An Anchored Retaining Wall in CSM

Un Soutènement Ancré en CSM

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ABSTRACT: Cutter soil mixing (CSM) is being recently used in Portugal in several applications. This paper describes a solution in cutter soil mixing reinforced with vertical steel profiles IPE270 for a retaining wall with 66 m long and 13 m high constructed in geological formations of landfill materials, Miocene sandy soils and sandstones, with a phreatic level around 8 m depth. This construction is done nearby commercial buildings. The solution is justified against more classical solutions for anchored retaining walls considering the following aspects: feasibility of CSM in the geological and environment conditions, predict behaviour during and post construction, simplicity of construction process, time of construction, economy and quality assurance. Numerical modelling using a commercial program is carried out, based in geotechnical parameters established at the project level, showing a good agreement of the observed data, in terms of horizontal displacements of the wall and also of the safety levels against bending, shear and compression.

RÉSUMÉ : Malgré l'utilisation du traitement des sols en profondeur dans les dernières décennies, la technique « cutter soil mixing » (CSM) est récemment utilisé au Portugal dans plusieurs applications. Cet article décrit une solution CSM renforcé avec des profilés verticaux IPE270 pour un mur de soutènement avec 66 m de long et 13 m de haut construit dans des formations géologiques de matériaux de remblayage, des formations du Miocène de sols sablonneux et des grès, avec un niveau de nappe phréatique autour de 8 m de profondeur. Cette construction se fait à proximité de bâtiments commerciaux. La solution est justifiée par rapport aux solutions plus classiques des murs de soutènement ancrés tenant compte des aspects suivants: faisabilité du CSM dans une vaste gamme des conditions géologiques et de l'environnement, prévoir le comportement durant et après construction, simplicité du processus de construction, le temps de construction, l'économie et l'assurance-qualité. Une modélisation numérique au moyen d'un programme commercial est effectuée avec l'utilisation des paramètres géotechniques établis au niveau du projet, montrant une bonne concordance des données observées, en termes de déplacements horizontaux de la paroi, autant que des niveaux de sécurité contre la flexion, le cisaillement et la compression.

KEYWORDS: soil treatment, deep soil mixing, cutter soil mixing, retaining wall.

1 INTRODUCTION

Deep Mixing is an in situ soil treatment method that makes use of a technology in which the soil is mechanically mixed with other materials, mainly binders. The composite material will have improved benefits in terms of resistance, compressibility and permeability (Larsson 2003, Bruce 2000). One of the variants of Deep Mixing is the Cutter Soil Mixing (CSM) technique, which produces panel elements with an accurate geometry, vertically and direction. Additionally, low disturbance is induced on the soil and nearby structures, making their use appropriate in urban areas. Furthermore, this technique has shown a great technical versatility and efficiency, as well as economical advantages, including the optimization of the construction schedule (Ameratunga et al., 2009, Capelo et al. 2012, Marzano et al., 2009, Pinto et al. 2011).

This paper describes an innovative solution involving CSM panels combined with a reinforced concrete wall, for a permanent ground anchored retained structure, with about 66 m long and 13 m high constructed in geological formations of heterogeneous landfill materials, Miocene sandy soils and medium weathered sandstones, with a phreatic level around 8 m depth. This construction is done nearby industrial buildings. Consequently their main purpose was to act as a support system maintaining the stability of the excavation against lateral earth pressures, while controlling the deformation and settlement of the surrounding structures (Porbaha, 2000).

