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Comparative analysis of the results of field testing and analytical calculation of piles in subsidence soil

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ABSTRACT:

In connection with the needs of modern times, the issue of optimal design of building foundations, taking into account the regional features of loess-like silty clay soils, common in Mongolia, becomes relevant. This article presents an overview of the theoretical justification and analytical methods for calculating the bearing capacity and regularity of the formation of a sphere-shaped compacted zone along the side surface and under the lower end in the process of driving a pile in subsiding soil. And also the results of a comparative analysis of the results of a field dynamic, static test and an analytical calculation of 6 piles of different lengths in a similar soil are given.

Key words: loess-like soil, technogenic moistening, dynamic and static tests, dependence curves of settlement and load, allowable settlement.

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I. INTRODUCTION

Various pile foundations are widely used in many countries of the world, and also in recent years have been widely used in the difficult soil conditions of Mongolia. In most cases, pile foundations represent an effective design solution and advanced technology compared to other types of foundations, and there are cases when they are the only possible solution for specific soil conditions. Currently, about 200 types of pile foundations are used as foundations for building and engineering structures. According to the change of researchers in this area, that numerous studies are constantly being carried out on optimizing solutions for pile foundations shows that the most effective option has not yet been developed. In the condition of loess-like subsidence soils common in Mongolia, the use of prismatic driven and bored pile foundations with a solid cross section, taking into account the inevitable pattern of increasing the moisture content of the base, the conditions of high seismic activity and long-term operation, is recognized as the most economically effective foundation [1; 2; 3; 4].

II. THEORETICAL JUSTIFICATION

According to the simulation of the operation of the pile foundation, the piles are immersed in subsiding soil with natural moisture, and then during the operation stage, for various reasons, including man-made reasons, it will be moistened, that is, the degree of water saturation of the base loess soil can increase to $Sr \geq 0.8$. Based on this provision, it becomes necessary to preliminarily determine the magnitude of the probable subsidence deformation and unequal settlement with high accuracy, taking into account the territorial features. The complexity of the issue of assessing the bearing capacity and uneven settlement of a pile in loess-like subsiding soils, taking into account the increase in humidity and the effect of a special combination of loads, is due to many circumstances, such as the mechanism of vertical displacement of the pile depending on the amount of soil friction with the side surface and the mechanism for the formation of a spherical zone of compacted soil under it. with a tip, an increase in the pore pressure of the soil during subsidence, a decrease in the bearing capacity in a state of rest after driving, have not been finally resolved and still remain one of the most difficult geotechnical problems of our time.
According to the studied history of this issue, since the mid-1920-s, C. Terzaghi [5] began to study the factors affecting soil resistance during pile driving, and developed a calculation scheme. Lapshin F.K.[6] according to studies similar to Terzaghi, he suggested that a cone of compacted soil is formed under the tip of the pile in a certain section, and the soil is pushed horizontally by this cone, acting on the principle of a wedge.

According to the results of numerous studies conducted over the past few decades, in the field of determining the bearing capacity of piles, depending on the frontal resistance of the pile during driving and the static sounding cone, 4 main theoretical directions have been established. Including:

Model of the theory of limit equilibrium. The method for calculating the limiting soil resistance under the tip of the pile foundation based on the theory of limit equilibrium was developed by Vesic A.S. [7], Berezantsev V.G. [8]. The calculation theory is based on the results of full-scale experiments, the mechanism of symmetrical displacement of the soil located at the top of the cone, and the pattern of penetration of the pile tip (cone) along the linear surface into the soil mass.

Theoretical foundations for the formation of the soil compaction zone at the tip of the pile. In the 1940-s, Bishop R.F., Hill R. [9] found that the pressure required to create a deep cavity in an elastic-plastic medium (in the absence of friction) is proportional to the pressure required to create an enlarged area from zero radius to a given radius expanding cavity.

Method for determining the soil deformation line. This method was developed between 1975 and 1985. Baligh M.M [10] from the Massachusetts Institute of Technology, USA, to determine the resistance of the pile tip (probe) in the laboratory using a tray with a transparent wall.

Application of the finite element method (FEM). The theoretical basis of the FEM for use in numerical simulation was developed by Segerlind L. [11], Fadeev A.B. [12] and is currently widely used in geomechanics and calculations of foundation structures. FEM in many ways surpasses analytical methods of calculation, for example, it makes it possible to idealize soil properties and geometric shapes, the calculation scheme is close to real conditions, reflections of anisotropic and isotropic soil properties and stratification.

