Effect of Injection Pressure Due to Micropile Installation on Relative Density of Sand

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***Abstract*— One of the most challenging issues in geotechnic engineering is injection. This paper intends to model injection due to micropile installation in saturated sandy soil, using finite element code (FEM) and then compare the results of the program with the results of site investigations. Finally the model was developed by some changes in spacing/micropile diameter (3m, 1.6m and 0.8m) and injection pressure (1cm, 2.5cm, 5cm, 10cm and 15cm). The outcome of these endeavour is expressed in the form of graghs based on relative density to compare with the relative densities of standard penetration test (SPT) results. Results show that by increasing injection pressure (boundry displacement), more modification takes place and what far micropiles are, modification requires more pressure to be applied. Also, the results of computer simulation and site investigations seems to be in a good agreement together. Because the evaluation of bearing capacity and settlement specification of soils requires some SPT data from every depth, and this process is too costly to do for medium projects, numerical modeling can be a useful method to lessen the costs of a project performance.**

***Keywords*— numerical simulation, sand, micropile, injection**

I. INTRODUCTION

Micropile is a multipurpose system combined two kind of improvement (stabilization and reinforcement) togheter. This system is very effective in many applications of modification to increase the bearing capacity and decrease the settlement in retrofitting existing foundations and stabilizing slopes by supplying lateral strength. Micropiles are used in some cases that ground has small mechanical strength or the amount of clay or silt or soft sand and every organic material is too high to construct classic and ordinary foundations.

Design methodology and implementation of this technique are described in FHWA-NHI-05-039 (2005) [1]. Specifications of micropile materials have given in ASTM-C150 [2] for Portland cement, ASTM-C595 [3] for slurry cement and ASTM-A615 [4] for rebars. Most of the researches on micropile accords to modification of gravitational bearing capacity and controlling settlement [5-13]. This led to definition of problem, whether the piles was loaded directly or indirectly considering group effect. In two past years the lateral strength of micropiles mobilized to supply stability of slopes have been investigated [14-21]. There are maximum and minimum space between micropiles to realize the single or group function of them. According to FHWA, for pressure grouted micropiles (type B, C and D) typical grouted diameter of 200 mm and minimum spacing of 0.75 m to 1 m is recomanded. D.A. Bruce et al. (2004) declared maximum and minimum space between micropiles for in line pattern are respectively 6d to 7d and 3d where d is the diameter of micro pile [22]. Whereas Jim Sheahan (2009) states minimum spacing of micropiles is 30 inches or 3d, whichever is greater [23]. Two concept of design influence micropiles spacing. one is improvement of bearing capacity and settlement and the other is slope stabilization. As long as the goal of design originates from type 1, micropile designs as a single pile however work in group. When designer concentrates on slope stabilization, group function of micropiles should be considered. Frictional resistance in micropile-soil interface and associated group of micropiles are the main mechanism of improvement. Few researches are available from recent studies, evaluating the effect of injection in reinforcement of soils by micropiles [24-26].

