XIV Международна научна конференция
„Проектиране и строителство на сгради и съоръжения“, 10-12 септември 2026 г, Варна
XIV International Scientific Conference
„Civil Engineering Design and Construction“, Sept. 10-12, 2026, Varna, Bulgaria
ISSN 2683-071X (online) ISSN 2738-7879 (CD)

СПИРАЛОВИДНИ ПИЛОТИ – СРАВНИТЕЛЕН АНАЛИЗ МЕЖДУ ИЗЧИСЛИТЕЛНИ МОДЕЛИ И СТАТИЧЕН НАТОВАРВАЩ ТЕСТ В БЪЛГАРСКИ ЛЬОСОВИ ПОЧВИ

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HELICAL PILES – COMPARATIVE ANALYSIS BETWENN COMPUTATIONAL MODELS AND STATIC LOAD TESTS IN LEOSS SOIL

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Abstract:
Helical piles are well known around the world. There is a lot of theoretical and experimental data available that provide guidelines for determining their bearing capacity. However, in Bulgaria there is no widespread practice of using them, which is why several static tests were performed to determine their behaviour. The tests were performed in an area with a loess horizon, which further complicates the prediction of their behaviour. The article presents results from experimental tests, as well as results from numerical calculations. The comparative analysis provides guidelines for calculation as well as recommendations for geometric dimensions of the piles.

Keywords:
helical piles, static load test, bearing capacity

1. INTRODUCTION

Among all types of piles in Bulgaria, reinforced concrete piles have entered en masse in both their variations - cast in place and driven. Steel piles in their classic form - driven are almost never used. However, small-sized piles are entering and they are suitable for light and not particularly responsible objects – such as fences, sheds, photovoltaic power plants, or light removable objects.

Screw piles are well implemented already, there is some test executed [1,2]. Some modification of IBO anchors are presented in [3]. But there is luck of information for helical piles.

Helical piles are widespread throughout the world. The first recorded helical pile use was by Alexander Mitchell for mooring in England in 1838. In 1850 more than 100 light houses were

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constructed along the east coast, the Florida Coast and the gulf of Mexico using helical pile foundations. However, in Bulgaria they are not yet widely used. Regarding helical piles, there is no established experience of their corrosion resistance and probably for this reason, they are not used for long-term structures such as houses, office buildings or bridges.

1.1. Bearing capacity

The bearing capacity of helical piles [4] depends on several main factors: the diameter of the helices, the number of helices, the distance between them and of course the soil in which the pile is set. There are two methods for determining the bearing capacity of a pile - the loss of bearing capacity under each helix (individual bearing capacity) and shear on a cylindrical surface formed by the number of helices

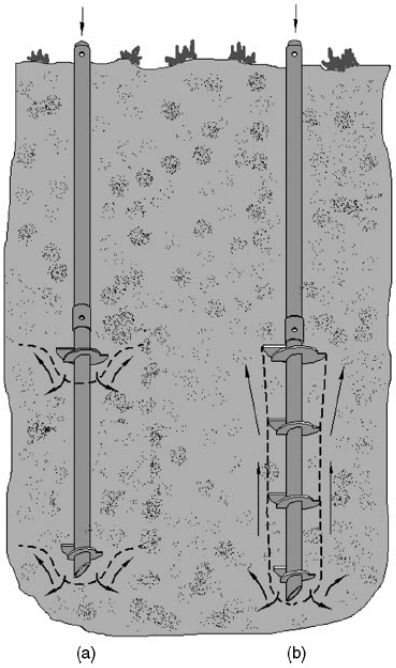


Figure 1. Models of helical pile failure a) individual failure b) cylindrical shear [4]

2. THE STATIC LOAD TEST

2.1. Soil profile

The soil profile of the site consist of 80cm hummus, which is not used as bearing soil. Below it there is a loess horizon of undetermined depth. At a depth of about 4 m the loess has the following soil properties: water content is w_n 68%, degree of saturation is S_r=0.88. The internal friction angle is φ=23°, cohesion is c=15 kPa. The SPT result at depth 4m is N_{spt}=10

2.2. Pile load toad setup

When testing a pile for vertical compression force, it is necessary to design a steel structure that allows to increase load gradually (Figure 2). The system consists of one test pile, on which the settlement is recorded as a function of the load, which is called the load-settlement curve. To absorb the reaction forces, two (or four) anchor piles are placed. It is assumed that the piles must be at a minimum distance of 3D from each other. In this case, the distance between the piles is 125 cm, so this rule is met.

