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Investigation of the effect of micropile driving angle on bearing capacity of problematic soils

Zahra Mardani, Mohammadreza Atrchian, Ali Neysari Tabrizi *

Islamic Azad University of Zanjan, Faculty of Technical Engineering and Science, Department of Civil Engineering

Abstract

Population growth and development of building industry in the recent years without considering geological and geotechnical aspects, have caused numerous engineering problems such as collapse or formation of cracks, uneven settlement in the building, and liquefaction of the soil during earthquakes. One of the solutions in facing problematic soils such as loose soils with low bearing capacities and higher settlement potential is the use of micropiles. According to construction method of the micropiles, different driving angles can be used relative to the vertical. The purpose of the present article is to investigate the effect of different angles of the micropile construction on the behavior of the micropiles in problematic soils to find an optimum design. The investigation method consists of modeling micropiles with 10, 20, and 30 degrees with respect to the vertical and presenting the ground settlement variations along with internal force profile of the micropiles. The results show that with increasing the angle of the micropiles, axial settlement is reduced, and also the internal moments and forces of the micropiles increases. This shows that there is no optimum angle for micropile construction, and the most optimal design should be made according to the propose of the design based on either controlling the settlement or structural design of the pile. According to the soil properties of the project and due to importance of limiting the maximum settlement of the structure foundation to 2.5 centimeters, an angle of 20 to 30 degrees and around 25 degrees is recommended.

Keywords: micropile, soil settlement, problematic soils, soil improvement, Abaqus

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Introduction

The use of micropiles has increased considerably since the 1950s and especially afterthe mid-1980s.Micropiles are basically used as reinforcing elements against static and dynamic loads, reinforcement of slopes, and stabilization of excavation walls. Population growth, increase in housing needs, and development of building industry without considering geological and geotechnical aspects, has caused many issues with problematic soil being one of the main ones. Collapse or formations of cracks in the buildings, uneven settlement, liquefaction in case of earthquakes are examples of such problems. These issues make geotechnical and geological investigation of the project site, an indispensable part of the job. Generally speaking, there are two main solutions in the hands of geotechnical engineers when facing problematic soils such as loose soils with low bearing capacity, big settlements potential, and liquefaction:

1- Use of load bearing elements in the soil
2- Improvement and correction of physical properties of the soil mass

Each of the mentioned methods have their own ways and specifications which has been developed during years. Some innovative methods are a combination of the methods above, and have the advantages of both groups of solutionsto some extent. Micropiles can be regarded in this manner.

According to recent studies, reasonable performance has been seen in micropiles. However, not enough studies have been done in this regard and the need for further research in the field of exact understanding of Micropile behavior is necessary and obvious; and this issue has led to utilization of numerical analyses such finite element modeling for deeper understanding of micropile behavior. In this regard, to study the deeper aspects and existing ambiguities such as effect of passive soil pressure, length, diameter, and angle of the micropile on the micropile-soil system, parametric study of the inclined micropile behavior under vertical static load in a specific soil type had to be done.

In the present study, the effect of driving angle of the micropile on improvement of the bearing capacity in a problematic soil with coral structure is investigated, and maximum and minimum optimum values determined for this parameter. In order to do this, soil and micropile has been modeled in three dimensions using comprehensive finite element programs, and the results has been presented in the form of dimensionless diagrams for further study of these parameters.

Parametric study of a single inclined micropile is done in this research. The purpose of parametric study is to investigate the extent of impact of micropile drivingangle on the response of soil-micropile system. To do this, some of the parameters that might have an impact on the system response is chosen, and by keeping the other parameters constant except the studied parameters, system response against the variations of that parameter will be investigated.

According to the mentioned points, it is necessary to verify, compare, and calibrate the numerical analysis of the soil-micropile system with field experiment or previous numerical study results. Hence, three-dimensional finite element analysis modeling was used due to complexity, nature, and asymmetrical geometry of the problem at hand. Therefore, Abaqus Ver. 6.10 finite element program was used to achieve this.For the surrounding and stabilized soil around the micropile,Mohr-coulomb constitutive model,and the steel casing, concrete, and reinforcing barare considered as elastic.

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Numerical modeling and analysis

Numerical modeling in this study is done using Abaqus program. First, the process of building themodel is presented and then numerical studies of the thesis will be explained.

1. Modeling

1.1. Model geometry

Surrounding soil is modeled as a 3D cylinder with a radius of 15 meters and depth of 30 meters in PART module and SOLID element and EXTRUSION type.

