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Effectiveness of jet grouting method for soil base strengthening

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ABSTRACT

This paper examines the effectiveness of technology using jet grouting. This technology is commonly used to strengthening the weak soil bases of buildings in dense urban areas. The paper presents the calculation research methodology and results of the effectiveness of this method on the example of shopping malls in St. Petersburg. Frame type buildings, having numerous cracks in the floor slabs, are considered. Bearing elements of these buildings are the columns, based on the individual pile foundations. Concrete floor slabs are supported by soil base. In the calculations, the soil base was modeled by volumetric finite elements and concrete floor slabs – by plate finite elements. Cement-soil elements (pillars) were modeled also by volumetric finite elements with different deformation modulus. It can be concluded from the calculation results that the above technique is effective in the presence of the weak soil layers and the increase in the modulus of cement-soil elements more than 400 MPa is impractical.

Content

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1. Introduction

Problems associated with the normal exploitation of the floors of the ground stories, which are arranged using concrete slabs laid on the soil base, often occur in existing buildings. These slabs are unevenly deformed under loads, and that leads to the inclination of slab surface and cause them to crack. Especially large uneven deformation of slabs takes place in cases of existence highly compressible (weak or soft) soil base under the slabs.

These problems arise, in particular, in the shopping and entertainment buildings which usually have frame structure. Foundations supporting columns of these buildings often performed with deep piles, the lower ends of which are immersed in soils of low compressibility. Floor concrete slabs of the buildings, with laid on highly compressible (soft) soil, are characterized by considerable unevenly deformation (inclination), which leads to disruption of normal operational suitability of the premises.

If there are weak soils at the base, then there is a need to take measures to strengthen the soil massifs to ensure the reliability and safe operation of buildings and structures. The object of the study is a soil massif at the base of a shopping complex in St. Petersburg. The relevance of the topic is explained by the wide spread of weak water-saturated soils in this territory.

Studies of the diagnostics of uneven deformations of soils and strengthening of soil bases are presented in the works of domestic and foreign authors [1-36]. In these works, a large number of solutions to this problem have been proposed, which require careful study for specific soils. Therefore, the purpose of the design study is to justify the optimal solution for securing a weak ground mass by the method of jet grouting. To do this, it was necessary to solve the problem of determining the optimum values of the depth and the modulus of deformation of cement-soil elements.

2. Methods and Results

To solve this problem, in order to strengthen the soil base of floor slabs the method of jet grouting is proposed in this paper. Investigations of this method effectiveness to create cement-soil elements (pillars) in the soil base (under concrete slabs) for an example of one of the shopping malls in St. Petersburg is presented. The complex is a building of frame type. The supporting columns are based on the individual pile foundations. The lower ends of the piles of these foundations immersed in a weakly compressible soils, so settlement of columns foundations is insignificant. The results of the detailed engineering and diagnostic assessment of structural elements of the building showed that the main damage in the form of cracks having different directions was formed in the floor slabs in the first years of its usage. Detailed diagnostics of detected damages, using probabilistic methods of recognition of these elements condition, showed that the cause of defects was different settlements [1, 2].

Geology surveys were performed by GUP "Trest GRII." The layer of silty sands of medium density with a thickness of 2.0 m, located under the lower floor surface. Modulus of deformation of these sands is 8.0 MPa. The layer of water-saturated peaty soil of high compressibility with a thickness of 2.0 m lies under the silty sands. Deformation modulus of this soil – 2.5 MPa. Silty water-saturated sands of average density are below, layer thickness ranging from 3.0 to 6.0 m. Deformation modulus of this sand is 18.0 MPa. The loamy sands and clay loams whose thickness is approximately 15.0 m are under the above silty sands. Deformation modulus of loamy sands and clay loams – 6.0 MPa. The sands and clay loams with a modulus of deformation from 21.0 to 45.0 MPa are below.

Considering these geotechnical conditions to prevent significant non-uniform deformation of concrete floor slabs one may use concrete piles, to support the slabs. In this case, the most reliable option would be design when the lower ends of the piles buried in soil of low compressibility and length of piles will be approximately 21.0 m [3]. Another possible decision can be usage of piles with the length near 5.0 – 7.0 m immersed by lower ends in silty sand (with deformation modulus 18.0 MPa), while the bearing capacity of piles for the second option is considerably smaller than for the first option, and the number of piles for this option will increase.

Most suitable for the production technology and cost-effective, in our opinion, is the third option of using jet grouting method for strengthening soil base of slabs with formation separate cement-soil elements (pillars).

Jet grouting is commonly used to improve the soft soil base of buildings and structures (including in dense urban areas), and to improve the base of embankments of roads [4 − 13].

This method using jet grouting is based on the energy of a jet for the destruction of soil structure and mixing of soil particles with cement mortar. This action leads to the appearance of a new material (cement-soil), which has sufficiently high strength characteristics and low deformability [14 − 24].

The main element of the machine for performing work on said above jet technology is being immersed into the soil injector (monitor) with holes (nozzles), from which the cement solution is going under high pressure (up to 70 MPa). When the injector rotation in the ground takes place simultaneously with its elevation, close to the cylindrical shape cement-soil elements (pillars) are formed. The diameter of these pillars can be up to 3.0 m [17].

