Retrofitting of foundation for controlling the settlement of a infrastructure by micro pile: a case study

Mohammad Mahdi Hajitaheriha[1], Abolfazl Eslami [2], Niloofar Behnami[3]
Davood Akbarimehr[4]

1-M.Sc. Faculty of Engineering, Imam Khomeini International University, Qazvin, Iran.
2-Professor, Department of Civil and Environmental Engineering Amirkabir University of Technology, Tehran, Iran
3-M.Sc. Student, Civil Engineering Department, Shahid Rajaee University, Tehran, Iran.
4-Ph.D. Candidate, Department of Civil and Environmental Engineering Amirkabir University of Technology, Tehran, Iran

Mahdi_Hajitaheri@yahoo.com

Abstract

Micropiles are mainly used to increase the bearing capacity and reduce the settlements particularly for strengthening the existing foundations. Frictional resistance between the surface of the pile and its surrounding soil and the associated group/network effects of micropiles are considered as the possible mechanisms for improvement. This paper is mainly devoted to investigation a case study in which foundation of a drilling rig was retrofitted by constructing a thick concrete ring confining the existing foundation which was supported by micropiles. The modelling was conducted by GEO 5 software in two phases including and excluding micropiles, respectively. Both phases were done regarding the existence of cracks around the foundation. The obtained results show that this method enhanced the bearing capacity and flexural stiffness of foundation. Also, this study provides valuable information about the design and application of micropiles.

Keywords: Micropiles, Foundation of the drilling rig, Retrofitting, Tank

1. INTRODUCTION

A Micropile is a small-diameter (typically less than 300mm) drilled and grouted Pile that is prevalently reinforced by a light steel frame. Micropiles not only act as a structural resistance to soil settlement but they also improve the surrounding soil mechanical properties (strength and behavior) regarding the injection of cement mortar. Micropiles are primarily utilized to support against uplift force, wind, and earthquake loads. Consequently, micropiles are utilized to prevent various issues. For instance, micropiles prevent vibration in structures such as, bridges and/or in structures that face dynamic loads. Lastly, micropiles stabilize the slope of the walls, the ground and in addition strengthen the ground. [1]Lizzi (1982) and Plumelle (1984) showed that micropiles create an in situ coherent composite reinforced soil system and the engineering behavior of micropile-reinforced soil is highly dependent on the group and network effects that influence the overall resistance and shear strength of composite soil micropile system. Shahrour et.al 2004 and Sadek et al 2004 stated that as the stiffness and resistance of vertical micropiles to lateral loading is generally small, the use of inclined micropiles presents an interesting alternative to withstand inertial forces and to ensure the stability of the foundations' system under seismic loading. [6, 7]Isam et al (2012) investigated a 3D elastoplastic analysis of the influence of micropiles inclination on the seismic performances of micropiles. They showed that the inclination of micropiles led to a good mobilization of their axial component and consequently to an important decrease in the shearing and bending loading. Since micropiles worked mainly with the axial component, the use of inclined micropiles in the seismic area presented an interesting alternative. [5]Using the soil improvement technique with micropiles will decrease the subsidences significantly. On the other hand, the equipment used for installation and operation of the micropiles are counted as light industry equipment so that in terms of execution and availability they are having suitable pace. Using micropiles in some conditions like partial or total subsidence of a building that we are facing limits in height can be taken as the most effective (or the only) method for soil improvement. The idea of using micropiles drafted in early 1950 in Italy with regards to the innovative techniques for creating backrest in historical buildings which had been damaged, especially in the Second World War. This technology spread and distributed so fast in the world in a way that in 1973, 1965 and 1962 the UK, Germany and North America applied this technology respectively. In 1980, in China, this technology was applied to the Hu QIU tower which is over one thousand years old (959) in order to protect the building. Han showed that micropiles used in the practical area have made an attitude in soil improvement which is lead to make it sticky and causes to higher the soils mechanical parameters. In1993, FHWA became the supporter of the micropiles studies and the results of those studies turn into complete guidance for the methods of executing micropile theory. [2]

