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Modelling effects of soil improvement methods on the deformations induced earthquakes

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***Abstract*— Earthquakes can cause soil deformations if there is no prevention and improvement. Failures occur as a result of intolerable deformations. Stone columns and Jet-Grouting methods are mostly used in Eskisehir, Turkey. In this study, the modeling studies of soil deformations are presented for improvement types and different earthquake effects. Models are performed by using Plaxis 2D software dynamic module and the results are compered. As a result, soil improvement techniques are needed and chosen carefully because some methods can be insufficient to prevent deformations caused by strong earthquakes.**

***Keywords*—deformations, earthquakes, plaxis, stone column, jet-grout.**

I. Introduction

Earthquake loads affect the soils and structures. Earthquakes can be defined as ground motions due to the breakages in the ground mantle [1]. Seismic waves occurred and shakes the ground surface. Different theories are presented to explain earthquake existing mechanism but the last and most accepted one is tectonic plate theory. According to this theory; plates are moved continuously and earthquakes occurred at the border lines. Earthquakes are identified with some parameters such as hypocenter, epicenter, hypo central distance, earthquake intensity and earthquake magnitude [1]. Previous records showed that all earthquakes have different characteristics.

Deformations caused by earthquakes can be said as follows: surface rupture, regional subsidence, slope movements, volumetric compression, liquefaction, settlement and bearing capacity failures, horizontal expansions and sand volcanos [2]. Liquefaction is the most common earthquake damage and causes settlement and bearing capacity failures because of shear strength loss and punching effect of the superstructure.

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Dynamic response of the soils can be determined by laboratory, field and model tests. Resonant column test, cyclic triaxial test, cyclic simple shear test and bender element test are examples of the laboratory tests. Field tests can be said as; standard penetration test (SPT), cone penetration test (CPT), pressuremeter, cross-hole test, down-hole test and other seismic tests [3]. Developments of the computer technology, software are started to modeling dynamic response of the soils.

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 [4]. Mostly chosen improvement methods are; compaction, mixing, grouting, stone columns, drains and dewatering.

Jet-Grouting method is cement water injection with high pressure and obtaining a soilcrete that has high modulus [5]. Example screen of the Jet-Grout application is given in "Fig. 1". Stone column method is a type of vibro-flotation and densification the soil by vibration and adding gravel with compaction [6]. The application steps of the stone columns is given in "Fig. 2".

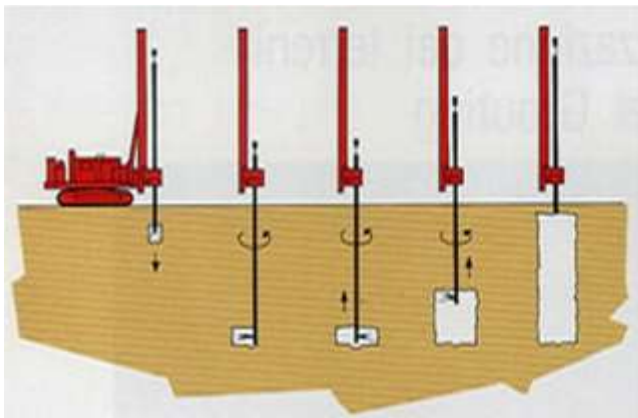

Figure 1. Jet-Grout application [5].

Gratchev et all. [7] performed laboratory tests on the clay type of soil samples. Wichtman et all. [8] determined deformations under dynamic loading for sandy soils. Bird et all. [9] presented a new methodology to identify structural damages induced liquefaction. Yuan and Tadunbu [10] improved a numerical method to determine soil deformations induced dynamic loads by using finite element, Biot and Lagrangian formulas.

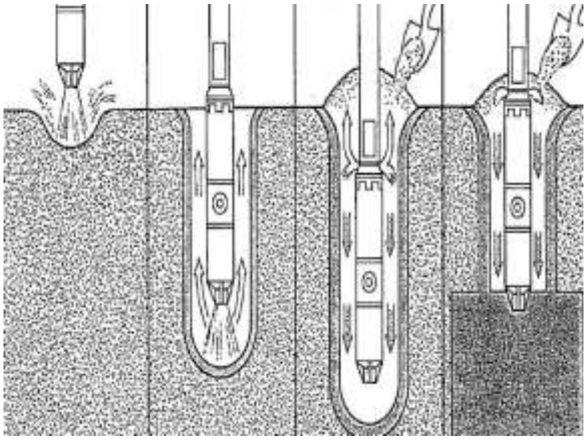

Figure 2. Stone column application [6].

In this study, the modeling studies of soil deformations are presented. Improvement methods used commonly in Eskisehir, Turkey are compared under different earthquake effects. Soil deformations are found by using Plaxis 2D and the results are discussed.

II. Modelling and Method

In this study, Plaxis 2D software was performed for the analyses. Plaxis is a commercially available finite element program and can solve the problems with 2D or 3D analysis, separately [11]. The software is used commonly for the deformation and stability analysis and can make numerical solutions based on the finite element method. For this study, 2D analysis was chosen and example screen of the Plaxis is given in "Fig. 3".

