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Research Article

The Evaluation of Effect of Jet Grout Columns to the Settlements in Soils with Numerical Methods

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ABSTRACT

Increasing population bring together the need for construction on weak soils. At this point, soil improvement methods gain importance in which the problematic properties of soils aimed to enhance. Among these, jet grout columns are widely applied method and have advantages such as increasing the bearing capacity, reducing settlements and the risk of liquefaction. In this paper, jet grout columns utilized to reduce settlements in weak soil layers and the effect of several parameters on settlement examined. The analyzes, performed with Plaxis 2D and Plaxis 3D. The jet grouts are modeled with both single columns and composite region by changing jet grout length, diameter and spacing. To assess the soft clay effect, columns were socketed into different clay layers. The results proved that improvement with jet grout reduces the settlements, but the change in diameter, length and spacing affects the results at different rates. Through 3D analysis, up to 22% reductions in settlements obtained in case where the longest columns were assigned at the lowest spacings. The most effective factor was found as spacing rather than diameter. The increase in diameter after a certain value led to lower the performance due to the group effect. In case of the composite region, 3D and 2D analyzes converge very much, so it would be practical to perform 2D analysis for the composites. However, the ones modelled with single columns predicted more settlement and remained on the safe side. Additionally, jet grout columns performed better than in weak soils.

1. Introduction

With the rapid change in population, the need for existing urbanization activities, the acceleration of high-rise construction or the high risk of earthquakes in our country, which is located within the three major fault lines, brings with it the construction on unsuitable (problematic) soils. For this reason, the risk of landslide, earthquake and liquefaction, especially insufficiency of settlement and bearing capacity of the existing construction areas, makes it necessary to carry out geotechnical studies. Within the scope of geotechnical studies, in cases where the engineering properties of the soils are not sufficient for any structure, it is not always possible to change the construction area or to remove the weak soil within the project area and replace it with a more strong material, both in terms of cost and technology. For these reasons, soil improvement studies are of great importance in order to minimize the soil problems that may occur in the structure over time and to make the soil structure suitable [1].

Soil improvement works include many application areas such as controlling and reducing the settlement of the soil under structural loads, increasing the bearing capacity of the soils, sub-foundation improvements, improving the tunnel soil, creating an impermeable curtain, providing slope stability and reinforcement against scour [2]. A soil improvement method is selected that is fast to

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apply, provide reliable results, economical and will satisfy criteria suitable for soil parameters.

With the developing technology, many soil improvement methods have emerged in geotechnical engineering [3, 4]. One of these methods is the jet grout method, which has been widely used in recent years [5-7]. In this method, high pressure (400 – 500 bar) cement grout is jetted onto the drilled soil with a special drilling machine, and the soil is ruptured and mixed. Thus, a cylindrical column (soilcrete) is formed in situ and the strength of the ground is increased. Jet Grout method preferred to increase the bearing capacity of the soil, reduce settlements and reduce the risk of liquefaction in case of earthquakes in terms of being more economical compared to other soil improvement methods, shorter application time and a wide application range on almost all soils [8].

The principles and application areas, parameters and effects of jet grouts are discussed by Şimşek et al. [5]. The study covers the main principles of jet injection, materials, post-behavior, strengthening effect and cost analysis. Among the parameters; it is stated that factors such as pressure, material, jet diameter and spacing, nozzle angle, time, water content of the soil and volume are decisive. As a result, it is emphasized in the study that, jet injection technology is an effective method for soil improvement and has a wide range of applications.

In the study presented by Ayvaz et al. [9], the performance of jet grouts was measured by applying variable diameter and spacings on different soil types. Jet spacings of 0.5D, D and 2D (D: jet diameter) are assumed and it is shown that the optimum spacing depends on the soil type. It has been suggested to use wider jet ranges, especially on sandy soils. In addition, it has been determined that larger jet diameters increase the performance compared to the different jet diameters used in the experiments.

This study makes an important contribution to help determine the optimum parameters in jet grout applications. According to the results of the research, it has been observed that as the jet spacing increases, the effective region also increases and a wider soil area can be improved. However, since the increase in the jet spacing means a decrease in the diameter of the jet; it has been stated that other factors such as jet diameter, soil properties and application conditions should be taken into account before choosing the optimum jet spacing. These results are important to improve the engineering parameters of the materials used in jet grouting applications and to increase the efficiency of the application.

Sönmez [10] analyzed the effect of jet grout columns on the stability of the deep bearing structure using the finite element method. In the research, by taking the İzmir metro Karşıyaka tunnel project as an example; depending on the strength properties of jet grout columns, improved soil area ratios and settlement types, different analysis combinations were created. Analyzes were made separately for sandy and clayey soil profiles, and Plaxis 2D and 3D finite element programs were used. The results are presented by comparing the obtained diaphragm wall displacements and moments, and the vertical displacements of the natural soil surface and the excavation level are also given.

Algın et al. [11] describes the three-dimensional finite element (3D FE) analysis of the foundation reinforcement process using jet grout method in order to prevent excessive settlement values under shallow foundations from occurring as a result of adjacent foundation excavation. Within the scope of this research, a typical application from the literature was taken as a basis and 3D FE modeling of the reinforcement system with jet grout columns was modeled using image processing technique. Thus, settlement analyzes were made both for the situation before the reinforcement system and for the situation after the reinforcement system, and a comparative analysis was made. As a result of the analysis, it was determined that the settlements were reduced by approximately 80% with jet grout reinforcement.

In the study of Horoz et al. [12] the production of 80 cm diameter and 15 m long jet grout columns placed at 2.20 m intervals in order to solve the expected bearing capacity and settlement problems under a building foundation is discussed. With this construction, the bearing capacity and settlement changes after soil improvement were analyzed with the Plaxis 2D program. According to the numerical modeling results, it has been determined that the settlement values obtained before and after the jet grout columns and soil improvement works under similar loading conditions are approximately 25-23%. These results show that soil improvements with jet grout columns are effective in solving the bearing capacity and settlement problems.

