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A CASE STUDY ON SOIL IMPROVEMENT WITH DEEP SOIL MIXING APPLICATION

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Soil improvement is defined as the improvement of the some soil parameters by using different methods when the soil properties are insufficient to prevent static and dynamic loads. The Deep Soil Mixing (DSM) is an in situ soil treatment technology whereby the soil is blended with cementitious and/or other materials. The method has gained its popularity after 1990's in the world and last ten years in Turkey. In this study, a case study on soil improvement with deep soil mixing application in Eskisehir, Turkey is presented. The application procedure was created according to steps of usual geotechnical projects. Firstly, soil investigation was done and soil parameters were defined. And then, bearing capacity of deep soil mixing columns was calculated and modelled by "All Pile" software. After the site application, core samples were taken and the load test was applied to the core samples. Finally, deep soil mixing is becoming a popular as a soil improvement method and gives succeeding results.

Keywords: Cement mixing, Geotechnical project, Ground modification, Ground strengthening, Soilcrete, Soil investigation.

1 INTRODUCTION

Soil improvement is defined as modification of soil properties when they are insufficient for the construction of the superstructure (Das 1984). For example, increasing the soil bearing capacity, decreasing the consolidation settlement and prevention against liquefaction for the foundation design, increasing the stability of earth fill dams and slopes are the common reasons of the soil improvements. Main improvement methods are classified as mechanical modification, hydraulic modification, chemical additives and reinforcement usage (Nicholson 2015). Mechanical modification involves all compaction techniques and the aim is to densify the soils. Hydraulic modification consists forcing pre-consolidation and decreasing the permeability of soil by dewatering and drainage methods to control settlement and water flow. On the other hand, soil properties are modified by additives with mixing or grouting processes and geosynthetics, nails and other materials usage increases tensile strength and friction resistance.

Deep soil mixing (DSM) is creating soilcretes by cement injection and mixing it into the in-situ soil by blades. Soilcretes are soil-cement columns having high elasticity modulus. DSM method was firstly used in USA, 1954 and gain popularities after 1990's. Application process is cutting the soil by blades to the certain depth and then cement injection is started while blending the soil and cement. The aim of this method

is to improve the soil properties, to support the excavations and hydraulic cut-off wall (Kilic 2013). The method is applied under the foundation to increase soil bearing capacity and decreasing liquefaction potential. DSM columns are formed as crossed columns for ground water flow and this application named as Hydraulic Cut-Off Wall. On the other hand, DSM is constructed as a wall for preventing horizontal deformations on the excavation surfaces. In-situ soil mixing process is given in Figure 1.

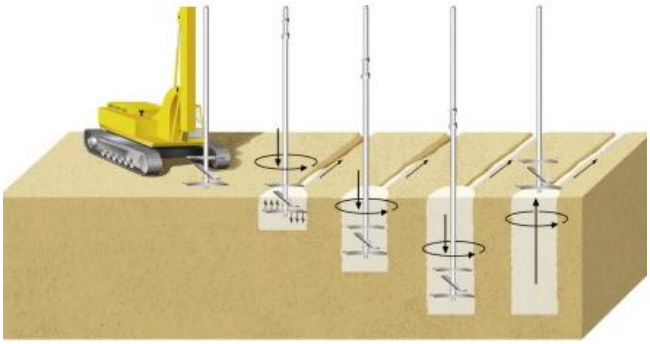

Figure 1. In-situ soil mixing process (Kilic 2013).

Onur (2007) investigated the soil deformations under earthquake loads and decreasing methods of these deformations by applying different improvement methods. He reported that the soil improvement methods show different effects due to the local soil conditions and earthquake characteristics. Andromalos *et al*. (2003) used the DSM columns for deep excavation supporting system and they observed that horizontal displacements are reduced and ground water level are controlled, easily. Madhyannapu *et al*. (2009) studied the DSM methods for the swelling soils and they obtained acceptable results. Holm (2005) gaves the history of the DSM method and past case studies. The research shows that the method can be applied to improve problematic soils, to prevent liquefaction potential and intolerable settlement all around the world. Fang (2006) modeled the improvement of the soil properties after DSM application by using numerical methods. Some differences between the field tests and numerical analysis results are found. Ye *et al*. (2006) compared the DSM method and drains with preloading for soft soils. The study showed that DSM method gives higher bearing capacity with cost and time consuming.

