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Reinforcement of the foundation base of the building with horizontal elements of increased rigidity

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A method for reducing the uneven deformations of a two-story building, which provides improving the construction properties of weak soils that lie at the base, by reinforcing them with horizontal soil-cement elements (SCE) of increased rigidity, carried out using a sand mixing technology, is described. SCEs are created in the mass under the base of the foundations and are formed as a result of the destruction of soil natural structure with its simultaneous mixing and injection of cement mortar under pressure. It has been established that the manufacture of SCE has a number of advantages: using of local soil as a material for their manufacture; adding to the soil only water and a binder, without additional aggregate; installation of elements on the site.

Keywords: soil reinforcement, grouting element, fixing, boring and mixing technology

Армування основи фундаментів будівлі горизонтальними елементами підвищеної жорсткості

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Підтверджено, що за час експлуатації будівлі, зведені на просадочних ґрунтах, отримують нерівномірні деформації, причиною яких, як правило, є замокання з мереж водогінних комунікацій ґрунтів основи. Описано ефективний спосіб зменшення потенційних нерівномірних деформацій двоповерхового адміністративного будинку. З’ясовано, що цей спосіб передбачає поліпшення будівельних властивостей слабких ґрунтів, котрі залягають в основі будівлі, шляхом їх армування горизонтальними елементами підвищеної жорсткості, що виконуються за бурозмішувальною технологією. Ґрунтоцементні елементи (ГЦЕ) створюються в масиві безпосередньо під підошвою фундаментів й утворюються в результаті руйнування природної структури ґрунту з одночасним його перемішуванням і нагнітанням під тиском цементного розчину. Доведено, що після твердіння суміш перетворюється в армуючий елемент високої міцності та жорсткості, яка регулюється за рахунок процентного співвідношення «цемент – ґрунт». Установлено, що виготовлення ГЦЕ має ряд переваг: використання як матеріалу для їх виготовлення місцевого ґрунту; додавання в ґрунт лише води й в’яжучого без додаткового заповнювача; улаштування елементів на місці; уникнення виймання ґрунту з масиву; виключення динамічного впливу на навколишні споруди; можливість створення як вертикальних, так і похилих та горизонтальних елементів; можливість створення елементів різної довжини та діаметра, а також з різним кроком і схемою розміщення; досить низька собівартість робіт; екологічна безпека цього матеріалу. Установлено, що завдяки включенню в основу армуючих елементів відбувається поліпшення параметрів міцності та деформаційних властивостей ґрунту, підвищується опір основи до динамічних і статичних впливів.

Ключові слова: армування ґрунту, ґрунтоцементний елемент, закріплення, бурозмішувальна технологія

Introduction. Reinforcement of bases is an effective method for improving the mechanical parameters of bases, by introducing into the mass of inclusions with higher mechanical characteristics in comparison with soil [1, 2]. In geotechnics, there is a vertical, inclined and horizontal reinforcement of soil mass with cylindrical elements. They use reinforced concrete piles, sand and stone columns, soil-cement elements (SCE).

SCEs are made by mixing soil with a water-cement solution, as a result of which soil cement appears, which has higher mechanical characteristics in comparison with the natural soil.

Analysis of recent sources of research and publications. The production of SCE has several advantages [4 – 9]:

– use as a material for the manufacture of local soil SCE;

– adding to the soil only water and a binder without additional aggregate;

– installation of elements on the site;

– avoiding of excavation from the soil mass;

– exclusion of dynamic impact on surrounding buildings and structures, soil mass;

– the ability to install both vertical, inclined, and horizontal SCE;

– the ability to create elements of different lengths and diameters;

– SCE installation with different pitch and layout;

– fairly low cost of work;

– environmental safety of this material.

The sequence of SCE production depends on condition of the soil:

– dense soils are first loosened by drilling without supplying the solution, then after several approaches, the soil is mixed with the solution;

– weak soils usually do not need preliminary loosening.

This technology is called boring and mixing.

SCE are used for: strengthening foundation base; erection of pile foundations; erection of dividing walls; insulating of buried waste; strengthening the slopes of the pit; securing the slopes [3, 6, 7, 9].

