Excavation Support and Foundation Ground Improvement Using Jet Grouting Method – A Case Study

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Abstract. One of the soil improvement methods is using soil-cement columns, and one of the most common methods of implementing these columns is the Jet grouting method. In this article, the performance of Jet grouting columns in soil improvement and excavation wall stabilization is investigated in a project located in Chalous, north of Iran, by implementing several experimental soil-cement columns in real scale at depths of 4, 8, and 15 meters and diameter of 80 cm. By comparing the soil settlement before and after the improvement, it was found that the average settlement, which was in the range of 186 mm before the improvement, reached about 68 mm after the improvement using the jet grouting method. It has been observed that the settlement of the foundation has been significantly reduced after improving the ground with soil-cement columns. On the other hand, the results of this study showed that this method has also been very effective in stabilizing the excavation walls. The maximum displacement of the crest of the wall is about 3.4 cm, and the maximum settlement behind the wall is limited to 12 mm.

Keywords: Soil improvement; soil-cement column; jet grouting method; excavation stabilization.

1. INTRODUCTION

The soil in a field may not be a suitable support for structures such as buildings, bridges, dams, oil tanks, etc., because the soil's safe bearing capacity may not be suitable. In order to improve the soil for the construction of these heavy structures, it is necessary to improve the soil with a series of reinforcement elements. Some of these methods have been developed in the last 50 years, such as sand column and vibro-compaction, deep soil mixing, slurry injection, jet grouting column, etc. In most of these methods, soil resistance is increased by creating a series of columns with higher resistance in the soil mass. Choosing the best method depends on the type of soil, geotechnical characteristics, and the type of application [1]. In soft clay soils with relatively low shear strength, two main methods of soil improvement by creating reinforcement columns can be used: (1) using a vibro compacted stone column, which includes creating a compact vibrating stone column in the soil. This method, called Vibro Replacement (VR) is the process of densifying granular soils and reinforcing cohesive soils with stone columns constructed with specialty down the whole Vibro-Probes. (2) Using "Jet grouting columns" which includes creating a column in the form of a mixture of local soil with cement or lime, etc. Jet grouting is a method of in situ mixing that is accomplished through erosion of the soil via a high-pressure jet of grout or slurry. The following method will be explained in detail.

Jet grouting is one of the methods of stabilizing and increasing the resistance and bearing capacity of in situ soil. Jet grouting is an in situ soil mixing process that uses high-pressure jets to simultaneously inject additives and mix them with the in situ soil. The purpose of jet grouting high-pressure injection is to create a soil-cement column. These columns are called jet columns or jet-grouted columns. Jet Grouting was used for the first time in Japan [2]. The idea of high-pressure water jet cutting was proposed in the early 1970s for use in coal mines in the United States and also in Britain, and then in the mid-1970s, the Japanese (Yamakado Brothers 1965) used this method not only for cutting and eroding soil but also used for simultaneous cement injection [3]. Karkush and colleagues have also done useful research in the field of grouting [4-7]. Jet grouting is generally performed from the bottom up. The process begins with drilling from the surface to the target bottom elevation using a low-pressure and low-flow fluid stream as the drill bit lubricant. Once the target bottom elevation is achieved, the pressure and flow rate are increased to about 300 bars and 100 m/s, respectively, and the drill rod is slowly withdrawn from the drill hole while rotating the jet [8]. The in situ soil properties, the rate of withdrawal, the rotation rate, the fluid pressure, and the flow all influence the diameter of the column created [9]. This diameter is usually in the range of 10 to 15 cm.

Normally, three methods for performing jet grouting injection are divided based on the number of fluids used [9]. Based on what system of fluid is employed for the grouting process, the method of jet grouting varies. The available techniques are grouped into three main jet grouting systems, namely Single, Double, and Triple fluid systems, Which are classified based on the number of fluids injected into the subsoil. The fluids are:

- Grout, i.e., water + cement for single fluid
- Air + Grout for double fluid
- Water, air, and grout for triple fluid

2. PROJECT DESCRIPTION

The considered project, the construction of an 11-story hotel, has been implemented in a site with an area of about 10 thousand square meters and a perimeter of about 450 meters in the city of Chalus. The project site is located 450 meters from the Caspian Sea. This project includes ground improvement up to 10 meters and excavation to approximately 4.5 meters. See Figure 1.

