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# Strength and Compressibility of Screw Piles Constructed in Gypseous Soil

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**Abstract.** The present work deals with the performance of screw piles constructed in gypseous soil of medium relative density; such piles are extensively used in piles foundations supported structures subjected to axial forces. The carrying capacity and settlement of a single screw pile model of several diameters (20, 30, and 40) mm inserted in gypseous soil is investigated in the present study. The gypsum content of soil used in tests was 40%. The bedding soil used in tests was prepared by raining technique with a relative density of 40%. A physical model was manufactured to demonstrate the tests in the laboratory. The model of screw pile has been manufactured of steel with a total length of 500 mm and helix diameters of 20, 30, and 40 mm continuous over the embedded depth of pile (400 mm). The results of tests showed decreasing the ratio of length to diameter (L/D) resulted in a higher axial carrying capacity of screw piles and low corresponding settlement.

**Keywords:** Screw piles; helix; gypseous soil; axial carrying capacity; settlement.

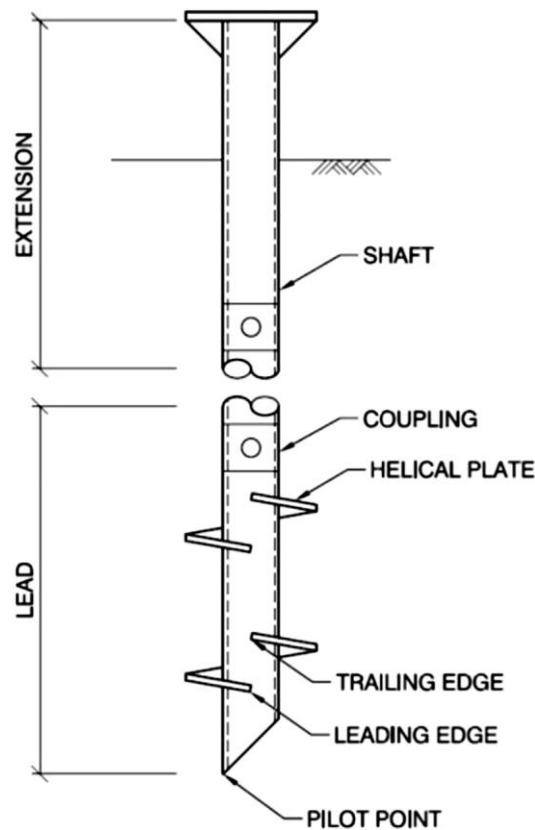
## 1. Introduction

The gypseous soils are spread in many areas of the world. The gypseous soils in Iraq covers about 30% of the area of the country [1]. Sometimes the gypsum content is high, causing serious problems for buildings and projects due to the dissolution of gypsum by running water through gypsum soil [2,3]. In general, gypseous soil is usually stiff when it is dry, but losses its strength upon wetting resulting from changing the water level or due to water leakage that may dissolve gypsum which causes large pores formation. The formation of cavities leads to increase the permeability of gypseous soils and these large cavities lead to collapses of buildings and failure of structures.

The screw piles differ from the usual piles, they are regularly made of high-quality steel. The screw piles consist of shaft and helix as the helix is fixed to the shaft at different spacing and has a pointed shape for easy installation in the ground [4]. Several elements can control the behavior of screw piles such as the diameters of shaft and helix and the spacing between the helices. Initially, the screw piles were mostly used as anchors and later used to support tensile loads such as power transmission towers. However, their use has been extended to include prone structures and parallel loading [5,6]. Screw piles provide essential structural resistance from the tensile, compression, and parallel forces along with the moments of inversion [7,8]. The basic components of the screw pile are illustrated in Fig. 1.

In the present study, the ultimate carrying capacity and settlement of screw piles made of steel of diameters (20, 30, and 40) mm inserted in gypseous soil of gypsum content and relative density of 40% has been investigated by conducting tests on laboratory scale physical model of piles. The ultimate carrying capacity of the screw pile is calculated from the load-settlement curve according to the failure criterion of 20% settlement that adopted in this study.





