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Ground improvement solutions using jet grouting columns

Solutions d'amélioration des sols avec des colonnes de jet grouting

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ABSTRACT
The aim of this paper is to present the main design and execution criteria related with ground improvement and foundation solutions using jet grouting columns, caped by load transfer platforms (LTP), formed by compacted granular fills reinforced by geosynthetics: polypropylene biaxial geogrids or high strength geotextiles.

RÉSUMÉ
L'objectif da la présente communication consiste en la description des principaux critères de conception et d'exécution considérés dans la définition des solutions de amélioration des sols et de fondations avec des colonnes de jet grouting, recouvertes par des plate-formes de transfert de charges formées par materiaux granulaires reinforcés par des géosynthétics.

1 INTRODUCTION

The constructions of new structures and new infrastructures at the Tagus river right bank has increased in the last years. From the geological point of view the last 60km of the Tagus river, between Santarém and Lisbon, are formed by a wide and deep muddy alluvium, with c_u sometimes lesser than 20kPa, resting over Miocene soils, with low resistance at the contact with the alluvium, q_c (CPT) of about 3MPa, increasing with depth.

At the same time and as usual, the construction owners keep looking for both short schedules and economical solutions. In order to face those challenges the solutions of soil improvement using jet grouting columns, resting at the Miocene soils, caped by LTP (load transfer platforms) has being proved as a reliable solution from both the technical and the economical point of views. In this paper some applications cases of this solutions under industrial buildings, railways and roads are presented.

2 LIGHT INDUSTRIAL BUILDINGS

The presented solution was adopted for both the improvement and the foundation of some light industrial buildings, where, at the ground level, the concrete pavement was built over a fill of about 2m high and designed for a surcharge load of 40kN/m^2.

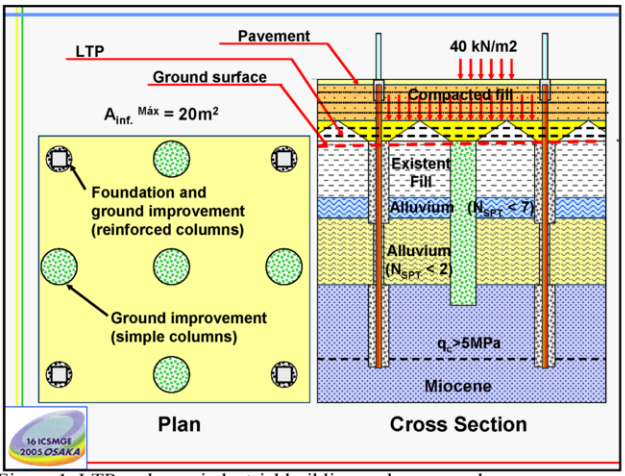

Figure 1. LTP under an industrial building: columns mesh.

The LTP platform, located at the base of a the 2m depth indoor fill, was formed by a compacted granular fill, reinforced at the base by two layers of biaxial polypropylene geogrids (ultimate tension resistance of 20 and 30kN/m), resting over a mesh of jet grouting columns with 1200mm of head diameter (ultimate compression resistance of 4MPa), each one with a maximum influence area of about 20m^2 (Fig. 1 and 2).

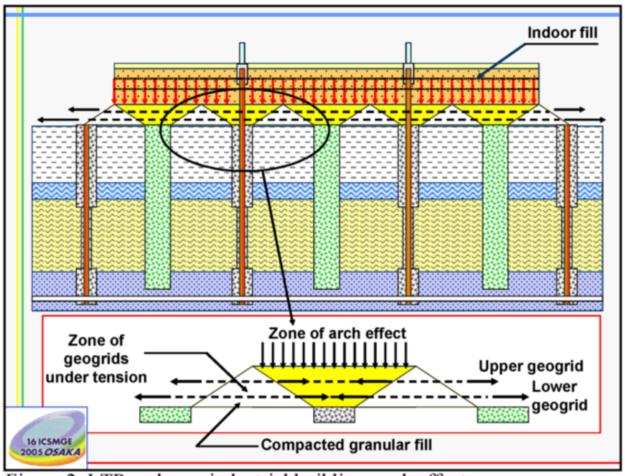

Figure 2. LTP under an industrial building: arch effect.

