Parameters Affecting Screw Pile Capacity Embedded in Soft Clay Overlaying Dense Sandy Soil

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Abstract. The screw piles application is constantly increasing due to their high efficiency and numerous advantages. Screw piles are supplying stability against compression, overturning moment, uplift tension, and horizontal loads. This investigation presents a set of model experiments performed on single screw pile embedded in soft clay soil over laying a sandy soil loaded in compression, at a constant strain rate. The sandy layer 20 cm thick was compacted in a test container of 30 cm diameter into four sublayers to attain a relative density of 70%. The 30 cm thick soft clay layer with Cu (undrained shear strength) 30 kPa was compacted in six sublayers on the sandy bottom layer. Three different pile length (30, 35 and 40 cm), single and double helix and pile without helix, (3D and 4D) helix diameter, (3 and 5) cm spacing between helix plate are used in this study. The experiment results showed that, the screw piles settlement for piles embedded in soft clay soil overlaying a sandy soil layer decreases (59-182)% with increasing depth of embedment in the sandy layer L/D from 35 to 40, number and diameter of helix those provide anchorage against settlement. The deeper screw piles with higher L/D ratios showed compressive capacity (24-55) times greater than the shallower piles (screw pile embedded in soft clay). In addition, screw piles demonstrated resistance to the applied compressive forces (9-16) times more than ordinary piles. The compressive force increases with rising number and diameters of helix plates.

1. Introduction
Soft clay soil is in large areas of Iraq, especially in some central governorates and many southern governorates. Soft clay soils are recent alluvial deposits that expected to have formed over the past 10,000 years, as described by its monotony and flat ground surface. As a matter of fact, There is no obvious definition for the term “soft soil”, [1] defined the soil is as soft when its Cu(undrained shear strength) in the range of 20 to 40 kPa while the term very soft referred to soil with Cu < 20 kPa. Usually soft clay soils are so sensitive to water and show a drastic change in their performance as the moisture content changes. In general, soft clay soils are stiff in the dry state and lose this property when they become moister [2]. The soils, which have such characteristics causes several problems to geotechnical engineering associated with low bearing capacity, settlements and stability problems [3]. Building heavy structures on soft clay soil is a very difficult task.

Piles foundations are the Structure's part that transmit the load during weak compressible layers into rock or deeper soil of high bearing capacity and less compressibility to avoid surface soil of low bearing capacity [4]. Pile foundations in more conventional civil engineering applications have a wide range of types and sizes and materials are used in practice [3]. Many investigations have been made to find the appropriate type of pile for various geotechnical and structural conditions. Because of their
many design advantages, screw piles are becoming increasingly popular, especially in projects where quick installation and fast loading of the foundation is required [5].

Screw piles consist of a central steel shaft that is either a square (solid section) or a circular (solid or tube) to which one or more helical bearing plate are attached [6].

In general, the design of the screw pile must take into account all, applicable permanent, or temporary loading conditions, such as, but not limited to: gravity loads, seismic loads, tensile loads, lateral loads, wind loads, snow loads, hydrostatic loads, torsional loads and negative effects of friction on the skin combined in accordance with the standard specification of screw pile design. The shaft and helix plate must be designed with structural and geotechnical capability in mind so that installation and design loads can be achieved. The diameter of helix plate ($D_h$) to the diameter of shaft ($D$) is between 2 and 4, and the helix pitch to helix plate diameter ($p/D_h$) is about 1/3 [7]. The spacing ratio ($s/D_h$) used in practice could range between 1.0 and 6.0 [8]. The spacing between helix is often chosen depending on the mechanism or type of failure to be obtained. Failure due to axial loading of the screw piles can happen either in a cylindrical shear model or in an individual plate bearing. The failure type can therefore affect the behavior of the piles and their capacity [9].

As the literature indicates, several failure criteria methods predict the ultimate load bearing capacity of screw piles from a load test. [10] Explained some of these methods, as the Davisson criterion, Brinch Hansen criterion, (L1–L2) method, Federal Highway Administration (FHWA) method (5% of the diameter of helix) and International Society for Soil Mechanics and Foundation Engineering, ISSMFE (10% of the helix plate diameter). The method, which called ISSMFE, adopted to find the load at a displacement level (settlement) of 10% of the helix plate diameter, [10-11].