2. Main issue

The site of the drilling rig is located in South of Iran. During our experiment, an under slipping occurred that caused some cracks in site of the field. A site investigation into the geometric specifications of the seams and cracks showed that the cracks have variable width from 10 to 30 centimeters with depth of 2 to 20 meters. Site investigation and field observations indicate that the cracks are formed due to lack of site resistance against compressive and tensile forces made by tectonic activities and a lack of ability against these forces causes formation of cracks. The soil above the site has high erosion capability due to the precipitation and its severity. As a result the soil has been eroded due to high erosion and permeability. Occurrence of scouring can be caused by the field tectonic activities. Due to the importance of the issue and the presence of important infrastructure, it was unavoidable to improve and strengthen the foundation and find the reasons behind the problem (governing factors of the problem). The use of micropiles under the foundation will act like springs which will strengthen the ring's foundation and also the foundation of the drilling rig. Moreover, the grout injection during the micropiles implementation can improve the site bearing capacity due to filling the porosities. One of the differences of micropiles and piles is that the porosity will reduce the bearing capacity of piles however in micropiles this porosity will enhance the bearing capacity. This can be considered as one of the main advantages of micropiles over piles.
Figure 1 illustrates the strengthening process of the drilling rig foundation schematically. In this figure, the concrete ring is labelled as the "new foundation" and the existing foundation of drilling rig is labelled as "existing foundation".

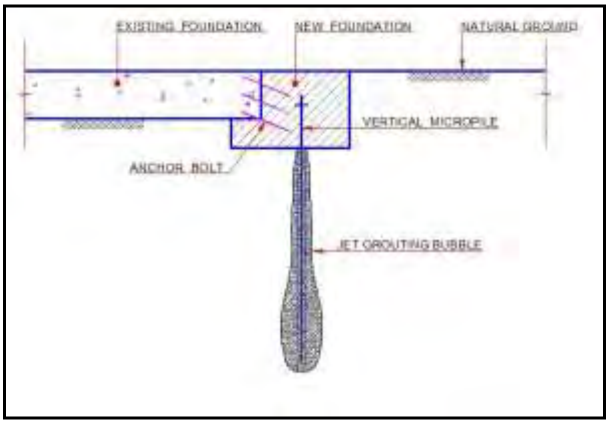

Fig 1: Cross section from the new and existing foundations and arrangement of vertical micropiles around it.

3. Geotechnical and Structural Bearing Capacity of Micropiles

For a geotechnical design of micropiles it has been considered that the force is transferred from micropiles to the ground by the interfacial friction between the soil and grout. The contribution of micropiles lid has been disregarded due to the following:
The allowable compressive and tensile bearing capacity of the micropile can be obtained by the following formulas;

$$P_{G-\text{allowable}} = \frac{\alpha_{\text{bond nominal strength}}}{\text{F.S.}} \times 3.14 \times \text{DIA.}_{\text{bond}} \times (\text{bond length})$$

The safety factor has been considered as 2.5 the injection diameter is 15 centimetres and the length of the bond area is considered to be 20 meters based on the holes on the buried pipe. As a result, the maximum allowable compressive and tensile load is obtained equal to 48.98 Ton. The allowable force of casing bond length can be obtained from following formula; for a geotechnical design of micropiles it has been considered that the force is transferred from micropiles to the ground by the interfacial friction between the soil and grout. The contribution of micropiles lid has been disregarded due to the following:

The allowable compressive and tensile bearing capacity of the micropile can be obtained by the following formulas;

$$P_{\text{transfer allowable}} = \frac{\alpha_{\text{bond nominal strength}}}{\text{F.S.}} \times 3.14 \times \text{DIA.}_{\text{bond}} \times (\text{bond length})$$

The allowable tensile force which can be supported by micropiles can be obtained from the following formula;

Or

The maximum bearable tensile force for the micropile can be obtained from the following formula;

$$P_{t-\text{allowable}} = 0.55\text{F}_{\text{y}-\text{bar}}\ \text{Area}_{\text{bar}} + P_{\text{transfer allowable}}$$

The allowable compressive force which can be supported by micropiles can be obtained from the following formula;

Or

The maximum bearable compressive force can be obtained from the following formula;

$$P_{c-\text{allowable}} = 0.40\text{f}'_{c-\text{grout}}\ \text{Area}_{\text{grout}} + 0.47\text{F}_{\text{y}-\text{bar}}\ \text{Area}_{\text{bar}\ bar} + P_{\text{transfer allowable}}$$

The allowable tensile and compressive micropile force for the foundation structure of the drilling rig is 116.66, 118.74 tons respectively. The allowable bearing capacity of micropile under tension and compression is equalled to the minimum of the mentioned items which is equalled to 48 tons. The bearing capacity of micropile's tip has been disregarded due to the safety consideration.

