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Effect of Diameter of Micropile on the Minaret Behavior during Earthquake, Virtual study

Mohamed Saad Hadi*	Haider M. Mekkiyah
M Sc. student	Assistance professor
Department of Civil Engineering	Department of Civil Engineering
College of Engineering	College of Engineering
University of Baghdad	University of Baghdad
m.alanbary1901m@coeng.uobaghdad.edu.iq	dr.Mekkiyah.h.m@coeng.uobaghdad.edu.iq

ABSTRACT

This study aims to suggest a technique for soil properties improvement of AL- Kadhimin shrine Minaret and to support the foundation, which has a tilt of roughly 80 cm from the vertical axis. The shrine of the AL- Kadhimin is made up of four minarets with two domes set in a large courtyard. The four minarets have skewed to varying degrees due to uncontrolled dewatering inside the shrine in recent years. However, the northeast minaret was the most inclined due to its proximity to the well placed inside shrine courtyard. When the well near the minaret is operated, the water level drops, increasing the effective stresses of the soil and causing differential settling of the minaret foundation. To maintain the minaret's foundation from potential lateral stresses, a micropile system has been proposed around it. PLAXIS 3D is used to do a three-dimensional numerical analysis in this study. A micropile system of several diameters has been considered for the suggested technique. In the analysis, the modeling and verification findings revealed that the suggested micropile system plays a significant role in incrementing the minaret's lateral load resistance (earthquake).

Keywords: Minaret; Earthquakes; PLAXIS 3D; Lateral load; micropile.

تأثير قطر الركيزة الدقيقة على المأذنة أثناء الزلازل, دراسة افتراضية

محمد سعد هادي	حيدر محمد مكيه
طالب ماجستير	استاذ مساعد دكتور
جامعة بغداد	جامعة بغداد

الخلاصة

الغرض من هذا البحث هو اقتراح طريقة لتحسين التربة والأساس للمئذنة التي يبلغ انحرافها حوالي 80 سم عن المحور الرأسي في مرقد الكاظمين في بغداد. يتكون الضريح من أربع مآذن ذات قبتان ضمن فناء كبير. ان المآذن الأربع مائلة بدرجات متفاوتة بسبب نزح المياه غير المسيطر عليه داخل الضريح في العقد القريب ، وعلى الرغم من أن المئذنة الشمالية الشرقية كانت الأكثر ميلاً بسبب قربها من البئر الموضوعة داخل فناء الضريح. عندما يتم تشغيل البئر بالقرب من المئذنة ، انخفض منسوب المياه ،

*Corresponding author
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مما زاد من الاجهادات المؤثرة للتربة مما ادى الى حدوث هطول متفاوت لاسس المنارات . ومن اجل حماية أساس المئذنة من الضغوط الجانبية المحتملة ، تم اقتراح نظام الركائز الدقيقة حولها. استخدم PLAXIS 3D لإجراء تحليل رقمي ثلاثي الأبعاد بخصوص هذه الدراسة لنظام الركائز الدقيقة المقترح وباستخدام عدة أقطار. في التحليل ، كشفت نتائج النمذجة والتحقق أن نظام الركائز الدقيقة المقترح يلعب دورًا مهمًا في قدرة التحمل الجانبي للمئذنة.
الكلمات الرئيسية: مأذنة, الزلازل, بلاكسيس D3 , الحمل الجانبي, لركائز الدقيقة.

1. INTRODUCTION

The Middle East is famous for its many historical buildings. This paper focuses on minarets or slender structures, and the countries that are famous for these buildings are Iraq, Turkey, and Iran, which have many minarets of historical and religious value, as shown in **Fig.1**; therefore, their historical value must be protected and supported it for **(Mammadov, 2013).**
Therefore, this study deals with the natural hazard that may have a big effect on stability, such as earthquakes, winds, and groundwater lowering, which will be focused on the state of earthquakes and how to support it, and the behavior of the minaret during earthquakes. Wells was discovered to be used in uncontrolled dewatering activities inside the shrine courtyard and near the northeast minaret. **(Shiekha, A, 2016)**.