In the works of the Russian and foreign authors the results of experimental studies of strength and deformation characteristics cement-soil materials, produced during the jet grouting process, are presented [15, 19 – 35]. In particular, it is noted that the value of the modulus of deformation of cement-soil materials increase hundreds of times in comparison with the values of the deformation modulus of soil. Thus, for peaty soil containing organic substances, deformation module of cement-soil materials can be from about 100 to 800 MPa.

To evaluate the effectiveness of soil base strengthening by jet grouting method series of calculations using the SCAD software were performed. The calculations were performed for the floor slabs of shopping complex and geotechnical soil conditions presented above.

When creating a calculation model four concrete slabs with the planned size of 7.0 × 10.5 m (according to the cutting of the total slab for blocks by deformation joints) and a thickness of 0.2 m (Fig. 1) were considered. The modeling section of soil base with the planned size of 41.0 × 34.0 m was considered, depth of compressible strata was assumed to be equal 15.0 m. The base were modeled by volumetric finite elements (mainly cubes with an edge of 1.0 m), concrete slabs - by plate finite elements of size 0.5 × 0.5 m. As shown by test calculations, further increase in the size of the soil base both in depth and in plan dimensions had no practical effect on the accuracy of calculations.

Provided by the project support of concrete slab angle on column foundation (and consequently on the pile grillage) was modeled as a hinge and fixed in the vertical direction, which carried out by the corresponding fixing one unit of the base under the angular slab element adjacent to the column (Fig. 1).

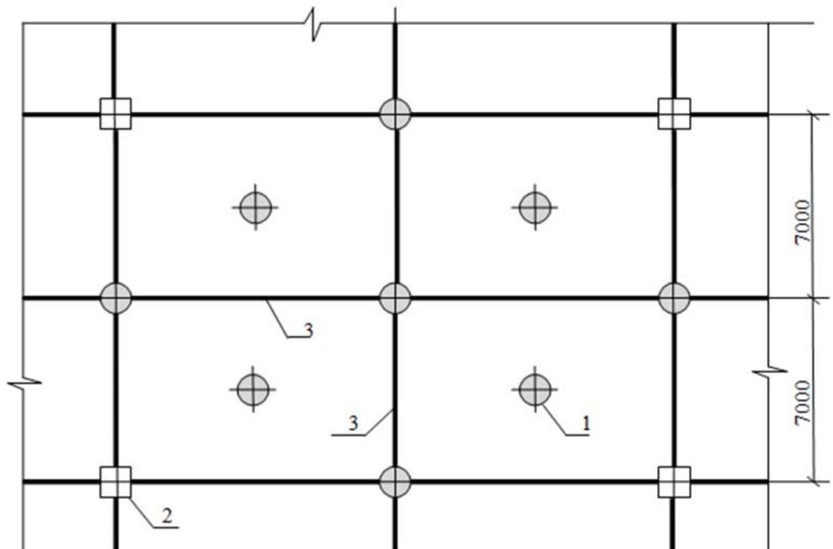

Figure 1. Schematic arrangement of slabs and cement-soil elements: 1 – cement-soil elements; 2 − foundations of columns; 3 − expansion joints.

Carried out by the corresponding fixing one unit of the base under the angular slab element adjacent to the column (Fig. 1). Cement-soil elements ("pillars") in soil having depth from 4.0 to 7.0 m were modeled by volumetric finite elements with dimensions 1.0 × 1.0 × 1.0 m and a modulus of deformation ranging from 150 to 800 MPa. Location of cement-soil pillars in the plan is shown in Fig. 1.

The variation of the above parameters is made to determine the intensity of their influence on the vertical displacement (settlement) of soil base and the concrete slabs.

The calculation of the stress state and displacement of the soil mass are made with conventional uniformly distributed over the area of the plates load with intensity of 10 kN / m².

3. Discussion

Fig. 2 shows the results of determination of the maximum settlement in mm depending on the value of the deformation modulus of cement-soil elements at the same depth of these elements equal 5.0 m. The settlement at zero cement-soil modulus corresponds to the absence of cement-soil elements.

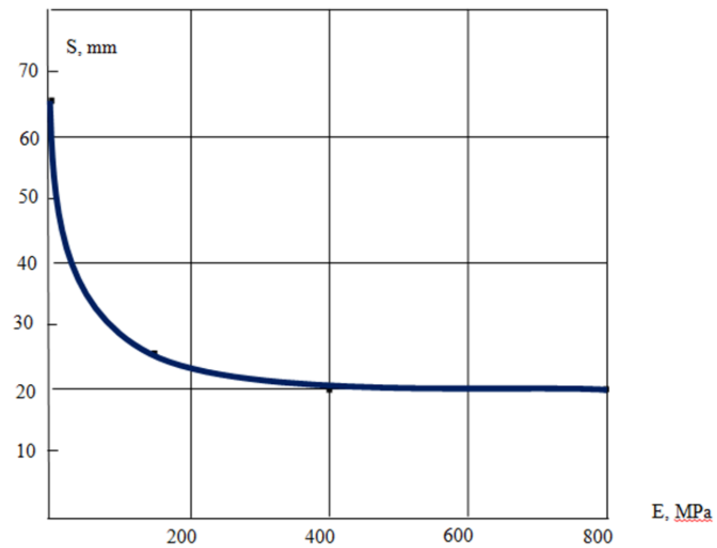

Figure 2. Dependence of maximum settlement and deformation modulus of cement-soil elements.