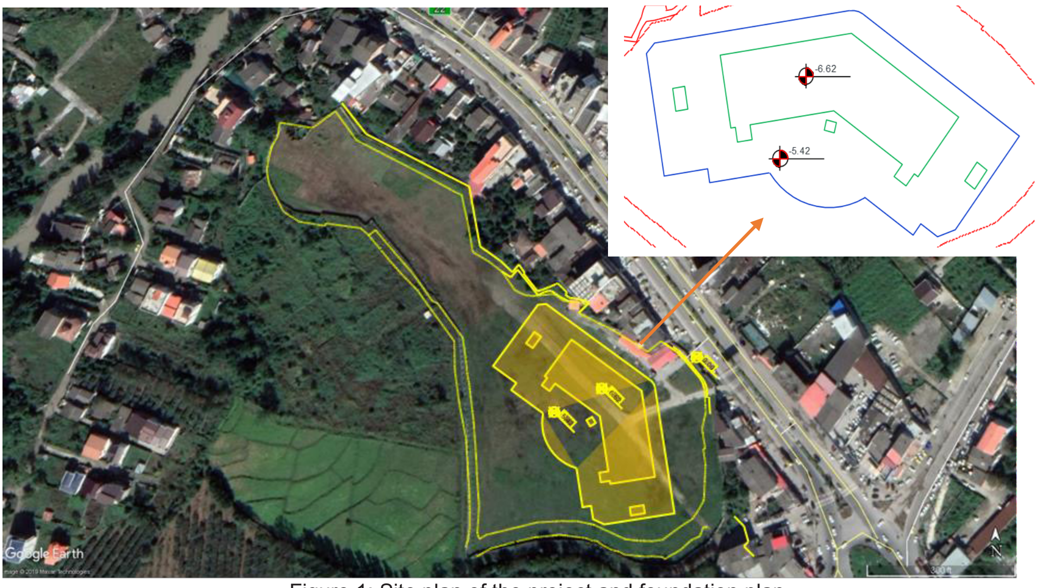

Figure 1: Site plan of the project and foundation plan.

3. SUBSURFACE CONDITIONS

The soil profile of the project ground, after passing through the 70 cm layer of surface soil, to a depth of 3 meters, is a clay layer with low plasticity (CL), then to a depth of about 9 meters fine-grained sand with clay (SP-SC) and then to a depth of about 17 meters Low plasticity clay with sand (CL) is reported. According to this report, from a depth of about 17 meters, there is a layer of coarse-grained sand with dense silt and sand (GP-GM). Also, the static level of water is at a depth of 1.5 meters (Figure 2 and Table 1).

Table 1: Soil characteristics table.

Soil characteristics	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7
Depth (m)	0-3	3-9	9-18	18-21	21-27	27-31	31-50
Friction angle	15.2	28.1	17.1	34.6	31.0	18.2	34
Cohesion (kg/cm^2)	0.18	0.09	0.26	0.03	0.07	0.31	0.03
Moist unit weight (gr/cm^3)	1.8	1.9	1.8	1.9	1.9	1.8	1.9
Poisson's Ratio	0.35	0.3	0.35	0.25	0.3	0.35	0.3