Figure 1. Some historical minarets **(Mammadov, 2013)**

The dewatering effect is complemented by differential settlement caused by higher effective stresses under the minaret's foundations, resulting in fractures and tilting. **(Tan et al. 2014).** Another issue with dewatering is the production of holes in the soil due to the washing out of soil particles due to the flow of water in the soil under the foundation. **(Mekkiyah and Saleh, 2018).**
The employment of a Micropile for this purpose might also be owing to abnormalities with the construction of foundations, such as changes in water level or stress, i.e., the release of soil pressure induced by neighboring excavations **(Zumrawi,** and **Hassan, E., 2017).**

Micropile is therefore regarded as soil improvement for massive conditions, foundations with limited access and permanence (due to the small equipment required), seismic reinforcement, and so on **(Bustamante, M.e Doix, B.1985)**. These articles go through some of the benefits of employing this technology. Others include the fact that confirmed settlements are exceedingly tiny at the time of installation. It is feasible to preload sensitive settlement structures with a socket, and ultimately, the experiment tests carried out are cost-effective.

This was in response to the demand to devise techniques to support historical and archaeological buildings that have been damaged over time, the typical construction of which is to dig the required depth of the pile, initial grouting, and put additional grout under pressure **(Lizzi, 1964)**.

Research Objectives

The study focuses on the causes of minaret tilting as well as possible solutions. The major aims of this study are to improve knowledge of historical tall structure stability and rehabilitation operations.

1. Collecting the physical qualities of the soil beneath and around the minaret's base.
2. Using the finite element approach to model the soil and minaret (PLAXIS 3D). The numerical analysis' goal is to identify stresses, settlement, and deformation of the soil and minaret in various scenarios Like Earthquakes, explosions, and winds.
3. The soil and foundations are reinforced by using micropiles. Numerical analysis is also performed after strengthening to evaluate and simulate research work.

2. MICROPILES CLASSIFICATION SYSTEMS

FHWA (Federal Highway Administration) in the United States also classifies micropillars as small diameter, 300 mm, molded and syringe "in situ" piles whose configuration is shown in **Fig.2**. This entity has standardized aspects of the design and implementation of this technology as its use has increased over the years passed.

Today, micropile and their deployment have become widely used in numerous projects, and many organizations, research academies, and companies have worked out on extending and developing micropile throughout the world. They continue to foster the growth of Micropile demand, largely through geotechnical contractors with design-build capabilities.

The piles are known to have modest diameters, have site-based casting, and have a diameter of less than 300 mm. Due to its flexibility, it is employed for axial and lateral stresses (compressive or tensile). It's employed in earthquake-prone areas and building sites under a variety of circumstances. It is used as a support to reinforce foundation bearings and to prevent excessive soil settling. It's also utilized as a foundation for construction and to keep the earth stable **(FHWA, 1997)**.

The micropile categorization system is based on two categories, according to the **(FHWA, 1997)** report: (1) philosophy of behavior (design application); and (2) grouting method (construction).

The usage of small-diameter piles and micropiles in seismic retrofitting or new construction in seismic zones necessitates an in-depth examination of the seismic-induced response for groups of flexible piles with inclined members. In fact, because the rigidity and the resistance of flexible vertical piles to lateral stress are often low, inclined piles are used small-diameter piles may be a viable option for mitigating inertial forces and ensuring the structural integrity of the foundation's system's stability under seismic loading **(Fattah, Kadhim, 2010).**