The retaining wall uses soil-cement panels with a minimum depth above the excavation level of 4 m and cross-section of 2.4 x 0.5 m^2, including 0.20 m of overlapping, were built using the CSM technology. The panels were reinforced with vertical IPE270 (S275JR) hot rolled steel profiles (Euronorm 19-57), spaced in average 1,1m, in order to resist both to the earth and water pressures, as well as to ensure a better control of deformations. The steel profiles were placed inside the panels, before the cement started the curing process. The wall was braced by four (case study) or three levels of permanent ground anchors, applied at the capping beam as well as at the distribution beams, integrated on the reinforced concrete lining wall (Figure 1). As already stated, the soil-cement panels were lined with a reinforced concrete 0.20m thickness wall, connected to the vertical IPE270 profiles with steel cantilevers, allowing the mobilization of the global resistance of both the steel profiles and the lining reinforced concrete wall, acting a Berlin wall combined with CSM panels. The design criteria, verifying Ultimate Limit State and the Serviceability Limit State, as well as the limitation of the water inflow, were established by the support of 2D FEM analysis using commercial PLAXIS® software. In this paper a comparison between the control and monitoring parameters with design parameters is done in order to support the discussion about the reliability of both the solution and the construction method.

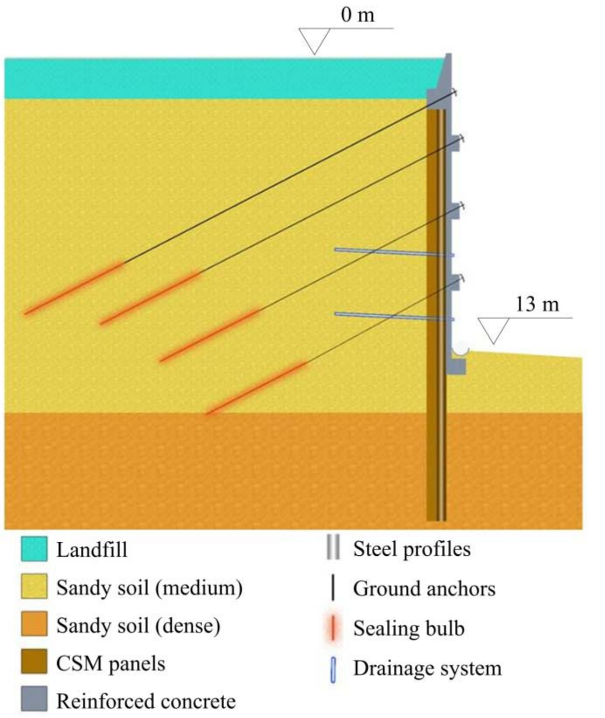

Figure 1. Representative schema of the solution proposed for the retained wall.

2 SITE AND SUBSURFACE CONDITIONS

The local geological conditions were heterogeneous. The excavation works intersected, from the surface, heterogeneous landfills and Miocene medium dense to dense sands and medium weathered sandstones. The ground water table was located about 5m above the final excavation level. Taking into account this scenario, an initial solution of Berlin walls was considered. A more detailed information about the site and subsurface conditions can be consulted in Pinto et al (2013).

3 CSM WALL MODELLING AND DESIGN CRITERIA

The modelling work was carried out using the commercial PLAXIS® software. The *Hardening-Soil* model was adopted for the different soil layers based in the available geotechnical laboratory and field data and taking into account all the excavation phases. Table 1 summarizes the main soil parameters.

Table 1. Main soil properties for modeling.

Constitutive model: Hardening-Soil	Landfill	*Sandy soil (medium)*	*Sandy soil (dense)*
γ_t (kN/m^3)	16	17	19
E_{50}^{ref} (kN/m^2)	10,000	20,000	35,000
E_{oed}^{ref} (kN/m^2)	10,000	20,000	35,000
E_{ur}^{ref} (kN/m^2)	30,000	60,000	105,000
Parameter m	0.5	0.5	0.6
c’	0	0	0
φ' (º)	22	33	35

For the soil-cement material produced by the CSM technology, using a cement consumption ratio of about 600kg/m3, the Mohr-Coulomb constitutive model was adopted and the parameters summarized in Table 2 were used.

Table 2. Main CSM panels parameters used in the modeling.

Constitutive model: Mohr-Coulomb	CSM panels
γ_t (kN/m^3)	22
E_{ref} (kN/m^2)	1000000
ν	0.3
c’ (kN/m^2)	600
φ' (º)	35

With the purpose to approximate the behavior of the structure to the real behavior , the three configurations shown in Figure 2 were considered: a) two half vertical IPE270 spaced in 1.1 m, b) two half vertical IPE270 spaced in 1.1 m plus lining wall and c) two half vertical IPE270 spaced in 1.1 m plus lining wall and CSM panels.