**Figure 1.** The basic components of the screw piles.

## 2. Carrying Capacity of Screw Piles

Different design methods determine the carrying capacity of screw piles in the literature. The most common methods are cylindrical shear method, individual bearing technique, and connection between torque for fixing of screw piles and carrying capacity of pile method. Using of the International Building Code encompasses these three design methods as well as different ways to find the carrying capacity of the screw piles [9,10]. The three hypothetical methods are based exclusively on estimating the maximum capacity of screw pile by equations, which differentiate whether the applied load is compression or tension and the pile is inserted in cohesive or cohesionless soil. However, the contact between the installation torque and carrying capacity is a formula based strictly on soil conditions as well as the characteristics of the screw piles. The carrying capacity of screw piles inserted in cohesionless soils can be calculated using Eqs. (1) to (4) [11]. The main variance in the analysis of cohesive and cohesionless soils under compressive loads is to take advantage of the internal friction of the soil as opposed to the undrained shear strength that is used in the analysis of cohesionless soil.

$$Q_c = Q_{\text{helix}} + Q_{\text{bearing}} + Q_{\text{shaft}} \quad (1)$$

$$Q_{\text{helix}} = 1/2 \pi D_h \gamma' (H_b^2 - H_t^2) K_s \tan \varphi \quad (2)$$

$$Q_{\text{bearing}} = \gamma' H A_h N_q \quad (3)$$

$$Q_{\text{shaft}} = 1/2 P_s H_{\text{eff}} \gamma' K_s \tan \varphi \quad (4)$$

Where

$D_h$ : the average diameter of helix;

$\gamma'$ : the effective unit weight of soil;

$H$ : the embedded depth of the pile;

$H_b$ : the depth to the bottom helix;

$H_t$ : the depth to top helix;

$K_s$ : the coefficient of lateral earth pressure in compression loading;

$A_h$ : the area of the bottom helix; and

$P_s$ : the perimeter of the screw pile shaft as suggested by Meyerhof and Adams [12].

$$N_q = e^{\pi \tan \phi} \tan (45 + \phi/2) \quad (5)$$

When the ratio of  $H/D$  is under shallow conditions, the shaft friction is negligible [13], so Eq. 4 reduces to:

$$Q_c = 1/2 \pi D_a \gamma' (H_b^2 - H_t^2) K_s \tan \phi + \gamma' H A_H N_q \quad (6)$$

The pile load test is used to determine the axial carrying capacity and settlement of piles [14]. The axial load is applied in an increment by using a fixed penetration rate method and the corresponding settlement is observed. Failure occurs at the point where the settlement continues to move downward without an increase in load, leading to plunging failure in the pile [15]. An ultimate pile load is then determined as the vertical asymptote between the point where the restricting skin opposition is mobilized and approaches point limit is reached, as the load settlement curve draws near a vertical gradient [16]. Different techniques for determining the ultimate pile carrying capacity from a load test have existed in the literature. Some of these techniques such as the Davisson criterion, Brinch Hansen criterion, L1–L2 technique, Federal Highway Administration (FHWA) (5% of the helix diameter), and ISSMFE (10% of the helix diameter) are outlined in reference [17]. Through previous experience and research concerning screw piles, it was found that most studies included the behavior of screw piles in clayey and sandy soils without gypsum. Therefore, the behavior of screw piles inserted in sandy soil containing gypsum with high rate reached to (40%) will be studied. The study would be including the effect of static loads and periodic loads on screw pile in gypseous soil by manufacturing a laboratory physical model for testing and conclusions.

### 3. Soil Sampling and Material Properties

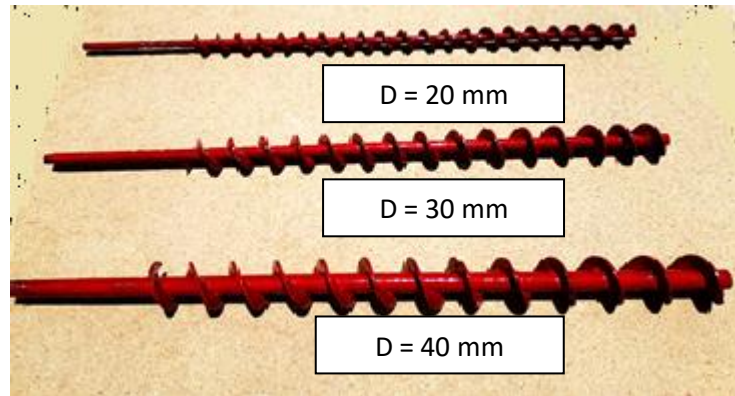
The gypseous soil is brought from the site of the University of Fallujah in Al-Anbar governorate. The soil has a gypsum content of 40%. The relative density of soil used in testing the model pile is 40% which considered medium to dense relative density based on DIN 1045 "verification of the safety of earthworks and foundations". The physical and engineering tests conducted on the soil in the laboratory. The properties of used soil are given in Table 1.