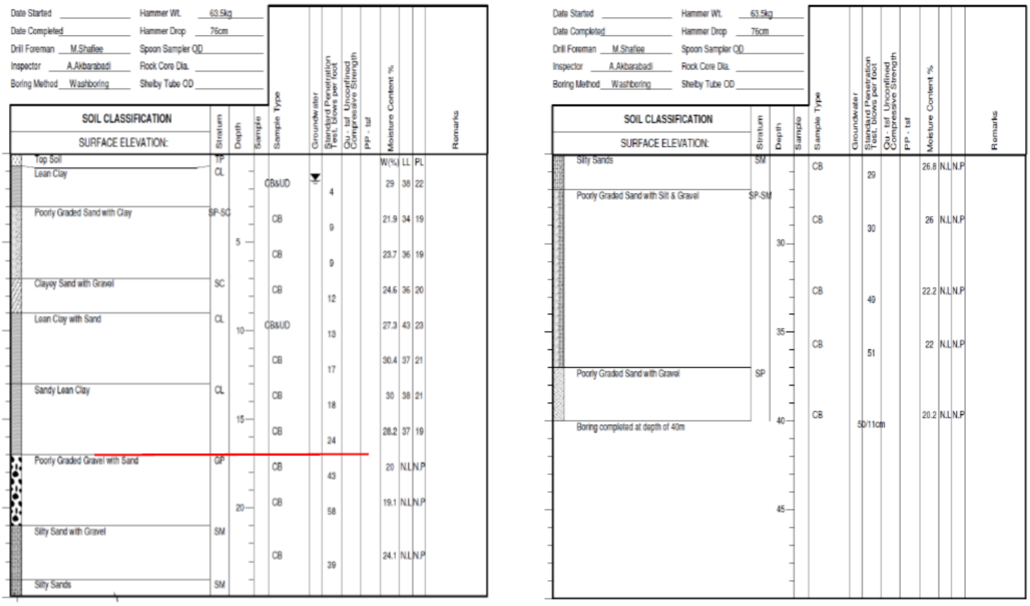

Figure 2: Soil profile.

4. SOIL IMPROVEMENT SYSTEM BY JET GROUTING METHOD

In order to control the settlement of the foundation in this project, soil improvement has been done by using cement soil columns. PLAXIS 3D FOUNDATION finite element software is used for numerical calculations of this design. To model the soil, the Hardening Soil behavioral model was used; which parameter values are presented below? In order to model the consolidation of the soil, the characteristics of the equivalent block of soil improved by jet grout columns were used. In this method, we model the improved soil with a homogeneous element with equivalent hardness by averaging the hardness of the elements see Figure 3.

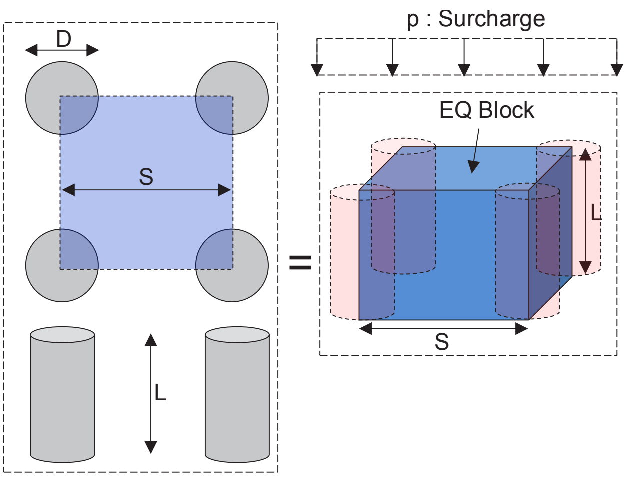

Figure 3: The geometry of the concept of equivalent block in improved soil to calculate the parameter values of the equivalent block of improved soil.

The design assumes that the final uniaxial resistance of the jet grout column is 2 MPa and 4 MPa in clay and sand, respectively (or 20 and 40 kg/cm^2). Also, the relationship E=150qu has been used to determine the elastic modulus of the jet grouting column element. In Figure 4, the PLAXIS Model of equivalent blocks is displayed. In

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this model, equivalent characteristic parameters were assigned to the improved area. The settlement resulting from the loading was obtained based on the analysis of the equivalent block concept.