In this case two types of columns were adopted: simple columns and reinforced columns. The last ones, with the double function of ground improvement and foundation elements, were reinforced with high resistance steel tubes (yield strength of 560 MPa), allowing the partial reduction of the columns middle cross section diameter from ∅1200mm to a minimum of ∅400mm. The columns were enlarged at the head, with ∅1200mm caps, in order to facilitate the transmission of the loads from both the structure and the LTP, preventing the LTP punching. The same columns were again enlarged at the base, to the same diameter, in order to allow the decrease of the total working stress transmitted to the soil, lesser than 1,6 MPa, allowing also the reduction of the columns overall length for about 9m (Fig. 1 and 2).

This solution allowed the columns to rest over the Miocene silty clay, with a q_c (CPT) resistance not lower than 5MPa, assessed through CPT "in-situ" tests. It should be pointed out that a traditional solution would have required the execution of bored or driven piles with a minimum overall length of about 15m, distributed through a much tighter mesh, if used for both foundation and ground improvement purposes.

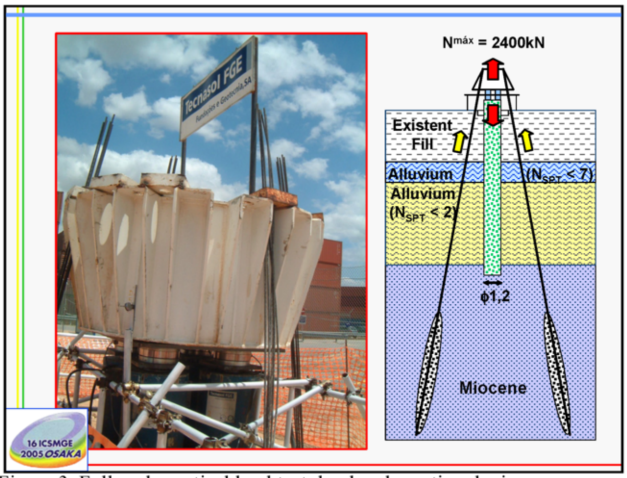

Figure 3. Full scale vertical load test: load and reaction device.

Taking into account that for this kind of solution reliable analytical prediction models are not still available today the presented solution was previously tested through a full scale vertical load test of a simple and constant ∅1200mm column. Four load cycles were applied and at the last one a maximum load of 2400kN was reached (2,1MPa working stress), about one and a half times the service load (1600kN). However it should be pointed out that this maximum load was restrained mainly by an inadequate behavior of the reaction ground anchors. The results of the performed test confirmed the elastic behavior of the column for the service load, after a plastic settlement with a value not bigger than the column elastic shortening, also necessary for the mobilization of the column lateral shaft resistance (Fig. 3 and 4). At the service load almost half of the load was transmitted to the soil by lateral shaft resistance with a maximum value of shaft resistance of almost 60kPa mobilized at the Miocene base layer. A creep analysis was also performed confirming as well the main design assumptions.

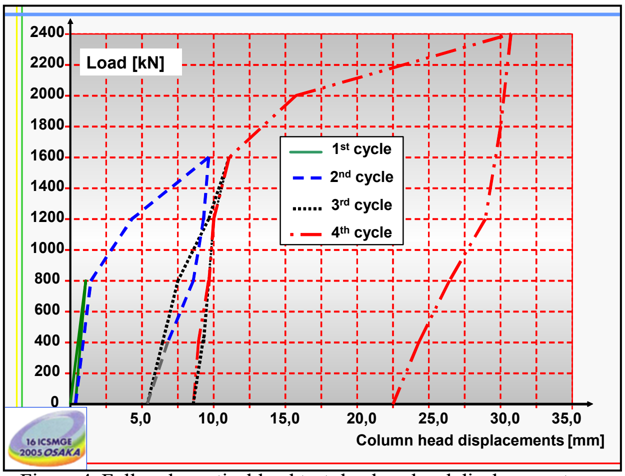

Figure 4. Full scale vertical load test: load vs. head displacements.

In the same site a similar solution was adopted for the ground improvement of some road platforms. In this case, only the simple and constant ∅1200mm columns were used, distributed through a mesh of about 25m^2 of influence area.

3 STATIC RAILWAY PLATFORM

In the same site, a similar solution was also studied for a railway platform through a static full scale load test. The decision for this study was considered taking into account the undergoing works for the modernization of the main portuguese railway line, Linha do Norte, as well as the construction in the next future of the first high-speed line (TGV), connecting the two main portuguese cities: Lisbon and Oporto.

In this case due to the loads amplitude, as well as to the geometry of the platform, the LTP was founded over a mesh of ∅1200mm jet grouting columns (ultimate compression resistance of 4MPa), caped by ∅2500mm columns, each one with an influence area of about 35m^2 (Fig 5 and 6).

