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UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF
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PULL-OUT CAPACITY OF DOUBLE-HELIX SCREW PILE IN ORGANIC SOIL

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IN
CIVIL ENGINEERING

BY
OMAR BAKR KHALEEL
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Pull-Out Capacity of Double-Helix Screw Pile in Organic Soil

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Supervisor
Prof. Dr. Hanifi ÇANAKCI

By

Omar Bakr KHALEEL

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This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for of the degree of consensus or majority Master of Science.

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Omar Bakr KHALEEL

ABSTRACT

ABSTRACTPULL-OUT CAPACITY OF DOUBLE-HELIX SCREW PILE IN ORGANIC SOIL

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M.Sc. in Civil Engineering
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The organic soil used in this study was obtained from Sakarya region, Turkey. According to the system of classification (USCS), the present soil is classified as an organic silt soil with high plasticity (OH). Standard and modified compaction, sieve analysis, specific gravity and organic content tests were done to obtain the engineering properties of organic soil.

An experimental investigations on single helical piles were conducted in organic soil. In this work, the effect of spacing ratio of double-helix pile and soil density on the pile performance under vertical pull-out static load were investigated. Double-helix piles were installed and loaded axially in two soil densities: soft and stiff organic soil. Up lift performance was predicted using the axial load versus displacement readings.

The pull-out load was applied vertically with the axis of the pile. Test results showed that the ultimate pull-out load capacities of double-helix pile are controlled by the spacing of helical plates. An increase in spacing ratios causing a decrease in ultimate pull-out capacity of helical pile in organic soil. Also, increasing the soil density increasing the ultimate pull-out load capacity. The study showed that the capacity of double-helix pile is greater when the spacing ratios 1 and 2 than 3 and 4. In general, the capacity of double-helix piles with a spacing ratios of 1 and 2 is ranged from 1.25 to 1.77 times the capacity of double-helix pile with spacing ratios of 3 and 4 in both stiff and soft soil respectively.

Keywords: Organic soil, helical pile, pull-out, soil classification, pile installation

ÖZET

ORGANİK ZEMİNE GÖMÜLÜ ÇİFT BURGULU KAZIKLARIN ÇEKME DAYANIMININ DENEYSEL İNCELENMESİ

KHALEEL, Omar Bakir

Yüksek Lisans Tezi, İnşaat Mühendisliği

Tez Yöneticisi: Prof. Dr. Hanifi Çanakcı

Eylül 2018

38 sayfa

Bu çalışmada, organik zemin içerisine gömülü tekil çift burgulu kazık çalışıldı. Çalışmada, çift burgulu kazıkların çekme kapasitesinin burgular arası mesafeyle ve zeminin yoğunluğu ile etkileşimi incelendi. Çift burgulu tekil kazık önceden hazırlanan organik zemin içerisine döndürülerek yerleştirildi ve eksenel olarak çekme yükü uygulandı. Kazıkların çekme kapasiteleri çekme kuvvetinin - deformasyona eğrileri kullanılarak tahmin edildi. Çalışmada Sakarya bölgesinden elde edilen organik zemin kullanıldı. Bu zemin birleştirilmiş zemin sınıflama sistemine göre yüksek plastisiteli siltli organik zemin (OH) olarak tanımlandı. Zemini geoteknik özelliklerini belirlemek amacı ile zemin numuneleri üzerinde standart ve modifiye sıkışma, elek analizi, özgül ağırlık ve organik içerik tayini deneyleri yapıldı.

Deney sonuçlarından, çift burgulu kazıkların nihai çekme kapasitelerinin burgular arasındaki mesafelerin değişiminden etkilendiği gözlendi. Burgular arasındaki mesafenin artmasıyla organik zemin içerisine gömülü kazıkların nihai çekme kapasitelerinin azaldığı belirlendi. Ayrıca, zeminin yoğunluğunun artmasıyla kazıkların nihai çekme kapasitelerinin arttığı belirlendi. Çift burgulu kazıklarda burgular arasındaki mesafe bir çap kadar olduğunda en yüksek çekme kapasitesi elde edildi en düşük çekme kapasitesi ise bu mesafenin dört çap kadar olduğu durumda elde edildi. Genel olarak, helikler arasındaki mesafenin bir ve iki çap olduğunda kazıkların çekme kapasitesi üç dört çap mesafeye göre 1.25 den 1.77 kata kadar daha fazla olduğu belirlendi.

Anahtar kelimeler: Organik zemin, burgulu kazık, çekme kapasitesi, kazık yerleşitirme.

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I am grateful to all my friends who extended themselves in many ways for the completion of this dissertation work. I am indebted to all of them. Especially, Dr. Majid HAMED

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CHAPTER 1
INTRODUCTION

1.1 General

A type of geotechnical foundations are the helical piles that can be used both as a compression or pull-out members and are consists of many of helical blades fixed around a central steel shaft with a square or circular cross section, as presented in Figure 1. The plates are constructed as a helix with a carefully controlled pitch. The helical pile can have one or more than one helix plate located at appropriate spacing on the shaft. The number of helical plates based on the conditions of the soil and on the required loading capacity (Schiavon et al., 2014). These helical piles are installed into the soil by applying torque to the upper end of the shaft. The central shaft is used to transmit torque during installation and to transfer axial loads to the helical plates. In the last two decades, the use of helical piles has widely used. Because it is have many advantages such as, fast installation, instant loading capability, and resistance to both uplift and compression loads have caused due to their being used in more traditional applications of geotechnical engineering.

1.2 Research Objectives

Helical pile foundations are used in conventional engineering practice to transfer the loads from the structures to the underlying soil safely and without stability or settlement problems. The aim of this project was to study the performance of double-helix screw piles installed in organic soil with different number of spacing, to evaluate how these spacing of the helical pile effect the pull-out capacity. To achieve these objectives, axial pull-out load tests were performed on double-helix screw piles with different number of spacing.

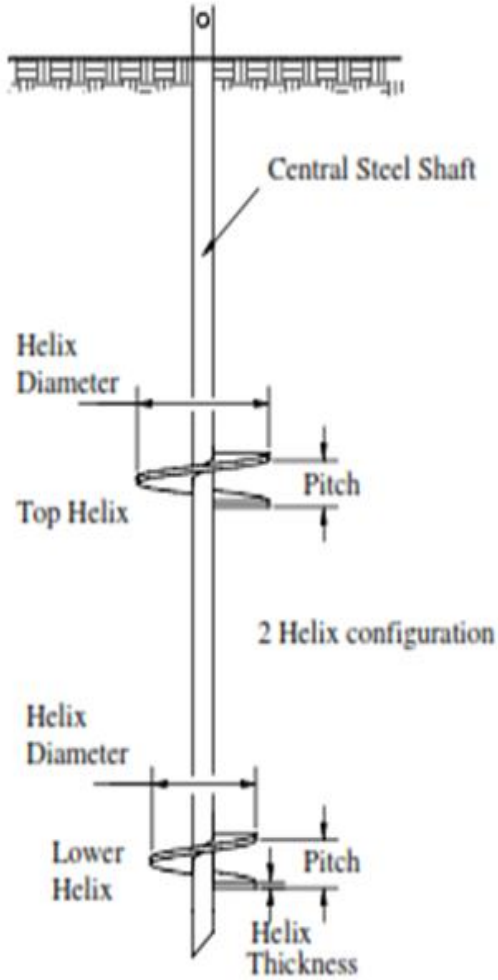

Figure 1.1 Helical pile definition

1.3 Organization of Project

The project is organized into four chapters. The second chapter consists of a literature review on helical pile and geotechnical properties of organic soil. The third chapter explains materials and method. The fourth chapter presents the results of organic soil properties and pile behavior under the effect of pullout load. At the end chapter five provides the conclusions and recommendations.

CHAPTER 2
LITERATURE REVIEW

2.1 General

Helical piles are a popular key for relatively low-capacity, recyclable or removable foundations supporting rail signage or road and related light structures. When used a helical pile, the designer must choose the effective length and the helical plate spacing ratio, which are controlled by the number, spacing and size of the separable helices (Stanier et al., 2013). Anchor piles have many important benefits when compared to other piles: they can be installed in with handy devices, which is significant in places, where heavy technology equipment is not available, for instance, under the bridges or in basements, etc.; the advantage of helical pile foundation is practically no vibration during the installation. These advantages make this type of pile foundation pretty on field that are environmentally sensitive. Installations close to available footings or foundations generally cause no damage effect, and the helical piles can be used frequently. Although, helical pile have some disadvantages, like the load boundaries because of the loading capacity of the handle, also the corrosion may be occurred due to unfavorable soil conditions.

2.2 Adopted Methods to Predict Pull-Out Capacity of Helical Pile

The first authors that was adopted procedure to estimate pull-out load capacity was Trofimenkov and Maruipolshii (1965) they was the first to submit a methods which defined the uplift load capacity as a function of a helical pile if a form of non-dimensional parameters. Based on these authors, for single helix pile, the ultimate load capacity of pile is the sum of the plate bearing capacity and the shaft resistance of helical plate.

