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Static Analysis, Using Finite-Element Method (FEM) for Micropiles Application Evaluation: Empirical and Numerical Perspective

Sayyed Yaghoub ZOLFEGHARIFAR[1,2], Hadi DARAM[1], Majid RAHIMI[1,*]

[1]*Department of Civil Engineering, Faculty of Engineering, Yasooj Branch, Islamic Azad University, Yasooj, Iran*

[2]*Department of Geotechnics & Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia*

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Abstract. The necessity of building structures on special sites with soils prone to liquefaction or with an inadequate bearing capacity (Problematic soils), reveals, more than ever, the significant importance of applying micropiles for transmission of structural loads toward the adequate beneath soil horizon. In this paper, the micropiles influences on soil bed response, has been investigated through static analysis performed by the powerful finite-element software, Abaqus. The results indicate that applying such equipment could make improvements in soils, so that displacements of such reinforced soil will decrease significantly. This kind of application would lead to a uniform soil stress distribution, along which elimination of irregularity in infrastructure response and, therefore, prevents possible twists and liquefaction, considerably.

Keywords: Micropile, Static Analysis, Finite-Element Method, Soil Improvement

INTRODUCTION

Micropiles are components made of steel, concrete, reinforced concrete (RC) and wood, used for constructing deep foundations or micropile foundations, when the soil bearing capacity is not sufficient for the structure to withstand in case of shallow foundation. Although using micropile foundations is costly, nevertheless they are applied in numerous cases to secure buildings against subsidence and other risks. Such composite system is called reinforced foundation system. It is economically cost efficient solution, thus affordable option, using multiple micropiles beneath raft foundations, whereby bearing capacity increases as well as total and differential subsidence decrease, when raft foundations, by themselves, don't satisfy the needs of designing for taking bearing and subsidence into account. Micropiles are divided in two categories of Driven (Displacement) micropiles and Bored (Replacement) ones. The driven micropiles are the ones that are well-found established in soil through drilling or vibration, while the bored micropiles are put in drilled places, precast or cast-in-situ. There are considerable advantages in applying micropiles, and followings can be noted: short execution time, soil bearing capacity and properties improvement, non-uniform settlement preventing, minimum interference in structure and soil environment, lowest noise creation during execution, pile inclining ability and horizontal/vertical bearing capacity. This is why it has become a hot potato among engineers who are willing to walk an extra mile to execute it in massive construction projects, especially in sandy soils.

Generally, to deal with problem soils such as loose soils with inadequate bearing capacity, high subsidence and liquefaction potential, and non-virgin soils, there are some solutions out there that might become handy for geotechnical engineers, including the following two:

* Corresponding author. E-mail: *Dboss_2001@yahoo.com*

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1- Using bearing elements
2- Physical-Mechanical improvement and modification of bulk soil

Each one of the above solutions has its own specific methods and properties, which have seen many developments over continuous years. To kill two birds with one stone, some innovative techniques though, have been made of a combining nature of the two that almost benefit from advantages of both, from which, we can point out a method consist of using micropiles along with cement grout or fine-grained concrete injection.

Some of the advantages of using micropiles in the foundation bed of new structures are: reduction in soil subsidence, incrementing in compression loading, providing tensile loading, incrementing in lateral loading, and likewise in existing structures: foundation subsidence control, foundation bearing control, foundation repairing or replacing, foundation scouring control, seismic retrofitting.

Micropiles are also used for in-situ soil remediation in cases like: Stabilization of Soil Slopes, constructing bulkheads, fighting liquefaction in potential soils, increment in bulk soil resistance with specific aims like tunneling, chemical protection of embedded parts of structures, etc.

