

Secant pile wall design and construction using CFA piles and Deep Soil Mixing

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ABSTRACT: This article presents an innovative solution for a challenging excavation pit within a residential project in Târgu Mureș, Romania. By combining secant deep soil mixing (DSM) columns with continuous flight auger (CFA) piles, we developed an effective, environmentally friendly, and cost-efficient approach compared to traditional secant pile pit enclosures.

A key objective was to design a robust retaining wall system that could withstand the excavation depth, while considering the constraints of surrounding buildings, nearby streets, and limited site dimensions. Given the presence of a 2-meter thick, non-cohesive soil layer and due to groundwater presence, our primary goal was to seal this layer to prevent water ingress into the excavation pit. To achieve this, 600 mm diameter DSM columns were installed using a specialized tool equipped with three levels of mixing paddles. Rigorous calibration of grout flow, advancement speed, and mixing RPMs were essential to attain the optimal Blade Rotation Number (BRN) tailored to the site's specific soil conditions. Real-time monitoring of these parameters ensured adherence to design criteria and effective performance. This paper details the design principles, technological implementation, and successful outcomes of this innovative solution.

KEYWORDS: Excavation; pit enclosure; deep soil mixing; sealing

1 INTRODUCTION

The proposed design aimed to provide a technical and economical solution for supporting an excavation for the residential project “DOX Apartments,” located in Târgu Mureș, Mureș County, Romania.

Given the limited area of approximately 780 sqm and the presence of neighbouring buildings, the site posed numerous challenges in terms of both execution and design (Figure 1).

The scope of work included the design and construction of a pit enclosure to ensure a 7.5-metre-deep excavation in an urban environment.



Figure 1. Site layout

2 SOLUTION

The soil stratigraphy identified in the geotechnical study consisted of a sequence of clayey sandy silt, followed by a 2-metre-thick non-cohesive layer containing groundwater, and finally a stiff marly clay.

The main solutions considered for safely reaching the design level of the raft foundation were either a diaphragm wall or a secant pile wall enclosure, both supported by a single level of struts.

Given the space constraints and the presence of neighboring buildings, the diaphragm wall option was not feasible, so the secant pile wall solution was further developed (Figure 2).

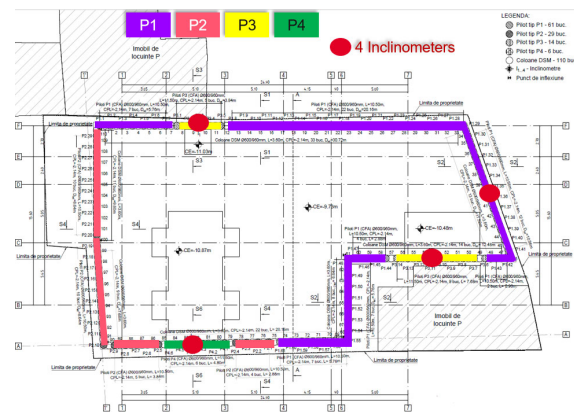


Figure 2. Pit enclosure layout.

Considering the specific soil stratigraphy in the Târgu Mureș area and the requirement to effectively seal a relatively thin 2-metre layer of non-cohesive soil, an alternative solution was proposed for this project, consisting of primary deep soil mixing (Colmix®) columns with a diameter of 600 mm and secondary CFA piles, also 600 mm in diameter (Figure 3).

This solution not only optimized the execution schedule and reduced material quantities but also significantly lowered the environmental impact, resulting in a much smaller carbon footprint for the entire project.

Given the role of the DSM columns, the most critical property of the treated soil was defined as permeability rather than UCS strength, to ensure proper sealing of the enclosure. The final mix was designed to achieve low permeability (between 10^{-8} m/s and 10^{-9} m/s) and an average UCS of 1–2 MPa, allowing the CFA600 augers (secondary piles) to break through the mixed columns with ease.

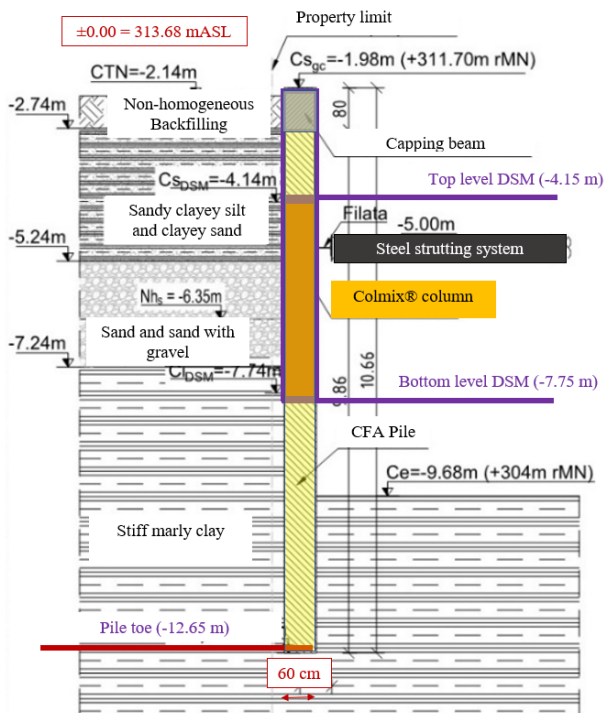


Figure 3. Characteristic section.

