical parameters, and due to the risky nature of the process's involved in this construction, it's indispensable to have an instrumentation and observation plan. This plan enables the monitoring of the behaviour of the construction and its neighbourhood buildings, allowing the execution of the works, managing safety, quality and economy [1].

This plan was elaborated analysing the principal risks associated with the work processes. Therefore, it was established levels of displacements and vibrations to the retained façades, the peripheral retaining walls and the neighbourhood buildings.

The instruments used in the registration of the construction behaviour where the following:

- Topographic targets, to evaluate horizontal and vertical displacements at the façade retaining structure and peripheral retaining walls.
- Topographic landmarks, to evaluate vertical settlements in the surface.
- Inclinometers, to evaluate horizontal displacements inside the contained terrains.
- Load cells, to evaluate the stress installed in the ground anchors.
- Crack monitors, to accompany the evaluation of the neighbour's cracks behaviour.

Overall, the construction registered very small displacements, very far off the alarm criteria established in project. In the other hand, it was noticed that the registration of the topographic targets in the retaining peripheral walls were obtained too late. The values of the first panel of the wall were obtained when the third panel was being executed, in some cases. In consequence, the most important history of the panel behaviour was lost (when the anchors were pre-stressed, and when the panel beneath the first one was executed).

2.6. Main Construction Phases

In any construction, in particular case ones with significant dimensions, the logistics are complex in order to give the construction a good efficiency. Therefore, it's important previously organize the main construction phases in order to optimize the works schedule.

In this construction, the generic schedule respected the following main phases:

- Execution of the micropiles for the façades retaining structure foundation and the underpinning beams. In parallel, the cement slurry columns were executed in order to give the specified pre-treatment to the fills.
- Execution of the underpinning beams, followed by the assembly of the façade retaining structure. In parallel, localized interior demolitions were being made.
- Once the façade retaining structure was fully complete, the heavy interior demolitions started.
- Execution of the second underpinning beam (from the interior), and installation of the pre-stressed bars of the *Gewy-Dywidag* type.
- Beginning of the excavations and execution of the peripheral earth retaining walls. The panels of the

King Post walls were made in different levels simultaneously depending on its location due to the fills treatment. This allows the works to have a good efficiency, increasing the production (Figure 6).

Figure 6 – Figure that illustrates the parallel execution of different levels of panels. The most delayed part of the excavation is near the entrance, in order to give access to materials and equipment.

- Deactivation of the temporary support elements (anchors, corner shorings and, in a last stage, the façade retention structure).

The slabs of the new structure provided horizontal support to the peripheral walls and to the façade. The façades were connected to the new structure through bolts, fixed in the façades with an epoxy resin, and embedded on the concrete wall that was cast at the perimeter of the façades internal face.

In Figure 7 we can see can observe a picture of the retaining walls and both ground anchors and shorings that horizontally stabilize it.

Figure 7 – Retaining walls.

3. Numerical Analysis

Due to the non-linear behavior of the soils, it is hard to achieve an analytical solution for retaining structures. In this context, special software has had great improvements on the recent past. In this thesis, it was made a numerical analysis using the software Plaxis 2D.

3.1. Plaxis 2D

As implied in the software's name, the use of this software approaches reality if you can simulate it by a two-dimensional analysis. In this case, the borders were considered far enough to simulate this state.

The software has different constitutive models that the user can select. In this study case, it was adopted to use of the *Hardening Soil Mode*l. This model gives good results, according to [6], in the analysis of excavations, since it properly simulates the soil stress-strain behaviors. This model is based on plasticity theories, and it accounts that the stiffness of a certain soil depends of the stress installed on it. Therefore, the stress-strain relation is not a linear one (as it is assumed in the *Mohr-Coloumb* model), but a non-linear one with a shape of an hyperbole (Figure 8).