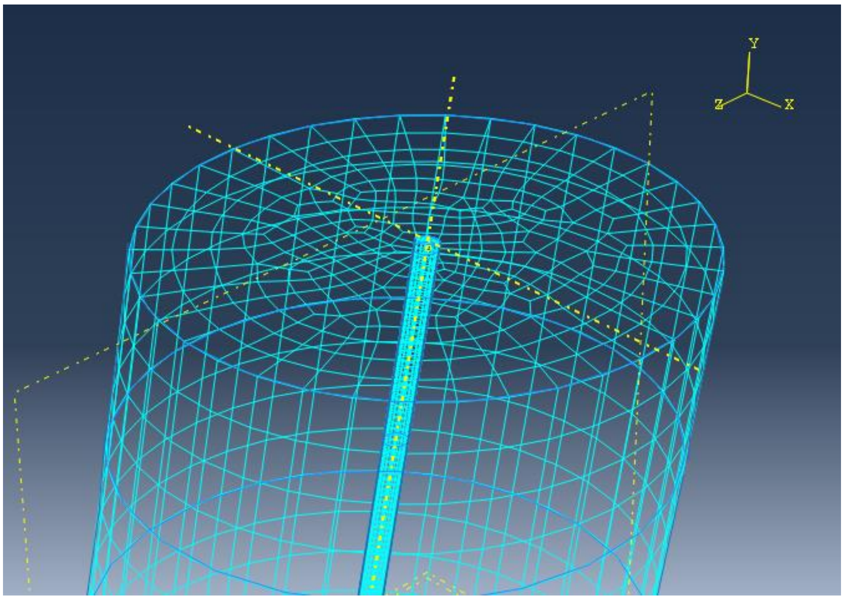

Figure 1. Soil model generation

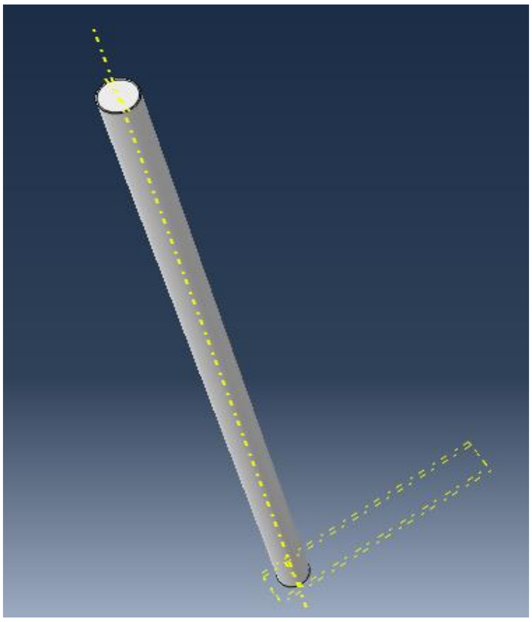

Figure 2. Micropile model generation

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2. Parameter assignment

To build the soil and micropile model, the parameters mentioned in table 1 have been used. The parameters have been extracted from a problematic site in south of Iran.For the surrounding and stabilized soil around the micropile, Mohr-coulomb constitutive model, and the steel casing, concrete, and reinforcing bar are considered as elastic. The micropiles have a length of 18 meters, diameter of 300 millimeters, and casing thickness of 3 millimeters.

a. Upper layer embankment: geotechnical parameters of this layer consists of a coarse-grained soil with varying thickness from 0 to 5 meters in the investigated area. With the assumption of sufficient compaction of this layer and correctness of the plate load test results performed during the compaction of this layer, the following can be assumed:	
$E_s = 50 - 60$ MPa	Elastic modulus of soil
$C = 0$, $\varphi = 34°$	Shear strength paramers
b. Porous rock layer (crushed limestone mass): Geotechnical parameters of this layer under the embankment with a thickness of 1 to 7 meters in the studied area is estimated as below:	
$\gamma_d \approx 17.0$ KN/m^3	dry density
$q_a = 1.5 - 2.0$ MPa	rock mass compressive strength
$q_s = 4.0 - 5.0$ MPa	intact rock compressive strength
$q_t = 1.0 - 2.0$ MPa	intact rock tensile strength
$E_s = 150 - 200$ MPa	Elastic modulus of rock mass
c. Relatively hard clay layer: Geotechnical parameters of this layer with a thickness of 5 to 9 meters which is located between the upper limestone layer and lower compacted Marl rock(claystone), are as follows:	
$\gamma_d \approx 18.0 - 19.0$ KN/m^3	moist soil density
$E_s = 15 - 20$ MPa	Elastic modulus
$C_u = 25 - 30$ KPa, $\varphi_u = 15°$	undrained shear strength parameters
$\acute{C} = 5$ KPa, $\acute{\varphi} = 22°$	Effective shear strength parameters (drained)
$C_c = 0.20$	Compression index
d. Very hard lower clay layer (claystone): Geotechnical properties of this layer which is identified as the lower layer of the drilled borehole is estimated as follows:	
$\gamma_d \approx 19.0 - 20.0$ KN/m^3	moist soil density
$E_s = 50 - 70$ MPa	Elastic modulus
$C_u = 75 - 100$ KPa, $\varphi_u = 10°$	undrained shear strength parameters
$\acute{C} = 5 - 10$ KPa, $\acute{\varphi} = 24°$	Effective shear strength parameters (drained)
$C_c = 0.12$	Compression index

Table 1. Parameters related to modeling micropile and soil

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3. Analysis steps

STATIC RIKS analysis method is used in the in current study. Analysis control is done in two ways in this method.

1- Via displacement of a specific point
2- Via the applied load amount

A picture of the assumptions made in this analysis in shown in Figure 3.