The method of installing screw piles is considered one of their advantages. The method consists of screwing the pile into the ground under a torque and compression force (axial). The equipment used for the installation must provide sufficient torque to the pile head without damaging it. The vertical speed and the number of revolutions per minute (rpm) depend on the pitch (P) of the screw pile [12]. The installation of a screw pile must be done in such a way that the screw pile penetrates into the soil at each full revolution at the height of the helix pitch (P), [13-14]. The penetration rate of the screw pile per revolution of the pile should be ($0.85 \text{ pitch} \leq v \leq 1.15 \text{ pitch}$) to reduce ground disturbances during installation [15].

Due to the relatively simple installation compared to conventional piles and the increasing acceptance of geotechnical engineering, the popularity of screw piles have increased significantly in recent decades [16]. Today, screw pile foundations have become popular in many countries. The use of this type of piles as a deep foundation option has augmented significantly in latest years to support various loads, ranging from small loads to multiple applications [17].

This paper presents the parameters affecting screw pile capacity embedded in soft clay overlaying dense sandy soil loaded in compression with varying depth of embedment, helix diameter ($D_h$), number of helix plate, helical plate spacing ratio ($S/D_h$), and length of pile ($L$), as expressed in figure 1.
Figure 1. The geometry of screw pile.

2. Materials Used

2.1. Soft Clay Soil
The soft soil used in this study was taken from Baquba Brick Factory Workers village within Diyala governorate, Iraq from a depth of two and a half meters from natural ground level. Before the soil preparation stage, trial tests were conducted to monitor the effectiveness of the method of preparation. Control tests were performed to determine the variation in shear strength at different water contents (or at different liquidity indices) several trails were made and typical results are showed in figure 2. The results of the laboratory tests are shown in table 1. Soil is classified as (CL) according to the ASTM standard classification for soil.

Figure 2. Variation in undrained shear strength versus water content for the remodelled soft clay after 48 hrs.
Table 1. The physical properties of soft clay.

| Item | Property                  | Value | Specification       |
|------|---------------------------|-------|---------------------|
| 1    | Specific gravity (Gs)     | 2.84  | ASTM D 854 - 2      |
| 2    | Liquid limit (L.L)%       | 38.5  | ASTM D 4318 - 00    |
| 3    | Plastic limit (P.L)%      | 23.3  | ASTM D 4318 - 00    |
| 4    | Plasticity Index (I.P)%   | 15.2  | -                   |
| 5    | Clay %                    | 51    | ASTM D 422          |
| 6    | Silt%                     | 45.7  | ASTM D 422          |
| 7    | Sand%                     | 3.3   | ASTM D 422          |
| 8    | Unified Soil Classification System (USCS) | CL | ASTM D 422 |
| 9    | Maximum Unit Weight (kN/m³) | 17.8 | ASTM D-1557         |
| 10   | Optimum Moisture Content (O.M.C)% | 18 | ASTM D-1557         |

2.2. Sandy Soil
This soil is used under soft clay soil, which serves as a stable zone. Fine clean sand from the Karbala Governorate site south of the city of Baghdad in Iraq. Before the testing stage, the sandy soil is dried in the laboratory for 24 hours at 105°C in a drying oven. Then sieved on No.40 sieve to remove the coarse particles. Laboratory tests were carried out on the sandy soil to find the physical and mechanical properties. The laboratory test results are shown in table 2. Here should be mentioned; the direct shear test was carried out at a relative density of 70%, which corresponds to (16) kN/m³ dry unit weight. According to the ASTM standard classification for soil, the soil classified as poorly graded sand (SP). Figure 3 shows the grain size distribution curve of sandy soil.