The scope of this work consists of reducing the settlements caused by the structural load in weak soil layers to lower levels with the help of jet grout columns, which is one of the soil improvement methods that frequently used in our country, and to examine the effects of changeable parameters on settlements with the help of numerical analysis. Numerical analyzes were carried out using Plaxis 2D and Plaxis 3D software, which is based on the finite element method and commonly used in determining the behavior of soils. In the analysis, jet grouts are modeled with both single columns and composite region.

The analyzes were repeated by selecting variable parameters for the jet grout length, diameter and spacing. While the three-dimensional analyzes were carried out to compare the effects of the variables in geometry, the two-dimensional analyzes were carried out to observe in which geometric conditions it would be helpful to converge with the three-dimensional and two-dimensional analysis. This inference shows that in some analyzes, by enabling the use of two-dimensional analysis instead of three-dimensional analysis, time and cost savings can be achieved. The most realistic three-dimensional analysis results helped to decide how the number, spacing, diameter and length of the jet grouts affect the settlements and to choose the optimum parameters. At the same time, jet grouts are modeled as both single columns and composite region in three-dimensional analysis. Thus, in three-dimensional analysis, a comparison was made between the analysis results of the composite medium and the individual columns, and it was examined which model reflects the reality. Finally, in order to determine the soft clay effect, two different analyzes were carried out for columns socketed into either normal clay or weak clay in Plaxis 3D.

2. Materials and Methods

2.1. Materials

Sakarya (Adapazarı) soils consist of alluvium transported by the Sakarya River. Although this river had an important role in the formation of urban alluvium in the past, the sedimentation process has been stopped due to the dams built on it and the banks built to prevent flooding. The groundwater level at the near surfaces of the Adapazarı soil is an important factor in the formation of failure types such as liquefaction, decrease in soil strength, foundation base swelling, loss of bearing capacity and settlement and increase in structural damage after the 1999 earthquake [13-15].

With this paper, the samples taken from the boreholes in Sakarya province, Erenler district, Sakarya Commodity Exchange Alancuma Corn Drying Facility site were subjected to soil mechanics tests (Atterberg limit tests, Wash and Dry Sieve analysis, Hydrometer test) in accordance with TS 1900/1 [16] and TS 1900/2 [17] in Sakarya University Geotechnical Laboratory and the soil section created by classifying according to the TS 1500 [18] standard. The soil profile is given in Figure 1. There are silt and sand mixtures with an average thickness of 1.5 m. A gravel layer with an average thickness of 4.80 m is observed under this layer. There is a thick layer of clay at deeper levels. In the near-surface parts, a clay layer is approximately 3.0 m thick and exhibits low to medium plasticity (CL – CI) properties; In the lower parts, it is 11.7 m thick and shows medium-high plasticity (CH – CI) properties.

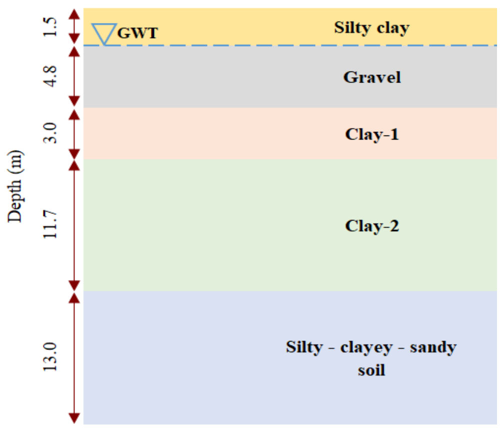

Figure 1. The Adapazari soil section used in Plaxis 2D and 3D analysis

2.2. Methods

Plaxis is a geotechnical engineering program that analyzes deformation and strength problems using the finite element method. A few years after the launch of Plaxis 2D, a 3D program was developed to be used in different application areas of geotechnical engineering and a three-dimensional version is now used [19]. In addition to the features of 2D, Plaxis 3D provides a great advantage in terms of making the analysis results more realistic and accurate. However, instead of solving some analyzes easily with Plaxis 2D, the use of Plaxis 3D, which needs more data and details than Plaxis 2D and therefore requires more computation time, can be disadvantageous.

In this study, the settlements in the aforementioned section were tried to be determined by both 2D and 3D Plaxis. The load that will cause settlement represented by the silo. The analyzes were repeated for both empty and loaded states of the silo and the settlements in the section were calculated. In order to reduce the settlements to allowable levels, the construction of jets has been included. Since it is thought that the number, diameter, spacing and length of the jet grouts will have different effects on settlements, the analyzes were carried out with variable magnitude of these. While the jet grout diameters and spacing are selected according to the common applications in projects, the jet lengths have been adjusted according to the soil into which they will be socketed. Jet grouts placed under the circular silo are modeled in three dimensions both as single columns and as composite region. Since it is not possible to model jet grouts individually in two dimensions, only analyzes of the composite region were carried out. In addition, 2 different analyzes were carried out in 3D analysis in order to evaluate the performance of the jet grout group socketed into the weak soil layer. The characteristics and codes of the analyzes performed are given in Table 1.

