Development and Research of Constructive and Technological Solutions Driven Drop-In Piles with Increased Bearing Capacity

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Abstract. The article presents the results of the study of the effect of the amount of large-size filler (fraction 5.0-0.65 mm), introduced into the fine sand at its angle of “internal friction”; the design of the developed pile with “pockets” on the side surface, which are filled with filler from the collar (funnel) on the surface of the soil and allows you to change the granulometric composition of the soil around the perimeter of the pile. Experimental studies of the interaction of the side surface of the models developed piles with large-size filler in the process of their driving in a soil tray with fine sand are presented, which showed that the proposed design and technological solutions increase the bearing capacity of the piles by 25% compared to prismatic ones without the use of filler. It is established that in the process of hammering the contact plane of the filler with fine sand is inclined from the vertical by about 100, which allows us to consider the developed pile as pyramidal. The method of calculation of bearing capacity of piles taking into account the proposed design and technological solutions is proposed.

1. Introduction

For some time past pile foundations, even under favorable soil conditions displace conventional foundations on a natural basis in civil and industrial construction. It can essentially reduce the amount of excavation work and material consumption, reduce the cost of preparing the base, and generally cut the cost and speed up the production of works.

The mainstreaming of pile foundation was required the development and usage of various types of driven piles constructions. Concrete piles are used the following structures: the pile of solid square section with non stressed reinforcement; piles of square section with a circular cavity; the tubular piles with a diameter up to 800 mm and the piles, which shells diameter is more than 800mm; pyramidal piles, a self-extracting (gantry) of the pile.

At the present time there are some ideas of improvement design solutions of driven piles: transformable pile [1], driven concrete pile for chemical grouting of loose sand [2,3,4]. There were attempts for usage coatings as increasing for the soil bearing capacity in the prior time [5].

However, the above-mentioned constructive and technological solutions about increasing the bearing capacity of driven hanging piles involve their usage in limited types of soil, the usage of rarely utilized scarce and expensive materials in the construction process, such as sodium silicate, phosphoric acid, fluosilicic acid, non-explosive destructive substance (NDS), etc.
Therefore, we had provided the development increasing method of the bearing capacity of driven hanging piles in all types of soil, without the usage of special chemical reagents. Nevertheless, we had to use standard mass-produced concrete piles with minimal change in their construction.

2. Main part

The purpose of this work is development and research the constructive and technological solutions of driven piles with increased load-bearing capacity.

It was necessary to solve the following tasks for achievement this purpose:

- to prove by experiments the possibility of increasing the bearing capacity of driven hanging piles by changing the particle-size distribution of the soil adjacent to the side surface of the piles;
- to develop structural changes in typical concrete prismatic piles, which allow to make changes in the particle-size distribution of the soil adjacent to the side surface of the pile, while exert measures aimed at the filling the "pockets" with filler by the loading collar;
- to establish increasing degree of the bearing capacity of the developed constructive and technological solutions on models of driven hanging piles in the soil tray;
- to develop a methodology for calculating the bearing capacity of the developed driven piles, immersed in the proposed technology.

For experimental substantiation possibility of increasing the bearing capacity by changing the particle-size distribution of the soil adjacent to the pile in the process of driving, in the laboratory on a shear device (the construction of the Institute Hydro project), we had researched the influence of the filler in the form of sand gravelly to the fine sand, on its internal friction angle [7,8]. At the same time, the fine sand (which was used in the soil tray) was added to the soil particles of size 5; 2.5; 1.25; and 0.65 mm, the percentage of which was changed with a step of 15%. The results of laboratory experiments are shown in figure 1.

Figure 1. The influence of content and particle size of the filler particles on the angle of internal friction of fine sand: 1 - filler content in the sand - 30%; 2 - filler content in the sand - 50%; 3 - fine sand without filler (330); 4 - the percentage of filler (diameter of the filler particles 2.5 mm) in the fine sand.

The results were showed us that the angle of internal friction of fine sand with the introduction into its composition of soil particles with a size of 5-0.65 mm in an amount of 50-60% increases from 330 to 420, i.e. by 27-28%. Therefore, we can consolidate that during its driving the introduction of coarse-grained filler along the perimeter of the pile can contribute to a significant increase in friction on its side surface.
For the purpose of supplying coarse aggregate on the perimeter and depth of the piles in the process of driving has developed a constructive change in the standard reinforced concrete square piles, manufactured by a series 1.011.1-10 under GOST 19804-2012 (Figure 2) [9,10]. The essence of the construction changes is shown in figure 3. While making changes, we had considered the location of the working and transverse reinforcement.

For the purpose of confirming the hypothesis of increasing the bearing capacity of piles by using the proposed constructive and technological solutions, experiments were carried out in a soil tray which was filled with fine sand to study the interaction of the side surface of the pile models with coarse-grained filler during their driving (Figure 4).

**Figure 2.** Structural changes in standard reinforced concrete square piles manufactured according to the series 1.011.1-10 according to GOST 19804-2012 [9,10].

**Figure 3.** Developed a constructive-technological decisions driven piles hanging piles.
There is a general view of the soil tray with fine sand and installation during the test piles static load on the Figure 4.

![Image of soil tray](image1)

**Figure 4.** General view of the ground tray with the installation for driving and testing models of piles: a) – and models of piles with cavities ("pockets"); b) – without them (basic) for laboratory testing.

For the purpose of studying the nature of the distribution of filler in depth models of piles with "pockets", driving models of piles produced at the transparent wall of the tray. The filler with a particle size of 1.25 mm was painted black and fell into the collar (Figure 3). The result of the obtained distribution of the filler when driving is shown in figure 5.