4. LOADING OF THE DRILLING RIG FOUNDATION

Fig 2. Illustrates the added foundation to the drilling rig. As a result of the weight of the drilling rig and the forces which are formed during digging, stresses can be caused in the foundation structure. This force is equal to 771.107 kilograms in the maximum situation which has been considered in the static state. Considering the impact factor equal to 1.2, the final maximum force is equal to;

$$\text{F} = 1.2 \times 1{,}700{,}000 = 2{,}040{,}000\ \text{lb} \cong 926\ \text{ton}$$

Fig 2: Digging boreholes of micropile into the duct to perform the new foundation

The force magnitude applied to each of the drilling rigs leg is equal to;

$$f = \frac{926}{2} \cong 463\ ton$$

It has been considered that this force is evenly distributed over the drilling rigs leg which has dimensions of 17*2.65. As a result, this force causes the following stress;

$$f = \frac{463{,}000}{17 \times 2.65} \cong 10277\ kg/m^2$$

5. Analyses of the drilling rig foundation on a cracked site without improvement

In this situation, the drilling rig foundation has been analyzed considering a crack occurred in the site which can decrease the bearing capacity of drilling rig foundation soil. Figures 3 to 11 show the results of this analyses.

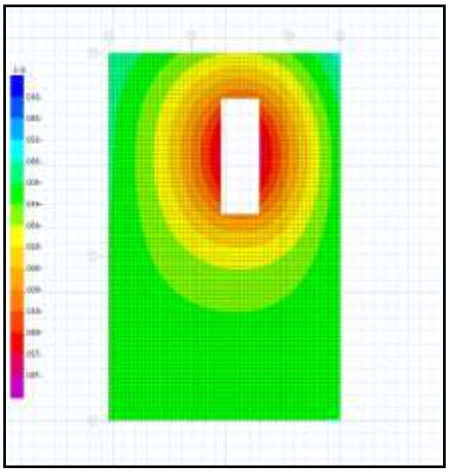

Fig 4: Modulus of subgrade reaction foundation of drilling rig's contour (unit is in Cm)

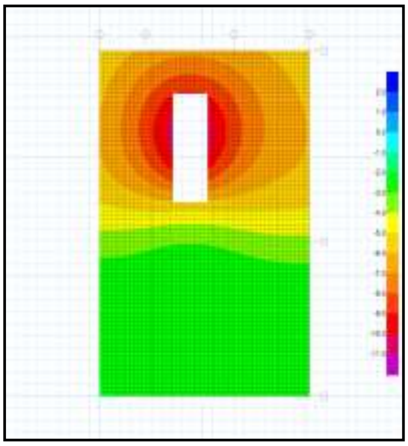

Fig 3: Settlement foundation of drilling rig's contour (Settlement unit is in Cm)

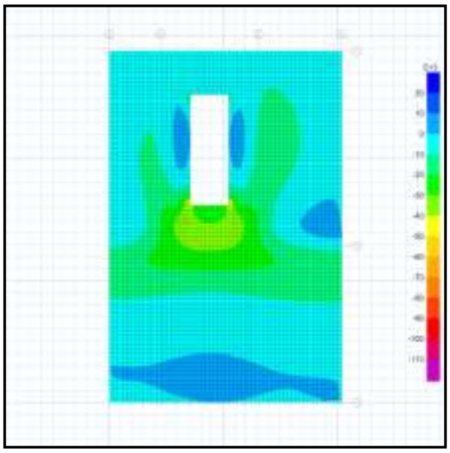

Fig 6: The minimum flexural moment formed in the foundation of the drilling rig (unit is in kilograms per cm in cm)

