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Application of Cutter Soil Mixing technology in retaining walls

Application de la technique Cutter Soil Mixing dans les structures de soutènement

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ABSTRACT: This article describes the Cutter Soil Mixing (CSM) technology as a solution for constructing peripheral retaining walls, presenting its characteristics, advantages over other technologies used in retaining walls, and how to design a retaining wall solution with CSM panels, which can be adapted to braced, anchored or top-down excavations. At the end, three case studies are listed, two braced retaining walls, one of which is prestressed, and one supported by slab bands, where the use of this technology proved to be important for the solution of excavation in an urban environment.

RÉSUMÉ: Cet article décrit la technique du Cutter Soil Mixing (CSM) comme une solution de construction de murs de soutènement périphériques, en présentant ses caractéristiques, ses avantages par rapport aux autres techniques utilisées dans les murs de soutènement, et la conception d'un mur de soutènement avec des panneaux CSM, qui peut être adapté à des excavations étayées, ancrées ou de haut en bas. Pour finir, trois études de cas sont indiquées, deux murs de soutènement contreventés, dont un précontraint, et un soutenus par des bandes de dalles, où l'utilisation de cette technologie s'est avérée importante pour la solution de l'excavation dans un environnement urbain.

Keywords: Urban excavations; deep excavations; Cutter Soil Mixing; CSM, retaining walls.

1 INTRODUCTION

The continued concentration of the world's population in large centres is forcing the construction of large habitable areas on an ever-smaller surface area. This is leading both to an increase in the height of buildings and the utilisation of the subsoil.

Due to the limited space and confinement of the available areas, excavations have to be made with a vertical face, requiring retaining walls near buildings or other structures that must be preserved.

Taking into account the growing public concern about environmental issues, it has become necessary to look for solutions that minimise the environmental impact of buildings, whether during exploration or construction. Over time, innovative and versatile techniques have been developed that allow local soils to be used as a construction material by mixing them in situ with stabilising compounds.

This article presents the Cutter Soil Mixing (CSM) technology as a solution for the construction of vertical, impermeable retaining walls capable of reaching great depths of known geometry, using soil as the construction material.

From a list of successful projects, it can be said that CSM technology is an interesting solution both technically and economically, and has been applied in various projects all over the world. This article lists three projects where this technology has been used to build vertical retaining walls in urban environments.

2 DESCRIPTION OF CSM TECHNOLOGY

Cutter Soil Mixing technology derives from Deep Soil Mixing (DSM) technology, combining its concepts with some of the principles of diaphragm walls, such as the use of hydromill and the geometry of the panels, as shown in Figure 1. A cutting tool for making CSM panels consists of two sets of cutting wheels that rotate around horizontal axes to produce soil-cement panels with a rectangular cross-section, unlike the DSM technology, which uses cutting tools that rotate around vertical axes to produce soil-cement columns (Stoetzer et al., 2006).

The cutting tool is attached to the bottom of a kelly bar, in a crawler crane fitted with a vertical tower.

The process of making a CSM panel comprises essentially two phases, the cutting phase and the extraction and mixing phase.

Figure 1. CSM equipment with rotation around horizontal axes and view of a CSM panel.

The cutting phase takes place during the descending movement of the tool to the required depth. As the cutting tool advances in depth, the hydraulic binder (usually cement grout) is added. The speed of the cutting tool and the volume of hydraulic binder added must be adjusted by the operator to optimise the use of energy and create a mass of homogeneous material that allows the tool to be lowered and raised easily. In difficult geological conditions or for CSM panels at great depths, it may be necessary to use bentonite during the cutting phase, with the cement grout being added to the panel only during the extraction and mixing phase (Peixoto et al., 2012a).

Once the desired depth has been reached, the kelly bar begins to rise by reversing the rotation of the cutting wheels and continuing to inject cement grout at low pressure. Figure 2 shows the execution process described.

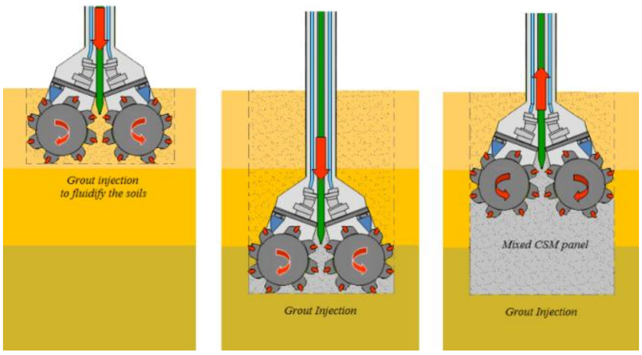

Figure 2. Illustration of the main phases of the execution of a CSM panel.