Table 1. The identification and code of the analysis of 2D

Model	d (m)	s (m)	L (m)	Silo Loading	Analysis Code
Natural 2D	0.6	1.5	2.5, 10.3, 11.3, 12.3	empty, full	D_2D_0.6d_1.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	0.6	2.0			D_2D_0.6d_2.0s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	0.6	2.5			D_2D_0.6d_2.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	0.8	1.5			D_2D_0.8d_1.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	0.8	2.0			D_2D_0.8d_2.0s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	0.8	2.5			D_2D_0.8d_2.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	1.0	1.5			D_2D_1.0d_1.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	1.0	2.0			D_2D_1.0d_2.0s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	1.0	2.5			D_2D_1.0d_2.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
Composite 2D	0.6	1.5	2.5, 10.3, 11.3, 12.3	empty, full	K_2D_0.6d_1.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	0.6	2.0			K_2D_0.6d_2.0s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	0.6	2.5			K_2D_0.6d_2.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	0.8	1.5			K_2D_0.8d_1.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	0.8	2.0			K_2D_0.8d_2.0s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	0.8	2.5			K_2D_0.8d_2.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	1.0	1.5			K_2D_1.0d_1.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	1.0	2.0			K_2D_1.0d_2.0s_(2.5-10.3-11.3-12.3)L_(empty - full)silo
	1.0	2.5			K_2D_1.0d_2.5s_(2.5-10.3-11.3-12.3)L_(empty - full)silo

Here; D/K implicates natural/composite models, 2D/3D used for indicating dimension of the model, d is the jet grout diameter in meters, s is the spacing in meters, L is the length of the jet grouts in meters, and empty or full silo indicates that the silo is unloaded or loaded with the materials to be stored inside it.

2.2.1. Model parameters

Soils

The properties of the materials used in the models made with the Plaxis were determined as in Table 2 by taking the data obtained from the soil section whose geotechnical parameters were previously determined. In this study, the type of material drained was chosen for all models, since it is aimed to predict long-term settlements.

Table 2. The soil parameters utilized in numeric analysis

Parameter	Silty clay	Gravel	Clay-1	Clay-2	Silty-clayey-sandy soil
Model	Hardening Soil Model - HS				
Type of material	Drained				
ρ_n (kN/m^3)	17.00	20.25	18.30	18.50	19.00
$\rho_{saturated}$ (kN/m^3)	18.00	20.50	18.50	18.70	19.50
e_0	1.18	0.65	0.62	0.59	0.60
E'^{ref}_{50} (kPa)	5000	20000	15000	20000	30000
E'^{ref}_{oed} (kPa)	5000	20000	15000	20000	30000
E'^{ref}_{ur} (kPa)	15000	60000	45000	60000	90000
Power (m)	1.0	0.50	1.00	1.00	1.00
Cohesion, c' (kPa)	5	1	20	25	10
Friction angle, ϕ (°)	21	38	20	20	35
Dilatation angle, ψ (°)	0	8	0	0	5
$R_{interface}$	0.80	0.67	0.80	0.80	0.80
υ_{ur}	0.2	0.2	0.2	0.2	0.2
p^{ref} (kPa)	100	100	100	100	100
$K_{0(NC)}$	0.6416	0.3843	0.658	0.658	0.4264
R_f	0.9	0.9	0.9	0.9	0.9
OCR	2	2	1.8	1.8	1.8
POP (kPa)	-	-	-	-	-

Silo

A silo load was used to represent the load on the soil and analyzes were made for both the empty and the corn filled. The unit weight of corn, which is accepted as storage material, is 7.2 kN/m^3 as indicated in Table 3. Based on the properties of the silo, the loads for each case of silo (loaded and unloaded cases) are calculates as in Table 4.

Table 3. Parameters of silo in the numerical analysis

Silo		Beam		Material (corn)	
d_{ext} (m)	20	Height (m)	2.0	ρ_{corn} (kN/m^3)	7.2
d_{int} (m)	19	Dia. (m)	20	W (kN)	24034.5
Height (m)	12	V (m^3)	50.3		
ρ (kN/m^3)	14.3	ρ (t/m^3)	2.5		
W (kN)	51640	W (kN)	1236		

Here; d_{ext} and d_{int} indicates external and internal diameters of the silo, respectively. ρ indicates the unit weights, W is the total weight, and V is the volume.

Table 4. Calculation of load at foundation level

	Silo (empty)	Silo (loaded)
Foundation dia. (m)		20
Height of silo (m)		12
Total weight (kN)	52876	76910
Net base pressure (kN/m^2)	1648	2404

Raft Foundation

In the analysis, a raft foundation is modeled using the plate element. Linear Elastic (LE) was used as the material model of the foundation. The LE model is based on the assumption that soil behavior obeys Hooke's law and is an isotropic linear elastic material. According to this model, soil behavior is considered as an elastic and the deformation is directly proportional to the applied stress. The basic parameters for the foundation are as in Table 5.

Table 5. Parameters of raft foundation

Foundation	
Model	Lineer Elastic (LE)
ρ (kN/m^3)	25
E (MPa)	30000
ν	0.15
Diameter (m)	20
Thickness (m)	1
Weight (kN/m/m)	25
EA (kN/m)	35000000
EI (kNm^2/m)	2917000

Here; E indicates the modulus of elasticity, v is the poisson ratio and ρ is the unit weight.

Jet Grout

The analyzes made within the scope of the study were carried out to examine the effect of jet grouts under the silo. For this purpose, three-dimensional analyzes were performed using the Plaxis 3D program. In some of the analyses, it was preferred to design the jet grouts as single columns by using the properties indicated in Table 6.

Table 6. Parameters of jet grouts

	Jet Grout
Model	Lineer Elastic (LE)
Diameter (m)	0.6 – 0.8 – 1.0
Length (m)	2.5 – 10.3 – 11.3 – 1.3
ρ (kN/m^3)	16.00
Spacing (m)	1.5 – 2.0 – 2.5
ν	0.3

Variable parameters in the geometry of the columns are: jet grout column diameter (0.6 m, 0.8 m, 1.0 m), jet grout column spacing (1.5 m, 2.0 m, 2.5 m), jet grout column length (2.5 m, 10.3 m, 11.3 m, 12.3 m). In Figure 2, the representation of the jet grout column lengths in the idealized soil profile is given.