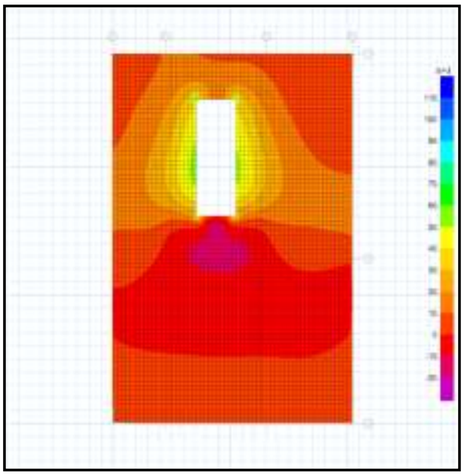

Fig 5: The maximum flexural moment formed in the foundation of the drilling rig (unit is in kilograms per cm in cm)

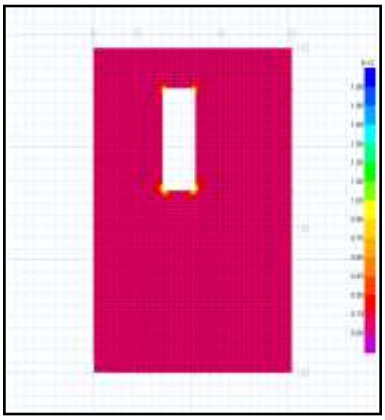

Fig 7: The maximum shear force formed in the foundation of the drilling rig (unit is in kilograms per cm)

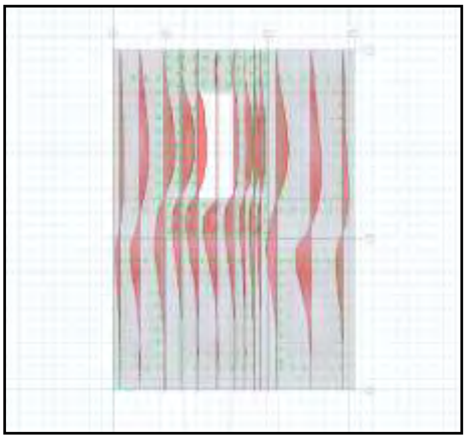

Fig 9: The flexural moment diagram formed in the foundation of the drilling rig along Y axis

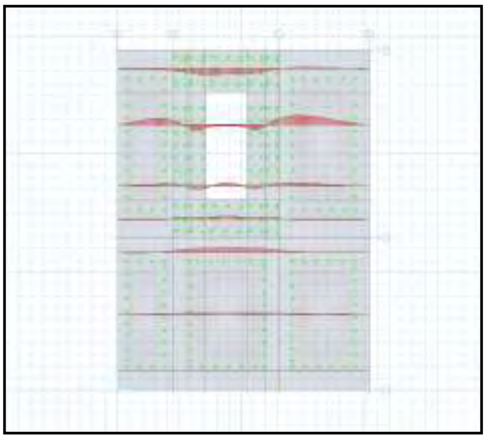

Fig 8: The flexural moment diagram formed in the foundation of the drilling rig along x axis

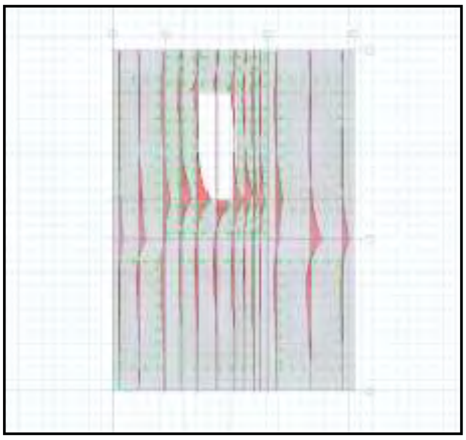

Fig 11: The shear force diagram formed in the foundation of the drilling rig along Y axis