III. MATERIAL AND METHODS

An empirical calculation method for determining the bearing capacity of a pile according to the method BNbD 50.01-16 and SP 24.133330 was developed in the 1950-s by A.A. Lugoi [13] based on the results of observations and tests of a large number of piles. Then, in NIIOSP Russia, a calculation method was developed to determine the bearing capacity of a pile, taking into account the resistance fi of the lateral surface in clay soil with the yield index $J_L = 0.7 \div 0$ and was developed under the condition where it was determined equal to the sum of the bearing capacities along the tip and the lateral surface.

$$F_d = \gamma_c(\gamma_{cR}\ R\ A + u \sum \gamma_{cf} f_i\ h_i), \tag{1}$$

where: γ_c - coefficient of the working condition of the pile in soft soil, is taken equal to γ_c=1; R -is the calculated soil resistance at the pile tip; A -is the area of the pile tip; u is the perimeter of the transverse section of the pile; f_i- design resistance of the i-th layer of soil in contact with the side surface of the pile; h_i-is the thickness of the i-th layer of soil in contact with the side surface of the support; $\gamma_c R$, $\gamma_c f_i$coefficients of the operating conditions of the tip and side surfaces of the pile.

V.G. Berazentsev [8], F.Kh. Kulhawy [14] calculated the resistance of the pile head in porous and dense sandy soils and plotted the comparison of the dependence of the bearing capacity and the depth of the pile (Fig. 1).

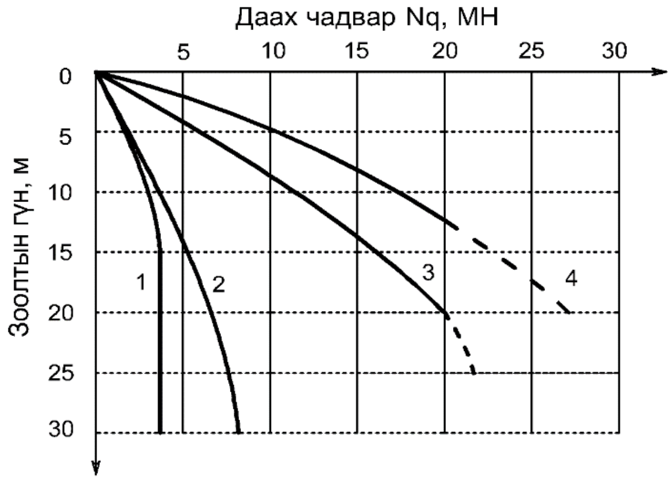

Fig-1. Graph of the dependence of the bearing capacity of the pile and the depth of the pile. 1- H_q of loose sandy soil (Berenzantsev, 1952); 2- H_q of leose sandy soil (Kulhawy, 1984); 3-dense sandy soil H_q (Berenzantsev, 1952); 4-dense sandy soil H_q (Kulhawy, 1984);

In design practice, the results of this experimental study are used as a rationale for preliminary calculations to determine the bearing capacity of piles in sandy soil. This methodology is reflected in the Mongolian BNbD 50.01-16.

For the purposes of a comparative study, the most commonly used international methods for determining the bearing capacity of piles are considered:

R.L.Nordlund method [15]. This method is semi-empirical and is widely used in world practice to calculate the bearing capacity of piles in sandy soil.

M.J. Tomilson method [16]. This method is widely used in the calculation of the bearing capacity of piles, and it allows to calculate the resistance parameters in the unfiltered state, and also allows for the simplification that the resistance of the pile side surface does not depend on the additional load on the soil surface.

The American Petroleum Institute method [17] uses the API method to calculate the bearing capacity of large-diameter shell-shaped metal piles buried in the base soil of an offshore oil rig.

Currently, there are many methods for calculating the bearing capacity of pile foundations, which are widely used in many countries of the world, give different results, and in some cases give solutions that differ several times from each other. The difference between the results of field tests and the calculation by the analytical method (according to the method specified in the BNbD) of the bearing capacity of the pile varies greatly, which confirms the need to improve the existing methods of calculation and numerical modeling. The concept of a high probability of the results of the calculation made using modern calculation programs is becoming dominant, but it is necessary to make a detailed decision in comparison with the results of natural experiments.