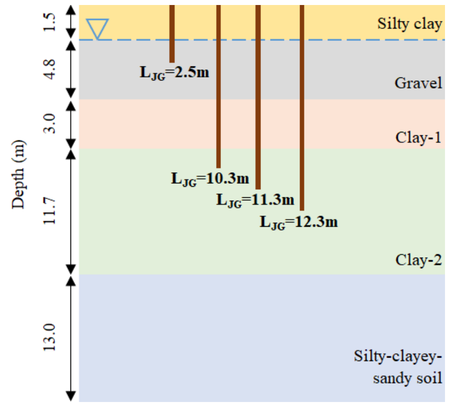

Figure 2. Soil profile and jet grout lengths

Composite Region

In this study, composite region was utilized in both two-dimensional and three-dimensional analysis. The purpose of using composite region is to determine in which geometric conditions the results of three-dimensional analysis can converge to the results of two-dimensional analysis. In addition, it is aimed to check the accuracy of the results by comparing the single column and composite modeling within the three-dimensional analysis.

When transferring the jet grout model to the numeric analysis, the region where the columns are clustered together with soil is considered as the composite region. Composite model parameters are calculated considering the characteristics of the soil and jet grout column. With this approach, the soil improved with jet columns is represented as a single material. Assuming that the improvement will be effective on the entire soil, the strength parameters of the jet grout columns and the soil before the improvement should be calculated.

These calculations are based on the area ratio (a_r). As a result of the calculations, the unit volume weight ($\gamma_{comp.}$), cohesion ($c_{comp.}$), internal friction angle ($\phi_{comp.}$) and deformation modulus ($E_{comp.}$) of the composite material were introduced by Erol and Bayram [20]. In order to calculate the composite region parameters, the properties of the jet grouted soil was taken from the study performed by Racansky et al. [21].

2.2.2. Geometry

Geometric models of variable parameters representing diameter and spacing of jet grout columns in three-dimensional analysis are as presented in Figure 3. Besides, in three-dimensional composite region and single column analysis, the representation of varying column lengths in the models are as shown in Figure 4 and Figure 5.

2.2.3. Mesh

In the analyzes of Plaxis, the boundary conditions must be determined correctly and the area where the FE mesh will be created must be large enough so that the model created can give the closest results to the reality. Brinkgreve [22] stated that in the models made for shallow foundation or filling, a working area should be created at least three times the plan width. In this study, the boundary conditions were determined as 50 m in the horizontal, since the model is axial symmetry in 2D. In 3D analyses, 100 m was chosen in both planes. The resulting FE meshes are given in Figure 5.

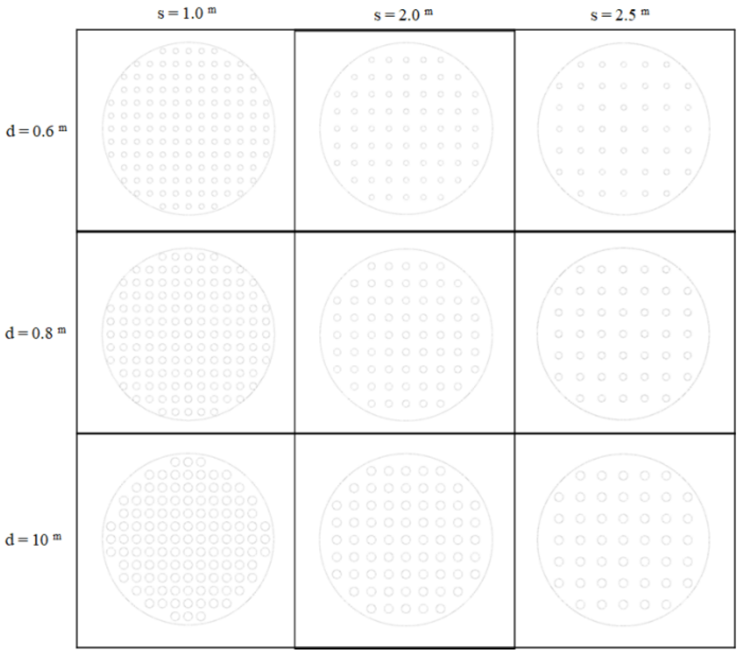

Figure 3. Top views of varying diameters and spacings of single columns in Plaxis 3D