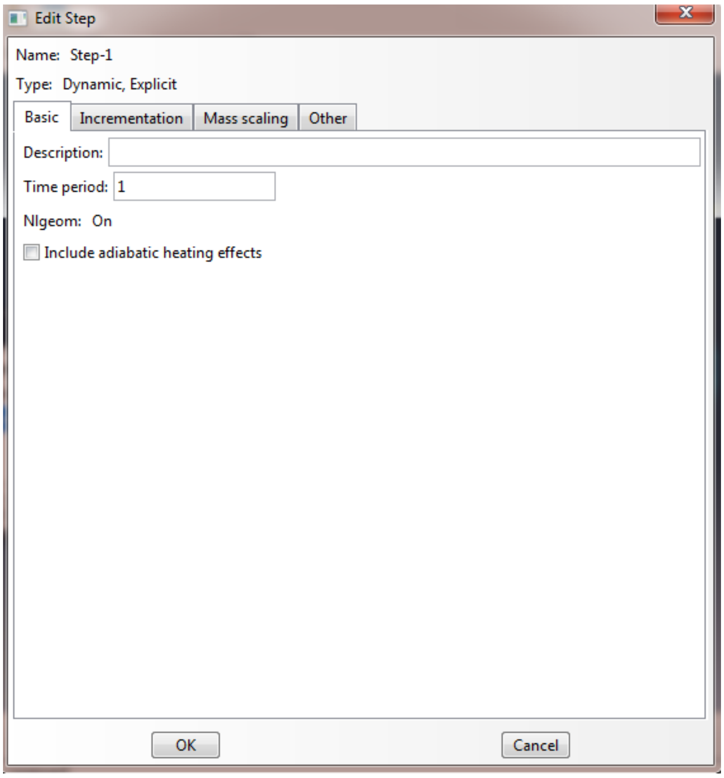

Figure 3. Using STATIC RIKS analysis

Definition of a contact surface is necessary for proper transmission of the forces between the soil and structure. Strength property is defined in this area by choosing a proper strength reduction value. This parameter shows the ratio of the structure strength parameters relative to that of the soil. Therefore, an interface element of “tangential behavior” is defined to cover the contact behaviors with friction coefficient of 0.3 as shown in Figure 4.

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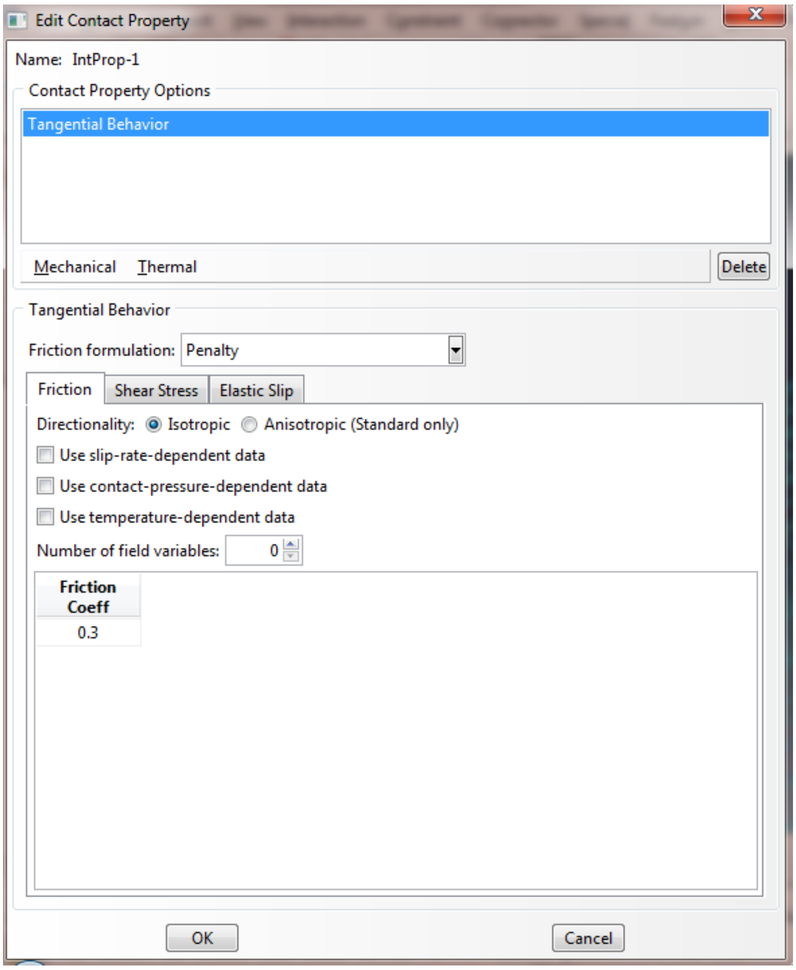

Figure 4. Using STATIC RIKS

4. Boundary conditions and loading

In the current modeling process, the load is applied as a compressive stress on top of the micropile, boundary conditions of the walls are defined as rollers, and the bottom is defined as fixed.