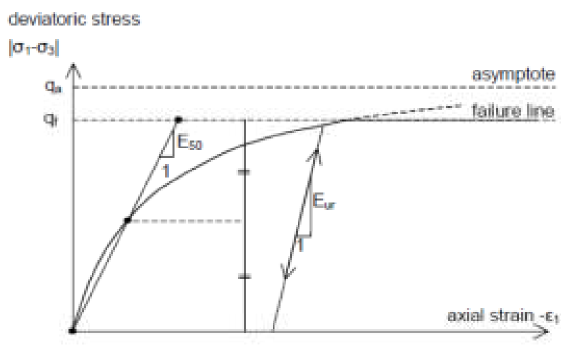

Figure 8 – Stress-strain relation of the Hardening Soil Model (taken from [7])

This model uses the Mohr-Coloumb failure criteria, dependent on the shear strength dilatancy angle and the friction angle (c', ψ and ϕ', respectively), and 3 stiffness modulus in order to recreate the non-linear relation of the soils: triaxial loading stiffness E_{50}, triaxial unloading stiffness E_{ur} and oedemeter loading stiffness E_{oed}. Therefore, this model accounts the stiffness increase with the pressure increase (the same soil has different levels depending on the depth, due to the pressure increase). Also, the yield surface is not fixed, but it can expand due to plastic straining. There are two types of hardening, shear hardening (in consequence of irreversible strains due to primary deviatoric loading) and compression hardening (in consequence of irreversible strains due to isotropic loading). Both types of hardening are contained in this model.

3.2. Modeling

The section 1 (Figure 9) of the peripheral retaining walls was analyzed. The geometry in the model was made in order to recreate the section as it was designed in the project.

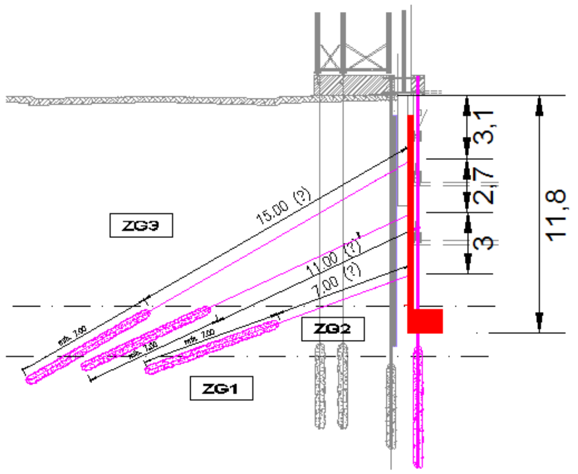

Figure 9 – Section 1 (in color are the elements that had to be characterized (adapted from [4])).

In order to characterize the materials, one has to input parameters (both to characterize the soils and the construction materials). The soil parameters were directly adopted according to the geotechnical report written by the company *CêGê*. They are as represented in the following table. To be noticed that the relations between the different young modulus where the following [7].

$$E \approx E_{50}^{Ref}; \tag{1}$$

$$E_{ur}^{Ref} \approx 3 * E_{50}^{Ref}; \tag{2}$$

$$E_{oed}^{Ref} \approx E_{50}^{Ref}. \tag{3}$$

Table 2 – Soil parameters adopted in the model

Parameters	Un.	ZG3	ZG2	ZG1
γ_{sat}	kN/m^3	18	19	22
γ_{unsat}	kN/m^3	18	19	22
E_{50}^{Ref}	kN/m^2	7000	50000	100000
E_{oed}^{Ref}	kN/m^2	7000	50000	100000
E_{ur}^{Ref}	kN/m^2	21000	150000	300000
ν_{ur}	-	0,3	0,2	0,2
c'	kN/m^2	15	80	150
ϕ'	º	28	30	35
ψ	º	0	0	0
K_0	-	0,53	0,500	0,426

For the construction materials, the parameters where calculated according to their sections and stiffness.

3.3. Design

Once the general conception was defined, and the proper materials attributed to the right elements, the program was ready to run. One of the advantages of this software, is that it allows to run the analysis by construction phases. This is very useful when modeling the King Post walls technology, since this is a phased work. The phases assumed defined in the model where the following:

1. Activation of the external loads.
2. Execution of the micropile (both stage 1 and 2 had the option reset settlements to 0 on, so the these stages wouldn't produce any displacements).
3. Excavation of the first level of panels.

4. Execution of the first level of panels and respective anchor.
5. Excavation of the second level of panels.
6. Execution of the second level of panels and respective anchor.
7. Excavation of the third level of panels.
8. Execution of the third level of panels and respective anchor.
9. Excavation of the fourth level of panels.
10. Execution of the fourth level of panels, and the wall footing.

One of the limitations of this software, being a two-dimensional analysis, is that it does not account the arch effect produced by the fills on the panels not open. A way to simulate this is to define the parameter *ΣMstage* = 0,5. By default, its value is 1, and reducing it means that the calculation will not reach its end (in this case, only 50% of it). Although this is not an exact solution, experience says it leads to good results.

