Permanent Excavation Support in Urban Area using Cutter Soil Mixing technology at Cannes, France

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ABSTRACT

This paper describes the general design and execution aspects of a peripheral retaining wall to the construction of the underground floors of “Hotel Montaigne” building, located at Cannes, France. Considering the geological and geotechnical constraints, the presence of high water table and the surrounding conditions near existing buildings, it was performed a retaining wall of soil-cement panels executed using the deep soil mixing technology, in particular the Cutter Soil Mixing (CSM) technology. The soil-cement panels were reinforced with vertical steel piles and temporarily supported by two levels of steel pipe struts. Besides allowing a safe vertical excavation and limiting the water inflow to the interior of the excavation, the retaining structure was designed as a secondary foundation element of the final structure together with a concrete wall executed against the CSM wall and the principal foundation elements constituted by micropiles. The main results of modelling and quality control of the work are also presented.

1. INTRODUCTION

This paper refers to the retaining structure executed to the refurbishment of the building “Hotel Montaigne”, located in the city of Cannes, France. The existing hotel was remodelled and expanded, with the construction of an additional high floor in the existing building and a new building block with seven floors high and three underground floors (Figure 1).
The retaining wall was designed to allow the excavation of the underground floors of the new building block.

Figure 1: Representation of “Hotel Montaigne” surrounding.

The excavation site plan, with a trapezoidal geometry, presents an area of about 300 m^2 and is bounded by streets and existing buildings (Figure 2).
The main challenge of this project consisted in the execution of an urban excavation with an average depth of 9 m under demanding ground and water table conditions.
The main concerns in the design of the retaining wall were the guarantee of minimum interference in the surrounding area, assuring the security during and after the works and, simultaneously, the reduction of

the water inflow to the interior of the excavation. In this context was defined a retaining wall formed by soil-cement panels executed using the Cutter Soil Mixing (CSM) technology. The CSM wall was reinforced by vertical steel piles and horizontally supported by two levels of horizontal struts.

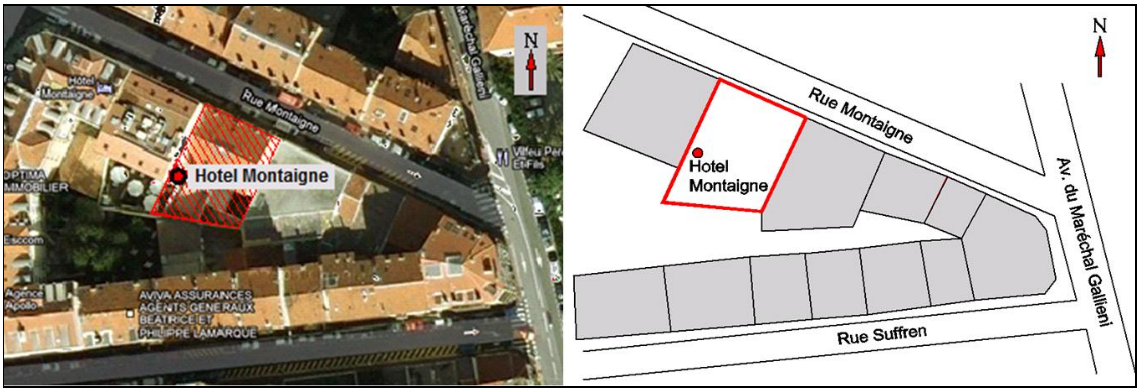

Figure 2: Site plan.

CSM was developed from Deep Soil Mixing (DSM) and is based on the mechanical mixing of the existing soil with cement slurry to form soil-cement panels in depth with a rectangular cross-section (Fiorotto et al., 2005; Gerressen et al., 2009).
The execution of CSM panels doesn't require the removal of the soil unlike other techniques, for example, concrete pile walls or diaphragm walls. There is no soil decompression during the execution of CSM panels which allows the minimization of the interference with the surrounding area.
The continuous wall formed by CSM panels was reinforced with vertical steel piles to satisfy simultaneously the following main objectives:

- allow a safe vertical excavation with the minimum interference in the surrounding area;
- foundation element of the internal structure;
- reduce the water inflow to the interior of the excavation.