IV. EXPERIMENTAL RESEARCH METHODOLOGY

Within the framework of the program for the development of technology for the installation of pile foundations, the territory of the city of Darkhan was chosen as a fulcrum and indicators of the physical and mechanical properties of the soil were determined. The following two layers of soil were found at the construction site, and the indicators of sandy loam soil are divided into various elements: with natural moisture for dynamic testing and moistened with water for static testing.

EGE-1. Light yellow low-moisture dusty sandy loam occurs at a depth of about 4.5-5.5 m from the soil surface and belongs to the 1st type in terms of subsidence. According to tables BNbD50.01-16 and the results of laboratory studies, the standard parameters of soil with natural moisture content are accepted: C_n=49 kPa, φ_n=34°, E=16.1 MPa After wetting at W_{sat}: C_n=12 kPa, φ_n=27°, E=4.3 MPa.

EGE-2. Dense or semi-solid in consistency Reddish-brown gravel loam, solid or semi-solid in consistency. It has the following characteristics in natural conditions. Regulatory parameters (dpQ(IV-III)) are given according to the results of laboratory tests: adhesion strength C_n=76 kPa, internal friction angle φ=21°, deformation modulus E=32 MPa. When drilling to a depth of 18.0 m, no groundwater was found.

Field experimental studies to assess the bearing capacity of the pile foundation were carried out in accordance with the provisions of MNS 3388-82 "Methodology of field tests for determining the bearing capacity of piles."

V. RESULTS AND DISCUSSION.

A. Dynamic test results. Based on the results of the dynamic test, graphs of the number of impacts and failures of driving piles with a length of 6.0, 7.0 and 9.0 m were plotted. The graphs of the results of dynamic testing of piles with a length of 6.0 m, 7.0 m and 9.0 m are shown in Fig 3, 4 and 5.

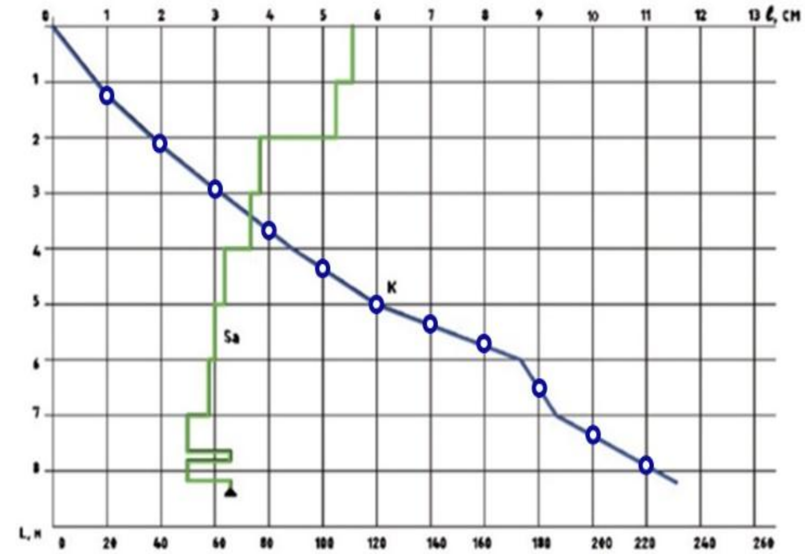

Fig 3. Graphs of the dependence of the number of impacts k and failures Sa on the depth of immersion of pile l=9.0 m.

