# Numerical Analysis of Failure Mode of Micropile in Cohesive Soil

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## Abstract

In this paper, finite element was used to study the behavior of micropile. The model was developed using PLAXIS 3D foundation program. Micropiles are tested by the static axial load testing of individual piles. In the FE-analysis the pile is assumed to be linear elastic and for the subsoil is assumed as Mohr-Coulomb model. The model was developed to simulate the micropiles type A where the grouting is applied by gravity. This modeliscompared with the results of the pile load test. A good agreement was obtained with the experimental results. Finally the failure pattern was investigated.

**مستخلص**

في هذه الدراسة استخدمت طريقة العناصر المحددة لدراسة الخوازيق اقل من 20سم (Micropile). وتم تطوير النموذج باستخدام برنامج بلاكسيس (PLAXIS 3D Foundation). اختبرت الخوازيق باستخدام ماكينة الضغط المحوري للخازوق المفرد. في هذه الطريقة تمت تطوير النموذج للخوازيق لتكون خطية ومرنة أما التربة فتمت نمذجتها حسب قاعدة مور-كولمب. تم تطوير النموذجليمثل الخوازيق ذات التصنيف (A) التي تم صبها باستخدام قوي الجاذبية فقط وبدون ضغط خارجي. تمت دراسة النموذج وقورنت نتائج النموذج مع النتائج الحقلية وكان النتائج مقاربة للنتائج الحقلية. وأخيراً تمت دراسة طريقة الانهيار للخوازيق.

***Keyword:***Micropile, Finite element, Failure load, Cohesive soil

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## 1. Introduction:

A micropile is defined as small-diameter (typically less than 300 mm), drilled and grouted non-displacement pile that is typically reinforced [1]. Based on the method of grouting (construction) they classified as: type A where grout is placed in the pile under gravity head only, and type B indicatesthat neat cement grout is placed into the hole under pressure.

In this paper finite element was used to study the behavior of micropile. The model was developed using PLAXIS 3D foundation program. PLAXIS 3D FOUNDATION is a three-dimensional PLAXIS program, developed for the analysis of foundation constructions including piles. The acceptance of numerical analysis in geotechnical problems is growing and finite element calculations are more and more used in the design. It's an effective way to study the behavior of micropiles as, once a model is verified, conditions can be changed with little effort to conduct a parametric study on the system variables.

The 3D finite element model used in the analysis was verified using field load test data preformed by Soorkty(2012) [2]. These micropiles were embedded in a cohesive soil on Khartoum-Soba. Micropiles are tested by the static axial load testing of individual piles until the pile reach failure. The failure occurs in the form of the sudden loss of load and increase in displacement. Numerical analysis of a load test on a micropile is shown and modeling aspects will be discussed. Also the failure pattern is shown, and finally the results of the models are compared with the results of the pile load test.

## 2. Finite element model:

The cross section of the geometry model was designed in accordance to Randolph Wroths (1978) [3] recommendations for the boundary: at least 50 times of the pile radius in the lateral direction, and 1.5 times pile length below the tip in the vertical direction, these boundary is necessary to provide sufficient accuracy.In this study the boundary of 40*40*20 in the direction of X,Y, and Z was chosen.

## 2.1 Model of soil and interface properties:

The soil was modeled as Mohr-coulomb [4] which is a model that can be considered as a first order approximation of real soil behavior. This elastic perfectly plastic model requires five basic input parameters young modulus (E), Poisons' ratio (V), cohesion (C), angle of friction (ф), and dilatancy angle (ψ).

The material parameters of subsoil profile considered for this study are presented in table (1) below (Soorkty, 2012) [2]. The layer of silty clay of low plasticity was encountered at top underlain by a clayey sand layer.

Table 1.The study soil properties

| Depth (m) | Group symbol | C (kPa) | ф (degree) | $\gamma_{sat}$ (kN/m³) | $\gamma_{unsat}$ (kN/m³) | E (kN/m²) | V | (ψ) (degree) |
|---|---|---|---|---|---|---|---|---|
| 1.5 | Cl | 245 | 13 | 16.5 | 18 | 1.0E+4 | 0.3 | 0.0 |
| 3.0 | Cl | 60 | 37 | 16.2 | 17.6 | 1.0E+4 | 0.3 | 0.0 |
| 4.5 | Cl | 20 | 41 | 17.4 | 18.7 | 1.0E+4 | 0.3 | 0.0 |
| 6-20 | SC | 15 | 45 | 16.7 | 16.7 | 1.3E+4 | 0.3 | 0.0 |

The interface between soil and pile is modeled with interface element to allow relative slippage when the shear stress mobilized on the shaft exceeds the limiting values.When using 15-nods soil element, the corresponding interface element are defined by 5 pairs of nods. The interface properties are calculated from the soil properties in the associated data set. The strength reduction factor, for rough interface between concrete and soil Rinter=1.

