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NUMERICAL RESEARCHES OF THE WORK OF THE PILE WITH END SPHERICAL BROADENING AS PART OF THE PILE GROUP

Abstract. *The article presents some aspects of the development of the theory of constructing design schemes for long pile groups with end spherical broadening and results of their numerical analysis of the load capacity of piles with end broadening in comparison with the operation of piles without widening in the Bush.*

As a result of a numerical analysis of the bearing capacity of piles with end broadenings in a comparative calculation with the work of piles without broadening in the bush, it was revealed that vertical and horizontal stresses in the soil mass increase with a decrease in the pitch of piles with broadenings in the group.

The direction of development of deformations (compaction) of the soil and its ejection from the heel and body of the pile with and without end broadening with a pitch of piles in the bush equal to 6 d show that the ejection of the soil affected the change in the initial physical and mechanical characteristics of the base.

Keywords: *bored piles, technologies of the performing, broadenings, shaping.*

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ЧИСЛЕННОЕ ИССЛЕДОВАНИЕ РАБОТЫ СВАИ СО СФЕРИЧЕСКИМ УШИРЕНИЕМ В СОСТАВЕ СВАЙНОГО ПОЛЯ

Аннотация. *В статье представлен анализ некоторых особенностей расчета длинных свай со сферическим уширением на конце, работающих в составе свайных кустов, а также результаты численного анализа их несущей способности в сравнении со сваями без уширения, работающих в составе свайных кустов.*

В результате сравнительного численного анализа несущей способности свай с уширениями на концах и свай без уширения установлено, что вертикальные и горизонтальные напряжения в грунтовом массиве возрастают при уменьшении шага свай с уширениями, работающих в составе группы.

Направление развития деформаций уплотнения основания и его выпора из-под пяты и тела сваи с торцевым уширением и без него при шаге свай в свайном кусте равном 6 диаметров сваи, показывает, что выпор грунта повлиял на изменение исходных физико-механических характеристик основания.

Ключевые слова: *буронабивная свая, технология устройства, уширение, формообразование.*

Introduction

The following domestic scientists made a significant contribution to the study of the issues of interaction of piles with soil in their group: Abbasov P.A., Abelev Yu.M., Barvashov V.A., Bartolomey A.A., Bakholdin B.V., Berezantsev V.G., Golubkov V.N., Grigoryan A.A., Gotman N.Z., Gotman A.L., Dalmatov B.I., Devaltovsky E.E., Doroshkevich N.M., Egorov K.E., Sorochan E.A., Pilyagin A.V., Znamensky V.V., Zaretsky Yu. K., Fadeev A. B., Fedorovsky V. G., Razvadovsky D. E., and etc. When analyzing these results, one of the main reasons that change the nature of the work of piles in the bush is the change in the initial natural state of the soil in the inter-pile space caused by the immersion of piles and the mechanism of piling broadening.

The authors [1-13] showed a significant difference in the work of single piles compared with a pile in the group. Differences in work are determined by the physical essence of the interaction of the pile's group through the soil, as shown in the work [Gotman N.Z.] the effect of “compression” of piles with soil occurs when loading, those additional normal radial tensions occur. The force of compression depends on the pitch of the piles and their length. As the distance between piles in the group increases, the crimping decreases to zero and increases as the pitch decreases. The results of the study show that the pile bush sediment is larger than the single pile sediment with equal loads on the pile. This position for prismatic piles is valid if the distance between piles is from 3*d* to 6*d*. The ultimate resistance of the base soil in the pile bush is significantly higher than that of a single pile and decreases with increasing distance between piles. Especially this compression effect, in our opinion, will be more effective when using piles with surface and end broadening. In SP 24.13, in the scientific literature there are no data on the study of work and the calculation of a group of piles with broadening. Therefore, the refinement of calculation schemes and methods for calculating piles with surface and end broadening in a group is relevant.

The bearing capacity of piles with surface and end broadening in the group is composed of soil resistance at the base of the pile, or end broadening, its lateral surface of the prismatic part and the lateral surface of the surface broadening.

