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Numerical analysis of soil strength improved by cement injection

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Abstract

For the safety of buildings and institutions that are established on weak or collapsing soils(sand and clay) characterized by high permeability and continuous subsidence, it has become necessary to improve and strengthen the soil. In this theoretical research, the focus was on the method of soil injection with the jet grout system through modeling models of clay and sandy soils with different geometrical properties dimensions (10 m x10m) based on the PLAXIS 3D 2020 program, load displacement curve was calculated and the soil bearing capacity was calculated on the shallow Foundation with dimensions (1m x1m) by injecting a single jet grout column with (D = 0.5 m) and (L =10 m).

The result of the improvement in bearing capacity was noticeable after injecting the jet grout column for clay soil types (soft, medium, and stiff) as well as for sandy soil types (loose, medium, and dense).

Keywords: Injection , jet grout column, soil improvement, finite element ,3D model.

1. Introduction

In poor soil layers, many ways for reinforcing foundation soils are unavoidable. Jet grouting and stone columns are two of the most widely employed ground improvement stabilization techniques, despite the fact that a number of soil treatment methods are accessible in practice. In the jet-grouting technique, high-pressure water-cement grout is pumped through very small-diameter nozzles. Stone columns that are vertical compacted aggregate columns are built using vibro-replacement processes Croce *et al* **[1]**. By forming a cylindrical soil and cement body, the injected grout treats the subsurface soil. Jet grouting offers an advantage over other stabilization methods and even injection procedures in that it can be used in practically every soil type, from clays to gravels, and it can be used independent of grain size distribution, void ratio, or pore size **[1]**. Figure out (1).

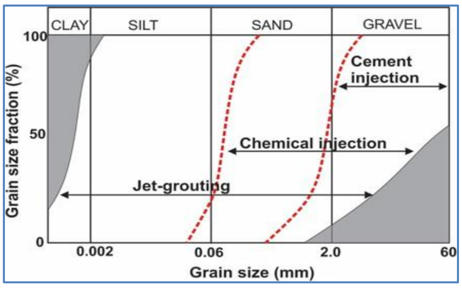


Fig.1 Jet-Grouting Application Limits for Various Soil Types **[2]**

To improve the hydraulic characteristics of granular soils, researchers Akbulut and Saglamer **[3]** investigated the use of these materials in geotechnical engineering and grouting. Suspension grouts of varying percentages were created with Fly ash, clay, and cement are examples of silica fumes. To achieve the required optimum grouting values, the parameters of such cement-based grouts were calculated. The grouts were then forced under pressure into soil samples that are grainy. The outcomes of the study provide useful information on the use of materials in soil treatment and enhancing soil hydraulic conductivity.

Were made in various percentages. The parameters of such cement-based grouts were determined in order to attain the requisite optimal grouting values. The grouts were then pushed into the granular samples of dirt under pressure. The study's findings reveal important information about the usage in soil treatment of materials and increasing the hydraulic conductivity of the soil.

Hassanlourad and Sarrafi **[4]** used chemical grout to test the groutability of sandy soils (sodium silicate). As a control, sand samples with four distinct particle sizes (coarse, medium, fine, and silty sand) and three relative densities (loose 30%, medium 50%, and dens 90%) were injected with three different viscosities of sodium silicate grout (sodium silicate to water ratio) (0.33, 1 and 2). The grout pressure can be changed between 0 and 100 psi (120 to 420 cm).

The experiment's findings show that particle size has the biggest impact on grouting and the other aspects discussed. The probability of grouting soil is lowered by reducing particle size, allowing for the addition of (50 percent) silt to soil, (50 percent) silt, and (50 percent) sand. It is impossible to grout the sample entirely without destroying it.

Injection radius vs. grout pressure for three different grain sizes of sands is shown in Figure (2).

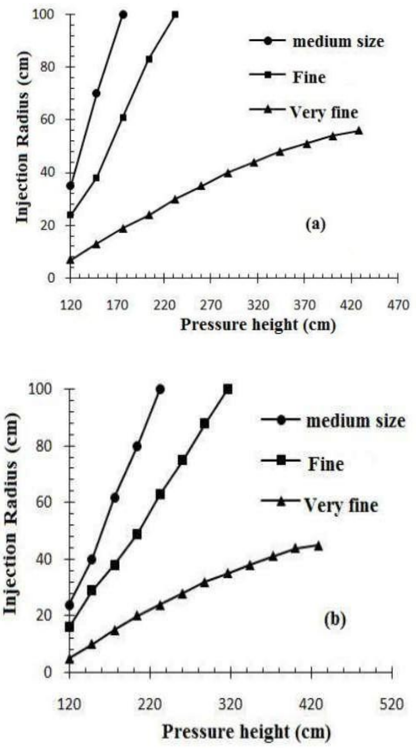


Fig .2 For three sands with various grain sizes, injection radius vs. grout pressure
(a) W/S=1 and Dr=%50, (b) W/S=0.33 and Dr=%50. **[4]**