Table 2. Summary of sandy soils properties.

| Item | Property                            | Value | Specification       |
|------|-------------------------------------|-------|---------------------|
| 1    | Uniformity Coefficient (Cu)         | 2.6   | (ASTM D-422) and ASTM D 2487 (2006) |
| 2    | Curvature Coefficient (Cc)          | 0.84  | (ASTM D-422) and ASTM D 2487 (2006) |
| 3    | Unified Soil Classification System (USCS) | SP | (ASTM D-422) and ASTM D 2487 (2006) |
| 4    | Specific Gravity (Gs)               | 2.63  | /                   |

Figure 3. Grain size distribution curve of sandy soil.
2.3. Model Piles
Thirty models of steel screw piles with length ranging from 300mm to 400mm were used in this study. Screw pile with circular solid section and diameter (10) mm was fabricated from high resisting steel as presented in Fig. 4. The diameters of helix plate (Dₕ) are used 30mm and 40mm with thickness 2mm. The helical plate pitch (p) is used 1/3 helix diameter (Dₕ). The helix plate were manufactured from steel and welded firmly and accurately to the pile shaft. Two spacing are used 30 mm(s=Dₕ) and 50 mm(s=1.6Dₕ). The termination of the shaft tip was a 45%, to aid keying during installation. Figure 4 show a screw pile geometry. The laboratory models were scaled with the field prototype as percentage (1:10) respectively.

![Figure 4. Different types of screw pile models.](image)

2.4. Soil container
Two steel soil containers (test tanks) were fabricated using a thick plate (4mm in thickness) having an inner diameter of 30 cm and a height of 55 cm. The base of the tank is square-shaped and contains two angle-shaped sections that help to make the container non-moveable during the process of pile installation and test. The container was equipped with four wheels for free movement; the container was firm enough to prevent side deformity during the soil preparation process and pile test. Figure 5 displays the details of the container.

The containers were painted with two layers of anti-rust paint and two layers of conductive base to withstand corrosion during the test period. In general, the soil steel container (test tank) dimensions are determined based on the effectively stressed zone of the mass of soil from the foundation edge [18]. It is considered that the failure stress extends about 2-4D under the tip of the pile for a single pile (D is the width of the cross section of the pile). The spread out load distribution on the single pile side is 2: 1 from the depth of L/3 from the tip of the pile [19].
3. Testing Procedure

Figure 6 shows the experimental program proposed for this study. The tests are conducted in the laboratory of civil engineering of the faculty of Engineering in Diyala University. After testing and soil preparation, self-design laboratory models, shown in plate 3 and 4 are using respectively to process of pile installation and testing.

![Flow chart of testing program](image)

**Figure 6.** Flow chart of testing program.
3.1. Soil Preparation

This stage begins after completions of the laboratory test required for the used soil in this study.

3.1.1. Sandy Soil
1. The required amount of oven-dried natural sand soil passing through No. 40 sieve was prepared at a dry density of 16 kN/m$^3$ that corresponds to the dense state.
2. The sandy soil layer was prepared by pouring the sand into four 50 mm-thick sub layers in the container and statically compacted so that the final thickness of the sandy soil layers reaches 200 mm.
3. All container insides are covered with petroleum jelly minimize the friction effect.
4. Many filter papers with a diameter of 150 mm were used between the clay and sand layer.

3.1.2. Soft Clay Soil
1- After drying and pulverizing the untreated soil, the soil bed was prepared with a water content of 30% corresponding to cu = 30 kPa.
2- 30 kg of natural soil was mixed with sufficient water to obtain the wanted consistency.
3- The operation of mixing was performed using electrical mixing device; each 10 kg of dry soil was mixed separately till completing the whole quantity.
4- After being thoroughly mixed, the moist soil was kept in tight polythene bags for 48 hours to obtain a uniform moisture content.
5- The interior of the soil test tank was painted with lubricating oil to reduce the frictional effect between the container inner surface and the soil.
6- The soil was placed in a container in six layers and each layer was gently levelled with a woody hammer, then the levelled layer was gently tamped with a 9.87 kg metal hammer and a (150 mm) diameter to remove trapped air. This procedure is continues for the six layers until the total thickness of soft clay layer in the container is 300 mm. Figure 7 show the soft clay preparation stages.