In the situation of multi-helix piles, the most used methods to calculate the uplift load capacity are, individual bearing method, cylindrical shear method and installation torque method.

2.2.1 Cylindrical Shear Method

The failure mechanism of the cylindrical shear method involves a general load capacity failure above the top plate of anchor, described by breakout factors, and cylindrical soil failure between the bottom and top helices (Mitsch and Clemence 1985).

In this method, the entire volume of soil between the plates is assumed to be generated. This kind in mechanism failure is shown in Figure 2.1. Because of the rigid nature of this type of failure mechanism, the pile shaft is improbable to contribute to the overall capacity. Ultimate tension load of a multi-plates pile is a mix of bearing capacity of the top plate and shear along the cylinder of soil between the plates and, given by:

$$Q_u = \pi D(n-1)S(c + \sigma_v tan\phi) + 0.25\pi D^2(1.3cN_c + \sigma_v N_q) \qquad (2.1)$$

Where D = average plate diameter; S = spacing between each plate; n = number of helical plate; σv = vertical soil pressure at the helix plate, c = soil cohesion; ϕ = friction angle of the soil; and Nc and Nq = factors of bearing capacity for general shear.

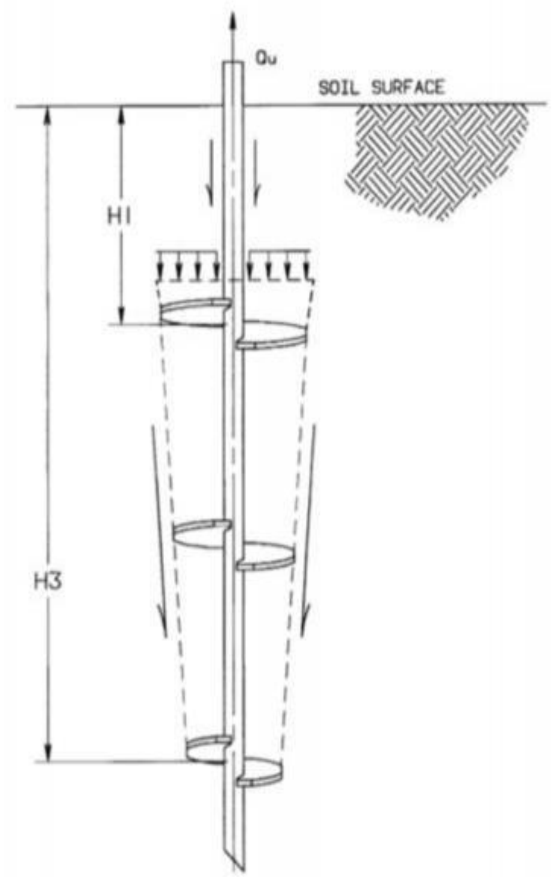

Figure 2.1 Cylindrical shear failure (Hoyt and Clemence 1989)

2.2.2 Individual Bearing Method

Adams and Kym (1972) adopted a number of pull-out experiments on multi-helix piles, with the ratio between the spacing of helix and diameter of helix ranging from 2.1 to 3.6, inserted in different type of soils. They concluded that each helix worked independently of the other, because the plates were widely spaced. Consequently, the pull-out load capacity of the multi-helix pile is the summation of the bearing load capacities of all helical plates and the resistance of the shaft (Figure 2.2). The individual bearing method assumes that a multi-helix anchor behaves as a group of independent single plates, and the uplift capacity of each helical plate can be estimated using the Terzaghi's bearing-capacity equation.

The manufacturers of helical pile think that, for deeply buried helix pile, the best calculation is the theoretical capacity using an "individual bearing" method depend on Terzaghi's(1943) equation for general bearing-capacity without modification. The supposed mechanism of failure in the "individual bearing" method involves of each helical plates displacing the overburden soil in a logarithmic spiral mode. Thus, the capacity of each plate can be predicted using the well-known the equation of Terzaghi for bearing-capacity. The total ultimate uplift capacity is the sum over n plates, as given by:

$$Q_u = \sum_n^1 A_n (1.3cN_c + \sigma_{vn} N_q + 0.5\gamma B N_\gamma) \quad \text{.....................................} \quad (2.2)$$

Where an = plate area. All remaining parameters are defined previously.

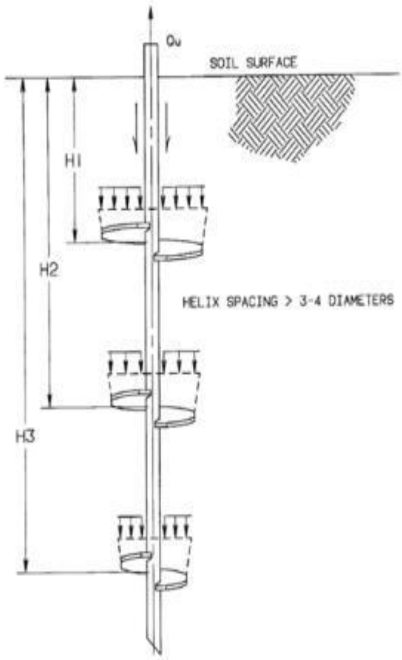

Figure 2.2 Individual bearing failure (Mitsch and Clemence 1985)

2.2.3 Installation Torque Method

The last theory presently used when predicting the capacity of multi-helix pile is depend on installation torque. Currently, this empirical procedures based on installation torque is frequently used by pile manufacturers who have access to massive quantities of helical site data. The details concerning these correlations and the data on which they are obtained are generally considered limited by the manufacturers. The essential torque is controlled during installation until the design depth for the is pile reach. The reading of the torque are then be in the region of the distance of the last three helices diameters of installation. The value of the average torque times the torque factor gives the ultimate load capacity of helix pile.

Anchor piles are fixed into the site by torque that was applied to the head of pile. This technique of installation products least value of vibration, soil spoils and noise, which creates it appropriate for construction in municipal areas. In addition, control the torque that was applied during installation permits predicting the ultimate capacity of helix pile and offers means for quality control/assurance. The existing installation torque, the axial load capacity can be estimated by using the following formula (Livneh and El Naggar 2008; Hoyt and Clemence 1989):

$$P_u = K_t T \quad \text{(2.3)}$$

Where T is the installation torque, Pu is the ultimate axial capacity and Kt is the capacity-to-torque ratio.

2.3 Failure Mechanism

The occurrence of individual bearing or cylindrical shear failure mechanisms depends mainly on the soil type and spacing ratio. Spacing ratio (S/D) is defined as the spacing between two adjacent helical plates divided by their average diameter (Sakr 2009). The field investigation of Lutenegger (2009) indicates that at workloads the response of helical anchors in stiff clays appears to be controlled by individual plate behavior above a space ratio of 1.5. For helical anchors in sand, Lutenegger (2011) concluded that the transition from cylindrical shear behavior to individual bearing behavior occurs at a spacing ratio of about 3.

The first thing expects the progress of the mechanism failure for each helical blades and determine the bearing capacity from the theoretical equation for such deep foundation, while the total axial compressive or pull-out load is calculated by adding the partial loads of blades. The cylindrical shear mechanism of helix pile was suggested by Narasimha Rao et al. (1991) when the pile is helical with more than two blades and installed into clayey soils. They revealed that, this type of failure mechanism is evidently established for a ratio s/D = 1.5–2.0, where s is the distance in vertical direction of the plates and D is the helical plate diameter.

A failure mechanism of helical pile is improved in sand was studied by Ghaly et al. (1991), who worked results of site tests, in order to calculate the pull-out load capacity. The Authors tested single plate or multi-plate of helical pile, with a many embedment depth and they found the failure surface was an inverted conic with the small base at the bottom helical blade and the wider one at the surface of soil. Young (2012) has calculated the available individual plate bearing and the methods of cylindrical shear and suggested new models of calculation. A enormous number of experiments on model helical piles contributed to the predicting of the failure type and to the understanding of parameters, which improve upon the prediction problem, chiefly of the pull-out ultimate load.

Ghaly et al. (1991), Nagata and Hirata (2005), Hanna et al. (2007), Ismael (1989). Their results in load tests for full scale are stated and determined from some authors e.g. Zhang et al. (1998) for pull-out and compression tests in cohesionless and cohesive soils, Bustamante et al. (2004) for axial compression loads in helical piles in silty sand and Sakr (2010, 2011) for pull-out and compressive loads in helical piles.

2.4 Effect of Installation on Helical Pile Behavior

Komatsu (2007) installed a small scale helical pile model in sand and in clay to investigate the installation effect, and observed the following: (i) during installation the soil rises upwards above the helix, (ii) the soil is pulled down close to the shaft due to the shaft friction, (iii) the soil is compressed below the helix. The visible tests of Nagata and Hirata (2005) illustrated the shear fracture zone formed by the helical pile driving in dry sand. The results of these visible tests confirm the statement of Kulhawy (1985), that significant disturbance does occur within the cylindrical installation zone of the helical pile. For this last author, the effect of disturbance can be estimated by doing a relations of the disturbed properties to the filed soil properties.