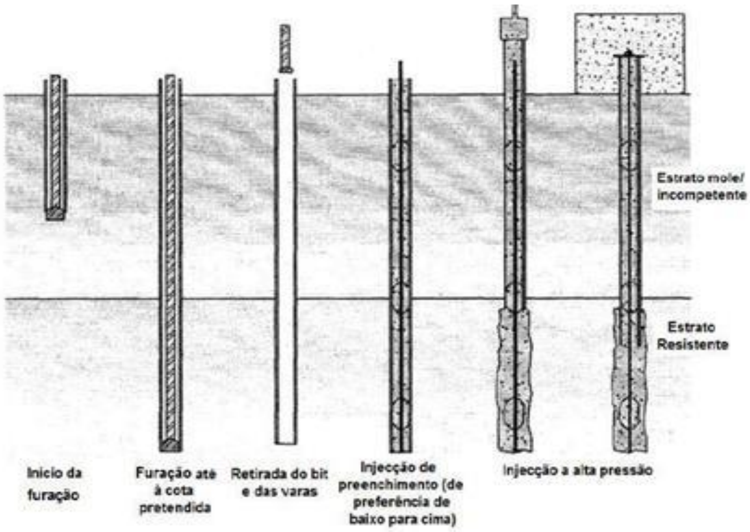

Figure 2. Molded and syringe "in situ" piles after **(FHWA, 2000)**

3. CASE STUDY and DESCRIPTION (AL- Kadhimin Minaret)

The minaret was constructed of bricks and plaster and is around 41.5 meters tall. The minaret superstructure is divided into three portions; the first indicates the minaret's height from the ground to the slab floor, which is approximately 11.2 m. The second portion has a height of 18.8 m and a diameter of 3.6 m, spanning from the slab floor to the top of the balcony. The last higher part reaches a height of 11.5 m. The foundations of the minaret consist of 3 steps. The dimensions of the first step are 3.6m × 3.6m and a depth of 2.5 m, and the dimensions of the second are 6m × 6m meters and at a depth of 1.5 m, and finally the last step is 8m × 8m at a depth of 1.5 m as illustrated in **Fig. 3** and **4.**

Figure 3. Al-Kadmain minaret (Engineering affairs unit)

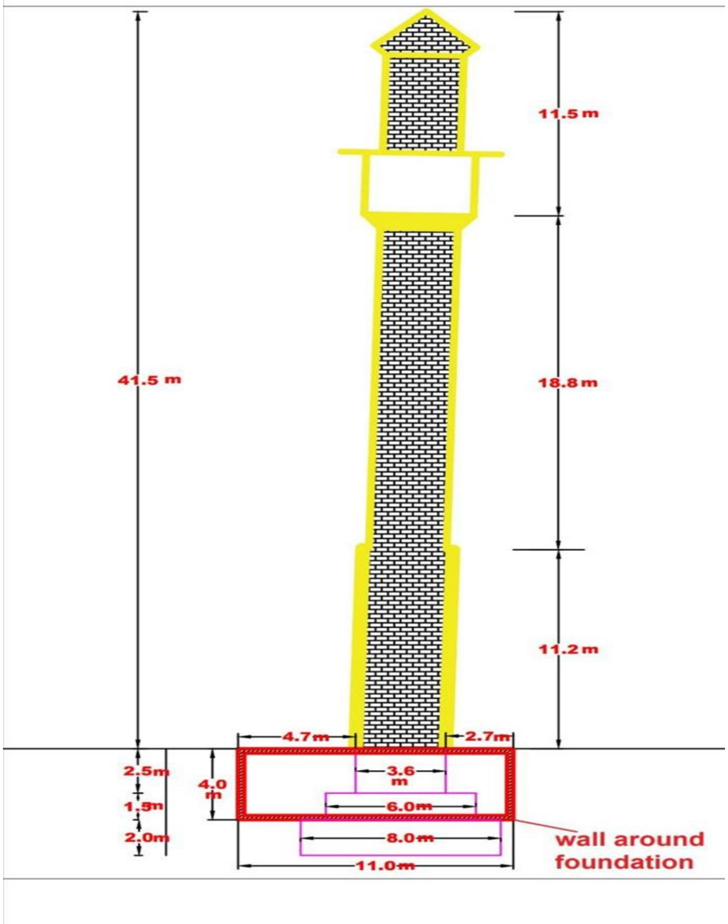

Figure 4. AL-Kadhimin Tilted Minaret

4. SOIL PROFILE

The soil profile shown **in Fig. 5** represents the stratification of soil layers under the ground surface at the (NEM) location. The most abundant soil at the site is a cohesive soil of brown to grey clay. The USCS classifies cohesive soil from Fat Clay (CH) to Lean Clay (LC) (CL). Then came poorly graded sand (SP) interspersed with highly graded sand (SW). **Table 1** shows the soil properties under the minaret.