In project, the initial pre-stress to install in the temporary ground anchors was 780kN. Plaxis demands a value by meter, which means that the user has to divide this value by the influence width, which would correspond to 280kN/m. This value produces a displacements towards the ground to big, especially in the upper part of the soil, thus it was adopted the value of 200kN/m, producing results more adequate to what was monitored.

3.4. Results

After running the calculation, the results can be analyzed in terms of stress's, strains and displacements. The program also allows the analysis of construction elements individually. The main displacements in the peripheral wall are shown in Figure 10.

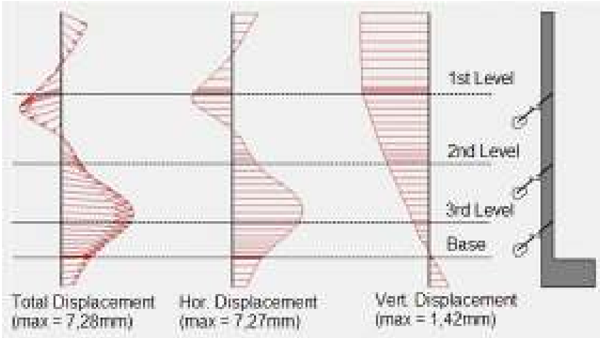

Figure 10 – Displacements of the peripheral wall (total, horizontal and vertical).

Analyzing the Figure 10, we can see that the maximum horizontal displacement is at the level of 3rd anchor, since the soil pressure is higher there than at upper levels. At the 1st anchor level, the movement is towards the interior of the ground. First, the soil pressure is reduced, since it grows with depth, and second, being an fill with low stiffness, its compressibility is bigger, resulting in a displacement towards the ground due to of the pre-stress effect.

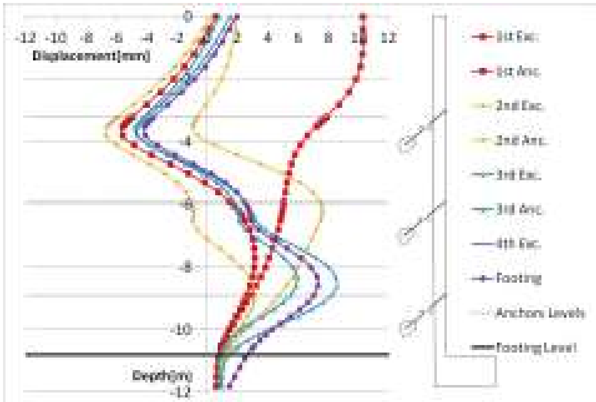

Figure 11 – Horizontal displacement of the wall by construction phase.

In Figure 11, it is shown the horizontal displacements by construction phase. The biggest displacement occurs in the excavation of the first panel level, where it registers 10,2mm towards the interior of the excavation. The little cohesion and stiffness that characterizes the superficial levels of this soil makes it very sensitive to the decompression that is associated with the excavation.

In terms of bending moments, we can see through Figure 12, that these are all positive, with a maximum of 84,23kN/m. The fact that the bending moments have all the same sign implies that the wall does not exploit its full potential. Perhaps the anchors are too close between each other, not letting negative moments be mobilized.

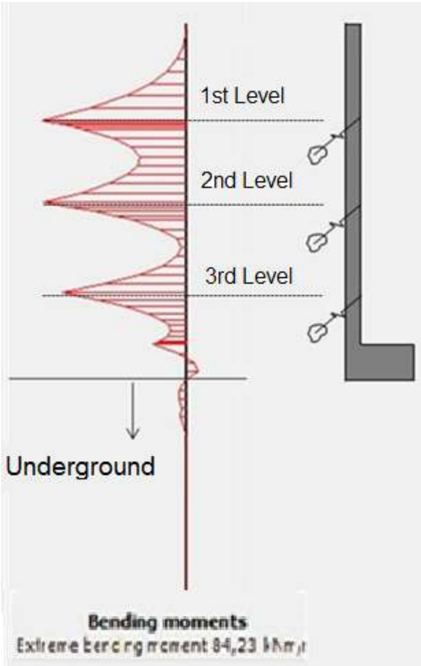

Figure 12 – Bending moments distribution in the wall.