![Figure 7. Soft clay soil preparation stages.](image)

3.2. Pile installation Process

The pile installation process conducted after the soil preparation and placing in a test tank (container). The model piles were screwed slowly into the ground by applying a torque (T) with appropriate downward force (N). The torque applied through the use of a hydraulic torque motor supplied the
rotational and axial forces required to install the screw pile in the center of surface of soil bed to the depth required. The amount of vertical speed and the number of revolutions per minute (rpm) are used depends on the screw pile pitch (P). The installation of a screw pile has been carried out so that the screw pile penetrates into the soil at each complete revolution with a value equal to the helix pitch (P) to minimize the disturbance of the soil. Therefore, for all tests, a controlled displacement installation with a penetration rate dependent on the 1/3 pitch to helix diameter ratio, and a rotational speed was used as shown in table 3. Figure 8 shows that the hydraulic torque motor has been used in the driven screw pile.

**Table 3. Penetration rate and rotational speed used in the pile installation process.**

| Helix diameter D_h (mm) | Pitch P (mm) | Penetration rate (mm/min) | Rotational speed (rpm) |
|-------------------------|--------------|---------------------------|------------------------|
| 30                      | 10           | 10                        | 3.60                   |
| 40                      | 13.333       | 13.33                     | 4.9                    |

![Pile installation device](image)

**Figure 8. Pile installation device (Hydraulic torque motor).**

3.3 Pile load test

In the case of loading, the vertical (compression) load is applied to a single screw pile through a 3-ton (S-shape) load cell. Use of the timer with a constant load, penetration rate of (0.5 mm/min), in the full test, program based on [20-21] for axial compression testing, which are concluded that the range of penetration rate (0.25 to 1.25) mm/min for cohesive soils. The test is in progress until a continuous displacement of the screw pile up to 12 mm (embedded depth) is recorded. Figure 9 illustrates the loading versus time for double helix screw pile with 400 mm length, D_h=30mm and s=30mm. The load is gauged by a digital weighing indicator linked to the load cell. Two digital dial gauges with a sensitivity of, (0.001 mm) were used to read the central settlement of the screw piles cap. Figure 10, shows the testing device.
4. Results and Discussion

The ISSMFE method (10% of the diameter of helix), was taken over in this investigation to that predict the ultimate bearing capacity of screw piles from a load test. The screw pile behavior can be better judged by the results of compression load tests. Different L/D ratios of screw piles were used 30, 35 and 40, in addition to single and dual helix with inter helix spacing (3 and 5)cm and two different helix diameters 3D (30mm) and 4D (40mm) was used in this study. As shown in (Figs. 7, 8 and 9) that rising of L/D ratio for screw piles decrease the settlement that results from axial compression load. This is due to the anchoring resistance of long piles in the deep soil layer even if this layer is in the stable zone of the soil. The obtained increase percentages in ordinary piles compressive capacity 14.3% when increasing L/D from 30 to 35 and the compressive capacity of ordinary pile with L/D 40 up to as much as 40.5 times the compressive capacity of pile with L/D 30 while for screw piles with single helix plate were (30.9% for Dh=4D) and, (37.4.8% for Dh=3D when increasing L/D ratio from 30 to 40 as presented in figure 11.

![Figure 9. The Load - Time chart during the process of pile testing.](image9)

![Figure 10. Pile Test Device.](image10)
Figure 11. The relation between the ultimate compressive capacity and L/D ratio for single helix screw pile.

Figure 12 shows the effect of L/D ratio for double helix plates screw pile with inter helix spacing (s=3cm) and for different helix diameter on ultimate compression capacity. It can be noticed the amelioration in value of ultimate compression capacities of these screw pile have reached (55.8 times for 4D helix diameter) and, (38 times for 3D helix diameter) when mounting L/D ratio from 30 to 40. The increasing in L/D ratio from 30 to 35 for these piles results in an increase in ultimate compression capacity values ranging of between (15-31) % while the increase in compression capacity values for L/D ratio 40 becomes equal to (1.7-2.3) times as much as the compression capacity values at L/D ratio 35.

Figure 12. The relation between the ultimate compressive capacity and L/D ratio for double helix screw pile with inter helix spacing (s=3cm).