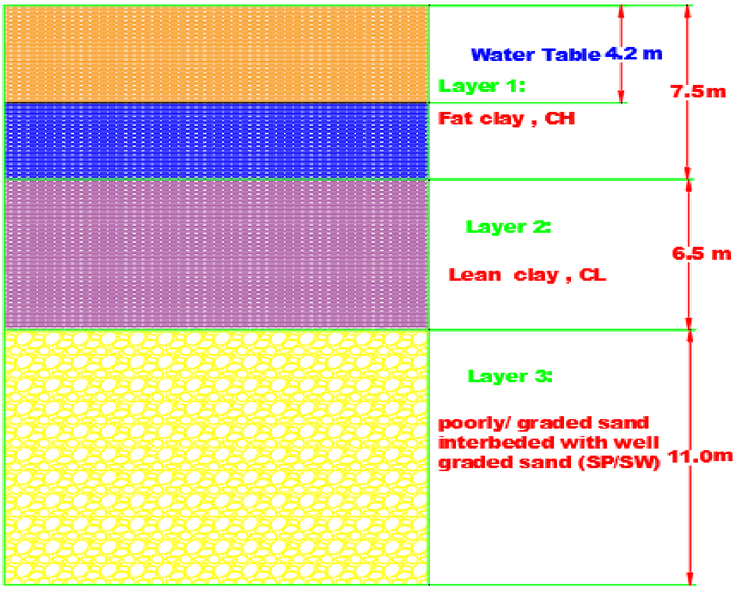

Figure 5. Soil Profile

The soil to a depth of (9-10 m) is virtually characterized by low seismic wave velocities (low stiffness modulus), indicating weak zones beneath the foundation and the surrounding wall of Al-Kadhimin shrine. The weakness was discovered at a depth of 3.0 m to 5.0 m below ground level (i.e. based on site investigation report). The water table level is 4.20 m below ground at the shrine's courtyard.

5. GEOMETRY of 3-D MODEL

This part gives a detailed description of the proposed system for maintaining the minaret's foundation, the micropile surrounding the minaret foundation was modeled using a linear elastic model with grout properties. The depth of the used micropiles is 12m with different diameters. The interface element between soil and micropile was also used to ensure their interaction. As for the body of the minaret and the foundation, they were modeled by using linear elastic for brick parts .

The important part of this study is to check the effect of the micropile surrounding the foundation of the minaret under the expected lateral loads such as wind loads, seismic loads, and the construction process near the minaret. Initially, the minaret was modeled in the current state with a tilt of 80 cm (The current situation of the northeastern minaret is 80 cm tilted due to the problem of dewatering) from the vertical axis by analyzing the weight of the minaret into two components, horizontal and vertical forces, and applied on the foundation in order to ensure the effectiveness of the micropile system around the foundation, PLAXIS 3D was used as a tool for analyzing this problem and showing the effect of the proposed system in the soil on the stability of the minaret foundation.

Concerning the proposed micropiles system, the studied variable are micropile diameter of micropile. The number of micropiles is seven on each side of the minaret on (the seismic line), and the distance between them is 0.5 m, and the distance between the base is 1 m.

Fig. 6 shows a three-dimensional model of the minaret surrounded by micropile, and a lateral force is applied to the foundation.

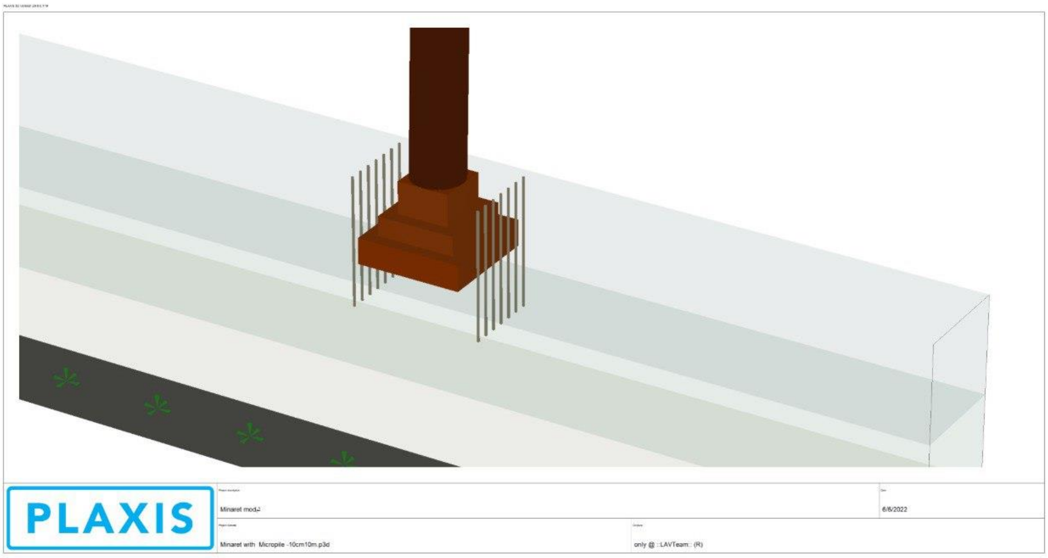

Figure 6. Three-dimensional model of the minaret and proposed micropile system around the minaret