The two tests were carry out in accordance with Eurocode 7. The test setup is shown on Figure.2

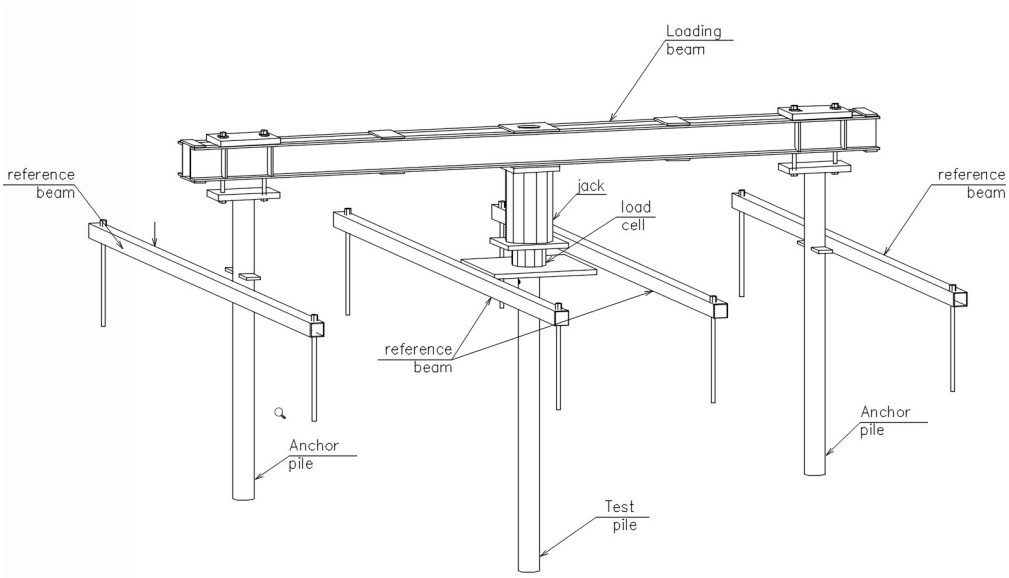


Figure 2. Load test pile setup

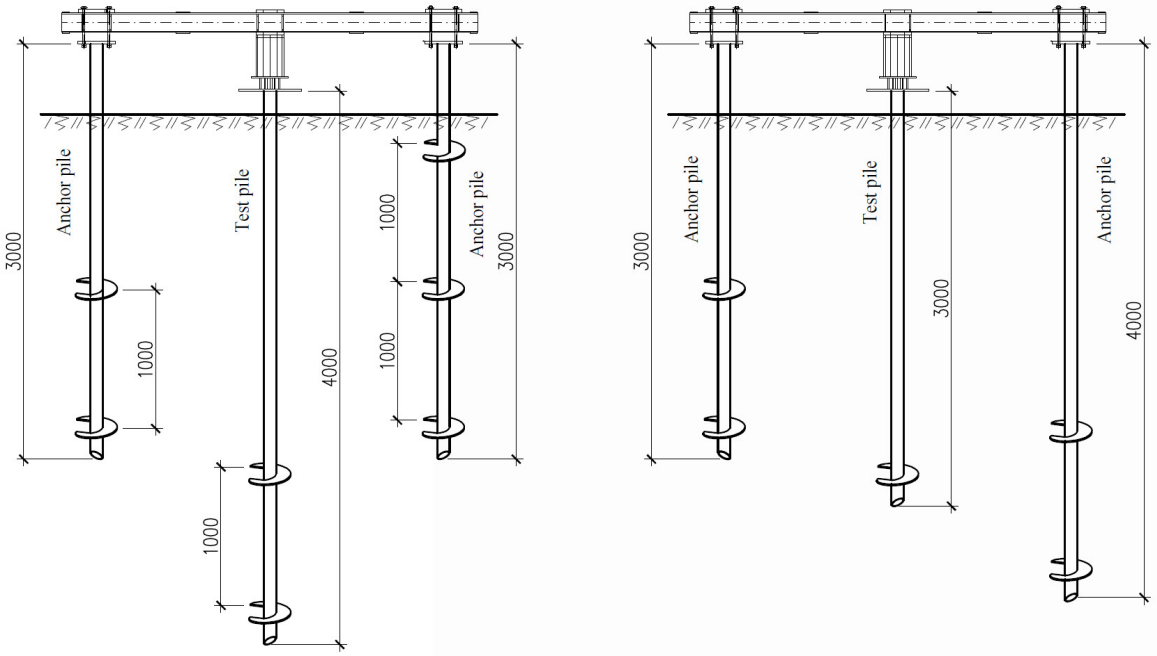
The load is applied by a jack with a range of 20t. The settlement of the test pile is measured with three dial gauges with a range of 30mm, and an accuracy of 0.01mm. The force is measured with a load cell, which transmits the information to a wireless data acquisition device. The information is visualized on an electronic android device through an application of the device supplier. The configuration is shown in Figure 3.