![Image of filler distribution](image2)

**Figure 5.** The nature of the interaction of the side surface of the pile models with the "pockets" with the adjacent soil tray during their driving in the presence of filler (painted black).

Based on the analysis of the nature of the distribution of the filler on the depth of piles with "pockets" found that while driving the angle of inclination of the plane of contact of the filler with the
host soil medium. The angle of deviation of the contact plane from the vertical (the taper of the pile), as shown by measurements on models of piles was 100.

The bearing capacity of the basic and developed piles with "pockets" in the presence of filler was determined by their static loading with loads using the installation (Figure 4). The results of pile testing are presented in the form of "draft - load graphs. Piles №1, 2 and 3 - basic (without "pockets"), piles № 3, 4 and 5 – are designed according to our design and technological solutions. The results of the experiments are shown on figure 6.

![Figure 6. Graph of precipitation models pile S from static load R: 1 - results of basic tests of piles No. 1, 2 and 3; 2-results of tests of piles with pockets No. 3,4 and 5; 3-load limit R_{ex}=49,7 kg for the base of the piles; 4-load limit R_{ex}=62,3 kg developed for piles with pockets; 5-base of the sediment pile at full load high=25mm; 6-sludge piles designed with the pockets at full load high=21mm.](image)

Analysis of the results of testing models of piles in a tray with fine sand was showed that constructive and technological solutions of driven hanging piles, which were developed by us, can increase their bearing capacity by 25.3% compared to the base prismatic piles. At the same time, the maximum draft of the pile models is approximately the same: 25mm for the base piles and 21mm for the developed piles, which indicates the reliability of the developed piles [8].

Due to the structural changes, which were made by us in the typical piles, the usage of filler and the formation of the angle of inclination of the contact plane of the filler with the surrounding soil environment, obviously, the method of calculating the bearing capacity of such piles requires clarification. The bearing capacity of a driven hanging designed pile working on compression must be calculated as the sum of forces:

\[ N = \gamma_{p,d} (R + T + R_{pak} + F_d), \]  

where \( R \) is the calculated resistance of the base soil under the lower end of the pile, calculated according to [7];

\[ T = \gamma_{s,d} (S - S_{pak}) \cdot f, \]  

where \( \gamma_{s,d} \) is coefficient of soil working conditions on the lateral surface, according to [7,8];

\( S - S_{pak} \) is the area of the side surface of the developed pile, without the surface area of the pockets on the four faces;
$f$ is specific friction force of the filler on the side surface of the pile, according to [7];

$R_{pok}$ is the design resistance of the soil in the "pockets" on the four faces, determined by:

$$R_{pok} = \sin 60^\circ \sum_{i=1}^{n} R_i \cdot A_{pok},$$

(3)

where $R_i$ is the design resistance of soil at depth $h_i$, determined according to [7];

$A_{sup}$ is the surface area of the pockets which accept the pressure of the soil;

$F_d$ - increase of the bearing capacity of the developed design and technological solutions of driven hanging piles, due to the formation of the angle of inclination of the contact plane of the filler with the host soil medium in the process of hammering (creating a taper angle of the pile), deg:

$$F_d = \sum_{i=1}^{n} A_i \cdot \cos \alpha \cdot c_{1,i} + \frac{d^2}{n_i} (P_i + n_2 \cdot c_{1,i}).$$

(4)

where $A_i$ is the area of the lateral surface of the pile within the i-th layer of soil (cm$^2$);

$\alpha$ is the taper angle of the plane of contact of the filler with the surrounding soil environment, hail;

$c_{1,i}$ is calculated value of adhesion (kgf/cm$^2$), i-th layer of soil;

$d$ is section side of the lower end of the pile (cm$^2$);

$n_i, n_2$ are coefficients, the values of which are given in table [7,8].

Soil resistance on the side surface of the pile (kgf/cm$^2$) is determined by the formula:

$$P_i = \left[ \frac{E_i}{4P_{0,i}(1-\nu_i^2) - 2P_{0,i} (2-\nu_i)} \right]^{\frac{1}{2}},$$

(5)

where $E_i$ is soil deformation module of the i-th layer (kgf/cm$^2$), determined by the results of pressometric tests;

$\nu$ is Poisson's ratio of the i-th layer of soil, taken according to [7];

$\xi$ is the coefficient, the values of which, depending on the angle of internal friction of the soil are given in [7,8];

Soil pressure $P_{0,i}$ is determined by the formula:

$$P_{0,i} = \frac{\nu_i}{(1-\nu_i)} \gamma_{s,i} \cdot h_i,$$

(6)

Where $\gamma_{s,i}$ is specific gravity of the i-th layer of soil (kgf/cm$^3$); $h_i$ is the average depth of the i-th layer of soil, m.

3. Conclusion

Thus, laboratory research have shown that the introduction of the filler into the fine sand increases its internal friction angle by 27-28%. In addition, it is established that the driven pile with "pockets" in the presence of filler in them, forms the angle of inclination of the plane of contact of the filler with the host soil medium. The taper angle was 100.

The experiments carried out in the soil tray allowed us to establish that the developed constructive and technological solutions of driven hanging piles increase their bearing capacity in comparison with standard prismatic piles hammered by the traditional method by 25%.

The method of calculating the bearing capacity of the driven hanging piles erected according to the proposed design and technological solutions takes into account not only the resistance of the soil under the lower end of the pile and on its side surface, as well as their soil resistance in the "pockets" on the four faces and the taper of the pile (when driving, the angle of the contact plane of the filler with the host soil medium is formed).
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