One of the particularities of this technology is that it allows the soil to be incorporated in situ into the retaining structure itself, with the retaining walls being executed sequentially by primary and secondary panels with a project-defined overlap length between them to obtain a continuous CSM wall. The fact that this technology allows soil to be used as a construction material, avoiding large volumes of material going to waste, is an advantage from an environmental and economic point of view compared to traditional technologies such as pile walls or diaphragm walls. A second advantage that should be emphasised is the knowledge of the exact geometry of panels in depth, since the equipment allows real time monitoring of the cutting tool's deviations during its advance in depth, making it possible to correct its positioning at any time. The process of mixing the hydraulic binder with the disintegrated soil can be influenced by various factors. In order to obtain CSM panels with the right characteristics, ensuring the homogeneity and reproducibility of the characteristics of the resulting material, it is essential to effectively control the execution parameters such as the speed of the cutting tool, the volume of grout added at depth, deviations of the cutting tool, among others (Bringiotti et al., 2009). Other advantage of this technology is that it can be applied to all types of soil, although the effectiveness of the application is not the same on all types of soil. Generally, the best results are obtained in sandy soils, as lower strengths are obtained in clay and silty soils for the same quantity of cement.

As illustrated in Figure 3, the use of soil-cement panels with a rectangular cross-section made using CSM technology for retaining walls has advantages when compared to the use of soil-cement columns made using DSM methods that use cutting tools that rotate around vertical axes (Fiorotto et al., 2005), and the following main advantages can be highlighted:

- reduction in the volume of soil treated to obtain the same effective treatment section and the consequent reduction in costs associated with this;
- reduction in the number of wall joints;
- the possibility of using different types of reinforcing elements for the panels, whose positioning in the panel itself can also be optimised.

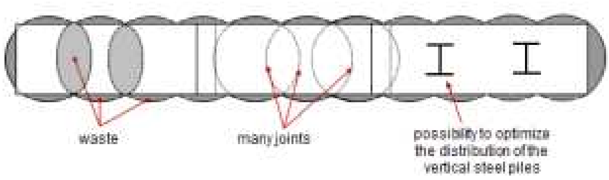

Figure 3. Comparison of the rectangular geometry of the CSM panels with the columns of the DSM methods.

3 RETAINING WALL SOLUTION

The most widely used peripheral retaining wall solution using Cutter Soil Mixing technology is the construction of a continuous wall of successive panels

2.4 metres wide and a constant thickness of 55 to 80 cm, depending on the project.

In order to ensure a continuous wall, panels are executed sequentially between primary and secondary panels, with an overlap length of 0.20 metres between them to ensure a good connection between adjacent panels in depth, as shown in Figure 4 (Peixoto et al., 2012b).

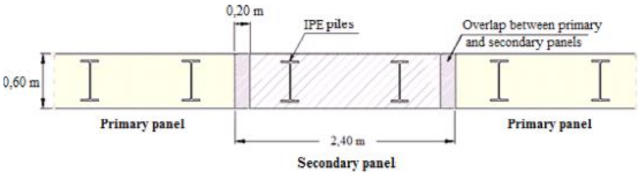

Figure 4. Primary and secondary panels of the CSM retaining wall.

The panels are made long enough to ensure the structural stability of the bottom and minimise the inflow of water into the excavation area.

Panels usually need to be reinforced to resist bending stresses. The most common method is to place steel sections inside the panel immediately after it has been made. The preference for IPE sections is due to the better flexural modulus to weight ratio. Placing the sections inside the CSM panels also protects them from possible buckling phenomena due to the confinement provided, and also minimises corrosion phenomena caused by the aggressiveness of the surrounding terrain.

The steel sections can be joined together with a reinforced concrete beam at the top of the wall.

The horizontal stability of the retaining wall is achieved in a similar way to the other types of peripheral retaining walls, such as horizontal bracing between elevations or for the excavation bed, temporary or permanent ground anchoring, or even through permanent slabs in top-down solutions. Due to the low shear resistance of CSM panels, horizontal forces must be redistributed to the anchors or struts through distribution beams.

The distribution beams or slabs that will resist the horizontal forces are supported on the retaining wall by steel sections, as shown in Figure 5.

In the case of permanent peripheral retaining walls, it is usual the construction of a reinforced concrete wall against the CSM panels. This wall can be built from the top down as the excavation progresses or from the bottom up when the structure is built. It is common to build this covering wall with a thickness between 0.15 and 0.20 m.

Figure 5. Photo of the HEA sections for connecting the slab at "Largo do Ambiente".

The Figure 6 shows a typical cross-section of a peripheral retaining wall executed with CSM panels and provisionally braced.