Due to the inclusion of reinforcing elements in the base, the strength and deformation properties are improved, the resistance to dynamic and static effects increases, and the reduction of uneven sediment of buildings and structures is fixed. The mechanical characteristics of ground cement increase with time up to 2.5 times, respectively, it is ideal for long-term use as a base reinforcement material [5, 10].

A method of strengthening foundations with the use of horizontal reinforcing elements is becoming increasingly widespread annually during reconstruction and major repairs of buildings and structures [11, 12].

However, there is a problem with the introduction of manufacturing technology and the question of the justified use of the method of soil reinforcement with horizontal elements of increased rigidity in the course of reconstruction and major repairs of buildings and structures.

Highlighting of unsolved aspects of the problem. A significant drawback in the implementation of SCE is one-off production of equipment for their device, poor knowledge of soil-cement parameters under various geotechnical conditions, the lack of a regulatory framework for their calculation, complexity of quality control of the made elements.

Formulation of the problem. In the present work, the aim was to prove with a specific example the possibility of increasing the strength and deformation characteristics of weak soils lying at the base of the foundations to reduce potential uneven deformations of the base and foundation of the existing building.

Main material and results. The administrative building was built in the 70s of the last century and was a one-story L-shaped structure in the plan. The constructive scheme of the building is frameless with longitudinal and transverse load-bearing walls. The building was erected without a basement. Strip foundations from concrete foundation blocks and partially brickwork. The walls are made of brick, 380 mm thick, internal and 510 mm external.

The geotechnical section of the site to a depth of 12.0 m is represented by sandy and loamy soils of upper and middle Quaternary age of various genetic origin, which are covered from above by filled soils with a capacity of up to 1.9 m. The groundwater level during the survey period to the depth of 12.0 m is not opened, presumably the groundwater lies at a depth of 15.0 – 17.0 m.

The foundations of the building are based on weak natural grounds: sandy clay, humous, loess-like, subsidental, and sandy clay, loess-like, subsidental, carbonized. In places of prolonged local soaking, sandy clay acquired a flowing consistency. The total subsidence of soils from its own weight when soaked can be up to 9 cm [13].

In 2012, the reconstruction of this building was carried out, which consisted in redevelopment of premises, superstructure of the second floor, improvement of the adjacent territory. After a while, after the reconstruction in the central part of the building, deformations occurred in the form of vertical cracks in walls and partitions, deformations of the foundations and floors of the building arose. The cause of the deformations that occurred was the prolonged soaking from the water-bearing communication networks of the base soils with subsidence properties.

To reduce potential uneven deformations of the building, it is envisaged to perform the transformation of the building properties of weak soils under the entire building by reinforcing them with horizontal elements of increased rigidity. The reinforcement of the base is carried out by horizontal elements of increased rigidity (EIR) with a diameter of 300 mm. EIRs are created directly under the base of the foundations and are formed as a result of the destruction of the natural structure of the soil with its simultaneous mixing and injection under pressure of cement mortar.

Fixing the soils of the basement of the administrative building is made from two pits. Works on SCE reinforcing are performed in a certain sequence according to the drilling-mixing technology.

The reinforcing elements are located in three tiers. The distance between them is 500 mm, the pitch between the elements is 800 mm. Figure 1 shows the layout of the lower row of horizontal soil-cement elements, as well as sections 1-1 and 2-2.

Works on the SCE setting are performed in a specific sequence using a sandmill technology, the essence of which is the following.

The drilling machine with the help of a special tooling, including hollow drill rods, at the beginning of which a drilling mixer is fixed, destroys the natural structure of the soil and at the same time injects a water-cement solution that is thoroughly mixed with a crushed soil mixer. After hardening, the mixture turns into a reinforcing element of high strength – 2.5 ... 3.5 MPa (depending on the percentage of cement-soil) and rigidity (deformation modulus 80 – 110 MPa).

