

# Fill of the “Terreiro do Trigo” Dockyard in Lisbon over Alluvial and Hard Soils

## Remblai de la Dock du “Terreiro do Trigo” à Lisbonne sur des Alluvions e de Sols Durs

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### ABSTRACT

The “Terreiro do Trigo” dockyard, at the “Jardim do Tabaco”, was filled in order to allow the construction of the new “Santa Apolónia” Cruise Terminal in Lisbon, at the Tagus River right bank. A load transfer platform (LTP), founded over jet grouting columns, allowed the construction of a 4,2m height embankment placed over a soft muddy alluvium layer (Cu lesser than 20 kPa) with about 20m of average thickness. The existent dockyard peripheral old walls were refurbished and underpinned using micropiles, capped by reinforced concrete beams, in order to accommodate the new embankment earth pressures. The main design and execution criteria, including the quality control and quality assurance of the jet grouting columns are presented, as well as the main results of the adopted monitoring and survey plan. Finally, the technical and economic advantages of the adopted solutions, comparing with some more conventional ones, are presented.

### RÉSUMÉ

Le dock du “Terreiro do Trigo” au “Jardim do Tabaco” a été remblaié pour permettre la construction du nouveau Terminal de Croisières de “Santa Apolónia”, dans la marge droit du Tage, à Lisbonne. Une plateforme de transfert de charges supportée par des colonnes de jet grouting a été construite pour permettre l’exécution du remblai avec 4,2m de hauteur, placé sur des alluvions avec une faible résistance (Cu inférieur à 20 kPa) et 20m d’épaisseur moyenne. Les murs périphériques du dock ont été renforcés avec des micropieux, enrobés par des poutres en béton arme, pour résister aux impulsions du nouveau remblai. Les principaux critères de dimensionnement et d’exécution et le contrôle de qualité et d’exécution des colonnes de jet grouting sont présentés, bien que les résultats de l’instrumentation et de l’observation de l’ouvrage. À la fin de l’article, les avantages techniques, et économiques des technologies adoptées sont surélevés et confrontées avec celles des technologies plus conventionnelles.

Keywords: jet grouting, micropiles, load transfer platform, underpinning

## 1 INTRODUCTION

The jet grouting technology is being used in Portugal since the last twenty years as ground improvement solution. At the beginning it was used mainly for tunneling and underground works. In the last years, due to the technology versatility, the application field is being widespread, includ-

ing ground treatment for foundations of every kind of structures [2], including load transfer platforms (LTP)[3], horizontal sealing slabs [1], slope stabilization, earth retaining structures [1] and underpinning of existent structures. The technology is being proving as appropriate in various ground conditions, including hard soils

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and weak rocks, a big advantage in sites with very heterogeneous geological conditions.

The future development of the jet grouting technology will depend on a better design, quality assurance and control of the adopted solutions, as well as the improvement of the environmental impact (spoil reuse). To achieve those objectives it will be important to prepare codes of practice, including factors such as the quality control and assurance, the life time instrumentation and the execution of full scale load tests.

In this paper it is presented a case history of the load transfer platform foundation adopted for the fill of the “Terreiro do Trigo” dockyard, including the closing and refurbishment of the “Jardim do Tabaco” centenary masonry quay walls. The site is located at the Tagus River right bank in Lisbon, where the jet grouting technology was applied with success on very complex neighborhood and geological conditions, including Miocene weak rocks, sandstones, and hard soils, dense sands (figure 1).

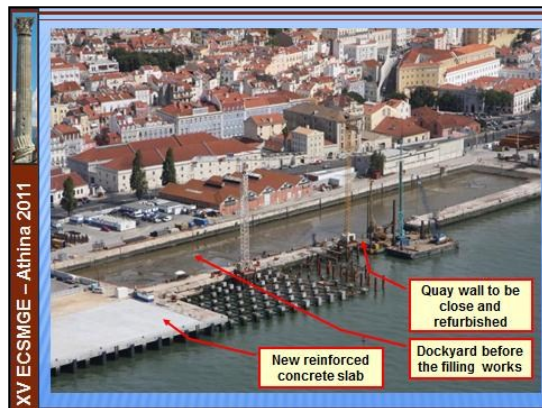


Figure 1. Over view of the dockyard and quay walls.

## 2 FILL OF THE “TERREIRO DO TRIGO” DOCKYARD

### 2.1 Main conditions

The landfill of the dockyard was performed on an area of about  $290 \times 56 \text{ m}^2$  with 4,2m height, over soft alluvium soils (muddy alluvium with  $C_u$  lesser than 20KPa) with 20m of average

depth, including at the bottom a layer of muddy sands, resting over the Miocene sandstones and dense sands. It was built with the purpose to allow the construction of the new “Santa Apolónia” Cruise Terminal. Also important was the compatibility with the reinforced concrete slab, built over bored piles at the river bed, allowing the operation of big ships (figure 2).