Figure 3. Load measurement setup. a) View of a loading device, strain gauge and dial gauges, android device for displaying force b) Wireless Portable FastDAQ

2.3. Pile dimensions

Two test piles have dimension according to Figure 4. The selected test is QMtest as Eurocode 7 allows. The settlement of anchor pile is not shown because it is not of interest. Test pile 1 has length 4m, with two helices. Equipped with three dial gauges, each with a range of 30mm; Test pile 2 has length L= 3m, one helix. Equipped with three dial gauges, each with a range of 30mm;

The dimensions of the piles are selected so that they are transportable, relatively light to move and, last but not least, have a considerable load-bearing capacity. Of course, the price is also of essential importance. When choosing piles, an optimal ratio between cost and load-bearing capacity is sought.



а) б)

Figure 4. Load and anchor pile dimensions a) Test pile 1 b) Test pile 2

2.4. Pile test results

To obtain the compression bearing capacity of a single pile, it is necessary to obtain the load-settlement curve as per Fig. 5, which shows the relationship between load and deformation. There are many criteria for obtaining the bearing capacity from this curve: for example, the limit load at which the settlement of a single pile does not subside; the force at which the settlement is 10% of the diameter, Davisson, Van Der Veen, method of two tangent and so on.

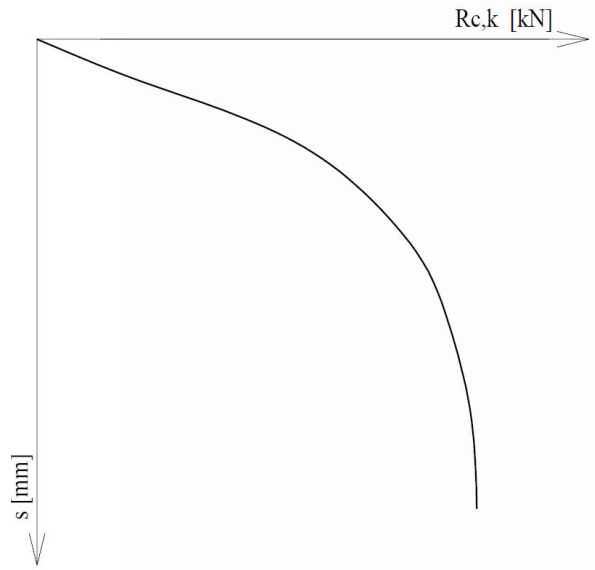


Figure 5. Typical load-settlement curve for compressive piles

The pile load tests were terminated when the settlement reached 10% of diameter – 35mm. The bearing capacity for different methods is shown on Table 2

3. BEARING CAPACITY BY CALCULATIONS

2.1. Individual bearing method

The most known expression for determining the pile bearing individual capacity is [4]:

$$P_u = \sum_1^n q_{ult}.A_n + \alpha H(\pi d)\,. \tag{1}$$

Where q_{ult} is limit bearing capacity below helical plate; A_n = area of helical plate; α is adhesion between soil and pile surface. The value of α was taken from the friction angle between the foundation material and soil layers; H is length of the pile foundation (from uppermost helical plate until soil surface); d = diameter around the shaft (diameter of pile foundation without helical plate)
Terzaghi [5] offers the relationship between c_u and N_{spt}

$$c_u = 6,25.N = 62,5kPa\,. \tag{2}$$

For fine grained soils [4]

$$q_{ult} = 9c_u = 562.5kPa\,. \tag{3}$$

So If friction between the pile shaft and the soil is neglected because of the loosening of the soil during turning the bearing capacity is for test pile 1 is:

$$P_u = \sum_1^n q_{ult}.A_n = 2.562,5.0,0961 = 108kN\,. \tag{4}$$

The bearing capacity for test pile 2 is:

$$P_u = \sum_1^n q_{ult}.A_n = 562,5.0,0961 = 54kN\,. \tag{5}$$

2.2. Cylindrical shear method

The most known expression for determining the pile bearing cylindrical shear bearing capacity is [4]:

$$P_u = q_{ult}A_1 + T(n-1)s.\pi.D + \alpha H(\pi d)\,. \tag{6}$$

Where q_{ult} = limit bearing capacity below helical plate; A_1 is the area of the bottom helix; T is soil shear strength; H is the length of shaft above the top helix; α is adhesion between soil and pile surface. d is the diameter of the pile shaft, and the term $(n-1)s$ is the length of soil between the helices. All other parameters have been defined previously.For test pile 1 expression is:

$$P_u = q_{ult}A_1 + T(n-1)s.\pi.D + \alpha H(\pi d) = 562,5.0,0961 + 62,5.1.0.35 = 75,94kN\,. \tag{7}$$