**Table 1.** Geotechnical properties of gypseous soil used in tests.

Property	Value	Property	Value
$\gamma_{sat}$ (ASTM D1556-00)	17.6 kN/m <sup>3</sup>	Specific gravity (B.S-13377: I976, No. 6)	2.4
$\gamma_{d,min}$ (ASTM D4254-00)	12.7 kN/m <sup>3</sup>	Soil classification	SC
$\gamma_{d,max}$ (ASTM D4253-00)	16.9 kN/m <sup>3</sup>	Passing sieve #200	14.5%
Relative density, $D_r$	40%	Cohesion, (ASTM D3080-72)	7.2 kPa
$\gamma_{d, used}$ according to $D_r$	14.1 kN/m <sup>3</sup>	Angle of friction (ASTM D3080-72)	36°
void ratio, $e$	0.7	Permeability (ASTM D 2434-68)	8.04×10 <sup>-4</sup> cm/s
Water content, $\omega$	25.1%	Gypsum content	40%

Screw piles consist of steel shaft and helix, which are distributed over the shaft with constant spacing. The helices are distributed along the steel shaft up to 400 mm and the rest of the shaft is 100 mm free

head of pile above the soil surface. The dimensions of manufactured screw piles are given in Table 2 and shown in Fig. 2.

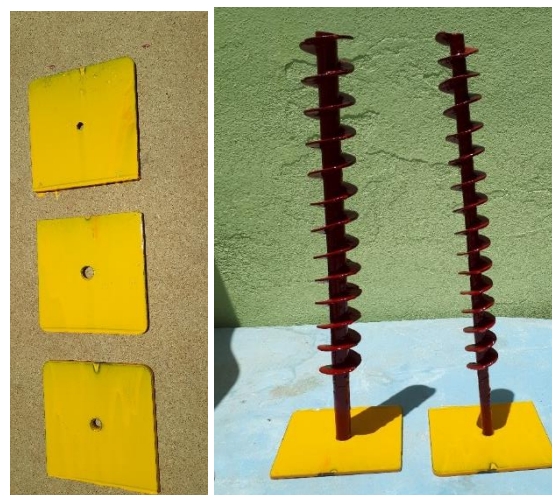


**Figure 2.** Models of used screw piles.

**Table 2.** Dimensions and configuration of used screw piles.

Screw pile of 20 mm helix diameter					
Shaft diameter	Helix diameter	Total length	Embedded depth in soil	No. of helix	Spacing between helix
8 mm	20 mm	500 mm	400 mm	22	18 mm
Screw pile of 30 mm helix diameter					
Shaft diameter	Helix diameter	Total length	Embedded depth in soil	No. of helix	Spacing between helix
12 mm	30 mm	500 mm	400 mm	15	26 mm
Screw pile of 40 mm helix diameter					
Shaft diameter	Helix diameter	Total length	Embedded depth in soil	No. of helix	Spacing between helix
16 mm	40 mm	500 mm	400 mm	13	30 mm

The pile cap is made of steel with dimensions of 120×120×6 mm. The screw pile is connected to the pile cap by making a hole in the center of the pile cap with the same diameter of the screw pile shaft to be by nut as shown in Fig. 3. The type of free pile cap was adopted in the tests used.