There have been vast studies on micropiles and effect of different parameters on their performance, due to their numerous usage, numerically and experimentally [5-1]. Ghamari and Ghorbani [6], investigated/studied the micropiles behavior under static lateral load using numerical modeling. The model results had a good correspondence with real test ones. Studying on micropile seismic behavior under lateral load indicated that in seismic analysis, soil non-linearity, results in inner forces reduction and displacement at the top of micropile. In other words, the plasticity reduces transitive energy into the structure and consequently, reduces inertia forces significantly. Khushecharkh et al. [7] compared the function of vertical micropiles against batter micropiles with angles consist of 45,35,30,25,20,15,10 and 5 degrees. Results of this study demonstrate that when the micropile inclination angle is increased, bending moment and axial force are increased as well, and the maximum displacement at pile cap occurs at about 25 degrees angle. Honarmand et al. [8] with use of the finite-element method investigate the soil parameters around micropile under bending moment. To get it done, the elastic and elastoplastic soil behavior has been considered using Mohr-Coulomb method. The results indicated that the maximum bending moment over the loading time has been occurred at the top of micropile, and decreased continuously as it got closer to the bottom of the micropile. It is also demonstrated that this value in elastic soils is higher than the counterpart soils with elastioplastic behavior; hence the elastoplastic soils enforce fewer loads to the micropile.

At first, micropiles usage was just considered as an improvement in buildings' poor soil bed, but gradually, with development and extension in its application in different countries, they have found their way in other geotechnical engineering fields such as slope stabilization and liquefaction remediation. Fig 1 shows reinforcing foundation with the use of piles for transmitting the bearing load from poor layer of soil to a more fortified one.

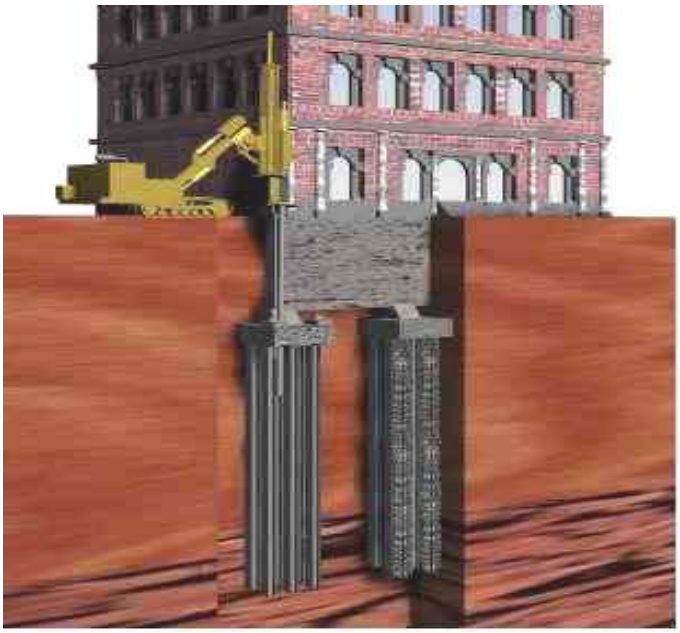


Figure 1. Using micropiles in an existing structure [9].

The type of soil bed, and the length and the number of micropiles are very important parameters in micropiles behavior. In many soil beds, the soil behavior differs in various horizons. Since, the effect of these parameters in general and on each other has not been comparatively measured yet, this study with use of a double layer soil of which, the above/higher soil is soft and the beneath/lower is stiff, investigates the effect of length and number of micropiles.

Finite-Element Modeling

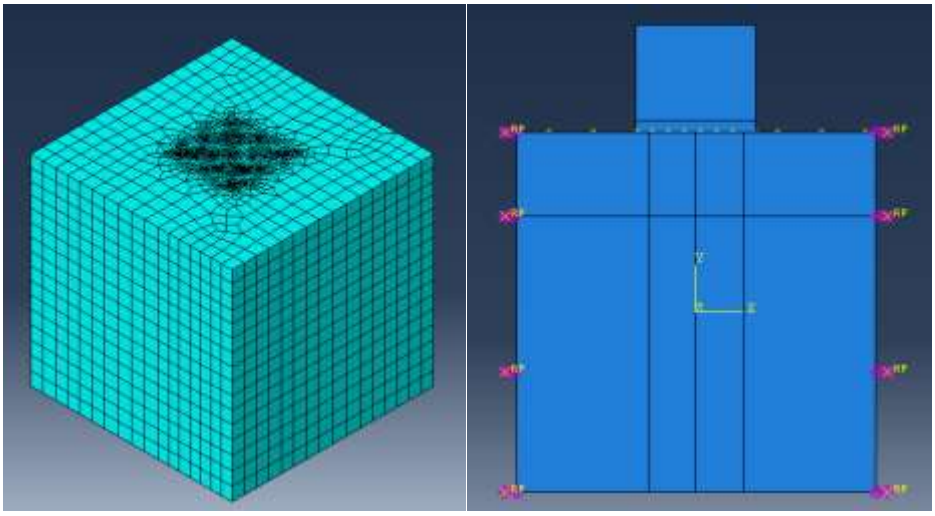
To analyze the group function of micropiles with different length and numbers on a two-layer soil bed, the Abaqus software and 3D modeling were used. To investigate the effect of the number of micropiles under static load, once, 4 micropiles and then 9 micropiles were applied, wherein other geometry conditions held steady.