Figure 2. Site location and perspective of the new Terminal.

Other main issues were the need for the preservation of the adjacent old buildings and infrastructures stability, including one  $\varnothing 1000 \text{ mm}$  water pipe and the Lisbon Metro line, as well as the quay walls integrity. In order to better resist to the new landfill earth pressures and to confine the soft soils under the fill, the quay walls were previously refurbished and the dockyard gate previously closed (figures 1 and 3).

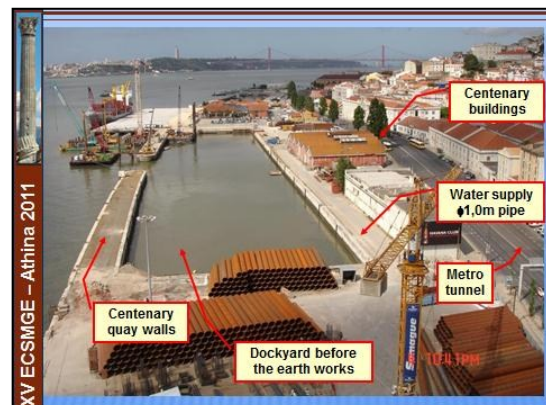


Figure 3. Main conditions of the site at the beginning of the works.

## 2.2 LTP foundation

Taking into account the existent conditions, mainly the complex working area, as well as the works schedule, the landfill was built over a load transfer platform (LTP), located over jet grouting  $\varnothing 1,5\text{m}$  columns on a  $5,7 \times 5,7\text{m}^2$  mesh and resting at the Miocene sandstones and dense sands, installed during low tide (figure 4). About  $550\text{kg/m}^3$  of pozzolanic cement was used in order to reach a UCS of  $3,7\text{MPa}$ .

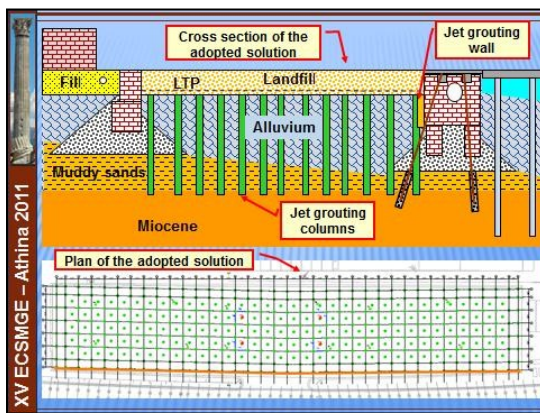


Figure 4. Adopted solution for LTP foundation

The LTP was formed by two layers of biaxial polypropylene geogrids (20 and  $30\text{kN/m}$  of ultimate tension resistance) under two layers of  $0,5\text{m}$  thickness of granular material. The LTP was also installed during low tide (figure 5).



Figure 5. Geogrids installation on low tide.

As already stated, the masonry quay walls were previously refurbished and underpinned us-

ing inclined tubular steel micropiles, capped by a grillage of reinforced concrete beams and slabs. The dockyard gate, with about  $40\text{m}$  length, was also previously closed using a sheet pile wall, as well as bored piles, both capped by a reinforced concrete slab (figure 6). Those works, together with a jet grouting wall,  $\varnothing 1,2\text{m}$  columns spaced  $1,0\text{m}$ , built at the quay wall internal face (figure 4), allowed the previous horizontal confinement of the alluvium materials. This confinement effect allowed also the decrease of the tides water level amplitude inside the dockyard, leading to the increase of the works performance.

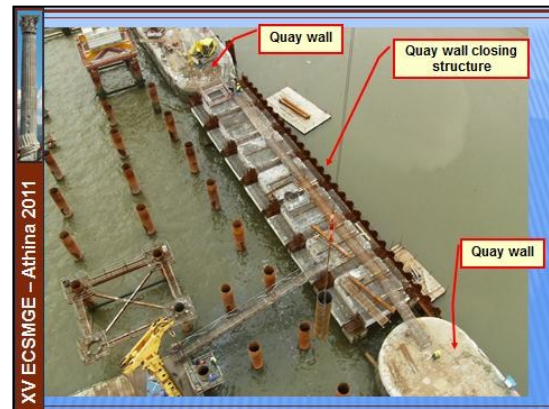


Figure 6. Quay walls closing structure.

## 2.3 Quay walls underpinning

As already stated, the existent quay walls were previously refurbished and underpinned using self drilling micropiles (figures 7 and 8).

