Performance of piled raft foundations under the effect of
dewatering nearby an open pit

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Abstract. The dewatering arrangement is required in execution works and it needs more attention due to the additional vertical settlement produced on the adjacent pile foundations. Raft foundations are being increasingly utilized for construction in cases of subsoil conditions with a high water table. Also, soil displacements in adjacent un-braced deep open pit may be a reason for high damages to the close buildings and foundations systems. The aim of this study is to examine the behaviour of piled raft foundations considering different pile locations under the effect of line drain and stage drilling of nearby open foundation pit. The line drain was used as dewatering process through the soil in this study. The pile vertical settlement and lateral displacement at various depths of excavation of an open pit in addition to the effect of line drain were investigated. A numerical modelling by using the three dimensional finite element package PLAXIS 3D is presented to simulate the problem. The soil is presumed to consist of two layers of deposit, the first is a clayey layer assuming soft soil criterion and the second is a sandy layer conforming to Mohr-Coulomb failure criterion. It is found that there is an obvious effect of dewatering by line drain with the drilling process for corner and face piles of a piled foundation whereas less effect for the centre piles.

1. Introduction

The dewatering system is necessary in erection works. In addition, it requires more interest due to its effects that produce further vertical settlement of adjacent pile foundations [1]. If the pile foundation is settled, that would be considered a possible failure type which can lead to title of the building. The vertical settlement of a pile as axial load is applied that consist of three parts: (a) Axial compression of pile; (b) Sliding between soil-pile boundary; (c) Whole vertical settlement of soil layer [12]. Rafts are being progressively used for structure in cases of subsoil circumstances with effect of water table. As soft soil the long end-bearing piles are required for transmission of the total load to stiffer and deepest soil layers. If the shear strength is reasonable for providing the required bearing capacity of a raft foundation only, the vertical settlement may be extraordinary. For that case, a piled raft foundation needs to be selected for decreasing vertical settlements. The piled raft foundation comprises of three load-enduring portions: raft, piles and subsoil according to their stiffness [13]. The analysis of the pile foundation with the effect of vertical and horizontal loading is a complicated problem. The pile behaviour is governed by soil movement. So, the situation is treated as soil-structure interaction [9]. Open pits for erecting tall structure in packed populated region have become much more a common widespread issue in civil engineering. If not, there is a good design for shoring support, this drilling process that is developed for lateral and vertical movements of the soil mass closes the drilled pits. Those movements may be a source of high destruction of the nearby structures. The design of these
open pits must consequently contain an assessment of soil movement in addition to a check of stability of the nearby structures [3]. The produced case study presumed at known place in Baghdad city for two kinds of piles all of which are underwater. Outcomes showed the effect of lowering water table on pile foundation vertical settlement, consolidation of soil nearby the pile, soil-pile interaction and negative skin friction [1]. A simple model using EXCEL type program had been suggested for simulating the piled raft in liquefied soil. The analysis showed that the pile settles if the soil strength decreases by 30% [12]. Negative skin friction happens as concrete piles are located in soft soils, consolidating soil-mass, etc., causing in a plunging force that increases vertical settlement of piles. Negative skin friction happens as the vertical settlement amount of the adjoining soils is more than that of the piles [12]. An increase in effective stress happens in soil layer as a result of lowering of water level. Moreover, the consolidation vertical settlement increases. The quantity of vertical settlement is influenced by soil stiffness and stress history [12]. Mutual simplifications that end-bearing piles settle are equal to the soil vertical settlement at the base elevation and friction piles with the ground surface vertical settlement present lesser and up amount that are only effective for specific ideal cases. The vertical settlement of piles with a high constituent of shaft friction is computed mostly by the real load on the pile comparative to the ultimate capacity of the pile. The lateral pile behaviour is depends mostly on the comparative rigidity of the pile to the soil. Figure 1 represents the model for long piles. These bending moments are very important. While for short piles that is very firm, multistrutted, deep excavations (two to three times deeper than the piles), vertical settlements are prospective to be much more significant than lateral deflections [8].