Mosquera et al. (2015) reported the results of a preliminary study to simulate numerically the effect of installation on the sand penetrated by a single helix anchor, tested in Tsuha et al. (2012). Two different numerical simulations were carried out by using the finite difference code FLAC 3D. For the first model the penetrated soil at the region above the helix is assumed to have the similar characteristics as the around soil that was intact the shaft. For the second model the soil characteristics assumed for the cylindrical volume above. Rao and Prasad (1992) commented that during helical anchor installation in sand, the soil that moves laterally transfers the stress to the surrounding soil, and at the same time, the limited overburden load allows upward movement of sand, and it may cause loosening effect. Consequently, after the end of installation, the values of the properties of the soil inside the cylinder above the helices are modified. This installation effect depends on the soil type and characteristics, and on the helical a nchor geometry, to simulate the effect of installation the helix are adjusted. Field experiments (Clemence et al., 1994; Sakr, 2009 and Lutenegger, 2011) have shown that, in certain sand sites, the quantity of increase in the pull-out load capacity of helix pile with the increase in the blades number is not as predicted. This fact 11 this Implis that the effect of installation on the uplift capacity of multi-helix anchors is more significant above the upper helices.

Wang et al. (2013) compared the results of helical anchor models in clay tested in a geotechnical centrifuge (with different combinations of the number of helical plates, plate spacing, and embedment depth) with numerical solutions from the LDFE approach and semi-theoretical solutions. These authors concluded that for multi-plate anchors, the predictions of uplift capacity obtained using an estimate of the remolded shear strength were found to be closer to the measured uplift capacities compared to predictions based on the intact shear strength.

The field tests described in Tsuha et al. (2015) showed that the installation of helical anchors in an unsaturated residual structured soil creates a breakdown on the structures of the natural soil that influence the pile behavior for uplift applications. In this cited study, the significant difference between the results of axial compression and uplift load tests carried out on the anchor piles validates the important effect of pile installation on the helix pull-out bearing resistance in the type of soil evaluated. Also, triaxial tests were carried out on undisturbed and disturbed (by pile installation) soil specimens at the depth of the helices.

2.5 Experimental Studies on Helical Piles

Clemence and Ghaly (2013) presented a complete review of model-scale laboratory (1g) investigations of helical piles. These authors stated that, although the model tests lie in the capability to inexpensively test various parameters with relative ease as compared with full scale tests, the scale testing has also disadvantages: lack of perfect similarity between model and full-scale tests, effect of boundary conditions, difference between natural soil in the field and a layer that is built under controlled conditions in the laboratory, and satisfying similitude.

Mitsch and Clemence (1985) performed laboratory and field investigations of the uplift capacity of multi-helix anchors in sand. This study indicated that a cylindrical failure surface developed below the top helical plate during pull-out and that, above the top plate, the failure surface was dependent on the anchor embedment depth. The "cylindrical shear method" (mentioned previously in this text) was founded on the results of this laboratory study. The method suggests that the uplift capacity is provided by the bearing resistance on the upper helical plate, frictional soil cylinder resistance, and friction on the shaft.

Ghaly et al. (1991) conducted an experimental investigation on single-helix anchor models installed in dry sand, submerged sand, and sand subjected to upward seepage flow. The model tests were performed in a masonry tank, 1.0 m long, 0.7 m wide, and 1.2m deep. From these tests, they proposed a reduction factor to be applied to the analytical equations, to account for the submersion or due to upward seepage flow.

Nagata and Hirata (2005) presented a model investigation on the uplift resistance of screw steel piles. They performed uplift tests on reduced-scale screw pile to clarify the relationship between the diameter of wing, diameter of pile, pile-end depth and the pull-out capacity at the end of pile. For this study, the pressure of ground when the pile driving and tension was measured. The model-soil tank was prepared with pressurizing abilities and installing ground pressure gauges at location about 20 mm from the wing edge to determine horizontal earth pressure. The soil confining pressures were applied as follows: the lateral pressure at 150 kPa and the axial pressure at 300 kPa.

Spagnoli et al. (2015) performed a series of laboratory model tests on helical pile models with different helix-to-shaft ratios in a large sample of sand. The results suggest that the installation results in compaction of the sand around the helical pile.

Mooney et al (1985) described the results of laboratory and field tests on multi-helix anchors embedded in silt and clay. They proposed a method for the estimation of the uplift capacity based on the soil cohesion and an empirical uplift coefficient based on H/D ratio.

Narasimha Rao et al. (1991) tested multi-helix anchors with varied spacing between the plates in clay. The helical blades were spaced conforming to predetermined spacing ratios (S/D). Based on their test results, they concluded that the spacing between the helical plates controlled the capacity of helical anchors in clays. The pullout tests revealed that very nearly cylindrical surface could be obtained between the top and bottom helices for anchors with the spacing ratio of 1 to 1.5.

Depend on the field and laboratory tests, Mitsch and Clemence (1985) found semi-empirical formulas in order to calculate the tension capacity of multi-helical for both

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Deep and shallow piles in sand. In terms of calculating the axial ultimate load capacity of screw piles, Meyerhof and Adams (1968) proposed an equation like to the simplified bearing capacity to determine the pile pull-out capacity depending on vertical failure surface. A improved theory on the failure mechanism of helical pile in sand was studied by Ghaly et al. (1991), who employed field tests results, in order to calculate the pull-out load capacity. They investigated single or multi-helix screw piles, with a several embedment depth and they found the small base of inverted conic failure surface at the bottom helical pile blade and the greatest one at the free surface of soil. Young (2012) has calculated the cylindrical shear methods and individual plate bearing and obtained new estimating models. A several number of experiments on model anchor piles participate to the exploration of the type of failure and to the accepting of parameters, which improve based on the problem of estimation, chiefly of the pull-out ultimate load, e.g. Ismael (1989), Nagata and Hirata (2005), Hanna et al. (2007), Ghaly et al. (1991). Results in tests of field scale load are declared and calculated from some authors e.g. Zhang et al. (1998) for pull-out and axial compression tests in cohesion less and cohesive soils (Alberta Canada), Bustamante et al. (2004) for axial loads in helical piles in silty sand and Sakr (2010, 2011) for pull-out and compressive loads in helical piles in clay till and sand.

2.6 Review Study on Organic Soil

2.6.1 Organic Soil Definition

The technical definition of organic material, any substances that includes carbon is termed "organic". Though, geologists and engineers applied a narrower definition when applying the term to soils. Soil of organic matter is one that includes a substantial quantity of organic content that was generated from plant remains. This means that it requires to be still in the decomposition process and fresh, thus holding a distinctive texture, odour and color (Huat et al., 2014). Larsson (1996) noted that organic matter in soils originates from living plants, animals and organisms. Especially, marine animals and plants contribute a major amount for the formation of organic material in the soil. During the transformation processes of plants, organic products such as peat and coal are created. The Soil Science Society of America (SSA) has designate soil organic substance as "the organic fraction of soil, contains animal, microbial residues, plant, and fresh and at all steps of decomposition, and relatively resistant soil humus" (SSSA, 1979). Stevenson (1994) reported that the soil 11
Organic material contains the total organic matter in soils, containing light fraction, litter, water-soluble organics, microbial biomass, and stabilized organic matter given the difficulties of soil organic matter. Organic matter can be classified into two main types: non-living organic matter and living organic matter. As reported by Chikyala (2008), the transformation of plants and animals into organic soils predominantly through bacterial activity, and this process is intensified by hot climate, suitable humidity and exposure to oxygen in the air as shown schematically in Figure (2.1). Muck, mucky peat, peaty muck, and peat are terms used in place of textural classification names for organic soils. For the formation of organic, the rate of decomposition must be slower than the rate of deposition, resulting in the accumulation of organic material (McDonald, 1993). It takes about 500 years to accumulate 30 cm of organic soil (McDonald, 1993). Organic soils are composed of different remains of animals and plant that have accumulated, in different phases of decomposition, in an environment that does not permit the materials to decay to take place quickly (Caldwell, 1977).