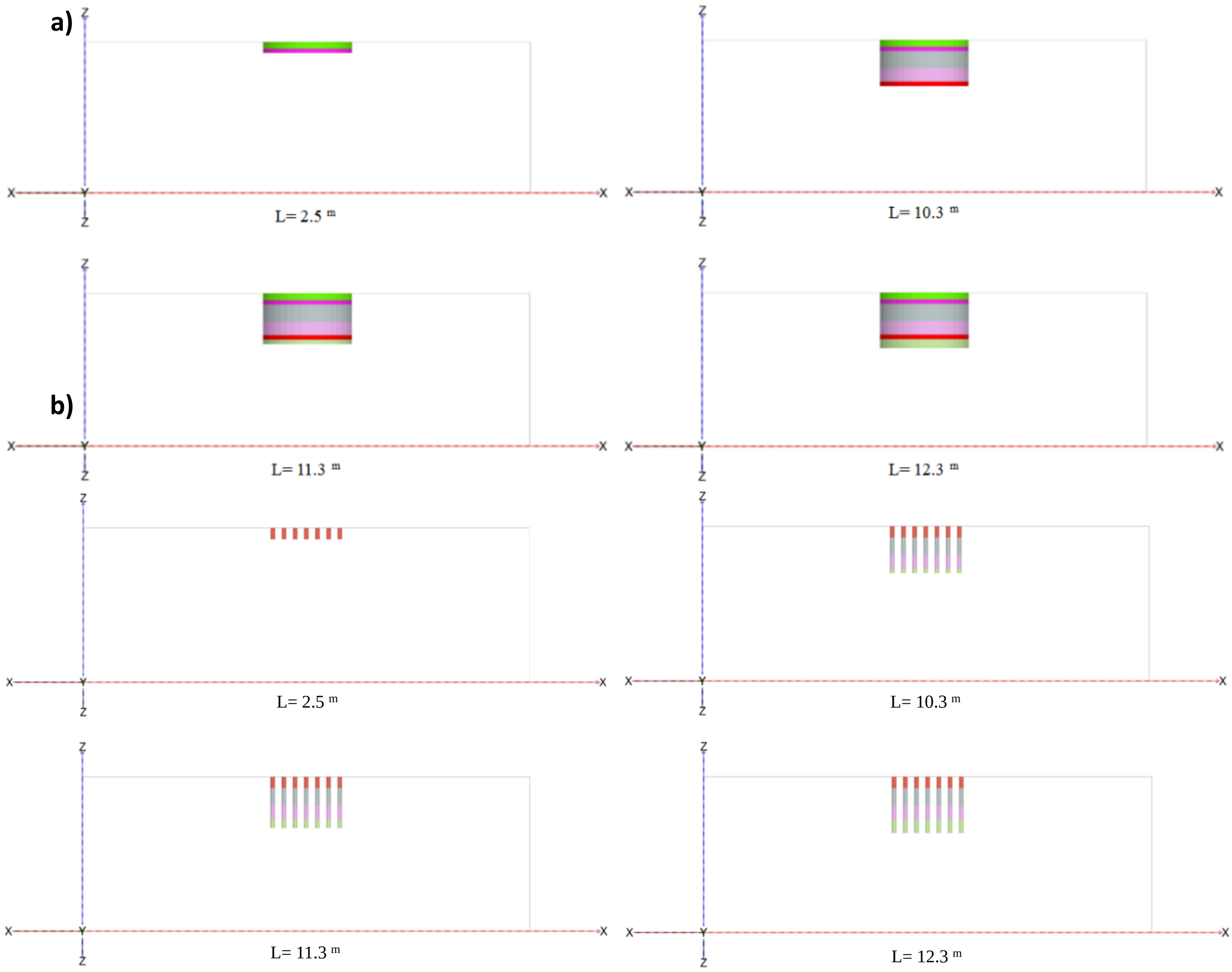

Figure 4. Display of varying column lengths in composite region in Plaxis a) 3D, b) 2D

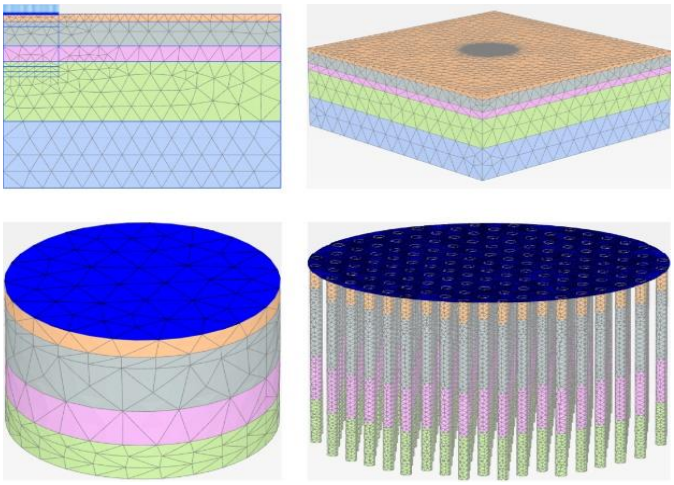

Figure 5. Finite element meshes of Plaxis models

2.2.4. Additional Analysis

In addition, alternative analysis, shown in Fig. 6, was performed to observe the effect of soft clay in two-dimensional as well as in three-dimensions. These analyzes were applied to observe how settlements would be affected by the presence of a weak layer under a stable layer in the soil section. In these analyses, the length of jets was chosen as 7.8 m and analysis were carried out using Plaxis 3D under full silo load (245 kPa). As in the previous analyses, the variables in the geometry of the jet grout column were taken as same as previous. In these analyses, the clay layer in which the jet grout columns were socketed by 7.8 m was weakened and compared with the normal situation. Softened clay parameters are given below:

Cohesion (c'): 5 kPa
Internal friction angle (∅): 20˚
E'^{ref}_{50}: 5000 kPa

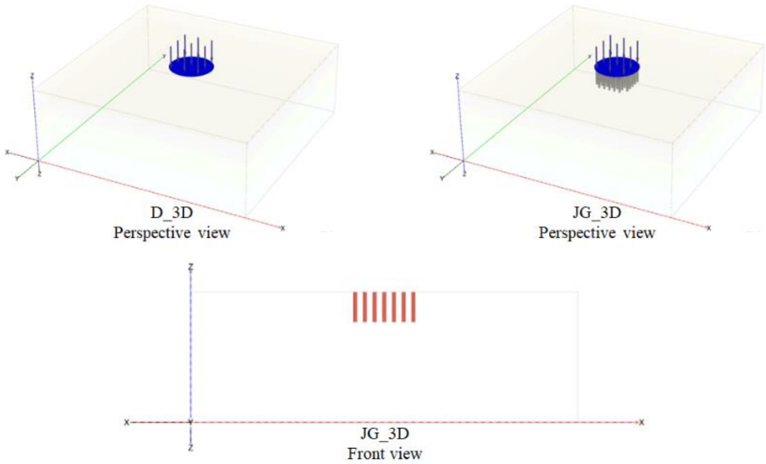

Figure 6. Geometries of additional analysis

3. Results and Discussions

Within the scope of this study, the effects of jet grout construction on the settlements on the soils were examined by numerical analysis methods. Numerical analyzes were carried out with Plaxis 2D and 3D programs, and the effects of parametric variables on the analysis outputs were examined. In this context, analyzes were carried out and compared in the case of an unloaded and loaded construction of a circular silo on a certain soil section, without jet grout groups of different diameters, spacings and lengths, and with jet grouts. With these analyses, optimum diameter, spacing and length will be determined. In addition to these analyzes carried out in Plaxis 3D, analyzes of the soil – jet environment modeled as a composite region are also included. Thus, the differences in modeling the jet grouts as single or composite region can be seen. In order to compare Plaxis 2D and 3D programs in terms of time and cost savings, analyzes consisting of composite region were repeated using 2D. This comparison will answer under which conditions variable jet parameters will necessitate the use of Plaxis 3D or in which cases there will be substantial differences between 2D and 3D.