Methods

We consider design schemes for two cases of a group of piles with end spherical broadening:

1) with terminal spherical broadening (rigid), spaced apart from each other at a distance a_1;
2) with end spherical broadening, with intersecting diameters.

The design scheme of such piles with broadenings in the group for determining the ultimate resistance is constructed using the basic provisions is constructed as follows.

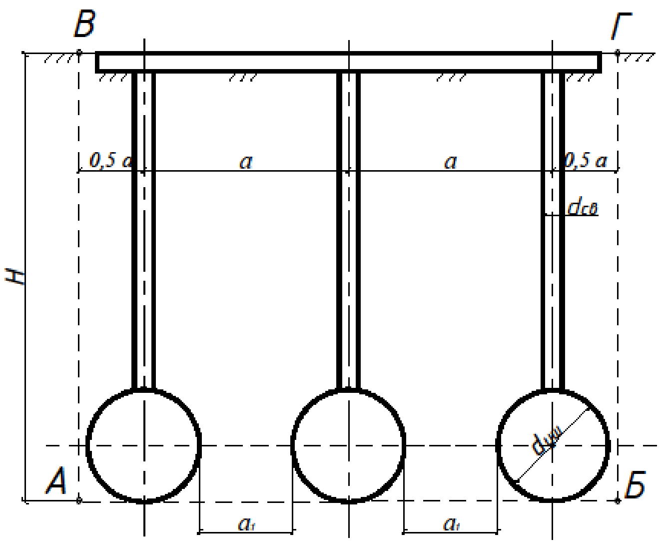

Figure 1 - The design scheme of a group of piles with end spherical broadening spaced apart by a distance a_1

In the diagram, we show in cross-section a bush of piles with end broadening with the number of piles of at least three. The definition of the boundaries of the conditional foundation when calculating the settlement of pile foundations with broadening is determined from below - AB plane, passing through the lower ends of the piles with broadening; from the sides - vertical planes AV and BG, spaced from the axes of the extreme rows of vertical piles with broadenings at a distance of 0.5 pitch piles (figure 1), but not more than 1.5*d* (*d* - diameter or side of the cross-section of the pile), and in the presence of inclined piles - passing through the lower ends of these piles; from the top - the ground level surface of the VG. A feature of the work of a group of piles with end broadenings according to the second design scheme, considered in figure 2 is the intersection of the radii of broadening at the end of the pile, for example, because of injection fixation of soil. In this case, the intersecting end broadening system works like a plate, and the group or pile of piles is included in the work after the broadening device as the foundation for the deep box-type foundation. In this paper, we consider a group of piles with broadening according to the first design scheme.

Calculation of settlement of the conventional foundation is carried out by the method of layer-by-layer summation of deformations of a linearly deformable base with a conditional restriction of the compressible thickness (look at SP 22.13330). The vertical normal stress, which determines the deformations and the depth of the compressible stratum, is calculated only from the action of the load applied to the pile foundation, that is, the weight of the soil within the conditional foundation is not taken into account. Initial stresses are determined to take into account excavation of the pit. When calculating the bases of the bridge supports, the conditional foundation can be taken as limited from the sides by the vertical planes AV and BG, spaced from the outer extreme rows of vertical piles at a distance a_1.

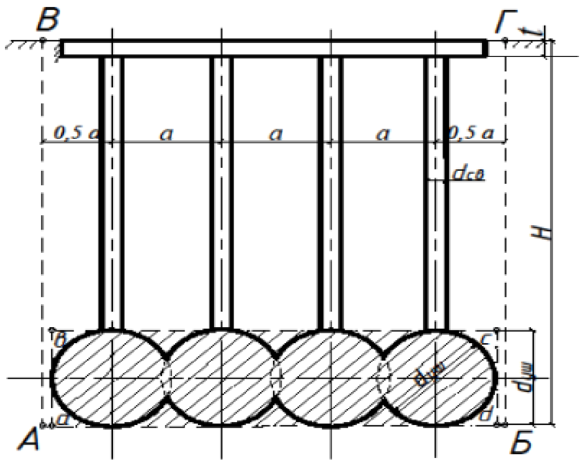

Figure 2. Design diagram of a group of piles with end spherical broadenings intersecting each other