The bored piles provide the actual bearing capacity of the retaining wall, designed in accordance with the applied loads, excavation depth, and ground conditions.

The deep soil mixing columns were designed to be executed from the natural ground level (-2.15 m) and to penetrate 50 cm into the marly clay layer (-7.75 m). Each deep soil mixing column had a drilling length of 5.60 m and a diameter of 600 mm.



Figure 4. Construction site photo.

An important parameter for assessing the mixing energy applied to the soil during the deep soil mixing process is the blade rotation number (BRN), which requires a careful balance between achieving thorough mixing and maintaining cost efficiency. For this project, the targeted BRN was 360, with a permeability goal of 10^{-9} m/s (lower if possible) and a maximum acceptable value of 10^{-8} m/s to ensure proper sealing of the non-cohesive layer.

Secondary CFA piles, 600 mm in diameter, were installed between the primary DSM columns, with drilling lengths specified according to the design. Four different pile types were executed, depending on their distance from neighboring structures, differences in working platform levels, or the locations of various sump pits.

Design approach and calculations were performed according to current regulations both Eurocode 7, (ASRO, 2004), corresponding national annex, ASRO (2007) and Romanian regulations regarding deep soil mixing and bored piles execution, ASRO (2005, 2015).

3 MATERIALS AND METHODS

The construction of stabilized soil columns consists of deep mixing and stabilization of weak soils by mechanically blending them with a cement-based binder. The materials used for the treated columns were water and cement. The grout composition used for DSM injection employed a water-to-cement ratio of 1:1. The total quantities per cubic meter of mixed material were: 755 liters of water per m^3 and 755 kg/m^3 of cement type CEM II/B-M(S-LL) 42.5R.

The CFA piles were executed using concrete of class C25/30. The concrete mix characteristics were as follows: maximum water-to-cement ratio 0.50; exposure class XC2; maximum aggregate size $\varnothing 16$ mm; consistency class S5. Reinforcement cages consisted of longitudinal bars made of B500B or B500C steel, stirrups, stiffness rings, and spacers.

4 COLMIX® PROCESS

The Colmix® process is a deep soil mixing technique that uses a single or multiple mixing tool to construct soil mixing columns. This tool must be mounted on a suitable piling rig.

A key part of the solution is selecting the appropriate tool and machine for the process. In this project, a single tool with three levels of mixing paddles was chosen (Figure 5). The tool is inserted into the ground and rotated while grout is injected into the soil. It is then raised, and the process is repeated until the required depth is achieved.

The combination of being relatively fast, efficient, and environmentally friendly made Colmix® the most suitable solution for this project. After selecting the appropriate equipment during the design phase, all construction parameters had to be evaluated and set according to the site and ground conditions.

Once the grout mix design for the mixing phase was established, several preliminary drilling tests were carried out to both validate the proposed parameters and calibrate drilling speed, penetration rate, and the overall quality of the mixing process.

To achieve the targeted blade rotation number (BRN) under local conditions, the required grout volume for mixing, the water-cement ratio, and the necessary cement quantity were determined.



Figure 5. Deep soil mixing tool

Following the first preliminary drilling tests, it was concluded that, although deep soil mixing was required only over a 3.6-metre section (from -4.15 m to -7.75 m), it was preferable to also treat the first two metres (from the working platform level to -4.15 m). This was done not necessarily for sealing purposes, but to prevent nozzle clogging and to facilitate reaching the desired top level of the DSM columns more easily.

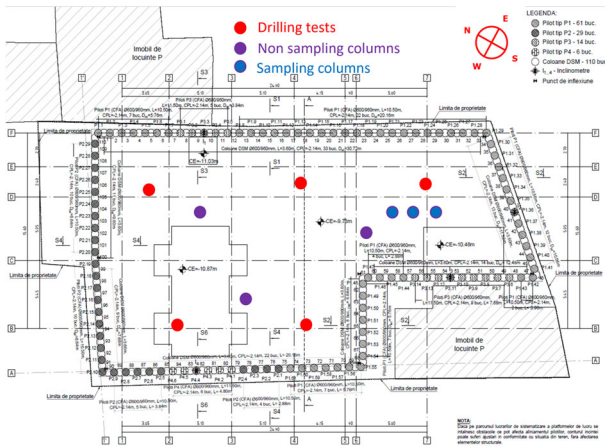


Figure 7. Testing plan layout.