They were modeled using linear elastic with brick properties. Soil properties that are used in numerical analysis are shown in **Table 1**. The properties of the micropile and the bricks are shown in **Table 2. (Engineering affairs unit at AL- Kadhimin holy shrine).**

Table 1. Soil properties

Description	Fat Clay, CH	Lean Clay, CL	Poorly /Well Graded Sand, SW/SP
Unit weight (KN/m^3)	20	20	20

Modules of elasticity (KN/m^2)	4000	6000	10000
Poisson's ratio	0.3	0.3	0.3
Cohesion (KN/m^2)	50	60	10
Internal angle ($\emptyset^{\circ}$)	8	10	35

The Virtual earthquake record was used as input motion in the analysis. The acceleration-time history of the record is given in **Fig. 7**. The file containing the earthquake data is available on **(Bentley Communities).**

Table 2. Micropile and Brick properties

Properties	***Micro pile***	***Brick***
Unit weight, γ	24 kN/m^3	17 kN/m^3
Elastic modulus of the grout of micro pile, Eg	$14.2*10^6$ kPa	$5.6*10^6$ kPa
Poisson's ratio, μ	0.2	0.2

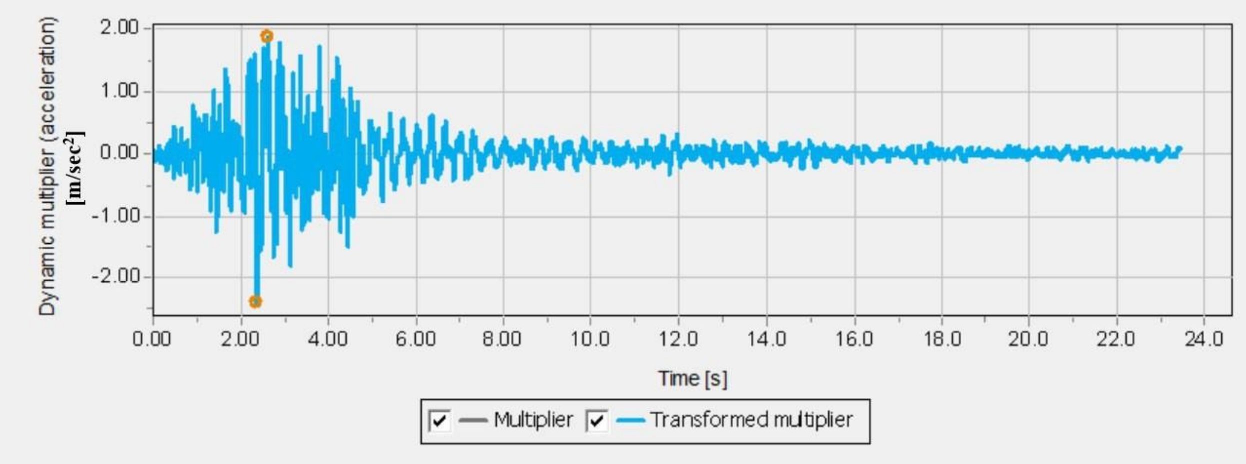

Figure 7. The acceleration time history of earthquake

Boundary Conditions

- (Deformation)The use of boundary conditions in numerical analysis is critical in the case of displacement; the boundary condition is applied as fixed on both sides of the model and bottom, but it is free on the surface
- (Dynamic analysis)The application of the model's boundary conditions (viscous) is essential in dynamic analysis in order to reduce the effect of reflected waves; **Fig. 8** shows the model's boundary condition.

Figure 8. Boundary conditions for dynamics calculations

6. NUMERICAL ANALYSIS RESULTS

This section discusses the effect of micropile diameter on the lateral resistance of the foundation. To gain firsthand knowledge of the influence of the little micropile surrounding the minaret's foundation shown in **Fig. 6**, the percentage increase in lateral resistance for each condition was determined using **Eq. 1**

$$P_{in} = \left(\frac{Lrp - Lrf}{Lrf}\right) \times 100 \quad (1)$$

Where:

P_{in} Percentage increase of the lateral resistance of the minaret foundation,
Lrp Lateral resistance of (foundation –micropile system).
Lrf Lateral resistance of foundation only.