There are some questions about maximum diameter of grout penetration in every soils. It seems to depend on many factors such as viscosity of grout, grading and classification of soil, injection pressure, relative density of soil, workability and water cement ratio (WCR) of grout for cement grouts and the time of gelation for chemical grouts, void ratio and permeability of soil, cohesive or granular nature of soil. Teunissen (2006), simulated a tunnel in 2d finite element program and exerted a radius pressure, as ordinary injection pressure used in naliling processes, perpendicular to the lining, and monitored the maximum total displacement around the tunnel to show the maximum radius of jointed rock, has been influenced by grouting [27]. Adam Bezuijen (2010) gathered some equations from earlier literatures to find the maximum penetration of grout around nails and the gradian of grout propagation by keeping out of the injection center in jointed rocks. He emphasized that the results of these formulations are underestimated [28]. Hassanlourad (2014), investigated sandy soils groutability by a kind of chemical grout made up of sodium silicate. He made some samples with 4cm in diameter and 100cm in height and injected in direction perpendicular to the direction of soil layers, poured and compressed in three relative densities (loose, medium and dens) and four different particle size (coarse, medium, fine and silty sand) by three different viscosities of sodium silicate (water to sodium silicate ratio). Tests results showed that, particle size has the greatest effect on the grouting and the other mentioned parameters depend on this factor. Reducing of particle size decreases the grouting potential of soil, so that adding 50 % silt to soil (50 % silt and 50 % sand) impossible to fully grouting of the sample without fracturing the sample. In addition for a pomp pressure of 1.2 MPa, water to sodium silicate ratio of 0.33, the maximium penetration of grout was obtained 19cm. In the same situation by water to sodium silicate ratio of 0.5 and relative density 0.5, the maximum penetration was estimated 27cm. This amount can be decrease by increasing in relative density (D_r) [29]. Eisa (2008); chang (2004) and Younes (2008) showed that it was rather difficult to create fractures in a sandy subsoil especially when the pressure conditions in the laboratory model are the same as the pressure conditions in the field [30-32]. In most cases the grout injected resulted in an irregular grout body ("potato-shaped"), but not in fractures. These results are different from the results of laboratory tests where epoxy was injected in kaolin clay that was normally consolidated to 140 kPa [33]. These tests found relatively thin fractures. The comparison is not fair, because Au et al. (2003) and Komiya et al. (2001) showed that, using a cement-bentonite grout, the shape of the fractures depends on the WCR ratio of the grout and the over-consolidation ratio (OCR) of the clay [33, 34]. Masoudi (2008) performed an analytical and numerical modeling of injection in jointed rocks base on experimental studies about the site of seimareh dam. He founded that the model released by Lombardi (1996) for determination of grouting in jointed rocks, has the best accurate to experimental and numerical studies. Then showed the maximum diameter of grout penetration. He said for a pomp pressure of 1MPa the maximum influence of injenction is about 7.7 m and for 4MPa is 15.5m [35].

According to FHWA maximium distance from the center of injection is between 125mm to 250mm that differ for every kinds of soils. AASHTO classification system method of installation of TITAN micropiles states the minimum grout cover of casing should be 20mm and minimum diameter of slurry occupied around casing are estimated for every kind of soils. Based on actual tests and experiences using the CTS/IBO TITAN system installed with appropriate drilling and grouting equipment, minimum diameter of grout body (D) outcamed as follows:

$$\begin{array}{ll} D \geq 2d & \text{for medium and course gravel} \\ \quad 1.5d & \text{for sand and gravelly sand} \\ \quad 1.4d & \text{for cohesive soils} \\ \quad 1d & \text{for weathered rock,} \end{array}$$

where d is drill diameter [36].

This paper intends to model micropile installation in saturated sandy soil that found to cover extensive areas in the low altitude strip of coastal land next to the Caspian Sea in the North of Iran, using finite element code and then compare the results of program with that one has been obtained in the site investigations. Since the relative density of the soil in the area is low and there is a possibility of liquefaction mechanism, the micropile injection was presented as an alternative method in this work to improve the bearing capacity and liquefaction remediation of the soil deposit. This project was carried out by Naeini and Ziaei (2012). In this paper the finite element code has been validated with the informations given from the site investigations (the properties of soil before and after micropiles installation in term of relative density) and develop the model by some changes in spacing/micro pile diameter and injection pressure. The outcome of these endeavour is expressed in the form of graghs that shows track and field experiments are a good match with numerical trials.

Because the evaluation of liquefaction has a direct relationship with reltive density of soil layers, and also making a very costly process to do SPT test and sampling, it seems necessary to do numerical simulation of this test and validate by the data extracted from SPT test in site before installation of micropiles. It can be a useful method to lessen the cost of a project performance.

II. NUMERICAL MODELING

A. Site Characterization

Naeini and Ziaei (2012) had determined the soil conditions at the experimental test site from a geotechnical site investigation comprised of both in-situ and laboratory tests. To identify soil layers three boreholes had been drilled using a rotary drilling machine to depths of 30m in specified locations. During drilling operations, standard penetration tests had been carried out. The undisturbed and disturbed samples had been taken at various depths in order to classify subsurface soils and determine their physical, chemical and mechanical characteristics using laboratory tests [37].