As seen from the graph in Fig. 2, with increasing deformation modulus of cement-soil elements above 400 MPa maximum settlement of soil base decrease only slightly. Since an increase in the modulus 2-fold (from 400 MPa to 800 MPa), the maximum settlement reduced by only 2 mm. This phenomenon can be accounted for by high compressibility of the soil base under the cement-soil elements, compared to the compressibility of those elements.

According to the graph in Fig. 3 the effect of increasing of the cement-soil elements depth from 4 to 7 m (deformation modulus is constant and equal 400 MPa) can be traced. Obviously, this effect is negligible, since the difference in the maximum settlement is only about 3.5 mm. This slight difference is also due to the high compressibility of the soil under the cement-soil elements.

The authors regret that in this case it is impossible to perform a comparison with the results of other authors since the corresponding research was not previously carried out for such structurers. At the same time, the authors this paper suppose that a comparison of the calculation results with the results of field observations can be carried out after the soil base strengthening of floor slabs.

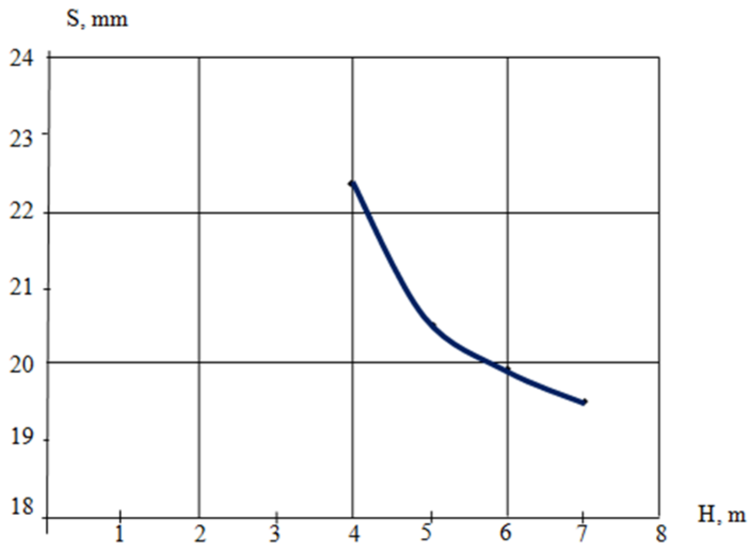

Fig. 3. Dependence of maximum settlement and depth of cement-soil elements.

4. Conclusions

1. The soil bases strengthening by an arrangement of the cement-soil elements (pillars) is effective especially in the presence of soft soil layers of high compressibility (e.g., peaty) and low thickness, occurring relatively shallow (up to 5 − 6 m from the surface).

2. Increase of the cement-soil pillars deformation modulus above 400 MPa is inefficient because it does not lead to a significant reduction in the maximum settlement.

3. The effect of increasing of the depth of cement-soil elements below the layer of high compressibility soil for concrete floor slabs settlements is insignificant, due to the high compressibility of the soil under the cement-soil elements.

4. This technique can be most effectively used in the case of soft layers in the soil base when increasing loads on the floor slabs in operating buildings occur, as well as in the case of new construction.

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Эффективность метода струйной цементации для закрепления грунтов основания

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ИСТОРИЯ

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КЛЮЧЕВЫЕ СЛОВА

Проблемы грунтов основания и фундаментов;
сильносжимаемые грунты;
закрепление грунтов;
«jet grouting»;
осадки грунтового основания;
бетонные плиты;
объемные конечные элементы;
трехмерная модель;
модуль деформации;

АННОТАЦИЯ

В данной статье рассматривается эффективность использования технологии струйной цементации. Эта технология часто используется для закрепления слабых грунтовых оснований зданий в условиях плотной городской застройки. В статье приводятся методика расчета и результаты исследований эффективности этого метода на примере торговых центров в Санкт-Петербурге. Рассматриваются здания каркасного типа, имеющие многочисленные трещины в плитах пола. Несущими элементами таких зданий являются колонны, установленные на отдельные свайные фундаменты. Бетонные плиты пола опираются на грунтовое основание. В расчетах, грунтовое основание моделируется объемными конечными элементами, а бетонные плиты пола – плитными конечными элементами. Цементогрунтовые элементы (столбы) моделируются объемными конечными элементами с различными значениями модуля деформации. По результатам расчетов можно сделать вывод, что данная рассмотренная технология эффективна при наличии слабых слоев грунта и увеличение модуля деформации цементогрунтовых элементов свыше 400 МПа – нецелесообразно.

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