P_{in} Or in other words, the percentage of improvement on the soil and the foundation to reduce the tilt by using this system

The effect of the diameter of the micropile on the lateral resistance of the foundation was studied; The depth adopted of the micro piles was 12 m.

The resistance of the lateral load is noted in the **Fig. 9** and **10**. When the diameters of the micropile are increased from 10 cm, 15 cm to 25 cm, the resistance to the lateral load increases from 1890 KN, 1943 KN to 1975 KN, and this indicates that the addition of the micropile and the increase in its diameter increases the strengthening of the support and the minaret.

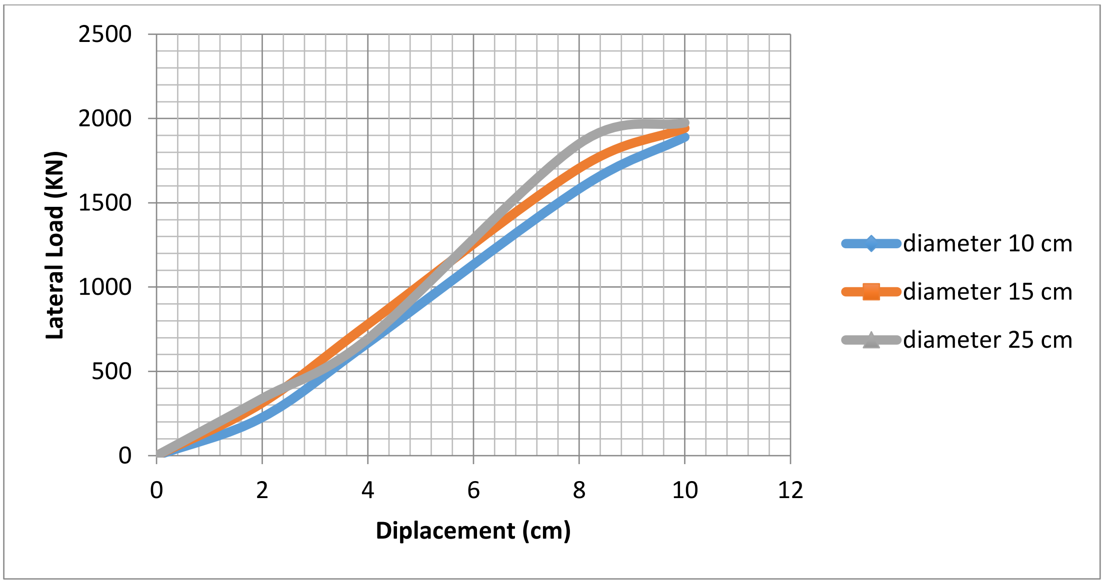

Figure 9. Lateral load resistance vs. displacement for different diameters of micropile.