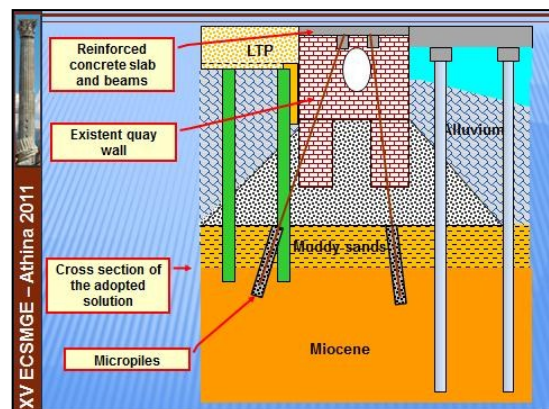


Figure 7. Existent quay walls refurbishment and underpinning solution.





Figure 8. Quay walls refurbishment and underpinning works.

In order to optimize the micropiles overall bond length, mini jet grouting single phase system was used during drilling, allowing the execution of a grout body diameter of about 1000mm mobilizing a big shaft resistance at the alluvial sandy layers.

#### 2.4 Design

For the design of the adopted solution a 3D FEM analysis was carried out, using Plaxis software. The maximum estimated vertical displacement at the top of the fill, after the conclusion of the earth works, was about 76mm (figures 9 and 10).

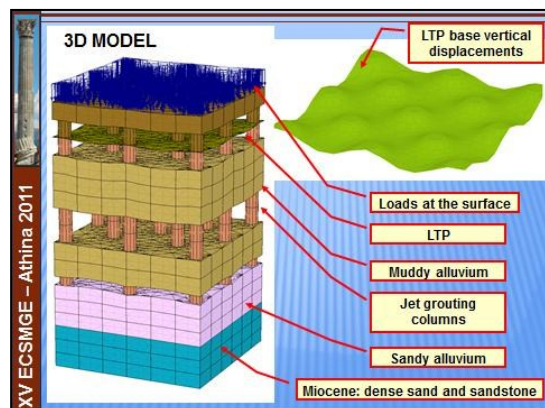


Figure 9. 3D FEM model mesh.

During the construction of the LTP and the landfill the maximum vertical displacements ob-

tained at the topographic marks were about 350mm (figure 11).

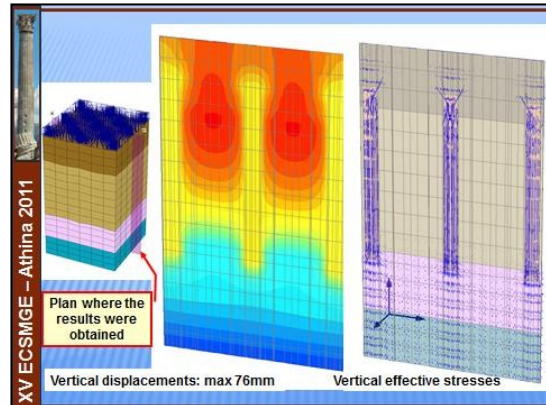


Figure 10. 3D FEM model main results.

#### 2.5 Monitoring and survey

The solution performance was accessed through an instrumentation plan, during the jet grouting and earth works. The instrumentation plan comprised the installation of topographic marks at the landfill base, as well as rod extensometers at the LTP geogrids and pressure cells at the jet grouting columns head (figures 11, 12 and 13).

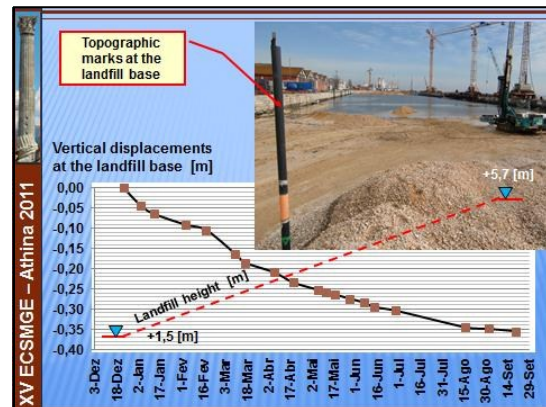


Figure 11. Vertical displacements at the landfill base.

According to the analysis of the instrumentation readings it was possible to conclude that, in spite of the jet grouting columns had been design to resist to all the loads due to the landfill weight and live loads (3,7MPa of unconfined resistance compression), only about 40% of those loads was directly transferred to jet grouting columns head.

The remaining 60% of the overall loads were resisted by the confined muddy alluvium and transferred to the jet grouting columns shaft at a small depth, minimizing the aluvium consolidation effects.