The LTP platform was formed by a granular fill with 2,7m high, reinforced, due to its overall high and span between the jet grouting columns, by two layers of geogrids, at the top (ultimate tension resistance of 20 and 30kN/m), and two layers of high strength geotextiles at the base (ultimate tension resistance of 100 and 200kN/m). The option for the mix of high strength geotextiles and geogrids was determined by the resistance required by the span between the jet grouting columns. The platform was monitored with topographic marks, located both at surface and at several depths. The central jet grouting column was also monitored with four pressure cells and one inclinometer (Fig 5 and 6).

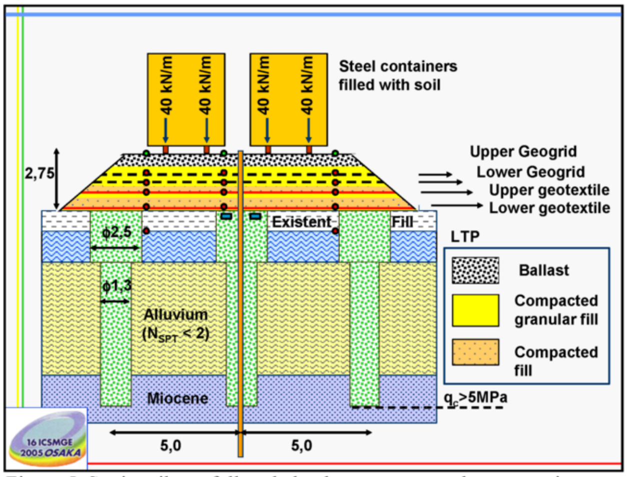

Figure 5. Static railway full scale load test: transversal cross section.

The platform was loaded by an equivalent train static load, simulated by steel containers filled with soil (Fig 7). Each row of containers was placed over pairs of "I" shape steel profiles in order to simulate a linear load of 40kN/m, similar to the portuguese railway code of practice design load (Fig 8).

After 3 months the load test was stopped due to logistic reasons. At that time the maximum settlements obtained were not bigger than 30mmm with apparent tendency to the stabilization (Fig. 8). However, the measured load transmitted to the central jet grouting column was just about 34% of the maximum theoretical load (Fig. 9), indicating that the remaining 66% was apparently transferred directly to the soft soil. In order to confirm this distribution, witch could be explained by insufficient cap geometry of the central jet grouting column, a set of DPSH tests were performed between and outside jet grouting columns.

The results of the DPSH tests confirmed that the resistance of the soil located between the columns increased about 3 times, comparing with the resistance of the same soil located outside of the LTP. This situation allowed the conclusion that the resistance of the confined soil, located between the jet grouting columns, increases if this soil is loaded and could be considered as an extra safety margin if, in any case, some part of the load is not directly transferred to the double function soil improvement and foundation jet grouting columns.

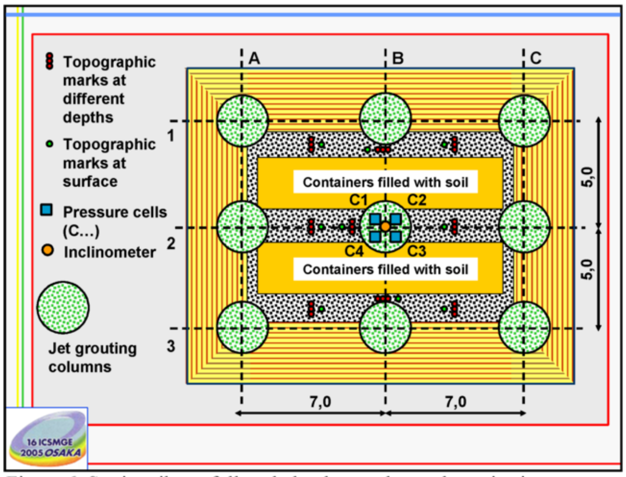

Figure 6. Static railway full scale load test: plan and monitoring.

Figure 7. Static railway full scale load test: filling of containers.

It should also be pointed out that at the discharge phase, after the containers have been removed, it was observed a tendency for the relieve of the maximum settlement, indicating a partial elastic behavior of both the LTP and the columns.