2. MAIN CONSTRAINTS

2.1. Geological and Geotechnical conditions

The soil characterization was based in two geotechnical studies, performed in different phases.
In an initial phase, with a restricted access to the work site, a preliminary study was carried out, including the installation of a piezometer to the measure of the water table, the execution of a drill boring test and the execution of a Ménard Pressiometer Test (PMT).
In another phase a second geotechnical study was carried out to complement the initial study. This second study included the installation of a piezometer, the execution of two drill boring tests, two PMT tests and laboratory tests in intact samples, particularly Triaxial tests.
The laboratory tests were carried out to identify the type of soils in depth and its geomechanical characteristics. Through the analysis of the in-situ and laboratory tests results, three distinct layers were identified (Figure 3):

- Heterogeneous clayey and silty fill detected from the surface to an average depth of 5 m (Geotechnical Zone 1 – ZG1);
- Sandy Clays under the heterogeneous fill until a depth of about 9 m (Geotechnical Zone 2 – ZG2);
- Sandstone Bedrock under the previous layer (Geotechnical Zone 3 – ZG3).

The water table was detected approximately 3.5 m below the surface.

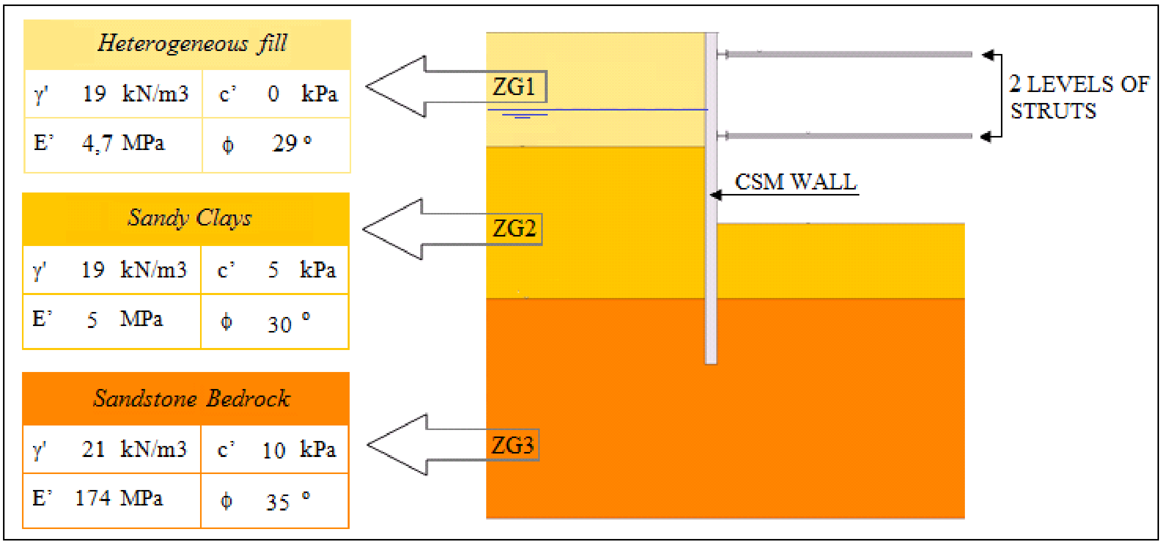

Figure 3: Main Geotechnical parameters and representation of a cross-section of the excavation.

2.2. Neighboring constraints

The work is located in an urban area with high neighbouring buildings and, because of that, one of the main concerns during the design of the retaining structure and the execution of the works was the guarantee of safety of neighbouring buildings and streets.

The excavation is bounded to the north by a street (*Rue Montaigne*), to the south by a building with three floors high, to the west by the building of the existing hotel with three underground floors and seven floors high and to the east by a small building to demolish before the start of the excavation.

At the time of the equipment installation in the work site, the demolition of the small neighbouring building hadn't been started and the space to the equipment installation was very conditioned (Figure 4).

Figure 4: Installation of the equipment.

2.3. Seismic conditions

The work is located in the city of Cannes, France, and the seismic risk was classified with the Standard Norms of the country.

According the Decree "nº 2010-1255" of 22th October 2010, in the French territory are distinguish five zones with different degrees of seismic intensity (Figure 5): very low (1), low (2), moderate (3), medium (4) and high (5).