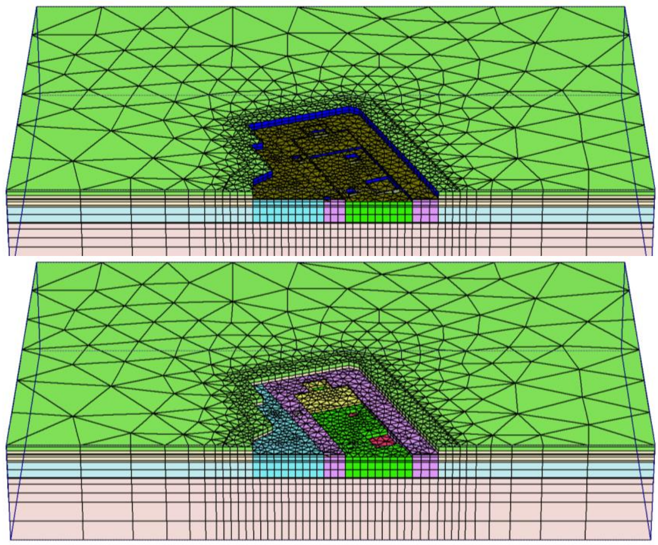

Figure 4: PLAXIS Model of equivalent blocks which represent improved soil by Jet Grouting method.

According to the analysis, it was seen that the settlements, strains in the soil, and the structural forces created inside the foundation had been reduced after the improvement so that the settlement was limited from a very high amount of 185 mm before the improvement to an acceptable amount of 68 mm after the improvement (Figure 5).

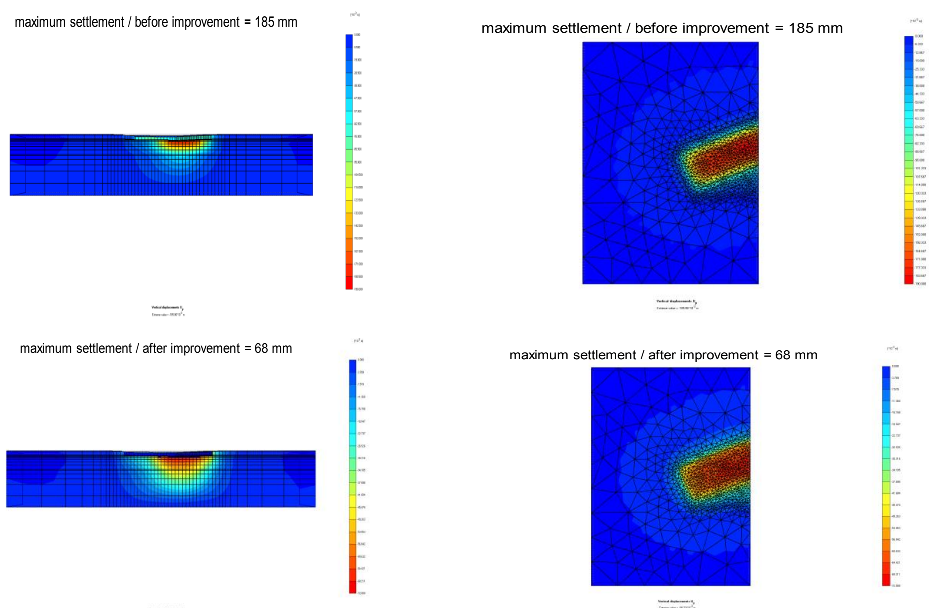

Figure 5: Settlement contour of the model before and after improvement in the plan.

5. SOIL-CEMENT COLUMN IN EXCAVATION STABILIZATION

In order to stabilize the excavation, the Jet Grouting method is used along with IPE180 steel profiles as the reinforcement. The depth of Jet Grouting columns is equal to 8 meters (from level -1 to -9), and their diameter is equal to 80 cm, and the overlapping between columns is also considered to be 30 cm. Also, the length of IPE180 profiles is equal to 6 meters, which should be installed at the level of -1 to -7 inside the Jet Grout columns. Finite element software for geotechnical works (PLAXIS) was used for numerical calculations. See Figure 6.