The first phase included several empty boreholes that were drilled across the site to calibrate drilling speeds, rotation speed (rpm), and the monitoring equipment. These tests ensured that the equipment and parameters were properly adjusted before commencing the execution of DSM columns.

The second phase included the following:

- Three columns, L = 3.00 m – no sampling performed; positioned within the future excavation area, with the objective of visually inspecting homogeneity differences between the tested configurations.
- Three columns, L = 6.00 m – fully grouted following the theoretical execution sequence.

Fresh samples of the treated soil were collected from the spoil (excavated material) generated when the mixing tool was withdrawn after completing the mixing process. Laboratory testing was carried out on three sets of samples, each consisting of three test cylinders taken from each DSM column, at 7, 14, and 28 days.

The tests included unconfined compressive strength (UCS) and permeability measurements performed in consolidation cells.

Permeability results (Figure 8) from fresh cylindrical samples were within the targeted range, between 10^{-9} and 10^{-8} m/s, while the UCS values (Figure 9) at 28 days exceeded the target of 2 MPa, with lower strengths recorded at 14 days (around 1 MPa) and at 7 days (around 0.5 MPa).

Column	Sample	@8 days		@14 days		@28 days	
		Permeability [m/s]	UCS [Mpa]	Permeability [m/s]	UCS [Mpa]	Permeability [m/s]	UCS [Mpa]
C1	P01.1	-	0.75	-	1.06	-	2.23
	P01.2	4.70E-09	-	3.48E-09	-	1.83E-09	-
	P01.3	1.55E-09	-	2.27E-09	-	2.21E-09	-
C2	P02.1	-	0.34	-	0.88	-	2.42
	P02.2	1.12E-08	-	1.6E-09	-	1.04E-08	-
	P02.3	2.49E-09	-	3.5E-09	-	1.57E-09	-

Figure 8. Permeability results

Col.	Depth [m]	Name sample	γ [kN/m ³]	n [%]	e [-]	S_r [-]	UCS [Mpa]	k [m/s]	Type of layer
COL01	3,5	P08	17,46	34,9	0,54	0,1	1,18	5,51E-08	sand
COL01	4	P07	16,8	38,1	0,62	0,14	2,16	2,11E-07	sand
COL01	5	P06	20,19	25,4	0,34	0,23	1,45	1,53E-07	sand
COL01	5,6	P05	17,47	35,4	0,55	0,14	1,58	2,04E-07	clay
COL02	4	P03	16,04	41	0,7	0,13	1,96	1,04E-07	sand
COL02	4,8	P02	15,48	43,2	0,76	0,13	1,97	6,31E-08	sand
COL02	5,6	P01	16,46	39,6	0,65	0,14	2,56	5,87E-08	clay

Figure 9. UCS results

Although the UCS values exceeded expectations, the primary DSM columns were easily drilled through using 600 mm CFA augers. Core samples (Figure 10) taken from several

columns also showed good UCS results, with an average of 1.8 MPa, and permeability values within the targeted range.



Figure 10. Core samples from a DSM test column

7 CONCLUSIONS

Deep soil mixing (DSM) columns are a proven and reliable ground improvement technique, offering several advantages over other methods, including cost-effectiveness, sustainability, and efficiency.

The findings reinforce the applicability of deep soil mixing as a viable alternative to traditional diaphragm walls, particularly where groundwater infiltration or limited execution space present significant challenges.

The performance of DSM-treated soil is dependent on precise control of mixing parameters and soil variability. Full homogeneity cannot be visually confirmed beyond the tested segments, and long-term permeability performance continues to depend on curing and soil–cement interaction characteristics.

For this project, the final solution—a combined retaining wall using deep soil mixing for the primary piles and CFA technology for the secondary piles (Figure 4)—proved to be the ideal balance between tradition and innovation. It resulted in a highly successful outcome, with an overall carbon footprint reduction of approximately 40 tons of CO₂ equivalent.

In summary, DSM columns represent a versatile and sustainable ground improvement method capable of delivering substantial cost savings and significant environmental benefits.

Future research should focus on long-term monitoring of DSM-treated soils, optimization of cement content for improved cost efficiency, and comparative analyses of environmental and economic advantages relative to diaphragm walls and other traditional retaining systems.

8 REFERENCES

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