## 2.2 Model of micropiles:

A micropile can be described as circular structure with a uniform radial cross section and loading scheme around the central axis. The micropile was modeled as linear elastic non-porous.This model presents Hooks law of isotropic linear elasticity. The model involves two elastic stiffness parameters:Young's modulus and Poison's ratio that were chosen to assume high enough value that the pile will not fail before the soil.For the simulation of load tests a point load (in the negative y-direction) was applied on the top of the center of pile (centric loading).

Generation of the mesh based on the rupost triangulation procedure which results on unstructed mesh, this mesh may look disorderly, but the numerical performance of such meshes is usually better than the regular structed meshes. After generation the mesh PLAXIS automatically imposes a set of general boundary conditions to the geometry model. These boundary conditions are generated based on the following rules:

- Vertical geometry lines for which the x-coordinate is equal to the lowest or the highest x-coordinate in the model obtain a horizontal fixity (Ux=0).
- Horizontal geometry lines for which the y-coordinate is equal to the lowest or the highest y-coordinate in the model obtain a full fixity (Ux=Uy=0).
- Plates that extend to the boundary of the geometry model obtain a fixed rotation in the point at the boundary (ϕz=0) if at least one of the displacement directions of that point is fixed.

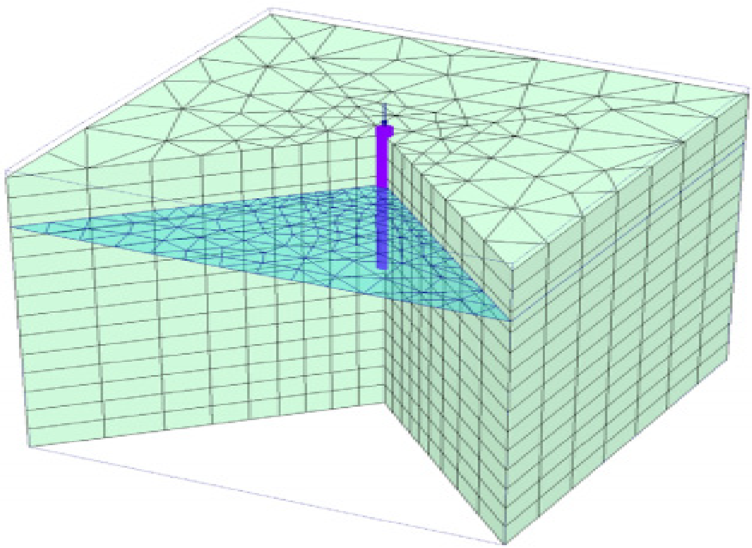

Fig. 1: Geometry model for micropile

- Type of element 15-Node element

- Number of element = 2432

- Number of node = 7124

- Average size of element = 3.63m

## 2.3 Results of the Model:

There are several criteria have been proposed to define the ultimate load of the Piles,AASHTO (1992)[5] and FHWA(1997)[6] recommend that theDavisson offset limit DOL [7] canbe used to determine the failure load.In this method (DOL) the failure load is defined as the load corresponding to a movement which exceeds the elastic compression of the pile when considered as a free column by a value of 0.15 inches plus a factor depending on the diameter of the pile (D/120), where D is the diameter of the pile in inches.

Failure point was determined following these steps:

1- Draw the load displacement curve

2- Draw a tangent line through the initial point of the load-displacement curve

3- Draw a line parallel to the tangent line at an offset equal to (0.15+D/120) (Where D= pile diameter in inches)

4- The load corresponding to intersection of the load-displacement curve and this offset in the slope tangent load ( Lst).

Hirany and Kulhawy [8] have proposed for micropiles that the failure load should be taken at $L2=f\times$ Lst, where Lst is the failure obtained from DOL , $f$ factor=1.18.