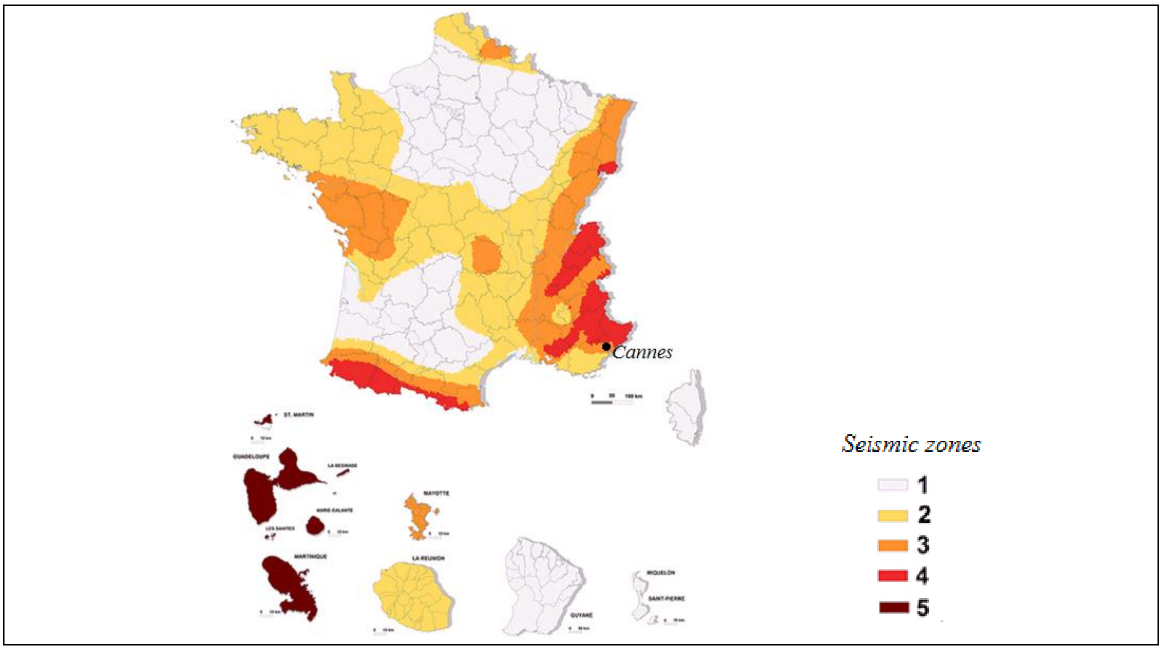

Figure 5: Zones of seismic intensity of the French territory (Decree "n° 2010-1255" of 22th October 2010).

The city of Cannes is located in a zone of moderate seismic intensity.
According to the same Decree, four Categories of Importance to the buildings are defined, by an increasing order of importance: Categories I, II, III and IV. The new building block of the "Hotel Montaigne" is inserted in the Category of Importance II (collective housing building with height up to 28 m).

3. CSM RETAINING WALL

The performed solution to the support of the excavation consisted in a peripheral CSM retaining wall with two horizontal levels of temporary steel pipe struts. In Figure 6 is represented a plan of the CSM retaining wall and the horizontal struts.