![Figure 1. Deep excavation with short piles and long pile](image)

Slight data is present in literature on behaviour of pile in piled raft with the influence of lowering of ground water level nearby open pit of foundation.

In this paper, the vertical and lateral vertical settlement of piles are dealt with for different pile locations in the piled raft of 0.50 m thick with the effect of line drain and adjacent open foundation pit of 4.0 m deep. The finite element package PLAXIS 3D is used to study the problem.

2. Modelling of the Pile-Soil System

In this analysis, the subsoil consists of 40 m deep, and is divided into two parts: an upper part of 10 m that consists of clay and a lower part of 30m which consists of sand. The soil properties are listed in Table 1&2. Figure 2 shows the grain size distribution of sandy layer. Ground water level is with the level of natural ground. A raft of 18m×18m of 0.50 m thickness is considered as the raft modelled as plate element. 8×8 square concrete piles of 0.40m×0.40m size are put on the length of 12.0 m as shown on Figure 2. The line drains are used as hydraulic condition that is utilized to describe lines inside the model as the excess pore water pressure is reduced. The formation of line drain same as a line, the line drain length in present analysis of 12.0 m and 0.50m of horizontal distance from the raft nearest edge and excavation face. The model dimension is selected as 80m×80m×40m. The plan area is 80 m×80m for modelling and analysis. A set of 3D finite element analyses are applied, by using
PLAXIS 3D Foundation program, to examine the effect of ground water movement with existing nearby foundation open pit of 15.0m × 22.0m on piles group behavior. Three examined piles are chosen as follows:

Pile (A): located at corner of group.
Pile (B): located the center of front row against open pit and line drain
Pile (C): located at the center of the group.

A 10 nodded tetrahedron element is used in the analyses. The clay is modelled as a soft soil as the soft soil model is a Cam-Clay type model particularly intended for primary compression of near normally consolidated clay. A sand layer is modelled as Mohr-Coulomb model. The dilatancy angle is set as zero for soft soil model (for cohesive soil $\varphi$ equals zero) but for non-cohesion the dilatancy angle depends on soil density and angle of internal friction, the dilatancy angle is set as 4.0 for sandy layer as shown in Table 2. [8] The drilling process is modelled as four stages. The relevant excavation depths of these stages are; 1, 2, 3 and 4m respectively.

### Table 1. Material properties of clayey soil.

| Parameter                  | Name       | Value   | Unit |
|----------------------------|------------|---------|------|
| Material model             | Model      | Soft Soil | -    |
| Type of material behavior  | Type       | Undrained (A) | -    |
| Unit Weight of soil        | $\gamma_{sat}$ | 17.00 | kN/m$^3$ |
| Stiffness Parameter        | $\lambda^*$ | 0.15 | -    |
|                            | $\kappa^*$ | 0.03 | -    |
| Cohesion                   | $C_{ref}$  | 25.0    | kN/m$^2$ |
| Friction Angle             | $\phi$   | 15.0    | °     |
| Dilatancy angle            | $\psi$   | 0.0     | °     |
| R inter                    |           | 0.7     |       |
| Data Set                   |            | USDA    |       |
| Model                      |            | Van Genuchten |   |

### Table 2. Material properties of sandy soil.

| Parameter                  | Name       | Value   | Unit |
|----------------------------|------------|---------|------|
| Material model             | Model      | Mohr-Coulomb | -    |
| Type of material behavior  | Type       | Drained  | -    |
| Unit Weight of soil        | $\gamma_{sat}$ | 20.00 | kN/m3  |
| Young’s Modules            | $E_{ref}$  | 15000   | -    |
| Poisson’s ratio            | $\nu$   | 0.25    | -    |
| Cohesion                   | $C_{ref}$  | 5.0     | kN/m2 |
| Friction Angle             | $\phi$   | 34.0    | °     |
| Dilatancy angle            | $\psi$   | 4.0     | °     |
| R inter                    |           | 0.7     |       |
| Data Set                   |            | USDA    |       |
| Model                      |            | Van Genuchten |   |