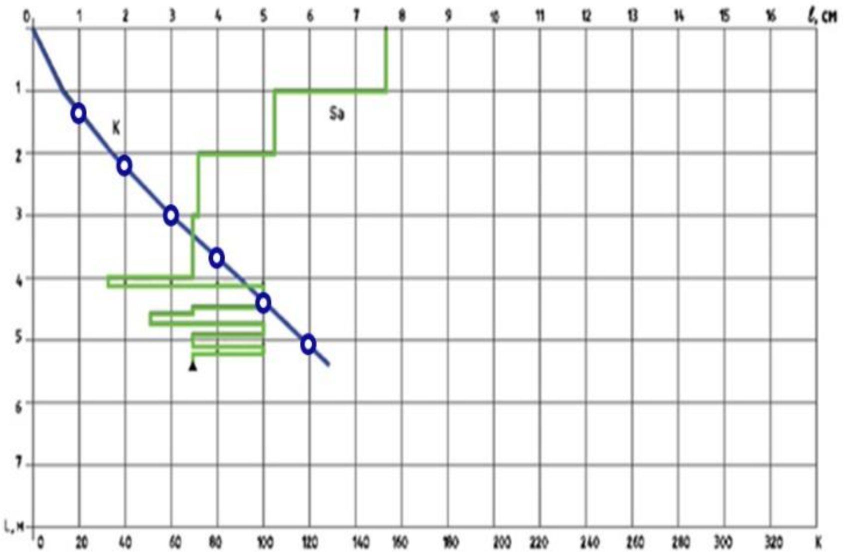

Fig 4. Graphs of the dependence of the number of impacts k and failures Sa on the depth of immersion of pile l=6.0 m.

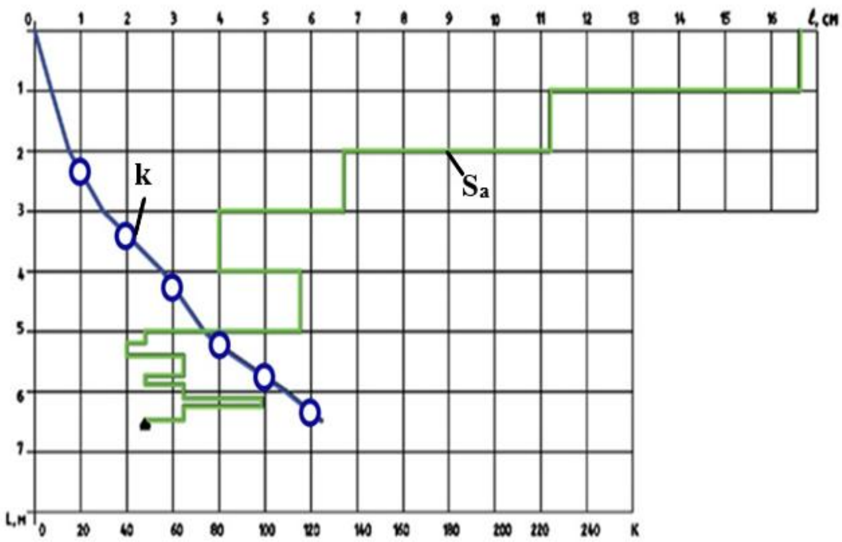

Fig 5. Graphs of the dependence of the number of impacts k and failures Sa on the depth of immersion of pile l=7.0 m.

Based on the results of dynamic tests, the bearing capacity of piles was determined according to the BNbD 50.01-16 method and N.M. Gersevanov [18]:

$$F^{c-2} = 33.14tn3F^{c-3} = 35{,}54\ \text{тn};\ \ F^{c-4} = 42{,}26\ \text{т}n;\ \ F^{c-5} = 32{,}0\ \text{т}n;\ \ F^{c-6} = 31{,}91\ \text{тn}.$$

B. Results of the static test. The values of the static load for the test were chosen depending on the calculated value of the bearing capacity of the piles and taking into account the wetting of the subsidence base, equal to 20 tn for a pile 6 m long, 25 tn for a pile 7 m long and 30 tn for a pile 9 m long. the tests were carried out after preliminary soaking of the soil to a value of Sr ≥ 0.8 according to the accelerated soaking method developed by V.I. Krutov [19]. The magnitude of the scalloped load, the number of their steps and the time interval for measuring the vertical mixing and other parameters for the static test are selected in accordance with the provisions of MNS 3388-82. The scheme of the static test for measuring the vertical displacements of piles is shown in Fig 5.