The 1999 Kocaeli Earthquake (Mw=7.4) hit a Turkish shopping mall whose soils had been stabilized with jet-grout columns. The soil profile on which the shopping center was built is made up of soft, alluvial sands soaked with Clays ranging from soft to medium, loose sands, and silts. The location's groundwater table is 2 meters beneath the surface level. The location is near the earthquake's epicenter and the ruptured fault system. Peak ground accelerationes of 0.24gram were recorded at the site during the earthquake. jet-grout columns are used to handle soft and loose sediments. were employed to improve the site, as indicated in figure (3).

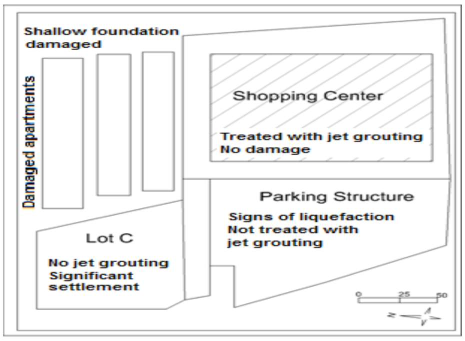


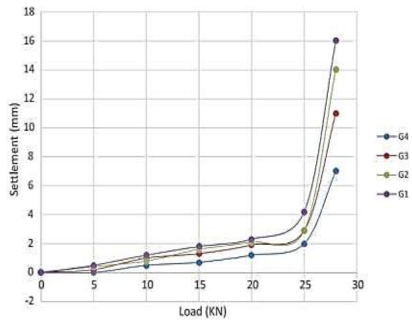
Fig.3 Site plan of shopping center area showing improved area and unimproved areas **[5]**

The main purpose of the site's soil alteration aimed to improve the foundation systems' carrying capacity as well as decrease the possibility for liquefaction of a 1–3 m thick silty sand layer that ran the length of the site. The jet grouting was not finished when the earthquake happened. Following the earthquake, measurements at the site indicated that the performance of upgraded and unimproved parts differed significantly. Settlements of up to 10 centimeters caused by liquefaction were found in unimproved landscapes and constructed buildings Martin et al **[5]** .

Khan *et al* **[6]** conducted a series of studies to investigate sandy soil and its physicochemical qualities, including shear strength, settlement reduction, and bearing capacity. They are improved after grouting materials like as cement are used.

The UTM (universal test machine) performs a plate load test on grouted soil with a 6-inch diameter plate, a mold filled with sand soil, and grouted by four PVC pipes, each with 36 perforated holes surrounded by sandy dirt. To inject soil, four different Water cement ratios ranging from 7:1 to 4:1 were utilized in the experiments.

The result of plate load test shown in Figure (4) below



Notation	Water	Cement
G1	7	1
G2	6	1
G3	5	1
G4	4	1

Fig .4 (a) Plate load tests with grouting in various Combinations
(b) Grout proportions and notations for mixing **[6]**

As a result, G4 was discovered to be the best cement grout mixture for coastal and desert construction on sandy soils, with the lowest settlement and highest bearing capacity.

In the following paragraph, it was explained how to model clay and sand models and represent them in the program PLAXIS 3D **.**

2. Modeling

2.1 General

Brinkgreve **[7]** PLAXIS 3D is a finite element program that works in three dimensions. for analyzing deformation, in geotechnical engineering, stability and groundwater flow are important considerations. It's part of the PLAXIS product series, which includes a number of programs with finite elements that are widely used in geotechnical engineering and design around the world. The Dutch Ministry of Public Works and Water Management initiated PLAXIS as a project at Delft University of Technology in 1987 (Rijkswaterstaat). The main goal was to create a simple 2D finite element code for river embankment an examination of the delicate soils of the Dutch low_lands. In the following years, PLAXIS was broadened to cover most other disciplines of engineering geotechnical. As a result of the company's ever-increasing activities. In 1993, the PLAXIS Company was founded.