2.3. FE method

The two helical piles was modelled in 2D FEM software. For convenience, an axisymmetric model has been chosen in which the solution is for one radian of the entire half-space. The soil was modelled with properties shown in Table 1. The model phases were as follows: Initial Phase; Pile Installation; Vertical compressive force. The force was varied until reaching settlement of 35mm, which corresponds to a displacement of 10% diameter. The selected soil model is XCM and the soil parameters are shown in Table 1. The pile is modeled with plate

elements with infinite stiffness, and the contact between piles and soil is replaced by interface elements.

Table 1. Soil properties of leoss horizon

Element	Pile 1, kN	Pile2, kN
γ_{unsat}	kN/m^3	18
e_{init}	-	0,5
E_{50}^{ref}	kN/m^2	10E3
E_{oed}^{ref}	kN/m^2	10E3
E_{ur}^{ref}	kN/m^2	30E3
c	kPa	15
φ	°	23

The deformations in the vertical direction are clearly visible in Figire 6. Since the distance between the blades is greater than 3D, no block failure is observed. However, it is seen how they begin to have common isolines, which means that at a distance smaller than this, the cylindrical form of loss of stability will already be activated.

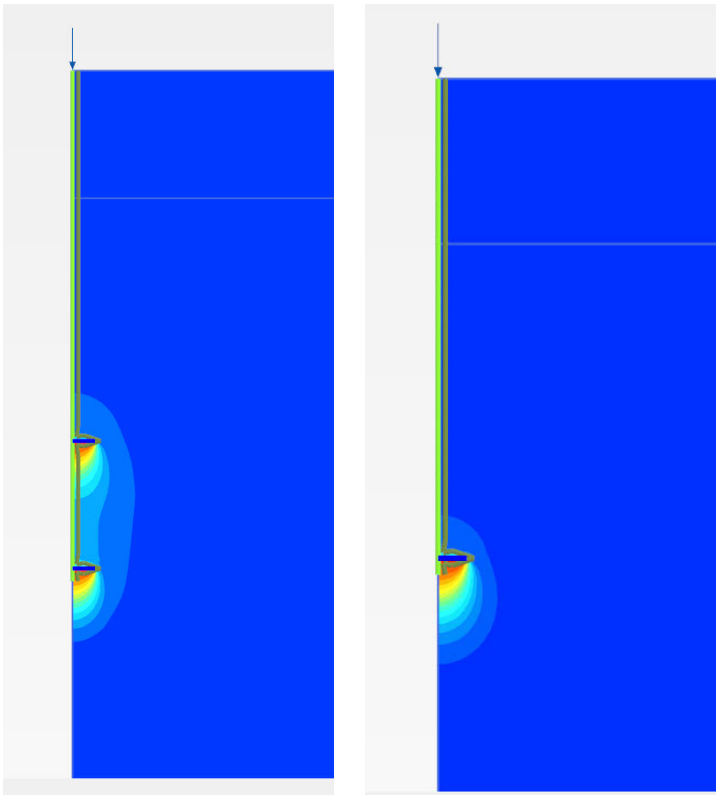


Figure 6. Vertical displacement of two modelled piles a) 33mm displacement at force 84,78kN b) 35mm displacement for Pile 2 at force 47,1kN

The FEM results summarized on Table 2.

4. ANALYSING THE RESULTS

Two piles with different dimensions were tested in compression. In addition, analytical calculations were made to check the individual bearing capacity, as well as the possibility of cylindrical shear. A parallel axisymmetric FEM model was made in which the bearing capacity was obtained.

The results of all methods are shown in Table 2.

Table 2. Pile bearing capacity, according different methods

Rule	Pile 1, kN	Pile2, kN
10%D	39	19
last load step with damping deformation	39	19
method of two tangent	30	14
Individual bearing method	108	54
Cylindrical bearing method	54	-
Axisymmetric FEM model	87.78	47.1

5. ANALYSING THE RESULTS

Two static load tests were carry out in leoss soil and the results were compared with some of the calculation results. Can be made some conclusions:

- Well known expressions for individual and cylindrical bearing capacity overestimates pile bearing capacity;
- Pile with two helices has double bearing capacity, as expected;
- If the helical distance is more than 3D, not always individual bearing method brings more bearing capacity then cylindrical;

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