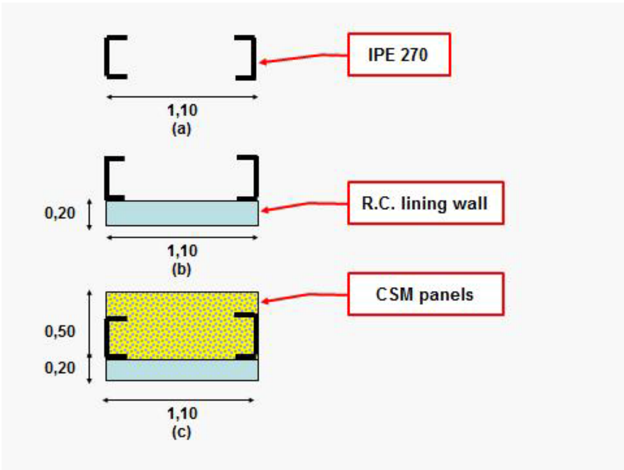

Figure 2. Configurations adopted in the modeling: a) two half vertical IPE270 spaced in 1.1 m, b) two half vertical IPE270 spaced in 1.1 m plus lining wall and c) two half vertical IPE270 spaced in 1.1 m plus lining wall and CSM panels.

For the structural analysis, load combinations for the Ultimate Limit State and for the Serviceability Limit State were defined according to Pereira (2011). The obtained results of 2D FEM analysis (mesh consisted of plane strain, 15-node elements) in terms of efforts and displacements are illustrated in Figure 3 and Figure 4 respectively.

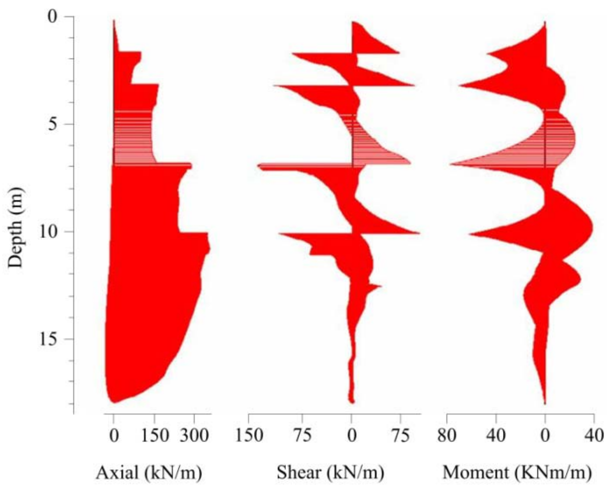

Figure 3. Efforts diagrams.

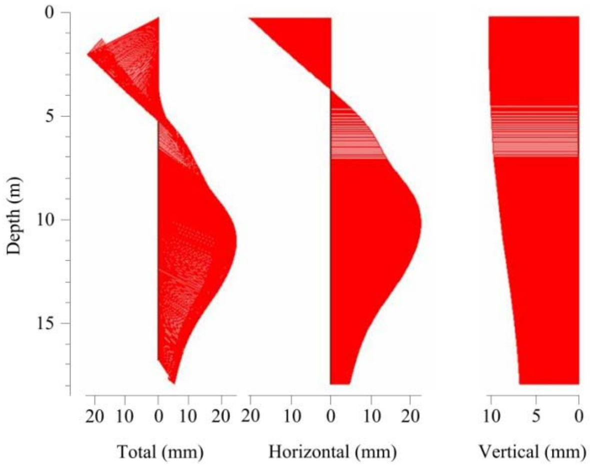

Figure 4. Displacement diagrams.

For the verification of the ultimate limit states was assumed a simplified approach. Thus, it was considered that the strength capacity is the individual combination of the strength resistance of the CSM panels, the IPE270 profiles and the reinforced concrete lining wall.