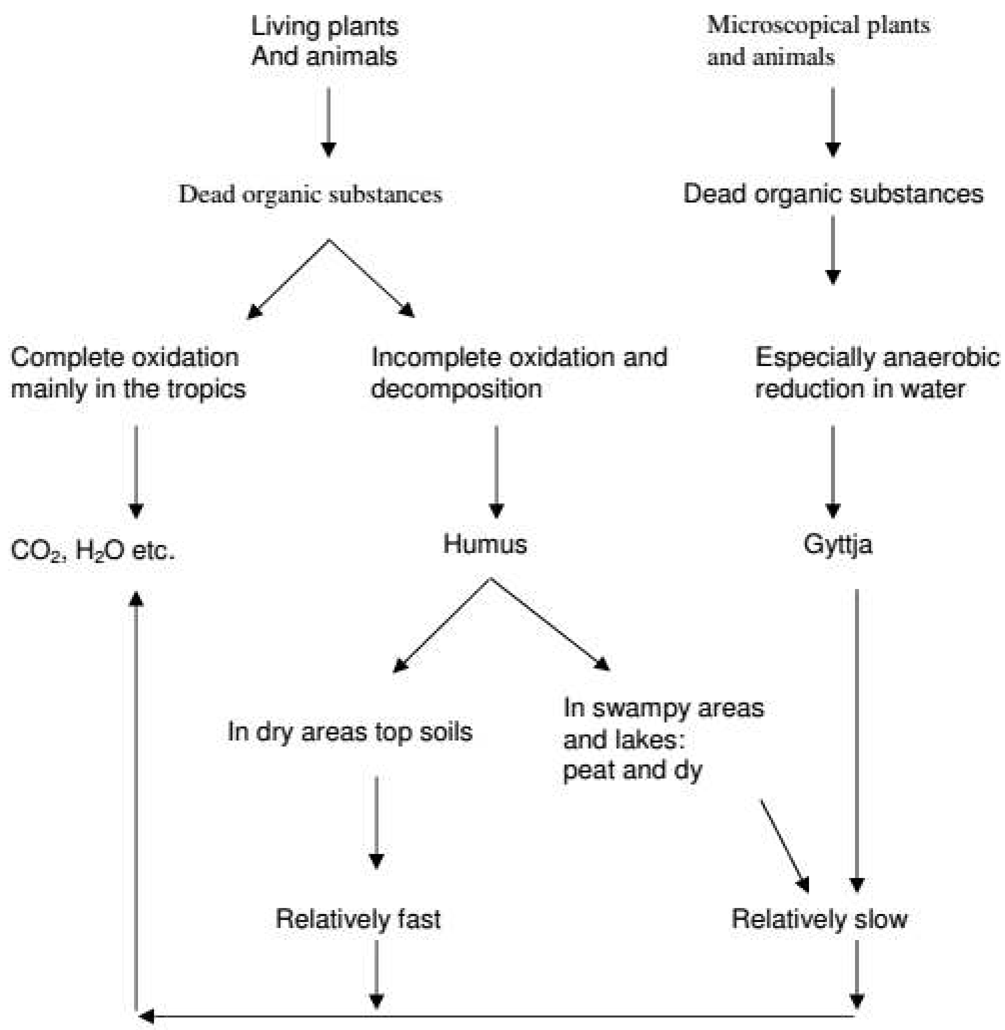

Figure 2.3 Schematic Processes during Decomposition of Biogenic Matter (Hallden, 1961)

2.6.2 Engineering Properties of Organic Soil

Organic soils identification is very imperative due to these soils are weaker and high compressible than inorganic soils. For most engineering projects, as similar they do not offer appropriate support. Traditionally, practically to bypass such soils, drive a pile though them or replace them (Huat et al.,2014). In soil mechanics conservative, soils are defined as particulate materials, as dissimilar to rocks, and can concurrently include three phases: liquid, solid, and gas. In the case of organic and peat soil, the solid phase contains two substances: organic substance and inorganic ground minerals. The physical and geotechnical characteristics of organic can be determined according to the relative proportion of these containing and their specific nature (Edil, 2003).

2.6.2.1 Index Properties

The details of engineering characteristics of organic soils such as specific gravity, water content, Attetberg limits, and density, are explained here. Soil water content can simply have calculated in the laboratory by using the test of water content (ASTM D2216 or BS 1377: 1990), which consist of drying a soil specimen in an oven at 105◦C for 24 hours. In case peat soils, the standard procedures for drying the soil at 105◦C during 24 hours could cause to burning of the organic constituent in peat, thus generating too large a figure for moisture content. Therefore, a lower temperature advocate the organic substances, between 50 and 95◦C. Kabai and Farkas (1988) and Skempton and Petley (1970) studied the effect, and found that the loss of organic substances at 105◦C is unimportant, while at low temperatures drying holds a small quantity of free water. Zainorabidin and Bakar (2003) inspected the effect of drying temperature for hemic peat soil and reported that for temperatures in the range between 100 and 200◦C the drying time required is between 24 and 60 hours.

For peat and organic soils, the liquid limit is based on the type of detritus of plant included, clay proportions and degree of humification in the present soil. For temperate peat, the liquid limit of fen peat varying between 200–600%, and for bog peat between 800–1500% (Hobbs, 1986). Skempton and Petley (1970) put the H3 of the von Post scale for the liquid limit as an approximate boundary and for the plastic limit H5 was used. In any situation, according to Hobbs (1986), to calculate the plastic limit of peat soil there is slight point because the plasticity gives little indication of their properties. Generally, the liquid and plastic limits of organic soils increased with increasing organic content (Tremblay et al, 2002). Landva el al. (1983) reported that the addition of organic carbon (organic substance) significantly increased both liquid limit and plastic limit.

The bulk density definition is the ratio of soil in dry mass to its volume. Bulk density is a function of organic content, void ratio, and specific gravity. Typically, the low bulk density of soils due to higher organic content, particularly if the fiber content is high. In organic soil the fibers generate a more open structure results in more voids. Holtz and Krizek (1970) studied such soils, and concluded that the increasing in organic content causing a decreased in maximum dry density of compaction, whereas the optimum moisture content increased with increasing organic content. The same conclusions was also reported by Schmidt (1965). The specific gravity of soil with 16 high organic content is generally in the range of 1.0-2.0. For high organic content, the typical value is 1.5 (huang et al., 2009). The specific gravity was increased when the mineral content increases; thus, specific gravities more than 2.0 are a sign of high mineral content of the soil (MacFarlane, 1969). Figure 2.2 presents a relationship between organic content and specific gravity. In general, when the organic content increases the specific gravity tends to decrease.

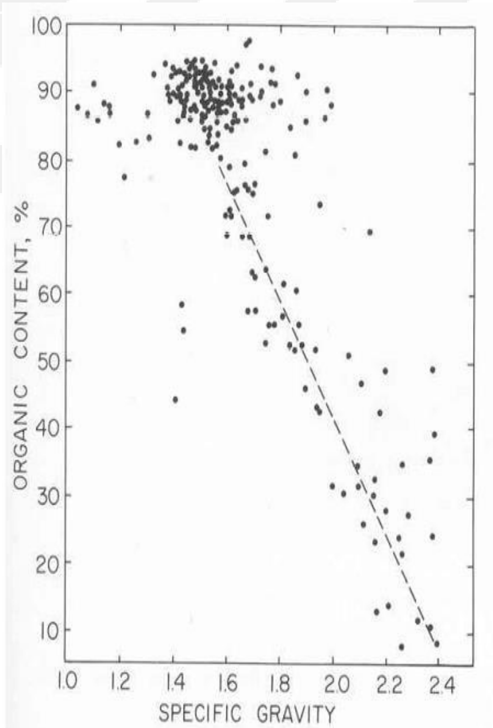

Figure 2.4 Organic content versus specific gravity (Radforth et al., 1996)

2.6.2.2 Shear Strength

In engineering design one of the most important factors is the shear strength when dealing with soil. This parameter was very important particularly throughout the pre- and post-construction periods, since it used to find the slope stability and foundation of soil. Exceeded the ultimate shear strength if it was occurred, the soil will fail or deform (Huat et al., 2014). The theory of elasticity and stress-strain relationship was used to develop the failure criterion. The strain value in soil is based on factors like the composition of the soil, the magnitude of the applied load, void ratio and past stress history, and also on the method in which the stress is applied (Anggraini, 2006). Organic soil are encountered in some geographical areas and because of their high water content and organic solids it show mechanical properties somewhat dissimilar than the customary behavior of inorganic soil (Edil and Wang, 2000). Shear strength changes due to future changes in subgrade stress situations are required for the construction of pavements on the organic soils since the effective stress state, and the stress history is strongly effect on the shear strength behavior of these soils (Lechowicz et al., 1996). Furthermore, understanding the shear strength and state of stress in the field is very important in the design of structures on organic soils (Edil and Wang, 2000). Shear strength parameters vary with the normally consolidated soil and plasticity (Larson, 1980; Edil and Wang, 2000). Arman (1969) revealed that the adding of fibrous organic matter increase the shear strength of a soil. Franklin et al. (1973) studied the shear strength behavior of inorganic soil mixed mechanically with peat under the effect of organic matter. They compared the performance of the tested mixtures with that of the same organic content for natural soil samples. They concluded that the performance of the mechanical mixture like to natural samples with the same organic contents, take into account that the mineralogy of the non-organic fraction is kept the same. The strength and stiffness of organic rich soils generally based on whether the organic substance is decomposed or containing fibers in it. If the organic matter is decomposed, the undrained shear strength and the stiffness, or modulus are reduced as a result of high water content and plasticity contributed by the organic matter. If the organic soil contains fibers, which can act as reinforcement, increases the strength (Mitchell and Soga, 2005). Mesri and Ajlouni (2007) revealed that the values of friction angle for organic or peat soil are in the range of 40o to 60°, as compared to smaller than 35° for soft clay and silt components. Edil and Dhowian (1981) also stated that the fiber content has 18 great effect on the friction of organic soil, at the same time not all the fiber is solid due to it usually includes water and gas. So that, the high value of friction angle does not really means the high shear strength of the soil. Celik and Canakci (2010) revealed that the moisture content has a significant factor on the angle of internal friction of organic soils. They showed that if the moisture content increased the angle of internal friction of organic soil gradually decreased.

