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Efficiency of Micropiles Surrounded by Sand to Avoid Uplifting Deformation of Strip Footing over Expansive Soils

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***Abstract**: Strip footing built over expansive soils may be subject to considerable upward movement, which can lead to undesirable structural cracks. The aim of this study is to investigate the efficiency of the use of micropiles surrounded by compacted sand as a strategy may be used with strip footing to increase resistance to upward movement caused by expansive soils. Series of numerical models have been developed using PLAXIS 3D and the necessary material properties and boundary conditions have been defined. The influence of micropiles surrounded by compacted sand, the active zone, and the expansion degree of expansive soils were evaluated and discussed. Findings show that the use of micropiles enclosed by compacted sand with a strip footing enhances the resistance against swelling pressure.*

Keywords— Strip footing; expansive soil; Uplifting; micropiles; PLAXIS 3D; Numerical models.

1. INTRODUCTION

Expansive soils are clay minerals that display major changes in volume when exposed to moisture changes[1]. Such soils swell as their moisture content increases and shrink when their moisture content decreases[1]. Damage due to expansive soils could occur on any type of structure, road and other civil engineering structure that is not properly designed to resistance swelling pressure. The previous reports revealed that the damages were caused by an inadequate identification and classifying of expansive soils, improper soil investigations and interpretations and a misunderstanding of safety relevant to foundation design [2]. To measure the amount of heave that could accumulate at a specific time it is important to know what active zone of soil is being wetted and the expansive nature of that soil [3]. Depth of the active zone can vary depending on serval factors including capillary rise, leak in utilities, and infiltration due to irrigation or precipitation.

Light structures constructed on strip footing such as one or two-story buildings, warehouses and fences are more susceptible to damage because the swelling pressure is greater than superstructural loads. Sometimes such light structures are not designed to deal with this additional stress. As a result, the light structures built on the strip footing are harmed by the swelling pressure. Various methods have been recommended to prevent problems accompanying with expansive soils. The uplift deformation of the foundations can be avoided either by reduce expansiveness of clay by modifying the properties of the expansive soils or by implementing special foundation techniques. The properties of expansive soils can be modified by the addition of cement, lime, fly ash and other chemical additives[1]. The modifying technique depends on a variety factors. Although most of them have many limitations and are very expensive [4]. The construction foundation options that are used to prevent expansive soil problems include the use of pile foundation, stiff raft foundation, isolated foundations positioned at levels beyond the depth of the active zone, sand column, micropiles, and granular pile anchors.

Micropiles are widely acknowledged as a remedial strategy for underpinning structures and as well as a conventional foundation technique. The bearing capacity of micropile is provided by interface friction between the micropile surface and surrounding soils. Lateral swelling pressure is induced on the surface of the micropile when water is absorbed in the active zone of the expansive soil. Simultaneously, the induced vertical swelling pressure directly beneath the strip footing tends to push the footing upwards and pull the connected micropiles upwards[5]. Therefore, the existence of part of the micropile in the active zone of the expansive soil makes it vulnerable to swelling pressure. On the other hand, the extension of the micropile to the stable zone behind the active zone allows significantly to improve resistance to uplift deformation. This behavior adds more challenge to the design of micropiles in expansive soils. Numerous fields and experimental studies have proposed the micropile as a foundation approach to prevent expansive soil difficulties [5]–[8]. This approach is currently being researched in order to test it in a range of foundation types and expansive soil conditions.

Inserting compacted sand around micropiles is a special technique recently used to isolate micropiles from the surrounding swelling pressure [5]. There is no numerical research on the use of sand around micropiles to prevent uplifting deformation due to expansive soils. The aim of this paper is to research the efficacy of micropiles surrounded by sand as a technique for controlling the upward movement of the strip footing over expansive clay. Series of Numerical Models have been developed using PLAXIS 3D to demonstrate the problem. This study focused on three scenarios, first strip footing supported by micropiles surrounded by expansive soil, second strip footing supported

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by micropiles surrounded by compacted sand, and finally strip footing over expansive soils without micropiles. The influence of micropiles, the active zone and the expansion of expansive soils were evaluated and discussed.