As mentioned, the soil consists of two layers with a 3.5 meters high soft soil as the top layer and an 11.5 meters high stiff soil, beneath. To study the effect of micropile length in that kind of soil 4 different length consisting of 2.5, 3.5, 5 and 7.5 meters, were exerted. The 2.5 meters high micropile takes place just in soft soil, and about the 3.5 meters high one, the bottom of micropile sits right at the border of two kinds of soils (soft and stiff). The 5 and 7.5 meters high micropiles obviously have a part in both soft and stiff soils. Pile foundation size is 5 by 5 by 1.5 meters wherein the distances of micropiles in 4 and 9 jointed groups are 4 and 2 meters, respectively. The soil bed dimensions are 15 by 15 by 15 meters. Also a cubical building with 5 by 5 by 4 meters dimensions has been modeled and placed upon the foundation. Since a non-linear static solver has been used, the element type of meshing was an eight-node element C3D8R.

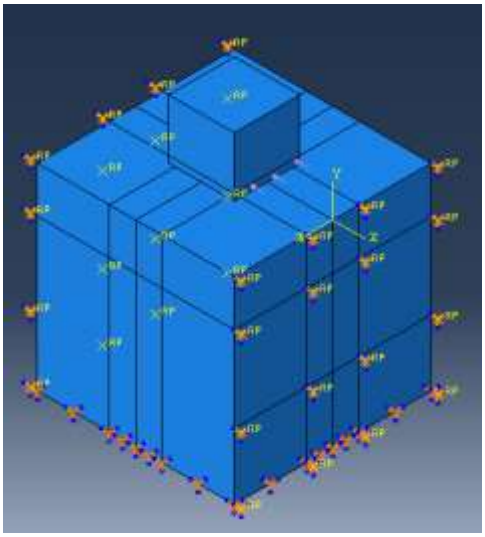
One of the important issues of problem analysis is boundary conditions. We applied two boundary conditions: 1- Set a limit for the soil bed floor. 2- Define and apply energy-absorbing boundary: considering the real model being semi-infinite, induced energy in the model should get out through these boundaries. There are various methods to apply energy-absorbing boundary, of which, one is the viscous boundary. In

this method, dashpot elements were put at the boundaries with a coefficient as $F_d = C_d \cdot u$, and this coefficient was assumed as $C_d = \rho V_s A$ for a surface, where ρ is the density of the soil, V_s is the velocity of shear waves, and A is the surface covered by each element. Static load also, was introduced to the foundation with a fixed slope, up until the ultimate pressure at 500 kPa was met. Fig (2) demonstrates meshing, boundary and loading conditions.

For this model, two kinds of materials (i.e. Concrete and soil) have been used where the sample soil bed poses the same mechanical properties of soil, and other parts (e.g. Piles, foundation and building) have been made of concrete. Density, elastic modulus and poisson's ratio of the concrete, were given to the software according to the table (1). To define soft and stiff soils' mechanical behavior, more details were given to the software and their non-linear behavior with the use of Drucker-Prager model were accounted for (Table 3).



(a) **(b)**



(c)

Figure 2. (a) Meshing on the block **(b**) Setting boundary conditions for absorbing energy **(c)** Setting a boundary to the soil bed floor and Applying dynamic loading upon the foundation.

Table 1. Concrete mechanical properties.