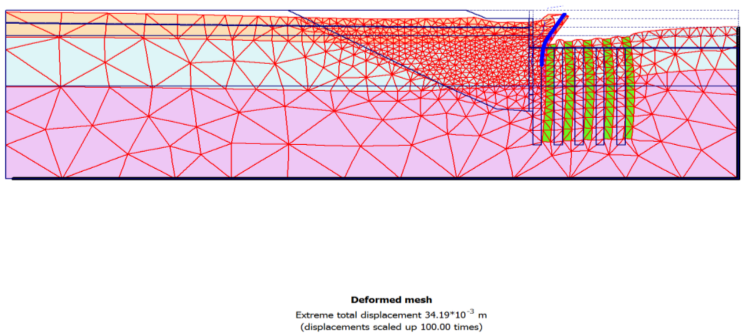

Figure 6: Deformed mesh of the numerical model.

According to the modeling results, the maximum displacement of the wall crown is about 3.3 cm. Considering that construction is around the excavation area at a close distance affected by the displacements caused by excavation, this amount of displacement is acceptable. Also, according to Figure 7, the maximum settlement behind the retaining wall is estimated to be about 12 mm.

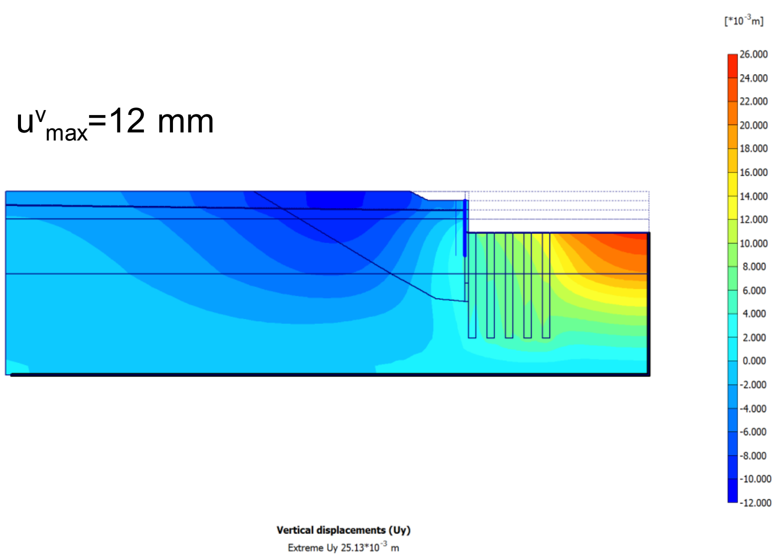

Figure 7: Vertical displacement contour in PLAXIS numerical model.

6. TEST COLUMNS

In the jet grouting method, before the main columns are executed, test columns are constructed in order to evaluate the quality of the implementation of soil-cement columns on site and to evaluate their efficiency and optimize and increase the confidence factor of the final design as much as possible; therefore, this stage of implementation is very important. At this stage, according to the geotechnical conditions of the site and the resistance and behavior parameters required in the initial plan, several tests with different execution parameters are performed. Then, by analyzing the obtained results, the most optimal execution parameter is selected for constructing the main columns. Hence, a safe and economical design is obtained. Therefore, a number of test columns were first constructed in two areas. Some of the test columns were implemented in the center of the project and some in the eastern corner. Figure 8 shows the plan of the areas where series 1 and 2 test columns have been constructed and tested. In general, the purpose of running these test columns is to control the quality of columns implemented in the excavation wall and beneath the foundation to measure the diameter and resistance of the columns and select the final technical and operational parameters.

