Збірник наукових праць. Серія: Галузеве машинобудування, будівництво

Academic journal. Series: Industrial Machine Building, Civil Engineering

http://journals.pntu.edu.ua/znp

https://doi.org/10.26906/znp.2018.51.1299

UDC 624.154/155:624.138.2

Economic efficiency of vibroreinforced soil-cement piles implemented in construction

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The results of the executed economic comparison of foil-cement piles reinforcement use by vibroreinforced - vibroreinforced soil-cement piles are presented. The comparison is based on the results of piles bearing capacity by field tests. Considering the results of field tests two variants of piles foundation have been designed for residential building. Economical comparison is made for implementation effectiveness of reinforced and non-reinforced soil-cement piles at the piles calculated bearing capacity on the soil that is greater than the calculated bearing capacity by the material. .Economical comparison is made for implementation effectiveness of vibrated vibroreinforced soil-cement piles and bored piles at their calculated bearing capacity by the material at times greater than that on the soil. The obtained results and the determined economic effect are analyzed. The results of comparison are used for design and implemented in construction.

Keywords: the vibroreinforced soil-cement piles, economic efficiency, economic efficiency, deep soil mixing method, the bored piles.

Економічна ефективність упровадження віброармованих ґрунтоцементних паль

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Доведено, що підвищення несучої здатності ґрунтоцементних паль завдяки збільшенню міцності матеріалу паль та підсиленню їх арматурними каркасами дозволяє значно збільшити несучу здатність ґрунтоцементних паль та зменшити їх кількість, що також позитивно впливає на зменшення ресурсомісткості зведення фундаментів будівель. Викладено результати проведеного економічного порівняння використання підсилення ґрунтоцементних паль віброармуванням – віброармованих ґрунтоцементних паль. В основу порівняння прийнято дані результатів натурних випробувань несучої здатності паль, що були проведені на будівельних майданчиках. Виконано економічне порівняння ефективності впровадження непідсилених та віброармованих ґрунтоцементних паль при розрахунковій несучій здатності паль по ґрунту більшій, ніж розрахункова несуча здатність по матеріалу палі, а також економічне порівняння ефективності впровадження віброармованих ґрунтоцементних паль та буронабивних паль. При цьому розрахункова несуча здатності по матеріалу для віброармованих ґрунтоцементних паль була незначно більша, ніж по ґрунту, а для буронабивних паль розрахункова несуча здатність по матеріалу в рази більша, ніж по ґрунту. Проаналізовано отримані результати та визначено економічний ефект використання віброармованих ґрунтоцементних паль. Виділена оптимальна сфера застосування, в якій ґрунтоцементні палі є ефективним та економічно вигіднішим видом пальового фундаменту. Результати порівняння впроваджені в будівництво.

Ключові слова: віброармовані ґрунтоцементні палі, економічна ефективність, бурозмішувальний метод, буронабивні палі

Introduction. Increasing the bearing capacity of soil-cement piles by increasing the piles material strength and reinforcing them with frames enables to increase the bearing capacity of the soil-cement piles and reduce their number significantly that also positively affects the resource volume reduction of the foundation and building or structure underground part. [1 – 6, 9 – 14]

Review of the latest research sources and publications. Works of domestic and foreign researchers are devoted to the study of soil-cement foundations: V. Askalanov, V. Bezruk, I. Boyko, Yu. Vynnykov, M. Zotsenko, V. Chrisan, I. Lartseva, V. Marchenko, T. Nesterenko, R. Petrash, O. Petrash, P. Rebinder, A. Tokin, V. Shapoval, N. Denies, A. Le Kouby, S. Lambert, F. Rocher-Lacoste, Osamu Taki, R. Bell, and others.

The conducted studies [1, 6, 7] have proved the economic efficiency of using the soil-cement foundations as an improvement ground. In particular, it is necessary to highlight a perspective using area of one of the soil-cement foundations types, namely, soil-cement piles as an alternative to reinforced concrete piles with a lower resource volume for the foundation.

Definition of unsolved aspects of the problem. The performed increase of piles bearing capacity on the material enables to expand the scope of vibroreinforced soil-cement piles using. [1 – 4, 11 – 14] Most of the pile foundations on the territory of Ukraine are made with friction piles that lean on the sandy soils on the heel, so the bearing capacity of the reinforced concrete piles on the material far exceeds the bearing capacity of the soil. To reduce the cost of foundation building rationally use piles bearing capacity on the material should in a small degree exceed the bearing capacity on the ground, which reduces the resource volume of the foundation.

Problem statement. The developed vibroreinforced soil-cement piles [8] need to compare their implementation with already known types of piles and a sufficiently widespread method of reinforcing the base with soil-cement elements, which uses similar drilling equipment.