Density (Kg/m^3)	Pascal Modulus of Elasticity	Poisson's ratio
2400	21e9	0.3

Table 2. Soil mechanical properties (Drucker-Prager Model).

Soil type	Density (Kg/m3)	Elasticity Modulus(MPa)	Poisson's ratio	Angle of friction	Flow stress ration	Dilation angle	Yield stress (kPa)
ft	1800	85	0.23	30	0.8	1	80
stiff	1700	40		22	0.9	1	30

The final stage of modeling relates to defining contact conditions between different parts of the model. To do so, the vertical contact between micropile and soil bed defined as hard, in which they won't have influences into one another, and contact friction coefficient was considered equal to 0.1.

RESULTS AND DISCUSSION

To determine the function of micropiles, the von Mises stress and emerged displacement on soil bed, have been investigated. Fig (3) Represents stress distribution over the soil for the case consisting of 9-jointed micropiles group. As you can see the maximum stress belongs to the forepart of the foundation, which painted in red, and as far we go back on the foundation, the stress decreases (back of the foundation is the direction that compression forces are applied, as in fig (1 c)). To more accurately survey from fig (3), The stress trend from the back to the forepart of the foundation has been presented for different length and number of micropiles in fig(3) for more precise survey (The starting and ending point of diagram in fig (3) has been shown by an arrow). In constructions consist of 4 micropiles, 2 stress-jump were observed, while in 9-joint micropiles systems, there were 3 jumps. These jumps are the result of created holes in soil. According to the figure, there are two points at which maximum stress is occurred, that belong to the forepart of both holes, which are under the pressure of micropiles, since the direction of induced pressure is the same as the arrow. Interestingly, stress variations between the two holes are ignorable. There is, of course, a stress jump at the position of the middle hole in the case of 9-jointed micropiles, where it has been shown that the introduced stress to the soil bed is much lesser than the first and last holes.

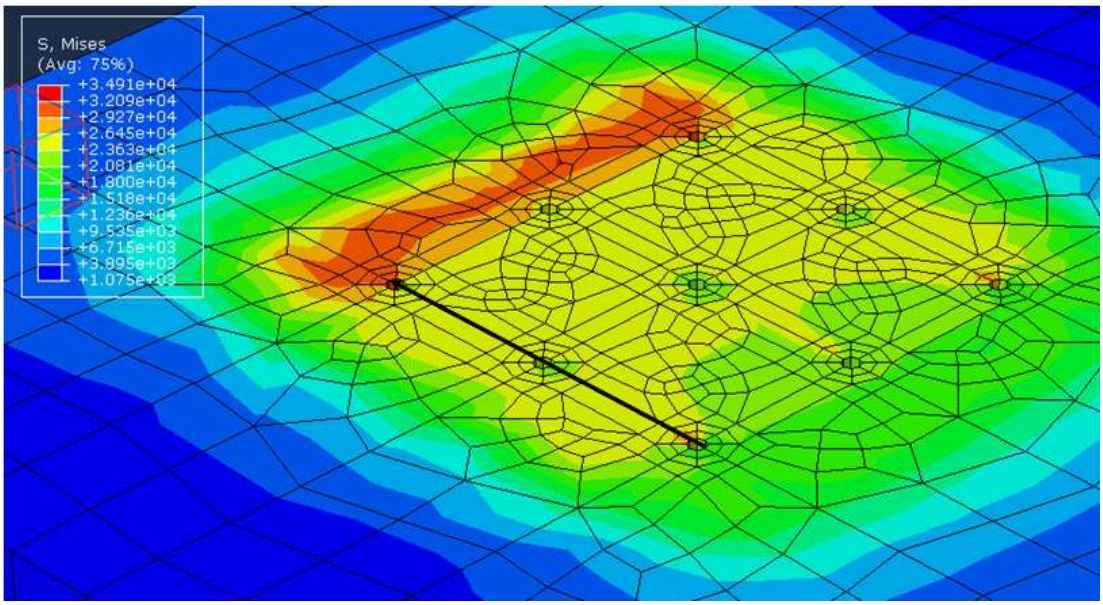


Figure 3. The von Mises stress counter to investigate stress distribution among the soil surface.