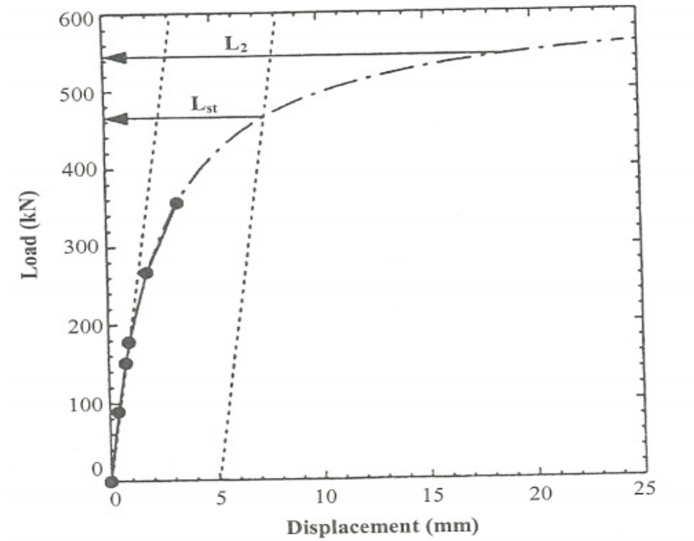


Fig. 2: Load-displacement curve

Figure 2, Illustrates points Lst and L2 on a load displacement Curve(Jeon and Kulhaw, 2002) [9].

## 2.3.1 Validation of the numerical model:

Comparison of the results between the field test and the FE results are shown in Table 2.

Table 2.Model validation of micropiles type A

| Test No | Diameter (m) | Shaft length (m) | Grout pressure(kpa) | Pile type | Failure load from field (KN) | L2 from numerical model(KN) | Discrepancy (%) |
|---|---|---|---|---|---|---|---|
| A | 0.10 | 4 | 0 | A | 129.3 | 140 | -8.3 |
| B | 0.15 | 4 | 0 | A | 235 | 213 | 9.4 |
| C | 0.20 | 4 | 0 | A | 265 | 236 | 10.9 |
| D | 0.25 | 4 | 0 | A | 445 | 354 | 20.4 |

The results in Table 2. show that for micropiles type a reasonable agreement between the field tests and the Numerical Model was achieved for piles of diameter 0.1m, 0.15m and 0.20m (≈±10). For test 4 capacity for micropile 0.25m diameter that is about 20.4% lower than that capacity obtained at the field.

As can be seen in that table, the values of numerical analysis are close to those of field test models. The differences between the experimental and the numerical values are dueto variety in environmental conditions in the field.

## 2.3.2 State of stresses:

To identify the failure pattern in the numerical model the stresses around the pile were plotted after the load test was conducted and when the failure was reached.

On **PLAXIS** there are different outputs of stresses; one of them is the relative shear stress $(\tau_{rel})$, which plotted as shadings over the geometry model.

The relative shear stress gives an indication of the proximity of the stress point to the coulomb envelope (i.e. the stress on the soil approached the shear strength of soil) and is defined as:

$$\tau_{rel} = \frac{\tau}{\tau_{\max}}$$

Where:

τ : is the maximum shear stress

$\tau_{max}$: is the maximum value of shear stress for the case where the Mohr's circle expands to touch the coulomb failure envelope keeping the intermediate principle stress constant.

Figures 3 to 8 show the results of relative shear stress for micropile d=10cm on:

- First step of calculation phase where there is only micropile without loading.
- Intermediary steps of calculation phase where the pile subjected to increment loading, and
- The final phase at the failure load.

These figures show the vertical section of the model and the coloured area representing the value of the relative shear stress, when $\tau_{rel}$=1 it can assumed that the failure was reached.

There are two ways for the pile to transfer the load; through the shaft and the tip. They are a function of the movement of pile that generates shear tension.In the cohesive soil the failure start at the tip and expanded upward and laterally around the shaft.

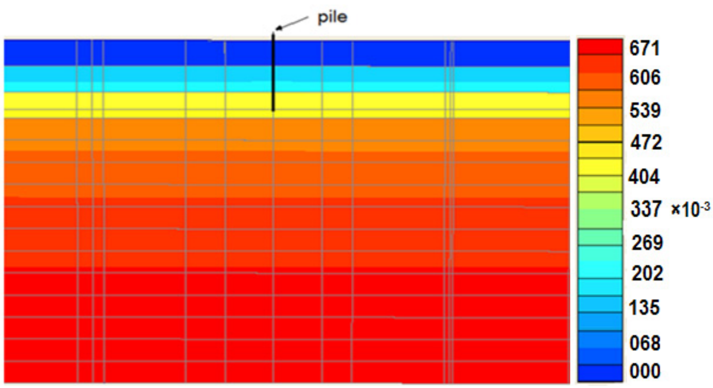


Fig. 3: Relative shear stress at first step (micropile without loading).