2.6.2.3 Compressibility

The compressibility of organic and peat soils more than other geotechnical soil (Mesri et al, 1997). The organic soils have a void ratio and natural moisture conent much higher than inorganic soils. Also, organic soils have the highest values of Cα/Cc (Mesri and Godlewiski, 1977). Due to the high moisture content of organic soils which, that cause low specific gravity of organic matter, is related with large void ratios, their compression index is very high. Mesri and Godlewski (1977) revealed that for any natural soil, there is a single relationship exists between and compression index (Cc) and secondary compression index (Cα). Based on the Cα/Cc concept, the magnitude and behavior of the compression index with vertical effective stress is directly affected on the magnitude and behavior of the secondary compression index (Cα) with time (Mesri et al, 1997).

Due to high compression behavior of organic and peat soils, settlement are usually happened (Edil and den Haan, 1994). Edil and Haan (1994) also reported that one dimensional compression behavior showed by the organic and peats soils is similar to those of clay and therefore, the consolidation curves of clays are used to calculate the value and settlement rate of the organic soils. Though, they also claimed that organic soils including high organic matter and fibrous content, with low degree of humification does not appear similar clay compression behavior, due to their soil structure and solid phase characteristics.

Cola and Cortellazo (1999) reported that organic and peats soils are one of the complex foundation soils that show unusual compression performance, by having a high magnitude of compressibility with important secondary compression stage. Furthermore, other factors like high in-situ void ratio, high moisture content and high magnitudes of compression index and secondary compression index magnitudes and these parameters are around ten times more than normal clayey soils. Furthermore, 19 performance of the mixture based on the properties of natural peat and soil history stress.

Consolidation of organic soil and peat deposits is more significant due to large secondary compression. For any natural soil, there exists a unique relationship between secondary compression index (Cα) and compression index (Cc). According to the Cα/Cc concept, the magnitude and behavior of the secondary compression index (Cα) related to the value and performance of the compression index with time and vertical effective stress (Mesri et al. 1997). The Cα/Cc idea can be useful in both over-consolidated and normal-consolidated regions, so that the Cc represents the slope of the compression curve in both of the regions. Table 2.1 summarizes values of Cα/Cc for different soils. The high value of Cα/Cc for peats is due to highly deformable organic particles. The high values of Cα/Cc and Cc for peats indicate that the secondary compression index (Cα) of peats is more than one order of magnitude higher than that of clay and silt deposits.

Table 2.1 Cα/Cc magnitude for different types of soils (Chikyala, 2008)

Soil type	Cα/Cc
Granular soils including rockfill	0.02 ± 0.01
Shale and mudstone	0.03 ± 0.01
Inorganic clays and silts	0.04 ± 0.01
Organic clays and silts	0.05 ± 0.01
Peat and muskeg	0.06 ± 0.01

CHAPTER3
MATERIALS AND METHODS
3.1 Introduction
This chapter presents the organic soil used in this research. An experimental procedure was planned and conducted to test the soils sampled from Sakarya region, Turkey. This study investigates the performance of helical pile in organic soil with the objective of better understanding the axial pull-out load on pile behavior in this soil. The following sections provide a summary of the test layout that include, the dimensions of soil tank and piles, and loading procedure.

Experimental tests were carried out to calculate the pull-out load of anchor pile. Though, experimental tests are not applied to the field tests for full-scale but laboratory experiments have a positive point of permitting a close control on many of the factors that was influence the pull-out capacity of helical pile. In this way behavior of the small scale pile in the laboratory could be of enormous help in emphasizing the performance of field tests for full scale helical pile in actual condition.
3.2 Materials
3.2.1 Helical Piles
Four helical piles with double helix each one were made of 16 mm diameter steel rod to which steel plates of 50 mm were fixed by welding at a pitch of 50 mm to form helical piles (Figure 3.1).

The spacing between the plates were varied, these helix piles were designated as P1, P2, P3, and P4, which have a spacing ratio (ratio of spacing between the plates to the plate diameter) of one, two, three, and four respectively.

In other words, the distances between the plates was varied 50, 100, 150 and 200 mm for P1, P2, P3 and P4 respectively. The final length of all the piles was 650 mm.

Figure 3.1 Helical piles used in the present study

3.2.2 Test Tank

Generally, the tank dimensions are decided depending on the zone of effective stressed of soil mass from the foundation edge. In the present study, vertical uplift tests were adopted in a square rigid steel tank. The tank frame having an internal dimensions (800 x 800 x 800 mm). The length and width of the tank was taken so as to prevent any scale effect which was considered to be minimal 2.5D (Mittal et al., 2010) where D is the diameter of helix plate (D=50 mm). While carried out the tests on four of helical piles, this scale effect along with the interference effect between the piles is also taken into consideration. Similar orders of testing were also adopted in the studies reported by Amde et al. 1997, Elnaggar and Sakr (2002), Banerjee et al. (2014). Thus to avoid the boundary effects, the spacing between the piles was maintained greater than 2.5D (2.5D = 125 mm), the setup of the testing is shown in Figure 3.2.

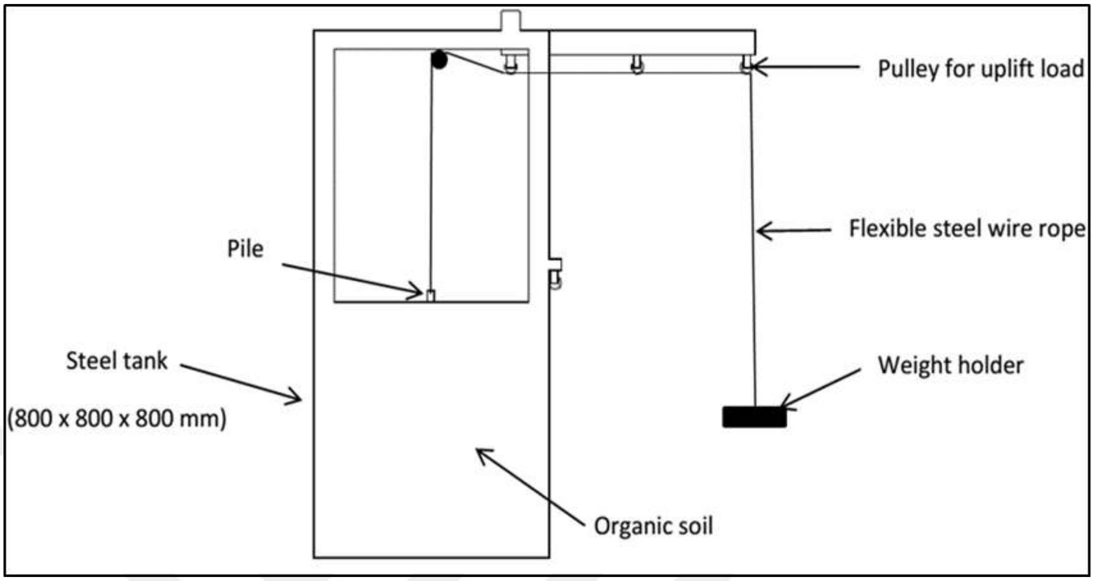

Figure 3.2 Experimental setup used in the present study

3.2.3 Identification of Present Soil

The organic soil used in this study was obtained from the Sakarya region of Turkey. The organic content (OC) of the soil was measured via ignition in a muffled furnace at 440^{o} C for 4 hours (ASTM D2974-14). Laboratory tests observed representative organic soil samples for gradation (ASTM D422), specific gravity (ASTM D854), and organic content (ASTM D1997). Table 3.1 shows some basic properties of present organic soil, a brief identification of these properties will be present in chapter four.

Table 3.1 Soil properties of organic soil used in the present study

Item	Quantity
Organic Content	23%
PH	6.7
Maximum Dry Density*	10.3 kN/m^3
Optimum Water Content*	39%
Liquid Limit	75%
Plastic Limit	45%
Natural Water Content	97%
Fine sand	23.4%
Clay and silt	76.6%
Specific Gravity	2.24
Internal friction angle at soil density of 8.5 kN/m^3	35^o
Internal friction angle at soil density of 5 kN/m^3	26^o

3.3 Preparation of Organic Soil Bed and Pile Installation

The tank height is separated into many layers of thickness 50 mm. Fully saturation organic soil with a two densities (8.5 and 5 kN/m3) were prepared, the selected densities represent the soft and stiff cases of organic soil. For the required densities of soil corresponding to 8.5 and 5 kN/m3, the weight of organic soil that must be put in each layer is determined and the soil is put homogenously in the adoptive layers. Organic soil is compacted with a steel plate hammer for all layers. The density of each layer and cumulative density were determined. It is well-known that this procedure of preparation for organic soil is approximate; however, excessive care has been taken to confirm that the organic soil bed is prepared with uniform density. The four types of piles P1, P2, P3, and P4 were installed after the soil bed has been finished. This proves that the prepared organic soil bed is similar for all tests and the procedure conducted in this work confirms the repeatability of work. During this process, it is important that the pile was kept vertical. This method of pile installation is assumed to simulate the stress situations around piles installed in the field. After one density test finished, all of the organic soil and the helical piles are removed from the tank and the same procedure is repeated for carried out the next test. Overall, 8 tests were carried out with 8.5 and 5 kN/m3 soil density. In addition, tests were repeated to ensure consistency and reliability of the test results, a close test results were obtained using the P2, A3 helical piles with 5 kN/m3 soil density. After the organic soil bed had been finished, the helical piles was slowly installed in organic soil layers with suitable torque and downward force until the required depth (600 mm) of helical pile was achieved.

