Ground improvement solutions at Sana Vasco da Gama Royal Hotel

Solutions d'amélioration du sol au Sana Vasco da Gama Royal Hôtel

A. Pinto, A. Pereira & D. Cardoso
JetSJ – Geotecnia Lda., Portugal, apinto@jetsj.pt, apereira@jetsj.pt, dcardoso@jetsj.pt

J. Sá
Tecnasol FGE – Fundações e Geotecnia S.A., Portugal, jrbasa@tecnasol-fge.pt

ABSTRACT

The aim of this paper is to present the main design and execution criteria related with ground improvement solutions, using jet grouting columns as foundation and cofferdam solutions, at the Sana Torre Vasco da Gama Royal Hotel, located next to the Vasco da Gama Tower, at the Tagus river right bank, in Lisbon, Portugal. The hotel building, with two underwater floors and twenty two upper floors, is located at the river, over alluvial soils with a thickness of about 17m, resting over Miocene soils. This complex scenario demanded the use of some unusual ground improvement solutions, related and interconnected with foundation and cofferdam solutions. The main results of the adopted finite element models are presented, as well as of the monitoring and survey plan.

RÉSUMÉ

Dans cet article sont présentés les critères principaux de conception et d'exécution connexes avec les solutions d'amélioration du sol, utilisant des colonnes de jet grouting, dans des applications des fondations et des parois de soutènement, au Sana Torre Vasco da Gama Royal Hôtel, situé à côté de la tour Vasco da Gama, dans la banque droite du fleuve Tage, à Lisbonne, au Portugal. Le bâtiment, avec deux planchers au-dessous de le niveau de l'eau et vingt-deux planchers supérieurs, est placé au-dessus des sols alluviaux avec une épaisseur d'environ 17m, sur des sols du Miocène. Ce scénario complexe a demandé l'utilisation de quelques solutions peu communes d'amélioration des sols, intégrées et associées avec des solutions de fondations et de parois de soutènement périphérique. Sont aussi présentés quelques résultats des modèles d'éléments finis et aussi du plan de surveillance.

Keywords: soil improvement, jet grouting

1 INTRODUCTION

The Sana Vasco da Gama Royal Hotel is being built with 24 floors and a plan area of approximately 1500m^2, with a semi-elliptical geometry, at the place of the existent and previously demolished building, which held the European Union pavilion at EXPO'98. The building had three upper floors. Its foundations consisted on driven steel piles, filled with concrete. The Vasco da Gama tower foundations consists on a massive peripheral box, made from diaphragm walls and filled in with plain concrete, resting over Miocene soils, with approximately 16m height and a total plan area of about 18x26m^2 (Figure 1).

Figure 1 – Bird eye view of the Hotel excavation works.

Due to the geotechnical and geological conditions of the site, with more than 17m of alluvial soils, as well as the occupation of the ground with the foundations of the existing building, it was necessary to study and apply some unusual solutions for ground improvement, integrated with foundations and cofferdam solutions.

2 MAIN CONDITIONS

2.1 *Geological and geotechnical conditions*

The ground at the site is composed by alluvium soils with an average thickness of about 17 m, resting over the Miocene heterogeneous materials, composed by sands and limestones.

The alluvium soils are essentially formed by silts and clays with NSPT blows not bigger than 3. The undrained shear resistance, assessed by Vane tests, range with depth between 8,5 and 22,0kPa.

Due to the site location, near a previous riverside wall, the site land side has heterogeneous sandy fills and a protection rip rap prism, over the original alluvium mud fills. Table 1 presents the main geotechnical parameters, obtained by the interpretation of the SPT tests and both UCS and triaxial laboratory tests.

Table 1 Main geotechnical parameters.