Finally, additional analyzes were carried out to examine the effect that would occur if the soil layer where the jet grouts were socketed was soft. In this section, the results of the analysis will be given and necessary comparisons will be made. Figure 7 shows the relationship between the vertical settlement values obtained as a result of 3D analysis and the diameter and length of the jet grouts in case the silo is loaded empty or full in case single jet grout columns are constructed. As can be seen from the graphs, the situation of the silo being loaded or unloaded did not make much difference in the relations, it only caused the total settlement value to change. For this reason, it would not be wrong to make basic inferences from the loaded state of the silo.

When the relationship between settlement and diameter is examined (Figure 7 (b)), it is seen that the increasing diameter affects the results to a small extent, and this effect is attenuated as the spacing decreases. In the study conducted by Arjmand and Mamaghanian [23], the column diameters were only increased in the sand lenses within the clay. According to the researchers, increasing the diameter in certain layers, rather than all layers, may be more beneficial. In this study, the minimal effect of diameter on settlement similarly leads to the same conclusion. This means that there is no need to increase the diameter when using low-spaced jets. In addition, as expected, the settlements decreased significantly as the jet grout length increased, but this effect reduced after the socket was provided to the lower clay.

According to Karahan and Sivrikaya [24], increases in jet grout lengths significantly affect bearing capacities. Therefore, the differences observed in settlement within this model are not surprising and have been consistent. The results of the analysis in which the 10.3 m long jet grouts are placed at 2.0 m intervals and the analysis result where the 11.3 m long columns are placed at 2.5 m intervals are exactly the same. Similarly, the curves of 11.3L - 2.0s and 12.3L - 2.5s and 10.3L - 1.5s and 12.3L - 2.0s overlapped. All these cases mean that a 1 unit increase in column lengths can benefit with a half unit increase in spacing.

The relationships given in Figure 7 (d) confirm the linear and inversely proportional relationship between increasing length and settlement. It is concluded from this that the lowest settlements are achieved in the least spaced conditions (1.5 m), but the highest diameter is not the most ideal situation as expected. It has been determined that 0.8 m diameter columns are more ideal and applicable instead of 1.0 m diameter columns. It is thought that this situation may be caused by the group effect in column groups as in piles and the decrease in performance in columns constructed close to each other. In Figure 8, the results of the 3D analyzes are given. The relationships given for the composite models show that if the jet grouts were modeled as a composite region, the change in the spacing didn’t change settlement. However, it was stated previously that the spacing affects settlement more than diameter.

This shows that the composite region should not be recommended in parametric comparisons. When the settlement values were compared, the single jet models gave higher settlements and thus remained on the safer side. In Figure 8 and Figure 9, when the relationships between the results of the 3D and 2D analyzes in which the soil-jet grout region is modeled as composite, there is a slight difference in the settlement values before the improvement. In 2D analyzes, it is determined that the settlement value is higher, and the effect of this situation is reduced in case of improvement. It was determined that the main differences occurred when the composite region was short, and the difference between the analyzes reached the minimum level as the composite region lengthened. For this reason, in cases where the soil - jet grout region will be modeled as composite, it is recommended to use 2D analyzes, which are more practical, less costly and safe, instead of 3D analyses.

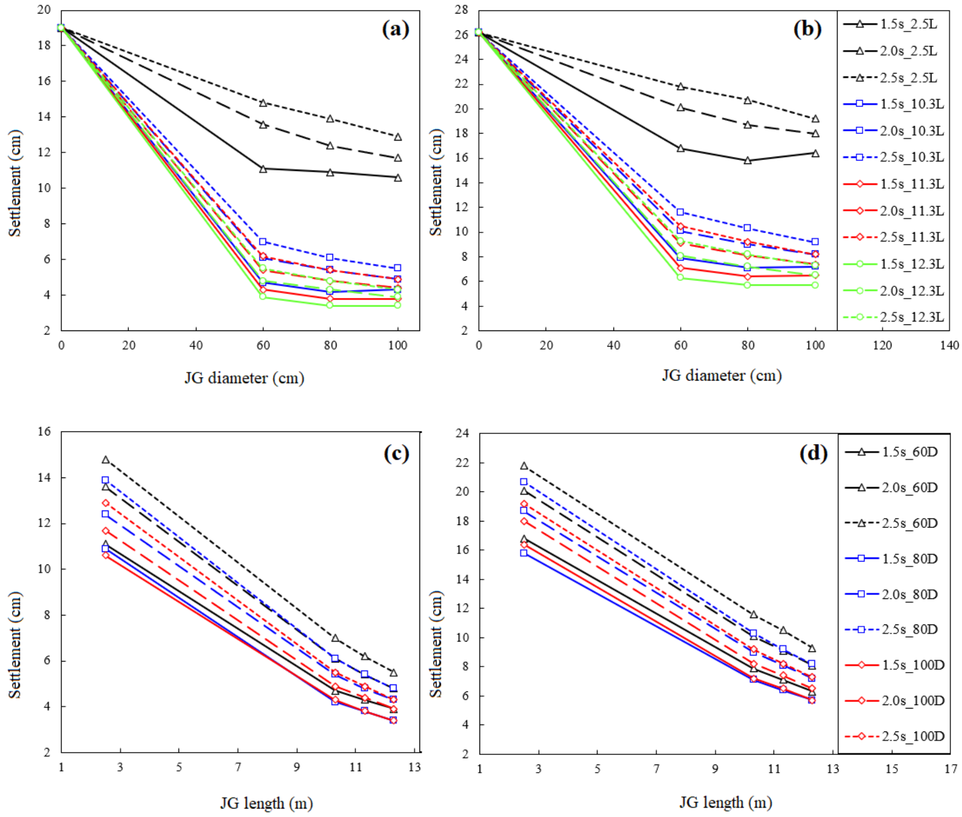

Figure 7. Relationships between (a) Settlement – diameter in 3D with jets when the silo is empty (b) Settlement – diameter in 3D with jets when the silo is full (c) Settlement – length in 3D with jets when the silo is empty (d) Settlement – length in 3D with jets when the silo is full