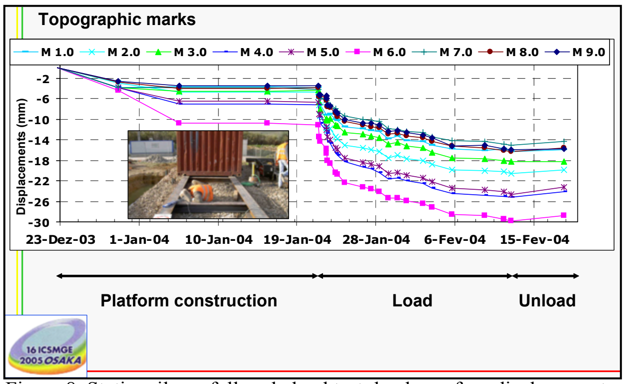

Figure 8. Static railway full scale load test: load - surface displacements.

In spite of the its short duration, the main conclusions of the performed full scale load test were very similar to those stressed by Znazingar and Gartung (2002). The data obtained during a period of just only 3 months apparently matched with the one obtained over a much wider period by Znazingar and Gartung (2002), showing that this kind of solution could be considered safe and apparently performing adequately with respect to the railway platform serviceability demands, as the main deformations occur under both the construction and the initial loads applied at the railway platform. In spite of this preliminary conclusions it would be desirable to repeat this kind of full scale load test during a longer time and using dynamic loads in order to access both the platform and the soil vibrations.

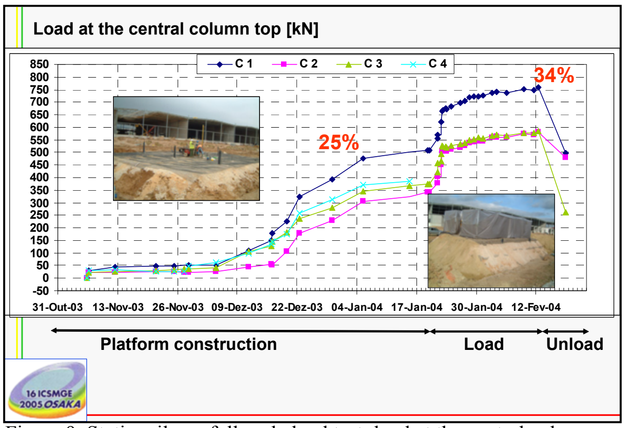

Figure 9. Static railway full scale load test: load at the central column.

4 ROAD PLATFORM

A similar solution was also proposed on a tender for the soil improvement of a road platform. In this case due to the thickness of the alluvium, sometimes bigger than 20m, it was proposed the foundation of the LTP over a mesh of jet grouting ∅1200mm columns (ultimate compression resistance of 4MPa), resting on Miocene soils, with a maximum influence area of about 30m^2 (Fig. 10 and 11).

The LTP platform would be formed by a granular fill with a total high ranging from 1,5m to 2,6m, reinforced by two layers of high strength geotextiles (ultimate tension resistance of 100 and 200kN/m). The option for the high strength geotextiles was determined by the resistance required by the span between the jet grouting columns (Fig. 10).

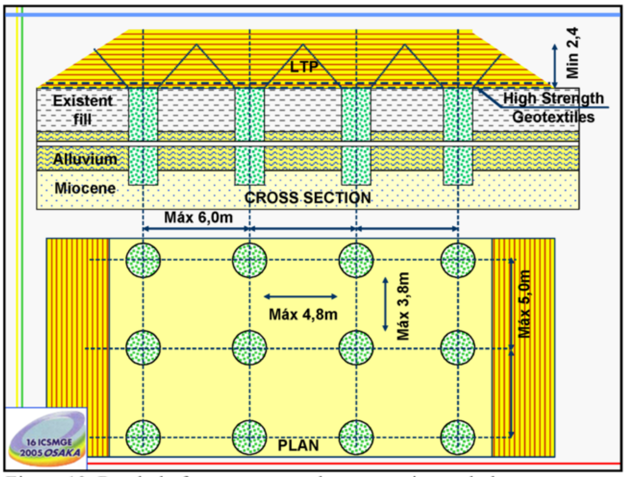

Figure 10. Road platform: transversal cross section and plan.

The main reason for the improvement of the road foundation was the construction of a fill above the existent ground level and also the restraint of the maximum allowable settlements to a value of 5cm after 10 years, as well as the incompatible schedule with solutions requiring excessive time for drainage and consolidation.