Material	N_{spt}	ϕ' (º)	c' (kPa)	C_u (kPa)	γ (kN/m^3)	E' (MPa)
Alluvium	<9	18	0	8-22	16	4-10
Miocene	>60	35	40	200	20	50
Jet Grout.	-	-	200-400	500	18	1.000

2.2 *Other conditions*

The land side of the peripheral wall, as well as some new foundations were located at the border of the Vasco da Gama tower's foundation, leading to a solution able to compensate the partially and temporary lost of confinement of the tower's foundation, due to the excavation works.

The foundation of the previously existent building was composed by 69 circular driven piles with permanent steel casing Ǿ630 × 8mm. The construction of the working platform for the driven works demanded the execution of sheet pile wall, braced by steel ties. A protection riprap was placed at the external side of the sheet pile wall (Figure 2).

Demolishing procedures of the pre-existing foundations were performed taking into account the need for compatible solutions between the new and the existent construction, mainly for: foundations, excavation and peripheral walls.

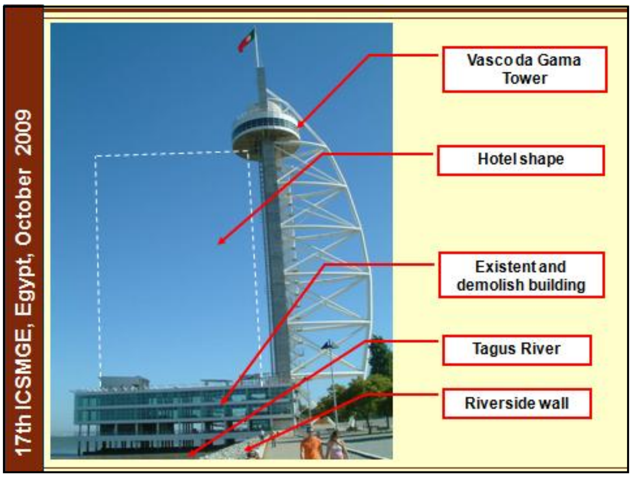

Figure 2 – Main conditions.

3 MAIN SOLUTIONS

3.1 *Introduction*

The main adopted solutions for the foundation and cofferdam retaining walls were the following (Figure 3):

- A temporary "hybrid" cofferdam, composed, at the riverside main perimeter, by a tied / propped sheet piles wall and, at the land side, by an anchored jet grouting columns wall;
- A bottom jet grouting sealing slab, to stiff horizontally the cofferdam and to prevent the water in flow from the excavation base;
- Large diameter reinforced concrete bored piles as foundation of the main structural vertical elements.
- Steel micropiles to nail the jet grouting sealing slab and as foundation of the lightest structural elements, in this case sealed inside jet grouting columns.

In order to obtain safe and permanent working conditions, above water level, the works started with the execution of a temporary working platform, formed by a granular fill, resting over a biaxial geogrid, made from polypropylene (tension resistance of 20kN/m), resulting on a local transfer platform of the load towards the existing foundations (driven and sheet piles), in order to support all the equipment necessary to the main geotechnical works.

Among the equipment, this fill supported a 100ton crane in order to the sheet piles driven from the site central area, correspondent to the location of the existent building, about 10m of distance from the driven point (Figure 4).

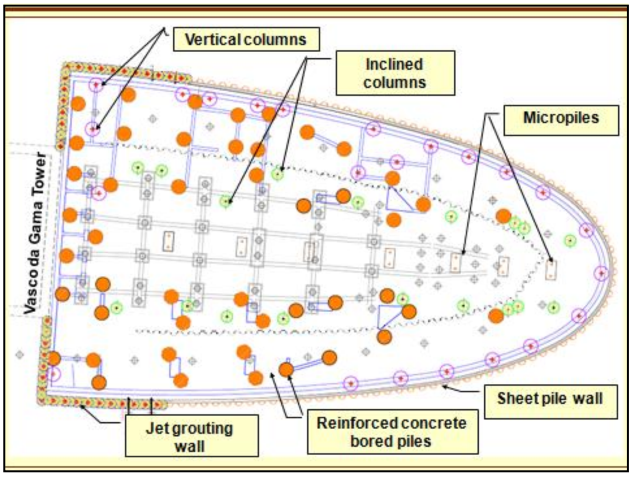

Figure 3 – Plan of the main adopted solutions.