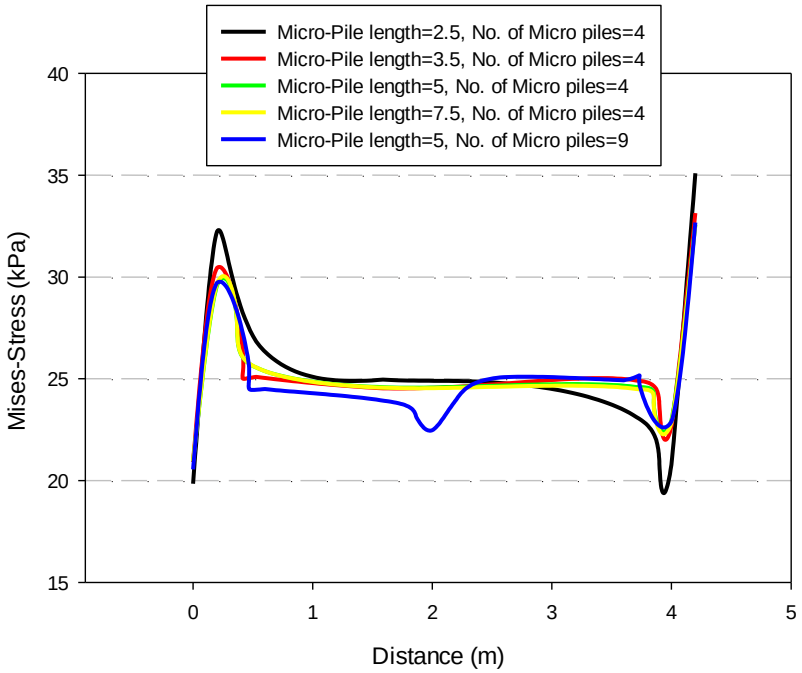


Figure 4. Stress variations flow from the back to the forepart of foundation.

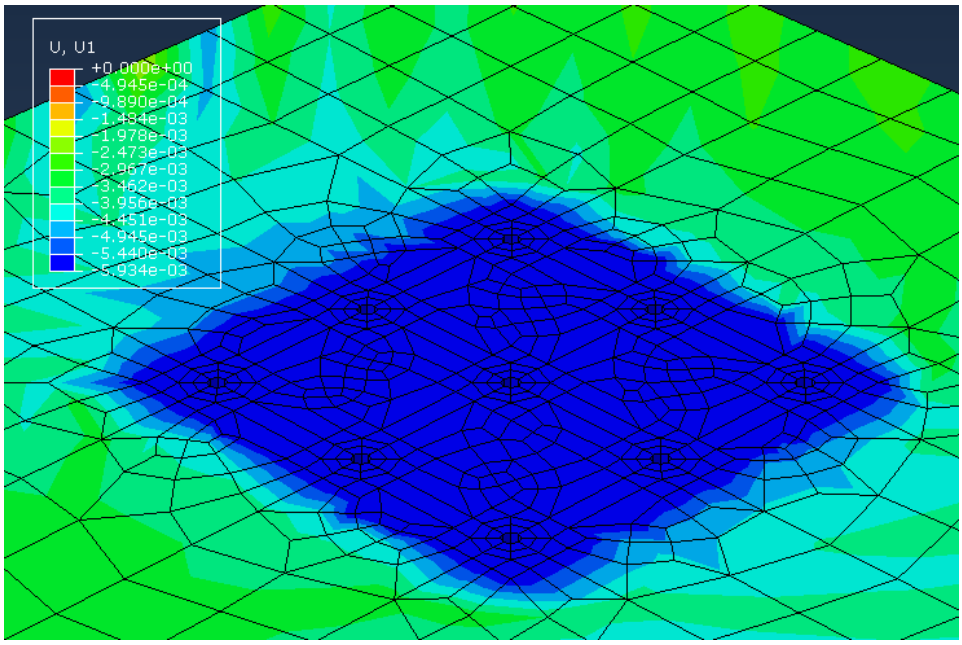


Figure 5. Displacement counter at the soil surface.