In this study, a case study on soil improvement with deep soil mixing application in Eskisehir, Turkey is presented. The application procedure was created according to steps of usual geotechnical projects. Firstly, soil investigation was done and soil parameters were defined. And then, bearing capacity of deep soil mixing columns are calculated and modelled by "All Pile" software. After the application, core sampling was done and the load tests were applied to the core samples. At the end, results were discussed and suggestions were given.

2 MODELING AND METHOD

DSM is an in-situ soil treatment technology whereby the soil is blended with cementitious and/or other materials. In this study, a deep soil mixing application was

analyzed. 8 storey hotel building with 1228 m^2 of foundation area was constructed in the city of Eskisehir, Turkey. The total structural load was 6000 tons and foundation depth was -4.50 meters. The process was ordered according to Earthquake Resistant Design Code of Turkey.

2.1 Soil Investigation

Borings were done by Yerteknik Company. Total 5 boring hole were opened up to -15.00 meters. Standard penetration tests were performed at every 1.50 meters and undisturbed samples were taken by using Shelby tubes at every 3.00 meters. The SPT numbers with depths were given in Table 1. The ground water level was found at -4.50-meter depth.

Table 1. The variation of SPT numbers with depths.

Depth (m)	SPT Number	Soil Type
-3,00	17	Silty Clay
-4,50	7	Silty Clay
-6,00	8	Silty Sand
-7,50	17	Silty Sand
-9,00	23	Sandy Gravel
-10,50	43	Sandy Gravel
-13,50	R	Very Stiff Clay

Laboratory tests were conducted on the disturbed and undisturbed samples. Consolidation test, unconfined compression test, triaxial test were performed on the undisturbed samples. Specific gravity, sieve analysis, hydrometer test and Atterberg limit tests were performed on the disturbed samples. Therefore, all properties of the sub-soils were determined. Soils were classified by using Unified Soil Classification System. Soil strength parameters were given in Table 2.

Table 2. Soil strength parameters.

Soil Type	Unit Weight (t/m^3)	Int. Friction Angle (^{o})	Cohesion (t/m^2)
Silty Clay	1.8	20	10
Silty Sand	1.9	35	-
Sand Gravel	2.0	40	-

Soil exploration report was prepared and allowable soil bearing capacity was calculated as 9 t/m^2 and also liquefaction potential was observed at Silty Sand layer. Therefore, soil improvement is suggested in the exploration report.

2.2 Bearing Capacity Calculation of DSM Columns

The most preferred improvement methods are stone column, jet-grouting and deep soil mixing in the city of Eskisehir. Stone column method is inadequate for this soil and load conditions on the other hand, jet grouting method is not economical. Therefore,

deep soil mixing method was chosen for this project. Designing the DSM application project was started with bearing capacity calculation of singular DSM column. For the calculation "All Pile" software was performed. "All pile" is a commercially available computer program using by many of geotechnical engineers.

The DSM columns were designed as 7 meters in length and 0.60 meters in diameter. And the location of the columns was between -4.60 and -11.60 meters in depth. Distance between the columns from center to center was 1.70 meters in x and y directions. Soil properties and the column dimensions are the inputs for the program and analysis was started with considering loads, stresses, settlement limits, axial and shear forces, moments and deformation limits. Allowable bearing capacity of one DSM column was found as 391.2 kN with 0.44 cm settlement with factor of safety 2. An example screen of the analysis was given in Figure 2.