Basic material and results. For the more effective use of soil-cement piles, the author solves the problem of low bearing capacity on the material of piles trunk. Experimental way has determined the basic physical and mechanical properties of soil-cement that affect its strength, methods of increasing piles bearing capacity and testing their effectiveness in laboratory and field conditions.

The conducted studies enable to distinguish a new type of improved soil-cement foundations - vibroreinforced soil-cement piles (VRSCP). [11]

Comparison of pile foundation variants and determination of efficiency and resource volume of methods application for increasing the bearing capacity of soil-cement piles was carried out at the design and construction of a 10-storey residential building bulk 8 in the Esplanada district of Sumy.

By comparison, two variants of soil-cement piles foundations were adopted: soil-cement piles without reinforcement (non reinforced) and soil-cement piles with reinforcement and vibration sealing of the material (reinforced) – vibroreinforced soil-cement piles. The piles can be arranged using a single set of equipment, and an additional deep-hole, pin-shaped vibrator is used for reinforcement.

The presence of sand inhomogeneous emulsions enables to construct the bored piles without fixing the walls of the well. The hammering of concrete piles was not used due to the close location of existing buildings.

For both variants of soil-cement piles the following is typical: length 9 m diameter 750 mm (area of the section 0,44 m^2), the bottom end of the piles based on firm middle sand.

The results of the variants comparison for foundations are shown in Table 1.

Table 1 – Comparison variants of soil-cement piles foundations

Index	Variants of soil-cement piles	
	non reinforced	vibro-reinforced
Bearing capacity, tons	65	105
Design load on pile, kN	510	824
Piles number	256	166
Full volume, m^3	1013,76	657,36
Cement cost, UAH	387 070	250 990
Armature cost, UAH	0	124 080
Production cost, UAH	1 317 888	920 304
The economic effect of piles, UAH		410 784
Grillage construction, UAH	717 000	591 000
The overall economic effect, UAH		536 784

Before the start of construction, static tests of pilot piles with and without reinforcement were performed. As a result, the bearing capacity of non-reinforced piles amounted to 65 tons, reinforced, in turn, 105 tons. These data were used to design two variants for pile foundations and grillage.

The analysis of the performed calculation shows that due to the increase of the bearing capacity of the soil-cement piles, their total quantity decreased, and hence the volume of resources for them. Reducing the piles number also enables to reduce the grillage width.

The overall economic effect is 536 784 UAH, which is 26,4%.

Vibroreinforced soil-cement piles were also introduced at the design of pile foundations for the Student Cultural Center for 500 places at Sumy National Agrarian University.

For the construction two variants of pile foundations were designed: from bored piles and vibroreinforced soil-cement piles (VRSCP). The two variants as a result of the calculation were designed with a depth of 6.5 m and a diameter of 500 mm, while the bearing capacity of the piles in the soil is the same.

Calculated bearing capacity of bored piles on a material from concrete C8/10 considering reinforcement, was 1470 kN. The lack of groundwater and soil types allow drilling wells for drill piles without forcing walls of the well.

The estimated bearing capacity of the soil-cement piles without reinforcement was 196.0 kN, which is less than the permissible estimated ground load, therefore it was decided to design vibroreinforced piles. The estimated bearing capacity for the material of the vibroreinforced soil-cement pile was 294.0 kN.

The results of options comparison for foundations are shown in Table 2.

The analysis of the performed calculation shows that in the case of soil conditions where the bearing capacity on the soil is low, there is a problem of material for piles made of concrete bearing capacity underutilization. At the same time, at the expense of the same work volumes, vibroreinforced soil-cement piles have a lower resource volume and production costs.

The introduction of vibroreinforced soil-cement piles was carried out in the construction of residential buildings in Sumy with the participation of the organization PrJSC «Sumbud».

The comparison of variants of pile foundations has shown the efficiency and resource intensiveness of application of methods of increasing the bearing capacity of soil-cement piles, reducing the resource volume of using reinforced soil-cement piles.

Table 2 – Comparison variants of piles foundations

Index	Variants of pile foundation	
	BP	VRSCP
Design bearing capacity bearing on soil, kN	334,0	334,0
Design bearing capacity bearing on material, kN	1470,0	294,0
Design load on pile, kN	238,57	238,57
Piles number	145	145
Full volume, m^3	178,36	178,36
Material cost, UAH	227 442	156 859
Production cost, UAH	259 844	249 704
The overall economic effect, UAH		80 724
Design bearing capacity bearing on soil, kN	334,0	334,0
Design bearing capacity bearing on material, kN	1470,0	294,0

The overall economic effect 80 724 UAH, what is 16,57 %.

Reducing resource volume has a positive effect on reducing the construction estimated cost, so it is a cost-effective solution.