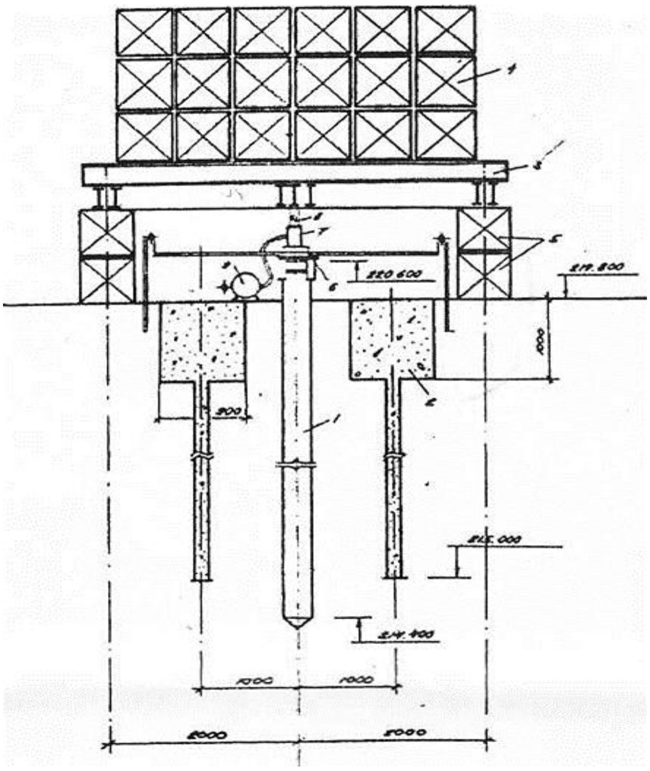

Fig 5. Scheme of a static test.
1 - tested pile, 2- well for soaking, 3-metal stand, weight 2.95 tons, 4 counterweight SP-6 block 18 pcs.Total weight 33.4 tons, 5-support SP-6 block 2 pcs, 6-reference system, 7- jack DG-100, 8-hydraulic jack station.

According to the results of static tests, the dependence curves between the pile settlement and the load S=f(P) were built, shown in Fig 6.

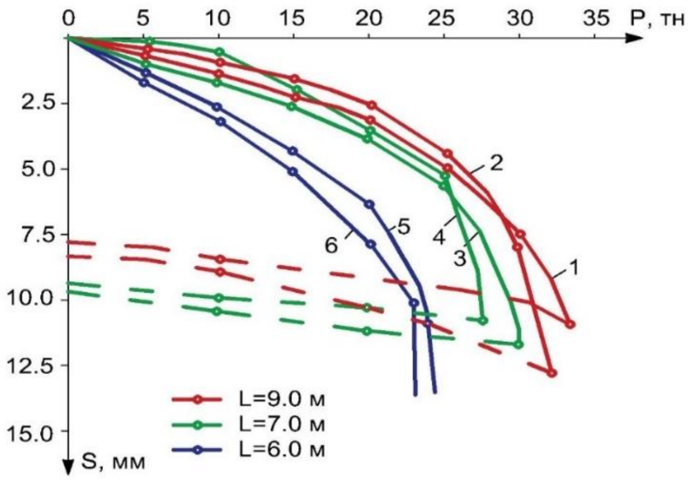

Fig 6. Dependence curves S=f(P) according to the results of static tests.

According to the results of static tests according to the formula BNbD 50.01-16, the bearing capacity of piles for a vertical load is determined and is given in tab 1.

B. Results of analytical calculation. To compare the bearing capacity of piles with a length of 6.0 m, 7.0 m and 9.0 m, determined by full-scale tests, the following section presents the results of an analytical calculation performed according to the methodology and the calculated indicators are selected in accordance with BNbD 50.01-16.

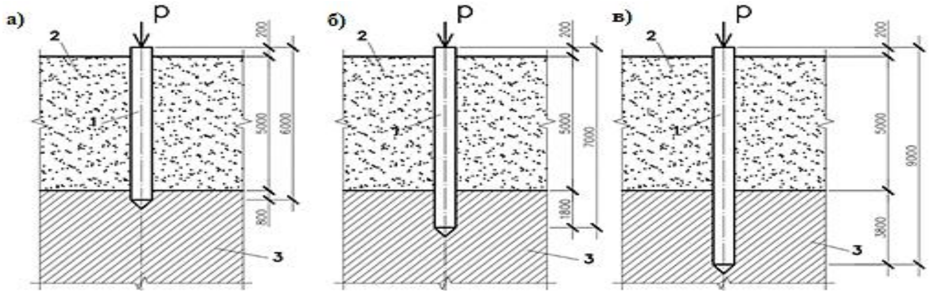

Fig 7. Calculation diagram of the bearing capacity of piles with a length of 6.0 m, 7.0 m, 9.0 m.