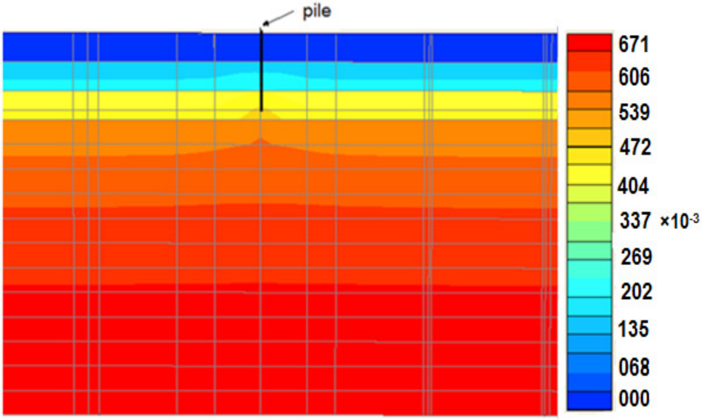


Fig. 4: Relative shear stress at intermediary step (load=30KN)

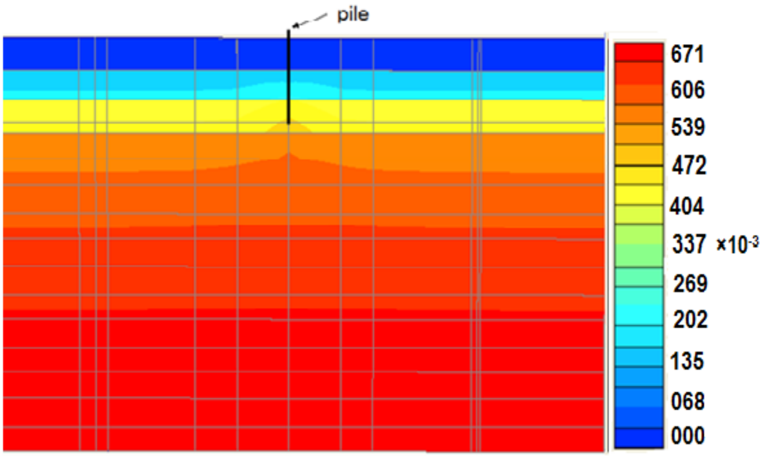


Fig. 5: Relative shear stress at intermediary step (load=50KN)

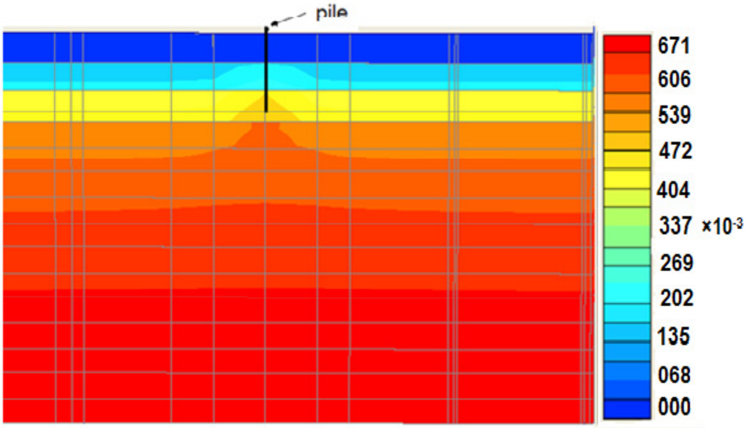


Fig. 6: Relative shear stress at intermediary step (load=80 KN)