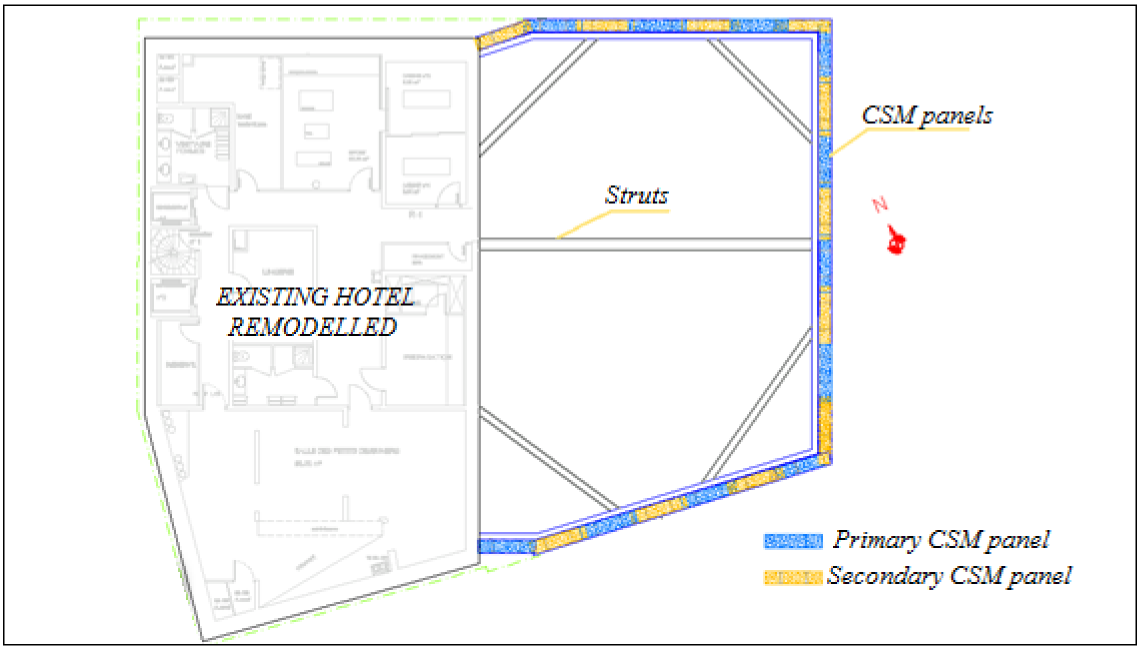

Figure 6: Plan of the CSM retaining wall and the horizontal steel pipe struts.

The continuous CSM wall was executed by overlapping primary and secondary soil-cement panels, with a rectangular cross-section with dimensions of 2.40 m x 0.55 m, considering a minimum overlapping between adjacent panels of 0.20 m to assure an effective connection throughout the height of the panels.
The reduction of the water inflow to the interior of the excavation was one of the main concerns during the conception of the retaining structure and, with this aim, was defined to the CSM panels a minimum penetration length of 3 m below the bottom of the excavation, into the sandstone substrate (ZG3).
The CSM panels were reinforced by vertical steel piles (IPE 450 piles), installed at 1.10 m intervals (two piles in each panel). The placement of the steel piles in CSM panels allows the protection of these elements against buckling problems, minimizing simultaneously possible corrosion problems.
The solution included also a 0.15 m thick concrete wall, executed from the bottom of the excavation, against the CSM wall.
The retaining wall was designed to support, together with the concrete wall and the micropiles performed as the principal foundation elements, the total vertical efforts transmitted from the permanent structure of the building.
The execution of a CSM panel comprises essentially two main phases:

- Cutting phase: the cutting head is vertically driven through the ground until it reaches the designed depth. The existing soil is desegregated by the movement of rotation of the cutting wheels while cement slurry is added simultaneously;
- Extraction and mixing phase: the cutting head is extracted while cement slurry is added to the homogenization of the mixture.

During the cutting phase, the soil matrix is broken up and cement soil is blended to fluidify the soil. The penetration rate of the cutting head and the cement slurry volume added to the soil must be adjusted by the rig operator to create homogeneous soil-cement panels. Depending on the characteristics of the existing soil, during this phase may be necessary the use of bentonite instead of the cement slurry.
When the design depth is reached, the extraction of the cutting head begins and the rotation direction of the cutting wheels is inverted. During this phase, the remaining quantity of cement slurry is added to homogenize the mixture.
In Figure 7 is presented the CSM execution process.