Reinforcing SCEs are arranged in three tiers. The entire volume of mass fixing is performed by sub-area, each of which provides for the following types and sequence of work:

– digging out pits to a designed depths with manual refining and bottom planning, arranging sump for collecting precipitation from the bottom of pits;

–preparation device from slag (capacity 100 mm);

– installation and fastening of rail tracks, connection of technological equipment;

– breakdown of the axes of reinforcing elements;

– preparation of a working water-cement solution using a mortar mixer;

– arrangement of horizontal SCE with the help of the UGB - 250A drilling machine by rotating the drill bit-mixer with a diameter of 300 mm and composite hollow rods Ø42 mm with a length of 1 m at a speed of 72 rpm and axial flow at a speed of 0.3 ... 0.75 m/min with simultaneous injection of the prepared solution through a swivel, rods and a crown using a diaphragm pump that creates pressure up to 0.5 MPa;

– removing the string of drill rods and boring bits from the well with repeated additional injection of the solution and mixing of the SCE material;

– plugging the wellhead, washing the sleeves, swivel and crowns-mixer;

– shutdown, rearrangement and connection of equipment to the next SCE.

After completion of the work on the device of the reinforcing elements of the lower tier, the pit is filled with local soil with compaction to the density of the soil in a dry state $\rho_d \geq 16.5$ kN/m^3 to a height of 500 mm and proceeds to the arrangement of the SCE of the middle tier. Similarly, go to the execution of the upper tier.

The SCE are carried out at air temperature above 50C. When the alternating air temperature, the GCE caps are insulated.

The composition of the water-cement mortar is «cement + water». Per 1 meter of soil-cement element the following are consumed:

– portland cement M400 – 25 kg;

– water – 80...100% by weight of cement (20...25 *l*.).

SCE are arranged next but one. The works on the missing element should start no earlier than in two days after the production of the nearby.

Before operation, in the process of fixing the base soils and during the SCE material strength set, the building is monitored, which includes high-precision control of changes in the spatial position of the fixed building as a whole, and individual structural elements separately, in order to determine possible uneven sediment of the foundations during work on the consolidation of the soil base.

Geodetic monitoring of the object will be carried out by a geodetic method and an automated complex using the «Monitoring» information-measuring system (once a week).

After completion of the work, the pits are filled up with a layer-by-layer compaction of the soil to the density of the soil in a dry state ρd≥16.5 kN / m^3.

The operational control parameters for the SCE are:

– the planned binding of the axes of the wells, according to the design or adjusted parameters;

– the size of soil densification zone;

– linear speed of the mud mixer pulling back (not more than 0.3 m/min.);

– water-cement ratio in the range of 0.8 ... 1.0;

– cement activity (not lower than M400);

– cement consumption per 1m of wells (absorption);

– solution injection pressure (at optimal pressure there is no soil ejection from the well).

When arranging the first SCE, according to [14], the technology and their technical parameters are tested in each tier. In the process of tested elements manufacturing should be determined:

– drilling and pulling back speed;

– water-cement ratio of the solution;

– well absorption;

– discharge pressure of the solution.

To determine the quality of soil densification, samples of ground-cement reinforcing elements are sampled during their manufacture and at the age of 14 days a test is made in laboratory conditions, according to [15], and the cubic strength of the soil cement should be at least 1.5 MPa, and on the 28th day should be 2.0 MPa. The number of test items must be at least one for each sub-area.