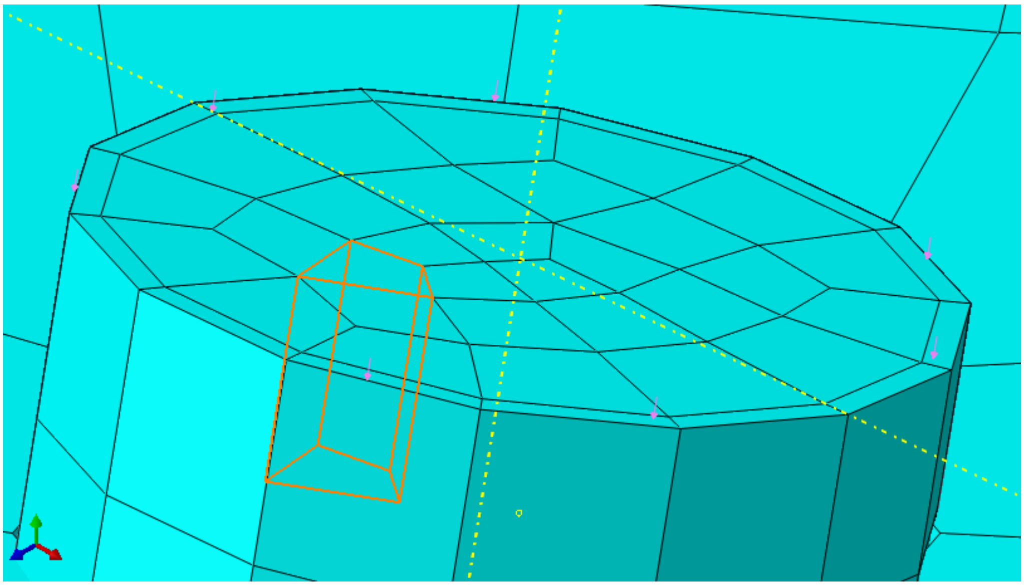

Figure 5. Model loading

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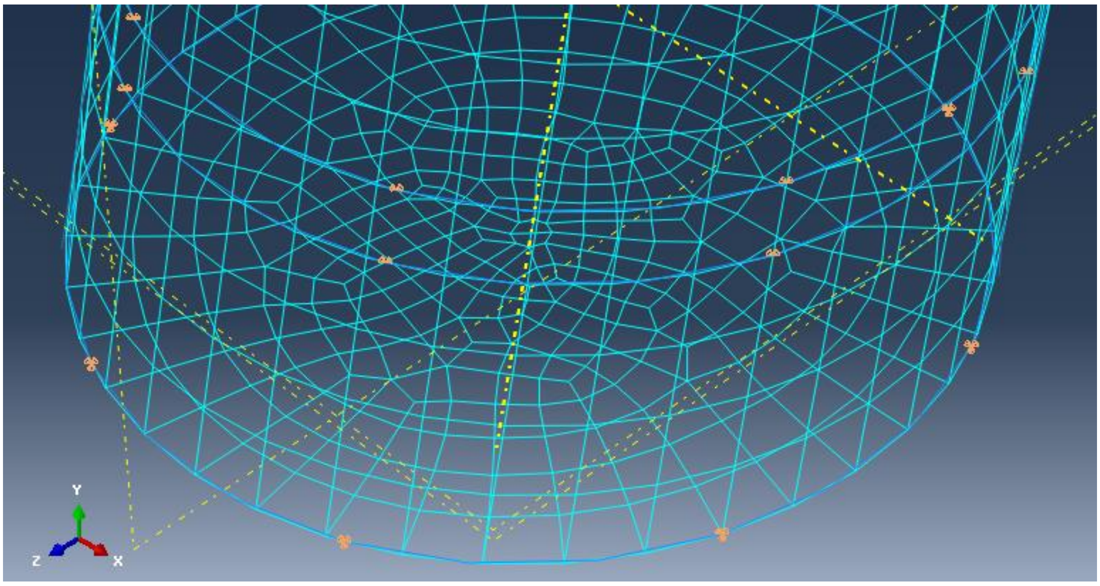

Figure 6. Boundary conditions of the surrounding soil

5. Mesh generation

Mesh element type of "Hex" with 20-node quadratic is used for micropile area due to stress concentration in this place; and mesh element type of "ted" with 4-node linear type is used for the surrounding soil.