Summarising the main results obtained are the following:

- M_{Rd} (resistant bending moment) = 167 kNm/m > 1.5 M_{ed} (maximum acting bending moment) = 119 kNm/m;
- V_{Rd} (resistant shear force) = 251 kN/m > 1.5 V_{Ed} (maximum acting shear force) = 207 kN/m;
- σ_{Rd} (resistant compression stress of CSM) = 2 MPa (with FS=2) > 1.5 σ_{Ed} (maximum acting normal stress) = 1.1 MPa;
- S_H (maximum horizontal displacement) = 22.7 mm at about 10m depth.

Based in these results the following design criteria were established: take into account the resistance and stiffness of both the steel profiles and the reinforced concrete lining wall. The contribution of the CSM panels was considered in order to protect and confine the steel profiles (exploration phase) and to perform as preliminary ground improvement, allowing the execution of the excavation works without any restriction, in each level.

4 QUALITY CONTROL / QUALITY ASSURANCE

4.1 *Control of production parameters*

One of the major issues of the CSM technology is the high quality control and quality assurance (QC/QA), allowing on real time the monitoring and correction of important parameters, such as: depth, inclination, speed of mixing tools, pressure (ground and binder slurry) on cutter wheels, rate and total volume of pumped slurry (Figure 5).

Figure 5. CSM on line execution control.

4.2 *Control of mechanical soil-cement properties*

The execution control is complemented by a tight quality control and quality assurance, allowing the confirmation of both the main resistance, homogeneity and deformability of the soil-cement (soil–binder) parameters. For this purpose, samples from fresh material (before on suitability tested panels and during construction) and cores from the executed panels (after a certain curing age ranging from 7 to 28 days) were collected in order to access the material homogeneity, as well as to perform laboratorial tests with different ages, mainly unconfined compression strength (UCS) and Modulus (Es50 – secant modulus at 50% of maximum stress of UCS). The results obtained confirm an UCS minimal of 4MPa and a Es50 not lesser than 1GPa, satisfying the design criteria (Figure 6).

Figure 6. Collection of soil - cement fresh cores.

Taking into account the results of the UCS load tests, mainly on the suitability test panels, the following parameters were adopted for the execution of the CSM panels are presented on Figure 7.

Water / Cement ratio of the initial slurry	Cement ratio of the initial slurry kg/m³	Initial slurry consumption l/m	Cement ratio for the panels execution kg/m³
0,9	750	1065	600

Figure 7. Adopted values for the CSM panels execution parameters.

Regarding the QC/QA of the solution, it should also be pointed out the execution of suitability and reception tests for all the permanent ground anchors, allowing the optimization of the anchors grout body length (Figures 8 and 9).

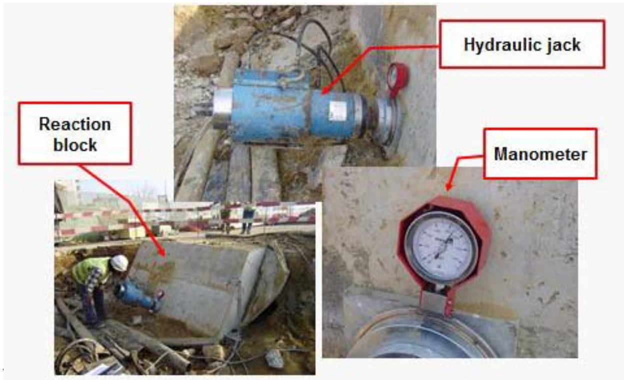

Figure 8. Permanent ground anchor suitability test.

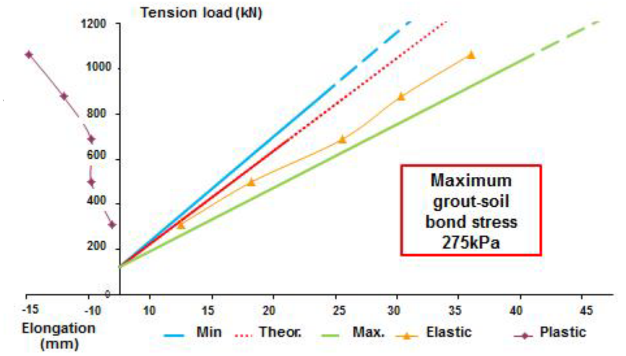

Figure 9. Main results of the ground anchor suitability test.