**Figure 3.** Screw pile with pile cap of dimensions 120×120 mm.

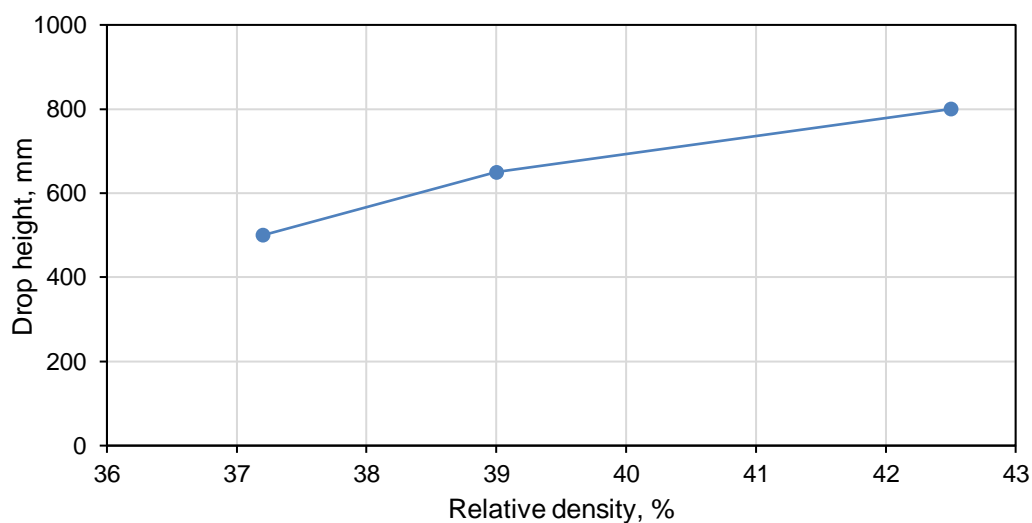
A steel box with dimensions of (700×700×600) mm was used for conducting the test where it was filled with gypseous soil to simulate field conditions as shown in Fig. 4.



**Figure 4.** Installation of screw pie in the steel box container.

#### 4. Testing Procedure

The raining technique was used to pour the gypseous soil in the test box and satisfy the desired relative density. To achieve a uniform layer according to the desired density, a special raining device was designed for this purpose. The pouring height and sand discharge rate mainly affect the density of the gypseous soil layer in the raining method. The height of the box was divided into 5 layers, each layer of 120 mm height, the weight of soil required to fill the layer is 83 kg depending on the adopted density of soil of  $14.1 \text{ kN/m}^3$  which satisfies relative density of 40%. The relationship between pouring height and the relative density of sand is shown in Fig. 5. The relative density of the gypsum soils used in all tests is assumed of medium density (40%), and to reach the specified relative density of 40%, the free fall height would be 720 mm.



**Figure 5.** Calibration curve of raining technique.

The following steps were followed to install the screw piles after finishing the placement of the soil in the container and applying loads on the pile cap:

- On the top of the screw pile, apply the manual torque to install the screw pile in the soil to the required depth of 400 mm as shown in Fig. 6.
- The tests included inserting three screw piles of different helix diameters (20, 30, and 40) mm in the soil to the required embedded depth of 400 mm, there is a gap of 100 mm thickness between the pile cap and surface of the soil as shown in Fig. 7
- Then a square plate (pile cap) is fixed on the top of the screw pile. Subsequently, the dial gauge and LVDT were installed vertically to measure screw pile displacement as shown in Fig. 8.
- The hydraulic jack system is installed with a compressor to simulate axial static loads on the screw piles, which inserted in gypseous soil. The used hydraulic jack of full capacity equals to 5 tons.
- The load cell was fixed on the head of the loading shaft of hydraulic jack and connected with the indicator to measure the axial loads on the screw piles.
- The test was carried out after 24 hours from inserted the screw piles into the soil to give a sufficient time to rearrange the granules of the soil and remolding.
- Axial force is applied gradually. The applied load increased from 0.1 to 1.2 kN, and the average downward movement of the screw pile is measured under each increment of loading using a dial gauge and LVTD.
- The application of axial loading on the screw pile continued to reach the point of failure, which defined as the load corresponding to a settlement value of 20% of the diameter of the helix [18]