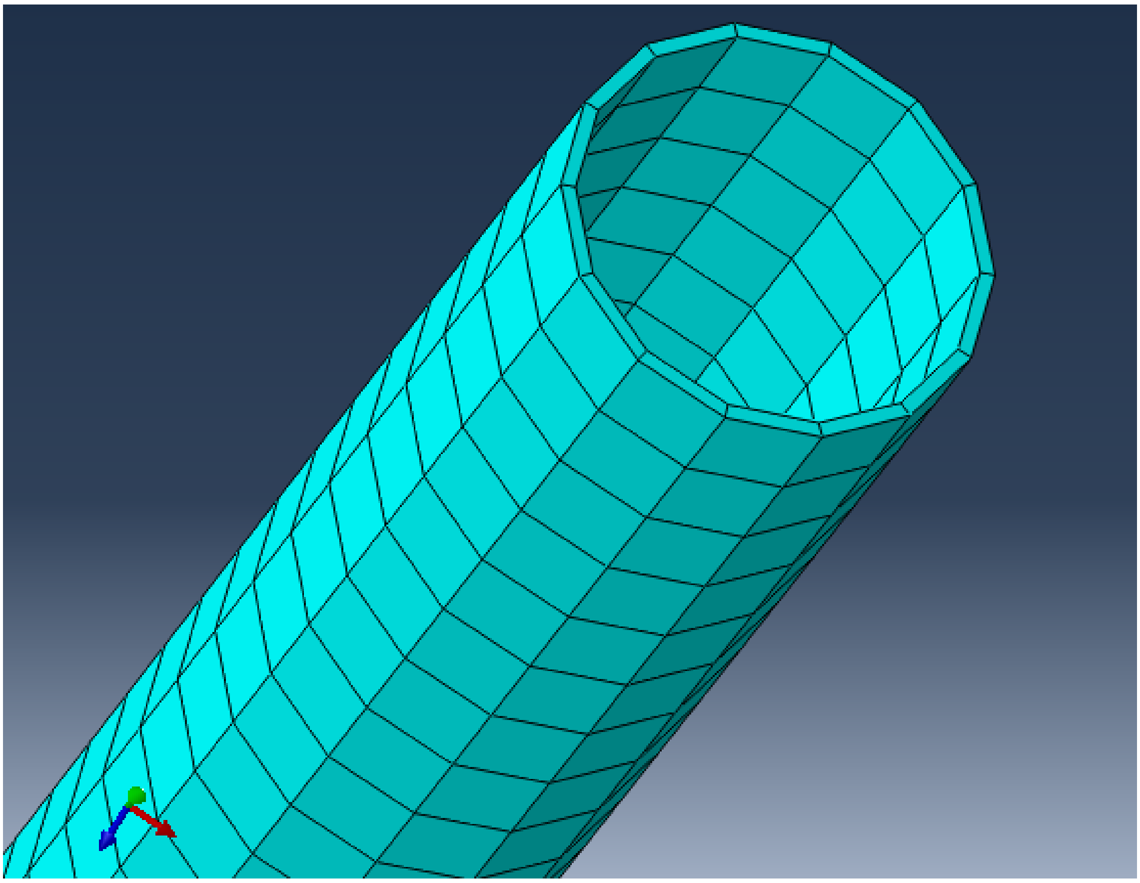

Figure 7. Micropile mesh generation

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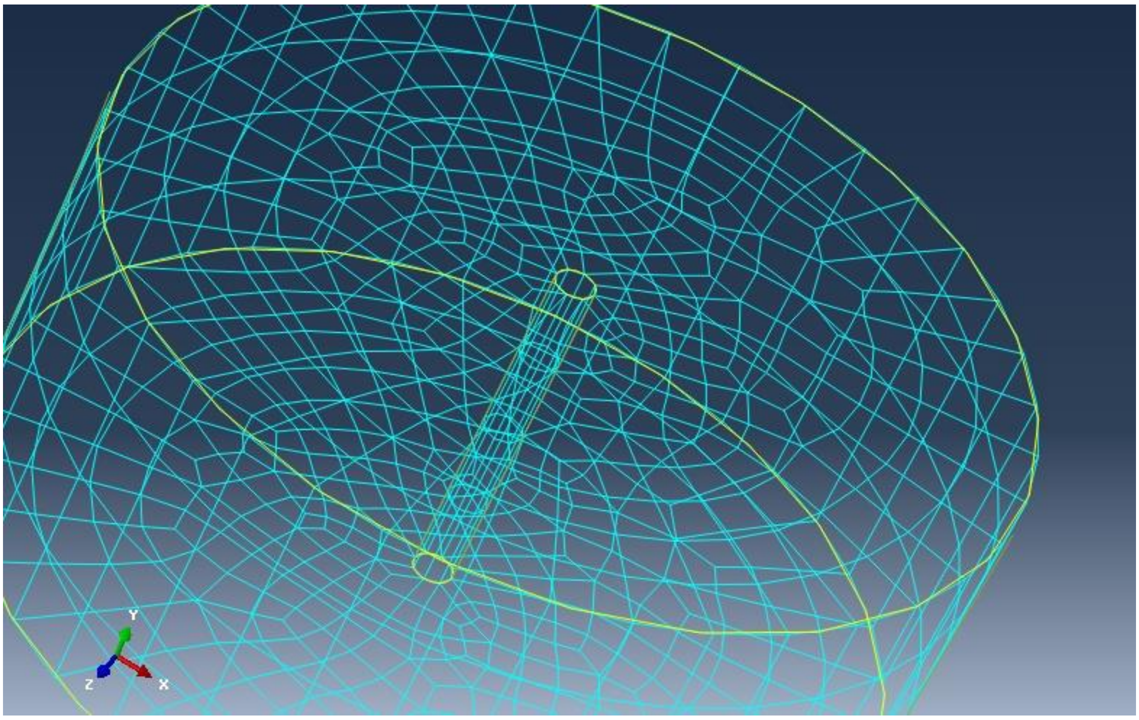

Figure 8. Surrounding soil mesh generation

6. Discussion and conclusion

The purpose of this article is to investigatethe behavior of inclined micropile and study the effective parameters such as inclination angle of the micropile relative to the vertical on the response of soil-micropile system under static vertical load on a bed of coral limestone (problematic soil). The analyses are done using non-linear 3D finite element numerical method.

6.1. Reference micropile analysis results

Vertical displacement diagramof the soil under vertical load is shown in Figure 9.

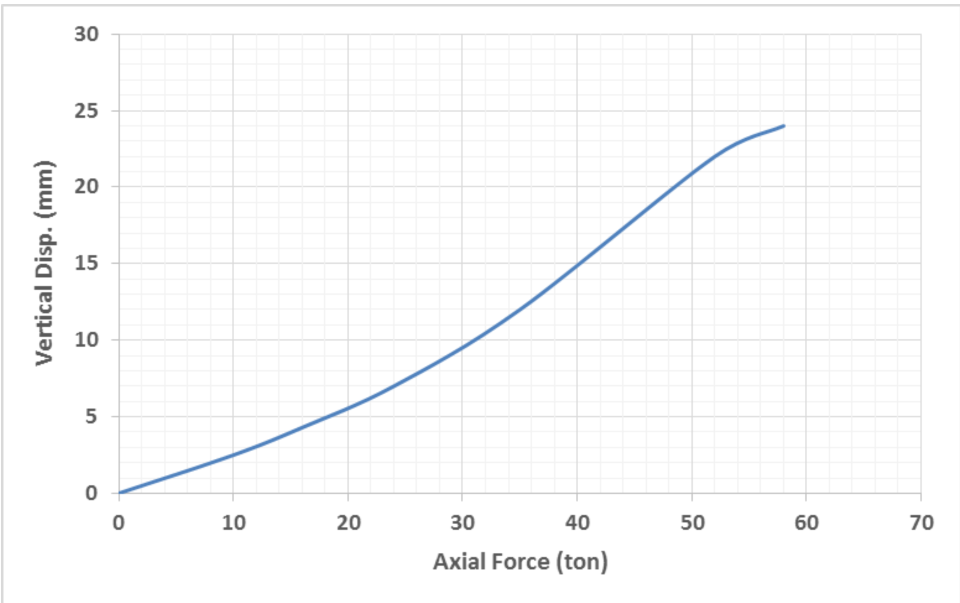

Figure 9. Vertical displacement diagram of soil and micropile under various loads