2.2 Finite Elements and Nodes

PLAXIS program contains many types of elements and nodes to accurately deal with geotechnical problems Brinkgreve **[7]**, the types employed in the current studies are listed in the following paragraphs.

2.2.1 Soil Element

The basic soil elements of the 3D finite element mesh are 10-node tetrahedral elements. Figure (5). Three local coordinates are available for tetrahedral elements .

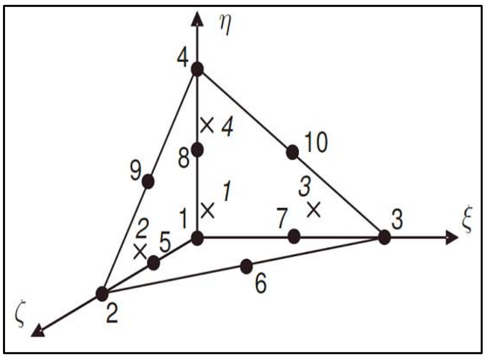


Fig.5 3D Soil Elements (10-node tetrahedrons) **[7]**

The soil elements use to represent soil model size of (10 m × 10 m × 20 m) (x-y-z axis) and represent jet grout columns with diameter 0.5 m, length 10 m was used for the analysis.

The representation of the columns of jet grout and the soil they're in was based on the as a first approximation of soil, the Mohr-Coulomb model MC linear elastic perfectly-plastic is utilized behavior generally.

2.2.2 Plate Elements

Plates are used for structural purposes components used to model two-dimensional ground structures with strong flexural rigidity (bending stiffness). Plates are made up of Six degrees of freedom per node in a six-node triangular plate element: three translational and three rotational (ux, uy and uz). Jet grout column under the shallow foundations were replicated using plate pieces (1m x 1m). A linear elastic model was used to model the footing (LE).

2.3 Input Program

To do an analysis based on finite elements with the PLAXIS 3D tool, a client must first create a three-dimensional model of geometry that includes various components, such as points, lines, surfaces, and volumes, as well as item attributes as well as boundary conditions. It's completed on the initial two tab pages of the input application (geometry modes). The computation phases' mesh creation and definition is completed throughout the previous three -tab sheets (forms of computation) of the program of input. The jet grout pile and its surroundings were represented using the MC model.

This model requires many soil parameters such as the internal friction angle (φ) as well as angle of dilation (Ψ), the cohesion (C), the modulus of elasticity (E_s) and Poisson's ratio (ν).

The footing is defined as the linear elastic model and (1m×1m) dimensions of the model were adopted in the program for this study; each node has ten elements, and these elements have tetrahedral that have been implemented. In addition, soil parameters are entered for each layer of soil. Tables (1) ,(2)and (3) show the characteristics of the materials used to make the program models.

Table 1 Input Properties of Material (jet grout+ footing).

Material	Jet grout column*	footing (concrete)
Model name	Mohr-Coulomb	Linear- Elastic
γ_{sat}(kN/m^3)	21.5	25
γ_{unsat}(kN/m^3)	21.5	25
c (kPa)	2700	-
$\phi°$	32.5	-
E (kPa)	10×10^6	25×10^6
ν	0.15	0.15
$\psi° = (\phi - 30)$	2.5	-

*After Tschuchnigg, 2008

Table 2 Input Properties of Material (clay types)

Material	soft	medium - stiff
Model name	Mohr-Coulomb	Mohr-Coulomb
$\gamma_{sat}(\text{kN}/m^3)$	22.5	22.9-22.3
$\gamma_{unsat}(\text{kN}/m^3)$	17.7	18.5-19.3
c (kPa)	19	65-84
$\phi°$	0	0
E (kPa)	22×10^3	$(51\text{-}77.6) \times 10^3$
ν	0.35	0.25-0.25
$\psi° = (\phi - 30)$	-	-

Table 3 Input Properties of Material (sand types)

Material	loose†	medium† - dense†
Model name	Mohr-Coulomb	Mohr-Coulomb
$\gamma_{sat}(\text{kN}/m^3)$	20	20-22
$\gamma_{unsat}(\text{kN}/m^3)$	18	18-20
c (kPa)	0	0
$\phi°$	30	38-43
E (kPa)	15×10^3	$(30\text{-}60) \times 10^3$
ν	0.27	0.27-0.25
$\psi° = (\phi - 30)$	0	8-13

†After Budhu, 2011

2.4 Mesh Generation

PLAXIS 3D employs an unstructured mesh that is automatically created and can be adjusted globally or locally. PLAXIS 3D has five mesh density settings, ranging from coarse to fine. For this study, a medium mesh size was used. The mesh is improved when jet grout columns are subjected to high pressures and strains.

