Effect of Screw Piles Spacing on Group Compressive Capacity in Soft Clay

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Abstract. Screw piles are considered as one of the solutions in different complications projects. Performance of circular screw piles group subjected to compressive load and embedded in two layers; soft clay and compacted sandy soils is investigated in this study. The thickness of two layers soft clay and sand soil is 250 mm and 350 mm respectively which are prepared after compacted to sub layers in the container. By choosing different slenderness ratios of L/D 25, 32 and 39, many model tests were achieved on screw piles group. Single and double helix plates were used in screw piles with constant of helix spacing 60mm. A square pattern of screw piles group with different spacing between piles (1.5Dh, 3Dh, 4.5Dh), where Dh is diameter of helix is adopted in this study. The results of this study showed that the ultimate capacity of piles group was increased by increasing the spacing between the piles until reached spacing 3Dh then begin to decrease when piles extended in sandy soil, while in soft clay the ultimate capacity increase with decrease piles spacing in two cases single and double helix. The increasing percentages for pile spacing 3Dh and 4.5Dh are (55.3% and 39.4%) respectively for L/D ratio 32 and (27.2% and 23.8%) respectively for L/D ratio 39. Also, it is recommended to use screw piles group in case of deep layer of soft clay laying on sandy layer due to high increase in compressive resistance capacity of group when extended in sandy layer.

Keywords. Soft clay, Screw pile, Pile group, Group efficiency, Axial load

1. Introduction

The soft soil is known through their low undrained shear strength Cu less than 40kPa also their height compressive (Cc =0.19 and 0.44), [1]. The soft clay soils in general, are hard when it is condition dry and loss stiff property when it becomes wet. Floods and rains want in vaporization because of roadways; structures are the common causes of cumulative water content in the clay soils, [2]. This kind of soil causes many problems related to geotechnical engineering with settlements, stability problems and low bearing capacity. Screw piles are deep foundation used to give strength to tension, compression and horizontal loadings [3]. The screw piles contain of a solid steel tube, square or circular tube having single or more of helix steel plates were welded with the pile end [4]. Helical piles design involves select of lengths, diameter and number of helix, spacing relation of helix above diameter of helix S/Dh and L/Dh ratio the length to diameter of helix, this limitations can be inclined in the ultimate bearing capacity of the screw piles [5]. The pile group may be defined as a group that contains number of separate piles that have same lengths connected to the same hard cap [6]. In reality, there is a large lack of data can be known done the literature concerning the reaction of single and group screw piles that...
are subjected to the axial load in soft clay soil, most previous readings dealt the problem of bearing capacity of piles. Group efficiency depends on some parameters as per, method of piles installation, type of soil, pile spacing. A study performed by [7] on pile group tests in the clay soil, by different the spacing between the piles and the number of the piles. It was determined that the soil between very closely spaced piles will fail as a block; though, as spacing between the piles group increases, the failure mechanism transitions, such that the individual piles fail locally. For group's performance local failure, the group efficiency decreased slowly with several solutions suggested to construct structures on this soft clay soil such as using screw piles [4, 8]. The decreasing in spacing; though, for groups performance block failure, the group efficiency decreased quickly with decreasing spacing between the piles [7]. The performance of helical piles group on model piles in sandy soil with different parameter, the sand density, the number of piles in the group and the spacing between the piles is investigated by [8]. It was resolved that in medium to loose sands the group efficiency increased as increases helical spacing, but in dense sand soil, efficiency group was greater than 100% at close spacing’s and it decreased with increasing spacing between pile. In dense sand, the connection of piles increased the bulk, causing in an increase in soil shear strength nearby the pile. Row and triangular group arrangements, with different spacing’s between pile groups, they originate that in dense sand, group capacity is decreased with decreasing spacing between pile, and that at an s p ≥ 5D there is negligible group interaction. In loose sands, it was defined that group performance was independent of spacing of a group, because of local pile failure [1]. A study using four bored concrete piles group in a square pattern and (L/D) ratios of (30, 50 and 70) with spacing between piles (2D, 4D and 6D) for each of the spacing conditions. The results of this study are illustrated that the group efficiency increased with increasing spacing between piles until reaches to 4D then reduced with the increasing spacing between piles. It is showed that the high efficiency happens on 4D, [10]. The behavior of single pile and pile groups of the load-displacement is carried out by [11]. The parameters are lead to investigate the effect of number of piles and pile spacing on the load-settlement reply of the piles group associated to a cap. The results showed that settlement of piles group was reduced by augmenting spacing between piles in the similar loading. Moreover, the efficiency of the group is augmented with increasing spacing between piles. Also, the results showed that the group settlement was reduced by increasing spacing between piles and augmented with increasing the number of piles [11]. The influence of pile spacing 2D, 4D and 8D on the load-settlement of 2x2 piles group is investigated using three-dimensional analysis. The results show that the efficiency group was augmented by increasing piles spacing until reaches to (8D), the failure mechanism slowly variations to the “single pile” mode [13]. Twelve micro piles group with four piles in a square pattern, with c/c spacing between piles of 2D, 4D, and 6D and with L/D ratio is (20, 35, 50, and 65) are fixed in sand layer that have relative density Dr% of (30%, 50% and 80%). The results showed that the greater efficiency of group is to be in spacing (4D), loose to medium dense formal of sand soil. In adding, the statement showed optimistic group effect in loose to middle state, while negative group effect is experimental in dense state (Dr of 80%). Furthermore, it was founded that the pile spacing, relative density and L/D ratio are greatest important effect on the group efficiency [13]. An investigation of behavior of screw piles group embedded in soft clay and extended to sandy soil is carried out on 18 models test. In this study, different parameters are considered such as length of screw pile, number of the helix and spacing between piles. The influence of compressive loading on screw piles group with these mentioned parameters are researched in this study.