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Bending moment diagram in the length of the micropile is shown in Figure 10.

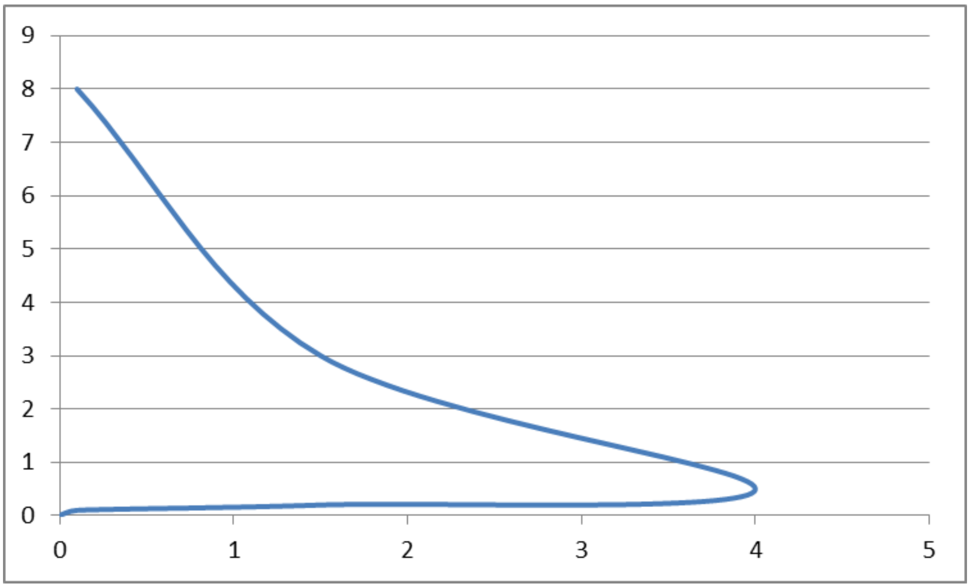

Figure 10. Bending moment diagram along the micropile length

Vertical settlement diagram of the reference micropile is also shown in Figure 11.

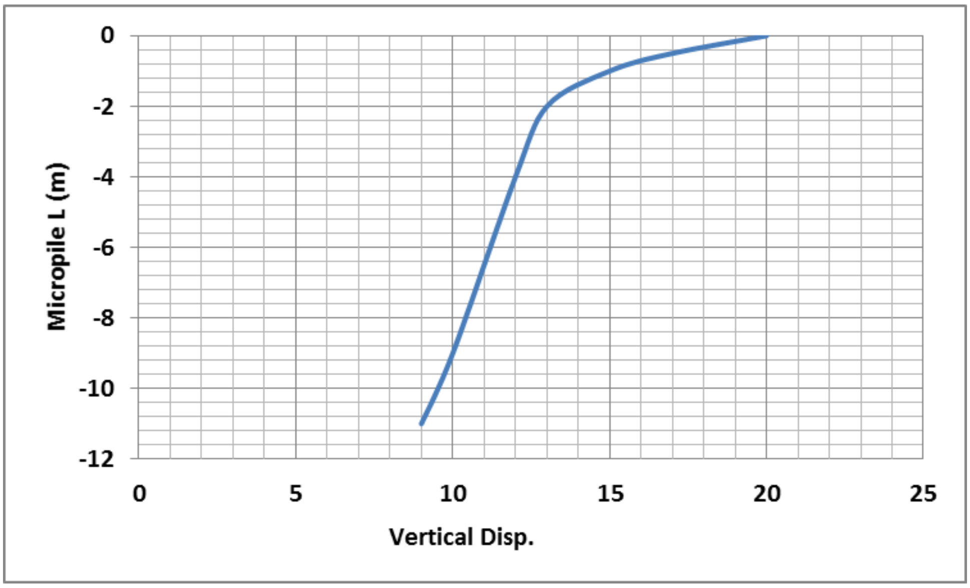

Figure 11. Vertical displacement diagram along the micropile length

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7. Inclination angle of the micropile

Generally speaking, load transmission is done in two ways in micropiles: 1- frictional and 2- bearing. Hence, from structural point of view, the applied load is decomposed into two axial and lateral components, with axial component transferred frictionally and lateral component transferred fractionally by the body of the micropile. Subsequently, the occurred settlement is caused by the two mentioned components. As the axial component causes displacement along the axis of the micropile, the lateral component causes deformations in the body of the micropile. Finally, vertical settlement is caused by vertical component of axial displacement and deformation of the micropile body. Naturally, by increasing the inclination angle of the micropile with respect to the vertical, the amount of vertical component is reduced and lateral component increased. Therefore, lateral settlement is reduced and deformation and vertical settlement of the micropile is increased.