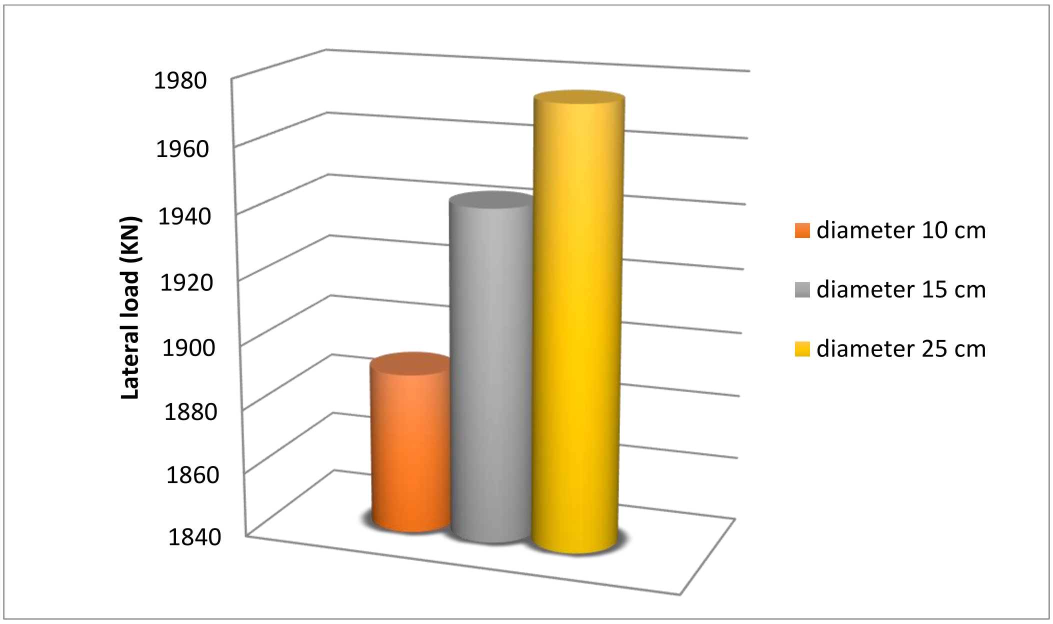

Figure 10. Lateral load resistance vs. diameter

The results showed that increasing the diameter of the micropile leads to an increase in the lateral resistance of foundation, as shown in **Fig. 11**. The effect of diameter on the percentage of increase in the lateral resistance of the foundation is clear as in **Fig. 12,** where the percentage of increase is about 23%, 26%, and 30% for micro-pile diameters, 10 cm, 15 cm, and 25 cm respectively.

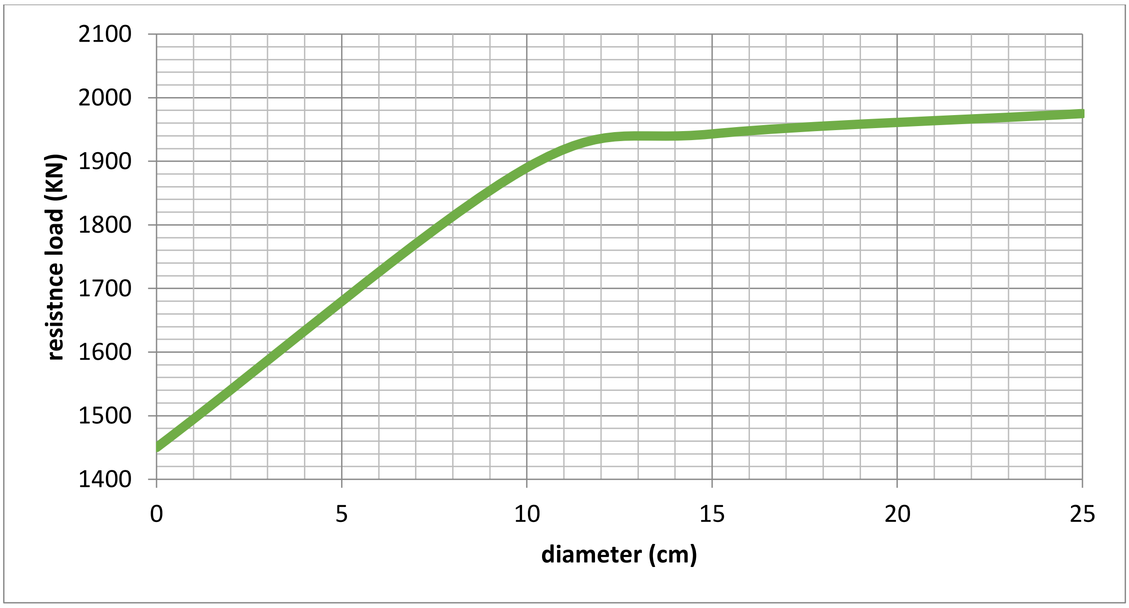

Figure 11. Lateral load Resistance for minaret foundation vs. diameter for micro-pile 12 m in depth

Figure 12. Percentage increase in lateral resistance at an increase in diameter

7- CONCLUSIONS

The following are the key findings of the current study:

1- The modeling findings demonstrated that surrounding the soil with a system of micropiles strengthened the lateral resistance of the minaret foundation when subjected to lateral stresses.

2- Based on simulation results, raising the micropile diameter from 10 cm to 15 cm and subsequently to 25 cm enhanced the lateral resistance of the foundation by around 23%, 26%, and 30%, respectively.

3- Based on the modeling, the proposed reinforcing system contains micro piles with diameters ranging from 10 to 20 cm and depths greater than the depth of the minaret foundation**.**

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