The displacement counter of soil surface is shown in fig (5). As is clear, the covered area by micropiles has a uniform displacement, which, indicate the strengthening of that soil area given by the micropiles system.

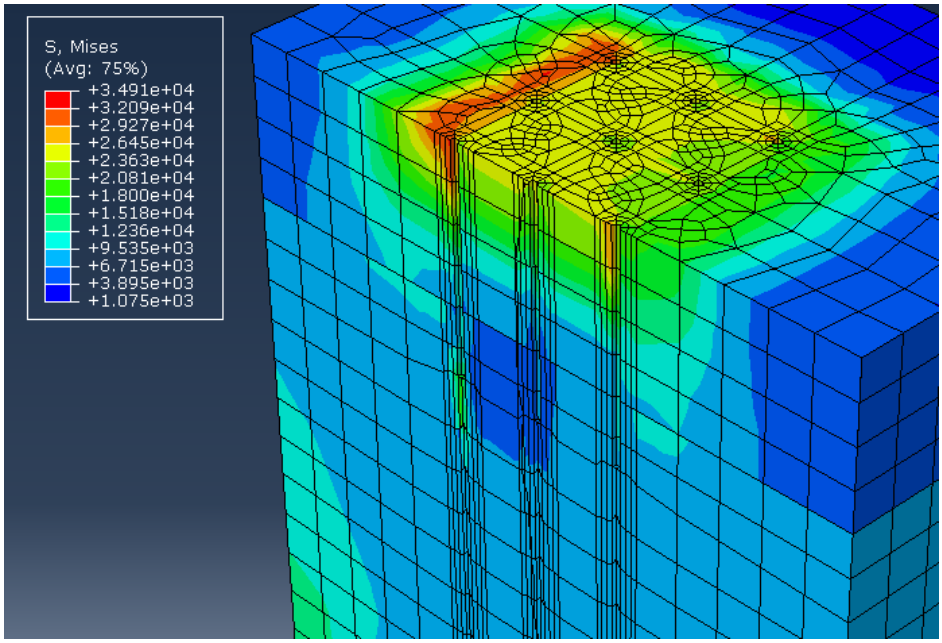


Figure 6. Stress variations counter at soil bed in line with micropiles holes

Fig (6) demonstrates the von Miser stress counter of soil bed in micropiles' direction, in which the maximum stress is at the top of the bed, and it decreases as we get nearby the bottom of micropile. To look more accurately, fig (7) demonstrates stress variations in micropiles' direction for different systems of micropiling. According to the diagram, for all cases except the one with short micropile located within the soft soil bed, the maximum stress is at the top of soil bed while decreasing toward the near bottom of micropile, and right at the bottom, the amount of stress increases en masse, wherein the stress concentration situation emerges. Thus when we're dealing with poor or inadequate soil, we can reinforce the interface of soil and bottom of micropile.

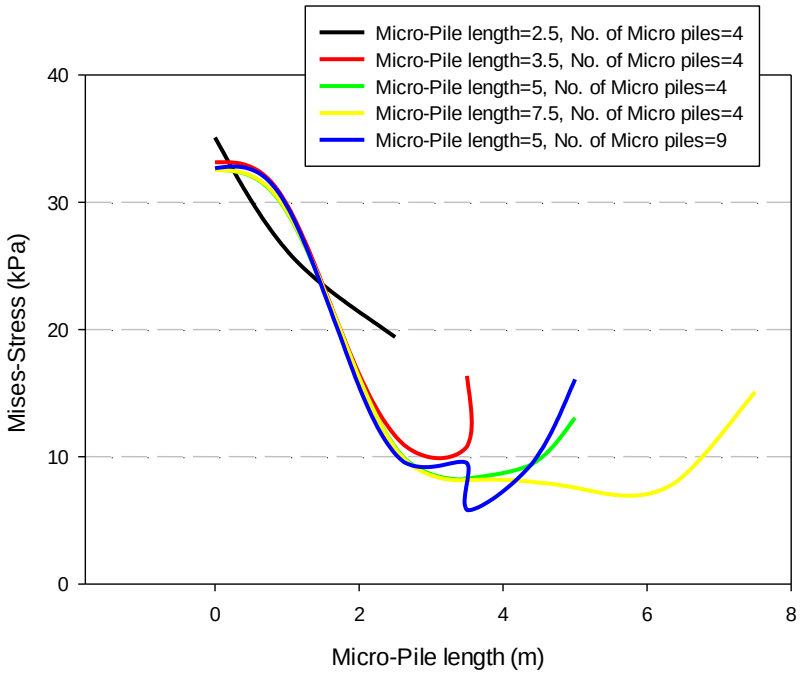


Figure 7. von Mises' Stress variations at soil bed in micropiles' direction holes.