2. Experimental work
The total work is carried out in laboratory, and no field model is used, although the full scale model will provide a better-close to reality data.

2.1. Soft caly soil
Soft clay soil utilized in current study was brought from a region lies in Diyala governorate, from depth of two and half meters from natural ground surface. The properties of soft clay soil are performed according to ASTM specification and results are showed in Table 1.
2.2. Sandy soil
The sandy soil layer utilized in this study is acted as bearing and shaft resistance with pile interaction. It was brought from region in Karbala Governorate south of Baghdad city. The unit weight of (16.7) kN/m$^3$ which represent relative density of 70% is prepared as a sandy soil layer below soft clay layer. The results of sandy soil properties are depicted in Table 2.

2.3. Models of pile and soil container
Twenty four screw piles were manufactured from high resisting steel solid section with a diameter of 10mm and with a length of (250, 320 and 390) mm as shown in Plate 1. The piles have single and double of helix plates with a diameter 20 mm, thickness 2mm and a screw plate pitch (p) of 70 mm, the spacing between two helix plates is constant 60 mm. The end of shaft is tapered with 45$^0$ to increase setting during installation process. The experimental tests were conceded on group screw piles (4piles) at square arrangement with a different length, number of helix and different spacing between screw piles. Two steel containers used in the work were manufactured a 4mm thickness plate with diameter 500mm and height 650mm as shown in Plate 2, The steel containers were coated with layer of rust paint to resist corrosion during the test period.

Table 1. Soft clay properties.

| Property                     | Value  | Specification          |
|------------------------------|--------|------------------------|
| Specific gravity (Gs)        | 2.72   | ASTM D 854 - 2         |
| Liquid limit (L.L)%          | 37     | ASTM D 4318 - 00       |
| Plastic limit (P.L)%         | 22     | ASTM D 4318 – 00       |
| Plasticity Index (P.I)%      | 15     |                        |
| Sand %                       | 4      | ASTM D 422             |
| Silt%                        | 45     | ASTM D 422             |
| Clay%                        | 51     | ASTM D 422             |
| Unified Soil Classification System (USCS) | CL | ASTM D 422 |
| Max. Unit Weight (kN/m$^3$)  | 19     | (ASTM D-1557)          |
| Optimum Moisture Content (O.M.C)% | 17.6 | (ASTM D-1557)          |

Table 2. Sandy soil properties.

| Property                               | Value  | Specification                      |
|----------------------------------------|--------|------------------------------------|
| Coefficient of Uniformity (Cu)         | 2.81   | (ASTM D-422) and ASTM D 2487 (2006) |
| Curvature coefficient (Cc)             | 1      | (ASTM D-422), ASTM D 2487 (2006)  |
| Unified Soil Classification System (USCS) | SP | (ASTM D-422), ASTM D 2487 (2006)  |
| Specific Gravity (Gs)                  | 2.61   |                                    |
| Cohesion(kN/m$^2$)                      | 0      | ASTM D3040-04(2006)                |
| Internal Friction Angle ($\varphi^\circ$) | 35.5 | ASTM D3040-04(2006)                |
Plate 1. Plate of model screw piles types.