Construction of a 10-storey 110 apartment residential building 8 in the district of Esplanade, in Sumy, finished in the 1st quarter of 2016. The building is built on 166 vibroreinforced soil-cement piles with a diameter of 750 mm, 9 m length, 6 m depth reinforced. The plan of the pile field is shown in Fig. 1.

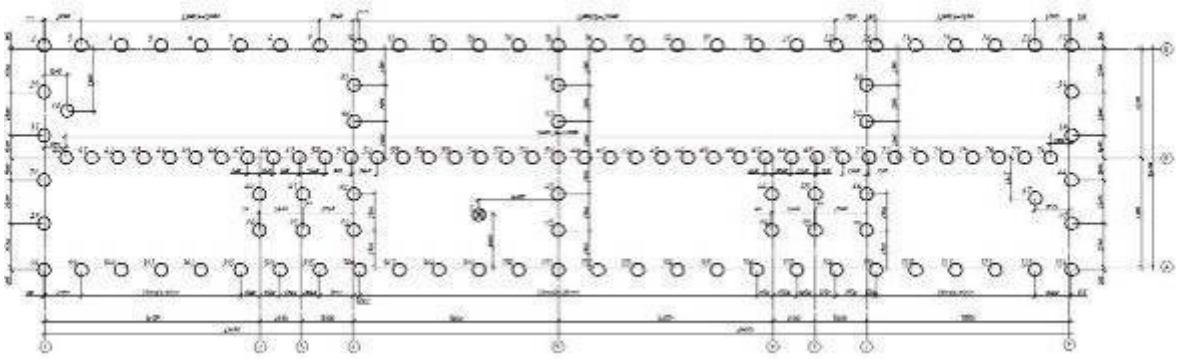

Figure 1 – Plan of the soil-cement piles field on construction of a 10-storey 110 apartment residential building 8 in the district of Esplanade, in Sumy

Figure 2 – Vibrireinforsing of soil-cement pile

The soils on the site are divided into 17 engineering geological elements (EGE), an array of nonuniform fine sand to a depth of 4.6 m; clay soils to a depth of 4.6 to 6.8 m; fine sands 6,8 – 11,0 m and from a depth of 11 m – medium sand.

After the economic comparison of different types of foundations, a pile foundation was designed. The analysis of soils showed the possibility of using the mixing technology for the placement of soil-cement piles. The detailed calculation of the dependence of the bearing capacity of the pile from the depth indicated the need for immersion of piles in the EGE VIII medium sands, with the calculated bearing capacity on the soil was 1491 kN.

It was decided to carry out the construction of vibroreinforced soil-cement piles with a depression in the bearing layer of soil not less than 1 m.

The VRSCP arrangement is carried out using a set of equipment which includes:

– drilling rig on the basis of RDC-250 with attachments. The working body for the soil destruction has openings for distributing the cement slurry throughout the well section;

– mortar mixer for making a cement slurry;

– mortar pump for injection of a slurry to a well;

– deep vibrator.

Composition of water-cement suspension – «cement + water». For 1 running meter of vibroreinforced soil-cement pile with a diameter of 750 mm (volume 0.44 m^3) is spent:

– cement M500 – 133 kg, 300 kg / m^3,

that is 1200 kg for 9.0 m SCP 3.96 m^3 (assumed by the project);

or

– cement M400 – 150 kg, 340 kg / m^3,

that is 1350 kg for 9.0 m SCP 3.96 m3 (assumed by the project);

– water – 60% of the weight of cement.

Water-cement ratio of the suspension W / C = 0,6.

Vibroreinforced soil-cement piles were arranged with a deep soil mixing technology without the removal of soil. The essence of the applied technology is that during the well drilling, the natural soil is loosened without taking it out of the well. In the well bore the solution pump a water-cement suspension, which is carefully mixed with the loose soil by the working organ. Loosening the soil, supplying the cement mortar and mixing it with the soil is carried out throughout the length of the soil-cement pile. In the newly made soil-cement piles, a metal frame is pressed, in the middle of which a high-frequency vibrator is placed, which simplifies the deepening of the frame. Constructive material is subjected to high-frequency deep vibrating when removing the vibrator up. After the mixture has dried, a solid soil-cement pile, which does not soak in the aqueous medium, is formed. Using the deep soil mixing technology without removing soil enables to made soil-cement piles below ground water level.

Conclusions The experience of introducing vibroreinforced soil-cement piles shows their use possibility in difficult engineering and geological conditions. The performed economic comparisons of work and materials cost indicate that vibroreinforced soil-cement piles are more economical and less resource volume variant of foundations compared to non-reinforced cement piles; if the load bearing capacity on the soil is greater than the bearing capacity of the material as well as in comparison with bored piles if bearing capacity of the soil is much smaller than the bearing capacity of piles material.

The vibroreinforced soil-cement piles have been used in the construction and design of residential and public buildings as a more economical version of pile foundations.

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