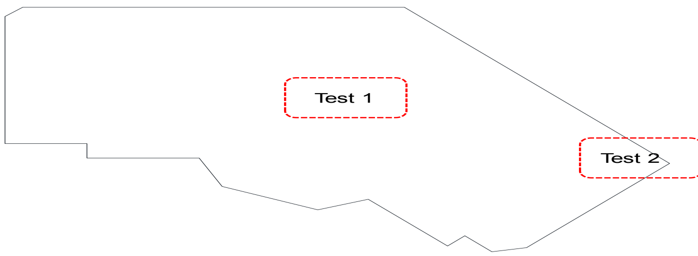

Figure 8: The plan of the areas where series 1 and 2 test columns have been implemented and tested.

6.1 The First Phase of Experimental Tests

Five columns with different operational parameters were implemented in the first phase of the implementation of test columns. These columns include R65, R66, R67, S65, and S67 as shown in Figure 9.

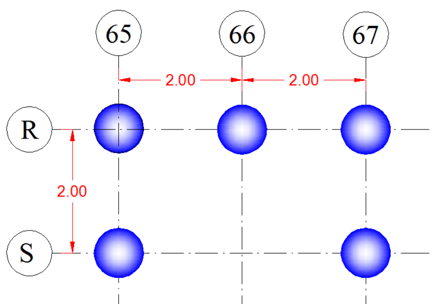

Figure 9: Axing plan of the first phase test columns.

Figure 10 shows a picture of the experimental columns implemented in the project land's middle area along with the set parameters' values. The results of measuring the diameter and compressive strength of cores can be seen in Table 2.

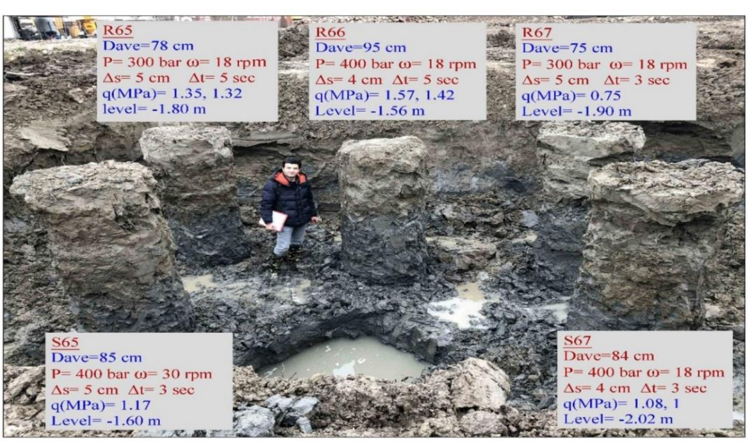

Figure 10: The experimental columns implemented in the site's middle area with the set parameters' values.

Table 2: Summary of the diameter and resistance results of the 1st phase test columns.

Col. Name	P (bar)	ω (rpm)	Δt (s)	Δs (cm)	D_{ave} (cm)	q_u average 13 days (MPa)	q_u average 18 days (MPa)
R65	300	18	5	5	78	1.54	2.25
R66	400	18	5	4	95	1.74	2.60
R67	300	18	3	5	75	0.87	1.86
S65	400	30	3	5	85	1.36	2.25
S67	400	18	3	4	84	1.21	2.65

As can be seen from the results, the majority of the columns have reached the 18-day resistance of more than 2 MPa and a diameter of more than 80cm. However, it should be noted that among the implemented columns, the R67 column could not overcome the clay cohesion and reach the desired diameter due to the semi-low pressure of 300 bars and the short time step (Δt). Also, despite the diameter and high resistance, the R66 column has low volumetric and energy efficiency, which cannot be accepted. Also, the results show that the rotation frequency does not have much effect on the diameter parameter, and sometimes, with the increase of the frequency, the resistance is also reduced to some extent. As the time step increases, the resulting diameter and resistance also increase. But the important point is to get the optimal time step.

6.2 The Second Phase of the Test Columns

In order to more closely examine some key parameters, such as injection pressure and injection time step, more experimental tests were carried out in the form of the second phase to increase the design's reliability factor even more. In this regard, the second phase of experimental columns with more columns was designed and implemented. In this phase, 101 test columns were executed, as shown in Figure 11.