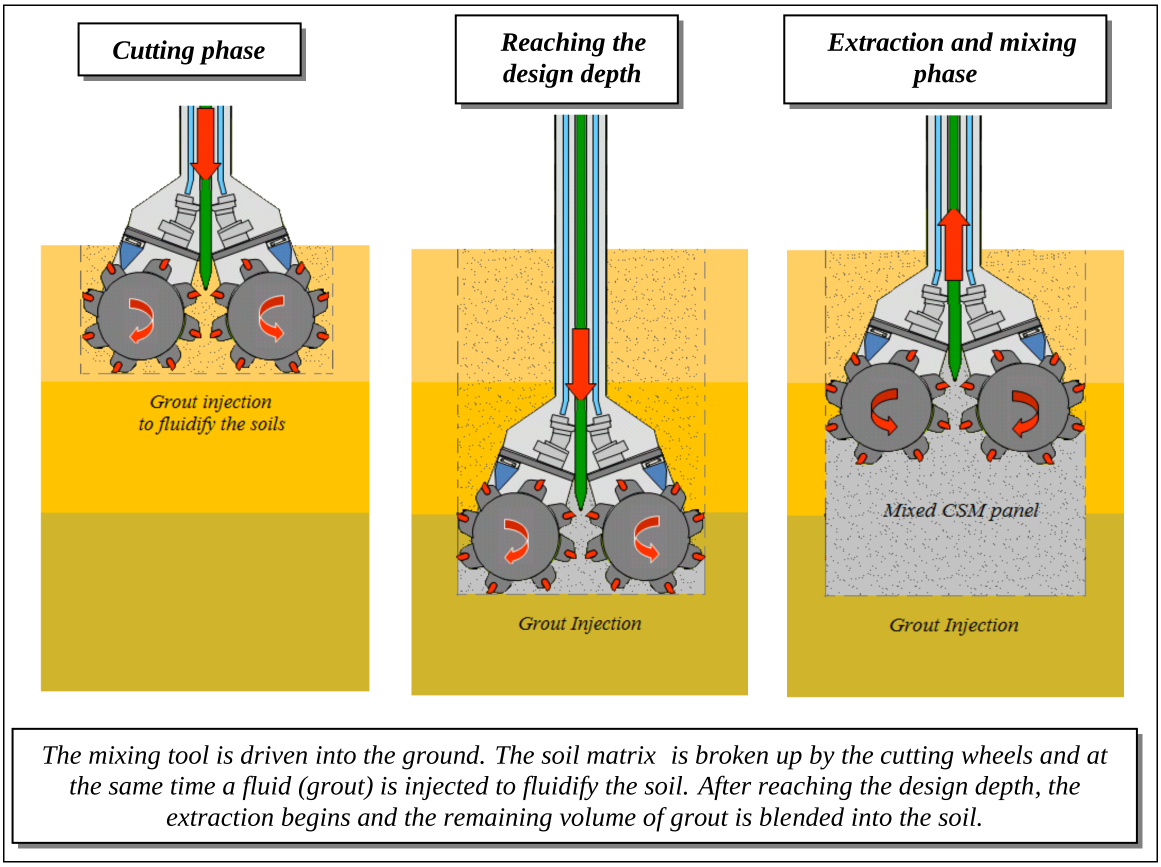

Figure 7: Illustration of the main phases of the CSM execution process.

4. ANALYSIS MODEL OF THE RETAINING WALL

The analysis of the retaining wall was carried out using a numerical model developed with the finite element program PLAXIS®.
The soil was simulated using the Hardening-Soil model with the geomechanical parameters already presented in section 2.1. The retaining structure was simulated with a one-dimensional linear beam element.
The numerical analysis was carried out in plane strain. The representative sections of the four elevations of the retaining structure were studied.
Figure 8 presents an example of one of the analysed sections (Section A), representing a cross-section of the north alignment, near a street (*Rue Montaigne*).

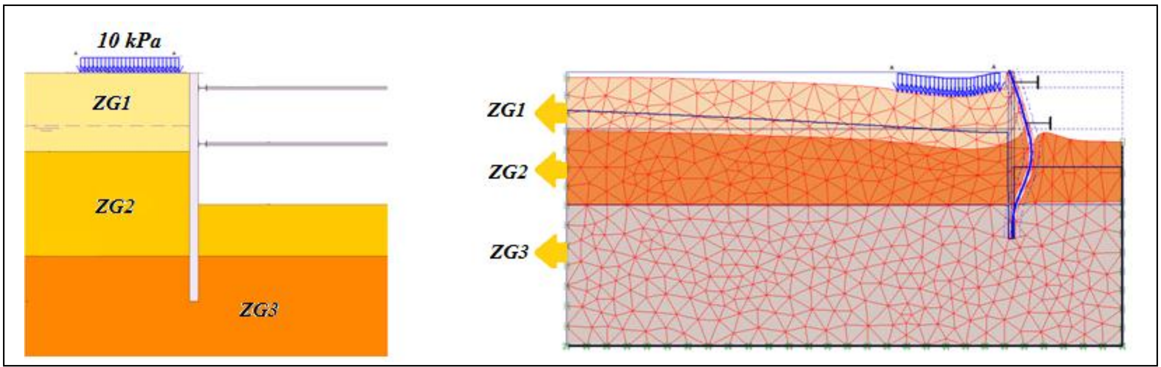

Figure 8: Section A: cross-section (on the left) and analysis model representing the deformation at the maximum excavation depth (on the right).

In the following table are presented the maximum values of the horizontal displacements of the retaining structure obtained in the numerical analysis of the Section A.

Table 1: Maximum values of the horizontal displacements obtained in the numerical analysis of the Section A.