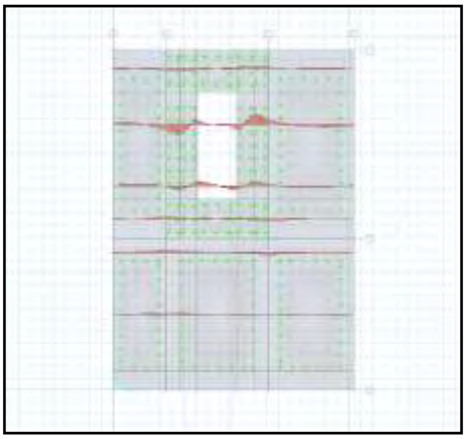

Fig 10: The shear force diagram formed in the foundation of the drilling rig along X axis

6. ANALYSES OF IMPROVED FOUNDATION BY MEANS OF MICROPILE:

In this section, the analyses and investigations of the drilling rig foundation have been presented taking into consideration that a crack had occurred in the site. The micropiles have been used to improve and strengthen the site. The results of this analyses are presented in figures 12 to 17. The total number of micropiles is equal to 73. The distance between the upper and lower micropiles are considered to be 1.5 meters and the distance between the left-hand sides micropiles are considered to be equal to 1.0 meter. This micropile pattern has been designed regarding the foundation situation. Due to the fact that micropiles transfer the high amount of concentrated load within the small diameter, they might cause punching shear failure, as a result, the flanges have been designed. Hence the punching shear has been evaluated for all micropiles and the maximum ratio of punching shear is obtained equal to 0.4.

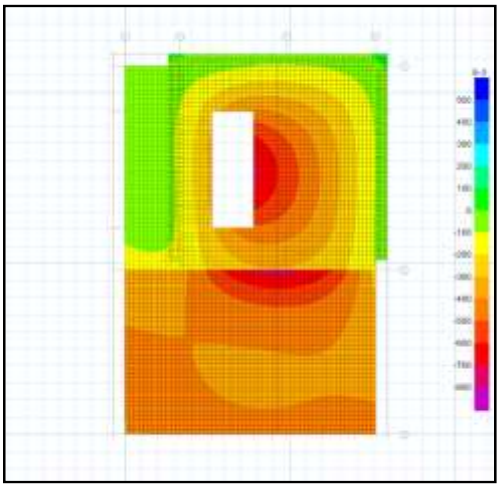

Fig 13: Modulus of subgrade reaction foundation of drilling rig's contour (unit is in Cm)

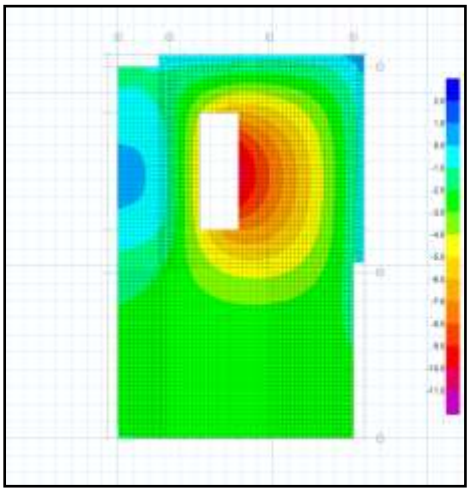

Fig 12: Settlement foundation of drilling rig's contour (Settlement unit is in Cm)

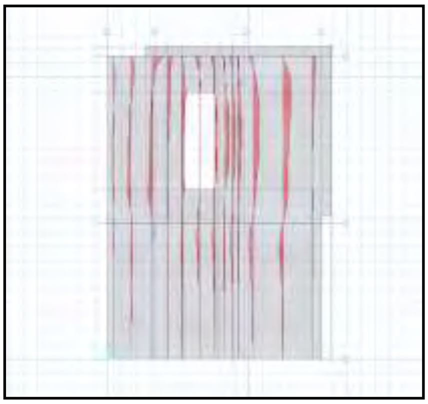

Fig 15: The flexural moment diagram formed in the foundation of the drilling rig along Y axis

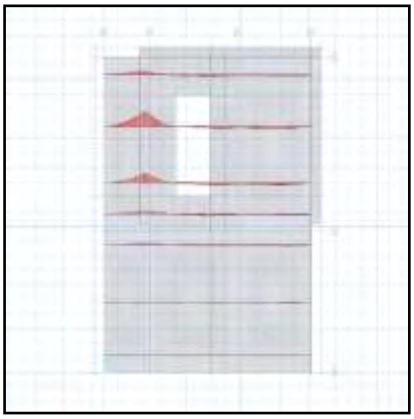

Fig 14: The flexural moment diagram formed in the foundation of the drilling rig along x axis