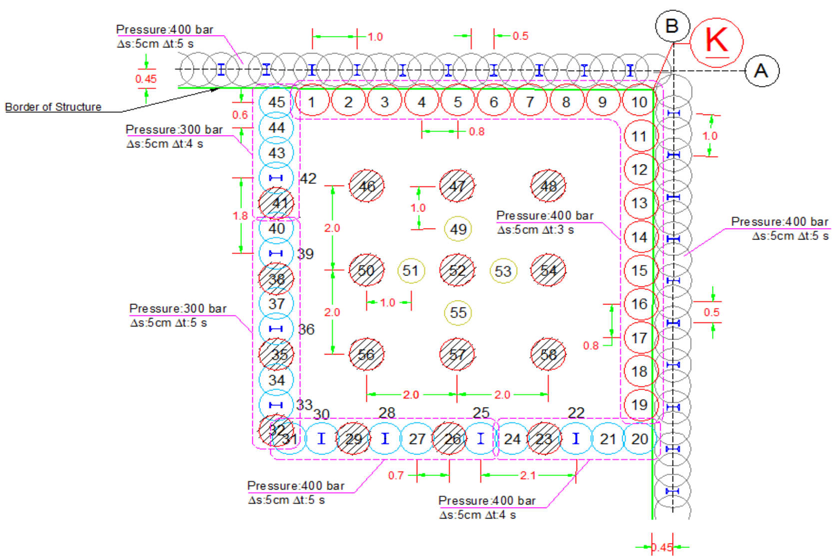

Figure 11: Test columns plan in the second test phase.

As in the first phase tests, core extraction was done from the executed columns in the second phase. The diameter and resistance results obtained from these columns are described in Table 3. Figure 12 shows the changes in the resistance and diameter of columns according to changes in injection pressure, nozzle rise step, injection time in each step, and injection flow rate, as can be seen from the graphs, with increasing pressure, the diameter and unconfined compressive strength of the column increase. The results of the first and second phase tests show that:

a) The compressive strengths of cement soil samples in clay soil (except for 1 case) are more than 2 MPa, and this resistance value was obtained with a pressure range of 300 to 400 bars.
b) In the columns of the second series, the diameter of the columns is 80 cm for pressures of 300 to 400. Therefore, the pressure between 300 and 400 bar is suitable for work.
c) In the R65 sample, according to the report, more clay clusters were observed, so the time of 5 seconds with a step of 5 cm and a pressure of 300 bars is not suitable. Also, a lot of clusters were observed in the S65 sample, so it seems that the step of 5 cm is not suitable.

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Table 3: Summary of the diameter and resistance results of the 2nd phase test columns.

Col. Number	D_{ave} (cm)	q_u average 18 days (MPa)
46	70	-
47	67	2.2
48	86	4.6
50	69	3.7
52	70	3.5
54	90	-
56	58	4.1
57	85	5.9
58	88	5.1