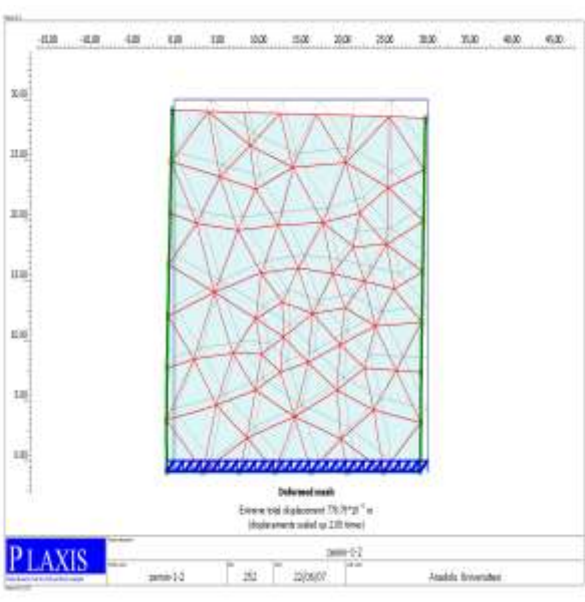

Figure 3. Example screen of the Plaxis dynamic.

Eskisehir is a city of Turkey and located in the second degree earthquake zone and affected by two fault zone [3]. The first one is North Anatolian fault and gain popularly after the 1999 Kocaeli Earthquake (Mw=7.4). The other one is Eskisehir fault and has the greatest earthquake record Mw=6.4 in 1956 [12]. Distance of the the faults from Eskisehir city center are 80 km. and 10 km.

Plaxis can perform with ".smc" data file for earthquakes but no record is exist about 1999 Kocaeli Earthquake and 1956 Eskisehir Earthquake. 2006 Hawaii Earthquake (Mw=6.0) and 2005 Northern California Earthquake (Mw=7.1) data files are used considering the similarities at the fault mechanisms. Strong ground motion records were taken from United States Geological Survey's (USGS) Earthquake Hazards Program official web site. Some parameters of the Earthquakes are given in "Table 1".

TABLE I. SOME PARAMETERS OF THE EARTHQUAKES

2005 Northern California Earthquake	
Magnitude	7,1
Epicentral distance	132,90 km
Peak value	5,27 cm/s^2
2006 Hawaii Earthquake	
Magnitude	6,0
Epicentral distance	63,20 km
Peak value	85,70 cm/s^2

Eskisehir has generally loose alluvial soil. The soil shows insufficient bearing capacity at first 7 meters deep and getting denser with the deep. Soil parameters are determined from literature and previous soil exploration reports for the area in the models. All soil profiles were considered fully saturated in the models. Some soil parameters were given in "Table 2".

TABLE II. SOME PARAMETERS OF THE SOIL MODELS

Soil Type	Silty Sand
Material Type	Mohr- Coulomb
γ_{dry} (kN/m^3)	18,00
γ_{Sat} (kN/m^3)	18,50
E (kN/m^2)	7500
c (kN/m^2)	1,0
ϕ (°)	16

Model designed for 4-storey and 8-storey buildings that can be seen ordinarily in the city center. Jet-grout and stone columns are designed as the real application in the Eskisehir. Especially, stone columns are constructed quite different from the literature. Stone column constructed as follows; firstly drilling a hole by auger, adding gravel to hole and compacting by a hammer. But this method gains no densification surrounding of the column.

In this study, stone columns and jet-grouts are considered as 0,60 cm in diameter and 6 meters in length and the spacing between the columns are 2 meters. The plan of an example model is given in "Fig. 4". Elasticity models of the columns are assumed as 250000 kN/m^2 for jet-grouts and 75000 kN/m^2 for stone columns.

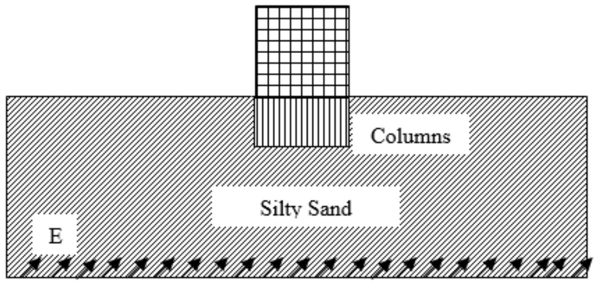

Figure 4. Example screen of the model.

III. Results

Plaxis 2D dynamic module is performed for the model calculations. Deformations were compared and maximum deformations are given in "Table 3".

TABLE III. MAXIMUM DEFORMATIONS OF THE MODELS

2005 Northern California Earthquake		
	4- Storey	8-Storey
No Improvement	48 cm	90 cm
With Jet-Grout	17 cm	33 cm
With Stone Columns	29 cm	47 cm
2006 Hawaii Earthquake		
No Improvement	29 cm	57 cm
With Jet-Grout	11 cm	23 cm
With Stone Columns	19 cm	38 cm

The results of the analyses show that; deformation increases with magnitude of earthquakes. Heavy buildings are much affected from earthquake loads. The maximum deformations are occurred in the models with no improvements. The models having jet-grout improvement shows less deformations than the models having stone columns.

Jet-grout method is more effective to prevent deformations induced earthquake loads than stone column method but non tolerable deformations can occur under great magnitudes and loads. Stone column shows insufficient performance under earthquake effects with application method in Eskisehir.

IV. Conclusions

Plaxis 2D dynamic module is performed to determine deformations induced earthquakes. Stone column and Jet-grout which are mostly chosen soil improvement applications in Eskişehir, Turkey are modeled and analyzed. Results show that, earthquake loads can create different deformations due to local soil conditions. It can be seen that soil improvements decrease deformations. On the other hand, stone column method in Eskisehir needs a new application strategy. Especially, using vibration can improve elasticity modulus of the columns and densification of the soil between the columns. Thus it can be a preventable method to deformations induced earthquake loads, otherwise this method cause negative results under heavy buildings and bigger earthquakes. And also jet-grout application shows good results in the models but it needs raising the diameter and lowering the spacing between the columns under heavy loads and strong earthquakes. This is a model study and needs further research to simulate realistic local soil properties. Dynamic laboratory tests and in-site tests should be performed to determine identify behavior of soils and improvement methods under earthquake loads.

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