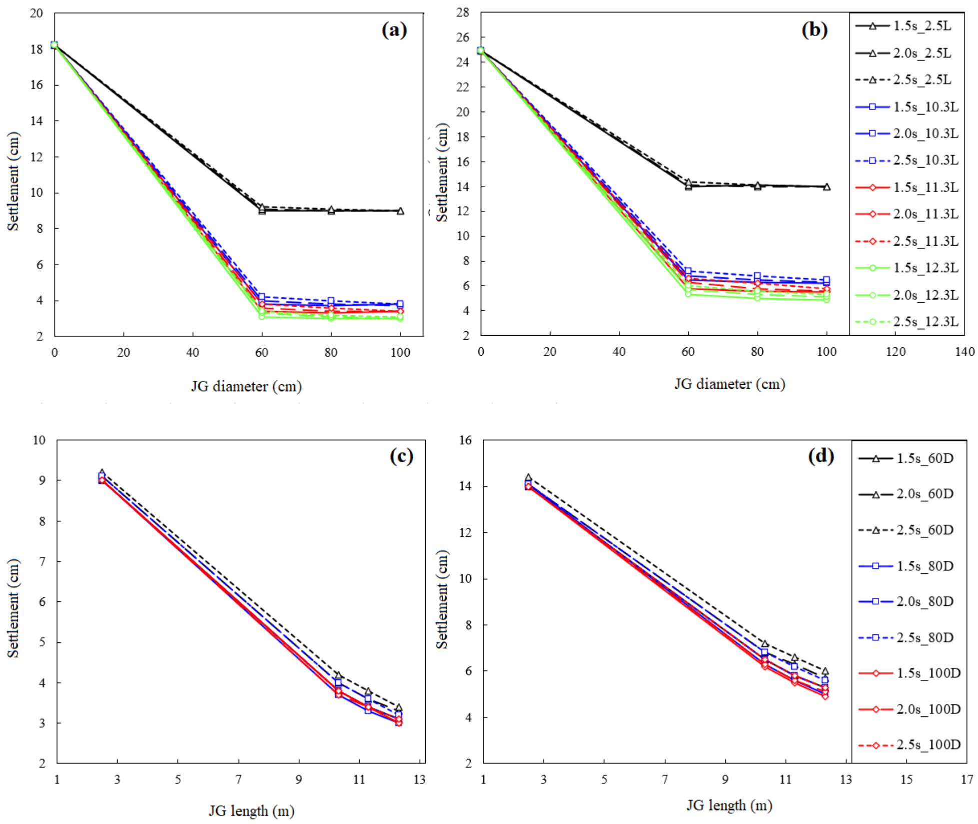

Figure 8. Relationships between (a) Settlement – diameter in composite 3D analysis (empty silo) (b) Settlement – diameter in composite 3D analysis (full silo) (c) Settlement – length in composite 3D analysis (empty silo) (d) Settlement – length in composite 3D analysis (full silo)