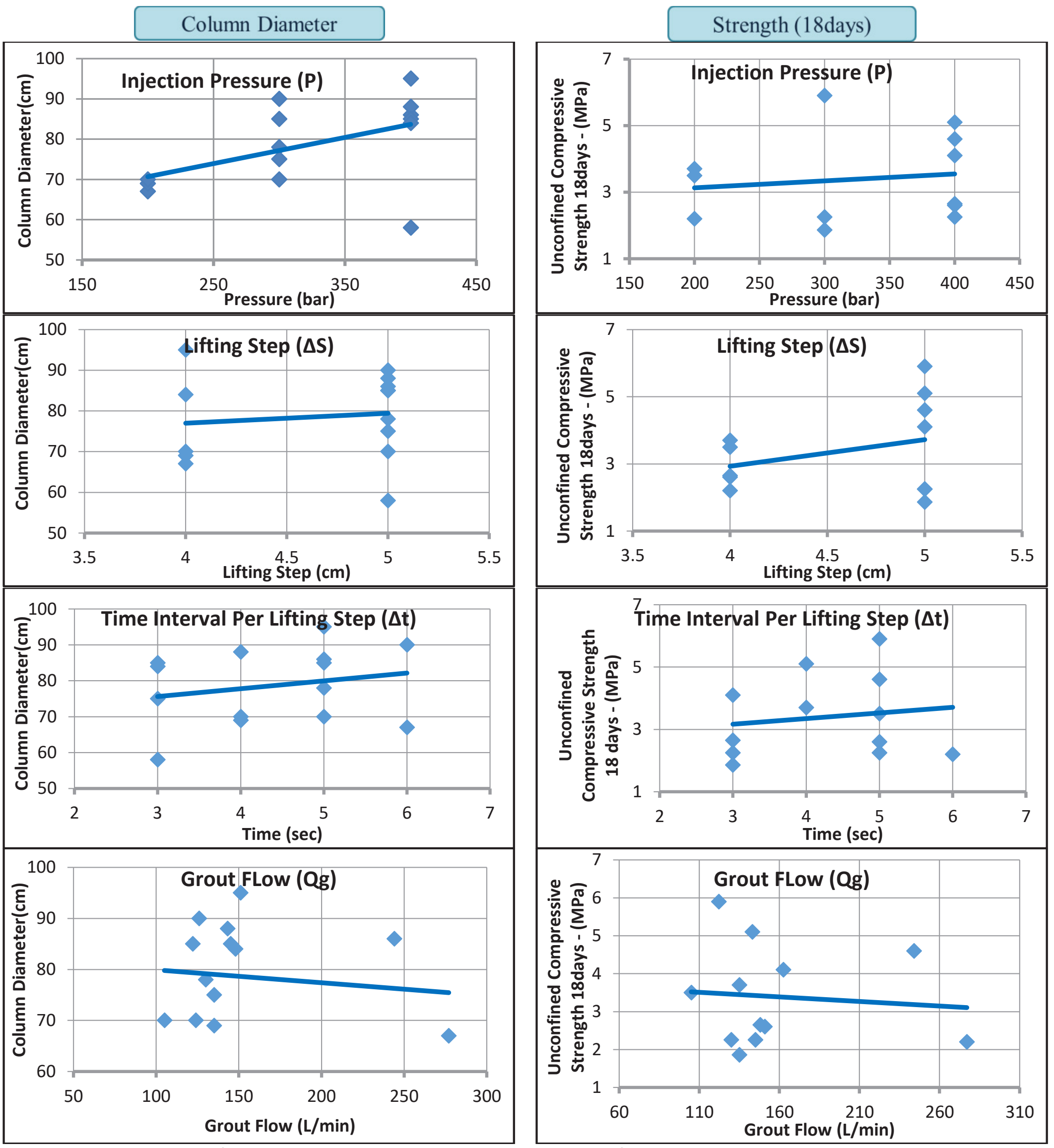

Figure 12: Analysis of changes in the resistance and diameter of columns according to changes in injection pressure, nozzle rise step, and injection time step and injection flow rate.

7. CONCLUSION

In this article, the effect of implementing the soil-cement column on the stabilization of the excavation wall and the improvement of the foundation bed soil and its settlement control has been investigated. Experimental cement soil columns were used at the site to investigate these effects. It was seen that columns with a diameter of about 70 cm and Unconfined Compressive Strength of about 5 MPa can be obtained. As mentioned earlier, the improvement performance in this method is based on mixing soil and cement slurry and forming high-resistance columns. As seen, implementing the jet grouting method has reduced the settlements caused by the structure's load to about a third. Hence, implementing soil-cement columns in projects similar to this study can significantly reduce foundation settlement. It was also seen that the maximum displacement of the wall's crest is about 3.4 cm, and the maximum settlement behind the wall is limited to 12 mm. Therefore, it can be concluded that this method is also suitable for stabilizing the excavation wall. Of course, it should be noted that all the above items depend on the equipment used and the conditions of the in-situ soil.

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