2. NUMERICAL MODEL

To examine the efficiency of the micropiles surrounded by sand in enhancing the strip footing behavior constructed over expansive soil, three independent numerical analysis were performed. First, strip footing supported by micropiles surrounded by expansive soil, second strip footing supported by micropiles surrounded by compacted sand and finally strip footing over expansive soils without micropiles. Fig.1 to Fig. 3 shows the typical schemes of the model was examined in this paper. In all cases, the strip footing is connected to the stable zone using the micropile Type A, space between the micropile is considered 3 m. The length of all micropile is 6 m and the diameter is 0.2 m. The soil profile contains an expansive soil layer with a thickness of 6 m and a stiff clay layer of up to 15 m beneath that layer. The cross section of strip footing adopted for the numerical study is $0.4\,m \times 0.4\,m$.

Finite element models (FEM) was conducted using PLAXIS 3D software. The soil layer profiles were modelled using borehole feature available in PLAXIS 3D. The expansive clay and stiff clay were modelled using Mohr-Coulomb material model with undrained conditions. The soil layers properties were obtained from previous studies done in Wad Medani City, Sudan [9]–[12]. The interface of the micropile to the adjacent soil is modelled automatically in the PLAXIS 3D software[13]. The mesh size is refined to produce the best and most reliable performance. The boundary condition was taken as standard fixity in which roller supports are assumed for vertical boundary surface and entirely fixed state at the base of the soil bed. The sand surrounding the micropile was modelled using a drained condition. The Material properties assigned to expansive soil, stiff clay and sand are shown in Table 1. The concrete of strip footing was modelled as a liner elastic material. The parameters of micropiles and strip footing are presented in **Error! Reference source not found.** and Table 3 respectively. The strip concrete footing and the surface layer of the soil have no interface element because there is no slippage between the concrete and the soil under it [14].

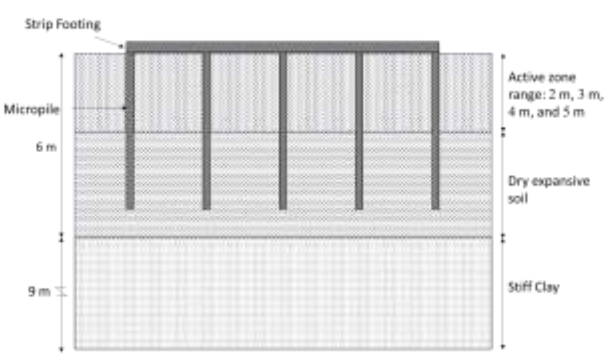

Fig. 1. Typical geometry of strip footing supported by micropiles.

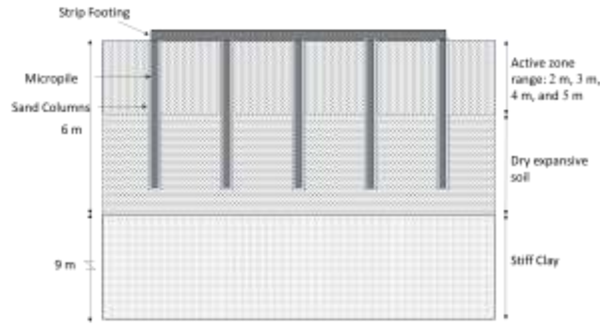

Fig. 2. Typical geometry of strip footing supported by micropiles surrounded by sand.

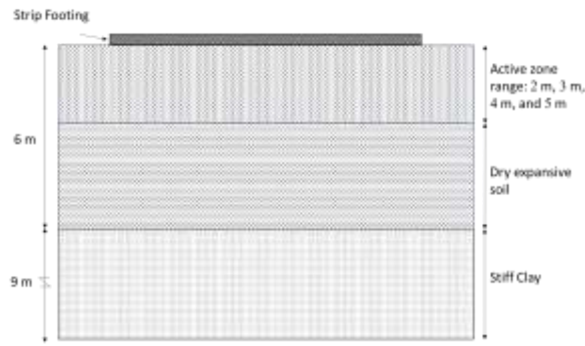

Fig. 3. Typical geometry of strip footing lying on expansive soil without micropiles.

Table 1: The value adopted for the FEM of soil layers and sand around micropiles.

Parameter	Expansive Soil	Stiff clay	Sand
Unsaturated unit weight, (kN/m^3)	17	19	18
Saturated unit weight,(kN/m^3)	19	20	20
Cohesion,(kN/m^2)	60	200	-
Friction Angle, (°)	20	27	22
Elastic Modulus, (MPa)	10	50	25
Passion Ratio	0.3	0.4	0.3

It is important to know what zone of soil is being wetted and its expansion in order to assess the heaviness of the soil

[1]. The active zone of the expansive soil is the moisture depths selected to be 2 m, 3 m, 4 m, and 5 m. In the wet active zone, the swelling deformation action is simulated by applying a positive volumetric strain to the active zone. The initial phase was considered before any structure has been built. The generation of initial affective based on the default k_0 procedure values is based on the formula $(1 - sin\phi)$for normally consolidated soils. The next step is the calculation process, which is divided into calculation phase, much like construction phases.