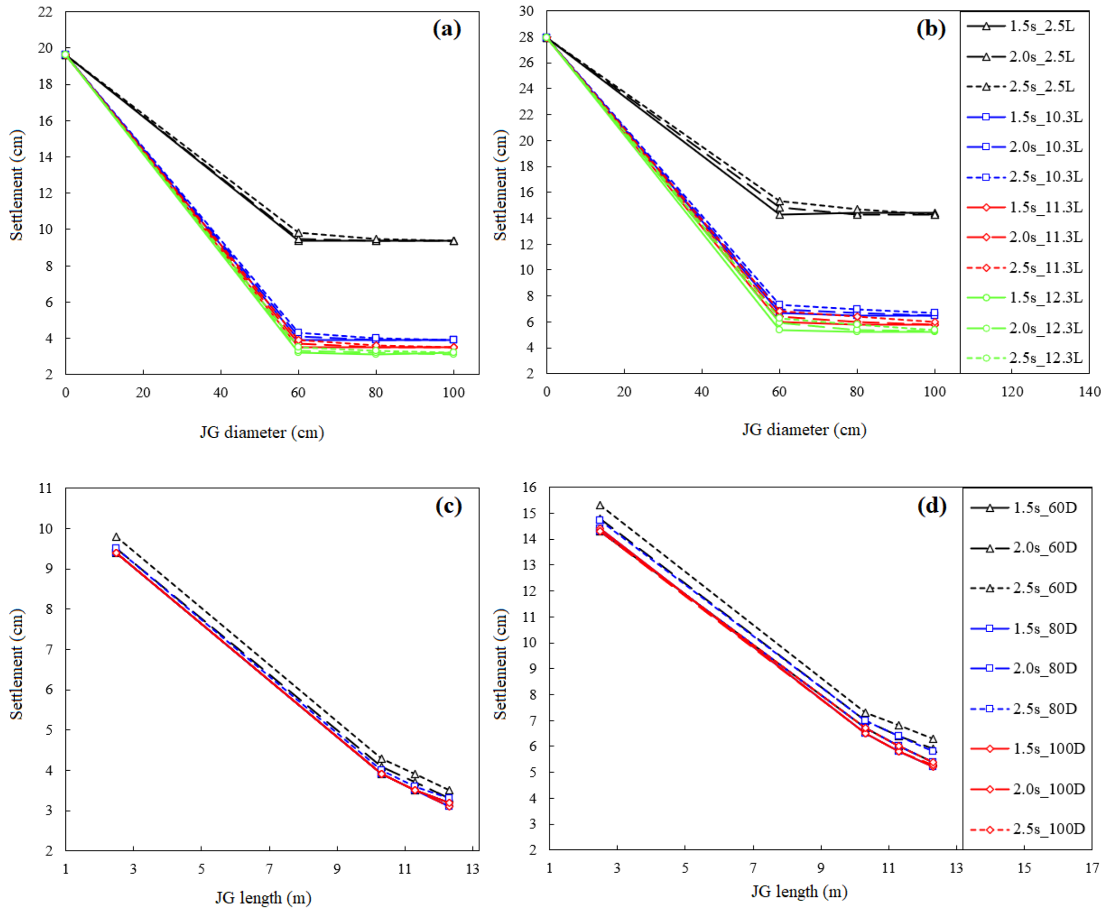

Figure 9. Relationships between (a) Settlement – diameter in composite 2D analysis (empty silo) (b) Settlement – diameter in composite 2D analysis (full silo) (c) Settlement – length in composite 2D analysis (empty silo) (d) Settlement – length in composite 2D analysis (full silo)

In Figure 10, the relationships showing the effect of the soft clay under the strong layer are given in line with the results. From here, increasing settlements draw attention when the clay softens. In addition, the effect of diameter and spacing on settlements was more dominant in soft clay. It seems that the production of 1.5 m spacing columns in soft clay can yield the same results as the 2.5 m spacing columns in normal clay. However, the continuity is broken for a diameter of 1 m. In any case, the large dia. is a disadvantage.

From the explained mechanism, one can be concluded that increasing the spacing instead of the diameter may be more advantageous if the columns with a diameter of 0.6 and 0.8 m are socketed into weak layer. This underscores the importance of spacing in jet grout column applications.

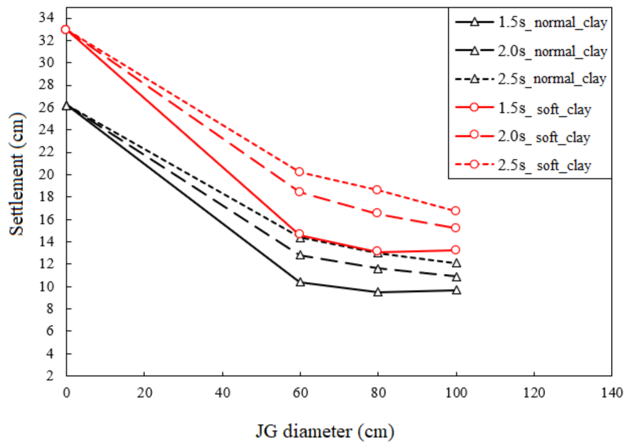

Figure 10. Soft clay effect in jet 3D analysis

4. Conclusions

Within the scope of this paper, the effects of jet grout columns on settlements were investigated by conducting a number of numerical analyzes for the natural and improved conditions of soil loaded with a circular section silo. Numerical analyzes were carried out with the help of Plaxis using the finite element method. In the study, in which 2D and 3D analyzes were carried out, jet grouts were modeled with both single columns and composite region. Single columns and composite region are modeled in Plaxis 3D, and only composite ones are modeled in Plaxis 2D. The main purpose of the analyzes is to examine the effects of variable parameters on settlement values. In this context, the diameter, spacing and length of jet grouts were changed and the analyzes were repeated for the empty (168 kPa) and full (245 kPa) state of the silo. In addition, two different analyzes were carried out and evaluated for normal clay and weak clay-socketed columns in Plaxis 3D to examine the improvement performance in case of softening of the layer where the jet grouts are socketed. The conclusions obtained as a result of the analyzes are as follows;

-As a result of the analyzes carried out in Plaxis 3D, in which the jet grouts are modeled as single columns, it is seen that up to 22% reductions in settlements can be obtained when the longest jet is placed at the lowest intervals. However, it was concluded that the same situation is not valid for diameter. The ideal diameter size was determined as 0.8 m, and it was determined that the frequent construction of columns with diameters above this would cause group effects. It has also been found that the longest jets cause less settlement, and an increase of 1 unit in length can be compensated by a half unit increase in spacing.

-It has been determined that if the jet grouts are modeled as a composite region rather than a single column, the change in the column spacings cannot be reflected in the results, so it does not change the settlement values and becomes ineffective. These results, which are inconsistent with the single column analyzes, where the jet spacing seems to affect settlement more than the diameter, are not reliable in variable ranges. When compared in terms of length, it was determined that lower settlement values were obtained in the composite environment and remained on the unsafe side.

-The model parameters in the 3D analyzes in which the soil - jet grout region is modeled as a composite were also applied in the 2D analyzes and it was seen that higher settlements were obtained. With these analyses, in cases where the improvement is represented by the composite region, it is suggested to use 2D analyzes that are applicable, economical and safer instead of complex and costly 3D analyzes.

-In the additional analysis, in order to observe how the jet grout columns socketed into the soft clay work, the strength parameters of the normal clay with single jet grout column ends in Plaxis 3D were reduced and it was observed that 26% more settlement occurred in this case. If the clay was softened, the change in the spacing and diameter of the jet grouts began to dominate the settlement amount more. It has been determined that the improvement effect is higher in weak clay than in normal clay.

All of the analyzes show that the improvement with jet grout can be represented both with single columns and with the soil-jet composite region in 2D and 3D in numerical analysis. However, considering the parametric variables, it has been determined that the most reliable results can be obtained from models created with single columns in 3D analysis. If the composite region is defined, it has been determined that 2D with almost the same results will be easier instead of 3D analyses. Parametric relationships, on the other hand, showed that the difference in jet spacing was more influential on the results than the change in diameter and length. In addition, it was judged that loading in weak layers may cause higher settlements, but with jet grout construction, improvement may perform better than normal.

Article Information Form

Authors' Contribution

The authors contributed equally to the study.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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