Regarding to the L/D ratio effect for double helix screw pile with inter helix spacing (s=5cm) on ultimate compression capacity which can be shown in figure 13. It can be concluded that the growing in value of ultimate compression capacities of these screw piles ranging (23.9-30.9) % when augmenting L/D ratio from 30 to 40. The increasing in L/D ratio from 30 to 35 for these piles results in...
an increase in ultimate compression capacity values ranging of between (9.2-18.6) % while the increase in compression capacity values for L/D ratio 40 becomes equal to (1.5-2.4) times as much as the compression capacity values at L/D ratio 35. The screw pile installed at a major depth, had ultimate capacities greater than the shallower ones, and for a given a diameter (D) and soft clay soil bed thickness (H) overlaying sandy layer, the ultimate compression capacity of screw pile increases with increasing embedded depth of screw pile in the layer of sand which are considered the stable zone. This behavior can be understood by the fact that when the screw pile is embedded in the sand layer, the anchorage becomes more mobilized, thereby increasing the compression capacity of pile. In general, the ultimate compressive capacity of screw piles increases with increasing piles length, that’s agree with [9, 22-23], who found that the compression load of screw pile carrying capacities increases with increasing the embedment ratio (L/D) from laboratory tests.

The effect of helix diameter on the compression capacity of screw pile is also referred to as the effect of the wings ratio or helical plate to shaft ratio (Dh/L) [24]. Two different helix diameters were used, 3D (3cm) and 4D (4cm), also single and dual helix with inter helix spacing (3 and 5) cm and different L/D ratios were used (30, 35 and 40).

It is observed that for a single helix screw pile, when the diameter of the helix is increased from 3 cm to 4 cm, the value of ultimate compressive capacity gets improved by 75%, as indicated in figure 14. When used screw pile with double helix with (s=3cm), it can observed that the ultimate compressive capacity value when the helix diameter 3 cm is close to the values of the helix diameter of 4 cm where they are 57 N and 60.8N, respectively. If the inter helix spacing (s) increases to 5cm, the ultimate compressive capacity will be (10.5-30.1) % greater than the ultimate compressive capacity values obtained when the helix spacing is 3 cm. So, the resistance against compression capacity of screw pile embedded in soft clay soil increases while helix diameter increases.
Figure 14. The effect of helix diameter on ultimate compressive capacity of screw pile embedded in soft clay soil (L/D ratio 30).

Figure 15 illustrates the effect of helix diameter on ultimate compressive capacity of screw pile embedded 5 cm in sandy soil layer through soft clay soil (L/D ratio 35). In case of single helix screw pile, 1045.7 N is the value of ultimate compressive capacity when the diameter of the helix is 4 cm, and this value is represent an increase rate of about 76.6% when the helix plate diameter of 3 cm. For double helix screw pile with (s=3 cm), the value of ultimate compressive capacity for screw pile with helix plate diameter of 3 cm is 930 N and this value increases to 1946 N when the helix diameter increase to 4 cm. This means that the augment in the diameter of the helix plate from 3 cm to 4 cm, in this case produces an increase in ultimate compressive capacity equal to 2.1 times the value extracted when the diameter of helix is 3 cm. In case of double helix screw pile with (s=5 cm), when increase the helix diameter to 4 cm, the value of the pile capacity rises to 1500.9 N and this value is 2.3 times the resulting value when the helix diameter is 3.

The effect of helix diameter on ultimate compressive capacity of screw pile embedded 10 cm in sandy soil layer through soft clay soil (L/D ratio 40) is displayed in figure 16. It can be noticed that the screw pile capacity for single helix plate raises to reach 1.45 to 3.5 times when increase the helix diameter from 3 cm to 4 cm. As for the double helix screw pile with (s=3 cm), the value of the ultimate compressive capacity was 2175 N when the diameter of the helix 3 cm increased this value to 3392.3 N when increasing the diameter of the helix to 4 cm. If the inter helix spacing increases to 5 cm, the ultimate compressive loads it will be 1570 N to 2395.2 N when increasing the helix diameter from 3 to 4 cm and these values are slightly lower than the values obtained when (s= 3 cm).