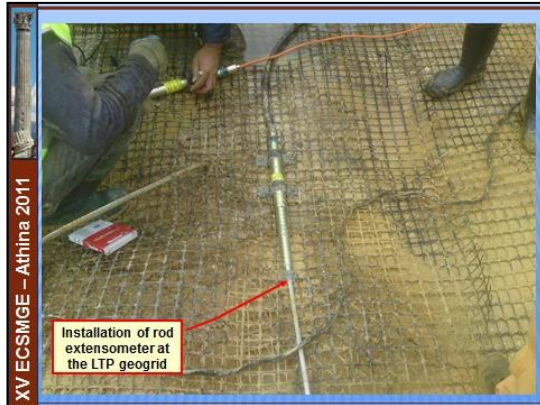


Figure 12. Installation of rod extensometers at the geogrids.

The main reason for this situation was the increase of the mud overall bearing capacity, due to the 3D confinement effect, which could be explained by the following main issues:

- At the top of the mud: due to the upper landfill;
- At the base of the mud: due to the Miocene layer;
- Horizontally: due to the jet grouting columns and to the peripheral quay and retaining walls.

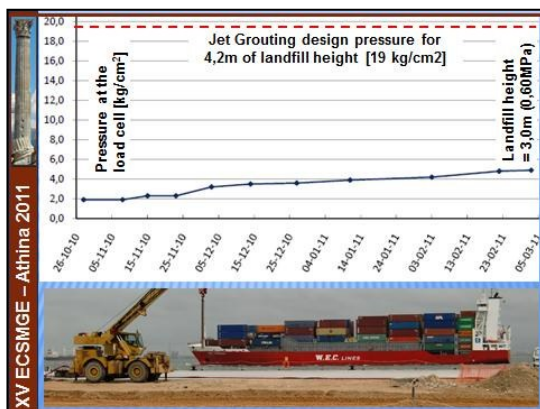


Figure 13. Load cells at the jet grouting columns head: main results.

## 2.6 Quality control and quality assurance

The execution of the jet grouting columns was complemented by a tight quality control and quality assurance, allowing the confirmation of the resistance, deformability and geometry of the columns. For this purpose, test columns were built and full length cores from test and final columns were collected in order to confirm the geometry and to perform laboratorial tests, mainly Unconfined Compression Strength (UCS), at different ages, including the measurement of the Young Modulus (figure 14).



Figure 14. Jet grouting columns core samples.

During the execution of the jet grouting columns a permanent registration of all the adopted parameters was also performed, allowing to confirm the columns overall length, mainly the columns toe at the Miocene sandstones and dense sands (figure 15).



Figure 15. Jet grouting columns execution control.

## 2.7 Solution remarks

In spite of the very difficult conditions, the adopted solution allowed the fulfillment of all the main objectives, specially the following issues: technical (low deformations at the landfill platform and at the neighbor structures and infrastructures) and control of both costs and construction schedule, confirming the good performance of the solution.

The adopted solution is being tested with full scale vertical and horizontal load tests in order to confirm its integration on the foundations solution for the new Cruise Terminal building. For this purpose and to be confirmed according to the full scale load tests results, the jet grouting columns located under the new building columns and walls will be reinforced with steel tubular micropiles in order to resist to about 2.500kN of axial service load.

It should also be stated that the adopted solution for the ground improvement and landfill foundation was design as an alternative to a stone columns solution, leading to the consolidation of the muddy soils, which would increase the vertical deformations to about 1,5m, including possible severe damages on the very sensitive neighbor buildings and infrastructures.

## 3 MAIN CONCLUSIONS

Taking into account the presented example and comparing with some more traditional solutions, is possible to point out the following advantages of the jet grouting solutions [1, 2 and 3]:

- Possibility to be applied to almost every kind of soils, with low vibration, low-noise and strong, but local, ground perturbation;
- Small dimension and small height of the jet grouting equipment, leading to big versatility, allowing the use of the technology on very complex scenarios;
- The ground is improved, using an hydraulic process, in order to be integrated on the final engineering solution with both economic and environmental advantages.

- The confinement effect on soft soils lead to the minimization of differential and total settlements, occurring mainly during the construction phase;
- No need of pre loading on soft soils. The consolidation effects are very small and occur close from the ground surface;
- Good execution control due to the sophisticated equipment, allowing in real time the registration of the execution parameters.

As main limitations of the jet grouting technology the following issues could be point out:

- Production of spoil, which could however be integrated on the earth works or in the next future reused;
- Very demanding quality control and quality assurance, as happening with the majority of the ground improvement techniques.

The presented case history of jet grouting applications, for foundations of an LTP as well as for the underpinning of centenary walls, can be considered as an example how the jet grouting technology is being used on complex structural and geotechnical scenarios, proving its technical and economic advantages.

## ACKNOWLEDGEMENT

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