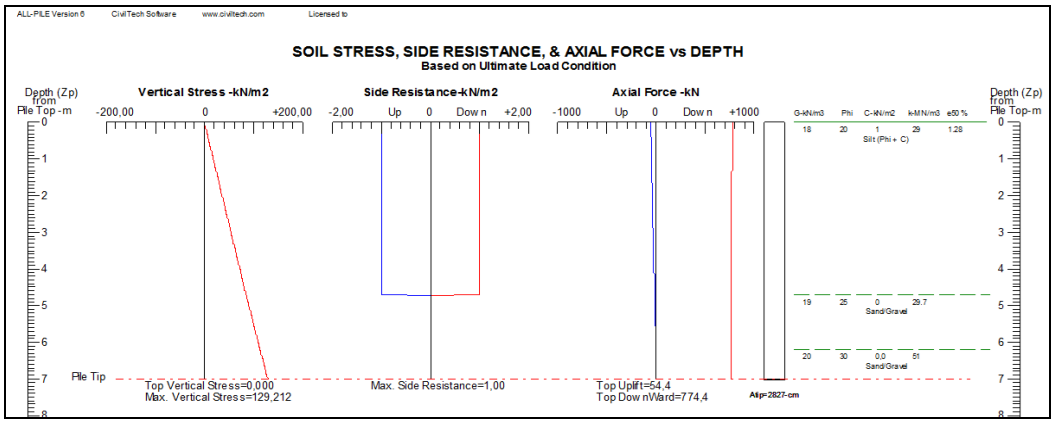

Figure 2. An example screen of the software.

2.3 Application of DSM

Firstly, a trial column was created at the construction site to control column diameter and to determine the application parameters. Some application parameters were given in Table 3. The trial column was excavated three days later and diameter was measured as 63 cm and it was given in Figure 3. The measured diameter was suitable so project was applied. Totally 476 DSM column was constructed in the whole area.

3 RESULTS

Quality control tests for the deep soil mixing applications are pile integrity testing or full length core sampling and compression tests on the cores. The integrity of the column is controlled by performing pile integrity testing or full length core sampling. The bearing capacity of the columns is controlled by performing compression tests on the cores. After the application, full length core sampling and compression tests on the cores were performed. The DSM cores can be seen from the Figure 4.

Full length core sampling showed that the DSM columns were formed between -4.60 and -11.60 meters in depth. And also, four core samples were taken from different columns to perform compression test. Average compression strength of the cores was

found as 24.09 N/mm^2. So bearing capacity of a single column was calculated as much higher than the design requirements. The results showed that the soil improvement was successful and subsoil now can carry the upper structure loads safely.

Figure 3. Trial column diameter measurement.

Table 3. Some application parameters.

Injection Pressure	0-100 Bar
Penetration Speed	50-150 cm/min
Nozzle Number	10
Nozzle Diameters	2,5 mm
Rotation Speed	5-40 rpm
Dosage	450 kg/m^3

Figure 4. DSM cores.

4 CONCLUSION

In this study, a case study on soil improvement with deep soil mixing application in Eskisehir, Turkey is presented. The application procedure was created according to steps of usual geotechnical projects. Firstly, soil investigation was done and soil parameters were defined. And then, bearing capacity of deep soil mixing columns are

calculated and modelled by All Pile software. After the application, core sampling was done and the load tests were applied to the core samples. At the end, results were agreeable and DSM method gave a good performance. Therefore, DSM method can be suggested to use as an improvement method against weak soils.

References

Andromalos, K.B, Bahner, E.W., The Application of Various Deep Mixing Methods for Excavation Support Systems, *Grouting and Ground Treatment, ASCE*, 515-526, 2003.

Das, B. M., *Principles of Foundation Engineering*, Brooks Cole Eng. Division, USA, 1984.

Fang, Z., *Physical and Numerical Modeling of the Soft Soil Ground Improved by Deep Cement Mixing Method*, The Hong Kong Politechnic University, Ph.D Thesis, 2006.

Holm, G., Deep mixing properties and applications, *Star Conference*, Cambridge, UK, 2005.

Kilic, H. O., Design and Application of Deep Soil Mixing, Anadolu University Msc Thesis, 2013.

Madhyannapu, R.S, Puppala, A.J, Bhadriraju, V., Nazarian, S., "Deep Soil Mixing (DSM) Treatment of Expansive Soils," *Work Shop on Ground İmprovement Technologies, ASCE*, 130-139, 2009.

Nicholson, P. G., *Soil Improvement and Ground Modification Methods*, Elsevier, USA, 2015.

Onur, M. I., Soil Deformations under Dynamic Effects, Anadolu University Msc Thesis, 2007.

Ye, G., Xu, C.A., Gao, Y., Improving Soft Soil Using Combined Cement Deep Mixing Column and Preloading with Prefabricated Vertical Drains, *Ground Modification and Seismic Mitigation, ASCE*, 152, 23-28, 2006.