In this case, the pressure plots under the lower end of the broadening will overlap each other. As a result, the maximum pressure under broadening in the group, as shown by experimental studies, exceeds the pressure value from one pile $\sigma_1 > \sigma_2$, the area of pressure transfer to the base also increases. In this case, as for simple piles, the draft of the pile bush with broadening at equal loads on the pile will be more than the draft of a single pile with broadening. This provision is true if c<3d. The effect of the mutual influence of piles on each other occurs. If the distance between the piles is c > 3d – this influence is almost negligible.

Numerical modeling and calculation using specialized software systems allow solving complex geotechnical problems, including for analyzing the operation of pile bushes with end spherical broadening. However, the interaction of the components of this system requires a theoretical justification of the resistance and analytical confirmation of the foundations in the soil environment, especially in difficult engineering and geological conditions.

Results and Discussion

The design model of piles with end spherical broadening formed by rammed crushed stone was created using a geotechnical complex Plaxis 2D Foundation (axisymmetric problem) according to (SP 24.13330.2011), as a cell with horizontal connections along the border of the influence of piles with neighboring piles, subject to uniform loading of neighboring piles. The soil was modeled with 15 nodal finite elements with the size of each 567.41×10^{-3}м. The transfer of force from a pile with broadening to the base causes a stress-strain state in the surrounding ground space. The shape of the shape and values of the stress diagrams are determined not only by the magnitude of this effort but also by the dimensions and geometry of the pile structure and the broadening.

The pile was adopted with a length of 17.5 meters with a radius of 400 mm and a broadening radius of 1.2 m. At the first stage, a study was conducted to simulate the stamping of crushed stone by compacting it with a column height of 0.8 meters in the well. After applying the load to the pile with broadening, we obtained the main stress vectors in the soil mass from vertical loading at the different pitch of piles from 3 to $9d_{\text{broadening}}$ (figure 3).

a) b)

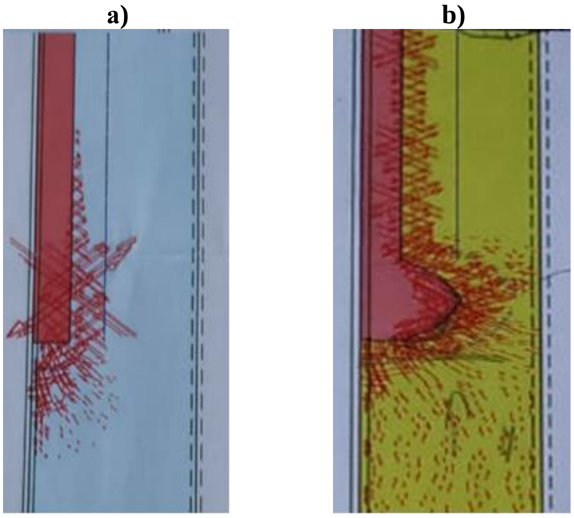

Figure 3 - The main stress vectors in the soil mass during vertical loading of a pile with end broadening (a) and without broadening (b) with a pitch of piles in the bush 6d$_{br}$

In figure 3, the arrows show the direction of development of deformations (compaction) of the soil and its ejection from the heel and body of the pile with end broadening (a) and without it (b) when the pile pitch in the bush is equal to 6$d_{broadening}$. The ejection of the soil affected the change in the initial physical and mechanical characteristics of the base.

At the second stage, iso-fields of vertical, horizontal, and shear stresses from vertical loading were analyzed (figure 4). The results of numerical modeling of the bearing capacity of piles with terminal broadening in a comparative analysis with the operation of piles without broadening in the bush are presented in Table 1 and in the graphs - figure 5 and 6. From table 2 it is seen that the mutual influence of piles with an increase in the pitch of piles with broadening to 6d_{br} decreases and at a distance 9d_{br} completely excluded.