The piles have been drilled and grouted within 5 to 12 inches diameter and one or multi reinforcer element in the center of borehole to resist the bulk of the design load, nominates micropiles. Namely micropiles are such a cylinder piles droven by a vibratory kobe tube and grouted by an injection system that provides various pomp pressure (1MPa to 8MPa) to pomp cement slurry in several steps. The micropiles adopted consisted of steel porous tubes with 75 mm outer and 68 mm inner diameter. Micropile reinforcement consists of a single reinforcing bar with surrounding grout Standard reinforcing steel conforming to ASTM-A615 with yield strength of 420 MPa is used. Because of saturated condition a cement-water grout mix with a W/C ratio about 0.5 had been used in this project. Plasticizer additives had been added to cement grout to achieve the required workability. Type “C” standard grout placement techniques (Two-step grouting process) had been used to micropile installation diameters of the reinforcing bar were 25 and 28 mm. At first, gravity grouting (Type A) had been performed and then after 15 minutes the secondary pressure grouting througth sleeved pipe with 1.2 MPa pressure were carried out. 300 to 340 lit/meter grout had been also used for each micropile installation. Therefore, it seems that the grout volume is ranged between 4 to 4.5 times of the theoretical value (excavated borehole volume), indicative of the very porous nature of the beach deposits.

The specifications and classifications of the soil layers, before and after installation of micropiles are given in the table 1.

TABLE I. IN SITU MECHANICAL SPECIFICATIONS OF SOIL LAYERS BEFORE AND AFTER INSTALLATION OF MICROPILES.

Z (m)		Φ (°)	γ (kN/m³)	E (kN/m²)	D_r (%)
3.5	N[a]	35	18	8000	60
	R[b]	40	20	11000	80
12	N	34	18	7200	55
	R	41	21	13500	85
13.5	N	35	18.5	6600	50
	R	38	20	11000	72
15	N	33	17	5000	37
	R	41	17.5	11000	68
17	N	38	19	9000	57
	R	45	20	12000	70

[a] Natural ground

[b] Reinforced ground

B. Model description

Since PLAXIS V.8.5 code is one of the easiest and the most plausible office software in geotechnic engineering, we were using it to analyze the problem. As grout injection procedure causes large deformation in soil, a lagrangian approach, must be used to reach converged answers. Lagrangian analyses do not require to make the stiffness matrix. So in large displacements every node updates at each time step and occurred displacements are added to the past coordinates of points. As the result, the elements supplanted and the geometry of model changes.

At first, a model simulated in axissymetry method to create surrounded pressure, considering the effect of nearby micropiles. Model consists of 15 node triangular elements arrange. The dimension of model was 20m height × 5m width. Validation of the model to in situ evidence performed by establishment of site condition and 3m spacing of micropiles as implemented. The soil behavior is described using an elastoplastic constitutive model based on the non-associated Mohr-Columb criterion. Proper boundry condition are use to ensure the displacement transmission through the center boundry of soil mass. Water table sets on the surface of soil block. Changing the stress level by applying undrained condition, non-occurrence of tensile crack and gradient changes in elastic modulus, are modeled approximately. In this paper the changes in injection pressure introduced as displacement to the model. Two step were introduced to run the analyses. The first step producted the geostatic situation and the second exerted the displacement into the boundry after reseting the displacements of the first step to zero.

C. Results

The results showed that simulation of injection, along with all its defects, is in perfect harmony with the event been occurred in the site as shown in Fig.1.

The numerical model was estimated error rate of less than15%. In other words, the main aim of this project is to run a simplex and efficient model of grout injection.

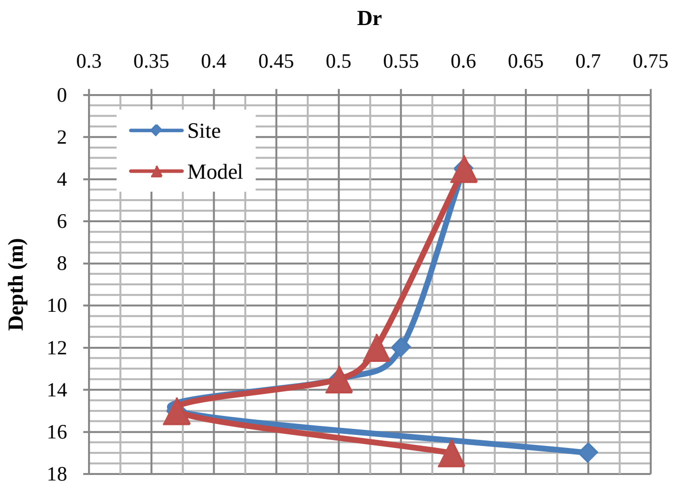

Fig. 1. Changing the relative density by depth to compare the site investigations with model results.