3.4 Procedures

The soil was tested directly after compaction and piles installed to avoid both re-consolidation and ageing effects. Pull-out loads (Fgiure 3.2) were applied with respect to pile axis by using flexible wire rope was attached to the pile top through a specially fabricated knob fitted at the pile top so that the load can be applied at the desired without inducing eccentricity. The other end of the wire rope was attached to the loading pan. A stress control test was utilized. Since, the loads were applied by dead weight over the loading pan starting from the smallest load, with gradual increases in stages. The displacement was measured in related with each load. The 25 load was applied incrementally, and each incremental load was kept constant until no significant change in displacement occurred at the pile head.

Table 3.2. Adopted pile models in the present study

Pile model	Helix (D) Diameter (mm)	Spacing (S) between helix(mm)	Spacy ratio S/D	Soil case	Loading case
P1	50	50	1	firm - soft	Pull-out load
P2	50	100	2	firm - soft	Pull-out load
P3	50	150	3	firm - soft	Pull-out load
P4	50	200	4	firm - soft	Pull-out load

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Introduction

Screw pile is a steel pipe pile (closed or open) with one or more helical plates placed at an intervals down the pipe to support additional load. Although, their first use was to carry lighthouse structures. Recently, helical piles traditionally used for onshore structures like the foundations for transmission towers and bridges.

Therefore, load tests of pile may be carried out at the start of the project or in the phase design to validate the appropriateness of the pile foundation system. Different research studies have been accompanied to know pile behavior under lateral and axial loading using experimental, numerical and theoretical approaches. Although these are valuable means for investigating pile behavior and undertaking foundation design, they require determination against measurements so their behavior can be evaluated and developments made to yield even improved design models. Therefore, this chapter presents the analysis and discussion of the tests results that was performed under pull-out loads.

4.2 Engineering Properties of Organic Soil

When the soil is found, it is essential to begin the method of characterizing the material. Soil classification and determination of index characteristics offer a starting point from which to begin to know the performance of the soil. The analysis of these properties gives a basis from which other soils from future or literature sampled soils may be compared. 26 To determine the moisture content of the tested soil British Standard (B.S1377, Test 1(A)) suggest a drying temperature of 60Co for soils holding organic substance and peats to prevent oxidation of the organic materials. So that, this test was conducted according to B.S. standard, in this specifications the modification in mass of a soil sample was obtained after a drying period under a temperature of 60 Co. The determined natural water content was found to be 97%. The tests in this study have been conducted on organic soil. The organic content (OC), of the soils was determined using

Ignition method in a muffle furnace (Figure 4.1) at 440o C for 4 hours, according to ASTM D2974-14. In this experiment, an oven dried soil samples was exposed to a temperature of 440º C until the weight of the specimen being constant upon further heating. The remaining “ash” can be defined as the mineral content of the soil, with the lost weight containing the organic substances (Figure 4.2). The organic materials may then be defined as a percentage of the original oven-dried mass. Organic content determined in this procedure was 23%.
The fiber content of the presented organic soil was approximately 22.31%. This would categorize this soil as sapric, an organic soil with fiber content less than 33%, according to the ASTM D1997. According to Von Post System this soil lies in between (H&-H10). The pH of the soil was determined and was found to be slightly acidic with a value 6.7.
To find the specific gravity in an accurate value of of present organic soil, experiments were conducted according to ASTM D854. The experiment was carried out using distilled water. In the experiment, a heat was applied to escape the entrapped air in the soil. Through the process of desiring, to ensure that small bubbles of airs could escape easily, the slurry was agitated often and the soil would not stick to the glass. The average values of specific gravity of organic soil are 2.24.
The analysis of the particle sizes was done by using wet sieve analysis and hydrometer method in combination, in accordance with ASTM D422. Organic substances can break or shrink when dried. So that, it is not simply to use the dry sieving method for soils including organic materials. For the present soil, the soil particles and organic materials should be isolated by using water for washing them. An hydrometer test was carried out to find the distribution of soil particle smaller than 2 mm in diameter (Figure 3.3). The particle distribution of the soil is shown in Figure 3.4. The soil were consist of 25 % sand, 67 % silt and 8 % clay. The calculation of the Atterberg limits of organic soil was carried out in accordance with B.S. 1377 using fall cone test (Figure 3.5) to calculate liquid limit, and ASTM D4318 to calculate plastic limit. The Atterberg Limits gives a useful procedure for classifying and identifying the soil of fine-grained particles. The liquid limit (LL) is defined as the moisture content when the soil transmissions from a liquid case to plastic case. The plastic limit (PL) is the moisture content when the soil transmissions from a plastic case to a semi-solid case. The difference between the plastic limit and the liquid limit and is termed the plasticity

index (PI). According to the test results the liquid limit and plastic limit was found to be 75% and 45% respectively. So that the plasticity index will be 30%.

Figure 4.1 Muffle furnace with organic soil samples

Figure 4.2 Organic soil samples (a) before burning (b) after burning

Figure 4.3 Hydrometer test for organic soil used in the present study

Figure 4.4 Particle size distribution of organic soil

Figure 4.5 Fall cone tests

4.2.1 Organic Soil Classification

Generally, in geotechnical engineer, all soils have an organic content more than 20% are defined as an organic soil. Since, the engineering definition of organic soil is depend on the mechanical characteristics of the soil. When the soil have organic content greater than 20%, the mechanical rules that based on the soil minerals (silt and clay) generally cannot be applied (Huat et al., 2014). After presenting a brief 11 review of organic soil properties such as, degree of humification, fiber content, organic content, and pH. The organic soil presented in this study can be classified into the following methods:

4.2.1.1 ASTM Classification

The simplest and most popular system to use for classification of organic soil is that used by ASTM. According to ASTM, peat soil has ash content lower than other organic soil. Additional classification of peat is then approached by using the quantitative properties of organic content, fiber content, absorbency, acidity, and botanical content (see Table 4.1).

Though this system is not predominantly comprehensive with respect to botanical origin, the designation of plant types is permissible for providing that a important percentage of the peat originates fr1om a particular plant. This classification system add a much more precise framework. This method of classification quantitative nature decreases the uncertainty related with assigning a classification to a soil (Huang et al., 2005). The natural organic soils are classified according to ASTM with a different classification system was given in Table 4.1.

Table 4.1 Classification of organic soil based on ASTM

ASTM Standard	**Criteria**	**Designation**	**Present Study**
Fiber Content (D1997)	>67 % fibers Fibric (H1-H3)	>67 % fibers	22.31% Sapric (H7-H10)
	Hemic (H4-H10)	33%-67% fibers	
	Sapric (H7-H10)	<33% fibers	
Ash Content (D2974)	Low Ash	<5% ash	77% High Ash
	Medium Ash	5%-15% ash	
	High Ash	15%<ash	
Acidity (D2976)	Highly Acidic	pH < 4.5	6.7 slightly Acidic
	Moderately Acidic	4.5 < pH < 5.5	
	Slightly Acidic	5.5 < pH < 7	
	Basic	pH > 7	

4.2.1.2 Unified Soil Classification System (USCS)

This method of classification the soil depend on its liquid limit and the distribution of soil particle. If the liquid limit of any soil after drying using oven at 105 – 110 °C is smaller than 75% of its liquid limit magnitude before oven drying is said to be an organic soil. Recent research by Huang et al. (2006) indicates that this reduction in liquid limit corresponds to an organic matter content in the 15-20% range. The Unified Soil Classification System (USCS) does not identify organic soils depend on the organic content. This System is the most commonly used standard for the soil classification. This type of classification include the applied group symbols and group names for soils based on their composition, grain size distribution, and Atterberg limits. The index properties of the presented soil showed that the liquid limie and plastic limit was 75% and 45% respectively. Atterberg limit tests on oven-dried specimens of the material are compared to those on soil in its natural state, the result showed that the oven dried samples have a liquid limit of 69 % of those on the natural soil. According to the system of classification (USCS), the present soil is classified as an organic silt soil with high plasticity (OH).

4.2.1.3 Von Post Classification

Von Post (1922) suggested a classification system depend on many parameters, like water content, degree of humification, content of fine, botanical composition, coarse fibers and woody remnants. There are 10 degrees of humification (H1 to H10) in the von Post system. According to this method the calculation is depending on the existence of soil water that is exit if the soil is squeezed by hand. In geotechnical engineering objects, the 10 degrees of humification are always decreased to three classes (Table 3.2): fibrous or fabric (least decomposed), semi-fibrous or hemic (intermediate) and amorphous or sapric (most decomposed), respectively (Magnan, 1980; ASTM Standard D 5715). The peat in this study was classified with respect to the degree of decomposition according to Von Post scale and also the fiber and the organic content. The von Post scale define the appearance of soil-water very little decomposed peat which, when squeezed, liberated water with muddy brown, nonetheless from which no peat can move between the fingers. Plant remains quiet identifiable, and no material of amorphous present, then the peat is classified as fibrous peat with H3 degree of decomposition according to von Post scale.