	Maximum horizontal displacements (mm)
At the top of the retaining wall	2.0
Along the height of the retaining wall	18.5

According to the surrounding conditions and the characteristics of the excavation, the following acceptable limits to the horizontal displacements of the retaining wall were defined: 5 mm at the top of the retaining wall and 20 mm along the height of the retaining wall.
In the numerical analyses of all studied sections were obtained lower values than the defined limits and, during the excavation, the horizontal displacements obtained were slightly lower than the expected values.
CSM panels were designed considering a compressive strength of 2 MPa (with a safety factor of 2) and an elasticity modulus of 1 GPa. These values were confirmed by laboratory tests (unconfined compressive strength tests), carried out on samples from the panels of the CSM retaining wall. The minimum acceptable result of the unconfined compressive strength tests was 4 MPa, to allow the use of a safety factor of 2. The results of the laboratory tests carried out are detailed in the section 6 of this paper.

5. EXECUTION PROCESS

The execution process started with the execution of the CSM panels before the excavation (Figure 9).
The equipment to the execution of CSM is constituted by a crane with a vertical tower (RTG RG19T) with a total height of about 23 m, associated to a kelly bar system with a height of about 20 m. The cutting head used (BCM 5 - Bauer Machinen) is held and guided by the kelly bar system.
To the reinforcement of the CSM panels, vertical steel piles were installed immediately after its execution as close as possible to the excavation face to allow the connection of the steel waler beams and the steel pipe struts (Figures 10 e 11).

Figure 9: Components of the equipment: cutter head and kelly bar.

Figure 10: View of the execution of a CSM panel (on the left) and installation of the IPE piles (on the right).

Figure 11: Detail of the steel waler beams connected to the pipe struts.

The continuous wall was formed by overlapping primary and secondary CSM panels, with an overlap length of 0.20 m. The secondary panels can be executed immediately after the construction of the primary panels, process known as “soft-into-soft” or after the hardening of the primary panels, process known as “soft-into-hard”. These two hypotheses are possible due to the versatility of the CSM cutting tool allowing the application of the technology to all soil types, although not all kinds of soils are equally suitable.

The next stage consisted in a small excavation to allow the execution of the concrete beam at the top of the retaining wall. After the construction of the concrete beam, an excavation to a maximum depth of 0.5 m below to the first level of struts was carried out. In this stage were executed the steel waler beams to the connection of the horizontal steel pipe struts.

The second level of excavation and the execution of the second level of struts were carried out by a similar process to that described to the first level.

After reaching the maximum depth of excavation, a concrete wall is constructed against the CSM wall. The temporary levels of struts are deactivated with the execution of the concrete slabs of the building structure.

Figure 12: View of the work after the execution of the second level of struts.

6. QUALITY CONTROL

The application of CSM technology allows the control, in real time, of the execution parameters by the rig operator through the monitor of the equipment (Larsson, 2005).

The variability of strength and deformability parameters of the soil-cement obtained using CSM technology is directly related with the degree of homogeneity of the mixture that is influenced by a lot of variables as the type of the existing soil, the water table presence, the distribution of the cement slurry in the desegregated soil, the chemical reactions during the process, among others. There are a lot of variables that can influence the quality of the final result obtained and, because of that, the effective control of the execution parameters is essential. During the execution of a CSM panel, the rig operator control and adjusts, in real time, the execution parameters as the speed of the mixing tool, the cement slurry volume added, the cement slurry pressure in hoses, the inclination of the mixing tool, among others (Figure 13).

The control of the execution parameters must be complemented with the execution of laboratory tests to the evaluation of strength and deformability parameters of the soil-cement obtained for the validation of the design hypotheses. Before the execution of the panels of the CSM retaining wall, test panels are executed to obtain samples to laboratory tests. This allows the calibration of the equipment. In a subsequent phase, the quality control is provided by laboratory tests on samples from the panels of the CSM retaining wall.

In the Table 2 are presented the values obtained in the unconfined compressive strength tests carried out on samples from the panels of the CSM retaining wall (average values).

To verify the evolution of the compressive strength of the samples along the time, laboratory tests were carried out on samples after 7, 14 and 28 days.