a) for pile L= 6.0 m after soaking: J_1=0.20=>R=409 t/m^2 , J_w=2.8 t/m^2 ;сваиL= 6,0 м послезамачивания:$J_1 = 0.20 =>$ $R = 409\ т/м^2, J_ш = 2.8\ т/м^2$;

$$F_d = 1.0 \cdot [1.04 \cdot 409 \cdot 0.09 + 1.2(1.0 \cdot 0.8 \cdot 2.8 + 1.0 \cdot 4.5 \cdot 2.2)] = 27.62тн;$$

b) for pile L= 7.0 m after soaking:

$$F_d = 1.0 \cdot [1.04 \cdot 418.5 \cdot 0.09 + 1.2(1.0 \cdot 1.8 + 1.0 \cdot 4.5 \cdot 2.2)] = 32.56тн;$$

c) for pile L= 9.0 m after soaking:$J_1 = 0.20 => R = 457\ т/м^2, J_ш = 6.22\ т/м^2$;

$$F_d = 1.0 \cdot [1.04 \cdot 457 \cdot 0.09 + 1.2(1.0 \cdot 3.7 \cdot 6.22 + 1.0 \cdot 4.5 \cdot 2.2)] = 56.87тн$$

G. Comparison of results. Table 1 shows the results of a comparison of the bearing capacity of driven piles with different lengths, determined by dynamic, static tests and analytical calculations at the appropriate moisture content (Nyamdorj S. [20]).

Table 1.

Comparison of the results of determining the bearing capacity of driven piles, tn

№	Pile length, m	Dynamic test atW_o	Static test atW_{sat}	Analytical calculation for W_{sat}
1	6,0	31,91	14,30	27,62
2	7,0	34,99	30,20	32,56
3	9,0	42,26	33,42	56,87

Figures 8, 9 and 10 show diagrams comparing the values of the bearing capacity determined by different methods, depending on the length of the piles.

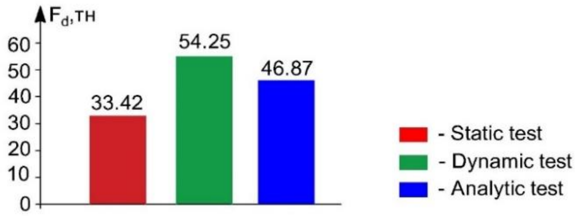

Fig. 8. Diagram for comparing the average bearing capacity with a length of 9.0 m.

Fig 9. Diagram for comparing the average bearing capacity with a length of 7.0 m.

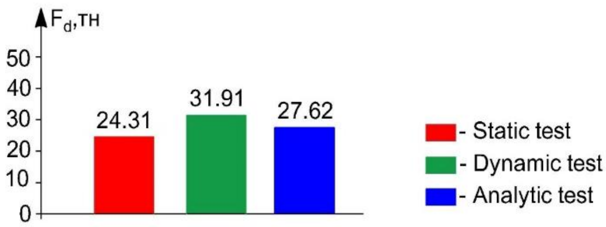

Fig 10. Diagram for comparing the average bearing capacity with a length of 6.0 m.

1. The bearing capacity of piles, determined during dynamic tests, is 13.7-44.8% more than static ones, 15.1-42.7% more than the results of analytical calculations, due to the fact that the piles will be driven into solid soil with low natural humidity.
2. The efficiency of the pile foundation is evaluated by the bearing capacity of 1.0 m3 of pile reinforced concrete:
a) for piles with a length of 6.0 m, it is 19.72 tn/m3 according to static tests and 18.72 tn/m3 according to analytical calculation;
b) for piles with a length of 7.0 m, it is 35.2 tn/m3 according to static tests and 37.95 tn/m3 according to analytical calculation;
c) for piles with a length of 9.0 m, it is 30.31 tn/m3 according to static tests and 32.54 tn/m3 according to analytical calculation.

VI. CONCLUSIONS

1. Based on the results of a comparative analysis of the bearing capacity of 1.0 m3 of reinforced concrete piles with a length of 6.0 m, 70 m and 9.0 meters with a cross section of 0.35 x 0.35 m, tested in pre-moistened loess-like silty sandy loamy soil, we can conclude that the lower end of a pile buried to a depth of 1.8 m in solid ground, the bearing capacity of a 1.0 m3 reinforced concrete pile with a length of 7.0 m is the largest.

2. Depending on the mechanical parameters of soils and the amount of penetration into the underlying solid soil at the lower end of the piles, taking into account the possible moistening of the loess-like silty sandy loamy soil of the area, it may be optimal from the point of view of the technical and economic assessment to be piles with deepened ends by (4÷5)d (where: d is the side of the cross section and the diameter of the pile).

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