3.2 *"Hybrid" cofferdam*

The execution of the temporary cofferdam comprised, due to geotechnical restraints, two main solutions: sheet piles at the riverside and main perimeter, with a semi-elliptical plan shape, and jet grouting columns on the land side, adjacent to Vasco da Gama tower. In order to decrease the water in flow and to stiff the cofferdam toe, its base rested at the Miocene layer. The sheet piles were driven using a guiding beam (Figure 4).

The cofferdam bracing system consisted in hot rolled steel profiles distributed on a grid shape, supported by distribution beam, at the cofferdam extremities. This steel grid allowed not only the confinement of the working platform fill, performed at 1,70m height (acting as ties during the working platform works), but also allowed the support of the cofferdam walls (acting as props during the excavation works), enabling, together with the jet grouting sealing slab, the stability of the cofferdam during all the construction phases (Figure 5).

In order to facilitate the excavation works the bracing system was vertically supported on steel micropiles, sealed at the jet grouting sealing slab, and located at a minimum height of 6m from the excavation base.

According to the architectural solution, it was necessary to build a permanent reinforced concrete wall, integrated on the final reinforced concrete structure, about 1m for the inside of the temporary cofferdam. This solution demand on a second stage the demolition and cut of both the jet grouting columns and the sheet piles located above the minimum water level.

Figure 4 – View of sheet pile driven operations from the site central area.

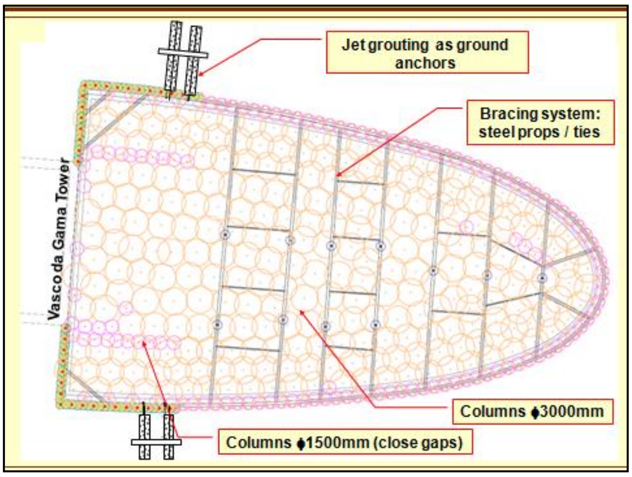

Figure 5 – Plan of jet grouting solutions and cofferdam bracing systems.

3.3 *Jet grouting: horizontal sealing slab, cofferdam wall and foundation*

The jet grouting technology was generally applied, as ground improvement technique, for different solutions.

Below the excavation level, the cofferdam wall was previously braced by one horizontal sealing slab, composed by jet grouting columns ∅3000 mm and ∅1500mm with a minimum thickness of 2 m, and also inclined jet grouting columns ∅1200 mm. This sealing slab allowed also to increase the cofferdam overall horizontal stiffness, as well as to reduce the water in flow from the excavation base (Figure 5). In order to reduce the overall thickness and the bending stress the sealing slab was nailed to the Miocene layer through both the existent and the new foundations: bored piles and micropiles.

The use of jet grouting columns as cofferdam walls was justified by the presence of pre-existing diaphragm walls, as foundation element for the Vasco da Gama tower, as well as the existence of heterogeneous fills, with boulders, not allowing the driving of sheet piles. Therefore, the solution was materialized by a jet grouting columns wall, ∅1000m spaced 0,60m, and reinforced with hollow steel tubes N80 ∅177,8 × 9 mm (API 5A), resting over the limestone substratum.