Plate 2. Plate of soil container used in this study.

3. Testing procedure
3.1. Sandy soil preparation: The desired quantity of sandy soil finer from sieve No.40 was prepared in a dry unit weight of 16.7kN/m³ which corresponding to dense state of 350mm thickness was pouring into five 70mm sub-layers and compacted manually by using a steel plate 9.5kg of dimensions (100x100)mm.

3.2. Soft clay preparation: This soil was prepared at Cu=35kPa which is corresponding to 28% water content. Weight of 60Kg ordinary soil was admixed with required amount of water to get the required consistency. Mixing process was equipped by utilizing electrical mixing for each 12kg of dry soft clay soil. After soil mixing process, the soil was located into five sub layers in a steel container until reaching 600mm of soil thickness, each layer was compacted using a wooden meddle with a diameter of (150) mm to remove the confined air.

3.3. Screw pile installation: After preparation process of soil, the steel container is laying inside the installation device of piles, the holder is install on the top edges of the steel container and install the circular plate with an outer diameter of 25mm and an inner diameter of 11mm placed inside the screw pile to keep the spacing between the piles from the center of the pile to the center of other pile. After that the pile is installed in a device and this pile was fixed slowly inside the soil by using torque. This torque is applied by using a hydraulic torque motor that providing the perpendicular and rotational forces
to install the screw piles in the required spacing of surface the soft clay soil to the limited depth. The perpendicular speed and number of revolutions per minute are depended on the pitch of the screw pile [14]. The screw pile must install in such a way that the screw pile enters the earth in a quantity equal to the pitch (p) of the helix for each whole revolution in direction to decrease the disruption of the earth [15]. Hence, an exact movement installation with a permeation rate of (7 mm/min) and a rotating speed of (2.5 rpm) that used for wholly tests. Duration of install the screw pile to the required depth in the soil varies according to the length of the piles, as the length 390mm took 60 minute while the length 320mm took 45 minute and the length 250mm took 30 minute. After completing the installation of the first pile, the device is turned off and separates the shaft from the pile and rotates the container to install the second pile with the required spacing. Repeat of these steps until completed installation of four piles in steel container inside required of the soil depth. Using this process to installation all the model tests used in this study. Plate 3 shows hydraulic torque motor used for installation of screw piles group.

Plate 3. Hydraulic torque motor using for installation screw piles.

3.4. Piles cap and group configuration of screw piles: Screw piles made of steel with constant shaft and helix plates diameters and different number of the pile lengths, helix plate and piles spacing (1.5Dh, 3Dh and 4.5Dh) arrangements to 4 piles (2x2) as a square pattern. The cap used in the study was designed from steel plate with thickness of 10mm, this cap is stiff to save the load transported similarly to all piles, and in addition, a space of 50mm from the cap to the soil surface and kept of 2D minimum edge space from face of screw piles as shown in Plate 4.

Plate 4. Models of cap used for piles group.
3.5. Pile load test: The cell load of 3 ton and S shaped is used to apply axial load on screw piles group. The rate of loading used in this study is 1 mm/min in the filled test on axial compression test according to ASTM (2018) standard D1143, the range of rate (0.25 to 1.25) mm/min for soft clay soils. The continuous movement of the screw piles group up to of (15 mm) fixed depth. The load is measured by using a digital weighing indicator allied with the load cell. The settlement of the screw piles group is read through digital dial gauge with sensitivity 0.001 mm placed on the center of the cap. Plate (5) shows the screw pile test device.

![Plate 5. The pile load test device used in this study.](image)

4. Model test results and discussion
The influence of screw piles spacing in a group on ultimate capacity and efficiency is investigated in this study.