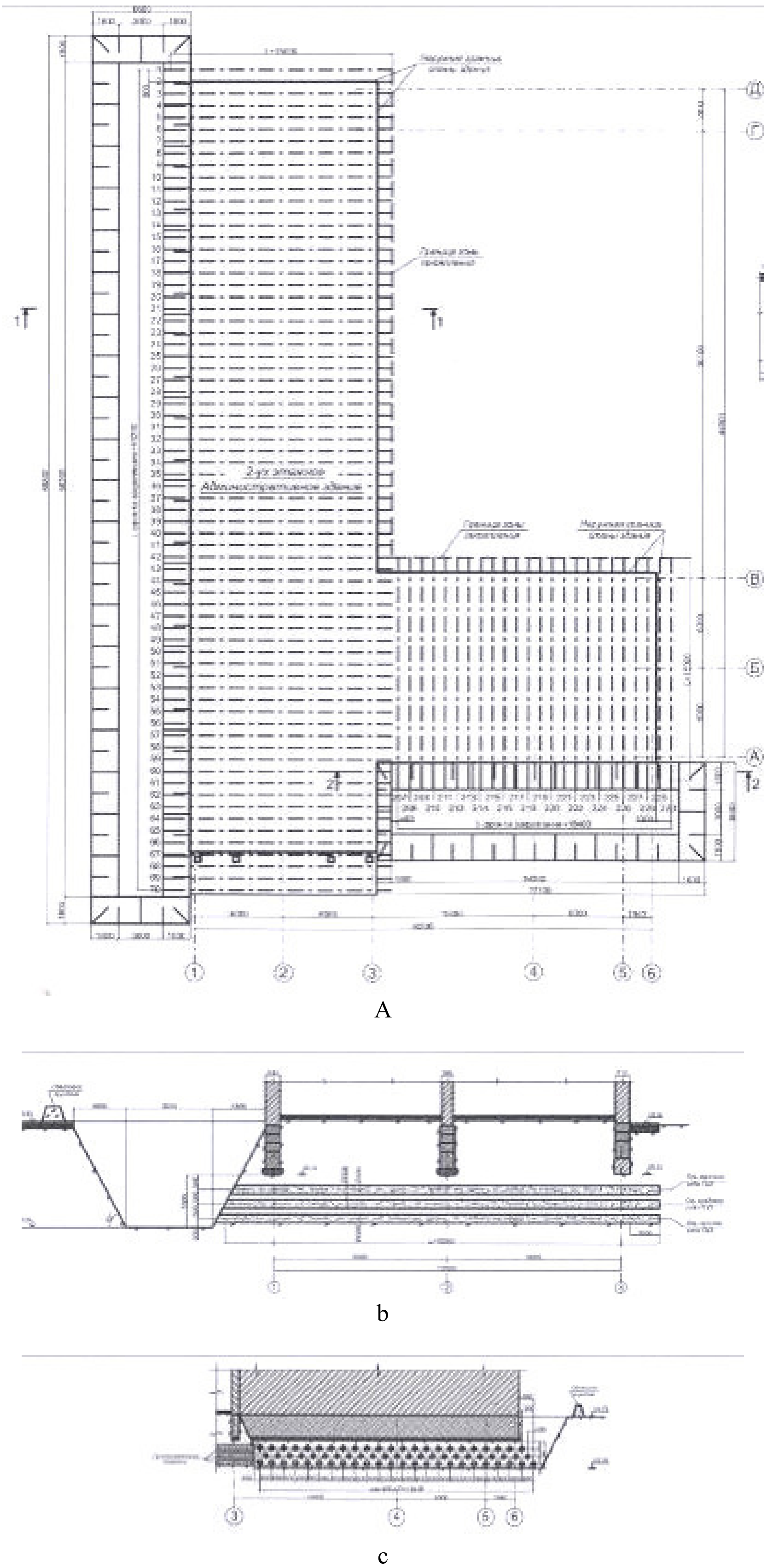

Figure 1 – Layout of lower row of SCE (a), sections 1-1 (b); 2-2 (c)

The control of the length and continuity of the SCE is carried out by the acoustic method. 10% of items are subject to control. After completion of the soil reinforcement of the foundation with horizontal SCE, considering that the type of geotechnical conditions of the territory and the site of the administrative building is referred to II by subsidence, all water-carrying communications should be reconstructed (replaced) and brought in line with the requirements of regulatory documents.

During exploitation of the building, it is necessary to inspect building structures, water-bearing communications and timely make preventive repairs. In the case of a leakage in the pipes of water-carrying communications it is necessary to rectify them immediately. Safe exploitation of the building can be ensured only with the prevention of ground soils watering.

Conclusions. The possibility of increasing the strength and deformation characteristics of weak soils lying at the base of the foundations of the building with the aim of reducing its potential uneven deformations by the method of reinforcing the soils with horizontal elements of increased rigidity, made by drilling and mixing technology, has been proved on the field site.

The stress-strain state of reinforced bases is influenced by the parameters of their reinforcement and the natural properties of the soil. Mechanical properties of reinforced soil mass are regulated by changing the parameters of reinforcement: step arrangement of elements; their diameter and length; layout scheme.

To reduce a base settlement, a method of their reinforcement with rigid horizontal SCEs, made by drilling-mixing technology, is promising, since the use of such elements improves the geotechnical properties of the soil, significantly reducing the settlement of the bases. Mechanical parameters of ground cement grow in time up to 2.5 times, respectively; it is highly effective for long-term use as a base reinforcement material.

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