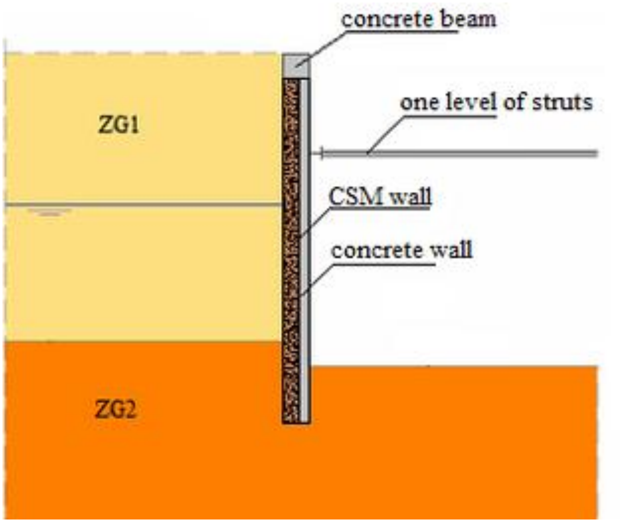

Figure 6. Cross-section of the retaining wall of the "Villa Paradisio" project.

4 DESIGN METHODOLOGY

In order to analyse the retaining wall, one or more calculation sections are defined that together represent the entire retaining structure.

The behaviour of each representative section is studied using analytical methods, such as free-earth support" or "fixed-earth support", or using automatic calculation programmes, such as PLAXIS® or PHASE2®.

All the elements of the retaining wall are designed in accordance with the legal standards, namely the Eurocodes in the European Union and Norway.

The vertical steel sections are designed to resist all the forces acting on the wall, disregarding the resistance of the soil-cement mixture, except for the seismic action in which the resistance is taken into account.

The soil-cement mixture, when in service, must have a sufficient compressive resistance to transmit the pressures to which it is subjected to the vertical steel sections. The transmission of these pressures is verified through the arc effect, as shown in Figure 7.

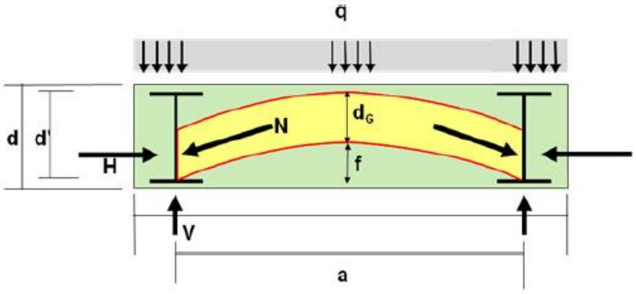

Figure 7. Distribution of horizontal stress in the cross-section of the retaining wall.

Horizontal support elements, such as anchors or struts, are designed in the same way as for other retaining wall construction techniques.

In the case of excavations below the water table, the hydraulic stability of the bottom of the excavation must also be verified, namely hydraulic uplift and internal erosion (piping), and the estimation of the volume of water that will flow into the excavation for designing the pumping system.

5 QUALITY CONTROL

The variability of the resistance and deformability parameters of the soil-cement resulting from the application of CSM technology is directly related to the degree of homogeneity of the mixture and it is influenced by various factors such as the type of soil involved, the presence of water, the distribution of the binder in the disintegrated soil mass, the presence of air as a component, the chemical reactions that take place during the mixing process, among others. For these reasons, it is necessary to take special care and carry out effective monitoring, both during execution and afterwards when evaluating the quality of the mixture according to the design requirements.

One of the main advantages of CSM technology over other alternative techniques, apart from the economic and environmental aspects (the use of in situ soil as a construction material), is the possibility of real-time control of the execution parameters by the equipment operator (Larsson, 2005). The operator has an instrument panel, as shown in Figure 8, that allows him to monitor and correct, in real time, parameters such as the advance speed of the cutting wheels, the amount of binder added, the density of the fluids involved (water-cement ratio) and the verticality of the panel, among others.

Figure 8. Cutter control panel.

In addition to the control made by the operator during the execution of CSM panels, the control is also achieved through laboratory tests combined with field tests on panels constructed for this purpose, which allow the execution parameters to be calibrated. Once the execution parameters have been calibrated, the construction of the CSM panels of the retaining wall can begin, from which samples are also taken for laboratory tests.

During excavation, monitoring is done following the Observation and Instrumentation Plan, which may include the placement of topographic targets on the retaining wall and neighbouring buildings, marks on the pavements, inclinometers, strain gauges installed in the struts and load cells in the soil anchors.

6 CASE STUDIES

6.1 Initial considerations

Cutter Soil Mixing technology is already being applied to retaining walls all over the world. This chapter presents two projects realised in the south of France and one in Luanda, Angola.