The bracing of the jet grouting cofferdam walls was assured by an anchoring system, were the steel wires were sealed inside jet grouting columns, taking the advantage of an existing alluvium with more sand and boulders at the land side. Comparing with the traditional procedure, the adopted one allowed the reduction of the ground anchors overall length, as well as the increase of the anchor stiffness (Figures 6 and 7).

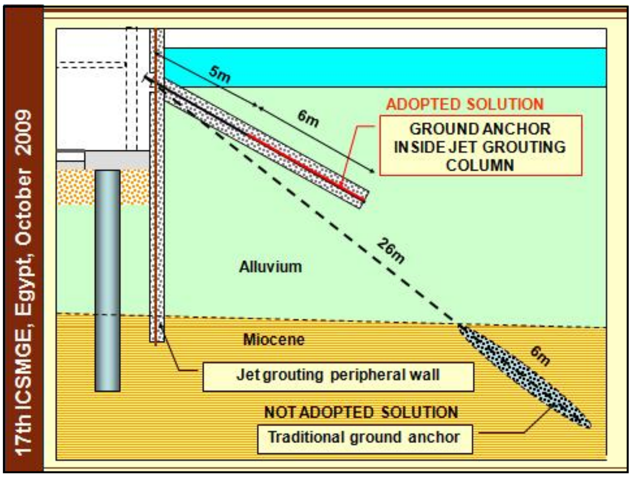

Figure 6 – Ground anchor using jet grouting columns.

Figure 7 – View of the jet grouting cofferdam wall and ground anchors execution.

3.4 *Foundation: bored piles and micropiles*

Taking into account the geological restraints and the carrying loads magnitude the main foundations of the Hotel are reinforced concrete bored piles ∅1500mm, built with top retrievable steel casing. The piles bottom length, including the embedment of about 4,5m at the Miocene layer, was drilled using stabilizing polymers. The equipment required to perform the drilling operations was a rotary "Kelly" ring, allowing both to drill and to clean the pile hole. The integrity of all bored piles was tested through cross hole tests.

As stated, steel micropiles with external couplers were used to nail the jet grouting sealing slab, accommodating tension axial loads, mainly during the excavation phase.

Steel micropiles were also used as foundation of the lightest structural elements, accommodating compression axial loads. In this case the micropiles were sealed inside jet grouting columns, in order to decrease its overall difference of stiffness, comparing to the bored piles one, as well as to allow a better confinement and corrosion protection.

Seismic loads are accommodated both through the bending of large diameter bored piles, as well as through some inclined steel micropiles, sealed inside jet grouting columns.

All the foundation elements, bored piles and micropiles, were capped by a reinforced concrete mat slab, cast against the horizontal jet grouting sealing slab (Figure 8).

Figure 8 – View of excavation works, bracing system, bored piles heads and jet grouting sealing slab.

4 DESIGN

The design of the cofferdam walls, including its bracing systems, was performed using a 2D finite element numerical model (Plaxis Professional V.8).

Internal forces and displacements at the cofferdam walls, as well as on the supported soil, were analyzed and predicted for all the main construction stages (Figure 9). All the main geotechnical parameters were established taking into account the results of previous laboratorial tests (Table 1).

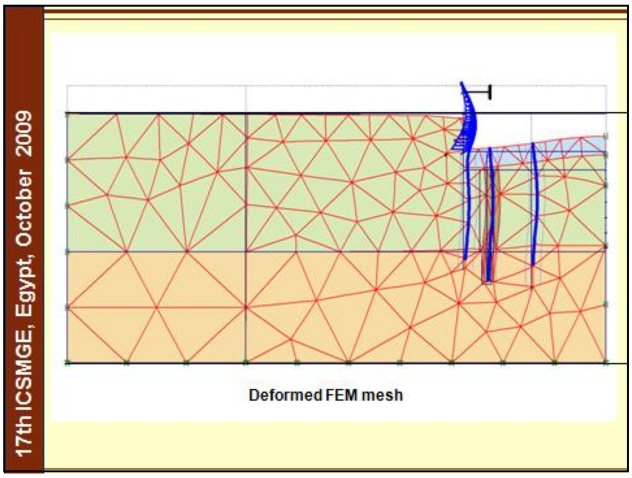

Figure 9 – View of the adopted 2D FEM model.