5 CSM WALL PERFORMANCE

The implemented monitoring and observation plan, is shown on Figure 10, including 2 inclinometers and 7 topographic targets.

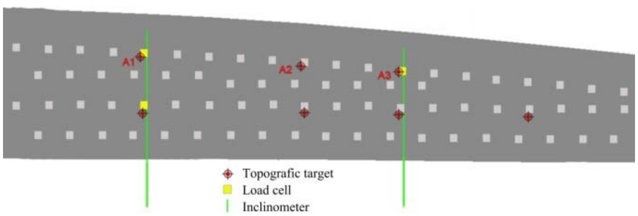

Figure 10. Monitoring and observation plan.

Figure 11 shows that the maximum displacement was observed at 10 m depth, corresponding to 15 mm (inclinometer I8).

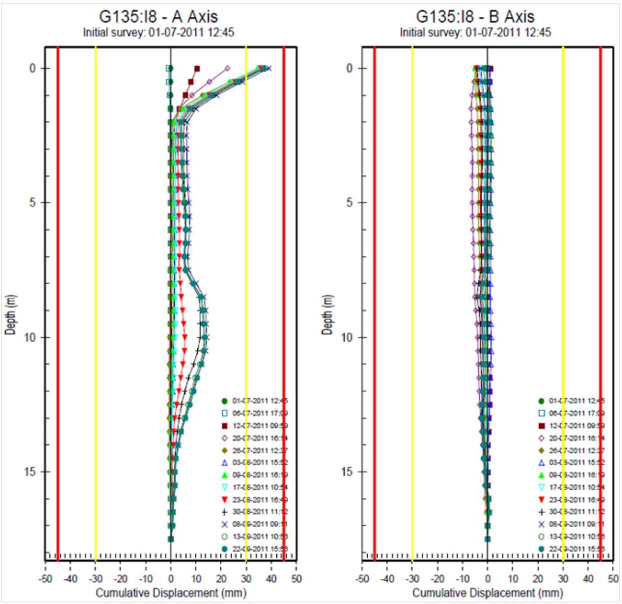

Figure 11. Displacement recorded at the inclinometer I8.

In Figure 12 it is observed that the maximum vertical displacement is 4 mm and that the maximum horizontal displacement is 17 mm.

These results show that the FEM analysis, with the presented input data, has given a good analytical prediction of the observed horizontal displacement, mainly confirming the depth where the maximum horizontal displacement occurred.

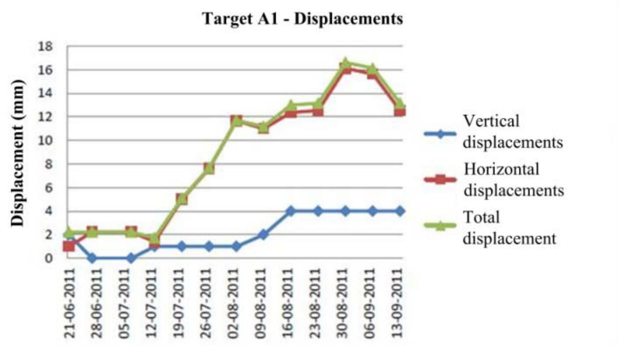

Figure 12. Displacement recorded at the topographic target A1.

6 MAIN CONCLUSIONS

The case study presented in this paper shows the good performance, mainly low deformations, of an anchored retaining structure, combining CSM panels with a reinforced concrete lining wall, leading to the optimization of both the construction overall schedule and budget in a complex geotechnical and site conditions. It was also shown that the use of commercial FEM software with appropriated input data gives a reasonable prediction of the main displacements, which are critical for the verification of both the ultimate and serviceability limit states, for all the excavation phases.

7 ACKNOWLEDGEMENTS

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