**Figure 6.** Insertion of screw pile in soil.



**Figure 7.** Gap between pile cap and soil surface.



**Figure 8.** Loading system of screw pile and gauges.

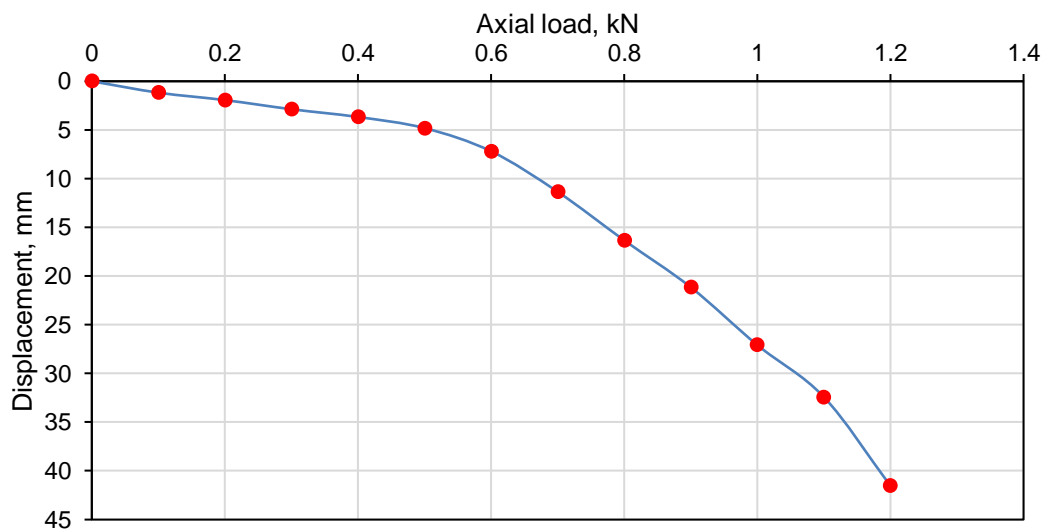
## 5. Results and Discussion

The laboratory tests were carried out for the carrying capacity of the screw piles under axial static loads. The test was conducted on screw piles of different diameters (20, 30, and 40) mm with an embedded depth of 400 mm penetrate in gypseous soil. The test continued to extremely reach the point of failure in the final displacement. The results obtained from tests can be summarized in Table 3, showing the diameters of the screw piles with displacement for each load increment of the screw piles.

**Table 3.** Displacement for each load increment applied on screw piles.

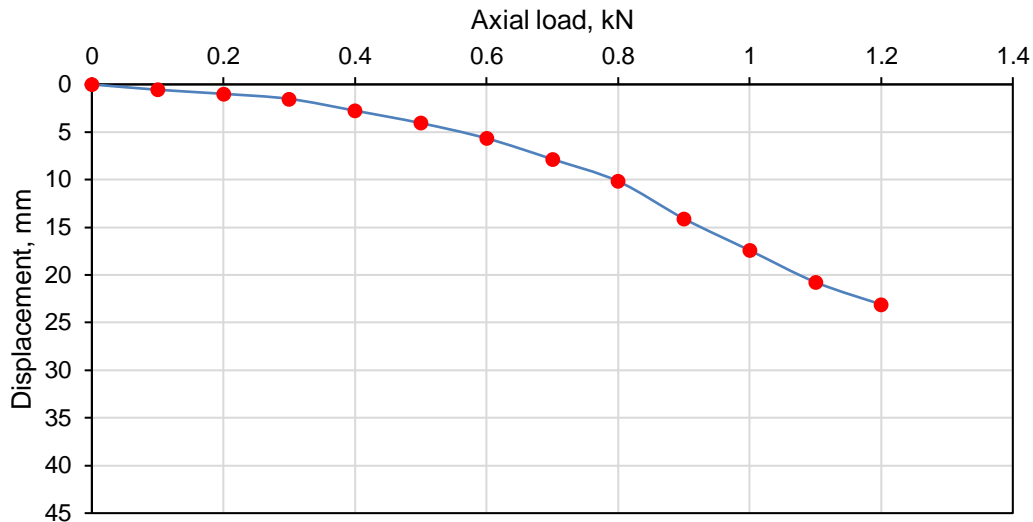
Axial load (kN)	Displacement of screw pile (mm)		
	D = 20 mm	D = 30 mm	D = 40 mm
0	0.00	0.00	0.00
0.1	1.17	0.56	0.22
0.2	1.93	0.99	0.74
0.3	2.87	1.52	1.28
0.4	3.67	2.76	2.37
0.5	4.81	4.06	3.28
0.6	7.19	5.66	4.46
0.7	11.35	7.85	6.72
0.8	16.33	10.17	8.98
0.9	21.15	14.09	10.90
1.0	27.08	17.42	12.18
1.1	32.42	20.76	14.41
1.2	41.54	23.10	16.87