Table 4.2 Peat classification depend on the degree of decomposition using Von Post

Designation	*Group*	*Description*
Fibrous peat	H1–H4	Low degree of decomposition. Fibrous structure. Easily recognized plant structure, primarily of white masses.
Pseudo-fibrous peat	H5–H7	Intermediate degree of decomposition. Recognizable plant structure.
Amorphous peat	H8–H10	High degree of decomposition. No visible plant structure. Mushy consistency.

4.2.1.4 Wüst et al. Classification

This type of classification depend on the examination of the morphology of the peat elements, the matrix and fiber content. The content of ash and these limits for organic soils permit the discrimination of four chief groups: peat, muck, organic-rich soil/sediment and mineral soil/ sediment. Peat is identified as including a muck content of 55–65%, ash content of 0–55%, organic-rich soil/ sediment 65–80% and mineral soil/sediment 80–100%. According to the classification suggested by Wüst et al (2003) shown in Figure 3.6 the soil classified as an Organic rich soil.

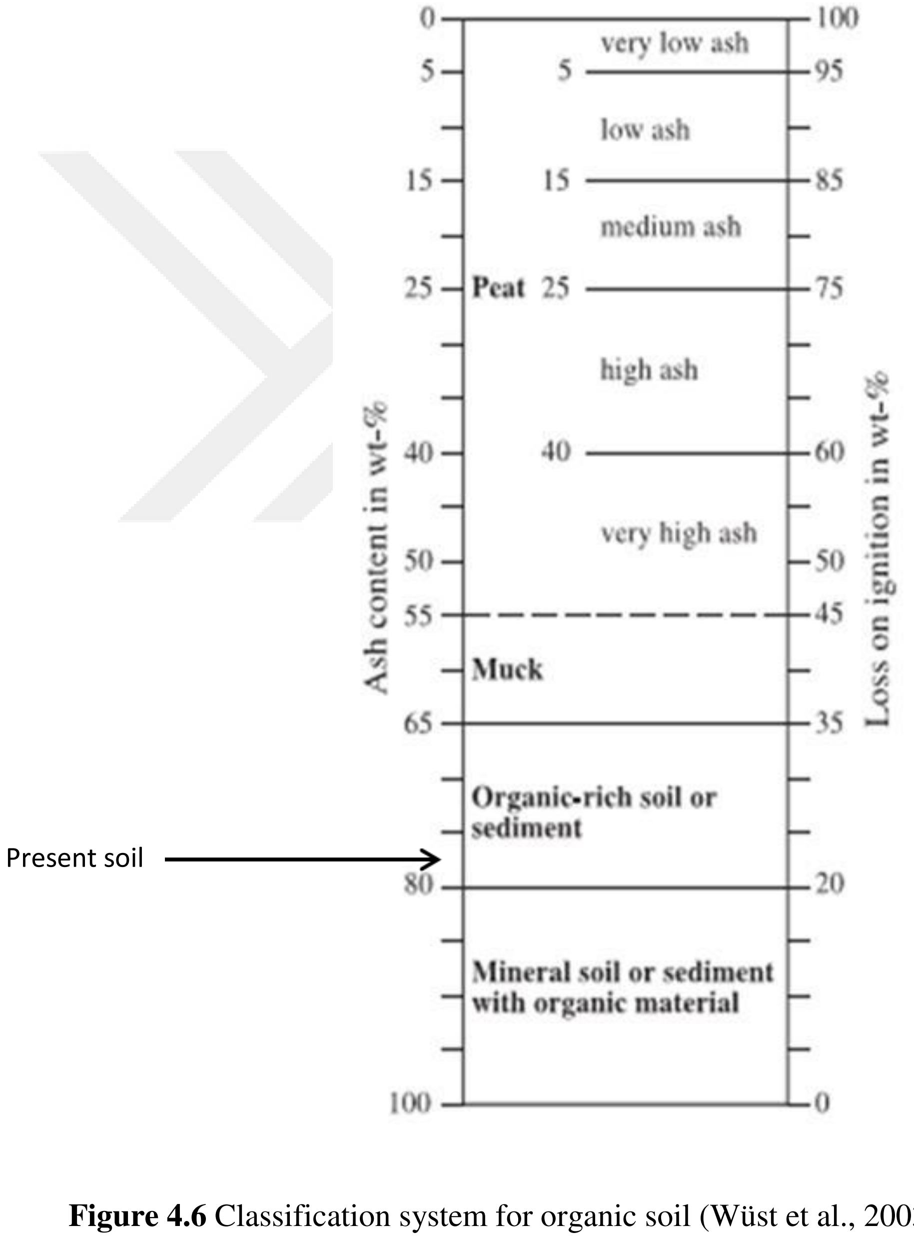

Figure 4.6 Classification system for organic soil (Wüst et al., 2003)

4.2.2 Compaction Characteristics

In order to calculate the optimum water content and maximum dry density of the soils in the current research program Modified and Standard Proctor compaction tests were conducted. The optimum water content of the soil is the content of water at which the soils are compacted to a maximum dry unit weight. Samples exhibiting a high compaction unit weight are preferred for supporting civil infrastructure since the void spaces are minimum and settlements will be less. Modified and Standard Proctor test method using procedure was followed ASTM D1557-12 and ASTM D698-12 respectively to determine the relationships between maximum dry density and optimum moisture content. Figure (3.7) shows that the maximum dry density at Modified Compaction is 11.3 kN/m3 at an optimum water content 35%. Also the same figure shows that the maximum dry density at standard impaction is 10.3 kN/m3 at an optimum water content 39%.

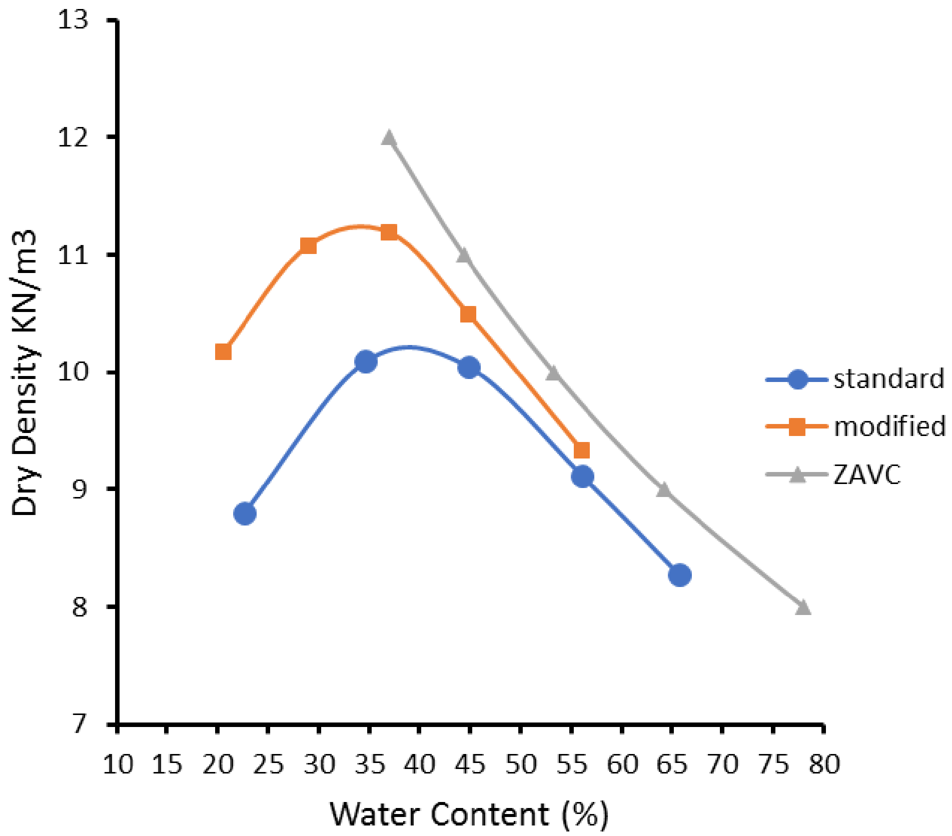

Figure 4.7 Dry density and optimum water content relationships

4.3 performance of Helical Pile

4.3.1 Load-Settlement Behavior of Helical Pile

Figs. 4 and 5 presents the load–settlement behavior of the four helical pile geometries (P1, P2, P3, and P4), loaded in both soft and stiff organic soil. Figs. 4 and 5 shows that the pull-out behavior of each pile configuration is almost identical, due to the deep embedment, H/D > 4, where, H is the distance from the soil surface to the top plate (H = 250 mm) and is the diameter of helix plate (D = 50 mm). An increased in pull-out pile capacity is observed with an increasing number of helices. Similar type of behavior was obtained by Hird and Stanier (2010), Tsuha et al. (2012) and Ghaly and Clemence (1998). Several research methods have been utilized in order to determine ultimate load capacity of helical piles. The ultimate uplift load of helical pile is obtained at the point where the slope of the load-axial displacement curve first reaches zero or a steady minimum value (the point of maximum curvature on the curve). The same procedure was adopted by Mittal and Mukherjee (2015); Mittal et al. (2010); Prasad and Rao (1996), and Ghaly and Clemence (1998). An increased in helix number can significantly modify the load-settlement performance of helical pile and improve the ultimate pull-out load capacity in accordance of organic soil density. The corresponding ultimate pull-out load capacities in soft density (5 kN/m3) were 62, 50, 40, and 35 N for the helical piles P1, P2, P3, and P4 respectively. While, these values in stiff soil density (8 kN/m3) are 92, 80, 63 and 52 N For the helical piles P1, P2, P3, and P4 respectively.