4.1. Influence of screw piles spacing on the ultimate load of group:
Total 18 models test of screw piles group are conducted under axial compressive load with 20% of helix diameter which equivalent to 4mm settlement depending on study [16]. Different parameters were used in soft clay soil over sandy layer, L/D ratio 25,32 and 39 with two cases of number of helix; single helix plate (S.H.) and double helix plates (D.H.) and different piles spacing 1.5Dh,3Dh and 4.5Dh. After the finishing pile installation in two layers of container, the test is beginning after 24 hours to provide sufficient time to soil recreation, distribution of stresses. Figures 1 and 2 showed the influence of spacing and helix diameter (Sp/Dh) ratio against ultimate compressive load with different lengths at (single and double) helix plates. As it can be seen from these figures that the ultimate bearing capacity of piles group is augmented with increase piles spacing to a maximum 3Dh in sandy soil, L/D ratio(32 and 39) and a maximum 1.5Dh in soft clay soil, L/D ratio(25). An increase the embedment depth of the pile in both single and double helix plates caused increased in the ultimate compressive load; when L/D ratio change from 25 to 39, the increase reaches (37-50)times in single helix and (34-47)times in double helix plates. This is due to anchorage resistance between helix plates and sandy soil which increased compressive capacity of pile group. When screw piles group embedded in soft clay only, the compressive capacity is high small and slightly changed with increase pile spacing.
4.2. Influence of screw piles spacing on the group efficiency:

The efficiency of group is a ratio between capacity of piles group and capacity of single multiplied by number of piles in group. Figures (3, 4 and 5) state the influence of piles spacing on the efficiency of piles group at different lengths with two conditions (single and double) helix. Also, from these figures, it can be shown that the group efficiency is increase with increase pile spacing with a maximum 3Dh in sandy soil while the group efficiency is increase with decrease pile spacing in soft clay soil. The piles group efficiency for different pile spacing at L/D ratio 39 is (1.2, 1.5 and 1.4) in single helix and (1.1, 1.4 and 1.3) in double helix respectively and at L/D ratio 32 is (0.85, 1.3 and 1.2) in single helix and (0.73, 1.1 and 1) in double helix respectively while the group efficiency at L/D ratio 25 was embedded in soft clay soil only is (0.68, 0.67 and 0.63) in single helix and (0.81, 0.76 and 0.73)in double helix plates. It is clear that the optimum spacing is 3Dh when screw piles group extended to sandy soil layer. This is related to different parameters such as stress bulbs, helix diameter and spacing between helix plates. When spacing between piles reaches 4.5Dh, the group begins to be done as a single pile. In general, the efficiency of piles group in soft clay soil is small in all spacing. This is due to low undrained shear strength of soft soil and loss of skin resistance between piles and soil. On the contrary, when screw piles group extended to sandy soil, the cylindrical shaft resistance and bearing resistance between pile, helix plates and sandy soil play an important role in increasing compressive capacity and efficiency of group.
Figure 3. Relation between the group efficiency with piles spacing to helix diameter ratio for single and double helix plates for slenderness ratio L/D=39.

Figure 4. Relation between the group efficiency with piles spacing to helix diameter ratio for single and double helix plates for slenderness ratio L/D=32.

Figure 5. Relation between the group efficiency with piles spacing to helix diameter ratio for single and double helix plates for slenderness ratio L/D=25.
5. Conclusions
Conclusions of this study are summarized as follows:

- The increase in slenderness ratio (L/D) of screw piles group from (25 to 39) in sandy layer makes an increase in the ultimate compressive capacity by (34-50) times.
- Increase number of helix plates in screw pile performs to augment in the ultimate compressive capacity of piles group.
- When piles spacing between piles in a group is augmented, the ultimate compressive capacity of pile group increased in sandy soil while decreased in soft clay soil. The increasing percentages for pile spacing 3Dh and 4.5Dh are (55.3% and 39.4%) respectively for L/D ratio 32 and (27.2% and 23.8%) respectively for L/D ratio 39.
- The maximum value of ultimate compressive load in piles group extended to sandy soil is when spacing equal to 3Dh while in soft clay equal to 1.5Dh.
- The change in spacing between piles from 1.5Dh to 4.5Dh leads to increase in group efficiency, the spacing 3Dh is maximum value of group efficiency.
- Group efficiency is equal or more than one for spacing (1.5, 3, and 4.5) Dh for group extended to sandy soil, but the group efficiency is less than one for all spacing embedded in soft clay.
- It is recommended to use screw piles group with single or double helix plates in profile of soil consists from deep layer of soft clay overlaying dense sand layer.

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