Noted that this model does not include the following effects:

a) Changes in stress level like what happens in reality,

b) Influence of the soil-micropile interface,

c) The injection pressure according to reality.

Grouting has a minimal effect on the angle of internal friction of sands up to 4.5°. It depends on moisture and time of curing. By increasing both of them, the friction angle increases [38]. But according to the main study (Naeini and Ziaei, 2012) internal friction angle may be changed up to 8°, within cementation occurrence. Markou and Droudakis (2013) declared that incrase in fine cement, decreases permeability of slurry. They said that coarse graded sands causes lower strength of cemented soil and higher failure strain than fine graded sands. They concluded that high void ratio of sand lessens the influence of increasing in strength and decreasing the permeability of the soil. Also by increasing the injection pressure, permeability of soil increases and the strength decreases. The distance away from the injection point, the amount of cement in the cemented soil is increased but in saturated soils this rate of increase is less seen [39].

The second process was to improve the model by applying some changes in micropile distance (3m, 1.6m and 0.8m) and boundry displacement representative injection pressure (1cm, 2.5cm, 5cm, 10cm and 15cm). As shown in Figure 2, 3, 4, by increasing the injection pressure, the relative density of the soil increases in every distance of micropiles. This phenomenon is clearly seen in all layers. Because the density of layers changes irregularly with depth, the effect of increasing depth should be neglected.

It seems to be a very weak layer between 13.5m to 17m as is clear in curves above. Due to saturated and undrained condition of the soil, it can be said that the displacement corresponding present injection pressure (1.2MPa) should be between 5cm to 10cm. Noted that by decreasing in micropile distances, the equivalent displacement decreases. Due to the ability of the code used for the study, the maximum

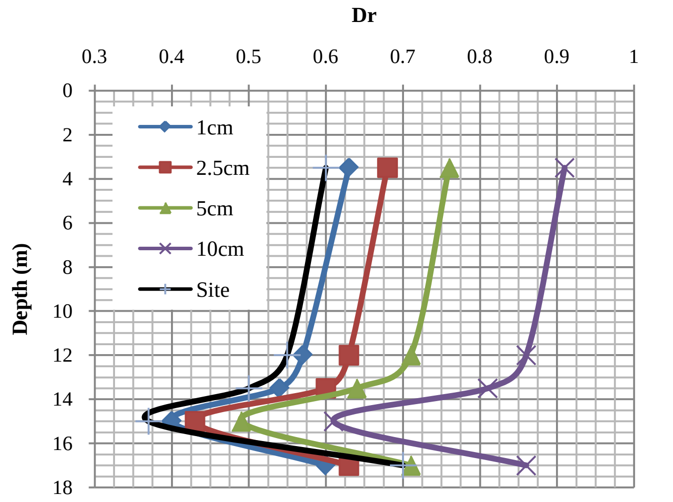

Fig. 2. Changing the relative density by depth to compare the site investigations with model results in 3m spacing of micropiles and for 4 boundry displacement.

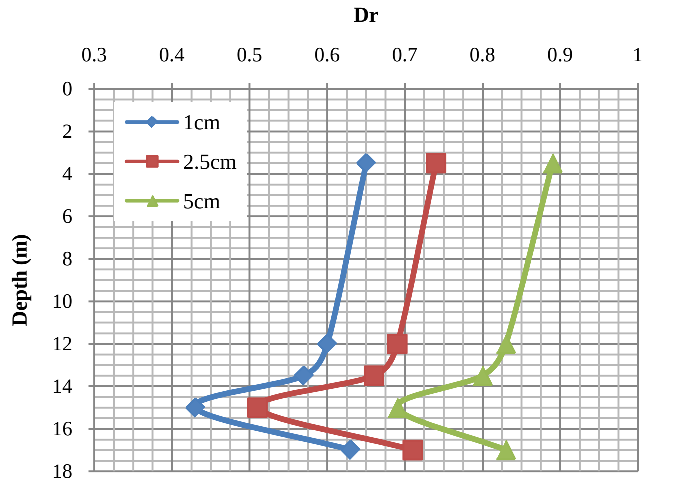

Fig. 3. Changing the relative density by depth in 1.6m spacing of micropiles ad for 3 boundry displacement.