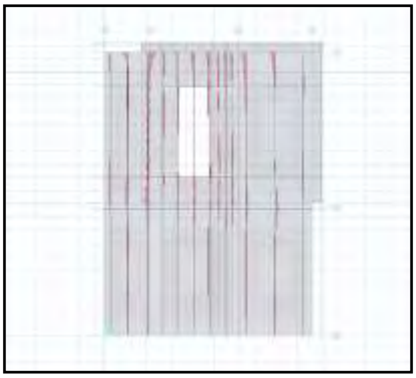

Fig 17: The shear force diagram formed in the foundation of the drilling rig along Y axis

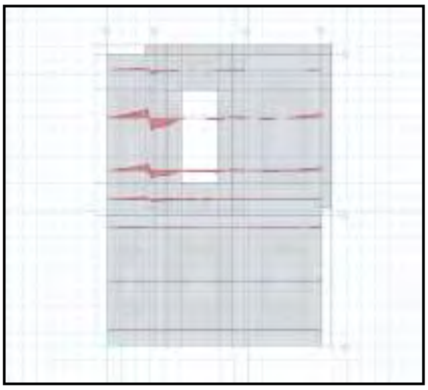

Fig 16: The shear force diagram formed in the foundation of the drilling rig along X axis

7. RESULT

This study presents the result of crack site analyses in two situations of unimproved and improved foundation by means of micropiles. By the implementation of micropiles the settlements and the reaction forces in the drilling rig foundation have been decreased. By comparison the results in two different scenarios, it can be found that this structural system can improve the foundation by means of increasing the load bearing area, the bending stiffness and decreasing the settlements and probable failures in the drilling rig foundation. As it can be observed in the diagram in the text, the foundation bearing properties in the improved state is much better than in the unimproved state.
I can be categorized the benefits of using micropiles in that case study in the following sections;
Maximum settlement of the foundation decreased more than halved from the non-reinforced foundation to the reinforced foundation: 8 to 3 millimeter.
Maximum modulus of subgrade reaction foundation of drilling rig decreased about around twice in both situations of analysis reinforced and non-reinforced, from 0.72 to 0.4 respectively.
The maximum flexural moment formed in the reinforced foundation of the drilling rig fell noticeably from 80000 kilogram per centimeter to centimeter in non- reinforced to 50000 kilogram per centimeter to the centimeter in reinforced.
The minimum flexural moment formed in the reinforced foundation of the drilling rig declined fivefold from 20000 kilogram per centimeter to centimeter to -80000 consecutively.

8. REFERENCES

1. FHWA (2000). " Micropile Design and Construction Guidelines – Implementation Manual", in Report No. FHWA-SA-97–070, Federal Highway Administration, U.S. Department of Transportation, McLean, Virginia
2. Han. J. (2006), ."A field study on the behavior of micropiles in clay under compression or tension". Department of Civil, Environmental, and Architectural Engineering, The University of Kansas, S.-L. Ye. Department of Geotechnical Engineering, Tongji University. NRC Canada, Can. Geotech. J. 43: 19–29;
3. Lizzi, F. (1982). "The pali radice (root piles)".Symposium on soil and rock improvement techniques including geotextiles, reinforced earth and modern piling methods, Bangkok, D-3.
4. Plumelle, C. (1984). "Improvement of the bearing capacity of the soil by inserts of group and reticulated micropiles". International symposium on in-situ reinforcementof soils and rocks, Paris, 83-89.
5. Shahrour Isam, Alsaleh Hassan, Souli Mhamed "3D elastoplastic analysis of the seismic performance of inclined micropiles" Computers and Geotechnics Journal 2012 doi:10.1016/j.compgeo.2011.08.006
6. Shahrour, Juran I. Seismic behaviour of micropile systems. Ground Improve J 2004;8(3):109–20.
7. Sadek M, Shahrour I. Three-dimensional finite element analysis of the seismic
Behavior of inclined micropiles. Soil Dynam Earthquake Eng 2004; 24:473–85.