Comparative evaluation of bearing capacity of a short driven pyramidal-prismatic pile using mathematical models

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Abstract

The article presents the results of research on mathematical models of bearing capacity of a short driven pile with the pyramidal broadening in the upper part. The research was carried out using the piles of the same length and various sizes of broadening. In order to evaluate the increase of the bearing capacity of a pyramidal-prismatic pile compared with the same prismatic pile the calculations were performed in the software package Plaxis 3D. The basis of the calculation was based on the well-known in soil mechanics the elastic-plastic model of Mohr-Coulomb. According to the data obtained the analysis was made concerning the increase of bearing capacity of short driven piles using a constructive solution - the broadening device at the top proposed by the authors.

Keywords: pyramidal-prismatic pile, bearing capacity of a pile, mathematical model of the "pile-soil" system

1. Introduction

Today, low-rise building construction in the territory of the Russian Federation is regaining its relevance [1]. Taking into account the current trend, the authors propose the driven pile structure with the broadening in the upper part. In our opinion such solution is ideal for use in the specified area of construction [2-7]. A method of increasing the bearing area in the upper part of the pile (the pile head) is interesting because it greatly simplifies the
manufacturing process rather than the broadening device under the pile foot. Also, a significant positive factor is the elimination of the gap emergence between the top of the pile and soil which can occur as a result of prismatic piles driving [8-14]. In order to evaluate the effectiveness of the proposed constructive solution the analysis of the research results was conducted on mathematical models of bearing capacity of a short driven pile with the pyramidal broadening in the upper part [15].

<table>
<thead>
<tr>
<th>Nomenclature</th>
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<tr>
<td>c</td>
<td>the specific cohesion, kPa</td>
</tr>
<tr>
<td>( \varphi )</td>
<td>the internal friction angle of a soil, degrees</td>
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<tr>
<td>( E )</td>
<td>the soil deformation modulus</td>
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<tr>
<td>( \rho )</td>
<td>the soil bulk density, g / cm(^3)</td>
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2. The finite element model development

In order to study the question of evaluating the increase of the bearing capacity of a driven pile due to the pyramidal broadening of its upper part in the software package Plax is 3d 2012 computational models of prismatic piles were created with the size of the cross section of 0.3 × 0.3 m and pyramidal-prismatic piles with the broadening in the upper part with the size of 0.45 × 0.45, 0.6 × 0.6, 0.75 × 0.75 m (see Fig. 1). Piles were made of elastic material with the characteristics of B20 concrete. On the border with the soil the so-called interface element was set- the surface imitating the decrease of the soil bulk density when it comes into contact with concrete. The friction angle has made 2/3 from the internal friction angle (according to the recommendations of the software system developers). The calculation was made using the elastic-plastic model of Mohr-Coulomb described by the characteristics of the soil deformation modulus: Young's modulus (deformation), Poisson's ratio and the soil strength characteristics. The size of the computational domain in the plan was 10.0×10.0 m, depth 5.0 m. There is no groundwater. The loam of semisolid, low-plastic and high-plastic consistencies was taken as the foundation soil. Their physical and mechanical properties are the following:

* semisolid: \( c = 24 \) kPa, \( \varphi = 22^\circ \), \( E = 20 \) MPa, \( \rho = 1.82 \) g/cm\(^3\);
* low-plastic: \( c = 19 \) kPa, \( \varphi = 18^\circ \), \( E = 12 \) MPa, \( \rho = 1.95 \) g/cm\(^3\);
* high-plastic: \( c = 12 \) kPa, \( \varphi = 10^\circ \), \( E = 6 \) MPa, \( \rho = 2.05 \) g/cm\(^3\).

The Poisson's ratio for loam was taken in accordance with the paragraph 5.6.44 CS 22.13330.2011 "Foundations of Buildings and Structures" [16] (0.35 - for semisolid, 0.36 - for low-plastic, 0.37 - for high-plastic).

Fig. 1. The finite element approximation of the computational domain: (a) in the three-dimensional statement, (b) in the two-dimensional statement.

Since the creation of the model the software system doesn’t allow to take into account the compaction of the soil.
around the pile during the driving, then to evaluate accurately by calculating the actual quantitative increase of the bearing capacity of the pile by the broadening device in the upper part was impossible. Therefore the qualitative comparison of the calculation results obtained was carried out.

3. The finite element model calculation

The calculation results are presented in the Table 1 and Fig. 2…4.

Table 1. The calculation results of the pile with various broadening sizes in different soil conditions.

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>The bearing capacity of piles determined by soil, tf</th>
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<tr>
<td></td>
<td>Prismatic</td>
</tr>
<tr>
<td>Semisolid loam</td>
<td>5,7</td>
</tr>
<tr>
<td>Low-plastic loam</td>
<td>4,5</td>
</tr>
<tr>
<td>High-plastic loam</td>
<td>2,5</td>
</tr>
</tbody>
</table>

Fig. 2. The field of plastic deformation development: (a) at gauss points, (b) in contour plots.

Fig. 3. Dependency diagram of the piles vertical settlement from vertical load in various ground conditions: (a) for a prismatic pile with cross-sectional dimensions 0,3×0,3 m; (b) for pyramidal-prismatic pile with broadening dimensions 0,45×0,45 m.
4. The comparative analysis of the obtained results

The qualitative analysis of the modeling results (Fig. 5) gives an idea that the broadening device in the upper part of the driven pile to pile creates a significant increase of the bearing capacity:

In stiff soil: 0.45×0.45 m up to 130%, 0.6×0.6 m up to 285%, 0.75×0.75 m up to 425%;

in low-plastic soil: 0.45×0.45 m up to 55%, 0.6×0.6 m up to 175%, 0.75×0.75 m up to 287%.

In high-plastic soil the increase of the bearing capacity has reached 12%, 40% and 168% which correlates with the results of gutter tests conducted earlier by the authors in the soil model with similar physical and mechanical characteristics.

Conclusion

The results of the research lead to the conclusion that the constructive solution proposed to increase the bearing capacity of short driven piles by the broadening device in the upper part is quite effective.

References

[2] T.V. Kuznetsova, Selection of an effective type of foundations in difficult geotechnical conditions (collapsible soil) // Traditions and innovations in architecture and civil-engineering: proceedings of the 69th all-Russian science technical conference according to the results of scientific research. Vol.2 / SSUACE. Samara, 2012, pp. 418-419


[14] V.I. Isaev, P.V. Ignatyev, Increasing the resilience of pyramidal piles to the forces of frost heaving // Traditions and innovations in architecture and civil engineering: proceedings of the 70th all-Russian science technical conference according to the results of scientific research 2012 / SSUACE. - Samara, 2013. - pp. 365-366 – Vol.2