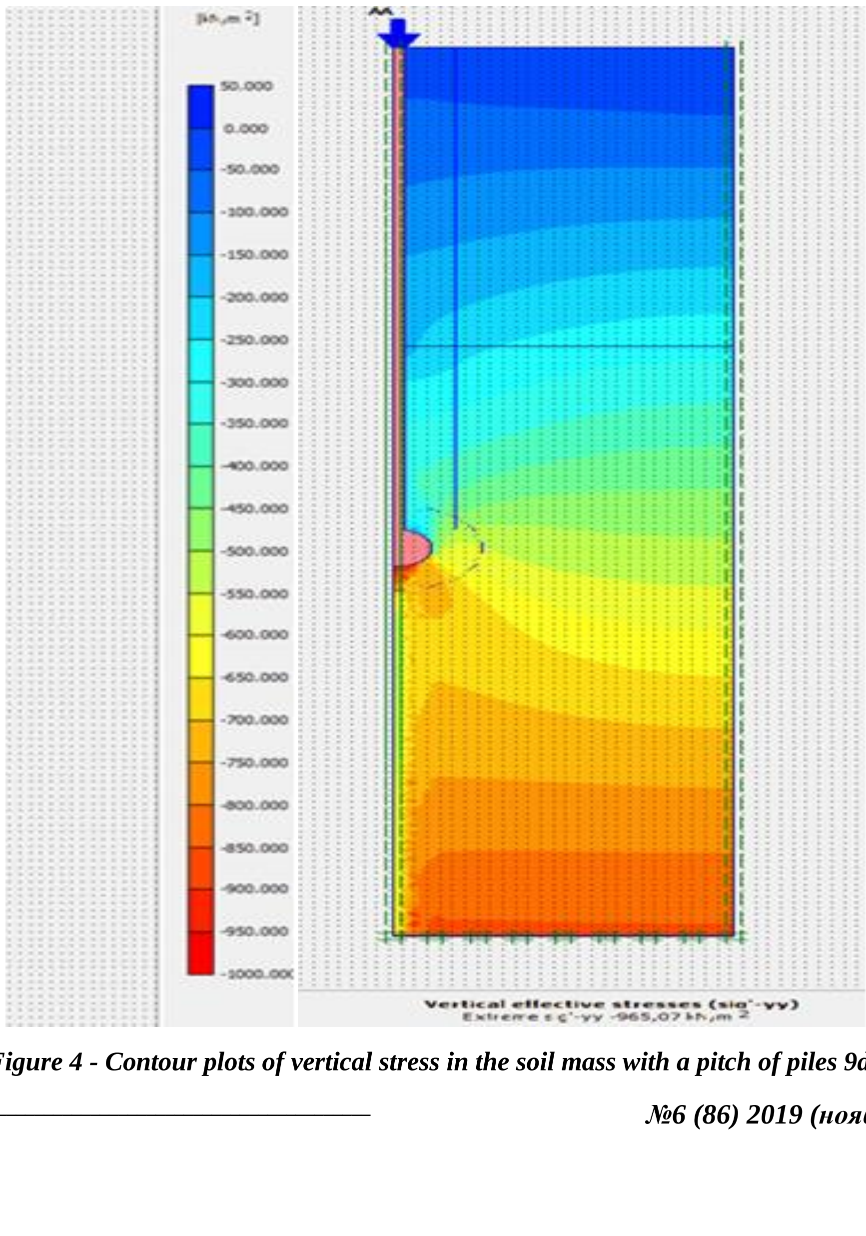

Figure 4 - Contour plots of vertical stress in the soil mass with a pitch of piles 9d$_{br}$

Table 1 – The results of a numerical analysis of the bearing capacity of piles with end broadening in a comparative calculation with the work of piles without broadening in the bush

No	Name of the construction	$9d_{br}$	$6d_{br}$	$4{,}5d_{br}$	$3{,}75d_{br}$	$3d_{br}$
1	2	3	4	5	6	7
1	Pile with broadening	86.708	105.557	134.46	159.593	207.345
2	Pile without broadening	72.885	82.309	93.6191	105.557	123.15
3	The relative increase in the bearing capacity of piles with broadening in the bush in relation to the bearing capacity of a single pile with broadening	1	1.22	1.55	1.84	2.39
4	The relative increase in the bearing capacity of piles without broadening in the bush in relation to the bearing capacity of a single pile without broadening	1	1.13	1.28	1.45	1.69