6.2 "Villa Paradisio" project

One of case studies is an excavation in Cannes for the construction of four underground floors of the "Villa Paradisio" building. The excavation site has a floor area of around 840 m^2, with an average excavation depth of 12 m, and directly faces neighbouring buildings and streets.

Despite the fact that the excavation is 12 metres deep in an urban context with the water table at about half the height of the excavation, the presence of the fractured dolomitic bedrock detected above the maximum excavation depth provided good support for the lower part of the retaining wall, allowing a solution that included only one level of horizontal metal struts. This solution, in addition to containing the excavation with a vertical face, had a second objective of limiting the inflow of water into the excavation area (Peixoto et al., 2012c).

In this context, a retaining wall solution was proposed and designed consisting of a continuous wall of soil-cement panels with a rectangular cross-section with a thickness of 0.55 metres, up to an average depth of 15 metres, in order to guarantee a minimum length of 3 metres below the bottom of the excavation, reinforced with two IPE 450 beams in each CSM panel. A horizontal support level was defined for the approximately 12 m of total excavation height, materialised by tubular metal struts associated with metal distribution beams built along the perimeter of the site, as shown in Figure 9.

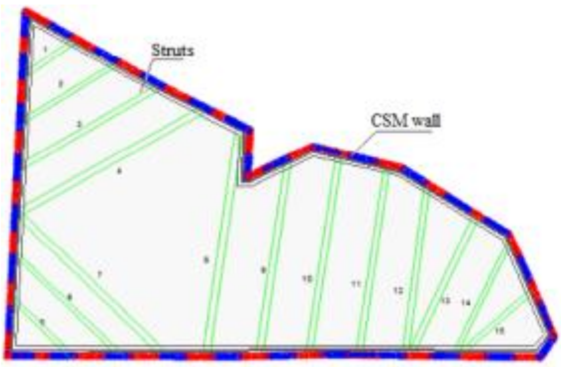

Figure 9. Plan representation of the retaining wall solution adopted for the "Villa Paradisio" project.

6.3 "May Flower" building

The "May Flower" building, located in Antibes, France, consists of eight elevated floors and four underground floors over an area of 317 m^2 and is bordered by streets and buildings.

The main challenge encountered in this project consisted of excavating to an average depth of 11 m in a densely constructed area, in the presence of soils with very variable mechanical characteristics, generally with low resistance values and high deformability to depths below the excavation base, and in the presence of a water table close to the surface (Gomes et al., 2016).

The solution proposed and designed consisted of a continuous wall of CSM panels, temporarily supported by four levels of metal bracing, with the lower three levels prestressed.

Limiting the inflow of water into the excavation was one of the project's concerns. To this end, a minimum embedment length of 6 metres was set from the bottom of the excavation and the panels were built to an average length of 17 metres.

Figure 10. Photo of the "May Flower" construction site before the application of the second level of bracing.

6.4 "Largo do Ambiente" underground parking

The "Largo do Ambiente" is an underground car park built in the city of Luanda, Angola. With capacity for 525 cars, it has two to five underground levels, corresponding to a variable excavation height between 8.0 and 17.4 metres. The excavation site directly faces existing buildings and streets and has a rectangular layout with an area of approximately 4,735 m^2.

Figure 11. Photo of the execution of the fifth and final slab band at "Largo do Ambiente".

The retaining wall was executed through soil-cement panels by the application of Cutter Soil Mixing (CSM) technology, reinforced with vertical steel piles. Taking in account the constrains related to the urban surrounding, including the proximity of buildings and streets, two to five levels of reinforced concrete slab bands were implemented, creating a rigid support system of the four elevations. The slab bands were incorporated on the final structure of the building and with this solution the execution of ground-anchors with big lengths that would lead to the occupation of the neighbour underground was dispensed. Furthermore, this solution brought some economic benefits, especially due to the incorporation of elements used in the final structure at the preliminary stage of the work. The main objectives of the retaining wall were allowing the vertical excavation assuring simultaneously the stability of nearby structures and infrastructures, and also reduce the inflow of water into the interior of the excavation during the construction (Peixoto et al., 2016).

7 CONCLUSIONS

The application of CSM technology in retaining walls allows, with different geological and hydrogeological scenarios, to carry out excavations to the desired heights without compromising the stability of neighbouring structures.

With regard to the advantages of applying CSM technology compared to traditional techniques, should be emphasised the possibility of knowing the exact geometry of the soil-cement panels and the deviations that occur in depth, as well as the versatility of the equipment used. In these cases, the advantages were particularly important since, on the one hand, the knowledge of the exact geometry of the panels and the deviations in depth made it possible to achieve an effective connection between panels and a reduction in the inflow of water into the excavation area and, on the other hand, the versatility of the equipment made it possible to pass through the different materials that form the subsoil.

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