Table 2: Material properties of concrete footing.

Parameter	Values
Elastic modulus, (MPa)	30×10^3
Unit Weight, ,(kN/m^3)	24
Poisson's ratio	0.2
Thickness, (m)	0.4

Table 3: Material properties of Micropiles.

Parameter	Values
Elastic modulus, (MPa)	20×10^3
Unit Weight (kN/m^3)	24
Poisson's ratio	0.1
Diameter, (m)	0.2

3. Results and Discussion

To assess the efficiency of the micropiles system for enhancing the performance of strip footings on expansive soils, three independent numerical analysis were performed. First, strip footing lying on expansive soil without micropiles, second strip footing supporting by micropiles and finally strip footing supporting by micropiles surrounded by sand. The numerical results of these three scenarios were obtained and discussed here.

2.1 Effect of Sand around Micropiles

The results showed that the upward deformation of the strip footing decreased in the case of the use of micropiles. Moreover, negligible vertical movement is developed when sand around micropiles is used. Fig.4 shows the uplifting deformation at the top of the strip footing resting on a 6 m thick expansive soil. The active zone and the volumetric strain adopted for this compression are 3 m and 2.5% respectively. It is obvious that when micropiles are used the upward deformation at the top of the strip footing decreased by 47.3 %, while a decrease of 97.8 % in the case of use of sand around the micropiles was reported.

2.2 Effect of Active Zone Depth

The depths of active zone of 1m, 2 m, 3 m 4 m and 5 m were studied. The volumetric strain applied to all active zone depth is 2.5%. Fig. 5 shows maximum uplifting deformation for three cases strip footing without micropiles, strip footing over micropiles surrounded by expansive soil, and strip footing over micropiles surrounded by sand. The uplifting deformation increases as the active zone increases in case of strip footing sitting on expansive soil and even in case of strip footing over micropiles, while slightly increases were observed when the strip footing was strengthened by micropiles surrounded by sand.

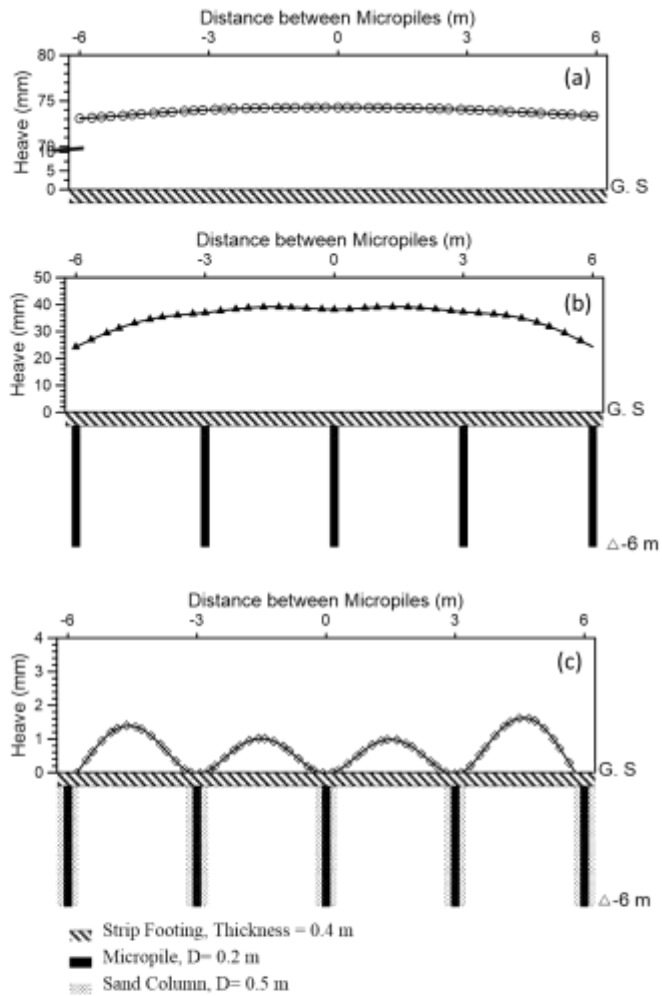

Fig. 4. Uplifting deformation at the top of the strip, (a) Strip footing lying on expansive soil without micropiles, (b) Strip footing supporting by micropiles, and (c) strip footing supporting by micropiles surrounded by sand.