In order to closely inspect the described behavior, 4 models with varying angles of 0, 10, 20, and 30 degrees with respect to the vertical is studied under constant soil and micropile conditions. These angles are the commonly used angles in micropile installation. The results of the effects of micropile inclination angle on the load-displacement curves is shown in Figure 12. As can be seen, with increasing the inclination angle of the micropile, maximum settlement under the 30-ton load is reduced. Maximum settlement of the micropile with different inclination angles under 30-ton load is also shown in Figure 13.

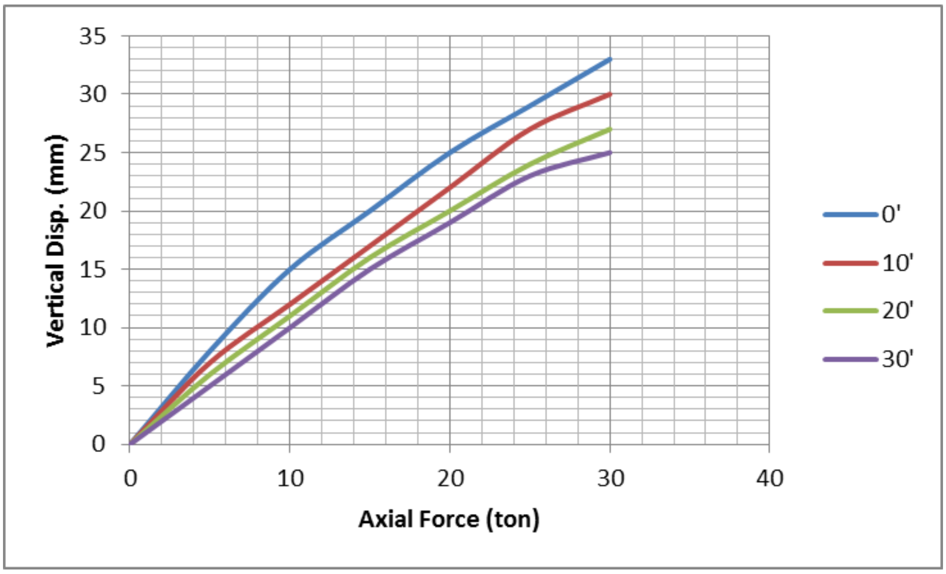

Figure 12. Diagram of variation of micropile inclination angle against load-vertical displacement curve

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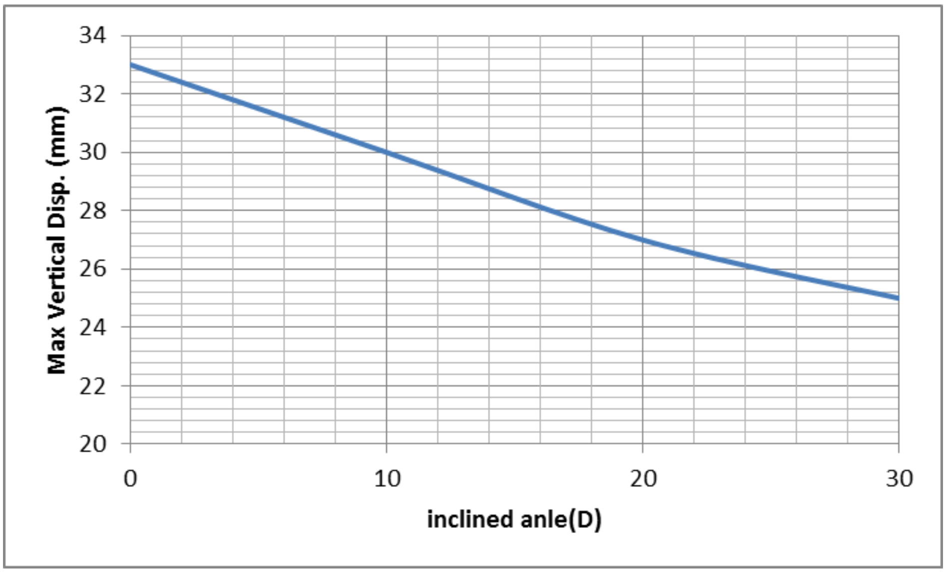

Figure 13, Diagram of variation of micropile angle against maximum vertical displacement

Bending moment diagram against micropile length is shown in Figure 11 for different inclination angles. As seen, maximum bending moment is increased as the inclination degree of the micropile increases. Maximum bending moment diagram for different inclination angles is also shown in Figure 12.