3.5. Back analysis

A back analysis was made in order to try to compare and analyze the differences between the results obtained in the model and those obtained from the monitoring. This comparison had some limitations, since the reading of the devices installed at the retaining wall started with a significant delay, like stated before. Therefore, there is no direct comparison, and the monitoring result from a topographic target located at the bottom part of the original façade was used, in order to try to get conclusions. Although these results were obtained before the excavations begun, the time between readings was sometimes bigger than two weeks, which makes it hard to have a precise control over the structures behavior. In Figure 13 we can see the results from the monitoring, and the results from the model (one with the initial parameters, and one with the young modulus E_{50} =28000kPa instead of 7000kPa).

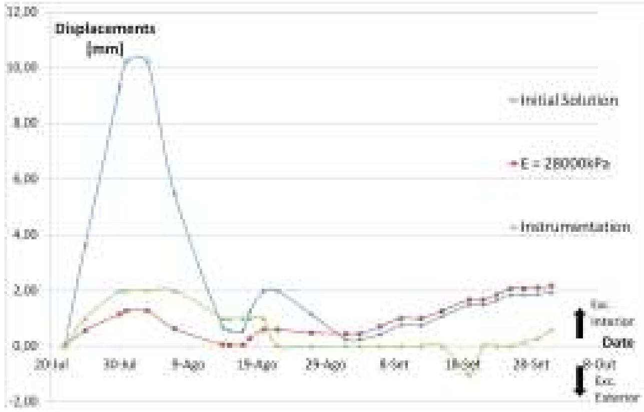

Figure 13 –Comparative graphic between the registered values in the monitoring and the modeled solutions

As shown at the Figure 13, the solution with bigger young modulus has a much closer approximation to the experimental values than the initial solution. This implies that the adopted parameter for the young modulus was probably too conservative. This might have happened for two main reasons:

- First reason, the cement slurry columns were not modeled, but it is probable that this treatment gives the soil some local cohesion and stiffness, reducing its decompression due to the excavation works.
- Second reason is related to the typology of the existent old buildings. The old façades were structural, and the forces were transferred to the foundations through them, and, consequently, it’s expectable that the soils underneath the façade haves a bigger stiffness than in the rest of the construction area.

4. Main Conclusions

This paper served to contextualize the general problems and conditionings that can be found in a construction of this type (*Fachadism*), as well as the general framework that goes along with it. Being a type of construction that’s becoming more common and being done with more frequency, its fundamental to know what one might find in a construction like this.

It was noted that the observation and instrumentation plan was not adopted properly, with the results being registered with a significant delay. It's imperative, in a construction with this nature and having a significant impact in the neighborhood, being in an urban center, to have a thorough plan in order to manage the safety and quality of the works.

At the end, it was observed that the wall movements were quite limited, and that the estimated soil parameters might've been too conservative – particularly the young modulus.

References

[1]Pinto, A., Pereira, A., & N*eves,* M., *Memória descritiva e Justificativa do Projeto de Execução do Recalçamento e Contenção de Fachadas, Fundações Indiretas, Escavação e Contenção Periférica, do Hotel na Rua Rosa Araújo nº6*. JetJS Geotecnia, Lda, Lisbon, 2010.

[2]Decreto-Lei nº380/99 de 22 de Agosto*, Diário da República nº175, 2ª Série*. Planeamento Urbano, Lisbon, 2009.

[3]Cruz, R. M. P., *Sistemas de Suporte de Paredes de Edifícios Antigos em Demolição.* Dissertation to obtain Master's graduation in Civil Engineering, Instituto Superior Técnico, Lisbon, 2008.

[4]Pinto, A., Pereira, A., & N*eves,* M., *Peças desenhadas do Projeto de Execução do Recalçamento e Contenção de Fachadas, Fundações Indiretas, Escavação e Contenção Periférica, do Hotel na Rua Rosa Araújo nº16*. JetJS Geotecnia, Lda, Lisbon, 2010.

[5]Brito, J. de, *Paredes Tipo Munique*., Support text to the subject Tecnologia de Contenções e Fundações, Mestrado em Construção. Instituto Superior Técnico, Lisbon, 2011.

[6]Surarak, C., et al. *Stiffness and strength parameters for hardening soil model of soft and stiff Bangkok clays*. Bangkok, 2012.

[7]Brinkgreve, R. B. J., With co-operation of Al-Khoury, R., Bakker, K. J., Bonnier, P. G., Brand, P. J. W., Broere, W., Burd, H. J., Soltys, G., Vermeer, P. A., .DOC Den Haag, *Plaxis 2D – Version 8*, A. A. Balkema Publishers, Netherlands, Delft, 2002.