In this scenario, a major issue were the transition zones between the areas where, due to the fill high, the soil treatment was necessary and the ones where, for the opposite reason, the same treatment was not necessary. The proposed solution for these zones was the gradual decreasing of the jet grouting columns overall length, at the same proportion of the decreasing of the fill high, in order to allow the control of the differential settlements (Fig. 11).

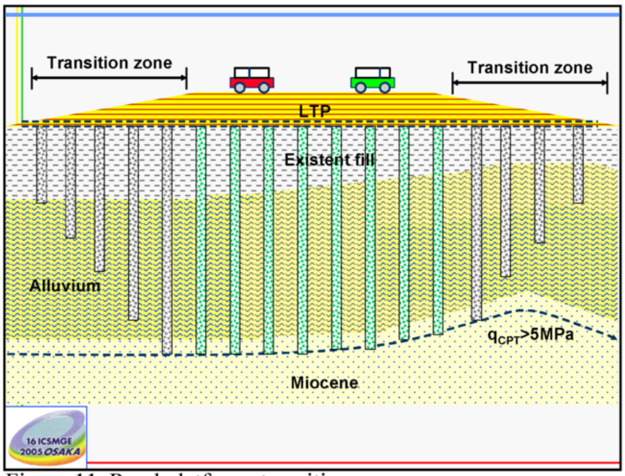

Figure 11. Road platform: transition zones.

5 MAIN CONCLUSIONS

The presented cases proved the increasing tendency for the using of the gosynthetics as reinforcement of LTP resting over piles (Kempfert et al., (1997), Horgan and Sarsby (2002)). Following this tendency it should be pointed out the advantages of combining the using jet grouting columns and load transfer platforms, due to the columns double function: soil improvement and foundation of light buildings and railway and road platforms, leading to the increase of the solutions overall predictability, versatility and flexibility.

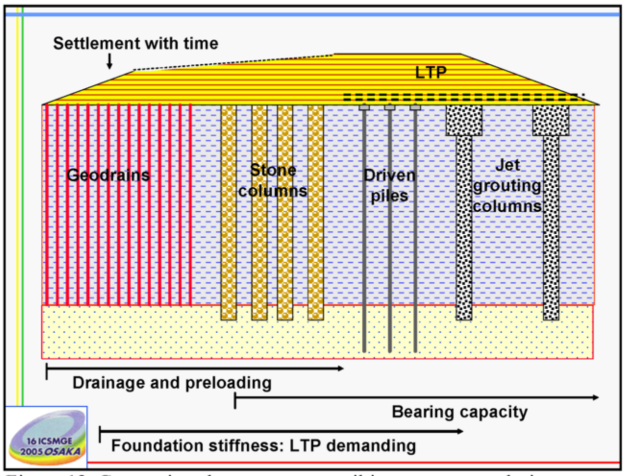

Figure 12. Comparison between some soil improvement solutions.

As example it should be pointed out the capacity of the jet grouting columns for the changing of geometry: diameters and inclination, allowing, for instance, the execution of both head and base caps, as well as the resistance improvement to horizontal loads, leading to the optimization of the LTP overall high and resistance. These solutions allow also the optimization of the columns overall length, mainly when the transition from the soft soils to the dense soils or to the bed rock is not abrupt. An other important advantage is the bearing capacity and the predictability, as there is no need for import/export of additional fill to accelerate consolidation or to compensate the settlements, with positive consequences to the construction schedule, comparing with the solutions where both the drainage and the consolidation of the soft soils are required (Fig. 12).

As points deserving further investigations taking into account that for this kind of solution reliable analytical prediction models considering the dynamic traffic loads are not still available today, it should be pointed out the need for extensive monitoring programs and full scale load tests, in order to confirm the main design assumptions and to predict the long term performance of the platforms (Fig. 13). In the same scenario it is possible to emphasize: the effect of the jet grouting columns confining the soft soil located between the columns, the dynamic effects under the railway and road traffic, including the mitigation of vibrations (Holm et al., 2002), the compatibility between the behavior of geogrids (confined and interlock mechanism) and high strength geotextiles (tension membrane mechanism), the eventual use of high strength geogrids (tension resistance bigger than 80kN/m), etc..


Figure 13. Static railway full scale load test: LTP under construction.

Finally and from both the technical and the economical point of views it should be stressed that the presented solutions can either be optimized if the jet grouting columns could be partially replaced by vertical soil-cement columns, formed through the in situ mechanical soil mixing procedure, mainly the hybrid deep mixing: SWING, JACSMAN, HYDRAMECH or TURBOJET, as stressed by Mosley and Kirsch (2004).

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