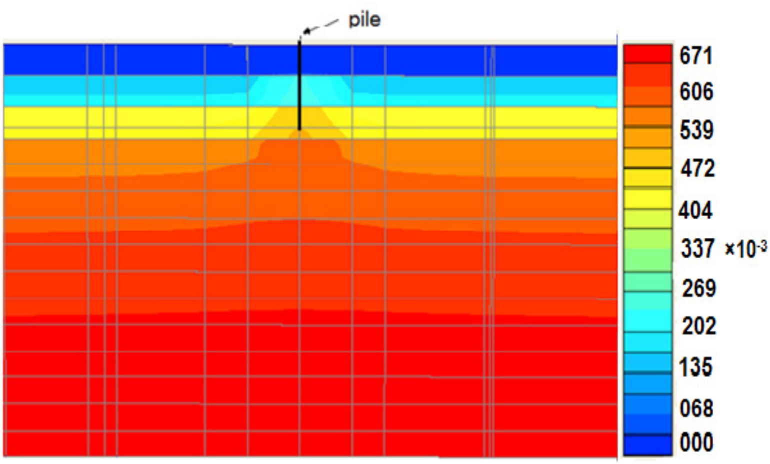


Fig. 7: Relative shear stress at intermediary step (load=110KN)

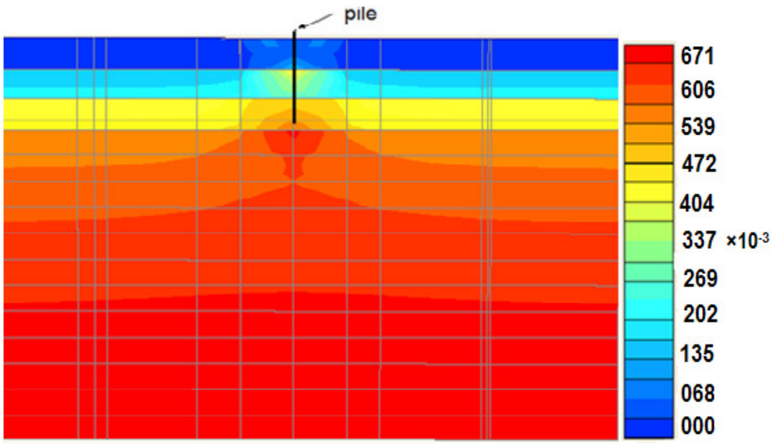


Fig. 8: Relative shear stress at final step (load =130KN

## 3. Conclusions:

- Numerical analysis together with a boundary condition using PLAXIS 3D program which uses finite element technique gives acceptable results in the micropiles computation.
- The model was developed to simulate micropiles type A where the grout is placed under gravity head only.The results of this model were verified against filed data.
- Davisson Offset Limit theory was used in this study to determine the failure point for micropiles type A ( L2 = f Lst ), and according to Hirany and Kulhawy [8] recommendation..
- The finite element analysis results show a reasonably good agreement with experimental results; with a discrepancy of within -8.3 to 20%.
- The failure pattern was successfully investigated and failure points was determined at any point and stage.

## 4. References:

[1] Federal Highway Administration 2005. "Micropile Design and Construction Guidelines – Implementation Manual" FHWA Publication No. FHWA-SA-97–070, US Department of Transportation, McLean, VA, USA.
[2] Soorkty. A, " Micropiles for light building" M.Sc thesis, Building and Road Research, University of Khartoum.
[3] Randolph, M.F., and Worth, C.P. (1978) " Analysis of deformation of vertically loaded pile", Journal of Geotechnical division, ASCE, 1465-1488.
[4] Brinkgreve, R.B.J., (1994). "Geomaterial Models and Numerical Analysis of Softening". Dissertation. Delft University of Technology.
[5] American Association of State Highway and Transportation Officials (AASHTO) (1977). Standard Specification for Highway Bridges. Washington, DC, 469pp., Revised 1992.
[6] FHWA, Drilled and Grouted Micropiles State-of-the-Practice Review. Report No. FHWA-RD-96-016/019, United States Department of Transportation, July 1997,
[7] Davisson, M.T. (1972) "High capacity piles" Proceedings, Lecture Series, Innovations in Foundation Construction, ASCE, Illinois Section, 52 pp
[8] Hirany, A. and Kulhawy, F.H. (1989) "Interpretation of load tests on drilled shafts – Pt. 1: Axial compression" Fndn. Eng. Current Principles and Practices, GSP 22, Ed. Fred Kulhawy, ASCE, New York, 1132-1149.
[9] Jeon, S. and Kulhawy, F., "Evaluation of Axial Compression Behavior of Micropiles," Foundations and Ground Improvement Proceedings, ASCE, Blacksburg, VA, 2002