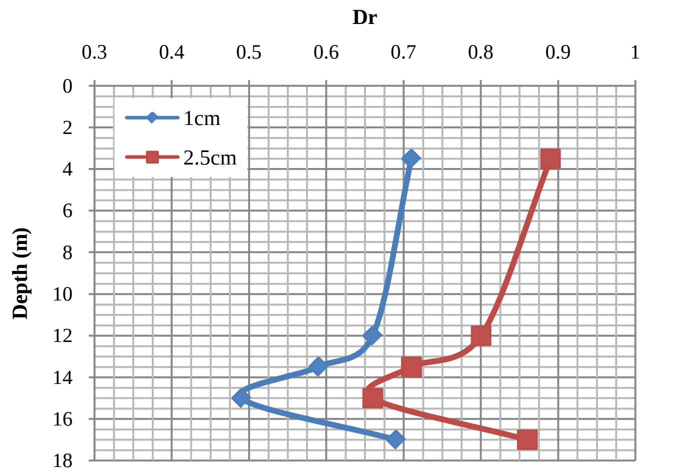

Fig. 4. Changing the relative density by depth in 0.8m spacing of micropiles and for 2 boundry displacement.

relative density might be greater than 1 that is logically incorrect. Therefore it can be seen that the maximum relative density attained by 10cm displacement of the boundry for 3m spacing of the micropiles, whereas it seems to be 2.5cm displacement of boundry for the maximum relative density of 0.8m micropile spacing.

In fact, the volumetric strains during injection cause some unusual results in graphs and make contradiction. Generally when a soil subjected to injection pressure, two phenomena occur [28]:

1) The slurry penetrates into the void of the soil and obeys the law of bernulli tube.
2) Move apart particles and provides localized failure.

If the vertical displacements due to the second phenomenon are large, the volumetric strains are more representative of the vertical displacements. Whereas the injection carry horizontally. Therefore, the loss of match in the result of the depth of 13.5m is due to the vertical strains.

Usually, it is enough to reach high relative density of the soil to ensure the bearing capacity and settlement. So the weak layer modified by acceptance of 10cm grout penetration in 3m space (as might be excepted) and 5cm in 1.6m space and 2.5cm in 80cm space of micropiles.

III. Conclusion

Modeling of micropiles installation shows the harmony between experimental results and numerical analyses. As the model was improved, the obtained results show some significant issues that can be interpret. Some of the main results are as below:

- By increasing injection pressure (boundry displacement), more modification takes place. Because the software are not smart, the changes in displacement grows up continuously. But in fact the displacements can not exceed the limited amount. Then geotechnical engineer is necessary to interpret the results.
- What far micropiles are, modification requires more pressure to be applied. So in less distances, desired factor of safty is achieved at lower injection pressures.
- The pressure of 1.2 MPa micropiles at a distance of 3m is equivalent to 5cm to 10cm change in boundry condition. This means that high injection pressures up to 8 MPa are used for unsaturated or drained loose soils. In the other hand, this amount of penetration has an good agreement with the results pointed (1.5d for sand and gravelly sand).
- Model responses are less than evidence changes. So numerical analyses present higher safty factor for injection projects. It imposes additional costs to the project because of increasing injection pressure and possibility of general failure subsequently. It seems to caliberate the model with the result of a SPT after installation to prevent this disadvantagous,

- Displacement changes at a same depth by changing injection pressure is estimated to be linear that shows the absence of hardening parameters. Nonetheless, exctracted results are in good agreement with experimental one.

Suppose that use discrete element method (DEM), for example PFC code, to simulate the penetration of SPT rod into soil and not to neglect the skin friction of rod body. To complete the model use documented data from an implemented project to extract hardening characteristic. For better validation, simulate other projects by very different specefications such as mechanical properties of layers, water level, injection pressure and etc.

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