3. **Finite Element Modelling Results**

A set of 3D finite element analyses are observed, by using PLAXIS 3D Foundation program [10]. **Figure 3** displays the generated mesh of model, to analyse the vertical settlement and lateral displacement for three examined model piles; Pile (A), (B) and (C) within pile raft group. The drilling process is presented as four stages. The drilling depths of these stages are; 1, 2, 3 and 4 m, respectively. The horizontal distance between raft face and unsupported open pit is about 1.0 m. A
group of line drains of 12.0 m length are extended in 1.0 m between each other and 0.50 m horizontal distance between open pit and raft edge. Figure 4 displays the modelling of raft, line drain and adjacent un-braced open pit in PLAXIS 3D, 2013.

4. The Verification with Computed Results

The verification of 3D finite element model is noticed by comparison with finite element model carried by Cho and et al., 2012 [4], where the number of bored piles is 9.0 with a length and diameter of 12.0 m and 0.50 m, respectively. Square raft is of 10.0 m width. Subsoil consists of soft and stiff clay. Table 3 displays the comparison between present analysis and Cho and et al., 2012 [3]. There is a good agreement between present and Cho results.

Table 3. Comparison of the results

| Results             | Vertical settlement in centre, m |
|---------------------|----------------------------------|
| Cho and et al., 2012| Stiff Clay: 0.135, Soft Clay: 0.610 |
| Present study       | 0.250-0.450                      |

5. Computed Results

Results of steps of loading and drilling without the working of dewatering system and with the working of dewatering system are shown below:

5.1 Loading

Figure 5, 6 and 7 illustrate the vertical settlement variation along model piles A, B and C, respectively for unworkable and workable line drains through the loading of piled raft. Generally, before the dewatering process the amount of vertical settlement for pile A is the least one as compared with B and C. Otherwise, the vertical settlement of central piles is the largest of other location for pile in group. In addition, it can be noticed that the vertical settlement essentially rises as the line drain is active as compared with vertical settlement variation in case of unworkable line drain. As well as the behaviour of two states is the same trend for three examined model piles. And the rates of increase in vertical settlement during the dewatering process are about 27%, 23% and 13% for model pile A, B and C, respectively.

5.2 Lateral displacement

Figure 8, 9 and 10 illustrate the lateral displacement over model piles A, B and C, respectively before and after dewatering process during the loading of piled raft. Before dewatering process the lateral displacement is corresponding for all examined model piles. After dewatering process the lateral displacement for central pile is slightly different from other piles. The central pile tends to be displaced through length which is less than 2/3L while the other piles which tend to bend over whole pile length. In addition, it can be examined that the lateral displacement of piles head is the same amount for all model piles because they are connected with raft foundation which restricts the head.
piles and causes moving the piles with the same displacement through the dewatering. Figure 11 displays the lateral displacement distribution over raft and piles.

**Figure 11.** Displays the lateral displacement distribution over raft and piles.

**Figure 4.** The modelling of raft, line drain and adjacent un-braced open pit in PLAXIS 3D, 2013

**Figure 5.** Variation of vertical settlement along pile (A) for loading without and with action of line drain

**Figure 6.** Variation of vertical settlement along pile (B) for loading without and with action of line drain

**Figure 7.** Variation of vertical settlement along pile (C) for loading without and with action of line drain.

**Figure 8.** Variation of lateral displacement along pile (A) in case of loading without and with line drain.
5.3 Stages of drilling