Figure 15. The effect of helix diameter on ultimate compressive capacity of screw pile embedded 5 cm in sandy soil layer through soft clay soil (L/D ratio 35).
To sum up all the results, we can see that the diameter of the helical plates is essential influencing screw pile capacity, for any L/D ratio and pile geometry, we can see how the compressing capacity of the screw pile changes, while changing the helical plate diameter. So the larger helical plate diameter provides greater compression capacity and can be attributed to the increased surface area that provides greater bearing capacity and greater anchorage for the screw pile when the diameter of helix increases, and that’s agree with [9, 11, 24-26]. So, in soft clay soil the increase in diameter of helix of the diameter of ordinary pile lead to increase in surface area that cause increase in anchorage resistance(increase in end bearing capacity). Moreover, the existence of helix plates in stable zone (sandy soil) leads to increase compression resistance of screw piles. This behavior may be attributed to increase in surface area of part of screw pile embedded in sandy soil (increase in end bearing in addition to skin friction) that cause increase in anchorage resistance.

The behavior of screw pile can be better assessed using the results obtained during compression load tests. So it is vital to conduct the compression tests on model pile without helical plate (ordinary steel pile) and with varying number of helix plate (single and double helix). The effect of helix plate number on ultimate compressive capacity of ordinary and screw pile model with (D_h=3D) for different L/D ratio (30, 35 and 40) is presented in figure 17. It can be noticed that the double helix plate screw pile(s/D_h ratio =1.6), double helix plate (s/D_h ratio =1) and single helix exhibits increased ultimate compression capacity estimated at (8, 7.2 and 4) times compared to the capacity of ordinary pile when L/D ratio 30.

For the same condition and L/D ratio 35, the value of ultimate compression capacity of ordinary pile is 120 N and can be seen as this value increases to 5 times when using a single helix screw pile. When increasing the number of helix to double with s/D_h ratio 1 and 1.3 the values of ultimate compressive capacity increased to (7.75 and 5.35) times the value of ultimate compression capacity of ordinary pile. For model pile embedded 10 cm in sandy layer through 30cm soft clay layer (L/D ratio = 40) the augment in number of helix from ordinary pile to single helix screw pile the ultimate capacity will raise 1207 N and this value equal to 3.79 times the value of ordinary pile capacity. When using double helix screw pile the ultimate compressive capacity will raise to 1570 N for s/D_h ratio 1.3 and 2175 N for s/D_h ratio 1 and that’s mean (4.93 and 6.84) times the value of ultimate compressive capacity of ordinary pile. Also, it can be deduced that the increasing in number of helix from single to double for all screw pile model with (D_h=3D and s/D_h=1) produces an increase in ultimate compressive capacity, 81.5% for L/D ratio 30, 57% for L/D ratio 35 and 81.2% for L/D ratio 40 while for the same diameter and (s/Dh ratio 1.6) 100%, 8.6%, 30% for L/D ratio 30, 35 and 40 respectively. These values are higher than the values obtained when the diameter of the helix is 1.5 cm is approximately double in the case of (s/D_h=1), and approximately similar when (s/Dh=1.6), except for

Figure 16. The effect of helix diameter on ultimate compressive capacity of screw pile embedded 10cm in sandy soil layer through soft clay soil (L/D ratio 40).
the pile model that are embedded in soft clay soil, the larger spacing ratio \((s/D_h)\) gives greater resistance to compressive loads and this can be attributed to the soil was confined in the space between the helical plates and gave a larger anchor resistance. The increase in area of cylindrical surface of double helix plates give large resistance in compressive loading.

![Figure 17](image.png)

**Figure 17.** The effect of number of helix on ultimate compressive capacity of ordinary and screw pile model with \((D_h=3D)\).

Figure 18 shows the effect of helix number on ultimate compressive capacity of ordinary and screw pile model with diameter of helix plate \((D_h=4D)\). Different L/D ratios were used (30, 35 and 40), respectively. For L/D ratio 30, It can be seen that screw pile model with single helix was about 7 times the measured capacity of ordinary pile whereas it was 8.7 times the measured capacity of ordinary for model pile of L/D ratio 35 and 5.5 times the measured capacity of ordinary pile for model pile of L/D ratio 40. For double helix screw pile with spacing ratio \((s/D_h=0.75)\), it was observed similar behavior to that investigated in single helix screw pile, but the increase in ultimate compressive capacity was found 7.75 times the determined capacity of ordinary pile for model pile with L/D ratio 30 and 16.2 times the determined capacity of ordinary pile for model pile with L/D ratio 35, while the ultimate compressive capacity for double helix screw pile with L/D ratio 40 was 10.7 times the compressive capacity of ordinary pile. Similar behavior is noticed for double helix screw pile with spacing ratio \((s/D_h=1.25)\), where the increase in value of ultimate compressive capacity was 9.75 the ultimate compressive capacity of ordinary pile with L/D ratio 30, and \((12.5, \ 7.5)\) times the ultimate compressive capacity of ordinary pile with L/D ratios 35, 40 respectively.
According to the results and all figures above, it is observed the increase in ultimate capacity when increasing helix number, regardless of soil type, helix diameter and L/D ratio. And that’s agree with [9, 24-25, 27].