2.5 Calculation Phases

Calculation can be performed after the generation of a finite element model, and the calculation type must be defined in this phase. Finite element calculations can be broken down into numerous stages. Each computation phase is associated with a specific loading or building stage. In the Staged construction mode, you can specify the construction stages.

1. Initial stress generation
2. phase 1: jet grout pile construction.
3. phase 2: foundation construction.
4. phase 3: loading (displacement control).

3. Results and Discussions

Foundation bearing results for clay and sand models obtained from the PLAXIS3D program before and after cement column injection are shown in the tables(4)and(5) below.

Table 4 The results of clay model obtained from the PLAXIS3D program.

Material	Clay	Clay
Type	soft	medium - stiff
Unimproved kN	275	1010 - 1495
Improved kN	910	2750- 3090
Increase %	230	172-106

Table 5 The results of sand model obtained from the PLAXIS3D program.

Material	Sand	Sand
Type	loose	medium - dense
Unimproved kN	150	510 - 1120
Improved kN	600	1280 - 2580
Increase %	300	150-129

The deformed mesh for the two soil layers model and the base drop, as shown in the figure(6).

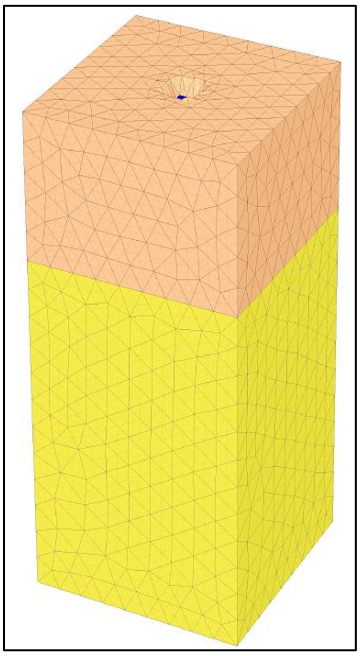


Fig.6 Deformed Mesh of the Two Soil Layers Model

The relationship between the three categories of clay soils is depicted in Figure (7) (soft, medium and stiff) and the amount of improvement that occurred after injecting the jet grout column, and the result of the improvement was very good for the soft clay soils (230%).

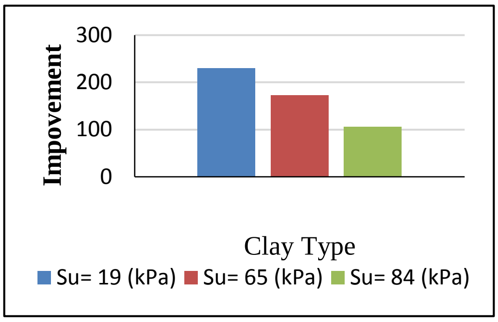


Fig .7 Improvement percent of the clayey soil

The relationship among the three categories of sandy soils is illustrated in Figure (8) (loose, medium and dense) and the amount of improvement that occurred after injecting the jet grout column, and the result of the improvement was very good for the loose sand soils (300%)**.**

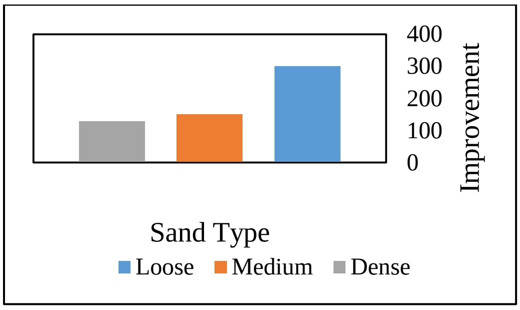


Fig .8 Improvement percent of the Sandy soil

Conclusions

In this paper, the application Plaxis 3D was utilized model the soil layers (sand and clay) and the improvement of this soil was done by injecting the soil by the cement column.

The main conclusion remarks can be summarized as follows:

1.We conclude the noticeable improvement in the ultimate bearing capacity of soft soil with jet grout column and without grout column by 230%.

2.When loose sand soil is treated with grouting materials such as cement, the mechanical qualities improve significantly by300%

3. When taking different types of clay (soft, medium, and stiff) as well as sand (loose, medium, and dense) and representing them with PLAXIS 3D program, a good comparison is obtained in improving the bearing of the foundation .

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