Fig (8) displays the soil bed displacement along the length of micropile. Broadly speaking, the soil displacement processes are similar in every micropile system, and the number and length of micropiles haven't been much effective on soil surface displacement, except at the bottom of micropile, at which, displacement is decreasing correspondent to increasing micropile length.

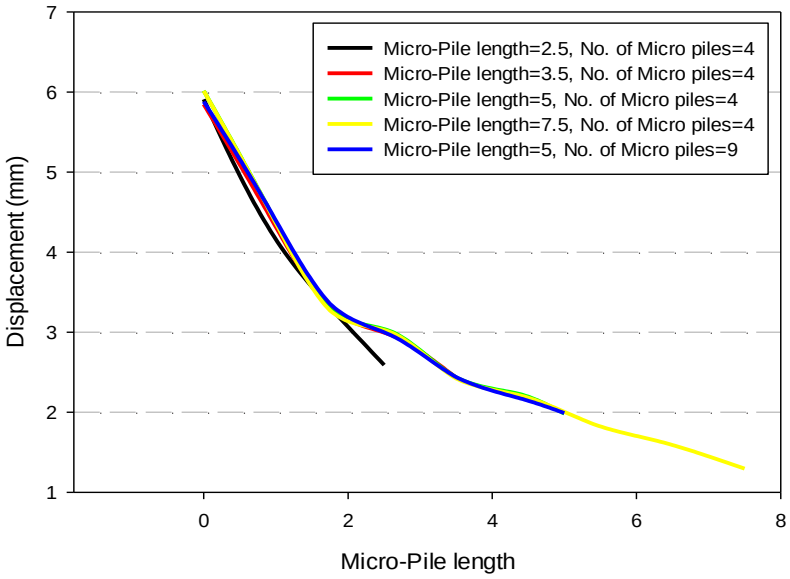


Figure 8. Displacement variations of the soil bed in line with the micropile hole.

CONCLUSION

In this study, with the use of finite-element method executed by Abaqus software, the effects of applying micropiles on site bed response, consist of two types of soils (Type one, which is nearby the earth surface, is the soft one and type two is the stiff one) has been investigated and the results are as follows:

- In models with 4-jointed micropiles, there are two stress jumps, while there are three, in models with 9-jointed ones, which indicate, adding more micropiles can be an effective approach to prevent sudden variations in amount of stress exerted on the soil bed.
- Stress variations between micropiles is too little, which indicates that a regular response of the structure foundation can be created using micropiles, and therefore, structure response irregularity prevented, which can result in heterogeneous distribution among forces and twist creation in infrastructure.
- With the use of micropiles, we have a reinforced soil with uniform displacement, offering partial ground improvement for group pile foundation.
- According to von Mises' stress counter of soil bed in micropiles' direction, clearly the utmost stress is at the above part of soil bed, and the closer we get to the bottom of micropile, the lesser amount of stress we observe.
- During our inquiry into stress variations in micropiles' direction for different micropiling systems, we reach to a conclusion that in all cases, but the one with short micropile placed in soft soil bed, the utmost stress is upon the soil bed and decreases until nearby the bottom of micropile, but right at the bottom, it suddenly increases because the stress concentration conditions come into play.
- For above situations, if we are dealing with poor or inadequate soils, we should reinforce the meeting point of soil and the bottom of micropile.
- In general, the soil displacement processes are similar in every micropile system, and the number and length of micropiles haven't been much effective on soil surface displacement, but with increasing in micropile length, the displacement at the bottom of micropile decreases correspondently.

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