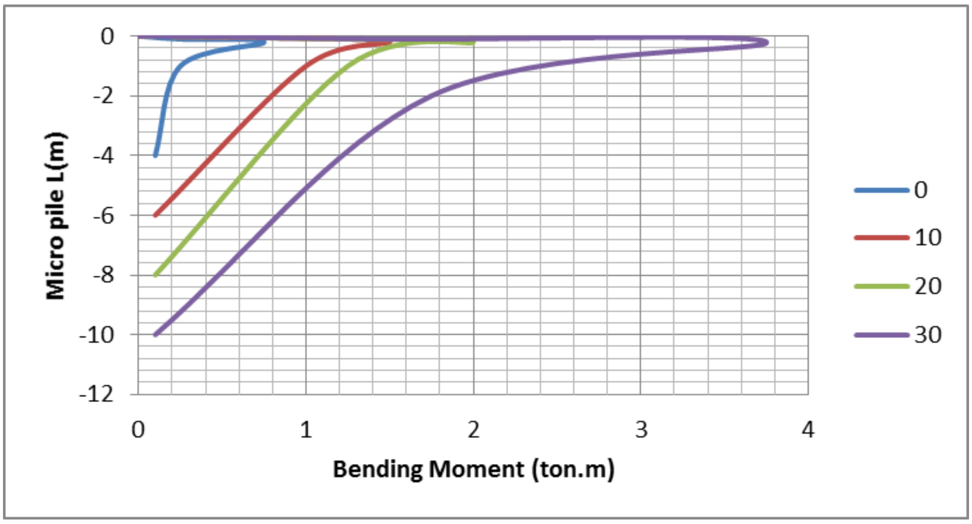

Figure 14. Bending moment diagram of micropiles for different inclination angles

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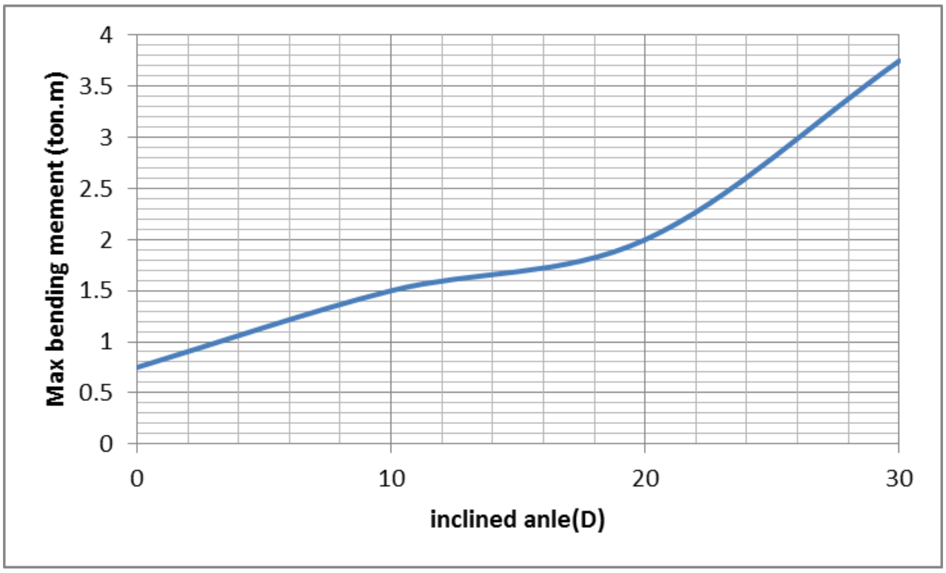

Figure 15. Maximum bending moment of micropiles for different inclination angles

As mentioned, as the inclination angle of the micropile with respect to the vertical increases, axial component is decreased and the lateral component is increased. Consequently, axial settlement is decreased. This decrease is visible up to 30% in vertical and inclined micropile results. However, with an increase in the inclination angle of the micropiles, internal forces and moments of the micropiles increases as well. Maximum bending moment along the micropile length with the20-degree inclination angle is about 4.75 times that of a vertical micropile. Therefore, as the inclination angle increases, settlement is reduced (by 30%) but the design moment of the micropiles has increased (by 375%) and this goes to show that there is no optimum design angle for micropile installation and it should be determined on the basis of design purpose which is weather focused on settlement control or structural design of the micropile.

Regarding the behavior of micropiles in problematic soils and considering the installation method and with purpose of improving the surrounding soil, micropiles are generally installed in soils which are lacking in bearing capacity or stiffness; and the modeled soil conditions are assumed with such conditions i.e., low strength parameters and categorized as problematic. Although modeling results of the current study in problematic soil can be compared with that of a model in good soil parameters, but it is out of the scope of the current article and is proposed as a recommendation.

With increasing the inclination angle of the micropile with respect to the vertical, axial component is reduced and the lateral component is increased. The main reason for this, is the behavior of the micropile which is mostly relied on the end bearing when the end is located in a soil with good strength parameters. Thus, as the axial component of the micropile is decreased, there is lesser force applied on the soil in end of the micropile which leads to lesser total settlements of the micropile. This decrease can be seen up to 30% between vertical and inclined micropiles. However, with increasing the inclination angle of the micropile, internal moments and forces of the micropile is reduced. The amount of maximum bending moment along the length of the micropile with 20-degree inclination angle is almost 4.75 times the bending moment of the vertical micropile. So, although the settlement is decrease with increasing the angle (30%), but the design moment of the micropiles has increased (375%), and this goes to show that there is no optimum design angle for micropile installation and it should be determined on the basis of design purpose which is weather focused on settlement control or structural design of the micropile.

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8. Result summary of the article

1. As seen, in analysis of the inclination angle of the micropile with respect to the vertical, increasing the inclination angle leads to reduction of settlement under a fixed load. Reduction percentage of the settlement in the micropile with 30-degree inclination angle is about 30% with respect to the vertical micropile.
2. With increasing the inclination angle of the micropile, maximum bending moment along the length of the micropile increased as well. While bending moment is negligible in the vertical micropile, increasing the inclination angle of the micropile leads to a steeper increase in bending moment of the micropile.

9. Recommendations

1. Comparison of the settlement and axial force results in micropile located in good and problematic soil
2. Investigation of the effect of length and diameter of the micropile in different inclination angles
3. Investigation of the effect of settlement and internal forces of the micropile under lateral load

Comparison of the two- and three-dimensional modeling of the inclined micropiles

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