2.3 Effect of Degree of Swelling Pressure

Volumetric strain of 2.5%, 5% 7.5%, and 10 % are considered in the analysis, the active zone depth adopted for this comparison is 3m. The effect of degree of swelling is shown in Fig. 6. The uplifting deformation increases as the volumetric strain increases for strip footing sitting on expansive soil and for strip footing over micropiles, while small growths were noted when the strip footing was reinforced by micropiles surrounded by sand.

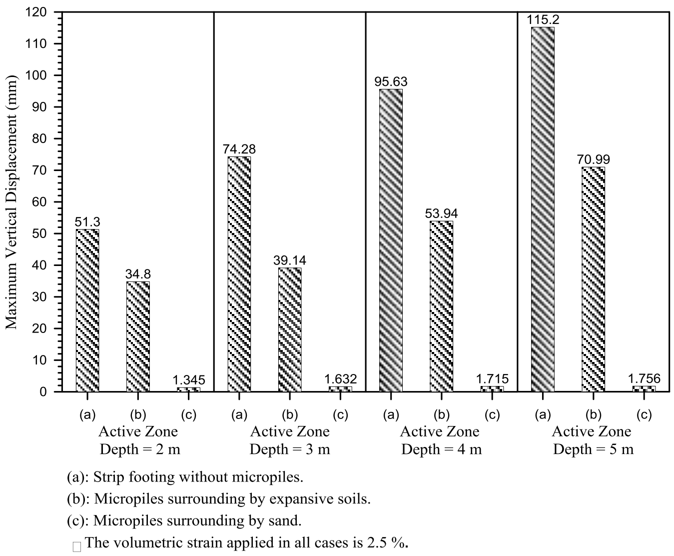

Fig. 5. Maximum Uplifting deformation at the top of the strip footing for active zone 2 m, 3 m, 4 m, and 5 m.

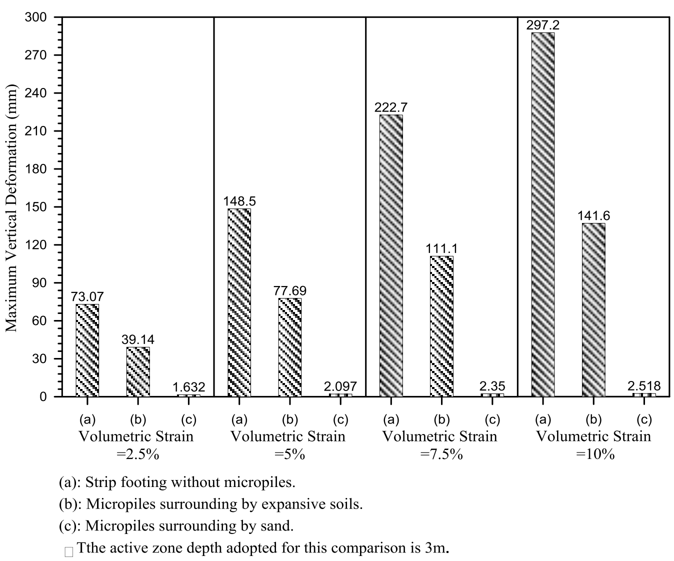

Fig. 6. Effect of swelling degree variance on uplifting deformation values

4. CONCLUSION

The paper focused on the effectiveness of the micropiles enclosed by sand to mitigate the heave of the strip footing laying on expansive soils. The conclusion reached from this numerical study can be summarized as follows:

1. The effectiveness of the micropile technique to avoid the heave of expansive soil can be further enhanced by using micropiles surrounded by sand.
2. It is evident that when micropiles are used the upward deformation at the top of the strip footing has decreased by 47.3 per cent, while a decrease of 97.8 per cent has been recorded for the use of sand around the micropiles.
3. The uplifting deformation increases as the active zone increases in case of strip footing resting on expansive soil and even in case of strip footing over micropiles, while slightly increases were observed when the strip footing was reinforced by micropiles surrounded by sand.
4. The uplifting deformation increases as the volumetric strain increases for strip footing sitting on expansive soil and also for strip footing supported by micropiles, while minor uplifting were noted when the strip footing was supported by micropiles surrounded by sand.

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