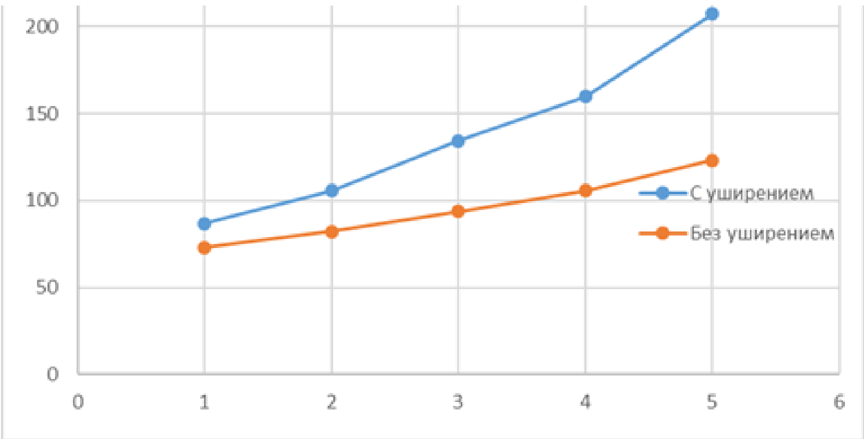

Figure 5 - Graph of bearing capacity (vertical - tn) piles with end broadening and without depending on the pitch of piles (horizontal 1- 9d$_{br}$, 2 - 6d$_{br}$, 3 - 4,5d$_{br}$, 4 – 3,75d$_{br}$, 5 – 3d$_{br}$)

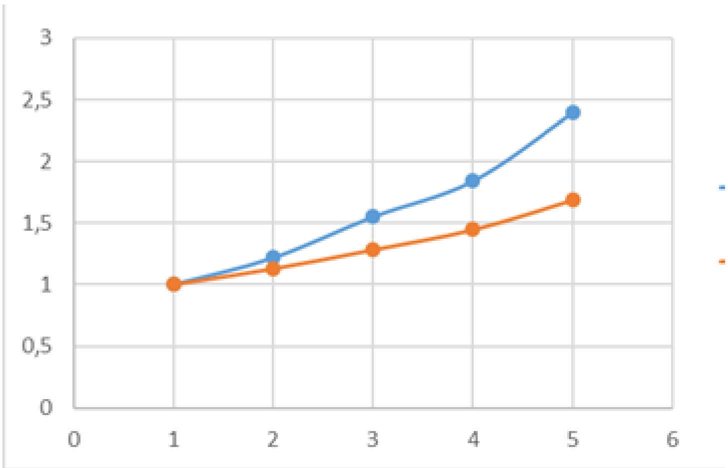

Figure 6 - The relative increase in bearing capacity (vertically - times) of piles with end broadening and without depending on the pitch of piles (horizontal 1- 9d$_{br}$, 2 - 6d$_{br}$, 3 - 4,5d$_{br}$, 4 – 3,75d$_{br}$, 5 – 3d$_{br}$)

Conclusions

As a result of a numerical analysis of the bearing capacity of piles with end broadenings in a comparative calculation with the work of piles without broadening in the bush:

- vertical and horizontal stresses in the soil mass increase with decreasing pitch of piles with broadenings in the group;

- the direction of development of deformations (compaction) of the soil and its ejection from the heel and body of the pile with and without end broadening with a pitch of piles in the bush equal to $6d_{br}$ shows that the ejection of the soil affected the change in the initial physical and mechanical characteristics of the base.

- graph of the bearing capacity of piles with end broadening and without depending on the pitch of the piles showed that there was a relative increase in the bearing capacity of piles with broadening in the bush with respect to the bearing capacity of a single pile with broadening by 2.4 times, and a relative increase in the bearing capacity of piles without broadening in the bush with respect to the bearing capacity of a single pile also without broadening - 1.7 time.

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