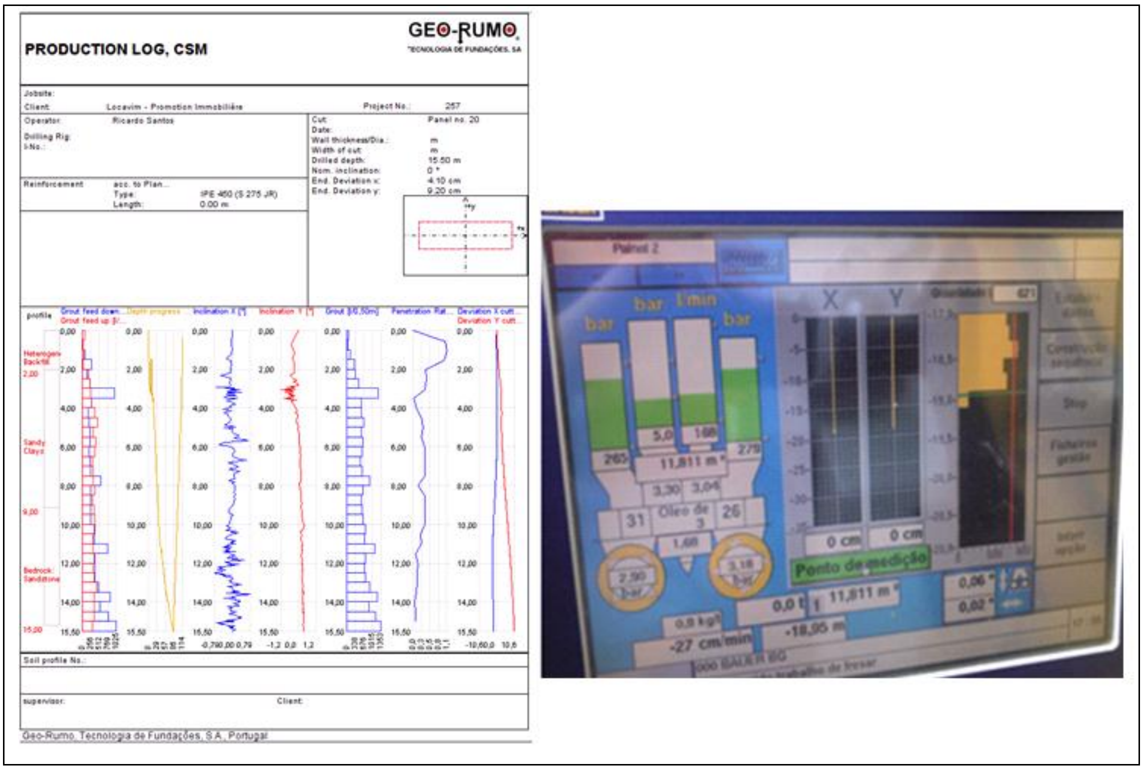

Figure 13: Production report (on the left) and rig operator's monitor for the control of the production process (on the right).

Table 2 : Values obtained in the unconfined compressive strength tests (average values to 7, 14 and 28 days).

	7 days	14 days	28 days
Unconfined compressive strength (MPa)	5.0	7.0	7.8

The samples tested after 7 days presented a value of unconfined compressive strength of 5 MPa (average value), a higher value than the required value of 4 MPa. This allows to the validation of the design hypotheses.

The control was also carried out through the monitoring plan implemented, including surveying targets placed in the retaining wall, inclinometers placed behind the retaining wall and extensometers placed in the pipe struts. Throughout the different excavation phases the recorded values of the displacements of the retaining wall were slightly lower than the expected values and the defined alert limits.

7. CONCLUSIONS

The execution of the Cutter Soil Mixing retaining wall for the excavation of the new building block of "Hotel Montaigne" constituted an appropriate option with technical, economic and environmental advantages, as demonstrated in this paper.

The main objective of ensuring the minimization of interferences in the surrounding area was achieved with the CSM retaining wall. During the excavation, the CSM panels allowed also the reduction of the water inflow to the interior of the excavation. The low displacements of the retaining wall during the excavation demonstrate the excellent performance of the adopted solution.

CSM technology has a wide-ranging application field and it can be applied to all soil types.

As it was referred in the paper, the quality and the homogeneity of the soil-cement panels depends on several factors that affect the execution process and, because of that, the control and monitoring of the work is essential, especially in urban excavations.

Regarding the experience of the company Geo-Rumo in the application of this technology, it has been sucessfully applied in Portugal and France in different types of works, especially the execution of retaining structures and the improvement of foundation soil.

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