5.3.1 Vertical settlement. Figure 12, 13 and 14 show the variation of vertical settlement for two cases of loading before and after dewatering which is mentioned previously over model pile A, B and C, respectively. In addition, each figure contains four profiles for influence of nearby drilling of depth 1m, 2m, 3m, and 4m on vertical settlement in case of operating line drain. In general, the vertical settlement trend is approximately the same through the drilling stages as soon as the loading before and after dewatering. In addition, it can be observed that as the line drain operates and joins together with drilling process up to 4.0 m deep, the vertical settlement increases slightly with an increase in depth of drilling by approximately 2% for piles A and B. While the increasing rate of vertical settlement throughout the drilling is less than 1 % for model pile C, Figure 15, 16 and 17 show the variation of vertical settlement for two cases of loading before and after dewatering which is mentioned previously for model pile A, B and C, respectively. In addition, each figure contains three profiles for influence of nearby drilling of depth 1m, 2m and 4m, respectively on vertical settlement in case of ineffective line drain. Also, the vertical settlement trend is nearly similar through the drilling stages, likewise the loading before and after dewatering. For ineffective line drain with the drilling process up to 4.0 m deep, the vertical settlement increases by approximately 11% as the drilling depth up to 4.0 m deep for piles A and B. But the less increasing rate of vertical settlement throughout the drilling is about 8 % for model pile C.
5.3.2 Lateral Displacement. Figure 18, 19 and 20 show the variation of lateral displacement for two cases of loading before and after dewatering which is mentioned previously for model pile A, B and C, respectively. In addition, each figure contains four profiles for influence of nearby drilling of depth 1m, 2m, 3m, and 4m on lateral displacement in case of operating line drain. Generally, the same trend of lateral displacement is noticed through the drilling stages, especially for piles A and B. But the behavior of pile C is slightly different especially for the lower part of model pile. It can be noticed the lateral displacement increases as the drilling process increases especially in the upper part of pile. The lateral displacement increases by approximately 40% over length less than L/2 as the drilling depth up
to 4.0 m deep for piles A, and B. But for model pile C the increasing rate of lateral displacement is being along pile length less than 2/3L. Figure 21, 22 and 23 show the variation of lateral displacement for two cases of loading before and after dewatering which is mentioned previously for model pile A, B and C, respectively. In addition, each figure contains three profiles for lateral displacement variation nearby drilling of depth 1m, 2m, 3m, and 4m in case of unworkable line drain. Generally, the lateral displacement increases along model pile with depth of drilling. The lateral displacement increases by more than twice along length.

**Figure 18.** Variation of lateral displacement along pile (A) in case of drilling stages with workable line drain.

**Figure 19.** Variation of lateral displacement along pile (B) in case of drilling stages with workable line drain.

**Figure 20.** Variation of lateral displacement along pile (C) in case of drilling stages with workable line drain.

**Figure 21.** Variation of lateral displacement along pile (C) in case of drilling stages without workable line drain.

**Figure 22.** Variation of lateral displacement along pile (B) in case of drilling stages without workable line drain.

**Figure 23.** Variation of lateral displacement along pile (C) in case of drilling stages without workable line drain.
6. Conclusions
   
a) There is an evident variation of pile movement before and after working of line drain during the loading process of piled raft.

b) The vertical settlement and lateral displacement increase as dewatering system is active as compared before the dewatering for all examined model piles. The largest rate of vertical settlement increasing is for outer piles then the central piles.

c) There is insignificant alteration of vertical settlement during work of drilling process represented by activate line drain for all examined piles. While there is an increase in vertical settlement by approximately 8-11\% during drilling process of depth 4.0m deep when the line drain is unavailable or does not exist.

d) Through the work of line drain in addition beside the effect of drilling process up to 4.0 m deep, the increasing of lateral displacement reaches approximately 40\% about before drilling for all examined piles. But in case of non-existent dewatering system and during drilling process up to 4.0 m the lateral displacement increases approximately as twice the quantity before drilling for all examined piles.

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