5 MONITORING AND SURVEY PLAN

Considering the context and the complexity of the described solutions, a monitoring and survey plan was applied taking into account the need to perform the construction in safe and economical conditions for both the site and the Vasco da Gama tower.

In order to accomplish this goal the following equipments/devices were installed: 7 inclinometers, 21 topographic targets and 5 topographic marks. Measurements were commonly performed, at least, twice a week until the cast of the ground level structural slab. The hotel structure is being monitored during its construction in order to access the foundations behavior during the loading process. Figure 10 shows the results of inclinometer I1, where is possible to point out the importance of the jet grouting sealing slab for the cofferdam horizontal stiffness.

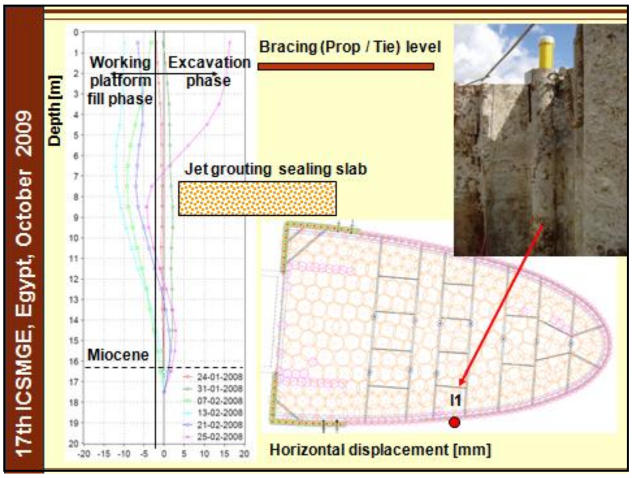

Figure 10 – Monitoring and survey plan: inclinometer displacements.

Figure 11 – Views of the Hotel structure construction.

6 MAIN QUANTITIES

The main quantities regarding geotechnical works are presented in Table 2:

Table 2. Main quantities.

Working load transfer platform over uniaxial geogrids	6.600m^3
Excavation	14.100m^3
Larssen 605 sheet piles	2.018m^2
Jet grouting columns ∅ 1000mm (peripheral wall)	1.476m
Jet grouting columns ∅ 1200mm (foundation and ground anchors)	288m
Jet grouting columns ∅ 1500mm (foundation and sealing slab)	736m
Jet grouting columns ∅3000mm (sealing slab)	783m
Steel tubes N80 ∅88,9 ×9,5mm (inclined columns)	276m
Steel tubes N80 ∅177,8 × 9.0 mm (vertical columns)	937 m
Reinforced concrete bored piles ∅1500mm	1.070 m
Micropiles N80 ∅127 ×9 mm (nailing of sealing slab)	348 m

7 MAIN CONCLUSIONS

In this paper the main design and performance issues of complex cofferdam and foundation solutions, for the Vasco da Gama Royal Hotel, using mainly jet grouting as ground improvement technique, were presented. It should be pointed out the versatility and the good interconnection between the adopted solutions, ranging from jet grouting to bored piles, micropiles and sheet piles, allowing the construction of the cofferdam and the foundations using the safest method: from the working platform, previously any excavation works.

The main conditions and adopted solutions were described. Some FEM models and monitoring results were also presented. Those results show that the obtained displacements were in general lesser than the predicted ones, confirming, together with the respect for the initial schedule and predicted quantities, the overall suitability of the adopted solutions. The building structure should be completed before the Summer of 2009 and until present its foundations are also having a good response to the loading process (Figure 11).

ACKNOWLEDGEMENTS

The authors are grateful to the Hotel owner, *AZITEJO – Empreendimentos Turisticos S.A.* for his permission to the presentation of this paper.