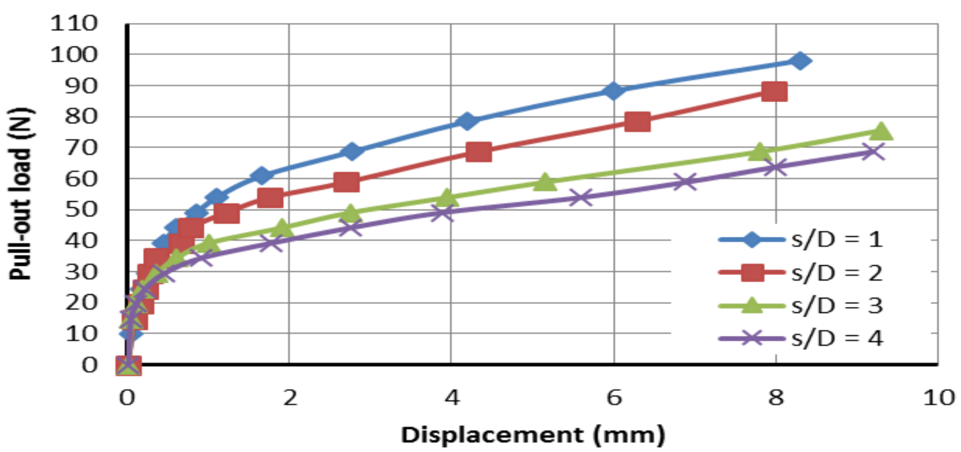

Figure 4.8 Load-deformation behavior of multi-helix piles in soft case

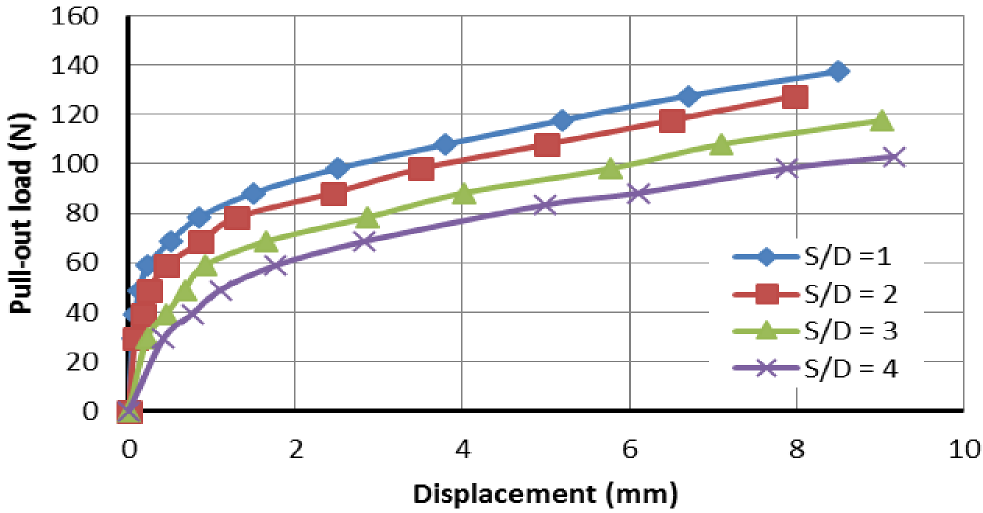

Figure 4.9 Load-deformation behavior of multi-helix piles in stiff case.

4.3.2 Effect of Spacing Ratio on the Pull-Out Resistance

To study the influence of vertical spacing of pile plates on the behavior of helical piles, the pile is providing with two plates. The lower pile helix is attached at the bottom end of pile, while the upper helix is welded at various spacing's above the lower helix. The ratio of helix diameter, D/d, is maintained constant 3.1 for all helical piles, while the vertical spacing ratio, S/D, was reformed to be 1, 2, 3, and 4. The pull-out response of the helical pile with double helices at various spacing's is shown in figure 8. By using the point of maximum curvature method mentioned later, the figure showed that the interaction between helices decreases when the spacing ratio, S/D, increases, and the helices be likely to to perform individualistically. These results are inconsistent with findings by Rao and Prasad (1993) and Abdrabbo and El Wakil (2016). It was found that the pull-out resistance of helical piles were increased with the increasing in the soil density and decrease in spacing ratio. These results are inconsistent with findings of past study by Rao and Prasad (1003) and Khazaie and Eslami (2016). From the experiments, it can be seen that the spacing ratios (S/D) selected was ranging from 1 to 4. That means both methods of cylindrical shear failure and individual bearing will be valid. Since, the cylindrical failure assumption can be valid up to 2 spacing ratio (Zhang, 1999), with the increase in pile spacing the cylindrical assumption may be incomplete. Therefore, individual bearing will be valid after 2 spacing ratio (Rao and

Prasad, 1993). In cylindrical method, the top helix creates a cylindrical shear surface that controls its performance. The soil between the two plates becomes an active cylinder if the plates are adequately close to each other. The resistance of shear along the interface is said to be governed by the angle of friction and stress state in the disturbed cylinder of soil above the helix plate (Kulhawy, 1985). In the case of individual bearing assumed that each helix behaved independently of the other, because the helices were widely spaced. Consequently, the uplift capacity of the multi-helix anchor is the summation of the bearing capacities of all helical plates and the shaft resistance (Clemence and Ghaly, 2013). Therefore, these methods explained the reason of increasing in ultimate helical load capacities with the reducing in spacing ratio (S/D) as seen in Fig. 7.

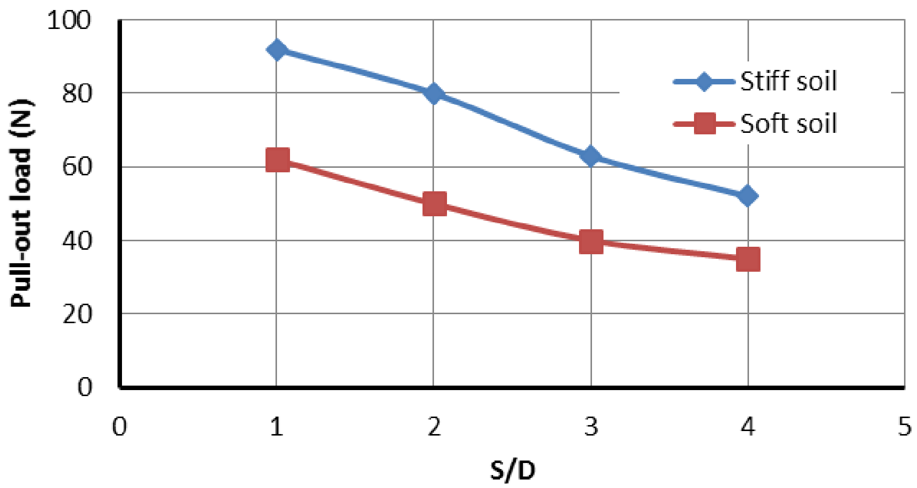

Figure 4.10 Effect of number of helix on the ultimate pull-out load capacity

CHAPTER 5
CONCLUSIONS

The performance of double helix piles under pull-out static loadings was explored using experimental load tests. Double-helix piles were installed and loaded axially in two soil densities: soft and stiff organic soil. Uplift performance was predicted using the axial load versus displacement readings. The following conclusions are achieved from this study:

1- The ultimate pull-out load capacities of double-helix pile are controlled by the spacing of helical plates.

2- A key point get up from this study is that using more closely spaced of double-helix plates leads to a stiffer load response and thus less immediate displacement in organic soils.

3- Designers of helical screw piles must take into account the advantage of this closer spacing ratios by specifying helical plate spacing ratios of less than 2. This is principally significant where modern, more economical.

4- An increase in spacing ratios causing a decrease in ultimate pull-out capacity of helical pile in organic soil. Also, increasing the soil density increasing the ultimate pull-out load capacity.

5- Double-helix piles have a suitable behavior to carried tension loads. Therefore, these piles are reasonable choices in where there are uplift loads, such as, transmission tower, submerged pipeline, etc.

6- The capacity of double-helix pile is greater when the spacing ratios 1 and 2 than 3 and 4. In general, the capacity of double-helix piles with a spacing ratios of 1 and 2 is ranged from 1.25 to 1.77 times the capacity of double-helix pile with spacing ratios of 3 and 4 in both stiff and soft soil respectively.

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