In Figs. 9, 10, and 11, there is a resistance of the screw pile to the displacement at the beginning of the tests. Since the failure occurred in screw piles when the displacement is reached more than 20% of the screw piles diameter. The failure load was 0.45 kN for the screw pile of 20 mm diameter which corresponds to a displacement of 4 mm, while the load that caused the failure of the screw pile of 30 mm diameter is 0.65 kN where the displacement reached more than 6 mm. The failure load of the screw pile of 40 mm diameter was 0.76 kN and the corresponding settlement is 8 mm. The failure mode in all cases is general shear failure that is one of the advantages of using screw piles to resist the axial loads in gypseous sandy soils. Therefore, the adopted criteria of failure may be extended to be 40% instead of 20%. This criterion can be approved by applying different theories to calculate the failure loads.

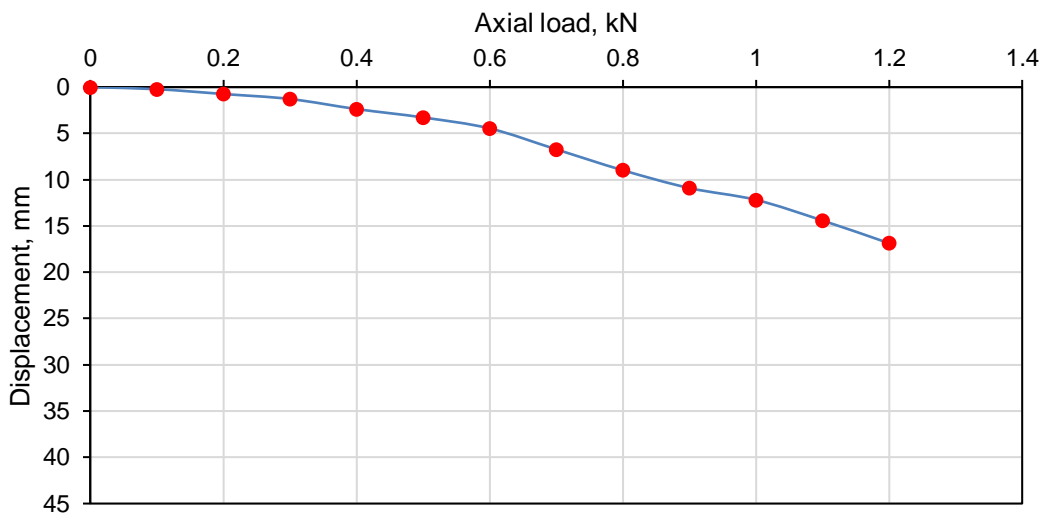


**Figure 9.** The load-displacement curve for a screw pile of 20 mm diameter.





**Figure 10.** The load-displacement curve for a screw pile of 30 mm diameter.



**Figure 11.** The load-displacement curve for a screw pile of 40 mm diameter.

## 6. Conclusions

In the current study the ultimate carrying capacity of screw piles of different diameters inserted in dry gypseous soil of medium relative density were investigated. Based on the results of the current study, the following conclusions can be drawn out:

- The ultimate carrying capacity of the screw piles increases with decreasing the L/D ratio.
- Increasing the diameter of screw piles inserted in gypseous soil gives high failure load and low displacement due to the high strength of dry gypseous sandy soil.
- Depending on the adopted failure, criteria, which specify the failure, load corresponding to 20% of screw diameter. The failure loads are (0.45, 0.65, and 0.76) kN and the corresponding displacements are 4, 6, and 8 mm for piles of 20, 30, and 40 mm diameter, respectively. The adopted failure criteria of 20% is very conservative and can be extended to 40%.

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