The spacing ratio \((s/D_h)\) is important factors on which the behavior of screw piles depends. This importance is attributed to the fact that the spacing ratio is determined the type or mode of failure. The relation between spacing ratio \((s/D_h)\) and ultimate compressive load for screw pile model with helix plate diameter \((D_h=3D)\) and double helix plates at three different embedment ratios 30, 35 and 40 is clearly shown in figure 19. Two different spacing ratios \((s/D_h)\), 1 and 1.6 were used. It was seen that the ultimate compression capacity for screw pile model with \((s/D_h)=1.6\) embedded in soft clay layer \((L/D=30)\) is 10.5% higher capacity than the screw pile model with \((s/D_h)=1\). In dense sand layer or for model screw pile with \(L/D\) ratios 35 and 40 the decrease in \((s/D_h)\) ratio from 1.6 to 1 leads to rise the ultimate compressive capacity 44.6% and 38.5% respectively.

![Figure 18](image1.png)

**Figure 18.** The effect of helix number on ultimate compressive capacity of ordinary and screw pile model with \((D_h=4D)\).

![Figure 19](image2.png)

**Figure 19.** The effect of spacing ratio \((s/D_h)\) on ultimate compressive capacity of screw pile model with \((D_h=3D)\).
Figure 20 demonstrated the relation between spacing ratio \( (s/D_h) \) on ultimate compressive capacity of double helix screw pile model with helix diameter \( D_h=4D \) at three different embedment ratios \( (L/D) \) 30, 35 and 40. Two different spacing ratios, 0.75 and 1.25 \( s/D_h \) ratios were used. It can be seen that when increase the \( (s/D_h) \) ratio from 0.75 to 1, the ultimate compressive capacity for screw pile model embedded in soft clay layer \( (L/D \) ratio 30) increasing 25.8%, Whereas for model pile embedded in dense sand layer with \( L/D \) ratios 35 and 40, the increasing in spacing ratio will reduce the ultimate capacity by 29.5%, 41.6%, respectively.

![Figure 20](image_url)

**Figure 20.** The effect of spacing ratio \( (s/D_h) \) on ultimate compressive capacity of screw pile model with \( (D_h=4D) \).

5. Conclusions

1. The raising in compressive capacity of screw piles embedded to sandy soil layer (stable layer) through soft clay reaches to (27-56) times when change the embedment ratio \( (L/D) \) from 30 to 40.
2. It is possible to conclude that addition of the helix plate to the pile shaft will be very efficient to enhance the capacity of the screw pile when comparing the screw pile and ordinary steel pile.
3. The compressive capacity of screw pile increases when increasing helix number, regardless of soil type, helix diameter and \( L/D \) ratio.
4. The compressive capacity of double helix screw piles mainly depend on the inter helix spacing \( (s) \).
5. The increasing in spacing ratio \( (s/D_h) \) for screw piles embedded in soft clay layer, leads to an increasing in the ultimate compressive capacity.
6. The ultimate compressive capacity of screw pile embedded (5 and 10cm) in dense sand through soft clay layer \( (L/D \) ratio 35 and 40) respectively decreases when the spacing ratio increase.

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**Acknowledgments**

Financial support from the Ministry of Higher Education and Scientific Research and the Ministry of Education is recognized. I would like to thank the Director and staff of the Department of Civil Engineering of Diyala University (Iraq) as well as the staff of the Soil Laboratory and the Road Laboratory for using their laboratories.